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Freezing physics

Heike Kamerlingh Onnes and the quest for cold

Dirk van Delft

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Translated from the Dutch by Beverly Jackson.

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Illustration cover: Detail of the schematic view of the bottom part of the cryostat with which Kamerlingh Onnes achieved the record low temperature of 0.83 K in 1921. (See illustration 55).

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Preface

I only have to shut my eyes for a moment and I am back at the Kamerlingh Onnes Laboratory. Not the grey measuring hall on the outskirts of Leiden, but the original labyrinth opposite Van der Werff Park on Steenschuur, in the very heart of Leiden. A few years ago this complex was transformed into the premises of the law faculty, and the old name blazoned in gold letters on the eaves in 1932 was truncated to plain KAMERLINGH ONNES. The unsightly bulges annexed to the main building, including the laboratory in which Heike Kamerlingh Onnes liquefied helium on 10 July 1908, were demolished to make room for new buildings. But that does not hurt me, and in my mind I let the old front door swing shut behind me, walk up the stairs to the right, and set off past the instrument-makers' workshops towards lab I, to Zeeman's windows.

I first saw those windows in September 1969, trying to find my way around the corridors as a first-year physics student. The building was full of funny little staircases, mysterious passageways, annexes and outlying rooms where pumps chugged away and researchers hunched intently over cases of electronics and cold flasks (cryostats), on their way to absolute zero. What a jumbled mess of a building! That was Heike's fault. As soon as he took charge of the laboratory's north wing in 1882, as the new professor of experimental physics, he decided on a thorough programme of renovation, and when the chemistry and anatomy departments doggedly stayed put in the rest of the building, thwarting his plans, he solved the problem of space with an endless series of annexes. Like a wayward growth, the complex expanded down the street, around the corner of Langegracht, into the back garden and into the front garden. Functionality overrode any aesthetic objections.

Arriving at the main building, I turn left. On the right, high up in the wall, halfway down the corridor with its chequered tile floor and harsh light, are three stained-glass windows, each one measuring 1.75×0.72 metres. Together they depict the discovery – and explanation – of the Zeeman effect. This phenomenon, the splitting (or rather widening) of light under the influence of a magnetic field, was discovered in August/September 1896 by Pieter Zeeman in the room behind the windows. Zeeman's superior, Kamerlingh Onnes,

submitted the first article on the effect to the meeting of the Academy of Sciences on his student's behalf, after which Lorentz produced an explanation for it within just two days. In 1902 Zeeman and Lorentz became the joint recipients of the Nobel Prize for physics. Twenty years later, Kamerlingh Onnes paid tribute to his two friends by commissioning these windows. Subdued and austere in form, they arrest the gaze of any passer-by. I look up and see Zeeman peering tensely at sodium light between electromagnets, while Lorentz is engrossed in his formulas. Art and science coalesce in geometrically shaped stained-glass panes, in a style reminiscent of Bart van der Leek.

It was years after my first acquaintance with these windows that I noticed the plaque beneath them with the artist's name: Harm Kamerlingh Onnes. Harm, I discovered, was the son of Heike's artist brother, Menso Kamerlingh Onnes. So there were several Kamerlingh Onneses, and the family apparently possessed an aptitude for art as well as physics. I was curious, and my curiosity nagged at me intermittently for years, until I decided to indulge both my passion for the history of science and my passion for writing by producing a biography of Heike Kamerlingh Onnes. That was in 1990. Since then, my mind has pulsed with the doings of the Kamerlingh Onnes family, and they have all become close acquaintances.

The problem was that my work as science editor for the daily newspaper *NRC Handelsblad* left me little time for the biography. The project did not really take off until 2002, when I was appointed as the first 'writer-in-residence' of the NIAS, the Netherlands Institute for Advanced Study in the Humanities and the Social Sciences. I am extremely grateful to Ben Knapen and Mai Spijkers of PCM Publishers and the then director of NIAS, Henk Wesseling, for giving me that opportunity, and to the chief editors of *NRC Handelsblad* for their generosity in letting me go for a while. NIAS was wonderful, its facilities superb, and within twenty-four hours I had forgotten that I was a journalist. After the term of my fellowship expired I had to return to the newspaper, but I was determined not to abandon the biography. For two years I straddled two worlds, and then it was finished. I should like to thank my science colleagues at the *NRC* for their patience with an editor who was often more preoccupied with cold than they would have wished.

By then, it had been decided that my biography would also be a PhD thesis. I would like to thank the science historians Rob Visser, Teylers professor in Leiden, and Frans van Lunteren, professor at the Free University in Amsterdam, for their willingness to act as supervisors. I recall with pleasure our progress talks at the Institute for History and Foundations of Mathematics and the Natural Sciences, (where both men have additional appointments). Their expert comments and constructive criticism, useful suggestions and practical advice stood me in very good stead. I am also grateful to the examiner and

other members of the doctoral committee: the professors Willem Otterspeer, Carlo Beenakker, Frits Berends, Harm Beukers, Rudolf de Bruyn Ouboter, Harm Habing and Frans Saris.

Many people helped in the making of this biography. It was H.A.M. Snelders, professor of the history of science at the University of Utrecht, whose fascinating lectures kindled my interest in this subject. In the exploratory phase, I had stimulating discussions with the professors R. de Bruyn Ouboter, H.B.G. Casimir†, P.W. Kasteleyn† and G.J. Sizoo†. De Bruyn Ouboter, in particular, helped me to navigate the archives in the attic of the old Kamerlingh Onnes Laboratory. J.J. Coremans†, too, the manager of the Huygens Laboratory (now the home of Leiden's physics department) provided invaluable assistance, including transcriptions of large swathes of Kamerlingh Onnes's correspondence.

Most of the archives relating to Kamerlingh Onnes, aside from those in the Huygens Laboratory, are in the National Museum of the History of Science and Medicine, Museum Boerhaave. From my very first request for a box of archives in 1990 onwards, the librarian Harry Leechburch Auwers and his colleagues were always extremely helpful. The same applies to the librarians and archivists of the other archives I consulted: the National Archives in North Holland, Haarlem, the Groningen Archives, the Kamerlingh Onnes School in Groningen, the Municipal Archives of Amsterdam, Leiden and Delft, Utrecht Archives, the Academic Historical Museum in Leiden, the Van der Waals-Zee-man Laboratory in Amsterdam, Utrecht University Museum, the hydrodynamics department of Delft University of Technology, the university libraries in Leiden and Delft, Philips Research in Eindhoven, the National Library and the National Archives in The Hague, Teylers Museum in Haarlem, the International Institute of Social History (IISG) in Amsterdam, the Holland Society of Sciences in Haarlem, the Niels Bohr Archives in Copenhagen and the Deutsches Museum in Munich.

I was also given permission to consult the private archives of D.B. Bosscha Erdbrink†, Titia Frieling-Van Osselen, G.A. Kamerlingh Onnes-Baroness van Dedem, J.C. de Knegt†, G. Prakke-Bijleveld and M.G. Wagenaar Hummelinck†. I am extremely grateful to them all. I also received assistance from Klaas van Berkel, Rienk Bijma, Dirk A. Buiskool, Dorien Daling, Kostas Gavroglu, H.A.L. de Haas, H.P. van Heel, L. Hettinga, Aukje Holtrop, W.J. Huiskamp, Johan Jeltema, P.H.M. Keesom, Peter Kes, Anne Kox, Anneke Levelt Sengers, Paul H.M. Meijer, F.T.M. Nieuwstadt†, Marieke van Oostrom and Arent Pol.

I want to say a special word of thanks to the Kamerlingh Onnes family. Heike Kamerlingh Onnes, one of the grandsons, took great interest in my project throughout, and it is extremely sad that he did not live to see its completion. Other members of the family too, including G.A. Kamerlingh

Onnes-Baroness van Dedem, her daughter Jeanne Kamerlingh Onnes, J.C. de Knegt, M.G. Wagenaar Hummelinck and his son Diederik, provided a great deal of assistance.

Since gaining my doctorate on 10 February 2005, I have remained active in the history of science. Following an initiative of Frans Saris, dean of the mathematics and natural sciences faculty of the University of Leiden, I was appointed on 1 August 2005 for one day a week as an associate professor in the history of science, alongside my work as a science journalist. I retained this part-time professorship when I took up my new position as director of Museum Boerhaave in Leiden on 1 September 2006. This museum owns a large number of instruments and appliances from the days of Heike Kamerlingh Onnes, including the helium liquefier that made Leiden into the coldest place on earth in 1908. It goes without saying that the celebrations planned for the commemorative year of 2008 will include an exhibition on the epoch-making cold produced in Leiden.

This English edition of my Kamerlingh Onnes biography was made possible by a generous subsidy provided by the Netherlands Organisation for Scientific Research (NWO). Beverley Jackson translated the text into English. I am extremely grateful to her for the professionalism with which she acquitted herself of this far from easy task. Her meticulousness and tenacity, the constant questions she fired at me, the ambiguities she identified and sought to clarify, our discussions on notes and indexing: this translation has greatly benefited from the efforts and expertise of a translator who also displayed a real commitment to the book. Any errors that may appear in the text are the sole responsibility of the author.

Finally, I should like to thank my wife and children. Writing a biography of this kind takes up a great deal of time, and many a time I neglected my family responsibilities so that I could do some Kamerlingh Onnes. Petra, Iris and Felix: please forgive me for having crept upstairs to my office so often. I dedicate this book to you.

Dirk van Delft, August 2007

Introduction

It was Bastiaan Willink, writing in *Hollands Maandblad* in 1980, who introduced the idea of the Netherlands' 'Second Golden Age'.¹ Or rather, re-introduced it, unaware of the speech that Melchior Jan Bos had made in 1914 as president of Groningen student fraternity, 'Vindicat atque Polit' on the occasion of his university's three hundredth anniversary. Bos too had spoken of a golden – or 'even diamond' – age.² He was referring to the early years of the twentieth century, when the natural sciences flourished in the Netherlands, most notably producing Nobel prizes for Van 't Hoff (1901), Lorentz and Zeeman (1902), Van der Waals (1911) and Kamerlingh Onnes (1913). A long period of decline was over; the country finally had great men of science again to rank alongside Christiaan Huygens, Antoni van Leeuwenhoek, and Jan Swammerdam.

Willink's PhD thesis (1988) dealt with the factors underlying peaks in scientific achievement in the Netherlands and other parts of Europe. His work was widely quoted, and 'Second Golden Age' soon became a commonplace. Still, Willink's approach may be criticised on several counts. A glaring omission in his list of top researchers (each of whom he measures up, quite literally, by totting up the number of columns devoted to them in the *Poggendorf* surveys) is his failure to mention the protagonist of this book, Heike Kamerlingh Onnes.³ One afternoon, in a seminar on the role of the Academy of Sciences in the Second Golden Age, held in the Trippenhuys building on 21 September 2001, Klaas van Berkel challenged Willink's emphasis on the overriding importance of the educational reforms of 1863 (introduction of the HBS-type secondary school) and 1876 (new Higher Education Act). Van Berkel himself

¹ B. Willink, 'Een inleiding tot de Tweede Gouden Eeuw. De wetten van 1863 en 1876 en de wedergeboorte van de Nederlandse natuurwetenschap', *Hollands Maandblad* 22 (1980) 3-9.

² Klaas van Berkel, 'De oude en de nieuwe universiteit', *Citaten uit het boek der natuur* (Amsterdam 1998) 149-150.

³ Bastiaan Willink, *Burgerlijk sciëntisme en wetenschappelijk toponderzoek: Sociale grondslagen van nationale bloeiperiodes in de negentiende-eeuwse bètawetenschappen* (Rotterdam 1988).

suggested the fast-changing social dynamics at the end of the nineteenth century as the wider cause.⁴ And anyway, he demanded, when had this Second Golden Age come to an end? Did it end with the First or the Second World War? Wijnand Mijnhardt even advocated abolishing the term ‘Golden Age’ altogether – the first as well as the second – because these terms were rooted in ‘a highly specific, timebound view of Dutch history, one bound up with the cultural preoccupations of 1900’.⁵ But the Second Golden Age found its way into the cultural history overview *1900* by Jan Bank and Maarten van Buuren all the same,⁶ and the interest in this period, as a special chapter in the history of science, has greatly increased.

With their four Nobel prizes, the Dutch physicists of the Second Golden Age made the Netherlands into ‘ein Grossmacht in der Physik’,⁷ with Leiden its undisputed centre. Yet this position has not been reflected in the surveys of Dutch physicists that have been published to date. The Utrecht physics presided over by W.H. Julius and L.S. Ornstein was the subject of a doctoral thesis by Han Heijmans in 1994,⁸ and a biography of Buys Ballot (by his successor, E. van Everdingen Jr) was published in 1953.⁹ In 2001, Ad Maas wrote his PhD thesis on physics in Amsterdam in the period 1877 to 1940.¹⁰ On J.D. van der Waals, whose ground-breaking dissertation of 1873 on the continuity between a liquid and its vapour marked the beginning of the Second Golden Age, a Russian biography was published in 1985, an English edition of which appeared eleven years later: *Van der Waals and molecular science*.¹¹

But there have been no general surveys of physics at Leiden or Groningen. While the latter, under Haga and Wind, was modest in scale and made little impact, Kamerlingh Onnes in Leiden was engaged in ‘Big Science’. Both he and his friend Lorentz, professor of theoretical physics, were internationally renowned. So there is every reason to remedy this hiatus in the history of science. This book discusses the experimental science conducted in Leiden under the leadership of Heike Kamerlingh Onnes. A.J. Kox, professor of the

⁴ K. van Berkel, ‘Stuwende kracht of deftig ornament?’, in K. van Berkel (ed.), *De Akademie en de Tweede Gouden Eeuw* (Amsterdam 2004) 8–9.

⁵ W.W. Mijnhardt, ‘De Akademie in het culturele landschap rond 1900’, in K. van Berkel (ed.) *De Akademie en de Tweede Gouden Eeuw* (Amsterdam 2004) 36.

⁶ Jan Bank and Maarten van Buuren, *1900. Hoogtij van burgerlijke cultuur* (The Hague 2000) 270–272.

⁷ Waldemar Voigt, *Chemiker Zeitung*, 11 December 1913, 1518–1520.

⁸ H.G. Heijmans, *Wetenschap tussen universiteit en industrie. De experimentele natuurkunde in Utrecht onder W.H. Julius en L.S. Ornstein 1896–1940* (Rotterdam 1994).

⁹ E. van Everdingen Jr., *C.H.D. Buys Ballot, 1817–1890* (The Hague 1953).

¹⁰ Ad Maas, *Atomisme en individualisme: de Amsterdamse natuurkunde tussen 1877 en 1940* (Hilversum 2001).

¹¹ A.Y. Kipnis, B.E. Yavelov and J.S. Rowlinson, *Van der Waals and molecular science* (Oxford 1996).

history of physics in Amsterdam, has been working on Lorentz for many years, and publication of volume 1 of his selection of Lorentz's scientific correspondence is scheduled for the end of 2007.¹² The life and work of Lorentz's successor Paul Ehrenfest are dealt with in Martin Klein's biography *Paul Ehrenfest: the making of a physicist*.¹³ Unfortunately, volume two of this work, which was to cover the period after the First World War up to Ehrenfest's tragic suicide in 1933, has still not been published, and seems unlikely to materialise. However, the Leiden PhD student Marijn Hollestelle embarked on a project on Paul Ehrenfest's Leiden years in 2006.

When Heike Kamerlingh Onnes took up his professorship in Leiden on 11 November 1882, he knew exactly what he wanted: to verify experimentally and elaborate on the molecular theories of his 'esteemed friend' Van der Waals. This programme led him to build up a cryogenic laboratory that was unique in the world, a technologically advanced and large-scale 'cold factory' that was continuously engaged in high-level experimental physics. The central question of this book is: how can we explain the extraordinary success of this enterprise, which was unique in the Netherlands of its day? Onnes's qualities as a scientist, his organisational talents, and his personality will all be explored along the way, and the latter two qualities, in particular, will emerge as the key to his success.

Closely related to this key question is the choice of genre – biography – to which I shall return presently. This book sets out to clarify not only the science practised within the walls of the Leiden laboratory, but also the surrounding context, which illuminates the way in which Onnes functioned as a scientist. We shall therefore be looking at his contemporaries, his environment, his relationship with both government and industry, we shall look at his national and international status, and seek to explain why he succeeded where his rivals failed. And in considering the man, Heike Kamerlingh Onnes, we shall look at his roots, at where he stood in this period of history, at his style, his views of research and education, and his methods. A far from trivial factor was his fragile health, with bronchitis an ever-present danger. The book will try, in short, to arrive at an assessment of the man who became known in some circles as 'Mr Absolute Zero'. In many cases, the most helpful sources turn out to be unpublished archival material, such as correspondence, budgets, notebooks and annual reports.

¹² A.J. Kox (ed.), H.A. Lorentz, *Selected scientific correspondence*. vol. 1 (New York 2007). A biography is in preparation.

¹³ Martin J. Klein, *Paul Ehrenfest, Volume I: the making of a physicist* (Amsterdam 1970).

Although no biography of Kamerlingh Onnes or cohesive overview of Leiden's low-temperature physics has been published before, many parts of the subject have been discussed. There is a fairly accessible account of Leiden's research and the development of the cryogenic laboratory (conveniently collected in the *Communications from the Physical Laboratory at the University of Leiden*) in the two commemorative volumes presented to Onnes when he celebrated first the 25th anniversary of his doctorate (1904),¹⁴ and later the 40th anniversary of his professorship (1922).¹⁵ These books (unlike the collections of rather disjunctive articles present to other professors on such occasions) provide a clear picture of the research that was carried out. But, unsurprisingly, they tell us nothing about irregularities and embarrassments such as the row between Van der Waals and Onnes about retrograde condensation, or the resounding triumph of Walther Nernst's Berlin group in the area of specific heat, leaving Leiden far behind. Another book published in 1922 is the biographical sketch of the Utrecht chemist Ernst Cohen, *Van Boerhaave tot Kamerlingh Onnes*.¹⁶ A quarter of a century later, two more appeared, radiating a similar air of admiration. Of these, the biography of August Crommelin (included in the series *Nederlandsche beelden der wetenschap*)¹⁷ is the most interesting. Crommelin started out as a student at the Leiden laboratory in 1903, becoming supervisor and deputy director in 1907.

The recent literature on Leiden physics as presided over by Kamerlingh Onnes and Lorentz has long been dominated (among Dutch science historians) by an article published in 1984 by the historian Jan Oosterhoff.¹⁸ Oosterhoff singled out the HBS (four years after Willink) as having paved the way for what would come to be known as the Second Golden Age. His description of Leiden physics is in general outstanding, although a few points of criticism may be made. The 'philosophical extracts' from the works of Fichte, Hegel and Kant that Oosterhoff describes Heike as having made as a student in Groningen were in reality little more than rather sketchy notes on Van der Wijck's lecture for university entrants. In addition, Oosterhoff's comment that Onnes seemed beforehand to have little chance of succeeding Rijke as professor in 1882 is incorrect: Heike had influential friends in Leiden, and went into

¹⁴ *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904).

¹⁵ *Het Natuurkundig Laboratorium der Rijksuniversiteit te Leiden in de jaren 1904-1922* (Leiden 1922).

¹⁶ Cohen, Ernst, *Van Boerhaave tot Kamerlingh Onnes* (Utrecht 1922).

¹⁷ C.A. Crommelin, 'Heike Kamerlingh Onnes', in Sevensma T.P., (ed.), *Nederlandsche beelden der wetenschap* (Amsterdam 1946) 201-238.

¹⁸ J.L. Oosterhoff, 'De opkomst van een "Vaderlandsche Natuurkunde" aan de Leidse Universiteit in de tweede helft van de negentiende eeuw', in W. Otterspeer (ed.), *Een universiteit berleeft* (Leiden 1984) 103-124.

the appointments procedure full of confidence. Nor is it correct to state that the plans for the new chemistry building worked to his advantage: although Onnes was promised the space to be vacated by the chemistry department shortly after he arrived, the plans were not realised for many years; by the time the laboratory finally acquired the extra space, in 1919 (the renovations were not completed until 1924), he was close to retirement. But the main shortcoming of Oosterhoff's article is that it never sets foot outside Leiden – most unfortunately, since Onnes's cryogenic efforts manifestly took place in an international arena.

Since Oosterhoff's article, Kamerlingh Onnes has been discussed in numerous biographical sketches for a wide readership, the best known of which are those by L. Beek¹⁹ and H.N. de Lang.²⁰ The slim book *Doctor Diepvries* ('Dr Deep-Freeze') by Marco Daane is unreliable in matters of detail.²¹ The same applies to *Absolute zero and the conquest of cold*, a lively history of cold by the outsider Tom Shachtman.²² More accurate – but likewise confined to a string of breakthroughs and without acknowledgments of sources – is *The quest for absolute zero* by Kurt Mendelssohn, a physicist who worked on the cryogenic front in Germany and England from the 1930s to the 1960s.²³ Extremely colourful are the passages on Leiden physics in the autobiography of H.B.G. Casimir.²⁴ More recent is an introduction by the Colombian engineer Simón Reif-Acherman.²⁵ In a wider context, Leiden physics features in Klaas van Berkel's *In het voetspoor van Stevin*,²⁶ (the English edition is included in *A history of science in the Netherlands*),²⁷ and in greater depth in an article by Frans van Lunteren on the rise of experimental physics in the nineteenth-century Netherlands.²⁸

¹⁹ L. Beek, 'Heike Kamerlingh Onnes: pionier van de lage temperaturen', *Pioniers der natuurwetenschappen: van Mercator tot Zernike* (Assen 1983).

²⁰ H.N. de Lang, 'Heike Kamerlingh Onnes 1853-1926', in A.J. Kox and M. Chamalaun (ed.), *Van Stevin tot Lorentz: portretten van Nederlandse natuurwetenschappers* (Amsterdam 1990) 209-225.

²¹ Marco Daane, *Doctor Diepvries: H. Kamerlingh Onnes (1853-1926)* (Leiden, n.d.).

²² Tom Shachtman, *Absolute zero and the conquest of cold* (Boston 2000).

²³ Kurt Mendelssohn, *The quest for absolute zero* (New York 1966).

²⁴ H.B.G. Casimir, *Haphazard reality: half a century of science* (Amsterdam 1983).

²⁵ Simón Reif-Acherman, 'Heike Kamerlingh Onnes: master of experimental technique and quantitative research', *Physics in Perspective* 6 (June 2004) 197-223.

²⁶ Klaas van Berkel, *In het voetspoor van Stevin. Geschiedenis van de natuurwetenschap in Nederland 1580-1940* (Meppel 1985).

²⁷ Klaas van Berkel, Albert van Helden and Lodewijk Palm (ed.), *A history of science in the Netherlands* (Leiden 1999).

²⁸ Lunteren, Frans van, "'Van meten tot weten": de opkomst der experimentele fysica aan de Nederlandse universiteiten in de negentiende eeuw', *Gewina* 18 (1995) 102-138.

Science historians and physicists have mapped out various aspects of Leiden physics since 1980. One example is Anne C. van Helden's description of the cascade for the liquefaction of oxygen.²⁹ The work on mixtures, including the Amsterdam component, is discussed in a detailed monograph by Anneke Levelt Sengers.³⁰ Her book, which presupposes a knowledge of physics to bachelor level, gives a thorough and lucid account of the work in this complex field, but fails to provide a science-historical context for the thermodynamics it deals with. This context is described, however, in two articles by Per Fridtjof Dahl which unravel the work on superconductivity in Leiden and elsewhere in minute detail;³¹ the articles were later published in book form.³²

Finally, the Greek science history writers Kostas Gavroglu and Yorgas Goudaroulis should be mentioned, who have published half a dozen articles since 1984.³³ Their focus is on methodological questions, related specifically to the discoveries of superconductivity and superfluidity. In 1991 these articles were integrated into an introductory text for a wide-ranging selection of articles by Onnes: *Through measurement to knowledge. The selected papers of Heike Kamerlingh Onnes 1853-1926*.³⁴ Superconductivity is very well represented, but instrumental science, an essential part of Leiden's work (and its success), is

²⁹ Helden, Anne C. van, *De koudste plek op aarde: Kamerlingh Onnes en het lage-temperatuuronderzoek, 1882-1923* (Leiden 1989).

³⁰ Johanna Levelt Sengers, *How fluids unmix. Discoveries by the school of Van der Waals and Kamerlingh Onnes* (Amsterdam 2002).

³¹ P.F. Dahl, 'Kamerlingh Onnes and the discovery of superconductivity: The Leyden years 1911-1914', *Historical Studies in the Physical Sciences* 15 (1984) 1-37.

P.F. Dahl, 'Superconductivity after World War I and circumstances surrounding the discovery of a state B=0', *Historical Studies in the Physical and Biological Sciences* 16 (1986) 1-58.

³² Dahl, Per Fridtjof, *Superconductivity: Its Historical roots and development from mercury to the ceramic oxides* (New York 1992).

³³ K. Gavroglu and Y. Goudaroulis, 'Some methodological and historical considerations in low temperature physics. The case of superconductivity, 1911-1957', *Annals of Science* 41 (1984) 135-149;

K. Gavroglu and Y. Goudaroulis, 'From the history of low temperature physics: prejudicial attitudes that hindered the initial development of superconductivity theory', *Archives for the History of the Exact Sciences* 32 (1985) 377-383;

K. Gavroglu and Y. Goudaroulis, 'Some methodological and historical considerations in low temperature physics II: The case of superfluidity', *Annals of Science* 43 (1986) 137-146;

K. Gavroglu and Y. Goudaroulis, 'Kamerlingh Onnes' researches at Leiden and their methodological implications', *Studies in the History and Philosophy of Science* 19 (1988) 243-273;

K. Gavroglu and Y. Goudaroulis, 'From Physica to Nature: The tale of a most peculiar phenomenon', *Janus* 73 (1990) 53-84;

K. Gavroglu, 'The reaction of the British physicists and chemists to Van der Waals's early work and the law of corresponding states', *Historical Studies in the Physical Sciences* 20 (1990) 200-237.

³⁴ Kostas Gavroglu and Yorgos Goudaroulis (ed.), *Through measurement to knowledge. The selected papers of Heike Kamerlingh Onnes 1853-1926* (Dordrecht 1991).

omitted altogether. The book also contains a brief overview of key moments in Leiden's cryogenics, larded with quotations from the *Communications*, by R. de Bruyn Ouboter, professor emeritus of experimental physics at Leiden University since 1998.

What many of these studies have in common is their neglect of archival material, especially that in Dutch. Yet Kamerlingh Onnes's correspondence with Van der Waals, Zeeman, Lorentz and Keesom, to name just a few of the leading figures in this story, not to mention his letters to the university's board of governors, bring to life, as nothing else can, questions of motives, tactics, and styles of leadership. Nor do any of the studies published thus far look in any depth at Heike Kamerlingh Onnes the man. But it was precisely his character, his social instinct, his courage, iron will, vision and shrewdness that ensured the success of his mission.

This explains the decision to cast the history presented in these pages in the form of a biography. Of course, biography has attracted plenty of controversy among science historians. In the early days of this field, the late nineteenth century, the biographical approach predominated. But this choice often revolved around factors other than a desire to clarify history; it was shot through with motives such as nationalism, as well as a desire to preach moral values and to invoke the salutary example of a glorious past.³⁵ Hagiography has little to offer the history of science. That genre provided great names, anecdotes, a succession of leaps forward – everyone who helped to build the temple of science was glorified for the stones he or she had added.³⁶ Books written in this strain are still being published today.

But there is an alternative. In his article 'In defence of biography', science historian Thomas L. Hankins, himself the author of a biography of the Irish mathematician Hamilton, provides a spirited defence of the genre.³⁷ He envisages a type of biography that fulfils three basic requirements. In the first place, the protagonist's science must not be detached from his or her personal life, so that the deeper motives underlying that science can come to the fore. For one thing, this implies not limiting the science to publications; such an approach robs the biography of all value to a science historian, who wants to know what motivated the person's choices, how his ideas developed, and how he tested them. Even if lab books and drafts of letters are almost illegible – 'copying the

³⁵ K. van Berkel, 'De beoefening van de wetenschapsgeschiedenis in Nederland in de tweede helft van de negentiende eeuw', *Gevina* 18 (1995) 181-191.

³⁶ Thomas L. Hankins, 'In defence of biography: the use of biography in the history of science', *History of Science* 17 (1979) 1-16.

³⁷ *Ibid.*

text out doesn't help', said Onnes; and that was after handing in some copy for a weekly magazine! – and even if some of that science is far from plain sailing for the biographer, the necessary effort will have to be made. It cannot do any harm to write a biography of Kamerlingh Onnes armed with a degree in experimental physics. Likewise, it can only be an advantage to have first-hand knowledge of the laboratory in which the protagonist worked. 'You can hardly write a biography without being involved', said Sem Dresden, the author of *De structuur van de biografie*³⁸ – and the brother of Max Dresden, the biographer of H.A. Kramers.

Hankins's second criterion is that the different aspects of the protagonist's life must be integrated into a coherent whole. Thirdly, the biography must be *readable*: 'Writing biography is unquestionably a literary art'.³⁹ The reader's interest must be engaged – something that can only be achieved by deploying literary devices such as style, narrative tension, balance, and so on. In short: 'A fully integrated biography of a scientist which includes not only his personality, but also his scientific work and the intellectual and social context of his times, is still the best way to get at many of the problems that beset the writing of the history of science.'

The challenge consists in striking a balance. One published biography of Einstein contains a bathful of family misfortunes diluted with a thimbleful of science, while Abraham Pais's 'Subtle is the Lord...' is virtually inaccessible to a non-physicist.⁴⁰ My book seeks to navigate between these extremes. This biography of Kamerlingh Onnes sets out to advance the history of science while reaching out to a wide readership.

³⁸ S. Dresden, *Over de biografie* (Amsterdam 1987) 245.

³⁹ Thomas L. Hankins, 'In defence of biography: the use of biography in the history of science', *History of Science* 17 (1979), 9.

⁴⁰ Dirk van Delft, 'Heike Kamerlingh Onnes en de geleerdenbiografie', *De Gids* 158 (1995) 96-102

Prologue

A little cup of helium

On the day that Heike Kamerlingh Onnes liquefied helium, Leiden briefly became the coldest place on earth. It was 10 July 1908, a wet and windy day shortly before the summer holidays. The local newspaper, the *Leidsch Dagblad*, had little to report. In Germany, Kaiser Wilhelm had sent 70th birthday greetings to Count Zeppelin, ‘the man who, by constructing a true dirigible balloon, had possibly provided the impetus for the biggest change in world transport and human societies since the discovery of the steam engine’. The week before, Zeppelin had successfully travelled from Friedrichshafen to Switzerland by airship. The military use of zeppelins during the First World War was to prove a bugbear for Onnes, since it made it harder for him to procure the helium he needed. For the rest, the newspaper reported that the fishing-vessel ‘Minister Kuyper’ had delivered the first herrings of the season to the fish market in Katwijk, and that the Netherlands’ ‘most famous singer-poet’ Koos Speenhoff would be performing in the open air that evening outside ‘t Posthof café in Oegstgeest (admission 25 cents).¹

Onnes, awakened before dawn by his wife Betsy (known as Bé), ordered a carriage at 5 a.m. to take him from Huize ter Wetering, his fine country house on the river Galgewater, to Steenschuur. There, in the city centre, opposite Van der Werff Park, stood the Physics Laboratory over which he presided. Since his arrival in 1882 he had applied himself with vision and perseverance to setting up a cryogenic laboratory, and on this 10th day of July, the anniversary of his doctorate, he would attempt to move another step closer to absolute zero.

Onnes donned his white coat as soon as he arrived at the laboratory. His technicians, led by manager Gerrit Jan Flim, were already hard at work. The day before, they had increased the stock of liquid air to 75 litres, and together with Onnes they had checked the apparatus for leakages, pumped it out to create a vacuum, and then filled it with pure gas.² Now, in the early morning,

¹ *Leidsch Dagblad*, 10 July 1908.

² Details derived from H. Kamerlingh Onnes, ‘Het vloeibaarmaken van helium’, *Verslagen der Afdeling Natuurkunde van de KNAW* 17 (supplement, June 1908) 163-179. *Comm.* 108.

the first task was to liquefy the hydrogen. While the pumps thundered away in lab Aa – the hydrogen apparatus had been in use since the spring of 1906 – Onnes and his assistants rushed around turning taps, connecting and disconnecting gas cylinders, and keeping an eagle eye on pressure gauges and thermometers. They did not stop for lunch. By 1.30 p.m., 20 litres of liquid hydrogen had been tapped into vacuum or ‘Dewar’ flasks, enough to launch the attack on helium in the adjoining room, lab E’.

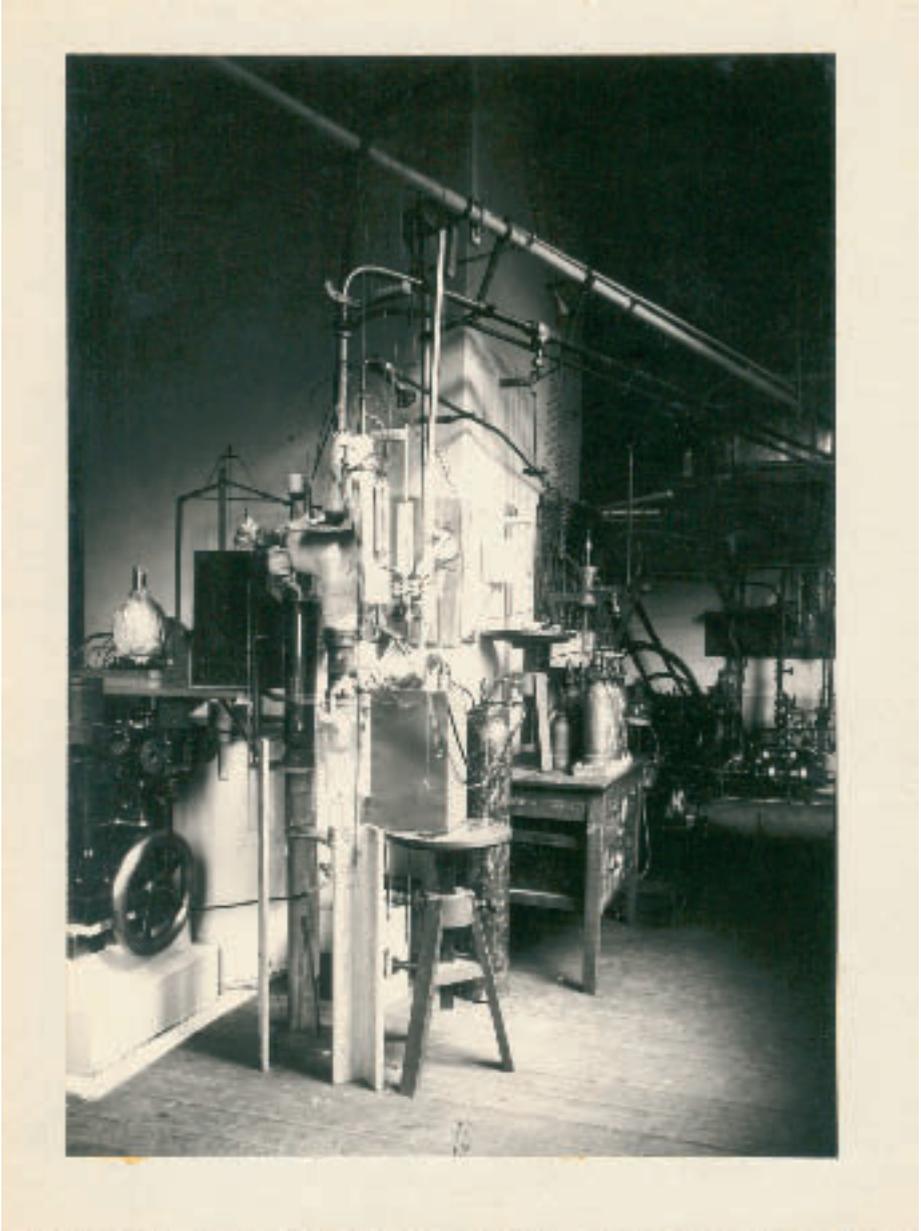
Onnes was less than optimistic about his chances of success; his previous attempt to subdue the last of the ‘permanent’ gases, in February, had been a fiasco. He had identified a flaky white cloud of material as solid helium, concluding that rapid expansion evidently caused the helium to change straight from a gas to a solid, like carbonic acid foam from a fire extinguisher. Elated, he had telegraphed James Dewar, his main rival in London, that the race was over: ‘Converted helium into solid’.³ Bé had also conveyed the great news to the artist Menso Kamerlingh Onnes, who was holidaying with his family in the English coastal resort of Torquay. ‘How wonderful that it went so superbly!’ Menso responded enthusiastically to his learned brother.⁴ The *Nieuwe Rotterdamsche Courant* of 13 March reported that Onnes’s achievement had been widely covered in the international press. Somewhat delayed (and mangled), the news reached the west coast of the United States. ‘Helium is Liquefied by German Professor’ wrote the *San Francisco Examiner* the following day. ‘Metal Heretofore Known Only as a Gas Reduced by Kammerlin Onnes at University of Leyden.’

All too soon, however, it became apparent that Leiden’s exultation had been premature. On further inspection the little cloud turned out to be hydrogen, which had been left behind in the helium as an unforeseen contaminant and had frozen during the cooling process. The students jeeringly referred to ‘hal-fium’, a joke that Onnes did not much appreciate. To make matters worse, the press and trade journals, including the *Globe*, the *Daily Telegraph*, and *Nature*, had immediately reported the news of the ‘solid helium’, so that there was no alternative but to issue a full public retraction.⁵ Dewar had already set the record straight in the *Times*, the newspaper to which he had first reported Leiden’s ‘triumph’ after receiving the jubilant telegram.

³ Telegram from Heike Kamerlingh Onnes to Dewar, 5 March 1908, archives of the Royal Institution.

⁴ Menso to Heike, 2 March 1908, MB, archives of Heike Kamerlingh Onnes, inv. no. 189.

⁵ *The Globe*, 3 March 1908; *Daily Telegraph*, 10 March 1908; *Nature*, 5 and 12 March, 16 and 23 April 1908.



Ill. 1. The installation with which Kamerlingh Onnes became the first to liquefy helium, on 10 July 1908. On that day, Leiden became the coldest place on earth.

For the new attempt, Onnes was using 200 litres of helium gas, with another 160 litres in reserve – substantially more than in February. It had been extracted from thorium-bearing monazite sand, which Heike's brother Onno Kamerlingh Onnes, director of the Commercial Information Office in Amsterdam, had helped to procure in large quantities from America, by way of Hamburg. Purifying the helium gas was a particularly gruelling task, which demanded the concentrated efforts of four chemists for several months. They heated the grains of sand, causing them to explode and release the gas. To eliminate impurities, they then cooled the gas with liquid air, burned it with oxygen over copper oxide, compressed it at the temperature of liquid hydrogen (-253°C) and passed it over a charcoal filter. At last, on 10 July, the helium gas was finally pronounced sufficiently pure.

While the hydrogen system faithfully turned out its four litres an hour from 8.30 a.m. onwards, a pump throbbed away, creating a vacuum in the helium apparatus, and the last remaining impurities were removed from the helium gas. Liquid air was introduced into the space between the outer and inner walls of the vacuum glass vessel, after which liquid hydrogen was poured into the vessel's interior. At 2.30 p.m. it was time to start cooling the helium. Only 30 minutes later, the temperature had already fallen to -180°C . At 4.20 – after a worried Bé had come to check on the scientists' progress and coaxed her toiling husband into taking a few bites of a sandwich – they started up a pump to circulate the helium. An hour later, the gas was under a pressure of 100 atmospheres. The trick was to allow it to expand in a vacuum – surrounded by glasses filled with liquid hydrogen and liquid air – during which its temperature would fall slightly, so that the helium flowing back would pre-cool the helium flowing in. The same principle was applied when liquefying hydrogen, but whether it would work with helium remained to be seen. Tensions were running high in lab E'.

They seemed to be heading for another failure. The helium thermometer was scarcely budging, and a second thermometer had given up the ghost. Then, to Onnes's relief, the temperature began to fall, and by 6.30 p.m., as the helium expanded at an accelerated rate, the temperature was already lower than that of liquid hydrogen. With fluctuations it gradually reached -267°C , only 6 degrees above absolute zero. Meanwhile, Onnes was down to the last flask of helium, which he had just attached to the apparatus. The helium had circulated twenty times, and there was still scarcely anything to be seen besides a little swirling.

Then at -269°C , the thermometer suddenly started to display a remarkably stable value. That was at 7.30 p.m. What was going on? The chemist Schreinemakers, one of a series of Onnes's associates who had come to see how the experiment was going, noticed that the thermometer appeared to be

standing in a bath of liquid. He was right. When Onnes peered at the glass containing the helium one more time, through the Dewar flasks, liquid air and liquid hydrogen, and pointed a lamp at it from an oblique angle below, he could see the surface of the liquid. The electric wires of the thermometer were clearly poking through it. 'After the surface had once been seen', Onnes wrote in his report for the Netherlands Academy of Arts and Sciences, 'it was no more lost sight of. It stood out sharply defined like the edge of a knife against the glass wall.'

The experiment had produced 60 ml of liquid helium, just enough for a little teacup. As soon as the circulation was stopped, it slowly evaporated. At 8.30 p.m., when only 10 ml of liquid was left, Onnes pumped away the vapour above the liquid in an effort to freeze the helium. Unfortunately, bringing the temperature down to about 1.5° above absolute zero proved insufficient. At 9.40, with just a few millilitres of liquid helium remaining in the plant, Onnes called it a day; they had done enough. 'Not only had the apparatus been strained to the uttermost during this experiment and its preparation', he wrote in his report to the Academy, 'but the utmost had also been demanded from my assistants. But for their perseverance and their ardent devotion every item of the program would never have been attended to with such perfect accuracy as was necessary to render this attack on helium successful. In particular I wish to express my great indebtedness to Mr. G.J. Flim, who not only assisted me as chief of the technical department of the cryogenic laboratory in leading the operations, but has also superintended the construction of the apparatus according to my direction, and rendered me the most intelligent help in both respects.'

Exhausted, Onnes stepped into the carriage that would take him home. Since the 'halfium' debacle still rankled in his memory, he decided against rushing to announce that he had successfully liquefied helium, choosing instead to spread the news through the Academy. By Tuesday the newspapers had heard the story from that source; *Nature*, deciding to be more circumspect this time, did not publish anything about it until 13 August. Onnes did send word that weekend to his pupil Pieter Zeeman and mentor Johannes Diderik van der Waals, both of whom were professors in Amsterdam.⁶ By chance, Van der Waals, whose theoretical work on gases and liquids had been a shining beacon to Onnes, was to give his parting lecture on Monday 13 July. Onnes, who was unable to attend, could not have given him a finer leaving present. 'So I hope that although I am unable to attend your farewell ceremony, I can in this way enhance your enjoyment of this day', wrote Onnes.

⁶ Heike Kamerlingh Onnes to Van der Waals, 11 July 1908, N-HA, Van der Waals archives; Heike Kamerlingh Onnes to Zeeman, 12 July 1908, N-HA, Zeeman archives, inv. no. 82.

The liquefaction of helium was an international milestone in experimental physics. The conquest of the final ‘permanent’ gas, on 10 July 1908, marked the end of an era. At the same time, it opened up a new world of low temperatures, an unexplored territory of extreme cold, full of potential surprises. Suddenly the path was clear for the discovery of superconductivity, which followed in 1911. For years, Leiden contained the coldest place on earth. The Physics Laboratory remained the only institute to have produced liquid helium until 1923, even though Kamerlingh Onnes had published the full details of his method. How can this be explained? In 1922, Onnes’s associate and prospective successor Johan Kuenen said, ‘Helium was tamed only by deploying every available resource and handling it in a strictly systematic way at every point. The victory can unquestionably be attributed to the painstakingly meticulous design and construction of even the smallest component, the refusal to rush anything, and steady progress along the chosen path without stopping to “try things out” along the way’.⁷

⁷ *Het Natuurkundig Laboratorium der Rijksuniversiteit te Leiden in de jaren 1904-1922* (Leiden 1922) 20.

1. Between Schiffpot and Noorderhaven

If we follow the trail of Heike Kamerlingh Onnes back in time, we end up in the terp area of northwest Groningen. The first inhabitants of this region settled here centuries before the Christian era, when it was a desolate place, scarcely protected from the wind and sea. Drawn by the fertile clayey soil, they first made their homes on sites where the mud flats had silted up high enough to be relatively safe. But amid that level, treeless land, traversed by gullies and channels that admitted seawater twice daily or drained rainwater from the sandy soil of Drenthe, where angry skies shaped the character of the landscape, they soon sought better protection, in settlements that were artificially elevated, using household waste and manure or – more effectively – clay and salt marsh turf. Dozens of these ‘terps’ came into being, following the edges of the old mudflats and dotting the landscape like strings of beads.

The Romans shook their heads at the locals’ forlorn battle with the water. Pliny the Elder (AD 23-79), who visited the area of the Friesian Islands as an army officer and wondered whether its soil belonged to the land or the sea, wrote in his *Historia Naturalis* of an ‘impoverished nation’ that lived ‘in huts on man-made hills or elevations’. ‘They resemble sailors when the water covers the surrounding area, and shipwrecked survivors when the water recedes. [...] With their hands they gather the mud, which is dried more by the wind than the sun. They use it to cook their food and to warm their limbs, which are battered stiff by the north wind.’¹

In the Middle Ages, the demand for more farmland prompted the people to build dikes. Thus polders were created among the inlets of the Wadden Sea and expanded in the course of time. A thousand years later, the result of all that human intervention is a landscape traversed by the meandering Reitdiep, which until 1877 linked the city of Groningen with the sea. Winding cart tracks closely follow the elevated areas of the old marshland. The remains of centuries-old dikes, rendered redundant by the locks at Zoutkamp, are still visible.

¹ Pliny, *Historia Naturalis*, book 16.

And the precious fertile soil of the terps has been plundered so eagerly that sometimes only enough remains to support a thirteenth-century church, always with its choir facing east and a separate tower with a gabled roof.

Amid this rugged Groningen landscape, halfway between the villages of Feerwerd and Garnwerd, at the intersection of the Aduarderdiep canal and the road known as Torensmaweg, a seemingly misplaced complex of sheds has been constructed of deep-red bricks and wood painted dark green. Today these buildings house a wholesaler's business in cattle feed, chemical fertiliser, sawdust and plastic covers for agricultural use, but until 1974 the firm that traded on this site – popularly known as 'Schifpot' – produced rooftiles, bricks and drainpipes in their millions. The old kilns and many of the drying sheds have since been demolished, but the pockmarked meadows round about – some plots of land have had clay gouged out of them down a metre in depth – bear eloquent witness to the brickworks that operated here for over a hundred years.

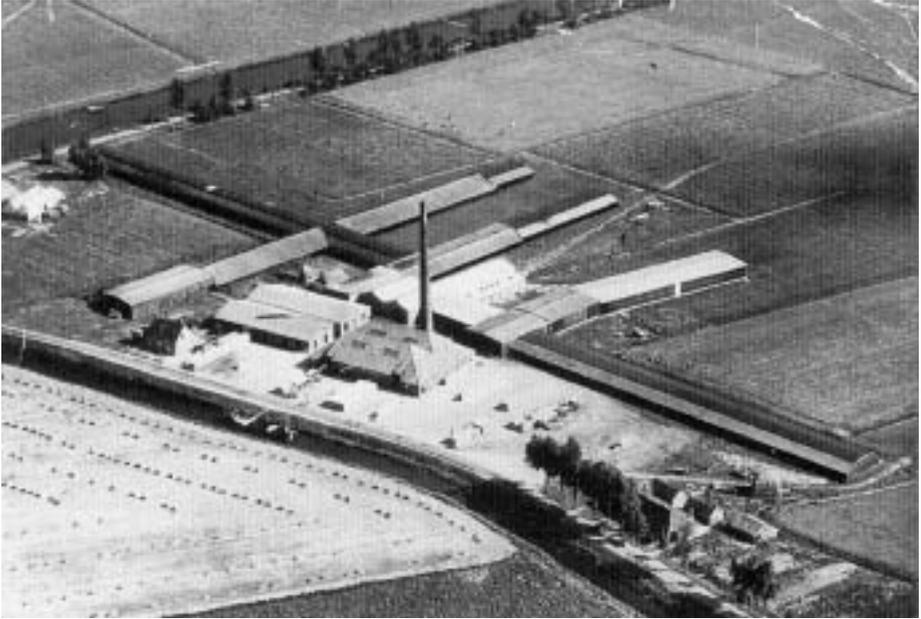
Those brickworks were established in 1855 by Harm Kamerlingh Onnes, Heike's father. Four years earlier he had started up his first brickworks on the banks of the Aduarderdiep, a little way past the terp known as Bolshuizen, and later on he would build a shell-lime kiln between the two factories.² In 1853, Harm and his brother Jeipe established the firm of H.K. Onnes & Co, and they were joined by a third partner, Roelof Blomberg de Boer from Feerwerd, from 1858 (when a large additional plot of land was purchased and a new injection of capital was welcome)³ until 1867. The business, whose offices were located at Kleine der Aa in the city of Groningen, and which also traded in construction materials, thrived until 1879 and kept the Onnes family in good stead. According to tax records the family's annual income rose to 3,000 guilders,⁴ which was equivalent to the headmaster's salary at the local state secondary school. Then came a crisis in agriculture that decimated turnover and forced prices down; the factory only narrowly evaded bankruptcy.

Bricks from Groningen were traded as far back as the Middle Ages. Bricks baked locally were used in 1193 for the church of Aduard monastery – which dug the Aduardiep two centuries later to improve drainage. While bricks were initially used only for churches, monasteries, strongholds, the occasional farmhouse, and houses for elite townspeople, around 1850 the demand for them increased sharply. The railways badly needed bricks to build stations and viaducts, the flourishing agriculture sector encouraged gentlemen farmers to

² Piet Lourens and Jan Lucassen, *Lipskeer op de Groninger tichelwerken* (Groningen 1987).

³ Deed of sale (*Koopacte*), 14 May 1858, archives of Mrs. Kamerlingh Onnes-Van Dedem.

⁴ Groningen Archives, archive 1469, inv. no. 768-794.



Ill. 2. Aerial photograph of the brickworks with drying sheds in Feerwerd, established in 1855 by H.K. Onnes, the father of Heike Kamerlingh Onnes (Groningen Archives).

undertake numerous building projects, and the new Fortifications Act (*Vestingwet*) of 1874 opened the way for the city of Groningen to build beyond its walls. In this favourable climate, brickworks mushroomed throughout the country; at one point there were five on the banks of the Aduarderdiep. They produced largely for the local market. The financial risks were limited: there was no need for major investments, and it was always possible to go back to farming. The Onnes family too, who were originally merchants, took the plunge; Harm was the first to do so, in 1851. The business soon proved successful, and he bought up one plot of land after another. Harm even proved to be a talented inventor: the shell lime kiln operated according to a patented procedure that he had devised himself.

As a boy, Heike, who was born on 21 September 1853, must have been enchanted by his father's brickworks and lime kiln. There was plenty of time to explore. The family spent the summer months at their country house in Feerwerd, a whitewashed villa with green window-frames and guttering, surrounded by trees and shrubs, which was known locally as Onnesbörg.⁵ Harm, in his

⁵ J.J. Delvigne (ed.), *Vroeger in Middag. Uit de historie van de gemeente Ezinge* (Bedum 1994) 67.

role of the proud father, doubtless coaxed his eldest son to come along on inspection tours of the site. Or perhaps Heike wandered around by himself – there was plenty to see at a brickworks. At the end of the holidays the Onnes family returned to the city by tow barge, or *smik*, the trip taking almost four hours. The children were allowed to take their finest pieces of self-made ceramics with them. At Zoutstraat 16, the premises near the Noorderhaven (Northern Harbour) that Harm purchased in 1866, the present-day owners discovered a toy horse baked from Feerwerd clay while they were restoring the garden to its original state.

Schifpot was the perfect place for a brickworks.⁶ All around lay an abundance of thick sea clay, which, with its high iron and low calcium content, produced the bright red bricks that give many buildings in Groningen their characteristic appearance. Since the clay deposits consisted of layers less than a metre thick immediately beneath the topsoil, there was the added advantage that deep pits were unnecessary, and the excavated area could remain in use as grazing land after the top layer had been put back in place. The clay was dug out by hand by day labourers and transported to the brickworks by tumbrel, and later by truck. The second raw material, peat, was shipped in from the area on either side of the border with the province of Drenthe.

Rather curiously, production at the Groningen brickworks was in the hands of seasonal labourers from the German principality of Lippe. Thousands of *Lipsker* had travelled the two hundred kilometres to the ‘wealthy’ coastal regions of the Netherlands as migrant workers since the seventeenth century, seeking employment mowing grass, cutting peat, or firing bricks. In this last area they became so skilled that they acquired a monopoly. Each brickworks had a team of six to eight *Lipsker* working from April to October under the supervision of a foreman. The team was put together by a *tichelbode* from Lippe, who had gone to see the owner of the brickworks in the winter to ask how many bricks would be needed in the coming season, and to negotiate the price per thousand bricks. The *Lipsker* slept at the brickworks and cooked their own food – often bean or lentil soup with a little pork, beef dripping, or potatoes. They worked until the light faded, which in the summer meant from 3.30 a.m. until 10 p.m. Sometimes the working day extended even longer: when the kiln was hot, peat had to be broken up and the men watched over the kiln in shifts. At the Schifpot factory, which produced bricks and tiles, *Lipsker* continued to work until 1869. The second Onnes factory, a little further away on the Aduarderdiep, employed them until 1884. After German unification in 1871, when

⁶ For information on the Groningen brickworks, see note 2; see also J.P. Koerts, *Uit de geschiedenis van de Groningse steenbakkerijen* (Groningen 1951); G.B. Jansen, *Baksteenfabricage in Nederland 1850-1920* (Arnhem 1987).

it became easier for the *Lipskers* to find employment in their own country, they were replaced by teams of Frisians from poor areas such as Zwaagwesteinde.

The first step in the manufacture of bricks was to knead the clay. In Groningen this was originally done by having a horse trample on clay with added water. Since tiles were fired from a heavier and better mixed clay, which was first laid aside for a time, the mixing at Schiffpot was done in a tile mill, a large wooden vat in which a horse turned a vertical spindle, to which were attached knives that cut through the clay and compressed it. The next step was to mould the clay into bricks or tiles. This was done in a shed. One member of the team passed the clay on to the *vormer* or moulder, who put it into a wooden mould that had been dipped in water and smoothed it over; a third team member would then lay out the unfired bricks and tiles to dry in special drying sheds with adjustable ventilation, which took a month. Slow and steady drying was essential for the rich Groningen clay, since otherwise cracks would develop.

As soon as 100,000 bricks or tiles were all dried and ready for the kiln, the firing could start. Groningen kilns consisted of vaulted stone chambers, each one placed separately in a firing shed with holes in the roof to allow the smoke to escape. The kiln was filled through an opening, after which the peat was lit, and the firing process, which took three to four weeks (just one week for tiles) and was regulated through stokeholes, could begin. When it was finished, the kiln was closed, to guarantee an even cooling process. The first bricks to be removed were still extremely hot. They were sorted into different grades, on the basis of their colour and sound, from pale bricks and grey clinkers to discoloured clinkers and first and second red. Outside, the bricks and tiles were piled up ready to be shipped. The Onnes family business also produced floor tiles on a smaller scale.

Heike watched all this in fascination. He loved making things, and eagerly explored his father's machines, feasting his eyes on them, reconstructing and improving them in his mind. 'I remember', Heike said later in an interview, 'giving my father the drawing of one of my new inventions on his birthday (I really can't remember what it was!) but it had to be something personal, something I'd made myself: my parents did not value a gift that had been bought. "But have you had that invention checked, my boy?" demanded my father; "Is it really something new and good?" "Oh!" I thought, startled: "So it's not enough to come up with an invention; you also have to check if it would really work!" That was the first time that the need for self-education and strict self-control was impressed upon me.'⁷

⁷ W. van Itallie-Van Embden, 'Prof. Dr. H. Kamerlingh Onnes. (1882 – 11 November 1922)', *Sprekende portretten* (Leiden, n.d.) 37-38.

For a boy like Heike, there was always plenty to see at Schifpot and in the vicinity. When the *Lipsker* workers were having their afternoon nap, between midday and 2 p.m., and there was nothing interesting going on at the Aduarderdiep either, he could always pay the 2 cents for the ferryboat to the other side, and go to Garnwerd. Beyond that village lay the river Reitdiep, used by steamboats and sailing vessels that were heading for the Wadden Sea or Groningen. Perhaps Heike went to see the flour and hulling mill on the dike just north of Ezinge, near the hamlet of Schoor, when it was demolished in 1864; perhaps he watched from close by, as a four-year-old boy, when the Joeswert mill was built in nearby Feerwerd.

Then there were trips to town. It must have been a great treat for Heike to travel in his father's tilbury. From the Onnesbörg villa they went at a trotting pace along the Lucaspad, a dirt path to Ezinge and Saaksum, after which they turned into a gravel road to Aduard. The astonishing beauty of the scenery can be seen in the serene watercolours of A. Schouman or the exuberant paintings of the group of artists known as De Ploeg. They entered Groningen along the Friese Straatweg. A journey of 20.5 kilometres, according to a contemporary signpost near Feerwerd – almost two hours' travelling time. While Feerwerd is two kilometres closer to Groningen than Ezinge today, the reverse applied in the past, before the towpath along the Aduarderdiep was replaced with a proper road.

By boat the journey led over the Aduarderdiep and Hoendiep canals (the Starckenborgh canal was not built until about 1930) and past the arched bridge at Steentil dating from 1700, a popular stopping-place. There must have been plenty of gossip in the deckhouse of the barge. Those sitting on deck would have seen in the distance the little church of Dorkwerd, which acquired a stone tower in 1869 to replace its wooden belfry. A schoolmaster's report from 1828, drawn up by Harm Guikema, provides some insight into the dominant character of the local population. The people of Dorkwerd – and there is no reason to assume that their fellows from Feerwerd were very different – were 'rather phlegmatic by nature, contemplative of demeanour, quiet, not inclined to be very sociable, hospitable to friends and acquaintances, but not to strangers [...]'.⁸ The schoolmaster also reported that they were superstitious and 'without any taste for the pursuit of the arts'. No wonder that when the British film director and artist Peter Greenaway announced his plans for a 25-metre high artificial terp and exhibition space at Dorkwerd in 2002, the project met with a frosty reception.

⁸ Quoted in *Noorderbreedte*, no. 2, 2001.

Never far from the Noorderhaven

Let us turn to Heike's family background. His great-grandfather Jeipe, born in 1744, was a sailmaker at the Noorderhaven and a member of Groningen's guild of sea-captains. His predecessors at the guild included Elle Onnes, who had settled in Groningen in 1650, Onne Elles, Elle Onnes and Onne Elles, the last two as guild headmen or *oldermannen*.⁹ Heike's grandfather, Heike Onnes, was a merchant and shopkeeper at the Noorderhaven. In 1815 he married Meisina Kamerlingh, the daughter of a timber merchant and building contractor, and he started a vintner's with her brothers Fokko and Willem Kamerlingh twelve years later.¹⁰ When Heike suddenly died in 1833 at the age of 42, he was survived by three sons and a daughter: Harm Kamerlingh, Jeipe, Heiko Menso and Frouke Heilina.

Harm, who thus retained his mother's last name as a second forename (a common enough custom at the time), was fourteen years old when his father died. The story is told in the Kamerlingh Onnes family that a wealthy uncle agreed to take care of Harm, while his mother ran a shop at the Noorderhaven.¹¹ After his uncle too died, this protected life abruptly ended, and Harm, who was then just 21 years old, had to fend for himself. 'Roll up your sleeves', said the uncle's three daughters, 'the silver and gold is for us'. Harm packed his things and left for Belgium, where he saw marble café tables and hit upon the idea of introducing them into the Netherlands. The idea proved a great success and he used the money he made to start his first brickworks on the Aduarderdiep in 1851.

Around the same time, Harm met a girl from Arnhem, Anna Gerdina Coers, the daughter of the architect Jacob Coers, who had designed Sonsbeek country estate. After the premature death of her mother, who left thirteen children when she died in 1843, the care for the entire household rested on the shoulders of the then thirteen-year-old Antje. She was an artistic girl, and it was she who was to introduce an artistic element into the Kamerlingh Onnes family. As for what Harm was doing in distant Arnhem when he had just started up his own brickworks; his sister lived there, and Antje's brother Gerrit Thomas, a timber merchant who gave his name to one of Arnhem's harbours, married Agatha Henderika Onnes from Groningen in December 1852.¹² Harm and Antje married a month later. It should perhaps be added that Heike Kamerlingh Onnes was distantly related (in the sixth degree),

⁹ *Gens Nostra* XV, 262-263; Patriciaatsboekje 1995, 275-286.

¹⁰ *Provinciale Groninger Courant*, 9 November 1827.

¹¹ Jenneke Nypels-Kamerlingh Onnes, *Jeugdberinneringen en familie verhalen* (Warmond 1994).

¹² For a genealogy of the Courts family, see www.robcoers.nl/gen/coers.htm

through the male Coers line, to the Arnhem-born-and-bred theoretical physicist Hendrik Antoon Lorentz, Heike's later colleague in Leiden.

Harm and Antje bought a house in Brugstraat near the Der Aa church in Groningen city centre. A watercolour by A.J. van Prooijen (1861) shows a clean, lively street with farmers' carts with wheels the height of a man, the church tower with a clock dial indicating 10 past 8, and, on the corner with the street known as 'Kleine der A', R.C. Faber's cake and confectioner's shop. It was in Brugstraat, in the premises designated 'G 206', that Heike was born, at 7 p.m. on 21 September 1853. Like his father he was given the second forename Kamerlingh. Heike did not start using 'Kamerlingh Onnes' as his last name until he went to university. Two years after Heike, his brother Albert Kamerlingh was born. Their sister Meisina, who was born in 1858, succumbed to whooping cough and died before her first birthday.

Meanwhile, the children's father Harm had contracted a pulmonary disease. Late one evening, as the family story goes, he had fallen asleep in the tilbury on the road to Groningen – the horse knew the way. When the horse arrived at the tollgates, and they remained shut, Harm slept on, possibly helped somewhat by his consumption of alcohol, and was chilled to the bone. Together with his wife Antje and his two sons, he left for Brussels at the beginning of June 1859 to spend a year undergoing treatment by a lung specialist. Harm was made to breathe the vapours of half a pound of salt dissolved in water every day, and the specialist assured him that if he followed this prescription dutifully he would live another thirty years. In the event it was twenty. In Brussels the couple's third son was born, Menso Kamerlingh.

In June 1860 the Onnes family returned to Groningen and moved into the house that belonged to the Kamerlingh family – where Harm's mother Meisina was still living – on the south side of the Noorderhaven. In their upstairs apartment, with five windows in its austere façade, were born Onno (1861), Jenny (1863) and Aldolph Johan, the youngest (1864). Meanwhile, business in Feerwerd was booming. When Meisina died on 23 December 1866 – Heike wrote a French epitaph for her in the style of the poet Nicolas Boileau – and the Kamerlingh family decided to sell the house on the Noorderhaven while settling the estate, Harm, as a tenant, had already made his preparations. On the day before his mother's death he purchased in Struve café on the Grote Markt, for 9,600 guilders, 'a spacious and well-maintained mansion' in Spinhuisstraat (now Zoutstraat),¹³ 'with a large garden, which has a summer-house and grape hothouse', while the adjoining warehouse Cork was also included in

¹³ *Groninger Courant*, 16 December 1866.



Ill. 3. Brugstraat in Groningen; at the back on the right is the house where Heike was born. Watercolour made in 1861 by A.J. van Prooijen (Groningen Archives).

the purchase. Harm had not done badly out of his brickworks, and he could consider himself a member of the prosperous burgher classes.

The city of Groningen

The Groningen of Heike Kamerlingh Onnes's childhood was still a fortified town. After Prince Maurits's conquest of the town in 1594, the so-called 'Treaty of Reduction' had brought it under the Republic's wings, and The Hague issued decrees on the measures to be taken by Groningen in the country's defence. In 1608, during the Twelve Years' Truce in the Eighty Years' War with the king of Spain, a start was made on building new fortifications, during which operation the town underwent considerable expansion to the north and east. Simon Stevin's plans provided for a seven-kilometre long earthen wall around the city, interrupted by a total of seventeen bastions.

By 1624 all this had been built and there was space for the population to double from 20,000 to 40,000. But the authorities' optimism proved unfounded,

and for the time being the new districts remained underpopulated. The city's population was 35,000 in 1850, and much the same twenty years later. It was not until the agricultural crisis of the mid-1870s precipitated an invasion from the surrounding *Ommelanden* that the population rapidly increased, until by the end of the century it stood at 67,000. By then the confining ramparts had long been demolished. It is worth adding that Groningen only suffered a single siege in all those 250 years: in 1672, the 'year of disaster', it was besieged by the Prince-Bishop of Münster, nicknamed 'Bommen Berend' (Cannonball Berend). After an artillery duel lasting a month, the attackers decided to give up. 'Oh Groningen, which from the rubble, ash and dust has risen, do not forget the blessings God has given', wrote the great Dutch poet Joost van den Vondel.

The town's appearance was dominated by the soaring Martini Tower, flanked by two churches, the Der Aa-kerk and Broerkerk. Most of the bastions were surmounted by octagonal smock mills that ground flour, and some of them contained ammunition stores. Slums and alleys had grown right up against the city ramparts, with one-room dwellings and inhabited basements. Living conditions were insalubrious. 'On the south side of the town, the ramparts deprive the neighbouring quarters not only of fresh air but of sunshine too', wrote the physician S.E. Stratingh in 1858. 'And this part of the city is particularly densely populated, and precisely by the lower classes, among whom at least twice as many people inhabit each space as is customary among those who are better off.'¹⁴ The north of the city also had its notorious slums, such as those near Violetsteeg. Building was continuing apace beyond the city walls, along Hereweg and around the Drekhaven. This was illegal: the 1851 Military Zones Act (*Kringenwet*) provided that in the event of war, the artillery must have a free field of fire extending for one kilometre. After the Fortifications Act of 1874, Groningen was free to demolish the ramparts. 'Come, bring your shovels and spades and raze those walls that so afflict our health and hold us down', rejoiced the *Provinciale Groninger Courant*.¹⁵ All the remaining city gates were pulled down, and large sections of moat were filled in.

As the country's third commercial city, Groningen had a strong position as an entrepot for grain.¹⁶ Large stocks of grain were piled up in warehouses at the Noorderhaven and on the streets Hoge der A and Lage der A, while countless flat-bottomed *tjalks* and *koffs* shipped cargoes of oats to other countries, sailing through the Reitdiep to the open sea. In the mid-nineteenth century,

¹⁴ S.E. Stratingh, *Groningen als woonplaats beschouwd. Eene bijdrage tot de geneeskundige plaatsbeschrijving van deze stad* (Groningen 1858) 47.

¹⁵ Quoted in P. Kooij, *Groningen 1870-1914* (Assen 1987) 195.

¹⁶ The socioeconomic information given here derives from P. Kooij (note 15).



Ill. 4. Noorderhaven in Groningen, c. 1870. Heike lived in Zoutstraat (Groningen Archives).

Groningen was home to 185 seagoing vessels. In 1877, after the locks at Zoutkamp had banished tidal changes from the Noorderhaven and the Eems canal had been opened, industry moved to the newly constructed harbour in the east of the city, the Oosterhaven. Meanwhile, in 1866 the city had finally acquired a railway link with Harlingen. From 1868 a little train chugged to and fro between Groningen and Winschoten, and the railway line to Meppel, with a direct connection to Amsterdam, was finished in 1870. Even so, the stage-coaches and iron barges remained in use for many years.

The city did not have much industry. Of the 364 steam engines that existed in the Netherlands in 1850, only five were in Groningen. Twenty years later the city still possessed only 19 out of the country's total of 1,750. W.A. Scholten built a sugar refinery and syrup factory on the Schuitendiep in 1862, and two years later the first Bos Atlas, which would become the definitive school atlas, rolled off the presses of the printers and publishers J.B. Wolters. Groningen also had Theo Niemeijer's coffee, tea and tobacco, Fonger's bicycles, and the occasional brewery. None of it amounted to much. Not until the 1880s would the number of factories in the city start to grow. But by then, Heike had left.

As a child it was wonderful to be living on Spinhuisstraat, right opposite the Noorderhaven and close to a shipyard of the former West Indies Company. Heike, a wiry boy with delicate lungs, was doubtless frequently to be found wandering around the harbour, where *tjalks* and koffs outnumbered galleons and schooners, and where one might occasionally find an impressive large barque or brig moored at the quayside.¹⁷ In the side-streets there were sailmakers and rope-makers, chain- and anchorsmiths, carpenters, mast- and pulley-makers, haberdashers, and countless wholesalers in groceries, items for cobblers, paperers, painters and plumbers. Further away were the markets Vismarkt and Grote Markt, where a toing and froing of delivery carts every Tuesday and Friday combined with the market ships to provide general goods transport between Groningen and the outlying Ommelanden.

The Onnes family lived in a house with a distinctive character built in 1733 by the master surgeon Schelto Fontein, who founded a cane sugar refinery on the other side of the road. Fifty years later it was expanded with the addition of an annex or *achterhuis*.¹⁸ The imposing 23-metre-long corridor had marble tiles and a little ‘Groningen baroque’ fountain, there was a spacious cellar and a connection to the gas grid – Groningen had possessed a gasworks since 1854; only Leiden had been earlier – and the room overlooking the garden boasted a magnificent fireplace. The live-in maidservant, on the other hand, had to make do with a tiny little attic space. The entire premises, including the warehouse with building materials of the firm H.K. Onnes & Co, were wedged in between a saltworks and a house of correction (spinning house) that was expanded into a prison. When this building was demolished in 1876, Harm and eleven of his neighbours petitioned the city council to change the name of the street ‘Spinhuisstraat’, which ‘derived from an institution that no longer existed, the memory of which is not so pleasant that it would be wrong to consign it to oblivion’, to ‘Zoutstraat’ (Salt Street). And the council agreed to do so.

Father Harm was a restless man. ‘His enjoyment came from working’, Heike later remarked in an interview, ‘not making money; that was only the consequence of working, not its purpose. When we went walking together, he always impressed that on me. [...] I remember one day he came home smiling happily, because he had bought a small farm and now the factory could be expanded. “I suddenly got to my feet in the carriage and cheered ‘Hurrah!’ to myself”, he said. “Boys, now the work can proceed at twice the pace.”’¹⁹ In his

¹⁷ J. Keuning, *De regio Groningen* (Groningen 1974) 63.

¹⁸ *Nieuwsblad van het Noorden*, 20 July 1988.

¹⁹ Van Itallie-Van Embden 35.

few leisure hours he ‘developed his mind’, his favourite reading matter being the monthly magazine *Revue des deux mondes*.

Heike’s parents did not socialise much with other people. ‘Merchants had different kinds of pleasures: they liked to eat and drink well, and to talk business. My parents had few acquaintances among men of learning. And so we stayed at home by ourselves, read a good deal, discussed works of art, deliberately developing our minds, you might say. We loved going for long walks in the countryside. There was no such thing as sport in those days; nowadays it is often an end in itself for young people. My parents saw everything else as subordinate to one single goal, “developing one’s humanity”. And it was only once an inner culture that was as strong as possible was combined with a highly cultivated outward demeanour – which neglected nothing and thus included being dressed well and with all due care – it was only then that the factors were present from which a human being could be developed. Was I not fortunate to grow up in *that* family?’

Antje too was an energetic presence. ‘When I was sixteen, and got up to work at 5 a.m. in the summertime’, said Heike in the same interview, ‘I always found Mother already at work in the garden. In our house we still did everything ourselves; the washing, collecting peat, preparing all the vegetables for the winter and summer.’ Getting down to work – sometimes, but not always, with the assistance of servants – was a way of life in the Onnes household, one which Heike instinctively absorbed. Before daybreak, when the sound of hammering had yet to begin at the shipyard, and the lowlifes, tramps, half-wits and drunkards in the Spinhuis were still fast asleep, Heike, then a student of the local secondary school, or ‘Hogere Burger School’, was poring over his books, preparing for his examinations.

2. That wonderful HBS

There was every reason to believe that Heike would be attending the local *gymnasium*, with its staple diet of Latin and Greek. In August 1863, at the age of nine, he presented himself at the school in Oude Kijk in 't Jatstraat, adjacent to the Harmonie arts complex. The premises had once housed Minerva art academy and technical school. After Minerva moved, the city council assigned the dilapidated building to a series of homeless institutions: the Groene Weeshuis ('Green Orphanage'¹), the department of public works, and, from 1861, the gymnasium. The school had urgently needed new premises; an inspection had shown that the old monastery that had housed the Latin school and its successor the gymnasium since 1817 was in imminent danger of collapse under the weight of the university library in the attic. 'It was not only in a figurative sense that the poor lads down there in the gymnasium toiled under the menacing weight of the ancients', wrote the historian Johan Huizinga in the University of Groningen's memorial volume.²

Heike had been admitted to the two-year pre-gymnasium that prepared boys for the gymnasium proper.³ Gymnasium pupils worked on their English, French and German in the first two years, while from the third to sixth and final year they spent 18 hours a week studying the classics. Parallel to this 'first division' for those intending to go to university, the school had a 'second division' in the third and fourth years, in which boys took extra classes in maths and English, French and German instead of the classics. Second-division boys left school after their fourth year (having completed what was referred to at the time as a 'civilised education') and enrolled in colleges such as the Royal Academy of Engineers and Colonial Service in the East Indies in Delft (converted into a Polytechnic in 1863), the Royal Military Academy in Breda, and

¹ The 'Green Orphanage' was so called after the children's clothing, which was green to distinguish them from the slightly better-off orphans in a separate institution, who wore red.

² Johan Huizinga, *Academia Groningana* (Groningen 1914) 154.

³ The information on the gymnasium and pre-gymnasium derives from P.J. van Herwerden, *Gedenkbboek van het Stedelijke Gymnasium te Groningen* (Groningen 1947).

the Royal Navy Institute (then located in Medemblik). It was also quite common for first-division pupils, especially prospective physicians and ‘natural philosophers’ (scientists), to leave gymnasium after the fourth year, or sometimes even after the third. The entrance examinations set by the University of Groningen were so undemanding that boys who had attended four years of gymnasium could easily pass them.

Heike was put in a class of 37 pupils. The headmaster of the pre-gymnasium, at which some of the boys boarded, was W.J. van Gorkom.⁴ He also conducted the school’s entrance examinations. Boys seeking admission to the pre-gymnasium (girls were still excluded from such schools in 1863) had to be good readers and to display ‘some proficiency’ in the ‘primary rules of spelling’. They also had to be able to apply ‘the four primary rules of integers and decimal fractions’ and to be sufficiently well versed in Dutch history and geography.

Once admitted, the boys followed a timetable including French (12 hours a week), Dutch (3), arithmetic (6), writing (2), geography (3), Dutch history (2) and general history (2).⁵ Prizes were awarded at the end of the year for the best pupil in each class and each subject, mimicking the real gymnasium. The headmaster presented the dozens of books (an expensive exercise), generally classics like Hildebrand’s *Camera Obscura* and Voltaire’s *Histoire de Charles XII*, at a festive gathering at the local concert-hall. Each lesson at the pre-gymnasium was a full 60 minutes. Classes were held from 9 a.m. to 12 noon, and from 3 to 6 p.m. The long midday break was devised to accommodate the townspeople’s idiosyncratic lunch arrangements: half of the families had their cooked lunch at 1 p.m. while the other half insisted on eating at 2 p.m. The annual school fees amounted to 60 guilders – or 72 for those attending art classes.

Heike did not have much fun at pre-gymnasium. While the building in Oude Kijk in ’t Jatstraat was not in imminent danger of collapse, it had little else to recommend it. The pupils endured freezing cold in winter and sometimes sweltering heat in the summer, and in January 1863 a ‘committee of medical supervision’, having inspected the premises, declared indignantly that the dank classrooms exuded an unsavoury fungal stench and that the ‘flower of Groningen’s youth’ was in jeopardy. Perhaps the damp and cold air further undermined the health of the delicate Heike, who developed bronchitis at the slightest sign of infection. After the 1863–64 school year, which he concluded with a ‘late examination’ in French, he fell ill and had to leave the pre-gymnasium.

⁴ ‘Multatuli’ was the pen-name of Eduard Douwes Dekker, a Dutch colonial official who became famous for his novel *Max Havelaar* (1860), exposing the evils of the Netherlands’ colonial regime in the Dutch East Indies.

⁵ Groninger Archieven, archives of the Latin School (*Latijnse School*) and gymnasium.

Heike was unable to attend school for twelve months. Following doctor's orders he spent a good deal of time in the fresh air, on a piece of land that his father had rented outside the city. There he received private tuition from the teacher H.J. van Woerd and spent the rest of his time reading and going for walks. He purchased thirteen volumes of Plutarch (in Dutch translation with notes in Greek) for one guilder at a book sale, and read *Hamlet* 'and the whole of Boileau, whatever I could get my hands on'.⁶ While Heike was ill, Groningen abolished its old-style pre-gymnasium in preparation for a new type of secondary school: the HBS ('Higher Burgher School'), which opened in September 1864. The pre-gymnasium was replaced with a three-year preparatory course with its own premises (also called a pre-gymnasium) for pupils intending to go on to either HBS or the now five-year gymnasium. Heike, who had recovered sufficiently to return to school by the summer of 1865, could skip the preparatory course, but hesitated as to which secondary school to choose.

Thorbecke's brainchild

The HBS was the brainchild of the liberal Jan Thorbecke,⁷ the man who had drafted the country's 1848 Constitution. When his second government took office in 1862, he introduced a Secondary Education Act in his capacity as interior minister, a post that included responsibility for education. With the economy booming and industrialisation finally gathering pace in the Netherlands, there was a growing need for trained executives in technology, trade and industry, and government. Well-trained manufacturers and industrialists were needed, as well as public officials and office staff, surveyors and engineers, heads of banking houses and able shopkeepers. Even the second division of the elite gymnasium did not fulfil this need, and schools providing a more elementary kind of education were wholly inadequate in this respect. Thorbecke took the German *Realschule* as his inspiration for the new type of school he wanted to create – one that would provide a general education attuned to the immediate needs of modern society, with plenty of emphasis on English, French, German and the sciences. This would tap into talents that had thus far remained unexploited. 'With our plans, Gentlemen', Thorbecke informed the Upper House of Parliament, 'we shall be doing our country a great, enduring service. We will generate forces and create institutions that will increase the intellectual and practical productive capacity of the heart of the population'.⁸

⁶ Van Itallie-Van Embden 33-50.

⁷ For the history of secondary education, see Cees Mandemakers, *Gymnasiaal en middelbaar onderwijs. Ontwikkeling, structuur, sociale achtergrond en schoolprestaties in Nederland, ca. 1800-1968* (Rotterdam 1996).

⁸ Quoted in Bartels, *Een eeuw middelbaar onderwijs 1863-1963* (Groningen 1963) 17-18.



Ill. 5. Heike Kamerlingh Onnes at 17, as a first-year student in Groningen.

Besides two ‘Higher Burgher School’ or HBS variants (involving three and five years of study, respectively) the 1862 bill envisaged more elementary ‘burgher schools’, ‘burgher’ evening schools, and agricultural schools. It also provided for the engineers’ course in Delft to be expanded into a polytechnic. Evidently, Thorbecke construed ‘secondary education’ not in terms of a particular age group, as today, but in terms of a particular section of society – the burgher classes. Despite later developments, the HBS was at first expressly not intended to prepare pupils for university. This remained the sole province of the classical gymnasium, which recruited its pupils from the intelligentsia or ‘scholarly classes’ and was therefore classified as ‘higher’ education. ‘The higher

burgher school will educate pupils for the future society of economic dynamism, while the gymnasium prepares pupils for higher academic study by inculcating a knowledge of the ancient Greek and Roman civilisations’, wrote Thorbecke.⁹

The Secondary Education Act that Thorbecke adroitly steered through parliament received the royal assent from King William III on 2 May 1863,¹⁰ and would remain in force for a hundred years. The new legislation had scarcely left the printing press when Groningen started planning its first HBS. On 9 May, Burgomaster De Sitter appointed a committee to advise the city council on the opportunities created by the new act in consultation with the local school committee and the governors of the local gymnasium and Minerva Academy. Its report was ready by 6 June, and ten days later – things were certainly moving very fast – the city council adopted an amendment introduced by J.A. Feith: ‘The Mayor and Aldermen shall be empowered to petition the Government for the establishment of a five-year Higher Burgher School in this municipality, and to inform it of the Council’s readiness, should such be required, to contribute substantially towards the establishment of such a school in Groningen.’¹¹ More than anything else it was this local contribution, consisting of a 10,000-guilder grant and a classroom, that swayed Thorbecke, raising many eyebrows; he allocated one of only five brand-new five-year state HBS schools to the remote city of Groningen.¹² The government intended these state schools to set a good example and serve as models. The new type of school was an immediate success. By 1870 the country had 44 HBS schools (32 of which were the five-year variant) and one secondary school for girls (MMS).

By this time, three national inspectors of secondary education had been appointed: Dr D.J. Steyn Parvé, Dr J. Bosscha, and Dr W.C.H. Staring, who was assigned the region of Groningen. Bosscha, later one of Onnes’s most ardent champions, was the son of a government minister and had personally offered his services to Thorbecke after a career as a physicist in Leiden and professor of mechanics at the Royal Military Academy in Breda. Thanks to his efforts, every HBS acquired its own properly equipped physics and chemistry laboratories, which were indeed so advanced as to outstrip many of the country’s university laboratories. They gave keen science pupils a taste of real science, firing many of them with a zeal to continue studying in these fields. Kamer-

⁹ J.R. Thorbecke, *Over de regeling van het hooger onderwijs* (The Hague 1876) 48. Quoted in Bastiaan Willink, *De tweede Gouden Eeuw* (Amsterdam 1998) 27.

¹⁰ *Staatsblad* 50.

¹¹ Report of a meeting of Groningen city council (*Zittingsverslag van de gemeenteraad van Groningen*), 16 June 1863.

¹² *Ibid.*, 9 January 1864.

lingh Onnes, Lorentz, Zeeman, Eijkman, Einthoven, Van 't Hoff, Bakhuis Roozeboom, Hamburger, Dubois and numerous other prominent (and less prominent) scientists all attended HBS. In fact six out of the seven Dutch Nobel Prize winners for physics, chemistry or medicine before the Second World War were former HBS pupils. The seventh, the physicist Van der Waals, taught at one before being appointed to a chair at the University of Amsterdam. Rather contrary to Thorbecke's intentions, the HBS soon grew to become the primary breeding ground for scientific minds – far more so than the classical gymnasium. 'I believe that a gymnasium would have dissipated much of my scientific ability', reflected the palaeontologist Eugène Dubois.¹³

Pioneers in Pelsterstraat

What was the best location for Groningen's state HBS? Once Thorbecke had given the go-ahead, the eye of the municipal executive soon fell on Pelsterstraat near the fish market, where the council had started building new premises for the gymnasium in May 1863. The new plan was to use the building for that purpose only for one year (1864-65), while the old premises in Oude Kijk in 't Jatstraat were demolished and a new school built there to house the gymnasium. Then, in August 1865, the Pelsterstraat premises would be re-assigned to the new state HBS.

It was a good plan on paper, but the arts society De Harmonie protested vociferously. De Harmonie had long wanted to expand its gardens, and saw the demolition of Minerva as an opportunity not to be missed. The city council was urged to find some other location for the school, 'to promote the benefit and enjoyment of a great many of the well-to-do townspeople'. When this proved impossible, there was a proposal to admit the gymnasium but assign the HBS premises elsewhere. The clamour died down when Thorbecke voiced his support for the Pelsterstraat site and insisted that the HBS open in 1864. One argument was that once the old-style pre-gymnasium had been abolished and the 'second division' moved to the HBS, the new building would be too large for the gymnasium. The upshot of all this was that the poor gymnasium was left languishing in the fungal odour at Oude Kijk op 't Jatstraat,¹⁴ while the Pelsterstraat premises were hastily modified to meet the demands of the new HBS. On 26 June Groningen acquired its Hogere Burgerschool, with the appointment of a headmaster and the first four teachers.

¹³ Quoted in Willink, *Tweede gouden eeuw*, 32.

¹⁴ The gymnasium finally moved into new premises at Martinikerkhof in October 1865. The pre-gymnasium occupied the ground floor, and had a separate entrance.

While all this was going on, Heike was out in the fresh air devouring books day in, day out, longing to be given a clean bill of health. There was a choice to be made: should it be HBS or gymnasium? ‘And I simply couldn’t choose’, he told Van Itallie-Van Embden, ‘Both struck me as equally wonderful. The HBS offered so many subjects that appealed to me, but the classics also beckoned almost irresistibly. [...] One day I burst into tears: I just couldn’t choose between the HBS and the gymnasium, but my father repeated that I had to choose myself. So the HBS it was. And I had such a wonderful time there! It was a brand-new type of school and its first teachers had a calling and a determination to give of their best’.¹⁵

The teacher who loomed largest in Heike’s school days was the headmaster and chemistry teacher Jacob van Bemmelen. He had taken on this dual role only after a certain amount of cajoling, since scientific research was his true passion. Born in Almelo as the son of the headmaster of a ‘Latin school’ (where classes were taught in Latin), he studied chemistry at the University of Leiden. In 1852 he became the assistant of Van Kerckhoff, Groningen University’s dynamic new chemistry professor, whose laboratory was very well-equipped, certainly after the gasworks opened. Van Bemmelen, who arrived after receiving his doctorate, experimented there to his heart’s content. His special interest in agriculture led him to study the composition of the terps (or *wierden*, as these artificial mounds are called in Groningen) and the local clay. From 1856 onwards he also taught physics and chemistry at the Minerva Academy, which included a technical school, and at the School of Agricultural Economics at Groningen and Haren. What he hoped for – given the impossibility of being employed as a researcher – was to secure a position at the projected State School of Agriculture. While Thorbecke’s original bill had included plans for such an institute, an amendment had been adopted deferring this decision indefinitely, to Van Bemmelen’s immense frustration.

In the summer of 1864 Van Bemmelen received a letter notifying him that Thorbecke had given him the headship of the new HBS in Groningen. He was far from overjoyed. ‘I wavered’, he wrote in the school’s second memorial volume, ‘uncertain whether it was right to accept a position for which I felt no enthusiasm, vocation or even aptitude. Yet I appreciated all too well that I had no other prospects. The State School of Agriculture seemed unlikely to materialise for many years; and that was certainly true, since it was another thirteen years before such an institute finally opened in Wageningen. So I ventured to accept the position, though in a less than cheerful cast of mind’.¹⁶ But the

¹⁵ See note 6.

¹⁶ J.M. van Bemmelen, ‘Herinneringen uit de jaren 1864-1869’, *Tweede Gedenkboek der Rijks Hoogere Burgerschool te Groningen* (Groningen 1904) 7.



Ill. 6. Jacob Maarten van Bemmelen, painted for his 80th birthday in 1910 by Menso Kamerlingh Onnes. Van Bemmelen was the headmaster of Groningen's State HBS, and also taught chemistry there. He was appointed professor of chemistry in Leiden in 1874.

energy and enthusiasm of his staff soon banished his gloomy outlook. ‘When one is young and can count domestic felicity among one’s fortunes, one’s spirits soon rally, even after a major disappointment’. All of this, however, did not change Van Bemmelen’s enduring ‘distress’ that his headship left precious little time to study or conduct experiments in the chemical laboratory.

The HBS’s first staff meeting, on 5 September, was attended by J.M. van Bemmelen (headmaster, chemistry), Dr F.G. Groneman (mathematics, botany and zoology, physics and mechanics, cosmography), L.M. Baale (French, English), J. Ensing (drawing), Dr J.W.A. Renssen (Dutch, geography), Dr E.J. Kiehl (history, political science), F. Worthmann (German) and W. Kreling (mathematics). Not only did half of the teaching staff have doctorates, but half of them had been teaching at a gymnasium the year before. What was the crux of the HBS’s appeal? There was the challenge of the new, of helping to develop a promising type of school. The new laboratories were enticing. At least as important, however, were the generous salaries. Van Bemmelen himself earned 3,000 guilders a year; staff with doctorates received 2,400 guilders, while most other staff received 1,800. The art master had to make do with 1,200 guilders,¹⁷ but even he received no less than an assistant lecturer – doctorate and all – at a university.

No wonder, then, that the HBS had at its disposal (leaving the foreign languages aside) a large pool of talented and skilled teaching staff – most of them holding advanced degrees, since the system of secondary school teaching certificates that Thorbecke had introduced together with the HBS was not working.¹⁸ Gymnasium schools were completely out of step with the high salaries of the HBS teachers; their English, French and German teachers without doctorates could not hope to earn more than 900 guilders. But even they were better off than some: assistant primary school teachers earned the meagre sum of 400 guilders a year, and had to take on odd jobs to make ends meet. ‘Never before had such happy teachers’ faces been seen in the Netherlands as in September 1864, when the freshly-appointed HBS staff entered their new schools’, declared Groneman, who took over from Van Bemmelen as headmaster in 1869, at the celebrations for the 25th anniversary of the Groningen HBS. Money, it seems, can buy happiness after all.

There was a great deal to be arranged in the echoing classrooms in Pelsterstraat in those first few weeks. Although the HBS curriculum and the examination requirements had all been laid down by law, the schools themselves

¹⁷ F.G. Groneman, ‘Redevoering uitgesproken tot sluiting van den vijfentwintigsten cursus der Rijks Hoogere Burgerschool te Groningen’, 1^e *Gedenkboek RHBS Groningen 1864-1889* (Groningen 1889)

17.

¹⁸ J. Groen, *Het wetenschappelijke onderwijs in Nederland van 1815 tot 1980*, vol. 3 (Eindhoven 1989) 192.

decided how many classes were to be taught in each subject, and which material was to be taught in each year; they also drew up their own booklists. The pupils, it was agreed, were to be given a large measure of freedom. 'I had a hearty aversion to anything that reeked of pedantry', Van Bemmelen recalled, 'to disciplinary measures and rules amounting to mere formalities or dogmas, which testified to a lack of faith in the pupils'.¹⁹ Instead, he placed his reliance in 'thought-provoking education'. Rather than lists of those guilty of misconduct or prizes for outstanding work, such as were customary at the gymnasium, the pupils' own desire to learn was to be the driving force. And to discourage teachers from ejecting disruptive pupils from lessons, Van Bemmelen provided that any pupil sent out of class was to be given an hour's detention at the end of the day – under the teacher's supervision.

There were also entrance examinations to be prepared and held that first week. Four of the candidates who failed this examination shrugged their shoulders and coolly enrolled all the same. They had every right to do so, they maintained, as long as their parents paid the annual tuition fees of 50 guilders on time: the liberal Thorbecke had established that freedom took precedence over all other principles, and that schools simply did not have the right to turn an aspiring pupil away. Even a pupil instructed to repeat the year could simply take his place in the next class after the summer holidays. The philosophy was that parents knew best what was right for their offspring. Such an idealistic view was bound to run into trouble. 'Groningen society was not yet ripe for such largesse', wrote Groneman.²⁰ Sometimes half the pupils in the class were completely unable to comprehend the material presented to them. It was an untenable situation, but even so, it was not until 1873, after Thorbecke's death, that entrance examinations and end-of-year reports gained ironclad authority.

Groningen's state HBS was the first in the country to open: it welcomed its first pupils on 26 September 1864, after a week of celebrations marking the 250th anniversary of the University of Groningen. At a sign from a presiding member of staff, three teachers ushered some sixty pupils (there were only three classes as yet) into the building on Pelsterstraat, which still smelt of fresh masonry. The people of Groningen viewed the event with misgivings, especially since almost all the teachers came from out of town. The first clash came after a month, when Van Bemmelen and his staff declared that a lunch hour lasting from 12 noon until 3 p.m. was unacceptable, and that it was time for the people of Groningen to synchronise their midday meals. The locals were enraged. Just who did those 'Hollanders at Pelsterstraat' think they were?

¹⁹ *Op. cit.* note 16, 11.

²⁰ *Derde gedenkboek van de Rijks Hoogere Burgerschool te Groningen* (Groningen 1914) 90.

Worthmann, who taught German, added fuel to the fire when he responded to some newspaper articles on the topic with a pedantic exposition in which he, as a German, saw fit to chastise some of the city's most prominent citizens for their incorrect use of language. Tempers were soon running so high that Van Bemmelen hastily withdrew his proposal to shorten the midday break.²¹

It was into this island of cheerful idealism, didactic freedom and youthful candour amid an unwelcoming city that Heike Kamerlingh Onnes entered the school at Pelsterstraat in August 1865. As he approached, he would have seen an austere red brick façade, classrooms overlooking the street, and staircases with wrought-iron banisters. Since the boys had no playground or gym, they were allowed to romp about in one of the empty classrooms during break, and their teachers did not stand idly by. 'When the boys competed to see who could jump highest or farthest, I joined in,' Van Bemmelen wrote. The corridors and staircases were also used for wild games during breaks. One popular game involved a group tossing one boy in the air and (hopefully) catching him again. Heike, who was as light as a feather and two years younger than his classmates, was thrown so high on one occasion that he landed on the stone floor, hitting his head. 'We grew even more concerned when the poor little fellow started behaving in a very peculiar way', one fellow pupil recalled. 'He jumped to his feet, dug his nails into the wall as if planning to walk up it, and oh! he acted so strangely!'²²

Van Bemmelen may have abhorred 'pedantry' and sought to foster a free-and-easy atmosphere at his school, but he was nonetheless a great believer in military drills. On the Pelsterstraat premises, the pupils *marched* from one classroom to the next between lessons, under the command of their teacher. 'This was always executed with pleasure and a certain sprightliness', wrote Van Bemmelen, adding that order was of the essence in this military approach. Drills were used (as at other schools) as a form of physical education, and were led by corporals of the garrison encamped in Groningen, supervised by a sergeant-major. 'When the pupils went to drill at the Helpen works on Saturday afternoons in the summer months, and marched there in company formation with a drummer in the vanguard', recalled Van Bemmelen, 'I always went with them, and some of the teachers accompanied us'. In 1866, the headmaster wrote to the Minister of the Interior at his pupils' request, asking for the boys to be issued with rifles. After consultations with the Minister of War, the state HBS was issued with thirty cadets' rifles and twenty smooth-barrelled rifles. The pupils reacted with wild enthusiasm.

²¹ The lunch break was shortened, after all, the following year.

²² J. Ritzema Bos, 'Het vrije kwartiertje', in *2^e Gedenkboek RHBS Groningen* (Groningen 1914) 4.

A timetable with 35 subjects

When Heike presented himself at Pelsterstraat in 1865 for his first day at school, there were 37 pupils in the first form. While the second and third forms each contained 28 pupils, by the fourth form the numbers were depleted to only 13, and the examination class had only 7 pupils.²³ The requirements were certainly anything but lax. Take the fifth form. The timetable included a full 35 subjects and subdivisions of subjects, as follows (with the number of hours a week in parentheses): algebra (1), geometry (1), trigonometry (1), descriptive geometry (1), mechanics (2), mechanical technology (1), physics (3), laboratory physics (2), inorganic chemistry (1), organic chemistry (1), laboratory chemistry (2), botany (1/2), zoology (1/2), geology (1), cosmography (1), political science (1), political economy (1/2), statistics (1/2), general history (1), Dutch history (1), Dutch language (1), Dutch literature (1), French language (2/3), French literature (1 1/3), High German language (2/3), High German literature (1 1/3), English language (2/3), English literature (1 1/3), bookkeeping (1), financial affairs (1/2), commercial law (1/2), freehand drawing (2), mechanical drawing (2), physical education (2) and, last but not least, military drilling (1 1/2).²⁴ Together these subjects accounted for an impressive 40½ hours a week – each class lasting a full hour, unlike the shorter classes that are common at many of today's secondary schools.

Even so, there were no complaints about an overly full programme in those early years. At the beginning, the HBS – in Groningen as elsewhere – attracted the intellectual crème de la crème of boys from the burgher classes. They were enthusiastic and enjoyed rising to a challenge. And anyone unable to keep up with a subject such as maths or physics could always give it up. In an extreme case, a pupil might attend only a few classes. This did not happen much in practice, partly because those wanting to sit for the school-leaving examination were required to do so in *all* subjects. Interestingly, inspector of schools D.J. Steyn Parvé ascertained in 1868 that the timetables were almost identical from one HBS to the next, in spite of the freedom schools had been given.²⁵ While the proportion of children attending secondary school in the Netherlands had seriously lagged behind that in the surrounding countries before the advent of the HBS, the gap now started to narrow. In 1870-71, 0.67 per cent of 12 to 18-year-olds attended HBS or gymnasium; ten years later the figure stood at 0.90 per cent, and by the turn of the century the Netherlands boasted 1.45 per cent,²⁶ rivalling Germany and rapidly gaining ground on France.

²³ 1^e *Gedenkboek RHBS Groningen 1864-1889* (Groningen 1889).

²⁴ Groninger Archieven, archief Rijks HBS Groningen, inv. no. 225.

²⁵ D.J. Steyn Parvé, *De inrichting van het middelbaar onderwijs in Nederland* (Leiden 1871) 33.

²⁶ Bartels, v63.

Heike was a brilliant pupil. ‘He had a feather-light little body, but the content of his head was streets ahead of us all’, one fellow pupil recalled. ‘There was only one boy who could occasionally compete with him.’²⁷ And when Heike came home (which by then was in Zoutstraat), he buried his nose in his books, as he related when interviewed by Van Itallie-Van Embden:

My father always told me that you have to read a lot; it gives one strength. Well, I bought a washing-basket full of books at the market, and Father paid. Six weeks later a large cart arrived at the house, full of books for me. ‘Have you already read the last load?’ my father inquired soberly. That question struck home: it is true, books are to be read, not to be arranged neatly in bookshelves. ‘No, Father’, I said, abashed. After that I bought no more books for a long time, but read all those I had acquired. Meanwhile I rummaged around at the university library, and one day I was looking at Stein’s *Staatsrecht* [Constitutional Law] when Professor Gratama spoke to me. ‘Is that the sort of thing you like to read? Then you should be learning Latin.’ Professor Gratama, who moved in very different, orthodox Christian, circles – he was a great champion of the ‘School with the Bible’ – soon became an older friend to whom I could turn for advice. And we would remain friends.

Heike was Van Bemmelen’s prize pupil. His partiality for chemistry was no surprise: he was fascinated by everything from the lye baths at the neighbours’ house on Spinhuisstraat to the kilns and glazing work in Feerwerd. The headmaster had not stinted on his own subject: an entire ground-floor wing of the Pelsterstraat premises was devoted to chemistry. Adjoining the teacher’s study, which was also used as a weighing room, was a classroom with a fume cupboard and demonstration table, a room for fifth-years to conduct chemical analyses, and another for fourth-years to conduct experiments – equipped with a heater and sandbath, forced-draft ovens and a still. When Inspector of Schools Staring turned up at the HBS one day, Van Bemmelen asked his brightest student to write out in full on the blackboard the chemical formula for lecithin – a rather complex organic compound ‘full of radicals and dashes’. ‘The boy, who was then fifteen years old, did not let me down, but fulfilled the assignment superbly’, recalled the proud headmaster.

Standards were high. ‘I think it fair to say’, pronounced Van Bemmelen, ‘that the young people who passed their school-leaving examinations in those first ten years were scarcely less proficient in chemistry than medical students sitting their first-year examinations.’²⁸ Groneman attained the same standard in physics, using Bosscha’s textbook *Leerboek der natuurkunde*. The practical

²⁷ *Op. cit.* note 22.

²⁸ *Op. cit.* note 16, 10.

skills of the HBS pupils were actually superior to those of university students. Fourth- and fifth-year pupils conducted experiments on Wednesday and Saturday afternoons, and Van Bemmelen did not shrink from having them prepare difficult compounds like ethylene bromide – a substance that would later be found to cause cancer.

It was not only during the dispute about the interminable midday break that the German master Friedrich Worthmann disgraced the Groningen HBS. He became notorious for his feud with the commercial studies teacher Carl Friedrich Teppe, another German, and his eccentric behaviour and lack of authority over the pupils also damaged the school's reputation. Things finally came to a head in March 1868. Teppe had told the pupils preparing to sit their school-leaving examinations not to leave their exercise-books in his cupboard but to put them on Worthmann's desk instead. The latter, incensed, stormed into the classroom during a lesson, armed with a lead-tipped cane. A furious row ensued, and Teppe fled the classroom for fear of being attacked. When the pupils too stood up to leave, Worthmann locked them in, and catching sight of a boy who had put his cap on, punched him in the face so hard that blood started pouring from his mouth. At length he left the room, shouting ugly threats. Although Van Bemmelen finally succeeded in restoring calm after this incident, Worthmann's 'unprincipled character and degenerate behaviour' did more harm than a dozen eminent colleagues could put right. He frequented houses of ill repute, had affairs with numerous women, and incurred debts of the kind that brought two of his creditors to his room one night to beat him up. Worthmann fought back and shut them out, went into hiding with one of his lady-friends, and at length made his way back to Germany. The records state that he was 'dismissed in absentia'.

Another member of staff whose talents did not include maintaining discipline was E.J. Kiehl, who taught history and political science. Having previously worked at the gymnasium in Leiden and the athenaeum in Deventer, he ventured the leap to Groningen in September 1864. He had high hopes of his pupils' potential, declaring at the first staff meeting that he planned to cover ancient, mediaeval and modern history in detail. He even assumed that his pupils would be capable of ploughing through all eighteen thick volumes of Schlosser's *Weltgeschichte* (A History of the World). His new colleagues were unable to suppress a grin at these ambitious plans, but Heike Kamerlingh Onnes was thoroughly captivated by Kiehl's erudition and dedication.

So Heike's two favourite teachers were Van Bemmelen and Kiehl. 'A good teacher is three-quarters responsible for a pupil's choice of career!' he asserted in 1922, when asked about Van Bemmelen's influence on his love of science, especially chemistry. 'But in my case it was more complicated than that; there was a second eminent teacher, Kie[h], who had studied under

Cobet. His history classes were marvellous. It was he who helped me with the Greek notes to Plutarch that I couldn't understand; he set about teaching me Greek for fun. If he had stayed ... but he left, and Van Bemmelen remained. Had the situation been reversed, I cannot say how it might not have changed the course of my life.²⁹

Kiehl left in 1867, when Heike had completed the second year. Van Bemmelen had urged him to seek employment elsewhere, after obtaining the Ministry's approval. 'His lessons were total chaos, especially in the lower classes', recalled the headmaster. 'Only a handful of the cleverest pupils respected his immense erudition, were able to benefit from it and spoke of him with reverence in later years.'³⁰ Heike, then, was one of this small group of admirers. In August 1870 he wrote to his former history teacher, who had moved to Middelburg, to tell him of his exam results. He had been given an 8 out of 10 for history. 'I am certain that you will find this very disappointing', said Heike. 'History has no longer been my favourite subject these past two or three years, and I have completely neglected it in the fifth year. I only enjoyed it under your tuition.'³¹

Heike's final year at school began with the move to the new building on Nieuwe Kijk in 't Jatstraat, 'in a quiet and healthy part of the city'. The new premises provided more space, 'cheerful surroundings, a large playground sheltered from even the fiercest winds',³² and a gym. Van Bemmelen had since moved on, to become headmaster of the HBS in Arnhem. Heike remained in contact with his mentor. At Christmas 1869 he wrote at length on his 'experiments with fermentation', suggesting, 'if I may be so bold', with copious explanatory notes, that Van Bemmelen had twice gone astray in his book *Eenige hoofdstukken der nieuwere scheikunde* (Some Chapters of Modern Chemistry). In Heike's view, the separation of lactic acid proposed in this book was incompatible with the law of the conservation of energy.³³ In the same letter Heike wrote that he was hard at work studying Latin and Greek and expected to take his university entrance examination straight after the summer holiday – unlike his classmate and close friend Conrad Mensinga, who planned to take a year to prepare for the exam. 'I've already read Homer and Xenophon, so there's not much left to do for Greek. I've almost finished the Latin list too, but Miss Dido still awaits.'³⁴

²⁹ *Op. cit.* note 6, 38.

³⁰ *Op. cit.* note 16, 14-15.

³¹ Letter from Heike Kamerlingh Onnes to Kiehl, 7 August 1870 (draft), MB, archives of Heike Kamerlingh Onnes, inv. no. 217.

³² *Op. cit.* note 20, p. 62.

³³ Letter from Heike Kamerlingh Onnes to Van Bemmelen, 26 December 1869, MB, archive 99.

³⁴ Virgil, *Aeneid*.

The new headmaster, Heike's physics teacher Groneman, imposed stricter discipline and curtailed some of the freedoms that his predecessor had allowed. Groneman kept meticulous records of misconduct, and so we know that Heike was ejected from Ensing's art class on Saturday 13 March 1869. Ensing taught freehand drawing – he had made portraits of all Groningen's professors in the 1850s – according to the Dupuis method, with wooden, iron and plaster models, and some of the pupils found it rather tedious at times. Heike was not ungifted, but on the Saturday in question he dashed off a careless drawing, crumpled it and threw it from one side of the classroom to the other; meanwhile, his friend Gratama, who had smuggled a snowball into class, was smoking a cigar. In October that year, at Nieuwe Kijk in 't Jatstraat, the physical education teacher Eden (whose son was to become the skating legend Jaap Eden) ordered Heike to leave, having previously caught him trying to play truant. Groneman even records that Heike once misbehaved so egregiously in Matthes's Dutch lesson that his father was summoned to school.³⁵ In spite of all this, however, the student records include a note by the headmaster stating that Heike 'always excelled in diligence, application and factual knowledge.'³⁶

The school-leaving examinations, a mix of oral and written tests, lasted from 18 to 21 July 1870. Heike's results were outstanding: he emerged as the best in his class in each group of subjects. He was awarded 9 out of 10 for maths and for science, 8 for commercial studies (including an ignominious 5, or bare pass, for bookkeeping), 9 for geography, 8 for history, 7 for English, French and German, and 10 for art. In his letter to Kiehl, Heike wrote that mechanics had 'gone completely wrong' (earning him 7) and that he should have scored higher than 7 for the written English exam 'since Mr Halliday [the English teacher] saw the copy and said I deserved at least 9'. Heike concluded that while the results were not 'brilliant' he was not unsatisfied. 'I derive some comfort from the fact that Mensinga got 30 or 40 points less than I did, and Rasker 60 or 70 less' – out of a total of almost 40 subjects.

Heike was in no doubt as to his choice of career, as he recalled in his interview with Van Itallie-Van Embden:

'So what do you plan to do next?' my father asked. And I immediately answered, 'I want to study chemistry'. Well, he approved the plan, although it was not immediately apparent what career it would lead to. 'But don't teach', said my father, 'and don't be a civil servant; work in the middle of life, fight if you have to, develop all your energies.' There was no such career as 'researcher' at the time. We arrived at a compromise:

³⁵ Groninger Archieven, archief Rijks-HBS Groningen, inv. no. 693.

³⁶ *Ibid.*, inv. no. 314.

I would study chemistry and then apply it in my father's business, where chemistry could prove very useful in devising new ways of preparing glaze and so on.

Two days before Heike wrote to Kiehl apologising for only attaining 8 out of 10 for history, he had told Van Bemmelen in Arnhem about his two 10s for chemistry – though grumbling that there should have been four on his final list. He made many of the same remarks he would make to Kiehl. In both letters, Heike said he was wandering in 'rocky Ithaca', quoted a sentence in Greek about Odysseus, saw himself encamped outside the gates of Troy – 'and behold Athene take enraged Achilles by the hair and drive his sword back into its scabbard' – and, under the influence of Bulwer Lytton's *Last days of Pompeii*, imagined himself at the Forum feeling the bite of Cicero's sarcasm. Occasionally, he added, he would put aside his books to play Mendelssohn's duet 'Ich wollt' mein Lieb' on the piano. And Heike wrote that he was still spending very little time on chemistry, 'otherwise there'd be no time for all the rest; but after the holiday...!' Heike ended his letter to Kiehl on this note of eager anticipation; but to Van Bemmelen he added a few words on the future. 'I have planned my studies as follows: September 1870, entrance examinations; July 1871, bachelor's degree; 1873, master's in chemistry, physics and mathematics; 1874, field trip around Germany; 1875, trips to France and England.'³⁷ Lofty ambitions, and not a word about roof tiles.

³⁷ Letter from Heike Kamerlingh Onnes to Van Bemmelen, 5 August 1870, MB, archive 99.

3. No drinking binges

When Heike Kamerlingh Onnes presented himself on 17 September 1870 at the office of the rector, B.D.H. Tellegen, to register as a first-year student, Groningen University was in desperate straits. So few students were enrolling that the country's third-largest university faced an uncertain future. The decline in enrolment, which had put a damper on the celebration of the university's 250th anniversary in 1864, was assuming dramatic proportions. While 290 students had been registered in 1830, only 186 remained thirty years later, and by 1870 Groningen's student population had shrunk to a miserable 146.¹ In contrast, Leiden had about 850 and Utrecht 500 that year.

Local opinion in Groningen blamed it all on the government. The Hague had left the north to fend for itself. True, the 'equipment grant' for Groningen University had increased from 8,000 guilders in 1854 to 12,000 in 1866, both the medical and law faculties had been given leave to appoint an additional professor, and the city had acquired a new library and an ultra-modern physiology laboratory,² but Groningen had still come off badly compared to Leiden and Utrecht with their expensive teaching hospitals. 'Groningen University has been ailing for several years', complained correspondent J.W.Q. in the student publications *Vox Studiosorum / Studenten Weekblad* 'Everyone in Groningen is well aware, and sees every day, that our university must do without even the most essential resources, that the powers-that-be are seeking to make this sick patient languish and die of starvation by depriving her of the primary necessities of life.'³

This dismal situation was set against the background of the new Higher Education Act being drafted to replace outdated legislation from 1815; many hoped that it would cure 'the disease that afflicts our higher education'.⁴ In

¹ Figures taken from Groningen Student Almanac (*Groninger Studenten-almanak*).

² Huizinga, 183.

³ *Vox Studiosorum / Studenten Weekblad*, 3 February 1875.

⁴ A.J. Vitringa, 'De ziekte van ons hooger onderwijs', *Tijdspiegel* 1867 II 274.

Groningen, however, many were not so sure.⁵ Some locals feared that their university, the smallest in the country, might be swept away in a wave of spending cuts. The first draft, submitted by interior minister Jan Heemskerk in 1868, lightened people's hearts a little. 'The closure of one or two universities is a measure virtually impossible to carry out, unless in revolutionary times', the conservative Heemskerk had written in his Explanatory Memorandum. So it was bad luck for Groningen that the government led by Cornelis Fock was just about to fall.

In the next government, this same Cornelis Fock, who now held the education portfolio, presented a new plan. Johan Huizinga notes that the Explanatory Memorandum accompanying the bill presented in March 1869 was 'decidedly lukewarm about the idea of three universities', so much so that it 'invited an assault'. A specially appointed advisory committee wrote that a large parliamentary majority no longer considered it acceptable to maintain three universities, and its provisional report of 11 August 1870 took a threatening tone: 'It is obvious that our financial and intellectual resources do not suffice to equip and maintain three universities such as to answer the requirements of our time in all respects'. Since Leiden was the clear favourite, Utrecht was flourishing and Groningen was languishing, the conclusion was obvious: 'Groningen and not Utrecht must go'. After all, even the Groningen history professor Willem Hecker had conceded in October 1869, when passing on the office of rector to Tellegen, that the university was scarcely breathing, that there were 'more benches than students'

Alarmed by the ominous reports from The Hague, Tellegen appointed a committee of concerned citizens that urged the king to preserve the university. The student body also sprang into action, despatching a deputation to The Hague in early September, even before the end of the summer holidays, to impress upon the Lower House that 'a university fosters the intellectual advancement of an entire region', and that the Groningen institution, like the others, could boast of a glorious past.⁶ The two actions triggered a snowball effect: throughout the autumn, nearby villages bombarded The Hague with letters, former students expressed their support, and even the neighbouring provinces of Drenthe and Friesland were sympathetic. Fortunately, the Fock-Van Bosse government fell that same year, and the despised bill vanished along with it. This averted the immediate danger of closure, though the situation remained worrying. It was not until 1876, when the Lower House decided after

⁵ For the state of affairs surrounding the new Higher Education Act and its impact on Groningen: see *op. cit.* note 2, chapter 8.

⁶ *Vox Studiosorum* 1970, 103-105.

a stirring debate that the north could keep its university, that the people of Groningen could let down their guard and celebrate.⁷

Heike is unlikely to have been more than dimly aware of the dark clouds gathering above the institution in September 1870. He had his entrance examinations to worry about. Under the old legislation, aspiring students who had not attended *gymnasium* or Latin School were examined in Dutch, Latin, Greek, French, German, algebra and geometry. Whereas his HBS friend Conrad Mensinga set aside a year to prepare for these examinations, Heike had used his leisure time in the final year at school to master the necessary material, especially in the classics. The eager new student passed easily, although he himself judged his performance ‘far from brilliant’.⁸

Meanwhile, international relations were descending into turmoil. Early that month, Prussia had won its war with France by crushing Emperor Napoleon III’s army near the little town of Sedan. The French had lost Alsace-Lorraine, and the rest of Europe watched in suspense. Groningen’s mediaeval defences, *Gruno’s veste*, had quickly been readied for a possible invasion: the city gates could be locked again and the Helpman line of defence in the south of the city was ‘activated’. After the outbreak of war on 19 July 1870, the Dutch feared that French troops might land on the coast of Groningen, with the aim of pressing on towards Prussia. When Tellegen, a professor of constitutional law, cried out ‘not German but Dutch!’ while passing the torch to the new rector on 13 October 1870, proclaiming the ‘majoritarianism’ of the Dutch Constitution superior to the ‘authoritarianism’ of the menacing Prussian giant, he received thunderous applause.

The first true challenge for the young student, who was not yet seventeen, was the initiation period in the Groningen student society *Vindicat atque Polit* (‘to maintain and refine’). Eighty per cent of the students belonged to the society in 1870, but then a phase of ‘nihilism’ (non-membership of the fraternity) set in, which combined with the fall in the student body to reduce its membership sharply to 116.⁹ Members paid a registration fee of 50 guilders and an annual membership fee of 22 guilders. *Vindicat* was in the process of drafting new statutes reducing the opportunity for ‘some individuals [...] to abuse freshmen’,¹⁰ but those admitted in 1870 still faced the harsher regime. Even so, excesses were rare in Groningen, partly because the society’s statutes expressly forbade second-year students (the fiercest group) from taking part

⁷ See also chapter 6.

⁸ Van Itallie-Van Embden 39.

⁹ I.B. Cohen, *Uit Vindicat’s verleden* (Groningen 1921) 333.

¹⁰ *Groninger Studenten-almanak* 1870, 83.

in initiation. Heike and 28 other first-year students underwent their induction in mid-November, not at the traditional grand feast and ‘installation party’ – which the new statutes had abolished to cut costs – but during a modest concert.

Heike later recalled his initiation in a draft letter to one of his teachers (possibly Kiehl; letters to Van Bemmelen have been preserved).¹¹ It had not been as bad as expected, he wrote, although Vindicat certainly had some ‘louts and rotters’ among its ranks. During initiation, you learned to introduce yourself correctly, walk around the Grote Markt wearing a top hat, make toasts and speak in public, and you were not a fully-fledged student until you had been admitted to Vindicat. But Heike took no interest in the drinking binges and midnight frolics – they did not suit his delicate constitution. Even so, he felt at home at Mutua Fides (‘Mutual Trust’), the society’s headquarters, although it was sometimes governed by ‘the law of the jungle’. His best friends were the older students Anton Tellegen (the professor’s nephew, who was studying medicine) and Herman Jan van Leeuwen (studying law). Heike’s recreational activities were walking, music, chess and riding. As a ‘working member’ of Vindicat’s riding club, he took part in costumed performances at Groningen stables such as ‘Rosalind and Agnes’, a farce set in the Shah of Persia’s palace, with singing and dancing and numerous horses. When it finished, all raised their glasses in toast after toast to the club’s good fortune.¹²

Correspondent for Studenten Weekblad

Heike’s spell as a correspondent was noteworthy in more ways than one. He wrote articles and reports for the *Schoolnieuws*, which second-year HBS pupils had founded in the autumn of 1870,¹³ and the still more recently established *Studenten Weekblad* (Students’ Weekly Magazine). The latter was subtitled ‘mouthpiece for the Northern and Southern Netherlands’ and appeared from 13 March 1871 onwards out of dissatisfaction with *Vox Studiosorum*. One much-voiced complaint held that Vox was too ‘elegant’ in design and appeared so infrequently that it could not deal with news items and did not offer students a platform for unfettered debate. The *Studenten Weekblad* set out to fill this gap. ‘We offer conservatives and liberals, the orthodox and the modern, royalists and republicans, aristocrats and democrats, space in our paper’, announced the editors (based in Leiden and Utrecht) in the first issue. ‘This publication will be a mouthpiece for anything of interest to students which

¹¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 217.

¹² Groninger Archieven, archives of Vindicat, inv. no. 1900.

¹³ Heike Kamerlingh Onnes to Van Bemmelen, 1870, MB, archive 99.

could add to their knowledge or experience or ennoble their character.’ The new weekly made good its claim to national coverage (including Flanders) by hiring correspondents in Amsterdam, Delft, Groningen, Ghent, Liège, Brussels and Louvain.

Heike made a false start as a correspondent. Since he had gone to Arnhem to spend the Easter holidays with Van Bemmelen, and failed to produce anything for the *Studenten Weekblad*, someone else was appointed to report from Groningen in his place. As soon as Heike – oblivious of his replacement – started sending in copy after all, the editors dismissed the stand-in with equal nonchalance. Heike thought this so objectionable that he promptly resigned. Even so, he submitted articles now and then. After a peculiar advertisement on 10 April (discussed below), Heike made his debut as a polemical writer in the *Studenten Weekblad* on 5 June 1871. His opponent was one ‘Theodoor’ from Utrecht. The subject was Aletta Jacobs, the country’s first female medical student, who attended Groningen University.

Theodoor had published an article entitled ‘Some reflections on the Emancipation of Women’ in the *Studenten Weekblad* of 15 May. The Utrecht student had taken umbrage at ‘a few words of praise’ that the feminist periodical *Onze Roeping* had given to ‘Miss Jacobs of Sappemeer’, because ‘as a pioneer in the Netherlands, she is seen as the vanguard of emancipation. For she was the first [woman] to dare to enrol at a university in this country.’ Was that such an achievement, Theodoor demanded, if you could be sure that every daily newspaper would print your name and virtually everyone would speak about you ‘with reverence and respect’? After which he accused Aletta Jacobs, ‘the trail-blazer for all, who must set an example to all and must therefore perform the most outstandingly of all’, of ducking the very first opportunity to take an examination and requesting an exemption instead. ‘How many more exemptions will Miss Jacobs be requesting?’ he jeered. Theodoor also broached the theme of ‘beauty’: ‘It has never ceased to amaze me that physical beauty is *lacking* in almost all those ladies who *strive* for emancipation and *present* in those who do *not*.’

Aletta Jacobs had enrolled at Groningen University in April 1871 with no qualifications other than a certificate as a student pharmacist. She had written to interior minister Thorbecke one month earlier, requesting exemption from both the entrance examination and the compulsory lectures in Greek, Latin and logic. Thorbecke was inclined to grant her request – how could she be blamed for not possessing the required certificate when girls were not even allowed to attend *gymnasium*? But he deemed it unnecessary to decide straight away, since matters did not have to be arranged until students took their first-year examinations; when these came in sight, Aletta passed with distinction.

That Groningen should have been the first Dutch university to admit a female student was entirely in tune with its ethos.¹⁴ Inspired by Johan Stuart Mill's *The Subjection of Women*, Professors Van der Wijck (philosophy) and Tellegen both produced pamphlets in 1870 advocating proper education for women. And the following year, Johan Tellegen (another son of the law professor) defended the proposition, in the law faculty's debating club, that 'the essence of woman's nature' did not justify 'the opinion that women are in general inferior to men'. After Aletta Jacobs had passed her first-year examinations, Bernard Tellegen provided the following apt comment on the climate at his university, writing in *Het Vaderland* of 25 October 1872. 'Something of this kind could not happen in Leiden or Utrecht. It was only possible in Groningen, in the radical north.'¹⁵

The *Studenten Weekblad* of 5 June 1871 carried a vehement response from one O. of Groningen, who was enraged by Theodoor's remarks, made three weeks earlier. 'This man, in ridding himself of every trace of chivalry and deeply insulting a young woman in public, seeks to provoke the wrath of all the ladies in the country. Ah, Theodoor! Never fear, *they* will take pity on you and merely shrug their shoulders; but among us Groningen students, some have suggested that you, student who is no student, man who is no man, should be...' O. held that since the required preparatory schooling was unavailable for girls, it was only logical that Aletta Jacobs should have applied for exemptions. He did not believe that she would request any further exemptions: not only did she have no more opportunity to do so, but given the zeal with which she was applying herself to her studies, she would 'benefit [...] sufficiently' from her academic education to be able to take her examinations. He concluded, addressing himself to Theodoor:

Miss Jacobs placed her trust in us, for which we are thankful; she showed that she was not afraid of finding Theodoors in our midst. This trust was not misplaced, and the students of Groningen may be proud of it. That is why your words offend them; that is why I have taken up the gauntlet on her behalf. [...] My only regret is that I was compelled, for such an odious reason, to have your name printed so many times in a weekly publication.

The writer calling himself 'O' was Heike Kamerlingh Onnes, and in her autobiography (*Herinneringen*) Aletta Jacobs later expressed her gratitude to 'the

¹⁴ For Aletta Jacobs, see Inge de Wilde, *Nieuwe deelgenoten in de wetenschap: Vrouwelijke studenten en docenten aan de Rijksuniversiteit Groningen 1871-1919* (Groningen 1998).

¹⁵ Quoted in De Wilde (1998), 7.

man whose research would earn him international fame' for 'the way in which he defended my rights when he himself was still a young student.'¹⁶

It should perhaps be added that, in the opinion of Groningen University's Senate, successive interior ministers had been too quick to hand out exemptions to aspiring students of medicine and of mathematics and physics. While most such applicants were army officers, military physicians and teachers, mature men with a certain standing in society and as a rule some knowledge of the classics, after the passage of the 1863 Secondary Education Act exemptions were granted to numerous HBS school leavers. The argument was that one could perfectly well study medicine or mathematics and physics without any knowledge of the classics – a view that Samuel Rosenstein, a professor of medicine at Groningen, propounded in his foundation day speech in October 1871. Even so, the Senate had told the States General six months earlier, during Rosenstein's term as rector, that it was unhappy about the immoderate strewing about of exemptions. It feared that they would create an undesirable precedent and undermine the gymnasium's prestige.¹⁷ A parliamentary committee endorsed this stern position, but Thorbecke – known for his aversion to barriers in education – thought the concerns a little exaggerated. After his death (on 4 June 1872) the Lower House persisted in its position: the exemptions would have to go.

On 9 and 16 October 1871, Heike published his strong views on the subject in the *Studenten Weekblad*. He viewed the entrance examination and the obligatory classics and logic classes as 'police measures' designed to force students to possess a certain cultural training 'for their own good'. The idea that *gymnasium* was the only way to achieve this cultural training might, he acknowledged, have been 'rational and practical' in 1815 when the legislation requiring it had been introduced. However, where the 'new disciplines' were concerned, Heike maintained that the best preparatory training was provided at HBS, which had 'deliberately and consistently accorded precedence to the philosophical [i.e. exact] sciences'. While HBS had not been set up to prepare pupils to study 'philosophy', it served this purpose admirably in practice. 'Thorbecke ploughed the field and found a pot of gold.'

But the notion that junior notaries' or assistant pharmacists' certificates should be viewed as any kind of preparation for law or medicine struck Heike as nonsensical. He concluded: 'Exemption from the entrance examination for philosophy – excellent! For medicine perhaps, but for theology and law it is impractical, and for the humanities inconceivable!' He considered exemptions

¹⁶ Aletta Jacobs, *Herinneringen* (Amsterdam 1924) 28.

¹⁷ Inge de Wilde (1998), 53–58.

for the humanities particularly disastrous, ‘and one rotten apple can spoil a great many others!’ Thus, the ‘philosophy’ student who had defended the exemptions granted to Aletta Jacobs with the argument that as a woman she had been precluded from attending a suitable school, now blamed Thorbecke for exempting others from subjects ‘the importance of which to [their proposed] studies cannot be denied’.

The muddy waters of Modderman

In between his visits to Mutua Fides, lectures at the society ‘De Harmonie’ (to which virtually all Vindicat members belonged), concerts, billiard evenings, foundation day activities, skating and cavorting on the ice, the annual ball and his journalistic activities for the *Studenten Weekblad*, Heike also studied zealously. He had enrolled in the maths and physics faculty with a view to graduating in chemistry. The ‘philosophical’ faculty had about 25 students ‘of its own’ in Groningen in 1870, and its main task was to provide first-year teaching for the medical faculty.¹⁸ The only prospect of employment for maths and physics students was as a teacher at an HBS or gymnasium – or, for a handful, in academia; not until the last quarter of the century did a few sporadic opportunities arise in industry. Heike had agreed to start work at the brickworks immediately after receiving his *doctoraal* (master’s) degree.

But first came the undergraduate course. This included an array of examinations in mathematics (algebra, geometry, trigonometry, stereometry, spherical trigonometry, higher algebra, analytical geometry, differential calculus) as well as physics, astronomy, chemistry, botany and zoology. Other subjects – logic, and Greek and Latin literature – had no examinations, but students were required to show certificates of attendance (without examinations) for logic and for Greek and Latin literature. Logic was taught by Van der Wijck, an inspiring teacher (a distinct advantage if your classes are on Mondays, Tuesdays and Wednesdays from 8 to 9 a.m.) and a liberal with wide-ranging interests who published articles on psychology, education, ethics, aesthetics and politics.¹⁹ The Latin teacher Francken (whose son had attended HBS with Heike) lectured on Tacitus and Horace on the same three mornings from 11 until midday. The duties of a professor were sometimes arduous. Some students were known to take their dogs with them to lectures, and the Utrecht philosopher Opzoomer (Van der Wijck’s mentor) evidently found lecturing to a listless audience so

¹⁸ M. Groen, *Het wetenschappelijk onderwijs in Nederland van 1815-1980*, vol. 2: maths and physics (Eindhoven 1988).

¹⁹ De Wilde (1998), 21-22.

disheartening that he handed out certificates of attendance to everyone, including students he had never seen in class.²⁰

Professor W.A. Enschedé, who taught mathematics, was not universally admired. This old-school instructor had been transferred to Groningen in 1843 after the closure of Franeker's secondary school, and he worked mainly as a librarian in the university library. His lectures on 'lower mathematics' were well attended, but he was also criticised. 'The professor displayed great diligence in teaching these classes', read the report by the maths and physics students in Groningen's student almanac for the year 1870-71, 'and we wish, if we might be so bold, that he displayed equal diligence in his lectures on higher mathematics.'

The chemistry lectures did not live up to Heike's expectations. Tjaden Modderman, Van Bemmelen's predecessor as principal of Arnhem's HBS, had taken over as professor of chemistry in March 1869. Modderman had a heavy teaching load, with lectures on organic and inorganic chemistry, pharmaceutical chemistry and mineralogy, as well as agricultural chemistry at the agriculture school in Haren. Chemistry was taught in a ground floor wing. While Kerckhoff, who had left to replace Gerrit Jan Mulder in Utrecht, had done much to modernise Groningen's chemistry laboratory (although without performing any significant research), his successor, Modderman, was 'more of a populariser than a chemist of any significance'.²¹ He scarcely concerned himself with new developments in his discipline. When J.H. van 't Hoff proposed the asymmetrical tetrahedral carbon atom in 1874, launching the new discipline of stereochemistry, Modderman was among those who labelled even this brilliant hypothesis 'precipitous'. His students in Groningen complained that he handled too little material in his lectures and left his assistant to supervise their experiments.²²

Heike complained bitterly about the state of affairs in the chemistry laboratory, writing that 'the assistant descended on students at 12 o'clock and coolly ordered them out of the laboratory until 1.30, whatever they happened to be doing; only a select few were allowed the special privilege of being locked in'.²³ Heike wrote of the 'bungling' methods applied at the laboratory and the 'muddy waters' of the qualitative analyses performed there every day.²⁴ Disappointed, he re-enrolled at the chemistry laboratory attached to the HBS.²⁵

²⁰ See Groen (1988), 10.

²¹ H.A.M. Snelders, *De geschiedenis van de scheikunde in Nederland*, vol. 1 (The Hague 1993), 110.

²² *Groninger Studenten-Almanak* 1870, 101.

²³ H. Kamerlingh Onnes, 'Levensbericht van R.A. Mees', *Jaarboek van de Koninklijke Akademie van Wetenschappen* 1888 (Amsterdam 1888) 80-98.

²⁴ Heike Kamerlingh Onnes to Van Bemmelen, February 1872, MB, archive 99.

²⁵ Groninger Archieven, archief Rijks-HBS Groningen, inv. no. 314.



Ill. 7. Main building of Groningen University, Broerstraat (Groningen Archives).

Physics was taught in a wing on the upper storey offering equally wretched conditions for experimental work, but no-one could fault the professor. Every year the almanac contained entries praising Rudolph Mees, a shy banker's son who had found his appointment as professor of physics in Groningen in the mail on returning from holiday in the summer of 1868. His lectures were described as outstanding, although some occasionally complained of his overzealous attitude at examinations. Mees, who was only 23 years of age when appointed, was a versatile man who loved paintings and travel and was devoted to Dickens and Walter Scott. He saw the university's primary task as Humboldtian *Bildung*, boldly entitling his inaugural address 'Education in the natural sciences: a necessary part of every civilised upbringing'.²⁶ His lectures in experimental physics were very polished. 'Mees's presentation could have been published as it was and would have constituted a textbook based entirely on the latest views', Heike later recalled. '[Leonard] Deutgen, his laboratory assistant,] performed the experiments referred to in the address flawlessly, each at exactly the right time. The reasoning was completely clear. [...] His lectures

²⁶ R.A. Mees, *Het onderwijs in de Natuurwetenschappen: een noodzakelijk bestanddeel van elke beschaafde opvoeding* (Groningen 1868).

inculcated a critical habit of mind in all but the least receptive. Once he had been speaking for a few minutes, he invariably became impassioned and spoke with infectious enthusiasm. It is scarcely surprising that students attended his lectures so faithfully.²⁷

The problem with physics was the lecture hall. Though it was spacious and – aside from a sturdy barrier separating students from the blackboard and demonstration tables – highly serviceable, the room’s location was awkward. You had to go through it not only to reach the professor’s sitting room and workroom, but also to reach the instrument room and laboratory. Mees did not have an assistant, and any student wanting to perform an experiment in Mees’s absence had to go down to Deutgen’s living quarters in the basement and cajole him into handing over the keys. There was thus no discreet way to enter either the workroom or the instrument room when Mees was lecturing; Heike would stand listening at the door, waiting for a suitable moment to slip into the lecture hall. Once he had done so, the way back was effectively cut off; disturbing the professor again was unthinkable. The awful thing was that neither the workroom nor the instrument room had any equipment. However trivial the task you had set out to accomplish, chances were you would need something from Deutgen’s workshop in the basement. Fortunately, Heike was on very good terms with the laboratory assistant (and his sister). He was given the key whenever he asked for it and was allowed to do as he pleased – ‘a *great* privilege’ – in the workroom. And when Heike hired Deutgen to assist him, the latter charged reasonable rates.

Amid these exasperating inconveniences, Heike was trudging through the entrance hall of the detested building one day when he noticed an announcement on the wall in Latin – ‘I was proud to be able to read it’.²⁸ Utrecht University had set a number of competitions, a tradition that all universities hoped would add lustre to their foundation day celebrations – although some competitions came and went without attracting a single entry – and that endured into the twentieth century. Utrecht’s maths and physics faculty challenged students ‘to make a critical study of the methods used to determine vapour density and of the results obtained by these methods, in the light of the relationship between the nature of chemical compounds and vapour density’. Heike relates: ‘Well, I was a student, and so I set to work.’ It is unclear whether he confined himself to a study of the literature or whether he did some laboratory work of his own. In the latter case, he probably performed his experiments in the basement of his parents’ house in Zoutstraat. The following account is taken from the interview with Van Itallie-Van Embden:

²⁷ See H. Kamerlingh Onnes (1888), 74-76.

²⁸ See Van Itallie-Van Embden, 40.

I was not entirely sure that I would not be thought a bit of a swot – at least, when my friend came to see what I was doing, my only thought was to hide it by removing the pipe from the heater and rushing out of the room with him to escape from the huge clouds of smoke. You see what a child I was? My father copied out the prize question; applicants were not allowed to send in entries in their own handwriting. Months later I was suddenly called out of a lecture and told to go home. It was my mother! She stood there waving a half-torn letter: recognition for my efforts.²⁹

The letter was from E. Mulder, secretary of Utrecht's faculty of mathematics and physics (and the son of Gerrit Jan Mulder), and it invited Heike to attend Utrecht University's foundation day celebrations on Tuesday 14 March, on which occasion he would be awarded the gold medal.³⁰ (The event was later postponed to 27 March because of the death of Friedrich Anton Willem Miquel, rector of the university.) The faculty's verdict praised Heike for his new method of determining vapour density.³¹ Though it was an unorthodox and surprising solution, it proved that the applicant was familiar with the full range of resources available in physics. The Utrecht faculty also praised the acuity of Heike's judgment, the accuracy with which the advantages and disadvantages of the various methods had been checked, and the weight attached to special conditions.³² When the faculty judges spoke to him, Heike later recalled, Buys Ballot 'just sat there beaming benignly throughout [...] he was delighted by such a young boy's achievement, and seemed to be thinking, "My word! we have to encourage a fellow like that!" His colleague [E. Mulder] looked rather disdainful, and thought Buys was adopting an altogether too casual approach to the occasion. And Donders said: "You should go to Germany now." I kept that suggestion firmly in mind.'³³

The *Studenten Weekblad* of 27 March reported on the 'ceremonial celebration' of Utrecht's foundation day. A busy programme had awaited the winners after the prize-giving ceremony: 'In the evening, the professors met for dinner at the Hotel des Pays-Bas, to which the prizewinning students had also been invited and which was said to have been very lively.' The university's students contributed by inviting the musicians' corps of the cavalry regiment in The Hague to their society building. 'Though not crowded, the festivities were very lively; the many toasts included one in honour of the prizewinners, who had joined us after the professors' dinner. The party went on until daylight crept through the windows.'³⁴

²⁹ See Van Itallie-Van Embden, 40.

³⁰ MB, archives of Heike Kamerlingh Onnes, inv. no. 233.

³¹ *Ibid.*

³² See also Ernst Cohen, *Van Boerhaave tot Kamerlingh Onnes* (Utrecht 1922) 6.

³³ See op. cit. note 8, 41.

³⁴ *Studenten Weekblad*, 27 March 1871.

This all-night celebration had a noteworthy sequel. Two weeks later, Heike published a bizarre advertisement in the *Studenten Weekblad*. Quoting part of the faculty's verdict of 27 March and referring to his alternative determination of vapour density as 'a major change to the Regnault method',³⁵ he called on students who were planning to put his new method into practice to contact him. 'Perhaps it might also be of some use to science', said Heike, 'to ascertain whether a method that has so much to recommend it in theory might also yield similar results in practice.' Van Bemmelen found this boastfulness astounding and sent his seventeen-year-old pupil a letter calling him to account. 'As far as that announcement in the student weekly is concerned', Heike responded, 'I myself consider it quite ridiculous but it was written in Utrecht in a state I would prefer not to describe. I could not fill in what your letter left unsaid with any words other than "folly" or "bragging"'.³⁶

Mees, 'an unusually harsh critic' [...] 'was not well pleased with all that fuss about someone so young', Heike recalled in 1922. 'Well, it was easy for him to show me how superficial my piece was and how little of it was new. I truly found him the perfect counterbalance to my outward success; and that was my good fortune and salvation.'

The day after the Utrecht prize-giving ceremony, Heike went to Arnhem, where he spent the Easter holiday with Van Bemmelen. In the laboratory of the Arnhem HBS, he helped his teacher test the level of nitric acid in spring water, for which Van Bemmelen duly thanked him in the *Maandblad voor Natuurwetenschappen* on 17 September 1870.³⁷ Taking part in experiments did Heike good; it rekindled his love of chemistry. He went on walks in the woods with Van Bemmelen and discussed his future, which clearly lay not in the brick-works but in science. 'My father accepted that relative disappointment straight away', Heike told Van Itallie-Van Embden. He said, "When you're finished you should try to secure a position as an assistant lecturer, then you'll have enough to live on; it won't provide a wealthy lifestyle, but you don't need that anyway; the only thing is that you must forego all thoughts of marriage for many years.' Van Bemmelen had high hopes of his protégée and made him promise never to become a teacher – or HBS principal – and not, for the moment, to fritter his time away with women. The two also discussed the places where experimental chemistry was of a decent standard. In Delft, where the Polytechnic had been founded in 1864, the introverted chemistry professor Oudemans

³⁵ Regnault was a nineteenth-century French physicist known for his high-precision measurements.

³⁶ Heike Kamerlingh Onnes to Van Bemmelen, c. April 1871, MB, archive 99.

³⁷ J.M. van Bemmelen, 'Bepaling van salpeterzuur in welwateren door indigo', *Maandblad voor Natuurwetenschappen* 1872, 49-61.

had recently established a new chemistry laboratory. But the Valhalla of experimental chemistry, they unequivocally agreed, was Heidelberg, the city of Robert Bunsen.

Back in Groningen, Heike had difficulty picking up the thread of his studies. After a fortnight of parties and horse-riding he started ‘cramming’, but it was more difficult than he had expected. Heike complained of health problems. ‘I have difficulty getting up in the mornings, and I frequently find myself despondent or irritable’, he wrote to Van Bemmelen. But he did not consider postponement an option. ‘I have decided to take my examinations on 24 June, just before the festivities at the agriculture conference.’³⁸ This plan proved unduly optimistic, and his examinations were postponed until 9 November, perhaps owing to illness. Armed with his registration card, pass sheets and 47 guilders, Heike Kamerlingh Onnes arrived at the university premises. His oral examination in the small lecture hall was soon followed by the first congratulations, and a telegram was despatched to Arnhem: ‘Did exams, *summa sine laude*. [ordinary pass] Please telegraph what you think best, Delft or Heidelberg. Onnes’.³⁹

³⁸ Heike Kamerlingh Onnes to Van Bemmelen, April 1871, MB, archive 99.

³⁹ Heike Kamerlingh Onnes to Van Bemmelen, 9 November 1871, MB, archive 99.

4. Heidelberg

In his novel *Fathers and Sons* (1862), Ivan Turgenev contrasts the old spiritual Russia with the modern rationalistic Germany. The aristocrat Pavel Petrovich grumbles that the Germans, once the nation of Schiller and Goethe, ‘all seem to have turned into chemists and materialists’. His opponent, the nihilist Bazarov, protests that German scholars are ‘a clever lot’ and that ‘a decent chemist is twenty times more useful than any poet’. In another passage, the independent woman Evdoksya Kukshina confides in the melancholy Bazarov that she plans to study abroad. Where? In Paris and Heidelberg. Why Heidelberg? ‘How can you ask! Bunsen lives there!’¹

The Ruprecht-Karl University of Heidelberg, to which Grand Duke Karl-Friedrich had given a new lease of life in 1803, was the pride and joy of the southern state of Baden. Before unification in 1871, the German-speaking territories were a patchwork of quarrelsome little kingdoms, grand duchies and electorates, the most powerful of which was Prussia. Locked into rivalry, they were all eager to bolster their identity and cultural status and did their utmost to entice eminent scholars – including scientists – to their universities. The authorities asserted that academic expertise boosted local agriculture, but this was in part mere rhetoric. By attracting academic luminaries, each state hoped to burnish its cultural image and outshine its neighbours.² A scholar who knew his worth could in turn exploit the situation by demanding certain facilities. Everyone benefited from such arrangements: the scholar, his discipline and the students themselves.

The University of Heidelberg, where Heike Kamerlingh Onnes registered as a student in November 1871, was a truly international institution. Over 80 per cent of its 850 students came from outside Germany. In the summer

¹ Ivan Turgenev, *Fathers and Sons*, translated by Constance Garnett, chaps. 6 and 13, eBooks@Adelaide, University of Adelaide Library, <http://etext.library.adelaide.edu.au>.

² Frank A.J.L. James, ‘Science as a cultural ornament: Bunsen, Kirchoff and Helmholtz in mid-nineteenth-century Baden’, *Ambix* 42 I (March 1995) 1-9.

term of 1872, the science faculty had a total of 152 foreign students and only 45 Germans.³ The main countries of origin were Austria, Switzerland, Great Britain, France, Russia, Poland and the United States – Heike was the only Dutchman. Arriving in Heidelberg at the age of eighteen, the new student encountered a vibrant academic life, the indisputable fulcrum of which was the chemist Robert Bunsen. Bunsen had been enticed to Heidelberg in 1852, appointed *Hofrat* [roughly: privy councillor] and chair of the philosophy faculty and provided with a brand-new laboratory. He immediately secured positions at the university for the physicist Gustav Kirchhoff and the physiologist Hermann Helmholtz. They tramped through the forest inspiring each other with their ideas; never before had the University of Heidelberg had such an illustrious trio among its ranks. But Prussia was not to be outdone, and managed to attract Helmholtz to a chair in Berlin after the German Empire was proclaimed in 1871. Kirchhoff joined him there four years later.

Heike jotted down his initial impressions of Heidelberg in a travel journal published in the *Studenten Weekblad* of 2 January 1872. He eulogised the city on the Neckar, as Romantics such as Lenau and Goethe had done before him, and started by addressing these illustrious predecessors:

On your journey up the Rhine you surely visited the Molkenkur and delighted in the marvellous view commanded by this near-unique spot. You stood there, allowing your gaze to sweep over the vast, fertile Rheingau, over the Neckar, which, strewn with wooden rafts, winds across the plain like a silver ribbon. You looked down on the houses and streets of Heidelberg, the ivy-covered ruins of the Schloss, which, with its gardens and towers, its archways and statues, its copses and groves, one may justly call the German Alhambra. Perhaps the last rays of the setting sun bathed this scene in a red glow, perhaps the church-bells were ringing and their notes echoed softly and melodiously in that narrow valley, mingling with the characteristic hubbub of a lively town, as a hymn to the life stirring and swarming down below.⁴

The lyrical student from Groningen then descended from the mountain to thrust himself into ‘the midst of the mass of humanity’, to see ‘if all that poetry would come to life again in truth and reality’! Heidelberg ‘really’ consisted – as Heike proceeded to relate in a more sober mood – of a single street running parallel to the Neckar between two gates, the Karlstor and the Mannheimer Tor. This main street, which was dominated by red sandstone buildings, had some ‘good, large shops’ but no fine houses. ‘But the people bustling about, the cafés and the businesses, are quite enough’, Heike observed. And anyone who

³ MB, archives of Heike Kamerlingh Onnes, inv. no. 218.

⁴ *Studenten Weekblad*, Monday 2 January 1872.

wandered down the street would hear ‘every conceivable language’, since Heidelberg was ‘a centre attracting foreigners of every kind – most notably Englishmen and Americans, who not only make the city large and expensive, but also enliven it with their free and easy ways.’

These expatriates lived in comfortable houses to the southwest of the centre. Heike had rented a ‘decent’ ground-floor apartment in that new quarter, in Gaisbergstrasse, from one Frau Reiss, the widow of a cigar manufacturer. It was ‘a splendid and relatively inexpensive place’, furnished with a desk, a piano, a sofa and a convection heater, and a balcony facing west with a splendid view.⁵ Most of the students lived in the old city centre, ‘Altstadt’, but Heike shuddered at their ‘ghastly hovels ... completely uninhabitable for a Dutchman’. Although Gaisbergstrasse was rather a long way from the town centre, it was only a few minutes’ walk to the chemical laboratory. And it was for the great Herr Bunsen that he had come to Heidelberg.

Robert Bunsen (1811-1899) was one of the greatest chemists of his day.⁶ The son of a linguist/librarian from Göttingen, he had established himself as a dyed-in-the-wool experimental scientist. Only experiments counted. In his lectures on general experimental chemistry, which he gave from 9 to 10 a.m. daily (in the summer from 8 to 9 a.m.) for 74 consecutive terms, he eschewed theory and confined himself to discussing research methods. His carefully-prepared demonstrations elicited appreciative applause from his students. One properly verified fact, Bunsen liked to say, was worth more than any number of theories. Bunsen did not even deign to make time in one of his lectures to discuss the periodic table, which his pupils Julius Lothar Meyer and Dmitri Ivanovich Mendeleev had formulated in 1869. Nonetheless, he impressed upon his pupils that a chemist could not dispense with training in mathematics and physics: ‘A chemist who is not a physicist is nothing at all.’

In 1852, after successive appointments at the universities of Marburg and Breslau (where he remained for less than a year), Bunsen was appointed professor of chemistry in Heidelberg. He would remain faithful to Baden until his retirement in 1889, at one point rejecting an offer of a chair in Berlin: he wanted nothing to do with Herr von Bismarck’s regime. In Heidelberg he initially worked in a monastery converted into a laboratory, but in 1855 he moved into modern premises on Plöckstrasse. Just before the new building opened, Heidelberg acquired its own gas grid, and Bunsen set about developing a new

⁵ Heike Kamerlingh Onnes to Van Bemmelen, February 1872, MB, archive 99.

⁶ See e.g. Henry Roscoe, ‘Bunsen memorial lecture’, *Journal of the Chemical Society* LXXVII (1900) 513-554; Georg Lockemann, *Robert Wilhelm Bunsen: Lebensbild eines deutsche Naturforscher* (Stuttgart 1949); *Dictionary of Scientific Biography*, vol. 2, 586-590 (New York, 1970). Part of the text on Bunsen has been taken from Dirk van Delft, ‘Robuuste hitte’, *Uit het depot* (Leiden, 1999) 8-10.



Ill. 8. Robert Bunsen (1811-1899) instructed Heike in practical chemistry in his year in Heidelberg.

type of burner, one that emitted a hot flame without sooting up. This Bunsen burner, which can still be found in every laboratory today, is his best-known invention, together with the zinc carbon cell, the first widely used battery, which he designed in 1841. Bunsen never bothered about patenting his inventions, believing that avarice impeded scientific progress.

A lifelong bachelor with hands like coal shovels, Bunsen had lost the sight in his right eye in a laboratory explosion involving cacodyl (a compound of carbon, hydrogen and arsenic). Even so, he was a brilliant experimental chemist, one of the few scientists who could seal a mercury tube with his thumb and invert it in a basin of mercury without admitting the tiniest bubble of air. He was also a skilled glass-blower, and his 'fireproof fingers' were legendary. Accuracy was the watchword in his laboratory, where it was perfectly unremarkable to spend six weeks toiling over a silicate analysis. Students from near

and far came in droves to master the techniques of practical inorganic chemistry under his watchful eye. Many famous chemists of the latter half of the nineteenth century obtained their practical training in Heidelberg. Bunsen helped his students all day long, demonstrating the proper techniques with a cigar dangling from his mouth. Even so, he found time to do his own research, tackling whatever problem arose without adhering to any system. The early mornings were reserved for calculations and writing articles. Bunsen wrote only one book, *Gasometric Methods*. It appeared in 1857 and provided an overview of the experimental methods he had mastered to perfection in his long career. The book contains no theoretical reflections whatsoever. Bunsen preferred to give his readers practical tips to help them to avoid, eliminate or at least minimise errors in measurement.

Heike arrived with a letter of introduction to Bunsen from A.H. van Ankum, who had taught him chemistry in his examination year at the Groningen HBS – he was not on friendly terms with Modderman. He was received ‘extremely cordially’ at the Plöckstrasse laboratory, and Bunsen ‘provided apt assistance with everything straight away’.⁷ Van Ankum had written that the student from Holland had little practical experience, and Heike decided not to make his teacher look foolish by putting the record straight – anyway, the comment would make his progress seem all the more remarkable. The winter term in the chemical laboratory began with exercises in qualitative analysis, including flame tests and working with tiny quantities of a fluid – Bunsen’s hobby-horses. Heike completed everything in six weeks and appeared cheerful. ‘Doing qualitative analysis with [Bunsen], you do not end up gazing into muddy waters, as we did for two hours every afternoon at the Groningen University laboratory.’

Bunsen’s laboratory was not rich in resources. In fact, Heike said it was ‘in itself very shabbily equipped’, and he had to pay ‘a substantial sum’ for items such as weights, platinum crucibles and glassware. Anyone caught ‘abusing’ the scales was required to pay a 50 cent fine. That did not bother Heike; he approved of the rule since it ‘created a good atmosphere’. He had few financial worries, his parents ‘slaughtered a few Spaniards’ to cover the costs of his stay in Heidelberg.⁸ When he first arrived, Heike dined in Hôtel Schruder and Bunsen and his fellow professors Königsberger, Ladenburg and Kühne invited him to join them. But that soon became too expensive.

It was when Bunsen started teaching quantitative analysis that students were truly struck by his brilliance. Heike was overjoyed at the ‘willingness, which I would almost call special treatment’ with which the champion of practical

⁷ Heike Kamerlingh Onnes to Van Bemmelen, February 1872, MB, archive 99.

⁸ Slaughtering Spaniards was a local metaphor for drawing on one’s savings.

chemistry assisted him. ‘I would happily work for a whole week to hear Bunsen say “sehr schön” or “sehr hübsch”.’ And he certainly worked hard. Heike rose at 6:30, rapidly devised a plan for the day, set to work in the laboratory at 8, taking a 30-minute lunch break, and returned home at around 8 p.m. Herr Bunsen was always close at hand to demonstrate how things should be done. ‘He does everything he can to make my work enjoyable,’ Heike noted cheerfully. Finally he was producing analyses that were accurate to 0.1 per cent – for instance, of the silver, copper, gold and tin content in coins. What a world of difference from ‘that bungling in Groningen’. By February, the Dutch demon had left most of his almost 60 fellow experimenters far behind him. He hoped to complete quantitative analysis before the Easter holiday, after which the curriculum contained gas analyses, experiments with rare substances, and individual research. He was looking forward to it. ‘And I believe I can count on receiving a fine certificate, which will certainly be valuable in all parts of Europe.’

Bunsen also helped in matters unrelated to lab work. On his personal recommendation Heike gained free access to Heidelberg’s university library and the library in the chemical laboratory, which housed scientific journals. In the Christmas holidays he read Kopp’s *Theoretische Chemie* and *Geschichte der Chemie* and Friedrich Mohr’s *Mechanische Theorie der Chemische Affinität* (which he dismissed as ‘rubbish’). That same week he reflected on a competition set by Groningen University: ‘The assignment is to provide a critical overview of the methods used to determine the quantity of heat released by chemical bonding and dissolution and of the results obtained by different researchers.’ Heike also developed a lecture for the Chemistry Society on an idea regarding chemical bonding.

In this latter subject, Heike hoped to have hit on something fundamental. He saw atoms as a species of tiny magnets, an idea that he would not easily relinquish. ‘This analogy [between valency and magnetic moment] was a ray of light to me’, he wrote to Van Bemmelen in January 1873, with a rough elaboration of this idea.⁹ It revolved around the notion that ‘the atomicity [valency] of an element = the magnetic moment of its atoms, i.e. the product of the distance between the poles and the magnetic fluid accumulated within’. Thus, the magnetic axis of a carbon atom, assuming the poles to be of equal strength, would be four times as long as that of a hydrogen atom. If two atoms bonded together, the north pole of one would cancel out the south pole of the other, producing a ‘trivalent atomic configuration’. According to this theory, valencies were ‘undoubtedly not whole numbers’. Chemical bonding

⁹ Heike Kamerlingh Onnes to Van Bemmelen, 19 January 1873, MB, archive 99.

would therefore be expected to produce a residue, which Heike characterised as ‘forces acting on molecular bonding, solutions, crystal formation and so on.’ The idea did not lead anywhere.

Student life in Germany

While Heike soon felt at home in Bunsen’s laboratory, he was ill at ease with German student life. Still, in January he had skated on the River Neckar as soon as he could. His first letter from Heidelberg reads: ‘The river is frozen solid and my Dutch heart is already yearning to don skates and fly past the Germans like a whirlwind.’ The Skating Club had recently opened an ice rink near the Bergheimer Mühle (a big mill in the west of the city) with a great deal of publicity. ‘The little cannons planted in the ice were fired ... every fifteen minutes, a momentous event preceded by a blast on a fairground trumpet. In spite of this warning, the German ladies were quite terrified, and in the consternation a very sweet blonde caught my eye.’ But Heike assured Van Bemmelen that he had never forgotten his ‘words in Oosterbeek’ – ‘the bride I have come to find in Germany is science’ – and that while he had enjoyed messing about on the ice and had attended several balls in Heidelberger Museum, he had not been foolish enough to fall in love.

But Heike disliked the constant boozing in the city centre, an everyday activity for students and men in general, and he made few friends. ‘Students do not entertain in the dismal caverns they call home’, he wrote in the second instalment of his travel journal in the *Studenten Weekblad*. ‘Only twice have I entertained some truly cultivated German students, whom one must certainly not confuse with the “louts” who are in the majority here.’¹⁰ True friends were people with whom you could converse in your student room; quoting Schiller, Heike wrote that ‘Austauschen der Seelen’ (‘a mingling of souls’) was incompatible with countless tankards in an ale-house. What he missed was a student society similar to *Mutua Fides*.

The pleasant walk to the pub, where one would always find students with whom one could converse, seeing all the students, the sense of being part of a student world – all this is completely absent here. Ten or twelve fellows drag themselves to an ale-house on certain evenings and with a few exceptions they are sent their separate ways by the police after midnight.

Heike missed the ‘pleasant afternoons, the parties ... the evenings on which we used to gather around the round table’. He reviled the affectations of flag-bearing

¹⁰ *Studenten Weekblad*, 29 January 1872.

associations, *Corps* and *Burschenschaften*, clubs that could be found at all German academies, none of which had more than a few dozen members.¹¹ They had their own bars, where they filled themselves with beer and created a public nuisance. Then there were the notorious *Mensuren*, student duels, provoked by a member of another fraternity or a *Bummler* (idler) saying, ‘*Sie sind ein ganz dummer Junge von mir*’ (‘I think you’re an absolute blockhead’), or words to that effect. The two brawlers would draw swords and try to scratch each other’s faces. Other things that Heike detested were ‘the stream of wealthy jokers’ that the nobility contributed to Heidelberg’s university, the class prejudices and the students’ social circles. ‘It is a narrow-mindedness, a pettiness, which makes the student aristocrats what they are, a narrow-mindedness that reveals a lack of one of the finest characteristics of our nation, namely respect for the individual.’¹² Perhaps the dark days of winter had lowered Heike’s spirits. In any case, after six months in Heidelberg, his laments turned to exultation.

Heike’s ideas about Germany and the Germans bear the unmistakable signs of Allard Pierson’s influence. This Walloon minister,¹³ a devotee of modern theology who had left the Dutch Reformed Church in 1865, had been a professor by private appointment at Heidelberg University since 1870. In his first year, when students had been caught up in the thick of battle and he had lived ‘amid the wounded and dying’, he had written *Herinneringen uit Pruisens geschiedenis* (‘Recollections of the History of Prussia’). It had been Van Ankum, once again, who had introduced Heike to this ‘marvellous circle of refined intellectual life’.¹⁴ He enjoyed it to the full and soon saw the Piersons’ house as a second home. The professor improvised wonderfully on the piano, and with Heike he discussed the latest theories about falling stars and spectral analysis, or developments in botany and comparative anatomy. His son Louis, a prospective banker, became ‘a great friend’ with whom Heike discussed ‘modern literature and art’ and played chess. The Piersons also introduced him to other families.

Heike’s comments on Germany in the *Studenten Weekblad* were fairly uncomplimentary. In Baden he was living among ‘a petulant and quick-tempered people’. German houses were ‘as ungainly as Prussian soldiers’ in contrast to the ‘neat and smart, delicately finished’ homes of the Dutch, and German family life likewise had little to recommend it. ‘Courtesy is not to the Germans’ taste. They prefer to kick or grovel.’ The result, wrote Heike in his second and third travel journals, was that joviality, domestic life, versatility, distinctive

¹¹ *Studenten Weekblad*, 2 April 1872.

¹² *Studenten Weekblad*, 4 March 1872.

¹³ For Allard Pierson, see J.C.H. Blom et al. (ed.), *Een brandpunt van geleerdheid in de hoofdstad* (Hilversum 1992) 247–266.

¹⁴ Van Itallie-Van Embden, 42.

personality and respect for the individual were all alien to Germans. That was why they loved drinking. ‘Business is the consuming passion of the German nation, and even the most highly educated Germans spend most of their lives in ale-houses.’ So Germany remained for him ‘a country of acquaintances, not of friends’.

But six months later, when Heike had become acclimatised, he saw everything differently, aiming his barbs of criticism at his home country instead. ‘That Dutch pride in money and aristocracy of money, that revolting distinction between club members according to whether they drink beer or wine, is unknown here’, he wrote to Van Bemmelen in July 1872. ‘In Holland dandies consort only with other dandies, the wealthy students generally close ranks, but here – except in the fraternities – none of this applies. For a Dutchman these genial relations are certainly an eye-opener.’¹⁵ Heike often joined in family outings. ‘We generally travel for half an hour to a valley, take a little boat to some tea-garden, play party games, sup, conclude the merrymaking with a few hours of dancing, and then walk home in the moonlight.’ Imagine such a thing in the Netherlands! ‘At home people spend all summer complaining about the heat.’

Assisting Gustav Kirchhoff

In the summer term of 1872, Heike divided his time between chemistry and physics. Besides his work in the chemistry laboratory with Bunsen, where he was occupied with platinum ore and pitchblende, he took part in Gustav Kirchhoff’s physics seminar and attended his lectures on theoretical optics – excellent presentations, though most of what he heard was familiar to him. There was an experiment to perform each Thursday in the physics laboratory at the Friedrichsbau: eleven in total. The aim of these experiments was:

- to determine the length of a second’s pendulum;
- to determine the refractive index of diverse types of glass;
- to determine the horizontal component of terrestrial magnetism, part 1;
- to determine the wavelength of sodium light;
- to determine the horizontal component of terrestrial magnetism, part 2;
- to determine the angle between the axes in an optical crystal;
- to determine the electromotive force of a Daniel cell;
- to determine the frequency of a tuning fork;
- to compare the frequencies of different tuning forks;
- to compare different resistances using the British Association standard;
- to calibrate a thermometer.

¹⁵ Heike Kamerlingh Onnes to Van Bemmelen, July 1872, MB, archive 99.

The students drew up reports of each experiment, including a theoretical introduction and a discussion of errors, and Kirchhoff commented on the experiments during his Monday afternoon lectures, though without naming names. ‘On the one and only occasion that he praised my experiments, it was a source of great satisfaction to me’, Heike wrote to Van Bemmelen in July. His reports were immaculate.¹⁶ He showed them to Louise von Grolman, a niece of Frau Rosa’s who was lodging at the Gaisbergstrasse at the time, and she corrected his German. She was happy to help the handsome Dutch boy with ‘large, sensitive blue eyes’, whom she admired for his scholarly books and laboratory coat with burn holes, and with whom she had enjoyed ‘the pleasure of dancing for the very first time’ at the Catholic ‘Kasino’.¹⁷

When Heike met Kirchhoff, the latter was 38 years old and confined to a wheelchair as a result of a fall in 1868. His disability made it impossible for him to do his own experiments or to lecture in experimental physics. This adversity was compounded by the death of his wife the year after the accident.¹⁸ He remarried around Christmas 1872, with the administrator of the ophthalmology clinic at the local Academic Hospital, an alliance that caused something of a stir according to Heike.

Kirchhoff, the son of a police officer from Königsberg, studied under Franz Neumann, who propagated a mathematical physics built on the work of early nineteenth-century French mathematicians such as Cauchy, Fourier and Poisson.¹⁹ These men, whose names are all linked to the École Polytechnique in Paris, were interested in applications in physics and mechanical engineering. Neumann, who, as a phenomenologist, confined himself to observable, measurable quantities, hoped his approach would bridge the gap between experiment and theory. Neumann and the mathematician Carl Jacobi introduced a significant innovation in 1883: a seminar in mathematical physics that encouraged students to conduct their own independent research. Gustav Kirchhoff was thus schooled in the unity of experimental and theoretical physics from an early age, and he took the seminar in Königsberg as the model for his own in Heidelberg. In 1847 Neumann opened a physics laboratory, where students

¹⁶ MB, archives of Heike Kamerlingh Onnes, inv. no. 33.

¹⁷ Louise von Grolman to Heike Kamerlingh Onnes, 17 November 1913, MB, archives of Heike Kamerlingh Onnes, inv. no. 220.

¹⁸ For Gustav Kirchhoff, see e.g. *Dictionary of Scientific Biography*, vol. 7 (New York 1973) 379–383; Frank James (see note 2).

¹⁹ David Cahan, ‘The institutional revolution in German physics, 1865–1914’, *Historical Studies in the Physical Sciences* 15 (1985), vol. 2, 1–65; Frans van Lunteren, “‘Van meten tot weten’: de opkomst der experimentele fysica aan de Nederlandse universiteiten in de negentiende eeuw”, *Gewina* 18 (1995) 102–138.



Ill. 9. It was Gustav Kirchhoff (1824-1887), in Heidelberg, who opened Heike's eyes to the wonders of physics and the fruitful combination of theory and experiment.

received practical instruction with ample attention to accuracy of measurement and error calculation. The Berlin professor Heinrich Magnus had also started a laboratory (in his own home) four years earlier, but his approach differed from Neumann's in its marked anti-theoretical, anti-mathematical bias. Magnus did pioneer a physics colloquium, however, at which lecturers and advanced students met weekly from 1843 onwards to tackle problems and discuss recent trends in their field.

After completing his PhD thesis and his *Habilitation* (a higher qualification required in Germany for aspiring professors), Kirchhoff transferred in 1850 to Breslau, where he gained an appointment as extraordinary professor. There he met Robert Bunsen, and when the latter moved to Heidelberg in 1852 he would not rest until he had arranged for his old companion from Breslau to join him there. In Baden the two men applied themselves intently to spectral analysis, in

which the Bunsen burner proved a valuable asset. They discovered that the gaseous form of every substance emits a characteristic spectrum of lines, which means that only highly specific colours (wavelengths) are emitted. In 1859 Kirchhoff discovered that a substance can absorb the same colours as those it emits when heated, and thus was born the science of spectral analysis. Thus, from the dark lines in the solar spectrum it can be inferred through which substances the sunlight has passed on its way to the terrestrial observer. Helium was first discovered on the sun, and only later on earth. Kirchhoff also discovered that the relationship between emission and absorption spectra is for all bodies a universal function of temperature and wavelength – the first application of thermodynamics to radiation phenomena.

Like his mentor Neumann, Kirchhoff had a phenomenological mindset. In his view, it was reasonable to posit the existence of atoms provided this led to a verifiable kinetic gas theory. But he would not accept physical arguments based on the properties or structure of atoms, however attractive, if they essentially relied on wild hypotheses. That rigor, combined with his capacity for meticulous and clear reasoning, made him an ideal teacher. His mechanics lectures were renowned, and once when Heike had the opportunity to borrow someone's notes on one, he copied them with alacrity.

Heike was full of praise for Kirchhoff's seminar, which provided 'a perfect way to familiarise oneself with physics experiments, besides which writing the reports constitutes a superb review of physics'.²⁰ Kirchhoff was so impressed with Heike's laboratory reports that he awarded him the seminar prize of fifty guilders, plus one of the two assistantships in the Physics Laboratory.²¹ He could start after the summer holidays. This close contact with an eminent physicist would be a crucial part of Heike's training.

Heike spent the summer of 1872 in Groningen. Friends in Heidelberg had tried to persuade him to join them on a trip to Switzerland and northern Italy, but after eight months abroad he was feeling too homesick. He had worked tirelessly right up to the end of term for both Bunsen and Kirchhoff. In the chemistry laboratory he was experimenting with the ice calorimeter, a device that Bunsen had rediscovered the year before. By inserting hot metal into it and measuring the quantity of ice it melted, the specific heat of the metal could be calculated,²² from which atomic weights and (in the case of compounds) chemical formulas could be derived. The advantage of Bunsen's device was that it

²⁰ Heike Kamerlingh Onnes to Van Bemmelen, July 1872, MB, archive 99.

²¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 218.

²² The specific heat of a substance is the number of joules required to raise the temperature of a kilogram of the substance by 1°C.

measured the volume rather than the mass of melted ice, a more accurate method which required only a small piece of metal. Heike used the ice calorimeter to make measurements for rhodium, molybdenum and chromium.

Shortly before the summer break, when Heike was about to perform an analysis of gunpowder for Bunsen, he received the news that he had been awarded a silver medal for his Groningen competition entry. Even so, the jury's verdict, as disclosed on 10 October amid the Foundation Day celebrations, was not wholly favourable. While the contestant had displayed 'sharpness of wit' and 'skilful ingenuity', he had also made numerous 'errors of a fairly serious nature ... in both the physics and the chemistry involved'.²³ Heike's interpretation of the verdict was that his work was unfinished; it contained 'rather too many minor matters' to which he had 'accorded too much weight'. Meanwhile, he considered taking part in another competition, preferably one in the area of physical chemistry, though physics or chemistry would be fine too. Heike was eager to tackle one of the most prestigious competitions, such as those set by the Utrecht Provincial Society or Batavian Society. If the subject appealed to Kirchhoff and Bunsen, it would be 'doubly delightful' to spend a year working on it in Heidelberg. Heike saw these competitions as a way to further his career. 'If I could capture first prize, it could soon be turned into a doctoral dissertation.' This plan did not work out, due to a lack of time and of promising topics, but basing a doctoral dissertation on a prize-winning competition entry was common enough. Pieter Zeeman and Johan Kuenen did so twenty years later – under the supervision of Professor Heike Kamerlingh Onnes.

After some serious partying in Groningen – including a reunion of old Vindicat members, the 200th anniversary of the Liberation of Groningen (during the Eighty Years' War), and Vindicat's initiation of freshmen students – Heike started on his third and last term in Heidelberg. He attended Königsberger's mathematics seminars and resumed his experiments with the ice calorimeter. In November 1872, Kirchhoff set his assistant an independent research assignment: he was to construct a small Foucault pendulum. Heike judged it 'a fairly simple experiment', but as the master said, 'One must always start with something small'. In the original version of the experiment, which had been executed in the Panthéon in Paris in 1851, an iron sphere hung from a 67-metre long cable. Heike's assignment was to design the same experiment on a smaller scale, suitable for demonstration at a lecture.

It soon became clear that if the experiment were to yield accurate results, its design would be anything but simple. Heike became so preoccupied with the pendulum that a second piece of experimental research he was supposed

²³ *Studenten Weekblad*, 28 October 1872.

to be conducting in Heidelberg, on ‘the influence of the closure time of the main current in Thomson’s system of absolute measurement of resistance’ completely failed to materialise. ‘I’m spending a great deal of time on it – far too much, actually’, Heike wrote about the pendulum, ‘but I also learn a lot about it, discussing it with Kirchhoff.’ The research in Heidelberg remained unfinished. Later, after returning to Groningen, Heike would decide to take the pendulum as the subject of his doctoral dissertation. It was to prove a grueling ordeal: he did not gain his doctorate until 1879.

As Heike toiled away on his miniature Foucault pendulum, his interest started to swing from chemistry to physics. Bunsen, whom he had worshipped the year before, had fallen from his pedestal. He was peerless for inculcating practical skills, and the genial atmosphere of his lectures was very pleasant, but Heike felt – and he was not alone in this view – that Bunsen was of little help to students wanting to conduct their own research. So Heike bade farewell to the ice calorimeter and the chemistry laboratory, and threw himself wholeheartedly into physics.

A key factor in his shift from chemistry to physics was his theoretical bias. This was not something you could share with Bunsen, whereas Kirchhoff’s mechanics lectures were marvellous, and it was exhilarating exchanging views with him about the theory underlying the pendulum experiment. At length it dawned on Heike that he lacked the requisite knowledge to work with Kirchhoff, that ‘understanding a few things here or there’ was not good enough, and that he needed a thorough grasp of physics, starting from basic principles. In short, he decided he would have to put himself through a comprehensive course of mathematics, mechanics and theoretical physics in Groningen, after which he would be properly equipped to return to Heidelberg and to truly benefit from Kirchhoff’s guidance. ‘My relationship with Professor Mees promises to be salutary in that regard.’ And perhaps he would be able to make friends with Kirchhoff after all, when he returned. Now he had only been able to discuss research with him, and found Kirchhoff ‘very reluctant and hesitant’ to pronounce an opinion on anything smacking of hypotheses. Heike was determined to resume his overtures in a few years’ time. ‘Hopefully he will come out of his shell then.’

By March 1873, as his *Wanderjahre* in Heidelberg neared its end, Heike’s life had become very enjoyable. His voracious reading included Auerbach, ‘almost two-thirds of Goethe’s masterpieces’, De Tocqueville (*L’Ancien regime et la révolution*), Van Hooff and Lichtenstein.²⁴ And he gained a close friend, ‘closer than I have ever had before’, in Adolf Holtzmann, the son of a German scholar,

²⁴ Heike Kamerlingh Onnes to Van Bemmelen, 20 March 1873, MB, archive 99.

who dedicated a poem to Heike that year.²⁵ He no longer had a bad word to say about the Germans; the young man from Groningen had found his niche. 'I am happy to say that they now refer to me as *krenzfidel* [roughly 'as happy as a sand-boy'] and *bierehrlich* [literally 'as honest as beer']. There are no stuffy classrooms or tobacco fumes here, and there is no hanging around until the small hours. People smoke little, sing more, talk, and perhaps drink a little too much beer.' He had been introduced to 'a whole crowd of families' and it was not uncommon for him to spend four evenings a week dancing. With so many 'beauties' around it was impossible not to develop 'crushes' from time to time, but Heike managed to stand firm, although he admitted that he was occasionally 'smitten'. In April 1873, laden with Heidelberg tankards, he returned to Groningen.

²⁵ MB, archives of Heike Kamerlingh Onnes, inv. no. 218.

5. Restless atoms

Once back in Groningen, Heike studiously avoided the chemistry classes of Tjaden Modderman and reported to Mees. This modest but highly competent professor was exactly the right person to help him gain a thorough grounding in mechanics, mathematics and mathematical physics. He was unlikely to be much help with experiments, though: like his Utrecht teacher Van Rees, Mees was first and foremost a theorist.¹ In his doctoral dissertation on the direction of vibration of linearly polarised light, he had already renounced any claim to experimental tours de force: 'I do not feel capable of adding to the accurate experiments conducted by experienced observers any fresh, equally accurate ones of my own'.² Besides, Mees had a heavy teaching load in Groningen: he lectured in higher mathematics and astronomy as well as physics.

Within a month, Heike had abandoned his project of gaining a firm grounding in basic science. In May 1873 he moved to Amsterdam to become Jan Willem Gunning's assistant. Gunning had succeeded Baumhauer as professor of chemistry at the Athenaeum Illustre in 1865, and he ran his Groenburgwal laboratory virtually single-handed. The irascible son of a Protestant minister, Gunning had studied under the versatile Utrecht professor Gerrit Jan Mulder. True to the principles of this 'gout-stricken militant character',³ who had ejected him from his laboratory in 1857 after a furious row, he swore by accurate observations. Gunning too favoured chemistry with practical applications (he was a government advisor at the Ministry of Finance) and like Mulder he was concerned to increase the popularity of chemistry. It was Gunning who succeeded in luring J.H. van 't Hoff to Amsterdam in 1877.

Gunning knew of Heike through Allard Pierson, his brother-in-law. Towards the end of Heike's period in Heidelberg, Gunning's eldest son, then 13 years of

¹ Van Lunteren, 'Van meten tot weten', 102-138.

² R.A. Mees, *De trillingsrichting in het rechtlijnig gepolariseerde licht* (Amsterdam 1867) 8-9.

³ M.J.A. de Vrijer, *Gunning Tragicus; Prof.Dr. J.H. Gunning Jr in den kring zijner broeders* (The Hague 1946) 38.

age, was staying at Villa Intermezzo, the centre of the Piersons' 'glorious intellectual life'. Flying in the face of Van Bemmelen's advice, Heike accepted Gunning's offer. In Amsterdam, he followed his parents' instructions and took lodgings with his boss, who had a splendid house on Plantage (now Nieuwe) Prinsengracht. The assistantship was a complete flop; Heike was back in Groningen before the end of the academic year. He blamed Gunning for the fiasco. 'His siren call, which made my head spin, was stronger at the time than your well-intentioned advice', explained Heike, excusing himself to Van Bemmelen; 'he lured me into the trap. Just how disappointed I felt – I might almost say deceived – and how bruised my heart was when I left him, I have not yet told anyone besides my parents and my friend Pierson [Allard's son]. I believe that my stay there was even highly detrimental to my studies... The amount of tact I had to deploy there in order to find a *modus vivendi* without undermining my self-respect I doubt I shall ever need again.'⁴

For the time being, Heike's wanderlust was cured. In September 1873, when the Delft chemist C.J. Oudemans Jr – another student of Mulder's with a practical bias – put out some feelers, he rejected the offer politely but firmly. An assistantship at the Polytechnic was an attractive idea, certainly now that Bosscha had been appointed professor of physics at Delft and had successfully bargained for a new laboratory, but Heike had no time. 'I think it is really better for me to stay here and to wait for another opportunity to go to Delft later on.'⁵

In Groningen there was nothing to distract Heike from immersing himself in theory. 'I find it... rather dull here', wrote Heike in the same letter to Van Bemmelen. 'One by one my friends are all leaving, the student society is full of younger people, and all in all I have every reason to devote this entire winter to my studies.'⁶

What kind of theory did Heike immerse himself in? We can get a good indication by reading his exercise books with lecture notes and summaries of books and articles, each one full and neatly labelled.⁶ His Groningen programme contained a sizeable infusion of mathematics. Using a German textbook (Aschenborn's *Lehrbuch der Arithmetik*) he mastered the theory of algebraic equations, besides which he studied quaternions (algebra with vectors), and digested a hefty portion of integral calculus. He also ploughed his way through the much-acclaimed *Treatise on Natural Philosophy*, a voluminous introduction to physics by the Scottish scientists Peter Guthrie Tait and William

⁴ Heike Kamerlingh Onnes to Van Bemmelen, 16 February 1878, MB, archive 99.

⁵ Heike Kamerlingh Onnes to Van Bemmelen, 12 September 1873, MB, archive 99.

⁶ MB, archives of Heike Kamerlingh Onnes, inv. nos. 15-45.

Thomson (the later Lord Kelvin). Thomson and Tait's book was notable for the central position it accorded to the concept of energy rather than dwelling on abstract mathematical kinetics. Mees's lectures included Jacobi's treatise on dynamics (*Vorlesungen über Dynamik*) and the latest theories of electricity and magnetism as propounded by James Clerk Maxwell and Wilhelm Weber. So Heike assimilated a combination of robust mechanics (the doctrine of dynamics, force and equilibrium) and modern, controversial views on thermodynamics and the kinetic theory of gases. The latter construes gases as legions of atoms or molecules that are constantly shooting past one another and colliding, and was a hot topic during Heike's university years.

Heike describes the lectures on mathematical physics as the 'brightest part' of his academic programme. 'It was here that [Mees] really came into his own. In his view, every formula had to resolve itself into a line of reasoning, every symbol into an image. He was never satisfied until the students had fully comprehended all the mathematical steps, understood why they had run into problems and how one had to proceed to reach the heart of an issue.... He managed to communicate his own passion for the clarity and transparency of his subject to his students.' Heike absorbed all this diligently and never requested an examination date unless he felt completely prepared: in his dealings with this strict teacher, whom he held in the highest regard, he was determined never to make a fool of himself. 'The idea that he would be assessing my knowledge of physics,' he wrote in Mees's obituary for the university, 'was enough for me to allow myself a few more years than was customary in between my bachelor's and master's examinations.'⁷ It was no waste of time: the broad basis of knowledge Heike acquired in Groningen served him well throughout his life.

Under Mees's guidance, Heike made a thorough study of the kinetic theory of gases. His lecture notes contain summaries of dozens of articles by such pioneers as Clausius, Maxwell, Boltzmann, Thomson and Rankine. One of the most recent treatises summarised in these notes is a famous 1873 doctoral dissertation on the continuity of the gaseous and liquid state (*Over de continuïteit van den gas- en vloeistofstoestand*) by J.D. van der Waals. Van der Waals's theories would serve as the beacon by which Heike Kamerlingh Onnes set his course in Leiden; they were crucial to his method for liquefying helium. But let us not run ahead of our story. We should first look at the state of thermodynamics and the kinetic theory of gases in Heike's Groningen years, including the historical background and competing theories. The following overview is based on the two-volume book *The Kind of Motion we call Heat* by the

⁷ Yearbook of the Koninklijke Akademie van Wetenschappen (Royal Academy of Sciences), 1888, 78.

American science historian Stephen Brush, a compilation of the scores of articles he has written in this area.⁸

From Boyle to Van der Waals

Let us begin our excursion with a visit to Robert Boyle, one of the first scientists to formulate an equation of state.

'London, 1675. Turn onto the south side of Pall Mall at St James's Palace, walking due east. Pass the houses of the celebrated physician Thomas Sydenham and Nell Gwyn. About half-way down the street knock at the door of a three-storey house belonging to Katherine, countess of Ranelagh, and report to the laboratory at the back of the house presided over by her brother, the chemist and natural philosopher Robert Boyle.⁹ This lively description by the science historian Steven Shapin indicates the place where the man who invented what became known as 'Boyle's Law', together with his assistants, conducted his experiments on air pressure.

In 1662 Boyle published a thick book parrying criticism of his ideas,¹⁰ partly based on a series of experiments. They showed that for a given mass of confined gas, at constant temperature, pressure times volume is a constant: $pV = C$. It is now one of the best-known laws of physics, although Boyle was the first to admit that he was not the first to have discovered it. He had previously argued that air possesses elasticity and that Aristotle's *horror vacui* should be discarded in favour of a mechanical explanation. To explain the phenomenon of air pressure, Boyle suggested the possible existence of atoms. In his work he discussed at length the 'vortices of ether' posited by Descartes, which supposedly preserved the distance between the tiny particles. Instead he favoured a static concept, envisaging air particles as tiny, springy balls of wool. This explained why air could not easily be compressed and why it filled all the available space.

The first to formulate a quantitative theory of gases with moving rather than static molecules was Daniel Bernoulli, in 1738. In his book on hydrodynamics, the Basel professor deduced the relationship between the pressure p , volume V , and velocity v of gas molecules: $pV = \frac{1}{3} Nmv^2$ (with N the

⁸ Stephen G. Brush, *The kind of motion we call heat: a history of the kinetic theory of gases in the 19th century* (New York 1976).

⁹ Steven Shapin, 'The Invisible Technician', *American Scientist*, Nov.-Dec. 1989, 554.

¹⁰ Robert Boyle, *A defence of the doctrine touching the spring and weight of the air, proposed by Mr. R. Boyle in his new physico-mechanical experiments: against the objections of Franciscus Linus, wherewith the objector's funicular hypothesis is also examined* (Oxford 1662).

number of molecules and m their mass). Bernoulli's contemporaries responded with little enthusiasm; it was not until the nineteenth century that the result was rediscovered and its true value appreciated. The scepticism was partly attributable to Bernoulli's inability to incorporate temperature into his formula.

Air contracts when the temperature falls, but how? One of the first to perform quantitative research on the relationship between the volume and temperature of a confined quantity of gas was the French physicist Guillaume Amonton. Working at the end of the seventeenth century, he reasoned as follows: since at constant pressure, volume is proportional to the quantity of heat in the air, there must be an 'absolute zero' temperature at which volume has shrunk to zero. Science historians have deduced from the notes on Amonton's own experiments that his calculations suggested an absolute zero of about -240°C (whereas the true value of absolute zero is -273°C).

Amonton too was ignored by his contemporaries. It was not until 1802 that Charles and Gay-Lussac formulated their theory of gases: at constant volume, pressure rises in direct proportion to temperature. But even the acceptance of this law did not lead to the rapid introduction of an absolute temperature scale starting at absolute zero. In 1820, the British scientist John Herapath posited the same formula that had previously been deduced by Bernoulli. Unlike his predecessor, Herapath did discuss the relationship between the temperature and the speed with which the molecules moved, although he posited a linear relationship instead of the correct quadratic one. Herapath was the first to use a kinetic theory of gases – in other words, a theory predicated on molecules that move and collide – to explain a variety of phenomena, such as the diffusion of gas, phase (or state) transitions, and the propagation of sound. In 1832 he tried to calculate the molecules' velocity. Eleven years later, another British scientist, J.J. Waterston, deduced that at 16°C , air molecules move at approximately 700 metres per second.

Sadly for Herapath and Waterston, the Royal Society, bastion of the British scientific establishment, thought their ideas on kinetic gas theory too 'wild' to warrant publication. By the time pioneers such as Krönig, Clausius and Maxwell started disseminating their views, in the 1850s, these reservations had evaporated. This was largely attributable to breakthroughs in thermodynamics: the law of conservation of energy (first law of thermodynamics) and the law stating the impossibility, in a spontaneous process, of heat flowing from a cold to a warm object (second law of thermodynamics). The second law is closely related to the concept of entropy introduced by Clausius. Entropy, a measure of the number of available states in which a system may exist, can only increase, and reaches its maximum value at equilibrium.

In 1856, the kinetic theory of gases started to progress in leaps and bounds. The new advances were triggered by an unassuming article by August Karl



Ill. 10. Johannes Diderik van der Waals (1837-1923), at about 35 years of age. Kamerlingh Onnes based much of his work on Van der Waals's theories.

Krönig, the editor of the journal *Fortschritte der Physik*.¹¹ Although in itself scarcely innovative, it attracted the attention of someone who raised the theory to a higher level: Rudolf Clausius. This minister's son, whose groundbreaking work on the second law of thermodynamics had earned him a chair in Zürich in 1855, was prompted by the publication of Krönig's article to present his own ideas on the kinetic theory of gases. In 1857 Clausius published a carefully reasoned article in *Annalen der Physik* that would determine the direction in which this theory developed for the rest of the century: 'Über die Art der Bewegung, welche wir Wärme nennen' (On the Nature of the Movement that

we call Heat).¹² The connection between heat and molecules in motion was no longer challenged, and Clausius assumed it to be widely known. He saw molecules as billiard balls that collide in complete elasticity against each other and against the walls of a container, and that exhibit rotation and vibration as well as translation (movement in a straight line).

In 1858 the Utrecht physicist Buys Ballot raised what at first seemed to be a powerful objection to the new theory.¹³ If the velocity of gas molecules was indeed in the order of hundreds of metres per second, as Joule, Krönig and Clausius had proposed, Buys Ballot observed that it was strange that the smell of perfume sprayed from a bottle in one corner of a room takes some time to reach other parts of the room. Clausius parried this legitimate criticism by formulating what he called the ‘mean free path’:¹⁴ gas molecules are constantly colliding with each other (molecules repel each other at close range) and in practice they therefore cover only small distances in a straight line, each time in a random direction. He also proposed a formula connecting this mean free path with properties such as heat conductivity, viscosity and diffusion.

When the Scottish scientist James Clerk Maxwell read a translation of Clausius’s article in the *Philosophical Magazine*, he immediately set to work to make his own contribution to the kinetic theory of gases. In 1860 he used a statistical approach to infer a velocity distribution for gas molecules,¹⁵ which proved to be a bell curve (a graph such as that showing the distribution of IQs in the general population). Maxwell also studied transport phenomena in gases. In 1868, his work prompted the enthusiastic young scientist Ludwig Boltzmann from Vienna to place Maxwell’s results in a wider context.¹⁶

The credibility of the kinetic theory of gases was boosted considerably by the fact that several scientists produced independent findings on the size of atoms. The kinetic theory proved to yield the most accurate results in this respect. In 1865 the Austrian Joseph Loschmidt, using the mean free path and measurements of viscosity, produced a value of a millionth of a millimetre for

¹¹ August Karl Krönig, ‘Grundzüge einer Theorie der Gase’, *Annalen der Physik und Chemie* 33 (1856).

¹² R. Clausius, ‘Über die Art der Bewegung, welche wir Wärme nennen’, *Annalen der Physik und Chemie*, 100 (1857).

¹³ C.H.D. Buys Ballot, ‘Über die Art von Bewegung, welche wir Wärme und Elektrizität nennen’, *Annalen der Physik und Chemie* 103 (1858).

¹⁴ R. Clausius, ‘Über die mittlere Länge der Wege etc.’, *Annalen der Physik und Chemie* 105 (1858).

¹⁵ James Clerk Maxwell, ‘Illustrations of the dynamical theory of gases’, *Philosophical Magazine* series 4, 19 (1860) and 20 (1860).

¹⁶ Ludwig Boltzmann, ‘Studien über das Gleichgewicht der lebendigen Kraft zwischen bewegten materiellen Punkten’, *Wiener Berichte etc.*, 58 (1868).

the diameter of a molecule of air,¹⁷ which was in fact too high by a factor of four. And in 1870, William Thomson published four methods of calculation (light diffusion, thermoelectricity, capillarity in soap bubbles and mean free path), all of which produced similar results.¹⁸

Meanwhile, Ludwig Boltzmann had published some noteworthy articles using statistics to relate the kinetic theory of gases to the second law of thermodynamics. In 1868, he placed the velocity distribution of the molecules of a gas deduced by Maxwell on more solid foundations,¹⁹ and four years later he published a pioneering article on the irreversible process whereby a gas achieves thermal equilibrium: 'Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen'.²⁰ It contained the derivation of what was later dubbed the H theorem, which shows at atomic level that the entropy in a gas increases in an irreversible process until a maximum is attained at equilibrium. This was an enormous step forwards. It furnished the macroscopic law formulated by Clausius and Kelvin with a microscopic explanation. But not everyone found the inescapable irreversibility proposed by Boltzmann convincing, and the H-theorem soon came under fire.

Heat always flows from hot to cold. But this irreversibility was not so much the result of a natural law, as Maxwell had observed in 1870, as a consequence of humans' inability to manipulate individual atoms. By way of illustration, he posited the existence of an imaginary creature – which came to be known as 'Maxwell's demon' – endowed with such powers that it could open the hole between a vessel containing a hot gas and one containing a cold gas only if a fast molecule happened to be coming from the cold gas or a slow one from the hot gas.²¹ Since whether a gas is hot or cold depends on the *average* velocity of the molecules, and there will always be exceptions at either end of the spectrum, a patient 'demon', as 'gatekeeper', could always manipulate the movements such that heat would flow from cold to hot, thus violating the second law of thermodynamics. It was years before this fallacy was disproved.

In 1874, William Thomson presented the following paradox (without discussing Boltzmann's H-theorem): if colliding gas atoms obey Newton's laws, and these laws retain their validity if the direction of time is reversed, how can moving, colliding atoms ever result in the irreversibility of the second law of thermodynamics?²² Boltzmann's defence, in response to this

¹⁷ Joseph Loschmidt, 'Zur Grösse der Luftmolecul', *Wiener Berichte* 52 (1865).

¹⁸ William Thomson, *Nature* 1 (1870).

¹⁹ See note 16.

²⁰ Ludwig Boltzmann, 'Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen', *Wiener Berichte* 66 (1872).

²¹ James Clerk Maxwell, *Theory of Heat* (London 1871).

²² William Thomson, 'On the kinetic theory of the dissipation of energy', *Nature* 9 (1874) 441.

irreversibility paradox, was that the one-way traffic of the second law of thermodynamics arose from the huge number of molecules. The number of possible ways of creating an ‘orderly’ state among such a legion of molecules (for example by putting all the particles in the bottom half of the vessel) is overwhelmingly smaller than the number of possible ways of creating a disorderly whole. And because the number of disorderly states is so high, the system will evolve in that direction – it is a question of statistics. Theoretically speaking, it is perfectly possible that the perfume molecules will eventually all return to the open bottle, but given the statistical probabilities, this bizarre situation will not happen for an astronomically large number of years, a time span in comparison to which the current age of the universe is the twinkling of an eye.²³

This brief tour of thermodynamics – which was ‘completed’ in the 1970s by the American J. Willard Gibbs – and kinetic theory of gases may be concluded with a glance at the doctoral dissertation of Johannes Diderik van der Waals from 1873. Van der Waals himself will be discussed at length below; what concerns us here is his *equation of state*. It involved an adjustment of the general gas law (which arises from a combination of Boyle’s law and Gay Lussac’s law). While an ideal gas is subject to the formula $pV = RT$ (where T is the absolute temperature, counting from absolute zero – -273°C – and R is the gas constant, as it is called), where real gases are concerned, matters are more complex. In this context it must be taken into account that molecules possess certain dimensions (as a result of which the effective volume declines), are impenetrable and attract one another (expressed in an additional ‘internal’ pressure). In his doctoral dissertation *Over de continuïteit van den gas- en vloeistoftoestand* (On the continuity of the gas and liquid state), Van der Waals applied these corrections,²⁴ formulating as a result his famous equation of state: $(p + a/V^2)(V - b) = RT$. In this equation, a and b represent constants related to the size of the attractive force that the molecules exert in relation to each other and the volume that they take up as a result of their dimensions, respectively (calculations show that b equals four times this volume).

This equation of state proved to be extremely effective to describe the transition from liquid to gas in theoretical terms. Van der Waals, a fervent believer in the existence of atoms, understood that nothing happened to the molecules or their properties in the transition from one state to another, and that the obvious differences between liquid and gas can be wholly explained by the attractive molecular forces operating in the system.

²³ Ludwig Boltzmann, ‘Über die Beziehung zwischen dem zweiten Hauptsatze der mechanischen Wärmetheorie und der Wahrscheinlichkeitsrechnung etc.’, *Wiener Berichte* 76 (1877).

²⁴ J.D. van der Waals, *Over de continuïteit van den gas- en vloeistoftoestand* (Leiden 1873).

Van der Waals's equation of state also provided an explanation for the phenomenon of *critical temperature*. In 1822, the French researcher Baron Cagniard de la Tour had demonstrated that a confined quantity of gas possesses a critical point, corresponding to certain values for pressure, volume and temperature.²⁵ Above the critical temperature only the gaseous state was possible, regardless of pressure. When De la Tour created a vacuum in a glass tube, then filled it to forty per cent with alcohol and closed it, he observed that when the fluid was heated it first expanded at the expense of the volume of alcohol vapour, until at one point, the meniscus (surface of the liquid) suddenly disappeared. The liquid had become gas, concluded De la Tour. But he could just as easily have reached the opposite conclusion. The conclusion was drawn that above the critical temperature, there was no longer any distinction between liquid and vapour, and there was only gas. The value of that critical temperature differed from one substance to the next: water 374°C, alcohol 243°C, carbonic acid 31°C, oxygen -118°C and helium (discovered on earth in 1895) -268°C, just above absolute zero.

To test his equation of state, Van der Waals was able to use the huge quantity of measurements that the French experimenter Regnault had taken since 1847 to determine corrections in gas thermometers. Measurements for carbon dioxide (CO₂), published in 1869 in the Royal Society's *Philosophical Transactions* by Thomas Andrews of Dublin, were also very useful.²⁶ Van der Waals read a German summary of his article, 'On the continuity of the gaseous and liquid states of matter',²⁷ two years after publication of the original, by which time he had probably already formulated his equation of state. In his 1871 book *Theory of Heat*, Maxwell drew a number of isotherms (lines along which the temperature is equal at every point) based on Andrews's measurements of carbonic acid in a p-V diagram (in which pressure is plotted against volume). Van der Waals reproduced them in his dissertation, and noted that his equation of state produced isotherms that could easily be made to correspond to experimentally determined graphs.

At high temperature Andrews's isotherms (see fig.11) take on a shape dictated by Boyle's law, a hyperbola, indicating that carbonic acid behaves like an ideal gas in that situation. But the lower the temperature, the more marked the deviations. Below the critical temperature (31°C), with compression, the isotherms actually flatten out: vapour starts condensing into liquid. At the end of

²⁵ C. Cagniard de la Tour, 'Exposé de quelques resultats etc.', *Annales de Chimie et de Physique* 21 (1822) 127-132 and 178-182.

²⁶ Thomas Andrews, 'On the continuity of the gaseous and liquid states of matter', *Philosophical Transactions of the Royal Society of London* 159 (1869).

²⁷ A.Y. Kipnis, B.E. Yavelov and J.S. Rowlinson, *Van der Waals and molecular science* (Oxford 1996) 41.

the horizontal section of isotherm, only liquid remains. Since even greater compression encounters great resistance, the isotherm bends steeply upwards at that point. The critical point in the p-V diagram is the point of inflection into a special isotherm: that in which the horizontal course has been reduced to zero.

Van der Waals's equation of state produces isotherms in a p-V diagram that neatly correspond to those plotted by Andrews, including the critical point. The only difference is that an 'S' bend replaces the horizontal section, such that the surface area is equal above and below the horizontal.

Although the equation of state was not derived strictly mathematically from the kinetic theory of gases, it made such an overwhelming impression on Boltzmann that he dubbed Van der Waals 'the Newton of the theory behind the deviations exhibited by non-ideal gases'. Maxwell published two separate pieces on Van der Waals's dissertation in *Nature* (in June and October 1874),²⁸ criticising certain elements while at the same time expressing his admiration for what the Dutchman had achieved. A year later, in an address given to the Chemical Society in London, Maxwell went so far as to advise his audience to master the 'Low-Dutch language' in which this 'exceedingly ingenious thesis' was written.²⁹

Even so, my life is as well-balanced as possible

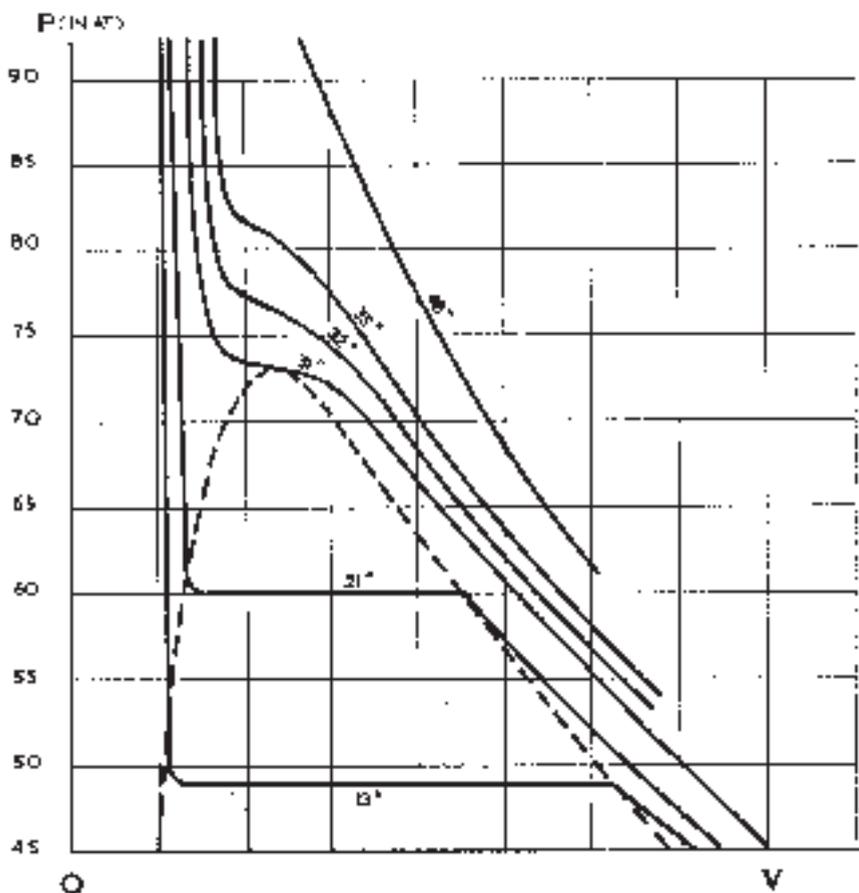
Back to Groningen. As already noted, the kinetic theory of gases was a hot topic while Heike was at university, with one development following another at dazzling speed. It was a field providing a wealth of theoretical and experimental challenges for a bright young physicist. It is clear from Heike's notebooks that in the years 1873 to 1876 after his return from Heidelberg, while improving his knowledge of basic physics, he was also intently preoccupied with the kinetic theory of gases. He studied Van der Waals's dissertation (the same notebook also contains excerpts of Andrews and Cagniard de la Tour), Clausius's *Abhandlungen* I and II (collected articles), Maxwell's 'On the dynamic theory of gases', Thomson's atomic vortex theory, and articles by Rankine and Boltzmann – the latter as part of Mees's lecture on 'dynamic gas theory'.

Just how thoroughly Heike tackled his studies in Groningen is clear from a letter he sent to Clausius in Bonn at Christmas 1874,³⁰ with detailed comments

²⁸ J.C. Maxwell, 'Plateau on soap-bubbles'. *Nature* 10 (1874) 119-121; 'Van der Waals on the continuity of the gaseous and liquid states', *Nature* 10 (1874) 477-480.

²⁹ J.C. Maxwell, 'On the dynamical evidence of the molecular constitution of bodies'. *Nature* 11 (1875) 359.

³⁰ MB, archives of Heike Kamerlingh Onnes, inv. no. 292, draft (this letter was formerly mistakenly believed to have been addressed to Bunsen).



Ill. 11. Isotherms of carbon dioxide (CO_2). Pressure is plotted along the vertical axis and volume along the horizontal axis. At temperatures well above the critical temperature (31°C), the isotherms follow Boyle's Law, below it, if volume is decreased, they flatten out to horizontal for some time and condensation occurs. The dotted line indicates the range in which liquid and vapour both occur (coexisting phases).

on 'Gleichung (17)' in Clausius's article 'Über die Zurückführung des zweiten Hauptsatzes der mechanischen Wärmetheorie auf allgemeine mechanische Principien'. This article, published in 1871 in *Annalen der Physik und Chemie*, connected the 'virial theorem' Clausius had formulated the year before,³¹ – which served as Van der Waals's point of departure for his equation of state

³¹ R. Clausius, 'Über einen auf die Wärme anwendbaren mechanischen Satz', *Annalen der Physik und Chemie* vol. 2, 141 (1870).

– with thermodynamics. The German celebrity immediately replied that Heike’s observations were ‘absolutely correct’.³²

Heike must have studied very hard until October 1875, when he became president of the ‘senate’ of *Vindicat atque Polit* (see chapter 6). And judging by a notebook with an 1876 article by the British scientist S.H. Burbury (‘On the second law of thermodynamics in connection with the kinetic theory of gases’), he continued to study physics after that. All these exertions rather undermined his health. ‘I look thin’, he wrote to Van Bemmelen (who had just been appointed to a chair in chemistry at Leiden), ‘tire easily and don’t always take pleasure in my work. Even so, my life is as well-balanced as possible, my social life is confined to dinners, generally with the professors, and festivities at which my presence is required’.³³

Heike’s interest in the kinetic theory of gases also prompted him to set up some experiments in this area. In the summer of 1873, after the fiasco with Gunning in Amsterdam, he had done some experiments in Mees’s instrument room at Groningen University to determine the coefficient of expansion of liquor.³⁴ Since term was about to start and all the available space was in use for regular laboratory work, Heike had suspended these experiments for the time being. He initially planned to resume them during the next holiday, but by then he was too busy with other activities. Responding to the challenge set in a competition, he designed and built a piece of apparatus, with the aid of the laboratory assistant Deugten, to determine the influence of electric current on the torsion of a wire. The idea was to make a torsion pendulum out of metal wire, to keep it immersed in water at constant temperature, and to compare the oscillation time with and without a current passing through the wire. Heike’s sturdy apparatus was completed in October 1873, and he started to use it.³⁵ Whether the experiments were successful seems questionable, since we hear nothing further about them.

Heike devoted considerable energy to an experimental piece of equipment to study the critical state of ammonia and sulphurous acid, which proved equally unsuccessful.³⁶ This experiment had been inspired by a competition set by Bosscha, newly appointed professor of physics at Delft, to determine ‘abnormal densities’ using ‘an air thermometer and related devices’.³⁷ Heike

³² Clausius to Heike Kamerlingh Onnes, 30 December 1874, MB, archives of Heike Kamerlingh Onnes, inv. no. 293.

³³ Heike Kamerlingh Onnes to Van Bemmelen, 9 April 1874, MB, archive 99.

³⁴ Heike Kamerlingh Onnes to Van Bemmelen, 12 September 1873, MB, archive 99.

³⁵ Heike Kamerlingh Onnes to Van Bemmelen, 12 October 1873, MB, archive 99.

³⁶ *Jaarboek van de Koninklijke Akademie van Wetenschappen*, 1888, 77.

³⁷ Heike Kamerlingh Onnes to Van Bemmelen, 12 October 1873, MB, archive 99.

realized that he was ‘desperately’ short of time to set up an experiment of this kind, but the subject interested him, and with Mees’s approval he set to work. Almost a year elapsed before he could start taking measurements: building the necessary equipment stretched Deugten’s powers to the limit. Meanwhile, Heike was busily assembling ‘a whole range of preparatives’, whereby the comparison of gas and mercury thermometers proved to be an exasperating task.³⁸ For a change, he helped his friend Anton Tellegen (who would be awarded a doctorate in June 1875 with a dissertation on primary renal sarcoma) by determining glucose values in ‘diabetic urine’ in the physiology laboratory.

Conditions for experimental work on the upper floor of Groningen’s university building were still abysmal. ‘The physics storeroom is fairly well supplied, but what with?’ Heike commented cynically.³⁹ He went on to observe that much of the equipment was ‘historically interesting’ and fine for experiments during lectures, but that there was only one iron stand with a clamp in the whole laboratory. Mees was not much help here. The physics professor had a heavy teaching load and was short of an assistant, and there was simply no money to set up a decently equipped experimental laboratory. ‘It is not surprising that Professor Mees, for whom Deugten sets up everything and scrapes together all the necessary equipment, scarcely notices all this and does not see any need to intervene’, wrote Heike. Mees was cooperative and obliging, but had little desire to concern himself with the work of others, certainly if it was unfinished.

But Heike was not completely alone in Groningen in his interest in the kinetic theory of gases. Conrad Mensinga, who had started studying physics a year later than Heike but who was awarded his master’s degree in 1875, chose to write his dissertation on heat conduction in gases. The dissertation, the formal defence of which took place on 8 September 1877, provided an overview of the theoretical work of Clausius, Maxwell and others, and discussed the experimental determinations that had been made in the sphere of heat conduction since Rumford (who had posited at the end of the eighteenth century that heat in gases can be transported only in currents). Mensinga had no theoretical insights of his own to offer, and his practical contribution to the subject was confined to repeating experiments with ‘incandescence phenomena’ in tubes with gas that Grove and Magnus had conducted around 1850.⁴⁰ Still, in his fellow student Conrad (who became a secondary school teacher after gaining his doctorate) Heike had a companion with whom to discuss the

³⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 42-45.

³⁹ Heike Kamerlingh Onnes to Van Bemmelen, 9 April 1874, MB, archive 99.

⁴⁰ Conrad Mensinga, *De warmtegeleiding in gassen* (Groningen 1877).



Ill. 12. Heike at 22 years of age.

kinetic theory of gases. Mees eventually expressed interest; he set up a series of experiments on the compressibility of water in 1876,⁴¹ and two years later subjected the theories underlying a Crookes radiometer (a set of fragile vanes mounted on a spindle in an airtight glass bulb containing a partial vacuum; the vanes, one side of which is painted black, turn when exposed to light) to a critical examination,⁴² but this was probably too late to help Heike.

⁴¹ R.A. Mees, 'Over de methode van Jamin ter bepaling van de samendrukbaarheid der vloeistoffen'. *Verlagen en mededelingen van de Koninklijk Akademie van Wetenschappen, Afdeling Natuurkunde*, second series, 14 (1879) 108-133.

⁴² R.A. Mees, 'Over den theorie van den radiometer'. *Verlagen en mededelingen*, second series, 13 (1878) 265-341.

On 6 June 1876, at 22 years of age, Heike was awarded a ‘first-class’ master’s degree. Earlier that year a new Higher Education Act had replaced the 1815 legislation (see chapter 6) but Heike’s master’s degree was granted under the old system. The master’s examination type A, intended for those wishing to go on to take a doctorate in mathematics, physics, or astronomy, contained the subjects mathematics, mechanics, mathematical physics and ‘theoretical astronomy’. Examination fee: 64 guilders. Students were required to solve problems shown to them the day before. They were also required to prove that they had ‘successfully’ attended Van der Wijck’s lectures on metaphysics and history of ancient philosophy. These lectures dwelt primarily on German philosophers: Fichte, Kant, Hegel, Jacobi, Schelling and Goethe.⁴³

Under the old 1815 legislation, the master’s examination included biology and applied chemistry, but the minister had been routinely distributing exemptions for these subjects for decades. Heike applied for these exemptions on 2 June 1875, which could mean that he had actually hoped to complete his master’s degree earlier.⁴⁴ The demands he imposed on himself, his firm resolve to make a good impression on Mees, whom he held in extremely high regard, and his ambition to continue in chemistry – unlike Conrad Mensinga – may have led him to postpone the examinations for a year. And there was another reason to postpone them: in the academic year 1875-76, Heike Kamerlingh Onnes was president of the ‘senate’ of the student society *Vindicat atque Polit*.

⁴³ MB, archives of Heike Kamerlingh Onnes, inv. no. 44.

⁴⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 217.

6. ‘Maintain and refine’

Heike was committed heart and soul to his membership of Vindicat atque Polit.¹ Although its headquarters Mutua Fides, at the corner of Grote Markt and Ebbingestraat, proved to be ‘full of a younger generation’ when he returned from his aborted adventure in Amsterdam,² this did not stop the student from frequenting the society’s cosy rooms in his leisure time while getting down to basics with Mees. In fact he had to go there, since as correspondent for the *Studenten Weekblad* – which he had joined properly in October 1893 after the false start in March 1871 – he regularly reported on Vindicat’s meetings. The year in which he served as correspondent did not provide much fascinating material. The ‘merry’ inauguration of fifteen new members, the ‘splendid beer party’ for Vindicat hosted by the society Omlandia, the ‘enjoyable’ foundation day celebrations, were all simply obligatory reports.

The most striking news from the student fraternity was that peace had been made with Utrecht. The quarrel had erupted in September 1871, when it became known that the publican E. Kock of Mutua Fides would take over management of the Utrecht society while he was still under contract to Groningen. Utrecht University’s Senate washed its hands of the matter, maintaining that the student fraternity operated quite separately from the society, and that the contract with Kock had been concluded with officials of the society *Placet Hic Requiescere Muis*. This explanation scarcely placated Vindicat, since the majority of Utrecht student society officials were members of the University Senate. After an inconclusive series of letters and angry motions on both sides, Utrecht severed friendly ties on 7 December 1871.³ The row was not defused until the official representatives of the students in Leiden stepped in to mediate. On 19 February 1874, over one hundred students held a special party in the Palace of Industry in Amsterdam to celebrate the reconciliation. The next

¹ Van Itallie-Van Embden, 44.

² Heike Kamerlingh Onnes to Van Bemmelen, 12 September 1873, MB, archive 99.

³ Groninger Studenten-Almanak, 1873, 101-106.

day there was a matinee and a gala performance at Circus Carré to cement the renewed ties. 'It would be worth falling out again to have another party like that', concluded Groninger Student Almanac.⁴

Having declined a request to edit the Student Almanac,⁵ Heike was elected a member of Vindicat's student senate at the fraternity meeting of 30 September 1875, by 58 of the 71 valid votes cast. Two weeks later followed his inauguration as president, at a public meeting of the senate in Mutua Fides. Conrad Mensinga, with whom Heike had attended the HBS and who was also studying under Mees, was elected secretary. 'I derive great pleasure in being presented with this ribbon,' said the 22-year-old Heike in his acceptance speech, which my close friends [Johan A.] Tellegen and Van Leeuwen have worn before me.⁶ Heike was fortunate in that the year of his presidency was an exciting one for both Vindicat and the university itself. The events gave him ample opportunity to develop his talents for organisation and test them in practice. He did so carefully and analytically, and his heart was always in his work.

Two matters dominated the agenda during Heike's term of office: the threatened closure of the university and the poor management of the society Mutua Fides. There was a crippling lack of funds, since only eight first-year students had enrolled by October – an all-time low. In previous years Vindicat had welcomed dozens of freshmen, and since each one was required to transfer the lump sum of 50 guilders to the fraternity's coffers over and above the annual membership fee of 22 guilders, the virtual lack of new arrivals in 1875 made a big hole in the budget. The statutory 25 or 50 cents fine for arriving late at a student senate meeting or failure to attend without notification did little to remedy the situation. In November, when forty members of the Flankeurs company, former students of the universities of Groningen and Franeker who had fought in the ten-day campaign against the forces of the Southern Netherlands in 1830, held a reunion in Groningen, the student senate debated long and hard on the question of how many cigars and what quality of champagne should be served to the brave old veterans at a musical soirée at Mutua Fides. The costs – besides beer and 'ordinary' wine, the party-goers got through 111 bottles of champagne that evening – were eventually borne by the entire membership of Vindicat.⁷

The closure of the university had been hanging in the air since 1870, when a majority in the Lower House had urged the government to take a 'courageous

⁴ Groninger Studenten-Almanak, 1875, 107-108.

⁵ *Studenten Weekblad*, 11 February 1874.

⁶ Groninger Archieven, Vindicat archives, inv. no. 80.

⁷ For the minutes of the senate and fraternity meeting, see Groninger Archieven, Vindicat archives, inv. nos. 80 and 81.

initiative' regarding the number of universities in the Netherlands, which seemed unambiguously to sound the death-knell for Groningen.⁸ But the fall of the Fock-Van Bosse government, in December 1870 meant a reprieve. The number of new enrolments also started to rise again, although this was largely attributable to the generous exemptions from Greek and Latin that Thorbecke had promised HBS graduates wanting to study medicine or natural science. After Thorbecke's death in 1872, Parliament tightened up the entrance requirements and student numbers promptly fell again. It became increasingly difficult to appoint capable professors. The university in the north of the country seemed to be a sinking ship; the only gleam of hope lay in the details of the long-awaited Higher Education Act. As Huizinga expressed it in his account of the affair in the *Annales* of 1871/72 'All the unrest resolved itself into a single impatient cry: "the new Act – let us finally have the new Act!"'

These anxious observers breathed a sigh of relief when, after Thorbecke's death, the position of interior minister went for a second time to J.H. Geertsema, who had served as secretary of the University of Groningen's board of governors from 1845 to 1864. As soon as he took office, he immediately filled the two vacant chairs in theology, at a time when the continued existence of the theological faculties was being debated at national level. After this generous gesture, it is scarcely surprising that Geertsema's draft for a new Higher Education Act, introduced into Parliament on 15 January 1874, was very well-disposed towards Groningen. 'The University of Groningen has been allowed to slip into decline, by denying it what it needs for its development and advancement', the bill noted, echoing the sentiments of Groningen's own population. What should the government do? Reinforce the teaching staff, expand and improve teaching aids and materials, and the institution would 'receive a new lease of life, and would be able to exercise a salutary influence, even more than it does now, as a centre of civilised culture.'⁹

Despite all these hopeful signs, however, the parliamentary report of 7 July 1874 on Geertsema's bill again argued that Groningen should relinquish its university. The problem was not money, but the difficulty of preserving intellectual standards at three universities at once. Again the government was called upon to take a 'courageous initiative' – an appeal it was unable to heed, since it had by then tendered its resignation. Heemskerk had a second opportunity to push through his own plan, and in December 1874

⁸ Johan Huizinga, *Academia Groningana*, chapter 8: 'Een langdurige crisis: de Groningsche hoogeschool en de Tweede kamer der Staten Generaal 1868-1876' (Groningen 1914).

⁹ Handelingen van de Tweede Kamer der Staten Generaal (Proceedings of the Lower House of the States-General) 1872/73 II p. 549-574, 28 and 29 November 1872. Quoted in Huizinga 1914.

an amended bill was sent to Parliament, which – like the one of 1868 – posited the existence of three universities. Groningen knew that lobbying for its cause could do no harm, and it was soon raining petitions and pamphlets in The Hague. Groningen city council set the ball rolling by arguing that under the terms of the 1594 ‘Treaty of Reduction’, the government had an obligation, on grounds of the public interest, to ensure that the north had its own ‘centre of civilised culture’ and not to impede the people’s intellectual development. That was on 4 January 1875. That same month, the Committee for the preservation of the University of Groningen convened at the Harmonie arts complex. In two petitions, it urged Parliament to retain Groningen – ‘do not extinguish the light, but place it higher up the candlestick’ – and commended Heemskerk for his efforts on Groningen’s behalf. These communications were signed by the Committee’s chairman, J.W.C. Baron van Ittersum, and 2,304 townspeople.¹⁰

Not wanting to be outdone, Vindicat’s student senate put a draft communication to the members on 3 February. Heike (who was not yet president) thought it a laudable initiative but objected to the content; in his view, the letter simply repeated the Committee’s arguments. Instead of emphasising local interest, he said, it would be better to focus on the benefits to be gained for scholarship in general. Higher education flourished in a broader-based academia, which promoted exchanges of ideas among scholars and diminished the tendency to trust blindly to authority. What is more, at a small university, professors could supervise students on a more individual basis. ‘The universities of Kiel, Rostock, and so forth have fewer students than Groningen, but the government would not dream of closing them.’¹¹ Heike’s views were applauded and many of his points incorporated into the new communication that was adopted on 8 February.¹² The argument that the Netherlands lacked the intellectual resources needed to maintain three universities was refuted, with reference to the legion of capable, well-paid HBS teachers who had materialised in a short space of time: if professors were given better salaries, all would be well.

Almost every individual municipality in the province of Groningen sent its own petition to The Hague. The adjacent province of Drenthe also joined in, and 19 municipalities of neighbouring Friesland (including Franeker, which had lost its own university in 1811) spoke out in Groningen’s favour. The board

¹⁰ *Vox Studiosorum / Studenten Weekblad*, 3 February 1875.

¹¹ *Ibid.*, 10/17 February 1875.

¹² The petition sent by Vindicat atque Polit was published in full in *Vox Studiosorum / Studenten Weekblad*, 10-17 February 1875.

of governors reacted at the beginning of May, when it had received parliament's report on Heemskerk's new draft. The report showed that parliament was now quite evenly divided on the issue of whether or not to retain the university: the stream of petitions seemed to have helped. The amended bill, which Heemskerk submitted in August 1875, provided for the university's continued existence.

But Groningen did not feel reassured, certainly not when the city also lost its court of appeal to Leeuwarden, in Friesland, in 1875. As the date approached for the parliamentary debate on the bill, concern about the possible outcome grew palpable. Meanwhile, the scene of battle had shifted to the local and national press. Opponents too were making their views heard. On 19 February 1876 the local newspaper *Groninger Courant* carried an article that had previously appeared in a Rotterdam paper (*Nieuwe Rotterdamsche Courant*), slating the Groningen institution. It referred to a great 'malaise' among the professors, students fleeing *en masse*, and professors being forced to compensate for their loss of income – because their lectures were so poorly attended – by becoming members of the city council or provincial executive, sitting on examination committees, churning out little books for general readers, or running large practices as physicians or lawyers. Groningen, the article concluded, was a 'penal colony' for those who had been prevented from studying in Leiden or Utrecht. And on 27 February, local people who were perfectly happy with their city specialising in commerce and felt it had no need of a university were also given an opportunity to vent these opinions in the *Groninger Courant*.

The battle was hard fought. When one S. claimed in the monthly *Spectator* that many of the university's supporters consisted of 'those who rent out rooms to students, run student cafés, or want to join Harmonie without a membership ballot', Dirk Huizinga, professor of medicine, responded furiously in the *Groninger Courant*: 'Anyone with such narrow-minded views had best keep them to himself'. A letter-writer in the *Provinciale Groninger Courant* heartily agreed: 'Excrement from persons of that kind should merely be deposited in the rubbish bin without comment.'¹³

On Saturday 4 March, Heike convened an extraordinary meeting of Vindicat's student senate. He had heard that the Committee for the preservation of the university had decided to send an open letter to parliament to urge its case once again now that the debate on the Higher Education Bill was imminent and the House was still divided. The university senate, which had remained silent until then (on the grounds that arguing one's own cause carried no weight), and the municipal executive would also petition The Hague. Vindicat

¹³ *Provinciale Groninger Courant*, 13 March 1876.

must also make its voice heard, insisted Heike. It could also take the opportunity to rectify certain slanderous allegations in the press, to the effect that the Groningen professors had lost their appetite for work. Together with secretary Conrad Mensinga, Heike drafted a text that the students received with ‘thunderous applause’ two days later. It claimed that small institutions had the advantage of militating against ‘coterie-forming and a blind faith in authority’ and stated that if the uncertainty of the university’s continued existence were dispelled and the inequalities rectified – in the period 1865-75 central government had paid out 3,529,334 guilders to the University of Leiden, 1,331,180 to Utrecht and a meagre 886,004 to Groningen – parents from the northern provinces would no longer have to send their sons to study elsewhere. The Vindicat petition concluded by noting dryly that students from Groningen had won more medals for academic competitions, proportionally speaking, than Leiden and Utrecht combined.¹⁴ The text was published in full in the *Groninger Courant* of 9 March, and the printers, J.B. Wolters, kindly supplied 350 copies free of charge.

Parliament had started debating Heemskerk’s bill the day before. After eight days of debates and voting, it reached the part that was crucial to Groningen – Section 32, which provided for the continued existence of three universities.¹⁵ The representative for Groningen, Sam van Houten, author of the 1874 Child Labour Act, had described to his fellow parliamentarians the danger of closing Groningen’s university in stark terms as ‘denationalising the north’. There had consistently been a majority in the House for closure, and the parliamentarian Van Kerkwijk announced an amendment, during the debate of 17 March, to achieve it. Meanwhile, Groningen and Amsterdam had struck up a deal, behind the scenes, in response to a proposal by J. Kappeyne van de Coppello, and reached a compromise: Groningen would be retained, and Amsterdam’s college, the ‘Athenaeum Illustre’ would be promoted to the status of university. Suddenly, the country was to have not two but four universities. Van Kerkwijk had evidently quite failed to notice these manoeuvres. In Huizinga’s words: ‘Just before the hammer-stroke whereby Section 32 was to be adopted without a ballot, Van Kerkwijk made as though to rise to his feet. The Proceedings do not reproduce the expletive that accompanied Van Houten’s gesture, as his hands pressed down on Van Kerkwijk from behind, preventing him from standing up. And the hammer fell.’

As soon as the telegram with the glad tidings reached Groningen, around noon, the city erupted into jubilant festivities. The *Provinciale Groninger Courant*

¹⁴ *Algemeen Nederlandsch Studenten-Weekblad Minerva*, 14 March 1876.

¹⁵ *Op cit.* note 8.

quickly printed the relevant text in giant letters and pasted it in strategic places around town, stealing a march on its competitor, the *Groninger Courant*. The latter hit back on Saturday 18 March by replacing its regular reports on parliament by a leading article on the front page with the heading ‘Long live the University!’ On this day that the university’s future was finally secured, the flags were hung out all over town, the carillon played merry tunes, and students and citizens embraced in the street.

Vindicat atque Polit had already prepared its celebrations – Plan B, a ‘solemn funeral procession’, complete with black gloves and funeral music, could fortunately be jettisoned.¹⁶ The festivities began on Friday evening with a glorious serenade (costing 260 guilders, including 6 guilders for the police and 4 guilders to pay for beer for the civic guard’s musicians). ‘For several days a consignment of torches has been waiting to be lit, and an equal number of torchbearers have been waiting for the command to sally forth’, wrote the *Vox*.¹⁷ The parade of carriages and ‘horsemen with spurs’, illuminated by fairy-tale Bengal lights, and accompanied by serenades, as Mensinga wrote, ‘mobbed by a huge rabble, that testified to its interest in the festivities by singing loudly, cursing, jostling with one another and quarrelling’,¹⁸ wound its way from the society *Mutua Fides* through Groningen’s city centre. There the participants paid tribute to the King’s Commissioner, the burgomaster, the professors gathered in the university building, and the Committee for the preservation of the university. Afterwards there was a musical soirée at the society for members and guests. As the Vindicat goblet was passed around, Heike compared the university to a virgin rescued from a dungeon, Professor D. Huizinga called the students ‘the steam of a locomotive’, and the state advocate Modderman spoke of ‘noble sons of the Muses’.¹⁹ After which the company burst into song, with ‘*To vivat*’.

On Saturday there was a soirée at the Harmonie. A dozen speakers proposed toasts in the hall, which was decked out in green for the occasion. Heike was the first to speak. ‘Scholarship’, spoke the student president, ‘is the queen of world history; it permeates all the pores of civil society; [...] it is the Mother of both truth and freedom. That it is why it is held in great esteem, it is much honoured among the free people of the North. [...] Therefore, long live the citizenry of Groningen! May the students cherish them!’²⁰ Whereas sickness

¹⁶ See notulen senaatsvergadering 4 March 1876, Groninger Archieven, archives of Vindicat, inv. no. 80.

¹⁷ *Vox Studiosorum / Studenten Weekblad*, 6 April 1876.

¹⁸ Groninger Archieven, archives of Vindicat, inv. no. 94.

¹⁹ *Vox Studiosorum / Studenten Weekblad*, 6 April 1876.

²⁰ *Groninger Courant*, 21 March 1876.

had prevented Heike from attending the reunion of the Flankeurs veterans and the inauguration of the new Vindicat members, the festivities held to celebrate the university's survival gave him every opportunity to flaunt his eloquence. The *Vox* wrote that the president 'had spoken throughout the festivities with a fluency sweeter than honey'.²¹

After a day's rest, the celebrations resumed on Monday morning with a musical matinée at the Harmonie, presented by the Student Ice-Skating Club – which, in the absence of ice that year, had plenty of money in its coffers and was glad of an opportunity to spend its regular grant. After that, Vindicat invited the Harmonie's members to an evening of music. The mood was 'if anything even more elated' than it had been on Saturday, 'especially after the interval, when the ban on smoking, which was as tiresome for the gentlemen as it was pleasant for the ladies, was withdrawn'.²² Once again Heike enchanted his audience with metaphors. This time he described the university as an oak tree. 'It has weathered the winter. [...] Some had wanted to fell it for firewood'. Fortunately all this was now a thing of the past, and Groningen's oak tree was soon to bring forth 'new blossoms, and new fruit'. And he continued:

The prosperity of the parts is the prosperity of the whole. Our parliament has understood this fact. Thus, the decision has forged closer ties between us and our common country, between us and the other provinces. And I therefore propose a toast to our dear Fatherland: long may it live, flourish, and enjoy progress!

After which the orchestra struck up *Wien Neerlands bloed* ('Who is of Dutch blood'), and all present joined in the patriotic song with gusto. The evening concluded with a party at Mutua Fides with free beer.

A fairly sedate Tuesday, with a splendid reception hosted by the businessmen's society Soranus, served as the prelude to the apotheosis of these celebrations: a costumed students' ball at the Harmonie on Wednesday. Heike, president of the organising committee, arranged for free dance cards, not wanting to leave anything to chance. The Harmonie was transformed into a pleasure-garden, with fountains, caves and rocks, busts, festoons, and giant mirrors. The evening cost 596,94 guilders, which, added to all the other expenditure that week, had to be paid for by levying 10-guilder contributions on every member of the student society. On Thursday, while the students were recovering their breath, the 'Society for public entertainment' organised games of *boegspritlopen* ('walking the bowsprit') at the Grote Markt. Those who lost their balance and slipped off the smooth horizontal mast fell into mounds of soot or powdered chalk.

²¹ *Op. cit.* note 19.

²² *Groninger Courant*, 22 March 1876.

The management of Mutua Fides

Life soon resumed its normal course, which included a ‘return party’ (hosted by the students’ guests), the May fair, and other entertainments. The student senate settled two more thorny issues before the summer holidays. Besides drafting clear rules for guests at Vindicat parties – a cause of endless wrangling in the past – Heike surprised the student society meeting with an initiative that was to transform the management of Mutua Fides.

Under Kock’s management, Vindicat’s saloon had gone steadily downhill, and complaints were pouring in. Objections to the kind of wine – and the quality of food – the landlord was serving had already been the subject of a meeting held just before the beginning of Heike’s presidency. One could accept the frequent unavailability of steak, but the absence of eggs was beyond the pale. There were no concrete accusations, however, despite occasional calls for the contract to be terminated. When the landlord turned out to have been lax with his administration and found himself in trouble with the tax authorities, Heike summoned him to a meeting of the student senate and reprimanded him. In his defence, Kock argued that the students constantly ordered on credit. Their debts had assumed such proportions that he was in serious financial distress.

To solve the problem, Heike reiterated a proposal that his friend Johan Tellengen had already submitted (with little success) in March 1872. Vindicat would take over the wine and beer side of the business, while meals, cigars and other items would henceforth be paid for in cash to Kock. The bar committee was given greater powers, and could impose fines on the landlord if he defaulted on his obligations. Heike and Conrad Mensinga devised a new credit system providing for beer and wine vouchers. The academic year was to be divided into three periods; each member would be allowed thirty guilders’ credit at the beginning of each period, provided he had repaid at least half his debt from the previous period and his entire debt from the period before that.

It was an ingenious system, which the members adopted on Saturday, 24 June 1876, two weeks after Heike had taken the examinations for his master’s degree. Moreover, it worked superbly in practice: Mutua Fides enjoyed a revival and the society’s finances flourished. Kock, whom Heike had given a second chance in spite of the mounting dissatisfaction, was dismissed in December 1876 after all, when checks revealed that he had been plundering the wine cellar. The losses suffered, according to the bar committee’s report of March 1877, amounted to about 40 guilders – a mere pittance compared to the 1,500 guilders ‘pure profit’ that had been made since the introduction of the new credit system nine months earlier.²³ So it was entirely appropriate that

²³ *Vox Studiosorum / Studenten Weekblad*, 12 April 1877.

a motion heaping praise on Heike Kamerlingh Onnes and Conrad Mensinga for devising the new credit system – proposed at the meeting of 4 December 1877, shortly after Heike had handed over the presidency to his successor – was adopted to ‘thunderous, deafening applause’.²⁴

On that same date, a matter arose that made it clear that Heike’s student years were at an end. The bone of contention was Groningen’s May fair. Since the abolition of the September fair, in 1854, the May fair, which lasted two weeks, attracted even larger crowds than before. Aside from ordinary attractions such as roundabouts, waffle stalls, acrobats, a variety of ‘freak shows’ and a tooth-puller, there were music and drama performances in marquees for the more cultivated members of the public. Students too loved the fair.

It was simply too vulgar, decided the University Senate. In a letter printed in the *Groninger Courant* of 29 November 1877, it urged the city council earnestly ‘to abolish the fair in the interests of academic education, or otherwise to order that it be held in the holidays’. This draconian measure was deemed necessary, it said, because of ‘the adverse effect of the fair on the students’ regular work.’²⁵ Lectures suffered from mass absenteeism, students scarcely worked at all, and many in fact regarded the advent of the fair as the beginning of the summer holiday. The professors, who saw the end of term as a time for setting examinations, to pluck the fruits of their endeavours, found their work seriously undermined by all this frivolity.

The proposal to abolish the May fair provoked considerable resentment among the students. The Senate was accused of offensive paternalism and ‘inappropriate academic discipline’. How dare it interfere? What is more, the professors did not uniformly back the proposal: seven signed a letter to the city council distancing themselves from the content of the letter. At the fraternity meeting of 4 December, there were calls for a motion of censure against the Senate. Heike, as a retiring member of Vindicat, opposed the motion. Doing away with the fair was not about restricting students’ freedom, he insisted. ‘Fairs have absolutely nothing to do with the student society.’ Anyway, Heike argued, the content of the letter was entirely true. The Senate was simply promoting the good of the university, and friendly relations with professors were too important to jeopardise with a motion of censure. He continued:

‘We should not, as a student body, wish to keep the fair. After all, it is only for peasant girls and servants; while it is true that we would lose the theatre marquees, we might be granted substantial compensation.’²⁶

²⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 217.

²⁵ *Minerva*, 6 December 1876.

²⁶ Groninger Archieven, archives of Vindicat, inv. no. 94.

Heike frequently consorted with professors, and his words fell on deaf ears. A ‘Motion Onnes’, proposing that the meeting ‘proceed to the order of the day’, was rejected by forty-five votes to four. On 8 December, Heike did his best to tone down the motion of censure. In the end, after a heated debate, it was decided to inform the University Senate that Vindicat atque Polit had ‘regretfully’ taken note of the ‘inappropriate’ petition to the city council. The Senate declined to respond to this weak protest, at which some Vindicat members took umbrage and proposed suspending official relations with the professors. Vindicat’s student senate managed to prevent this, after which the controversy fizzled out.²⁷

It was time for Heike to bid farewell to student life, and to concentrate on a project that would require a colossal effort: his doctoral dissertation.

²⁷ Cohen, *Uit Vindicat's verleden*, 252-253.

7. Foucault's pendulum

The Panthéon in Paris, the domed church where France preserves the remains of its deceased heroes, was the scene of one of the most famous demonstrations in the history of physics. It was here, in the spring of 1851, that Léon Foucault conducted his pendulum experiment, watched by a spellbound crowd. Here, at last, was convincing proof that the earth rotated on its axis.¹

The triumph in the Panthéon was the culmination of a series of experiments on which Foucault had embarked in his own basement, on 3 January 1851.² There, on Rue d'Assas, where the confirmed bachelor lived with his mother, Foucault hung a copper sphere weighing 5 kilo from a 2-metre steel wire and allowed it to swing freely. At the first try, the wire broke, but five days later the experiment succeeded, and Foucault could notify his colleagues of the results. These were so surprising that Francois Arago, director of the Paris Observatory, invited him to repeat the experiment at his institute, this time using an 11-metre wire. This too proved successful, and through the mediation of Napoleon's brother Louis-Napoleon Bonaparte, who was then president of the Republic and a keen supporter of science, the spectacular crowning event followed in the Panthéon on 26 March.

Beneath the majestic dome, Foucault hung a 28-kilo ball from a wire measuring 67 metres. A stylus attached to the underside of the sphere traced lines in the ring of moist sand that had been spread on the floor at the outermost points of the pendulum's oscillation. Once the string that pulled the ball to one side had been burned through, a long series of hypnotic swings commenced. The essence of the experiment was to show that the place where the stylus brushed the sand every 16 seconds gradually shifted. Five hours later – that is how long it took before the amplitude of the swing had been diminished by damping to such an extent as to form a hindrance – the plane of oscillation had

¹ The passages on Foucault derive from Dirk van Delft, *Uit het depot* (Leiden 1999) 36.

² For Foucault, see William Tobin, *The life and science of Léon Foucault: the man who proved the earth rotates* (Cambridge 2003).

rotated clockwise through an angle of some 60° . This rotation is illusory: in reality the plane remains constant in relation to the ‘fixed stars’, as the rules of classical mechanics teach us. Thus the pendulum proves that the earth rotates.³

Lecture demonstration for Kirchhoff

In the spring of 1876, shortly before the examinations for his master’s degree, Heike decided to write his doctoral dissertation on the subject of the Foucault pendulum. He did not have to start from scratch: Kirchhoff had given him the ‘fairly simple’ subject in Heidelberg in the autumn of 1872. Heike’s struggles with the pendulum reached their apogee in Groningen, but the toil and trouble had started in Baden.

As the winner of the ‘seminar prize’ for 1872, the student from Groningen had the honour of being invited to serve as Kirchhoff’s assistant at the Friedrichsbau physics laboratory in Heidelberg, a wonderful opportunity that he seized eagerly. The man who had invented spectral analysis asked his new assistant to design a lecture experiment featuring a small version of a Foucault pendulum, with the aim of using it to research the ‘sine factor’.⁴ Only if a Foucault pendulum stands at the north or south pole will it complete a rotation in precisely 24 hours; at the equator, there is no apparent rotation at all. As Foucault had surmised, the sine of the geographical latitude determines the rate of the apparent rotation. Heike’s task was to design a pendulum so accurate as to enable verification that the observations tallied with the latitude of Heidelberg.

‘One must always start with something small’, Kirchhoff had said to Heike, but the project soon mushroomed. Constructing a miniature Foucault pendulum was not the problem. After the sensation in the Panthéon, which had rapidly been followed by repeat experiments in cathedrals such as the San Ignazio in Rome and the cathedral of Cologne, demonstration pendulums had been built for use in ordinary rooms. In 1855 the Haarlem instrument-maker Willem Logeman produced a 42-centimeter Foucault pendulum for the physics laboratory at the Teylers Museum, with a glass bell-jar to eliminate draughts.⁵ Jacob van Breda, who had succeeded Martinus van Marum as director, could use it – in accordance with the Dutch custom at the time of leaving original research to others – to check the truth of the reports from Paris. But a qualitative confirmation was all that could be achieved.

³ Léon Foucault, *Recueil des travaux scientifiques* (Paris 1878).

⁴ Heike Kamerlingh Onnes to Van Bemmelen, 27 November 1872, MB, archive 99.

⁵ Gerald L’E. Turner, *The Practice of Science in the Nineteenth Century: Teaching and Research Apparatus in the Teyler Museum* (Haarlem 1996) 47.

In his article in the Académie's *Comptes Rendus*, Foucault – whose grounding in mathematics was not especially thorough – was unable to provide a comprehensive theoretical treatise explaining the oscillations in the Paris observatory. He did state, however, that his experiment illustrated the ‘deflective force’ attributable to the earth’s rotation mentioned by Poisson in 1837 – later named the ‘Coriolis effect’ after one of Poisson’s students, who formulated it. But Foucault did not comment on Poisson’s aside that this force exerted no noticeable influence. In practice – in Paris and elsewhere – the pendulum began after some time to describe an elliptical path, while the rotation effect was undiminished. This phenomenon too was initially poorly understood.

It was entirely possible, of course, to have the pendulum describe an elliptical path from the outset: the cone pendulum with its circular path is a special case of this. In 1854 the French scientist Auguste Bravais experimented with cone pendulums that he caused to rotate either clockwise or anti-clockwise. The rotation of the earth causes a slight discrepancy in the oscillation time: the oscillation is faster in the same direction as the rotation.⁶ Bravais also studied the theory of elliptical paths, following in the footsteps of the British scientists J.A. Galbraith and Samuel Haughton.⁷ George Airy, the British Astronomer Royal,⁸ and the Danish researcher Peter Andreas Hansen,⁹ were also studying ellipses. But no one had yet provided a comprehensive treatise on the Foucault pendulum, and the experiments were so inaccurate that only qualitative, not quantitative, conclusions could be drawn. Kirchhoff evidently found this situation unsatisfactory.

Full of optimism, Heike had set to work on the pendulum in the autumn of 1872. His plan was to produce a one-metre model consisting of a copper tube with a lead ball at the end. To follow the pendulum’s movements, he attached a small mirror surmounted by a prism above the suspended device. This enabled an onlooker standing a few metres away to follow the pendulum’s swings exactly. The advantage of this ‘Porro mirror’ method of reading¹⁰ was that it enabled one to work with small amplitudes – only then would a comparison of the findings with the theory be significant.

⁶ Auguste Bravais, ‘Sur l’influence qu’exerce la rotation de la terre sur le mouvement d’un pendule à oscillations coniques’. In *Journal de Mathématiques pures ou appliquées (Liouville)* XIX, 1854.

⁷ J.A. Galbraith and Samuel Haughton, ‘Apsidal motion of a freely suspended pendulum’. In *Philosophical Magazine* 2, 1851.

⁸ George Biddell Airy, ‘Vibrations of a free pendulum in an oval’. In *Memoirs of the Astronomical Society* XX, 1851.

⁹ Peter Andreas Hansen, ‘Theorie der Pendelbewegung mit Rücksicht auf der Gestalt und Bewegung der Erde’. *Neuesten Schriften der naturf. Gesellschaft zu Dantzig* V, 1856.

¹⁰ *Comptes Rendus* 35, 1855.

Heike opted for gimbals, since attaching the pendulum to the ceiling in one place limited the experiment's scope and caused an undesirable twisting of the suspension rod. In his cardanic suspension system, sharp-edged steel wedges rested on small mat glass plates, enabling the rod with its lead ball to swing independently around two perpendicular axes. These axes of rotation both lay in exactly the same horizontal plane.¹¹ When the ball was released from its position of equilibrium, a complex oscillation resulted.

Without the rotation of the earth, with oscillation times that were identical around both axes, the ball in general described an ellipse (or what is called a 'Lissajous figure') – the line was a special case of this ellipse. But in practice, the two oscillation times soon began to diverge slightly, as a result of differences around the axes. Furthermore, the rotation of the earth made itself felt through Coriolis forces – which was precisely the point of the experiment. Then there was the factor of friction to be taken into account. All these factors greatly complicated the ball's movements. An initially flat swing changed into a variable ellipse. Heike described the problem as 'a matter that has not yet been dealt with theoretically, and which has exercised my mind considerably'. He also referred to 'a good deal of confusion in the literature, including every conceivable sort of nonsense'. As an example of such nonsense, Heike cites the idea of distinguishing between oscillation times parallel to the meridian and perpendicular to it.

In March 1873, a month before he was due to leave Heidelberg, Heike wrote to Van Bemmelen summing up his progress thus far. The pendulum had been made in close consultation with the instrument-maker, and Heike was busy elaborating his observations. The problem was that the mathematics of the pendulum was proving to be overwhelming. Heike had progressed quite far, and was on the right track, but even so, he had an uneasy sensation that he lacked the basic knowledge needed to gain a proper theoretical grasp of the pendulum. He never considered giving up, although he conceded that he had spent far too much time on the experiment. 'Still, I believe that I have derived great benefit from it, in particular from the constant discussions about it with Kirchhoff.'¹²

Back in Groningen, Heike set the Foucault pendulum to one side. But then, with his examinations looming, he chose it as the subject of his doctoral dissertation. He planned to gain his doctorate in one year, which was not unusual at the time. Things would turn out differently, however, largely because of the abysmal conditions under which he had to work in the university building. In his obituary for R.A. Mees, he recalled those days in horror. 'The space itself was even worse than the equipment', wrote Heike:

¹¹ Heike Kamerlingh Onnes to Van Bemmelen, 27 November 1872, MB, archive 99.

¹² Heike Kamerlingh Onnes to Van Bemmelen, 20 March 1873, MB, archive 99.

‘Searching for somewhere to suspend a cardanic pendulum that would be free of vibrations, the only place I could find was the wall of a narrow cupboard used to store peat as fuel. This cupboard did overlook a large downstairs room in which the laboratory technician [Deutgen] stored glass, metal and odds and ends. But entreating the man whose obliging assistance I needed so badly to lend me this space was out of the question. After all, it was indisputably part of his own accommodation, and was – in the circumstances – indispensable to him. When it became clear that the cardanic pendulum just mentioned would have to be mounted such that it was not connected to the building, Mees could only express his regret that he was unable to oblige. I could consider myself fortunate when I was eventually permitted to use some space in another storage room full of rubbish and bones, presided over by a different laboratory technician [for the chemistry lab], which I shared with his hunting dogs. There it was decided, after many doubts as to the proper authorisation, to turn a blind eye when I removed a few stones from the floor in order to drive stakes into the ground; I was also permitted – at my own expense – to place a stove in this damp cavern, and to insert the stove-pipe through a window to the open air.’¹³

Heike had wanted to work with a two-metre pendulum, but in the circumstances he settled for one measuring a mere 1.2 metres. The apparatus he built in Groningen were designed – partly thanks to Deutgen’s ingenuity – ‘with the utmost care’.¹⁴ He contributed some of the costs from his own pocket. Elaborating the suspension system he had used in Heidelberg (with knife-edged thin wedges on small glass plates), Heike used two such wedges attached at right angles, the lower one being fixed to the ground while the upper one bore the pendulum (see Ill. 13). The pendulum was ‘wrapped’ in an airtight metal case, *ƙ*, ‘a cone-shaped mantle of sheet-iron plates, riveted and soldered together’.¹⁵ A copper plate was soldered to the underside, while the top could be covered with a glass bell-jar. By linking the tap *i* to an air-pump, a near-vacuum could be created throughout the system to eliminate the influence of air friction. In practice a pressure of 0.1 atmospheres sufficed.

Conducting pendulum experiments in a damp basement was not much fun. Heike complained of having to work in a ‘Cyclops’ cave’,¹⁶ and being forced to expose his eyes to ‘the adverse effects of making numerous precise measurements by the light of a paraffin lamp’.¹⁷ He was under little pressure to work faster, partly since his future was uncertain: ‘whenever I thought about what I would do

¹³ H. Kamerlingh Onnes, ‘Levensbericht van R.A. Mees’, Yearbook of the Royal Academy of Sciences 1888, 81.

¹⁴ H.A. Lorentz, ‘Het proefschrift van prof. Kamerlingh Onnes’, *Physica* (1926) 165.

¹⁵ Heike Kamerlingh Onnes, *Nieuwe bewijzen voor de aswenteling der aarde* (Groningen 1879) 240.

¹⁶ Heike Kamerlingh Onnes to Van Bemmelen, 16 December 1877, MB, archive 99.

¹⁷ Kamerlingh Onnes, *Nieuwe bewijzen*, 259.

after gaining my doctorate', Heike wrote to Van Bemmelen, 'I always ran up against a big question-mark, and that is partly why I have been dallying.' Meanwhile, however, after some 'impassioned' exchanges with his father, he had decided to aim for an academic career; only then could science be a source of real enjoyment. So his goal became to obtain a professorship, and Heike hoped to complete his doctorate, an important step towards that goal, soon after Easter.¹⁸

Ill. 13. Schematic representation of the pendulum with a suspension system using knife-edge thin wedges attached at right angles; the lower one was fixed to the ground while the upper one bore the pendulum. The pendulum was 'wrapped' in an airtight metal case, k , 'a cone-shaped mantle of sheet-iron plates, riveted and soldered together'. A copper plate was soldered to the underside, while the top could be covered with a glass bell-jar. By linking the tap i to an air-pump, a near-vacuum could be created throughout the system to eliminate the influence of air friction. In practice a pressure of 0.1 atmospheres sufficed. ►

The pendulum consisted of a copper tube, marked n , which was inserted into a 15-kilo pierced lead ball q . The plate marked c at the top of the case bore the weight of the actual pendulum. Attached to c was a knife s_1 , of hardened steel or agate, to which a second knife s_2 was pressed at right angles, from which the pendulum hung. The device t , consisting of two plates ground smooth and screwed together, with grooves for the two wedges, served to keep these perpendicular to one another. Completing the suspension device were the plates marked z , to which s_2 was attached, and v , which bore the pendulum rod n , all of which was connected by means of the rods marked p (which ran through holes pierced in plate d). In order to adjust the oscillation periods in relation to the two knives, weights could be placed on the top plate A . For the rest, the small cup of oil D and the stirring rod C could be used to create a damping effect. If necessary, one (or both) directions of the swing could be blocked using the screws marked l and the springs m .

To start the pendulum moving, the lever h , which was linked to the 'outside world' by a series of rods, pushed the ball q in the desired direction; as soon as it shot back, the swinging movement would begin.

All that remained was to observe. To make this possible, a horizontal ring was attached to the underside of the pendulum rod with a tab, with a set of cross-hairs in the ring that intersected (when the pendulum was at rest) precisely in line with n . As the ball swung, the cross-hairs moved between two prisms, θ and γ . If light fell through the window OR through the wall of the case onto θ , it would be reflected upwards through the cross-hairs to γ , where it would be reflected again and travel out again through a second window. There it travelled towards a telescope focused on the image of the cross-hairs. The eyepiece of the device was equipped with a micrometer in order to follow the movements of the intersection point P of the cross-hairs. In this way, the orientation of the oscillation plane, or the lengths of the axes in the case of an elliptical path, could be recorded precisely.

¹⁸ Heike Kamerlingh Onnes to Van Bemmelen, 16 February 1877, MB, archive 99.

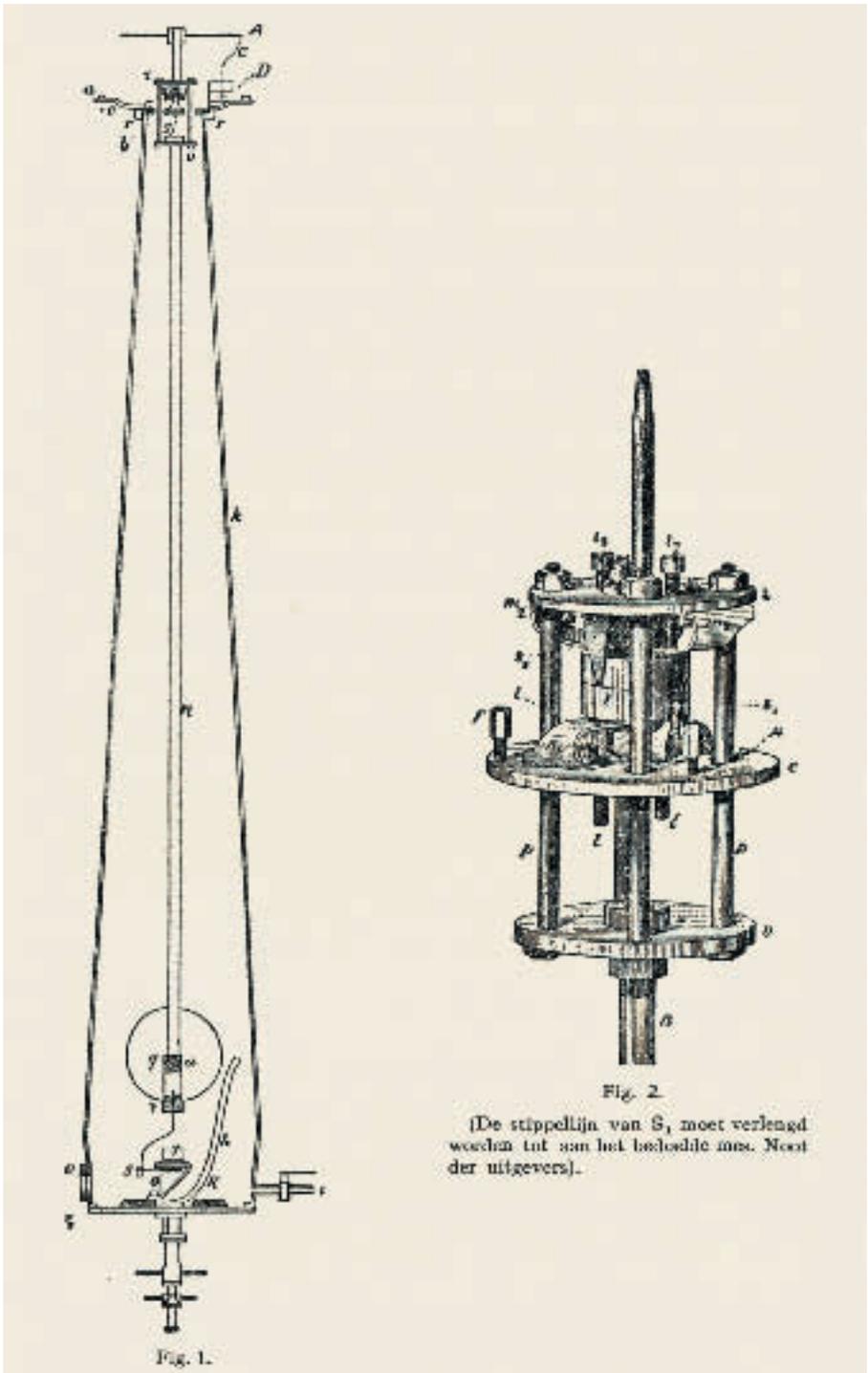
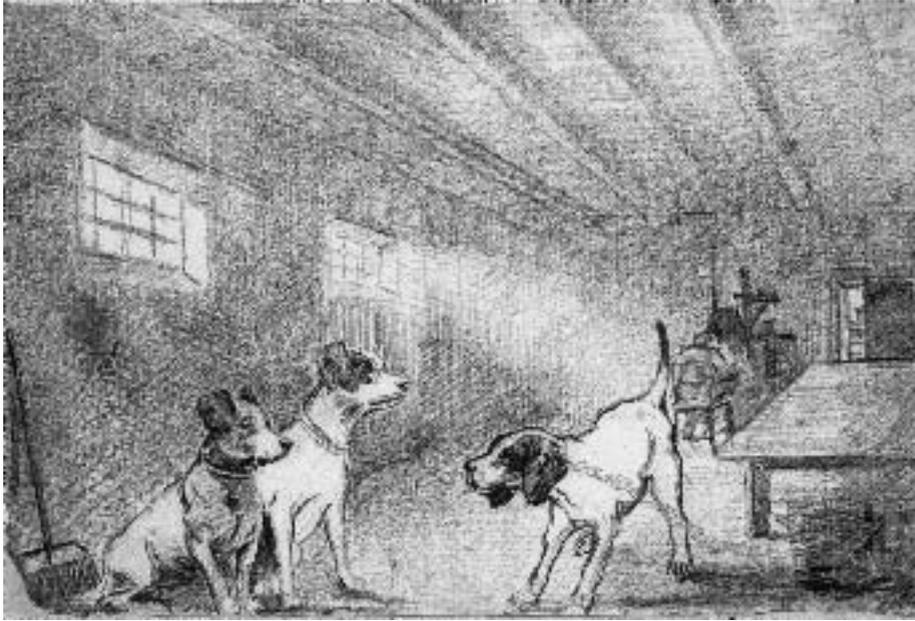


Fig. 2.
 (De stippelijne van S, moet verlengd
 worden tot aan het bodschik mes. Naest
 der uitgevers).



Ill. 14. ‘Cyclops’ cave’: the basement of the main building of Groningen University, where Heike did his pendulum experiments so as to eliminate disruptive vibrations. Drawing by Menso Kamerlingh Onnes, 1904 (Wagenaar Hummelinck Collection).

Easter came and went, Christmas and New Year came and went, and still Heike had not taken his doctorate. Why? Heike wrote frankly to Van Bemmelen: ‘But I hear you wondering – whatever has gone wrong with your dissertation, that it is taking such a terribly long time? And this question touches on a very sensitive issue, since I am not entirely blameless.’¹⁹ The problem was not the theory – although Heike said that a ‘will-o’the-wisp’ had ‘enticed’ him for several weeks into searching for a non-existent simplification of a theorem. No, it was the experiments that were bogging him down. In July he had experimented ‘diligently’ to check whether his compound pendulum was behaving in accordance with the theories he had derived.

‘But in this I was disappointed. In the main, that is to say in a qualitative sense, my pendulum experiment yielded the desired results; the earth’s rotation was clearly demonstrated. But at the same time I recorded deviations exceeding the limits of observation error. I felt that these must be explained before I could complete my dissertation; that was where I drew the line.’

¹⁹ Heike Kamerlingh Onnes to Van Bemmelen, 16 December 1877, MB, archive 99.

At the end of July it began to dawn on Heike what was wrong, and he decided to adjust his pendulum. By mid-September he could start measuring again. His heart sank: the deviations were bigger, not smaller, than before. Heike found himself possessed by ‘a certain agitation’; instead of taking the time to calmly perfect his equipment, he kept looking for quick solutions. This was bound to cause frustration:

‘The immense effort and time it cost to remedy these defects, the wretched accommodation of which you yourself [Van Bemmelen] have personal knowledge, all have made the burden of my disappointment heavier, tending to foster something to which I believe no scientist should succumb, namely discouragement. I am to blame for giving in to this from time to time, and I have paid for it primarily by seeing my parents’ disappointment, and by the fact that I have missed many opportunities to be considered for various positions.’

But there was no question of giving in. Towards the end of 1877 Heike finally saw some light at the end of the tunnel, and prepared to embark on a new series of measurements. He worked at night time, to be rid of vibrations from passing carriages and suchlike; even then he had to stop the experiment if a strong wind shook the building, since his pendulum was not firmly anchored in the ground.²⁰ The new series of observations turned out to be excellent, and he could breathe a sigh of relief.

By then Heike had virtually completed the theoretical section of his dissertation. This had become an autonomous exercise in mechanics, inspired by the theory of the pendulum’s swing on a rotating earth but wholly transcending this subject. The result was a substantial, in-depth treatment of the subject of *relative motion*, the area of mechanics that deals with movement of point-mass objects under the influence of forces, viewed from a non-static system of coordinates. Heike built on the methods developed by Hamilton and Jacobi, according a key role to Schering’s ‘force function’. Applying this to a pendulum with cardanic suspension and with oscillation times that may differ for the two axes, he arrived at a classification of the possible kinds of motion. The ‘ideal’ Foucault pendulum, which did not move in an elliptical path and in which the plane of oscillation gradually turned as a result of the earth’s rotation, proved to be a special case of a whole group of phenomena. As the difference in oscillation time became greater, the path of the pendulum became an ellipse that was alternately more and less elongated, and with a rotational direction that sometimes underwent periodic reversal. Heike showed that the proportions of the ellipses and the periods with which they

²⁰ Kamerlingh Onnes, *Nieuwe bewijzen*, 269.

moved demonstrated the earth's rotation just as convincingly as Foucault's classic experiment.

Although Mees had little to offer when it came to laboratory work, for the theoretical part of his dissertation Heike could not have hoped for a better supervisor. 'Professor Mees has now gone over most of my thesis meticulously and made numerous valuable suggestions,' he wrote in December 1877. Heike considered sending the mathematical part of his dissertation to *Crelle*, the celebrated German journal of pure and applied mathematics. It was eventually published in two parts (in 1878 and 1879) in the *Nieuw Archief voor Wiskunde*,²¹ a journal set up by the Mathematics Society a few years earlier with the motto 'Energy and persistence conquer all things'. The *Nieuw Archief* published (as it does today) a potpourri of dry academic fare and lighter material. In-depth studies of quaternions (a type of vector) appeared side-by-side with competition solutions and historical accounts. Shortly after attaining his doctorate, Heike added a sort of postscript.²² Editor-in-chief David Bierens de Haan, professor of mathematics at Leiden and a member of the Academy, presented a summary on behalf of H. Kamerlingh Onnes on 29 June 1878 at the monthly meeting of the Academy's mathematics division. The summary, which was a little over two pages long, was intended to safeguard Onnes's priority.²³

Heike completed his dissertation in Delft, where he was appointed as Bosscha's assistant in September 1878 (see chapter 8). In improving and honing his theory of relative motion he enlisted the aid of Professor G.F.W. Baehr.²⁴ Baehr had been awarded his doctorate in Groningen (on the strength of a dissertation on partial differential equations and Lagrange functions) and taught mathematics and physics from 1854 to 1864 at Groningen gymnasium – during the school year 1863-1864 Heike was in the same building at the 'pregymnasium'. At the launch of the Polytechnic in 1864 he moved to Delft, where he attracted attention by prescribing French textbooks.²⁵ Baehr was well-informed about the material concerned, as is clear from his articles in the Physics Proceedings of the Academy²⁶ and in *Grunerts Archiv der Mathematik*

²¹ Heike Kamerlingh Onnes, 'Over de betrekkelijke beweging', *Nieuw Archief voor Wiskunde* 5 (1878) 58-121. *Ibid.* (1979) 135-186.

²² *Nieuw Archief voor Wiskunde*, 6 (1880) 173-182.

²³ Official reports of the General Meetings of the physics division of the Royal Academy of Sciences (Processen-verbaal van de Gewone Vergaderingen der Koninklijke Akademie van Wetenschappen, afd. Natuurkunde), Saturday 29 June 1878.

²⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 285.

²⁵ *Gedenkschrift van de Koninklijke Akademie en van de Polytechnische School 1842-1905* (Delft 1906) 143-144.

²⁶ G.F.W. Baehr, 'Over de draaijende beweging van een lichaam om een vast punt en de beweging der aarde om haar zwaartepunt', *Natuurkundige verhandelingen der Koninklijke Akademie van Wetenschappen* (1857) 1-30.

und Physik.²⁷ He also published on the Foucault pendulum in 1853.²⁸ Heike referred to these articles in his dissertation. Since Heike had largely completed the theoretical part before leaving for Delft, he may well have contacted Baehr while still in Groningen.

The last mile was certainly the longest. Heike's parents were very worried about their eldest son's career, and upon receiving the news that their second son, *enfant terrible* Albert, had made a fortune in the East Indies as the inventor of a sugar centrifuge and was being driven around Surabaya like a prince, Heike wrote to them: 'It must be a source of great satisfaction to you that everything has turned out so well [for Albert]', and continued:

'It saddens me greatly that I have not yet been able to provide you with a similar satisfaction by gaining my doctorate; indeed I might have been able to do so by now if I had worked a little harder of late. Everything had finally seemed propitious for my work; nothing to do in the laboratory [with Bosscha]; at least, so little as to be negligible, the prospect of possibly taking over the lectures of [the sick] Mees, for which a lector might perhaps be appointed; and yet it has gone so badly; every calculation rises up before me as a mountain, and as soon as I have conquered it a new one appears. This last part of my work is demanding the most effort and depressing me. I am reasonably satisfied with the first two sections, after the corrections I made here in Delft; but the experiments have not fulfilled the expectations I had of them after the improved calculations and now everything must be presented to best advantage. I had always shrunk from repeating them, in the hope that I would be finished sooner, but in retrospect it might have been better, or at least have saved time, to do so. It is too late to change that now of course; it does not perhaps detract a great deal from the dissertation, but it truly saddens me and that constrains my letter-writing.'²⁹

First-class doctorate

On the afternoon of Thursday 10 July 1879, Heike Kamerlingh Onnes was awarded a doctorate at the university premises on the strength of his dissertation *Nieuwe bewijzen voor de aswenteling der aarde* (New proof of the earth's rotation on its axis). This was eighteenth months after the 'breakthrough' at the end of 1877. But the result was something to be truly proud of. Heike appended nineteen propositions to his dissertation, including ten on the kinetic

²⁷ G.F.W. Baehr, 'Sur le mouvement d'un corps solide autour de son centre de gravité, lorsque'on suppose que ce point est fixe par rapport à la terre, et entraîné avec elle dans son mouvement diurne'. *Grunerts Archiv* 24 (1855) 241-263.

²⁸ G.F.W. Baehr, *Notice sur le mouvement du pendule* (Middelbourg 1853).

²⁹ Heike Kamerlingh Onnes to his parents, 8 June 1979, De Knecht collection.

theory of gases. Proposition 15 was typical: ‘There is no essential difference between research methods in mathematics and physics’.

The faculty members were so impressed by Heike’s defence of his dissertation that when he finished they did not ask him briefly to leave the hall as was customary, but instead immediately awarded him a ‘first-class’ doctorate.³⁰ Mees’s absence cast something of a shadow over the ceremony. The mathematics professor Enschedé stood in as supervising professor.³¹ When Heike later wrote Mees’s obituary, he described the sickness that had struck him down: ‘In the spring of 1879 he was first afflicted by the lung disease which was to cause his death just a few years later.’ It was up to J.C. Kapteyn, the new astronomy professor, to subject Onnes to the traditional public grilling on his dissertation in Mees’s absence. In a letter to his fiancée, Kapteyn complained of the time he was having to spend on this extra work.³²

Heike’s dissertation consisted of a 226-page ‘mathematical section’ and a 60-page ‘experimental section’. They are entirely separate, and appear to have been intended for two different readerships. Even so, they belong in the same book. In his introduction, Heike made no bones about his firm belief that a physicist must be at home in theory as well as in the laboratory. ‘In preparing this dissertation, I have tried to adhere to Helmholtz’s advice for aspiring physicists in his ‘Gedächtnisrede auf Gustav Magnus’:

‘It seems to me, and the belief is indeed rightfully gaining ground, that in today’s advanced state of science, only those with a thorough understanding of theory are capable of conducting useful experiments and know how to ask and pursue the right questions; and conversely, only those with wide-ranging experience of conducting experiments can develop useful theories.’

Interestingly, Helmholtz’s address goes on to cite the discovery of spectral analysis (by Kirchhoff and Bunsen) as a recent example of this intimate connection between theory and experiment.³³

The mathematical section of *Nieuwe bewijzen* consisted of two separate parts. The first dealt with ‘relative motion’ and was an unrevised reprint of Heike’s article in the *Nieuw Archief voor Wiskunde*. Re-using these pages (from J.C. Drabbe printers in Leiden) enabled Heike to cut costs: the nationwide agriculture crisis had also hit his father’s business. The disadvantage was that he was unable to make any corrections, so that all the original printing errors were reproduced. The rest of the dissertation also contained a good many

³⁰ Ernst Cohen, *Van Boerhaave tot Kamerlingh Onnes* (Utrecht 1922) 10.

³¹ Groninger Archieven, archive 46 Senaat & Faculteiten, inv. no. 334.

³² Kapteyn to Elise, 5 May 1879, Groningen University Library, Kapteyn correspondence.

³³ See note 30.

careless slips; it was clear that Heike had drafted the text relatively late – too late – in the day. On 8 April the proofs of part of the new text, furnished with many corrections and additions, were returned to the printers from Delft.³⁴ There will have been some deep frowns in Leiden at the sight of Heike's handwriting: the dissertation opened with four pages of errata.

The second part of the mathematical section, 'On the motion of a pendulum with cardanic suspension, taking into account the earth's rotation and the effect of friction', reflected the difficulties with which Heike had grappled in the autumn of 1877. Examination of the experimental findings in the light of the theory set forth in the first part of the mathematical section revealed 'regular deviations' that could only be explained if this theory was expanded. The second part, presenting this expanded theory, was thus written specifically to illuminate the experimental section. The simple assumptions about the pendulum made in the first section were adjusted only where necessary to ensure compatibility with the experimental measurements. These adjustments related to matters such as the location of the pendulum's centre of gravity, its precise shape, and the amplitude of the oscillations. Heike was compelled to make the latter larger than he would have liked from the vantage point of his theory, because of the lack of a truly rock-solid base in his Cyclops' cave. The influence of friction was also dealt with. At one-tenth atmosphere, the air friction was small enough to keep corrections theoretically 'digestible', and the theory also took account of the contact friction between the two knife-edged wedges. The application of this theory to pendulum experiments led Heike to conclude that pendulum swings sometimes belonged to a different category of motion from what might be expected on the basis of the theory developed in the first section. This made the 'depressing' measurements taken in September less unpalatable.

Heike's improved theory also explained deviations in the flat Foucault pendulum – suspended from a single point – that had been observed by other scientists. A month after the Panthéon demonstration, the British scientist Thomas Bunt had launched a series of experiments with a 16-metre Foucault pendulum that he suspended in the church of St Nicholas in Bristol. Bunt observed that flat oscillations invariably became elliptical after a time and he recorded the shape of these ellipses accurately.³⁵

More extensive still were the series of measurements taken in 1868 by Volkert van der Willigen in Haarlem. After earlier pendulum experiments in

³⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 13.

³⁵ Thomas G. Bunt, 'Pendulum Experiments', *Philosophical Magazine*, series IV, 1, 552-554; 2, 37-41, 81, 158-159, 424-427.

Deventer had come to nothing, he made a fresh attempt, as curator of the physics laboratory in the Teylers Museum. Van der Willigen had a hole bored through a beam structure in the 'Oval Room' and clamped a suspension device in it (as one would clamp a bit into a drill) from which he hung a 10.5-metre wire attached to a 9.4-kilo ball. For two months he set his pendulum in motion and recorded its paths, as it swung within a draught-screen, preferably on days when the museum was closed. He published his results in the brand-new journal *Archives du Musée Teyler*: they comprised a multitude of measurements and calculations presented in the form of fold-out tables. He was at a loss to decide what to do with them: the theory behind the ellipses was simply inadequate. 'Although the results obtained may perhaps be of little significance', remarked the curator, 'I believe they should be published.'³⁶ Heike was grateful to him. In Van der Willigen's series of measurements he recognised one of his special cases: when the oscillation plane approached certain orientations as a result of the earth's rotation (in Haarlem 125.1° or 30.9° in relation to the meridian), the path became more markedly elliptical; as the oscillation plane receded from these orientations again, the ellipses flattened out.

In the introduction to the experimental part of *Nieuwe bewijzen*, Heike summarised the essence of his dissertation. His experimental proof of the earth's rotation was based on 'an understanding of the factors interfering with the motion of a point through the rotation of a system of coordinates, in relation to which it would describe – aside from this rotation – Lissajou figures for two virtually identical oscillation times in two perpendicular directions.'³⁷

Before presenting his experimental results, Heike made a few concessions to readers less interested in theory by giving a vastly simplified derivation of the formulas he needed, which featured in a wider context in the theoretical part of his dissertation. In a second chapter he described his apparatus and measuring procedures, including the variant used in Heidelberg. He then gave the measurements that he had recorded for the different classes of oscillation. The experiments had been conducted in December 1877, July 1878 and October 1878. Agate knife-edged wedges produced the best results. The angular velocity of the oscillation plane, averaged over the entire set of results, proved to be 12.04° per hour, while the theoretical value for Groningen was 12.03° per hour. A superb result, although Heike was the first to put the near-perfect agreement into perspective: 'the accuracy of the observations using my equipment could yield certainty only to the penultimate decimal'.³⁸ From the letter

³⁶ V. van der Willigen, 'Le Pendule Foucault', *Archives du Musée Teyler* 1 (1868) 341-363.

³⁷ Kamerlingh Onnes, *Nieuwe bewijzen*, 229.

³⁸ *Ibid.*, 274.

that he wrote to his parents a month before the defence of his doctoral dissertation, we know that he had hoped for more.

It had all taken rather longer than expected, but the research assigned by Kirchhoff in 1872 had finally been brought to a satisfying conclusion. Just how satisfying is clear from a comparison with the results achieved in Haarlem by Van der Willigen. He had conducted 11 hours of measurements from which he derived an angular velocity of 12.88° per hour, and another 4-hour series yielding one of 11.24° per hour, compared to the theoretical value of 11.91° per hour for Haarlem. In Heike's results, the largest deviation between the two series was 0.8° per hour. The average of the 60-hour series in Haarlem was scarcely any more accurate than Heike achieved in 5 hours, while the total average achieved over 240 measuring hours in Haarlem was more inaccurate than the roughly 45 hours that Heike had spent recording his measurements – even though Heike's pendulum was only 1.20 metres long, rather than the 10.5 metres in the Teylers Museum, and he had conducted his entire experiment by the light of a paraffin lamp instead of in the grand surroundings of the Oval Room.

Praise from the Vatican

Let us briefly look at the reception of Heike's dissertation. The *Groninger Courant* and *Provinciale Groninger Courant*, both of which had gone to town when Aletta Jacobs gained her doctorate,³⁹ went back to its customary five-line notice for *Nieuwe bewijzen*. Rather than sit back and wait to see how his work would be received, Heike distributed copies of the dissertation. In the autumn he sent one to Ernst Schering – the inventor of Schering's 'force function' as relied on in *Nieuwe bewijzen* and a mathematical astronomer at the observatory in Göttingen. Schering showed some interest, but after a few months he requested a better Dutch-German or Dutch-French dictionary than that available in Göttingen and said he would also be glad of a Dutch grammar. Otherwise he simply could not read it. The linguistic obstacles were at length surmounted, and Schering wrote a lengthy review for the *Göttinger gelehrte Anzeigen* of 17 and 24 March 1883.⁴⁰ It was extremely favourable. 'Mr Onnes's work is indeed so rich in new research', Schering concluded on the *Nieuwe bewijzen*, 'that an edition published in a more widely-read language would find its way to many grateful readers.'⁴¹

³⁹ Aletta Jacobs was the first woman to gain a medical degree in the Netherlands.

⁴⁰ Schering to Heike Kamerlingh Onnes, 31 March 1880, MB, archives of Heike Kamerlingh Onnes, inv. no. 309.

⁴¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 289.

Museum Boerhaave possesses a German version of the first section of the dissertation translated by Heike himself, full of corrections, deletions and new passages pasted over old ones.⁴² Concealed among the pages are a note dated 1900 from one Dr Furtwängler requesting a book for the Royal Library of Berlin and an undated rough note in French, not in Heike's handwriting. It is unclear when Heike produced his German translation. He cannot have done so in 1877-78, when he was toying with the idea of sending the first section of his dissertation to *Crelle*; otherwise he would have sent this piece directly to Schering. Nor is it likely that he produced the translation after 1882, since he gained a professorship in Leiden that year and had other things on his mind. There is every reason to believe that Heike embarked on his translation after receiving Schering's request for dictionaries, and that he worked on it in Delft whenever he had a spare hour.

Meanwhile, a second, no less enthusiastic review had been published in the *Jahrbuch über die Fortschritte der Mathematik* (1879 edition, which appeared two years later). The Leiden professor of mathematics and mechanics Pieter van Geer, who acted as a sort of correspondent for the Netherlands, called *Nieuwe bewijzen* a 'most interesting dissertation'. 'Without a doubt', he wrote, in concluding his review, 'this piece of work can be described in terms of both theory and experimental findings as the most detailed and thorough of all studies published thus far with the aim of proving the earth's rotation ... with the aid of a pendulum.'⁴³

In short, with his theories and apparatus, Heike had subjected the Foucault pendulum to such rigorous examination that other researchers decided there was nothing left to say about it. Even the Vatican, which took a natural interest in the earth's rotation, appreciated Heike's achievement. It did take thirty years before this appreciation became known, however. In 1911, R.P. Hagen, director of the Vatican's observatory and author of the multi-volume *La rotation de la terre, ses preuves mécaniques anciennes et nouvelles*, praised the Groningen findings in the *Catholic Encyclopedia*. A year earlier, Hagen's book had been furnished with an appendix entitled *Les preuves de M. Kamerlingh Onnes*. The author of this 70-page treatise was Father Johan Stein S.J., who was then working as Hagen's assistant.⁴⁴ Stein, who had gained his doctorate in Leiden in 1901 under the supervision of the astronomer H.G. van de Sande Bakhuyzen,⁴⁵ had revised

⁴² MB, archives of Heike Kamerlingh Onnes, inv. no. 14.

⁴³ P. van Geer, *Jahrbuch über die Fortschritte der Mathematik*, vol. 1879 (Berlin, 1881) 658-662.

⁴⁴ Dr. J. Stein, *La rotation de la terre, ses preuves mécaniques anciennes et nouvelles: Appendix: Les preuves de M. Kamerlingh Onnes* (Rome, 1910).

⁴⁵ Dorien Daling, 'De Tweede Gouden Eeuw: Pater Stein S.J. (1871-1951)', *Gevina* 26 (2003) 96-114.

Heike's dissertation and translated it into French, to the author's great satisfaction: 'Please accept my heartfelt thanks for sending me the work in which you have conveyed the substance of my dissertation in a both felicitous and original manner', Heike wrote to the Vatican. 'By doing so you have fulfilled a long-cherished desire: namely, to make my findings more widely known than before.'⁴⁶

Finally, a few isolated reactions to the dissertation. After the death of Heike Kamerlingh Onnes, in February 1926, Lorentz discussed the main points of this treatise in his Monday morning lecture of 1 March in Leiden. 'I would remind you how clearly he displayed his genius in his first piece of research, the subject of his doctoral dissertation.'⁴⁷ Hendrik Casimir, who arrived at Leiden University as a new physics undergraduate in September 1926, acknowledged Onnes's mathematical insight and experimental ingenuity but was unenthusiastic about the pendulum. '[B]ut the choice of subject always struck me as rather pedestrian, not to say dull. One could expect what one would find and the work did not even lead to a striking demonstration experiment.'⁴⁸ E.O. Schulz-DuBois of IBM Research in Zürich took a very different view. He paid tribute to Heike Kamerlingh Onnes in 1970, describing his analysis in *Nieuwe bewijzen* as 'probably one of the earliest examples of a special case of doubly degenerate perturbation theory'.⁴⁹

Arnold Sommerfeld, professor of theoretical physics in Munich for over thirty years, referred to Heike in the first volume (Mechanics) of his *Vorlesungen über theoretische Physik* (Lectures on Theoretical Physics). At the end of the section on relative motion, he emphasised the quantitative aspect of the Groningen study, something that had gone over the heads of Foucault's other followers.⁵⁰ The absence of any reference to Heike in Kirchhoff's *Vorlesungen* is perfectly understandable, since the first volume, on mechanics, appeared in 1878.

As for Heike's pendulum: Mees bought it from him for a token amount – fair enough, since Deutgen had charged very little for his work. Shortly after Heike's death, the Groningen professor Dirk Coster was kind enough to entrust the virtually intact structure to the care of the physics laboratory of the University of Leiden, where it was set up in the attic until its eventual transfer to the storage facility of Museum Boerhaave.

⁴⁶ Heike Kamerlingh Onnes to Stein, 28 July 1911, archives of Specola Vaticana, archives of P. Stein, quoted in Daling 2003.

⁴⁷ H.A. Lorentz, 'Het proefschrift van prof. Kamerlingh Onnes', *Physica* (1926) 165–180.

⁴⁸ H.B.G. Casimir, *Haphazard Reality* (New York 1983) 160.

⁴⁹ E.O. Schulz-DuBois, 'Foucault pendulum experiment by Kamerlingh Onnes and degenerate perturbation theory', *American Journal of Physics* 18 (1970) 173–188.

⁵⁰ Arnold Sommerfeld, *Vorlesungen über theoretische Physik*, vol 1 *Mechanik* (Leipzig 1943) 168.

8. Delft: corresponding states and other matters

‘It strikes me, looking back over the past year, that I have accomplished a good deal’, Heike wrote to Van Bemmelen from his parental home in Zoutstraat.¹ After a glum letter written shortly after he had obtained his doctorate,² lamenting the end of his student life and dwelling on the close friendships he had forged over the past nine years, Heike’s thoughts turned to the laboratory once again. He felt that his ‘hour of achievement’ in Delft was approaching.

At home, however, there were dark clouds on the horizon. As 1879 drew to a close, Heike’s father Harm Onnes saw in the New Year with his family for the last time. He was now seriously ill. In August 1877 he had been diagnosed with a severe lung condition and after a month of treatment in Germany he had coughed up blood repeatedly in a three-week period. At the end of November he was able to rejoin his family at the dinner table, just in time to celebrate his silver wedding anniversary. The family’s problems were exacerbated by the national crisis in agriculture; the yield from farms had declined, and the brickworks in Feerwerd suffered badly as a result. Harm’s ill health compelled him to leave his less competent brother Jeipe to manage the business. Suddenly it became necessary to count every penny. Heike had no wish to see his brothers fare worse than himself, and trimmed his expenses accordingly. He decided not to attend the reunion festivities at the university of Groningen, and a visit to his Adolf Holtzmann (‘a jewel of a man’) was also judged too expensive. This was doubly regrettable, since a trip to Germany would have benefited his health.

Harm’s lungs deteriorated to such an extent – he probably had tuberculosis – that the family decided to sell the Zoutstraat house.³ On 8 June 1880 the ‘spacious and extremely solidly built gentleman’s residence’ came under the auctioneer’s hammer. Potential buyers could view the house on the day of the

¹ Heike Kamerlingh Onnes to Van Bemmelen, 31 December 1879, MB, archive 99.

² Heike Kamerlingh Onnes to Van Bemmelen, 21 July 1879, MB, archive 99.

³ *Nieuwe Groninger Courant*, 2 June 1880.

auction and the day before, for a nominal fee of ‘25 cents for the parish poor’. The house fetched 10,575 guilders and the adjoining warehouse another 2,950.⁴ Harm needed to breathe good clean air, and in the village of Hengelo in the province of Gelderland the family rented the splendidly situated house ‘t Waerle’, with its own lanes and ponds and a ‘substantial farm’ in the middle of the woods. Heike came back from Delft to help with the move. Unfortunately, Harm was not able to enjoy the fresh air for very long: he died on 5 October 1880, at the age of 61. Once debts and taxes had been paid off, the estate was found to be worth 27,247 guilders.

Albert was already back in the East Indies when his father died, having spent some time in Paris and London promoting the centrifuge he had invented. As far as he was concerned, business was booming, or as Heike put it, ‘my brother seems to be heading for a glorious future’. To the disappointment of Delft graduates, Albert decided to call himself ‘A.K. Onnes, mechanical engineer on Java’. He later established a reputation as an architect. His success had been a long time coming. When Albert started at the HBS in Groningen in 1869, Heike – who was only eighteen months older – was already preparing for his school-leaving examinations. Albert was known at school as a difficult, fidgety child who was not, however, incapable of study.⁵ He was kept down for one year, ‘gave rise to complaints’, and studied only languages, history and geography, since he had expressed a desire to become a painter. He was constantly at loggerheads with teachers, and in March 1872 Harm decided it was time for him to leave school. Albert traded in colonial merchandise and travelled around Germany. It was rumoured that he kept racing horses, and that when his father went to Berlin to chastise him for wasting money, he refused to let him in.⁶ But in the East Indies, Albert calmed down and eventually became a ‘grand seigneur’.

Menso, who was far less quick-witted than Albert, also failed to keep up with his studies at the HBS. In the second year he gave up mathematics and German, and other subjects too soon fell by the wayside. He struggled along from one year to the next and was often ill. In June 1880, when the Onnes family moved to Hengelo, Menso left school without any qualifications. When Albert came to the Netherlands on a visit from the East Indies, Heike suggested that Albert might take Menso back with him and give him work. But Menso would not hear of it.⁷ In December 1880, Heike, who had become the

⁴ Deed of sale (*verkoopakte*) of 9 June 1880, 211 folio 63 recto, section 7.

⁵ Groninger Archieven, archief Rijks-HBS, inv. no. 314.

⁶ J. Nypels-Kamerlingh Onnes, *Jeugdberinneringen en familieverbanden* (Warmond, n.d.).

⁷ Menso to Heike, 22 November 1879, coll. De Knecht.

head of the family since his father's death, brought his young brother to Delft. Menso rented a room at Koornmarkt and attended lessons in decorative painting with A. le Comte, a teacher at the polytechnic and a friend of Heike's. The idea was that Menso would gradually become independent under his brother's watchful eye, study arts and crafts in Delft and after a year go to Brussels to be trained as an artist. Things were to turn out differently, however.

Heike thought art and science a promising combination. In one of his letters to Menso,⁸ he wrote enthusiastically about galvanoplasty, a technique enabling cheap but tasteful reproductions of household objects to be made in precious and semi-precious metals using electrolysis. He had visited a factory in The Hague where cast iron objects were given a coating of silver, gold, nickel or bronze. The director of such a company, Heike told his brother, would benefit from possessing both 'scientific expertise and taste', a combination to which few artists could lay claim. Why didn't Menso look into the idea?

In the same letter, Heike gave his brother the address of Adolf Holtzmann. Menso's lungs were troubling him, and Heike wanted him to leave for a healthier climate abroad without delay. Holtzmann, who was living in Munich by then, was very happy to receive Menso and to help him find his feet in the applied arts. When Menso arrived in Munich, he conceived the plan of taking a doctorate in aesthetics or art history, hopefully without making too much of an effort. Heike displayed little enthusiasm for the idea. How did this fit in with his earlier plans to become an artist or an art dealer?⁹ Moreover, Heike had little confidence in Menso's capacity for sustained study and questioned whether obtaining a doctorate would bring in any money. And what was the point of it? If Menso was thinking of a career in trade or industry, good vocational training was what he needed. If his preference was for art history, why not go to Italy, where he could specialise in the Renaissance? Besides, a stay in Florence would do his weak lungs the world of good. Heike expressed his disapproval of Menso's calculating attitude: where was his idealism? Heike was perfectly happy to send him money in his role as head of the family, provided that Menso pursued a sensible course of action instead of pursuing 'phantoms'.

In March 1882 Menso left with Holtzmann for Italy, stopping on the way in Vienna, where he visited the studio of Hans Makart. This made a great impression on him. He enjoyed Verona and Venice, but initially bypassed Florence since he wanted to be in Rome before the summer heat set in. From Rome he sent a series of reflections on art to a German newspaper, and he

⁸ Heike to Menso, 27 September 1881, coll. De Knegt.

⁹ Heike to Menso, 23 November 1881, coll. De Knegt.

experimented with making watercolour portraits. He was eager for Heike's opinion, and wouldn't it be good if he could sell such portraits for twenty guilders apiece? He was also interested in interior design. At Heike's request he sent some suggestions for the drawing room at 't Waelre', including a design for a plaster relief.¹⁰ Menso journeyed to Naples and Capri, sent work to Le Comte – who was enthusiastic about his progress – and on the advice of his teacher in Delft he decided to abandon the decorative arts. He would become a painter, a field in which he was entirely self-taught.

Onno, who stuttered badly, did gain a HBS certificate in 1880. A year later he started work at Amsterdam's new sales kiosks, where he made a good impression. Adolf, the youngest, was more of a problem. Something of a libertine, he played truant from school. When his father died he was fifteen, and his mother Antje found it difficult to control him. At Heike's initiative, Adolf was apprenticed to his uncle Jeipe at the Feerwerd brickworks in 1882, but after a year he packed his bags and boarded a ship for America. There he worked for a while as a cowhand, then put to sea again and his travels eventually brought him to the East Indies. On Sumatra he was a jack-of-all-trades and master of none, until the fabulously wealthy Tjong A Fie, the 'Major' (highest representative) of the Chinese minority, took him under his wing. Tjong presided over a commercial empire with many thousands of employees. In time Adolf became his right-hand man, acquiring power and a high standing in the community, and set up a flourishing administrative office in Medan.

Little is known of the female members of the family, Heike's sister Jenny and mother Antje. Jenny, an artistic girl, was undoubtedly given a decent education, and may have attended the girls' secondary school (MMS) in Hofstraat. The MMS opened in 1872, whereas the HBS did not receive state approval to admit female pupils until 1890.

An academic career

While Heike was working on his doctorate (1876-78) he had been torn by doubts about his future. What should he do? He could not decide. He did know what he did *not* want: he would accept 'no teaching job at a HBS or grammar school, unless compelled by necessity'. This he had solemnly promised Van Bemmelen. After some 'impassioned' discussions with his father, Heike decided to aim for an academic career; only then would he derive pleasure from science. His aim was to secure a professorship.

¹⁰ Menso to Heike, 31 March 1882, coll. De Knegt.

The next question was where to start this career. Mees did not have an assistant, so Groningen was out of the question – even though Heike was convinced that he would have something ‘sensational’ to show for himself within a few years. When an opportunity arose in Leiden in February 1877, Heike therefore professed his keen interest. He heard that Dr Brutel de la Rivière had given up his position as the assistant of Rijke, professor of experimental physics. Heike asked Van Bemmelen to rate his chances (physics and chemistry were in the same building in Leiden); did Rijke already have one of his own students in mind for the position? In Leiden, regarded as the ‘centre’ of Dutch science, Heike hoped to be able to work as an unsalaried lecturer, teaching mathematical physics or mechanics. He considered the question of timing: he expected to gain his doctorate after Easter, so it would be ideal if he could start in Leiden at the beginning of the next academic year, October 1877. If he were appointed any earlier, it would undermine the work on his dissertation. And how splendid it would be, Heike’s daydreaming continued, if he could spend the summer term in Berlin, with Kirchhoff and Helmholtz. ‘If you approve’, Heike concluded his letter to Leiden, ‘I am sure you will broach the matter to Professor Rijke.’ Van Bemmelen will undoubtedly have spoken on his behalf, but in the event Dr B.J. Goossens was appointed as Brutel de la Rivière’s successor.

By December 1877, Rijke found himself looking for an assistant again: Goossens had left after only nine months. Van Bemmelen promptly offered to mediate again, but this time Heike demurred. This was because of the appointment in Leiden, in November, of Hendrik Antoon Lorentz as professor of mathematical physics (see chapter 9). Heike suddenly saw the scope for him to lecture there drastically curtailed; he could hope for little more than a class in thermodynamics. In any case, his wretched doctoral dissertation was still not finished. Van Bemmelen’s warning of June 1877 to make haste struck home with redoubled force. After consulting his father and Mees, he decided to abandon the idea of seeking a position as Rijke’s assistant, to give the pendulum absolute priority, and to hope that a new opportunity in Leiden would soon arise.

Six months went by, and Heike had still not finished with his pendulum. His doctorate was becoming an embarrassment; he had to find himself a job in academia. Fortunately he received an offer from Delft. This time it was not the chemist Oudemans who wanted him but the physicist Bosscha, who had been appointed director of the Polytechnic in August 1878 after the sudden death of Cohen Stuart. This created a gap in applied physics, and it would be Heike’s job to keep the laboratory running and to participate in research. He started in mid-September, for an annual salary of 1,200 guilders.

The Polytechnic, a product of the Secondary Education Act, had opened in 1864. It replaced the Delft Academy, which, besides training scientists, had

turned out dozens of ‘first- and second-class East Indies officials’ every year – until Leiden was given a monopoly in this area. The budding scientists, fresh from the HBS, were taught applied physics, with a curriculum including heat, electricity and magnetism, and later sound and light.¹¹ The lectures were taught by Grinwis and subsequently by Van de Sande Bakhuyzen, after Grinwis left to take a position in Utrecht. Physics was initially taught in the main building overlooking the Oude Delft canal, but in 1867 the physics and chemistry departments both moved into new premises on Westvest. Unlike Oudemans’s chemistry laboratory, the physics laboratory provided very limited scope for advanced students to conduct practical experiments.

This changed in 1873 with the arrival of Johannes Bosscha, who took over from Van de Sande Bakhuyzen when the latter was appointed in Leiden to succeed the astronomer Kaiser. Bosscha had been inspector of secondary education for nine years; now he was eager to return to academia. He came from a family of classicists and politicians (his father had served as a government minister), was a creditable experimental physicist, and he had already performed a great service to Dutch physics with his secondary-school textbook (*Leerboek der Natuurkunde*) and his determined efforts to provide HBS pupils with well-equipped laboratories. He had inherited from his teachers Kaiser (Leiden) and Van der Willigen (Deventer and Amsterdam) a penchant for accurate measurement – which drove him to urge the introduction of Dutch standard meters – that he communicated to students such as Heike Kamerlingh Onnes and Herman Haga, who would succeed Mees in Groningen in 1886.

Bosscha had gained his doctorate in 1854 under Rijke’s supervision, with a dissertation on the differential galvanometer, a sensitive instrument for measuring electrical currents.¹² After a brief stay in Berlin, he resumed the thread of his studies in Leiden, working as Rijke’s assistant, where he studied the new principle of the conservation of energy. He conducted highly precise measurements to determine whether the development of heat in an electrical circuit corresponded to the chemical energy consumed in the battery (‘Daniel element’). Bosscha saw the conservation of energy (which he preferred to call *arbeidsvermogen* or *quantité de travail* rather than *vis viva* or living force, or energy) – as an organisational principle for the entire field of physics. He had remained faithful to physics while working as a schools inspector; he had corrected mercury thermometers to take account of the expansion of their glass

¹¹ J.A. Snijders, ‘Het onderwijs in de natuurkunde voor aanstaande ingenieurs’. *Gedenkschrift van de Koninklijke Akademie en van de Polytechnische School 1842-1905* (Delft, 1906) 243-256; appendix VIII, 1-14.

¹² H.A. Lorentz, Johannes Bosscha (1831-1911), *Verzameld Werk* 9, 391-403.



Ill. 16. Johannes Bosscha (1831-1911) at 70, drawn by Jan Veth. At the Polytechnic in Delft (the later University of Technology), Kamerlingh Onnes worked as Bosscha's assistant from 1878 to 1882.

casing, for instance, on the basis of the measurements taken by the French physicist Regnault.

Heike referred to Bosscha as his ‘intellectual benefactor’. He was attracted to quantitative research; this had been abundantly clear in Heidelberg, his Groningen pendulum experiments testified to it, and in Delft he found himself again in congenial surroundings. ‘I absorbed Bosscha’s insistence on the most meticulous accuracy in scientific work’, Heike later recalled, ‘and it was the greatest gift that I could possibly have been given.’¹³

Delft’s science graduates resented from the outset the Polytechnic’s classification as secondary education. They felt that this second-rate status was wholly unjustifiable, since mathematics, mechanics, physics and chemistry were all taught at Delft by academics with doctorates. The strength of Delft graduates, according to Professor J.A. Snijders, was not their mastery of ‘slide rules and technical tables’ but their development of a clear understanding of the laws of physics.¹⁴ Indeed, some employers complained that Delft students were fed more theory than was good for them and that they could not compete with technicians with more practical training. The Polytechnic eventually achieved the status of an institution of higher education, but not until 1905.

Bosscha gave a considerable boost to this ‘academisation’ of applied physics. He had attached two conditions to his acceptance of the position: he wanted a new physics laboratory, with a large lecture hall and several rooms where students could perform experiments, and an assistant who could take over his lectures at times – he was frequently away on business for the International Metre Commission to which he belonged – and supervise the laboratory work. Both demands were met. With practical exercises for *all* students, at the beginning of their studies, Bosscha was well ahead of what was offered at university. Simple experiments were considered sufficient. The primary aim was to ensure that students learned to observe accurately, to make calculations based on their measurements, and to acquire a certain proficiency in handling instruments.

In Heike’s first year in Delft, he led what he called a rather hermit-like existence. He found a room on the Oude Delft canal, not far from the director’s house now occupied by Bosscha. ‘The emphasis must now be on my health and on a *modus operandi* that will make it possible to achieve most in the longer term’, Heike wrote to Van Bemmelen.¹⁵ And he confided in his brother Menso that he had followed his doctor’s advice and stopped dancing. He

¹³ Van Itallie-van Embden, 44.

¹⁴ *Op. cit.* note 11, 243.

¹⁵ Heike Kamerlingh Onnes to Van Bemmelen, 21 July 1879, MB, archive 99.

missed club waltzes – giving them up was ‘no small sacrifice’ – but ‘gallopad-ing’ was an activity he was more than happy to forego. Heike no longer attended balls.

His students included Gerard Philips, who would later start a lightbulb factory in Eindhoven with his brother Anton, and Hugo Tutein Nolthenius, who would become director of the Calvé factories. Heike was delighted to be working with Bosscha. ‘His secondary school textbook, which awoke in so many pupils an interest in experimental work such as Regnault’s, had already communicated Bosscha’s love of quantitative research to me at an early age’, he wrote in the weekly *De Amsterdammer* after Bosscha’s death (in 1911). Though any obituary will naturally tend to err on the side of flattery, these remarks nonetheless shed light on Heike’s relationship with his superior in Delft:

‘The way in which Bosscha prepared his crystal-clear, absorbing lectures, the way he organised the laboratory work, his probing critiques of observation and discussions of results, all were equally edifying. Working according to Bosscha’s instructions and exchanging views with him on a wide variety of topics, which he was always willing to do, left me with an indelible impression of those years. In addition, he provided inspiring leadership with a fatherly affection that forged a lifelong friendship. His confidences made it clear to me that he cared about science and science alone, without any ulterior motive, and revealed his passion for truth and justice.’¹⁶

When Bosscha invited him to dine at the grand house at which he resided as director of the Polytechnic, Heike found himself rubbing shoulders with scholars such as the astronomer brothers Henricus Gerardus and Ernst Fredrik van de Sande Bakhuyzen, the mathematician Diederik Johannes Korteweg, Hendrik Antoon Lorentz, Herman Haga and Johannes Diderik van der Waals, ‘exceptional men, shrewd researchers, archetypal scholars’. He also met Bosscha’s daughter, Anna Jacoba, six years younger than he, artistically gifted but physically unattractive. Her love for her father’s new assistant remained unrequited;¹⁷ Heike’s thoughts were totally taken up with his laboratory. He realised, however, that ‘I have become unsociable and friendships with young ladies thus assume a rather painful quality. I am aware that I have disappointed several female friends in Delft, and that I am surely robbing myself of a great pleasure if I withdraw from the world this year.’¹⁸

Heike found organising the first-year physics laboratory work a very demanding task. Dozens of students were involved, and the new assistant took

¹⁶ H. Kamerlingh Onnes, ‘J. Bosscha’, *De Amsterdammer*, 20 April 1911.

¹⁷ C.C. Erdbrink-Bosscha, ‘Herinneringen’, archive Bosscha Erdbrink, c. 1955.

¹⁸ Heike Kamerlingh Onnes to Van Bemmelen, 21 July 1879, MB, archive 99.

his work extremely seriously. If a diligent first-year student wanted extra work, Heike would prepare a 'small piece of original research', and he was always willing to help advanced students who were doing some extra optional laboratory work to improve their practical skills. 'Some of my youngsters want to continue working on their experiments with filtering sand through water after their examinations', Heike wrote proudly at the end of his first year in Delft. Supervising students properly was very time-consuming. What is more, his dissertation was still not finished. So it is not surprising that he could not turn his mind to romance.

On top of all his supervisory work, Heike started on some experimental research of his own. Bosscha, who, as director of the Polytechnic, carried on with his lectures on applied physics for first- and second-year students, scarcely had any time for his own research – while Heike was in Delft, all Bosscha published was a short article on the theory of lens systems.¹⁹ In July 1879, shortly after gaining his doctorate, Heike wrote that he was looking forward to researching the refractive index of carbonic acid, 'which promises to yield splendid results'. One month later he joined the Utrecht professor H.J. Rink for a lengthy series of experiments to determine electrical resistances (using the damping of a magnet oscillating in a small coil) that would keep him occupied until the summer of 1880.²⁰ Heike also tried to dissolve a solid in liquid that had been heated above the critical temperature. In a Cailletet tube (U-shaped and made of robust glass that could withstand very high pressure) he experimented with mercury chloride dissolved in ether, and later with sulphurous acid – until December, when two British scientists beat him to it by publishing a 'very good piece' on the same subject in *Nature*.²¹ The resistance experiment, for which he designed an improved piece of equipment that 'delighted' Bosscha and Rink, also failed to lead to a publication.

Lack of time was certainly in part to blame. In the academic year 1880-81, Heike took over the teaching load of his sick colleague J.A. Snijders, his predecessor as supervisor of the physics laboratory work, who had been appointed professor in September 1878. Snijders had his own calibration laboratory at the Polytechnic, and lectured in weighing and measuring, mathematics and mechanics. Snijders recovered from his illness after a year, but in the summer holiday of 1881, Bosscha himself fell victim to a serious illness. Once again it was Heike who jumped into the breach, by taking over the lectures in applied

¹⁹ J. Bosscha, 'Over de algemeene eigenschappen van geconcentreerde optische stelsels', *Processen-verbaal der Kon. Akad. van Wet., Afd. Natuurkunde*, 27 December 1879.

²⁰ MB, Archives of Heike Kamerlingh Onnes, inv. no. 65-70.

²¹ MB, Archives of Heike Kamerlingh Onnes, inv. no. 58.

physics. This meant teaching a two-year course involving three hours of lectures a week, one year being devoted to heat and light, and the other to electricity and magnetism. In 1881-82 it was the turn of the second group.²²

The curriculum contained a certain amount of theory (laws of electricity, magnetic induction, thermal action of electric current) but also included applications (lightning conductors, the influence of the iron components of ships on the ship's compass, telegraphy). There was a good sprinkling of demonstrations on each subject – Heike asked Buys Ballot (in vain, as it turned out) to provide some interesting old-fashioned electrical devices for these occasions.²³ He made sure that everyone had a good view of the demonstration, and wrote down both the recorded measurements and the appropriate theory on large sheets of paper.²⁴ ‘Lecture going well’, he wrote to Menso in November, ‘always 60 to 70 students, some of them very content; now engaged in horribly difficult experiments that can only succeed if all sorts of precautions are taken.’ Three months later he confessed to his brother that he was having ‘a lot of difficulty’ with the lecture. ‘The students are simply biased against the theoretical parts of the subject, and it requires an immense effort to persuade them to engage with it, even though I am convinced that it is indispensable to them.’²⁵ Attendance shrank to thirty students, but as soon as he started to deal with applications again, the absentees returned. The Delft Student Almanac expressed ‘sincere thanks’ to Heike for his lectures,²⁶ and Snijders praised his flexibility. ‘While retaining a broad theoretical basis, Onnes added so much technical substance to his lectures that he may be said to have provided the Polytechnic’s first course in “electrical engineering”’.²⁷

Heike had long ceased to live like a hermit. Having moved to Choorstraat, he had made friends with the decorative painter Le Comte, the mathematician Legebeke, the HBS teacher Haga (a classmate of Lorentz’s whom he had met at Van Bemmelen’s house in Arnhem and who was conducting research at Bosscha’s laboratory), the chemist Gratama (a classmate from the HBS in Groningen), the architects Klinkhamer and Kerckhoff, and Van Marken, director of the Gist- en Spiritusfabrieken (Yeast and Methylated Spirits Factory), who was known for his progressive social policies. Heike was also on very friendly terms with the Bosscha family. One summer when the Bosschas were

²² MB archives of Heike Kamerlingh Onnes, inv. nos. 7 and 8.

²³ Buys Ballot to Heike Kamerlingh Onnes, 7 September 1881, MB, archives of Heike Kamerlingh Onnes, inv. no. 292.

²⁴ Haga to Lorentz, 22 April 1882, N-HA, Lorentz archives.

²⁵ Heike to Menso, 23 November 1881 and 25 February 1882, coll. De Knegt.

²⁶ *Delftsche Studentenalmamak 1883*, 329.

²⁷ *Op. cit.* note 11, 253.

holidaying quite near to Heike's own house, 't Waelre', he arranged visits back and forth and a communal picnic near Ruurloo.²⁸ And in May, when his lectures were finished, Heike gave a 'gala performance' at Bosscha's house, during which he demonstrated carbon lamps and electric lightbulbs, projected and drew silhouettes of faces, and invited the ladies to generate static electricity.

Closer working relationship with Van der Waals

By far the most important friendship that Heike made in Delft was with Johannes Diderik van der Waals. They had known each other since 1873, the year of Van der Waals's dissertation on the continuity of the gaseous and liquid state. In the autumn of 1879 they embarked on a scientific collaboration that would last for almost 40 years, proving extremely fruitful and profoundly influencing Heike's career. Van der Waals's 'masterful' dissertation had aroused Heike's admiration from the outset, but Heike relates that it was the *Law of Corresponding States* that brought them into closer contact.²⁹

At the beginning of this collaboration, Van der Waals had held a professorship in Amsterdam for two years. When the Athenaeum Illustre was promoted to (municipal) university status in 1876, Bosscha was at the top of the wish-list of the capital's new faculty of mathematics and physics. So alarmed was Cohen Stuart, director of the Polytechnic, upon hearing this news, that he immediately contacted the Minister to arrange for Bosscha to be given a 1,000-guilder salary increase. Bosscha stayed in Delft – but only after having insisted that *all* the staff of the Polytechnic should be given the same pay rise.³⁰ Amsterdam responded by snapping up Van der Waals from under Leiden's nose (while Leiden snapped up Lorentz from Utrecht!). The new professor was not one to waste time. Van der Waals was known as an introverted and rather unapproachable man with little sense of humour, and many students feared his inflexibility and sharp tongue. But those who took their science seriously, said Heike, found Van der Waals to be a 'kind-hearted man'.

Bosscha (1831) and Van der Waals (1837) knew each other from The Hague.³¹ They came from completely different backgrounds. While Bosscha, who had grown up in Breda, was destined for the elite of the middle-class

²⁸ Heike to Menso, 29 July 1882, coll. De Knegt.

²⁹ H. Kamerlingh Onnes, 'Ter herinnering aan Prof.Dr. I.D. van der Waals', *De Telegraaf*, 11 March 1923.

³⁰ *Gedenkschrift van de Koninklijke Akademie en van de Polytechnische School 1842-1905*, 115.

³¹ Frans van Lunteren, 'Bosscha's leerboek en Van der Waals' proefschrift: aantrekken de krachten in Den Haag', *Gewina* 23 (2000) 247-265; A.Y. Kipnis, B.E. Yavelov and J.S. Rowlinson, *Van der Waals and Molecular Science*, 14-27.

intelligentsia, the Leiden carpenter's son Van der Waals had a long journey through the forest of teaching certificates and a career as a primary school-teacher before finally reaching university. From 1862 onwards he attended lectures in Leiden, and three years later he had secured certificates placing him on an equal footing with candidates with a PhD in mathematics or physics when applying for a job as an HBS teacher. In 1866 Van der Waals secured a post at the gymnasium – and the HBS that had arisen from it – having been recommended by Kaiser, on whom he had made a good impression as a student, and he used Bosscha's textbook *Leerboek der natuurkunde* from the outset. At the end of 1871 he was awarded a Master's degree, and on 14 June 1873 he gained his doctorate under the supervision of Rijke. After that, his star quickly rose.

Bosscha had lived in The Hague since his appointment as Inspector of Secondary Education in 1863. His eldest son Jan was in Van der Waals's physics class at the HBS, but the most important place where the two men met was the physics society *Diligentia*. Bosscha was in the society's executive committee. Its primary activity was organising physics lectures (on subjects from the entire field of the natural sciences) that were organised for the 250-odd members on alternate Friday evenings. Of prime importance to Bosscha and Van der Waals, neither of whom had yet been appointed to an academic position by 1870, were the scientific journals they could read at *Diligentia*, which helped them remain up to date.

It was Bosscha who advised Van der Waals to write a dissertation.³² They corresponded about molecular forces in fluids in 1871.³³ That was the year in which Bosscha published the first part of volume four of his *Leerboek*, including a chapter on molecular forces that dwelt at length on subjects such as cohesion, soap bubbles, diffusion and capillarity. In his Preface, the author thanked Van der Waals for having collected a 'substantial body of material' in this area. The two men kept in contact after Van der Waals moved to P.C. Hooftstraat in Amsterdam: they met at Academy meetings every last Saturday of the month at the *Trippenhuis* on Kloveniersburgwal in Amsterdam, besides which Van der Waals occasionally showed up at *Diligentia* and frequently visited Bosscha in Delft.

It must have been during one such visit to Delft that Kamerlingh Onnes and Van der Waals struck up a friendship, in the autumn of 1879.³⁴ Heike avoided *Diligentia*, just as he had avoided the physics society in Groningen

³² Heike Kamerlingh Onnes to Kasterin, 8 and 10 October 1898, archives of M.V. Lomonosov University of Moscow.

³³ *Op cit.* note 31, Van Lunteren.

³⁴ Heike Kamerlingh Onnes to Van der Waals, 19 July 1919, N-HA, archives of Van der Waals.

(where Mees had given numerous lectures), aside from the lecture and demonstration he had given there in January 1878 on 'The causes of consonance and dissonance in musical sounds'.³⁵ In the autumn of 1879, Van der Waals had an additional reason to visit Bosscha: in July 1879, at the request of the Ministry of War, the Academy had appointed a committee consisting of Bosscha, Rijke and himself to draft a report on lightning conductors on the roofs of state-owned buildings in Delft. The committee presented its final report at the Academy's November meeting, after a round of inspections taking in the city's engineering workshops, the armoury, the pyrotechnic workshop, and the ammunition factory and iron foundry.³⁶

It was in August that Van der Waals derived his Law of Corresponding States. According to this law, which follows from the equation of state in his dissertation, all substances behave in the same way provided pressure, temperature and volume are expressed as functions of the substance's critical pressure, temperature and volume (determined by the two constants a and b from the equation of state corresponding to the mutual attraction between the molecules and the volume they take up). Once pressure, volume and temperature are expressed in terms of critical pressure, critical volume and critical temperature, the equation of state is transformed into a universal form from which all the specific properties of the substance have been eliminated. In his Nobel Prize acceptance speech of December 1910, Van der Waals said that the 'essential importance' of the law of corresponding states was that it established that all substances belonged to a single genus, 'just as all human beings belong to the genus *Homo*'.

The law of corresponding states is an extremely powerful tool in the hands of an experimental scientist. If the behaviour of a reference substance is known, and the critical pressure, critical volume and critical temperature of the substance to be investigated are known, one may confidently predict the behaviour of this second substance, for instance its coefficient of expansion, thanks to the law of corresponding states. For Kamerlingh Onnes, the principle was a beacon that guided his research. Thus in 1907, he was able, on the basis of measurements of isotherms of hydrogen around the critical point, and using the law of corresponding states, to make a realistic estimate of the critical temperature of helium; the result told him that an assault on helium had some chance of success.

³⁵ Groninger Archieven, archive 1454, inv. no. 5; *Groninger Courant*, Sunday 3 February 1878; MB, Archives of Heike Kamerlingh Onnes, inv. no. 35.

³⁶ *Verslagen en Mededelingen der Koninklijke Akademie van Wetenschappen, afdeling natuurkunde*, 2nd series, 15 (1880) 33-37.

Van der Waals gave a brief presentation of his law of corresponding states at the Academy's September meeting in 1880. Two months later, also at the Academy, he discussed some of the consequences arising from the principle.³⁷ On both occasions he offered an article for publication. The two articles were published in the Academy's annual proceedings (*Verhandelingen*) for 1880.³⁸ By then the first reaction had already been received. 'I had informed the Royal Academy of the law of corresponding states', Van der Waals later recalled, 'and even before it had been published, so that Onnes could only have known about it through hearsay, he produced a treatise in which he derived it from more general principles.'³⁹ He was referring to the *Algemeene Theorie der Vloeistoffen* ('General Theory of Liquids'), the first part of which Heike submitted to Van der Waals in December 1880. That same month the latter submitted it to the Academy's meeting for publication in its *Verslagen en mededelingen*.⁴⁰ A committee (consisting of Van der Waals, Bosscha and Grinwis) approved the piece a month later,⁴¹ and was equally pleased with the sequel submitted in February. Both pieces, running to 47 pages in total, were published in the Academy's 1881 Proceedings.⁴²

How had Heike known about Van der Waals's law of corresponding states? It seems obvious that Bosscha, who had attended that Academy meeting, must have told him about it. In his *General Theory of Liquids*, Heike wrote that he had been encouraged by both Lorentz and his superior in Delft. The object was to derive the principle of corresponding states by applying 'the principle of equivalence of motion', which Heike attributed to Newton, to 'molecular theory'. To do so, he took as his basic premise, as Van der Waals had done in deriving his

³⁷ 'Proces-verbaal van de Gewone Vergadering der Afdeeling Natuurkunde' (Official report of the General Meeting of the Physics Section), Saturday 25 September and Saturday 27 November 1880.

³⁸ J.D. van der Waals, 'Onderzoekingen omtrent de overeenstemmende eigenschappen der normalen-verzadigden damp – en vloeistofflijnen voor de verschillende stoffen en omtrent een wijziging in de vorm dier lijnen bij mengsels', *Verhandelingen der Koninklijke Akademie van Wetenschappen* 20, no. 5 (1880) 1–32.

³⁹ J.D. van der Waals, 'Over de coefficienten van uitzetting en van samendrukking in overeenstemmende toestanden der verschillende vloeistoffen', *Verhandelingen der Koninklijke Akademie van Wetenschappen* 20, no. 6 (1880) 1–11; J.D. van der Waals, 'De arbeid van Kamerlingh Onnes voor de Vaderlandse Natuurkunde', *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de jaren 1882–1904* (Leiden 1904) 86.

⁴⁰ 'Proces-verbaal', 24 December 1880. Although the appropriate title for this dissertation would be 'General Theory of Fluids', thus including gases, it is widely cited as 'General Theory of Liquids', which title will therefore be used here – transl.

⁴¹ *Verslagen en mededelingen van de Koninklijke Akademie van Wetenschappen, afdeling Natuurkunde*, January 1881.

⁴² H. Kamerlingh Onnes, 'Algemene theorie der Vloeistoffen', *Verhandelingen der Koninklijke Akademie van Wetenschappen* 21 (1881) 8–43.

equation of state, that the molecules of all liquids and gases are ‘*identically shaped*’ elastic bodies of dimensions that do not undergo any perceptible change’ and that mutual attraction produces a net effect only at the surface of the fluid. Moreover, Heike posited that the kinetic energy of the molecules was proportional to the absolute temperature.

Two fluids were in a corresponding state if, after length, time and mass had been aligned appropriately, it proved possible to induce in them the same kinetic state. Phrased in modern terms: films of the molecular motion of two fluids can be transformed into replicas of each other by aligning the initial positions and velocities of the molecules, temperature and volume.⁴³ In this argument, without statistics, the precise form of the equation of state was irrelevant, so that Heike’s derivation of the law of corresponding states had a more general basis than that of Van der Waals. It may be added that this law, like the equation of state, was only approximately correct, much to Van der Waals’s chagrin. Heike’s *General Theory of Liquids*, an abridged version of which appeared in the *Archives Néerlandaises*,⁴⁴ (published by Holland Society of Sciences in Haarlem) examined the size of the deviations that occurred at high pressure, on the basis of observations recorded by Andrews, Regnault and Roth.⁴⁵

The *General Theory of Fluids* was the only publication that Heike had to show for his four years in Delft. He had worked on it for less than a month. With all the commotion surrounding the replacement of Snijders and Bosscha, he had suspended his experimental research. No one in Delft blamed him for doing so. But was Heike now an experimental or a theoretical physicist? In Leiden this was certainly a sensitive issue – especially when a controversy flared up around the choice of Rijke’s successor.

⁴³ Johanna Levelt Sengers, *How fluids unmix. Discoveries by the school of Van der Waals and Kamerlingh Onnes* (Amsterdam 2002) 25–36.

⁴⁴ H. Kamerlingh Onnes, ‘Théorie générale de l’état fluide’, *Archives Néerlandaises* 30 (1881) 101–136.

⁴⁵ MB, archives of Heike Kamerlingh Onnes, inv. no. 280.

9. To Leiden

In Leiden, the historian Hendrick Quack tells us – writing in 1875 – university professors walked around the city ‘as gods’.¹ It was here, in the heart of Dutch academia, that Heike Kamerlingh Onnes – to whom we shall now generally refer by the last part of his surname – sought to fulfil his ideal of securing a professorship. The first opportunity arose in 1882. After the summer, Pieter Leonard Rijke, professor of experimental physics and meteorology at Leiden, was to retire, and after four years of working as Bosscha’s assistant, Onnes was ready for the move from the Polytechnic to the country’s oldest university.

Professors Van Bemmelen (inorganic chemistry) and Lorentz (mathematical physics) agreed that Onnes’s time had come, and they were eager to have him as a colleague. A year before Rijke’s retirement, Lorentz found himself worrying whether their friend, who had been such a delightful hiking companion in the woods outside Arnhem, would want to come; was there no opening for him in Groningen? Van Bemmelen reassured him. The professor of astronomy in Leiden, Van de Sande Bakhuyzen, had heard from his Groningen counterpart Kapteyn that Onnes had no chance of being offered anything there: it was fanciful to imagine that a second professor would be appointed alongside Mees. And Van Bemmelen went on (drawing partly on his experience as Onnes’s chemistry teacher at the HBS):

‘It may be true that Onnes has gradually moved towards the theoretical side, but that does not mean he is lost for experimental physics. He has never stopped experimenting. Had it not been for Snijders’ illness, which compelled Onnes to teach, his major research project [measurements of resistances] would already have been published, or at least completed. With Bosscha he was constantly performing experiments. I therefore see not the slightest objection to his coming to Leiden.

If Onnes has a good assistant, he will not have to exhaust himself so much with the lectures, as Rijke has always done – largely because his method of setting up the

¹ W. Otterspeer, *De wiekslag van hun geest. De Leidse universiteit in de negentiende eeuw* (The Hague, 1992) 402.

experiments was poor and because he wanted to demonstrate everything – and he will be able to spend most of his time performing experiments with his students, which Rijke never did.²

Still, there was no harm in honing one's experimental skills, and during a dinner at Van Bemmelen's, the host urged Onnes, in a 'wide-ranging' conversation, to focus on his research in Delft during the coming academic year, 1881-82. 'And Onnes entirely agreed with me.' Reassuringly, he wrote to Lorentz, who was away on his honeymoon: 'I am therefore confident that Onnes will accept if he is offered a chair in physics.' How this physics was to be tackled was clear: '... it is certain that experiments without a sound theoretical basis are of little note nowadays.' Van Bemmelen therefore saw no grounds for pessimism: 'There is no danger of us losing Onnes as things stand. We shall therefore not give up hopes of securing him.'

Rijke, an experimental physicist *pur sang*, had been appointed at the University of Leiden in 1845.³ He came from the Royal Athenaeum in Maastricht, where he had taught applied chemistry as well as physics. His doctoral dissertation (1836, Leiden) was on the origins of voltaic electricity (Volta was the inventor of the 'column' named after him – the voltaic pile, the precursor of the modern battery). Rijke was the first Dutch professor whose research and teaching commitment was confined to physics from the outset.⁴ He was 'a friendly man with a gruff demeanour' about whom it was 'not easy to say something pleasant'.⁵ The student Co Modderman, later to be professor of chemistry in Groningen (in which capacity he was unable to arouse the interest of his first-year student Kamerlingh Onnes) tried to do so all the same:

'Very thorough were the physics classes taught by Professor Rijke, who spoke clearly, if not eloquently, and presented his material lucidly. [...] He found it most important that students attended his lectures faithfully, which in fact almost everyone did, partly to see the excellent and illuminating experiments, which seldom, if ever, failed to go as planned. Absentees could be almost certain of being questioned about the material they had missed at the following lecture. We took this into account and took notes from a friend who had attended. Still, after one lecture I had missed – a rare omission in my case – he asked me: 'Now where did I leave off yesterday?' I had no choice but to answer that I had not been there, eliciting a stern exhortation to attend regularly. So he was rather schoolmasterish, but for the rest he was a superb teacher.'⁶

² Van Bemmelen to Lorentz, 8 July 1881, N-HA, Lorentz archives.

³ H.A.M. Snelders, 'Rijke, Petrus Leonardus', *Biografisch Woordenboek van Nederland* 3 (1989) 511-512.

⁴ Frans van Lunteren, 'Van meten tot weten', 53-54 and 63.

⁵ W. Otterspeer, *Wetenschap*, 121.

Rijke's love of the laboratory reflected an early nineteenth-century German tradition in which physics and chemistry were closely interrelated.⁷ The practically-oriented research of physicists such as J.C. Poggendorf and H.G. Magnus had a heavily anti-theoretical, anti-mathematical bias; both men saw empirical physics as their field's vital core. Rijke agreed. 'Precision measurement played no appreciable role', writes Frans van Lunteren: 'there was no link whatsoever with theory, and the emphasis was on electrical phenomena. Most of his [Rijke's] research related to the spark gap, the duration and nature of electrical sparks in diverse conditions, and the various properties of induced currents. His most notable research was produced in the 1850s, after which he published very little.' Rijke acquired international fame with his invention of a tube creating thermal-acoustic vibrations, later dubbed 'Rijke's tube'.⁸

The students were full of praise for Rijke's experimental physics lectures with their wonderful experiments, but his classes in mathematical physics prompted growing criticism. This field, practised since the early nineteenth century by scientists such as Fourier, Laplace, Cauchy, Lagrange, Liouville, Hamilton and Jacobi, had gained enormously in significance since the advent of theoretical edifices such as thermodynamics, the kinetic theory of gases, and Maxwell's electromagnetic theory of light. In contrast to the suggestion in the Leiden student almanac of 1864 that the classes in mathematical physics be left to a mathematician, ten years later, the faculty reporter argued strongly in favour of a separate chair in mathematical physics.⁹

This chair was finally installed at the end of 1877. Under the terms of the new Higher Education Act, enacted by Parliament the previous year, the university's primary task was no longer to educate students to join the 'scholarly classes', as laid down in the previous legislation (dating from 1815), but to 'educate and prepare students for the independent pursuit of academic learning, and for positions in society that demand academic training'.¹⁰ The new Act created ample scope for the steadily advancing trend towards specialisation. The concept of the unsalaried 'private lecturer' was imported from Germany, widening the range of lectures, and seven Master's (*doctoraal*) examinations in science were instituted: mathematics and astronomy, mathematics and physics A (with the emphasis on theory) and B (with the emphasis on empirical science; applied chemistry and meteorology instead of theory of functions), chemistry,

⁶ W. Otterspeer (ed.), 'De studententijd van Co Modderman', *Leids jaarboek* 78 (1986) 102-133.

⁷ Frans van Lunteren, 'Van meten tot weten', 43-46.

⁸ Lord Rayleigh, *Theory of Sound*, vol. 2 (New York 1945) 232.

⁹ *Almanak van het Leidsch Studentencorps* (1864) 25; (1874) 207.

¹⁰ *Handelingen der Staten Generaal*, annexes on the parliamentary session 1874-1875, no. 30.1, 'Gewijzigd ontwerp van de wet', 11.

geography and mineralogy, botany and zoology, and pharmacy.¹¹ All these changes, especially the establishment of theoretical and experimental mathematics and physics as two separate branches, multiplied the number of professorships.

By the beginning of 1878, the mathematics and physics faculty had deposited a hefty package of demands with the Senate of the University of Leiden. Physics wanted three professors, two for the experimental and one for the theoretical branch. It also requested a larger laboratory, to incorporate what was then the chemistry wing (estimated cost: 20,000 guilders) and a steam engine (costing 4,320 guilders) to generate electric light.¹² Other faculties too translated the new Higher Education Act into fervent pleas for substantial expansion. Many requests were turned down. Physics did not get the requested extra laboratory space, and had to wait until 1906 to appoint its second professor of experimental physics. The chair in mathematical physics was also held back until the minister was convinced that the university did not have anyone suitably qualified.¹³ Rijke's first choice for this position, his student J.D. van der Waals, promptly opted for Amsterdam, whose Municipal University operated more decisively, and had no wish to change his mind. Leiden lost him.

Next in line was the then 24-year-old Lorentz, who had been awarded his doctorate in 1875 under Rijke's supervision, with his dissertation on the theory of the reflection and refraction of light.¹⁴ At the end of August, Rijke wrote to Lorentz that now that Leiden had lost all chance of appointing Van der Waals, he, Lorentz, was 'the ideal candidate ... when we again raise the matter to the successor of the present minister.'¹⁵ There was apparently no great rush: Rijke suggested that Lorentz, who had been teaching secondary school evening classes in Arnhem since 1872, should start by switching to a teaching job at the *gymnasium* in Leiden, besides which he could teach some classes at the university as an (unpaid) private lecturer in anticipation of his appointment to the chair.

The decision-making suddenly accelerated when Utrecht made a bid to appoint Lorentz to a chair in mathematics – the Delft professor Baehr, though already appointed, had withdrawn when he discovered how few important lectures he was to be allocated.¹⁶ Rijke sounded the alarm and managed to

¹¹ M. Groen, *Het wetenschappelijk onderwijs in Nederland van 1815-1980*, II (Eindhoven 1988) 32-34.

¹² UB Leiden, Archief Senaat en Faculteiten, II, wiskunde en natuurkunde (mathematics and physics), inv. no. 1.

¹³ BZ to *curatoren*, 5 July 1877, UB Leiden, Archief Curatoren.

¹⁴ *Over de theorie der terugkaatsing en breking van het licht*; first published in English in 1997: Hendrik Antoon, *On the Theory of the Reflection and Refraction of Light*, ed. Nancy J. Nersessian and H. Floris Cohen Amsterdam/Atlanta, GA, 1997. See also Oosterhoff, 103-124.

¹⁵ Rijke to Lorentz, 23 August 1877, N-HA, Lorentz archives.

¹⁶ *Ibid.*, 3 and 7 November 1877.

persuade the faculty to dash off post-haste a ‘most forceful petition’ to The Hague entreating the minister to appoint Lorentz without delay, enclosing the board of governors’ ‘highest recommendations’. Rijke’s fear that the minister would balk at appointing Lorentz and argue that mathematical physics could perfectly well be taught by mathematician, proved unfounded. Lorentz took up his position in Leiden on 17 November 1877, and on 25 January 1878 he delivered his inaugural address on the molecular theories in physics.

At this point, the university physics landscape in the Netherlands looked as follows.¹⁷ In Groningen there was Mees, still working without an assistant. Utrecht, with its new physics laboratory on Bijlhouwerstraat (besides a few rooms for practical exercises, the monumental building had only one laboratory suitable for physics research), had Buys Ballot and Grinwis, who taught all the lectures in mathematics and physics between them: Buys Ballot, who was also director of the Meteorological Institute, taught geometry as well as physics, and Grinwis, who taught mathematics and mathematical physics, was also responsible for experimental physics. Besides this heavy teaching load, the Utrecht professors had to do without assistants, which meant that their practical exercises were just as insubstantial as those in Groningen. At the new University of Amsterdam, Van der Waals, having spent five years improvising in the premises on the Singel canal and at Oudemanhuispoort, acquired a brand-new laboratory on Plantage Muidergracht in 1883, as well as an assistant. Finally, Leiden had Rijke – who had an assistant – and now Lorentz. We shall discuss the Leiden laboratory in more detail later on.

Heike Kamerlingh Onnes versus Willem Röntgen

It was Onnes’s firm intention to become Rijke’s successor in Leiden after the summer of 1882. In January that year he mused in a letter to his brother Menso about the financial consequences (more about the family’s financial worries below),¹⁸ and he rejected an offer from the Polytechnic in Delft to accept a chair in mechanics (after which the position went to his friend Legebeke, in January 1882).¹⁹ He wrote to Lorentz from his parental home ‘t Waelre’ on 4 April that he felt he must not give in now, although he had expected to have to conduct some major research [with Bosscha] before he could hope to be considered for the *summus honoris*.²⁰

¹⁷ Van Lunteren, ‘Van meten tot weten’.

¹⁸ Heike to Menso, 7 January 1882, coll. De Knegt.

¹⁹ *Ibid.*, 28 October 188.

²⁰ Heike Kamerlingh Onnes to Lorentz, 4 April 1882, N-HA, Lorentz archives.

At the end of April, when the procedure in Leiden had already lasted for two weeks, he reported on the state of affairs to his brother in Italy. According to Onnes, Rijke had asked Bosscha ‘if he wanted to be his successor’ but Bosscha had refused, because his directorship of the Polytechnic was ‘higher than a professorship’.

‘At the same time he recommended me. This would mean skipping a generation in the progression from assistant to professor [Bosscha was Rijke’s assistant]. Now it seems that Rijke does not favour me, or that he considers that other faculty members, with whom he is on poor terms, are too partial to my candidature; in short, he asserts that the only outstanding Dutch scientist is Röntgen,²¹ professor at Giessen. And I could agree with him, if Röntgen could be regarded as Dutch. It is true that he is of Dutch parentage, and lived in Holland until he was 16, but since then he has become wholly Germanised, and he has certainly undergone naturalisation as a German. So it is scarcely tenable to label him a Dutchman.’

Whatever the case may be, Onnes thought it an honour for his name to be mentioned ‘in the same breath as that of an esteemed German professor’ and realised that his qualities as a teacher might tip the balance in his favour: in contrast to his own successful lectures in Delft, Röntgen ‘scarcely speaks Dutch any more ... which makes it difficult to teach, especially when one is dealing with the general run of students (especially medical undergraduates)’. That Leiden also wished to put Van der Waals’s name forward did not worry Onnes, ‘since this would create a vacancy in Amsterdam’. In the meantime, he had long noticed, from the behaviour of Haga, Bosscha, Van de Sande Bakhuizen and Lorentz, that something was brewing, and he was not worried about the outcome:

‘The result is that my chances with the faculty are good, as things stand; of course, one never knows what the board of governors and the minister will do, but fortunately some fairly powerful friends are taking an interest in the matter. The opinion of the professor of the other half of physics – Lorentz – as to whom he would prefer as his colleague is bound to be one of the decisive factors, and he is very fond of me. For my part, I am certain that we would have a very pleasant and fruitful working relationship.’²²

Meanwhile, what had been going on behind the scenes? On 12 April 1882, the board of governors had asked the faculty of mathematics and physics for a list

²¹ Wilhelm Conrad Röntgen, the inventor (in 1895) of X-rays, known in Dutch- and German-speaking countries as ‘Röntgen rays’.

²² Heike to Menso, 30 April 1882, coll. De Knecht.

of candidates.²³ After ‘most careful consideration’, the faculty duly produced two names: J.D. van der Waals and H. Kamerlingh Onnes. In their letter, the chairman and secretary of the board of governors (K. Martin, professor of geology and mineralogy, and H.A. Lorentz) stated that the new man must be both a fine experimental scientist and a good teacher, and professed their good fortune in being able to nominate ‘two Dutch physicists, the appointment of either of whom would be of outstanding benefit to the university’s interests’. The faculty did not express a preference for either candidate.

Regarding Onnes, the faculty observed that Bosscha was extremely pleased with the diligence he had displayed in Delft. When Bosscha’s illness in September 1881 had compelled Onnes to take over his lectures in applied physics, the latter had spared neither time nor trouble to fulfil his obligations. ‘With [Onnes’s] numerous fine experiments, many of which he devised himself to clarify new insights in physics, his lectures are, from an experimental vantage point, among the best ever given. His inventiveness and ingenuity, which have once more been demonstrated here, hold out great promise for the future.’ The faculty also considered Onnes’s dissertation to be ‘outstanding in every respect’. Onnes had succeeded in ‘illuminating much that had hitherto remained obscure’ in relation to the Foucault pendulum. He had also set up ‘some extensive experimental research projects’, although these had not yet been completed.

The faculty had less to say about Van der Waals; good wine needs no bush. It merely noted that while he was primarily concerned with theory, his lectures in Amsterdam and the research findings recently presented to the Academy showed that his experimental work was of a similarly high standard. In short, Van der Waals was the more experienced teacher of the two, while Onnes was the better experimental scientist. ‘Both, however’, wrote the faculty in concluding its nominations, ‘are men who are passionate about science, outstanding in both skill and originality, and may be expected to have an inspirational influence on students and to encourage them to pursue their own independent scientific research.’

The unanimity reflected by the above quotations appears somewhat remarkable in the light of Rijke’s views, and the divided truth soon emerged. On 15 May a second, more detailed, letter than the one signed by the chairman and secretary was sent to the board of governors, this time signed by Rijke, Van Geer (mathematics), Franchimont (organic chemistry) and Hoffman (zoology). This ‘gang of four’ expressed a preference for W.C. Röntgen, ‘presently

²³ Unless stated otherwise, the documents concerning Rijke’s succession may be found in the NA, archief Kabinet van de Koning, 2.04.26.02, inv. no. 294, doc. 128.

professor at the University of Giessen, but born and bred in the Netherlands' and hence opposed the majority advice of Lorentz, Bierens de Haan, Van Bemmelen, Van de Sande Bakhuyzen, Suringar (botany) and Van der Burg (pharmacy). They even claimed to be a gang of five, invoking the name of Martin, a German, who had professed neutrality but supposedly favoured Röntgen; later he disclosed that he in fact supported the Van der Waals/Onnes nomination.

Rijke *cum suis* argued as follows. Since the entry into force of the 1876 Higher Education Act, physics at Leiden had been divided in two. Rijke, having previously been held sway over the whole field of physics, now confined his attention to experimental physics and meteorology, while 'Theoretical or so-called Mathematical Physics' had acquired its own professor with the advent of Lorentz. With Rijke's retirement in the offing, all attention must focus on the interests of teaching in experimental physics. Secondary school physics also cried out for sound practitioners of experimental physics. But Lorentz's success had diminished youngsters' enthusiasm for physically demanding experiments. Perhaps the only possible counterbalance could be provided by 'the personality of the man to be entrusted with the experimental branch'. No one with the necessary personality was to be found at a Dutch university, and Röntgen was therefore proposed. At Rijke's request, Van Geer, who was on a summer trip in Germany, had sounded Röntgen out at the Academy's annual festivities in Würzburg regarding his interest in a position at Leiden. 'He gave me his word', said Van Geer, 'that he would accept such an appointment.'²⁴

Willem/Wilhelm Röntgen, born in 1845 in the small German town of Lennep, emigrated with his parents to the Dutch town of Apeldoorn as a child of three. In August 1862 he moved to Utrecht, where he enrolled at the technical school and boarded with the family of Jan Willem Gunning (in 1873, when Gunning was professor of chemistry at the Athenaeum Illustre in Amsterdam, Onnes briefly served as his assistant). Initially, Röntgen's teachers were very pleased with his progress, but his performance gradually deteriorated: there were complaints about insolent behaviour and neglected homework, and the boy's school report of 2 May 1864 described his diligence and progress in physics as 'very poor'. The young Röntgen was expelled before the end of the school year. Six months later he failed an entrance examination to the University of Utrecht. He sat in on various lectures, until the father of a former classmate at the technical school told him that he could enrol at the Zürich Polytechnic (Eidgenössischen Polytechnikum) without taking an entrance examination. At the end of November, Röntgen left for Switzerland. He gained

²⁴ *De Nederlandsche Spectator* 49 (1904).

a doctorate in Zürich under the supervision of August Kundt (an experimental physicist who based his work on sound theoretical foundations), followed him to laboratories in Würzburg and Strasbourg as his assistant, and after an intermediate stay at Stuttgart, ended up in Giessen, where he was appointed professor of physics in April 1879.²⁵

In their letter of 15 May, the ‘gang of four’ referred to the ‘superb’ quality of Röntgen’s teaching, and gave a detailed list of his academic achievements. The letter concluded by commenting drily that the biggest obstacle to Röntgen’s return to his native country was the appreciation of these ‘achievements abroad’. Röntgen was accused of having forfeited his Dutch nationality. But had Röntgen not written ‘aus Holland’ [from Holland] at the end of his first article in Poggendorf’s *Annalen*? Had anyone ever considered depriving Thorbecke of his Dutch nationality because he had worked as a private lecturer in Göttingen? And what about Christiaan Huygens, whom Colbert had enticed to Paris; had that cost him his nationality? Germans who had worked abroad had no problem securing academic positions upon returning to their *Heimat*. ‘We Dutch’, the letter concluded, should take such acceptance as an example.

Had there been a vacancy in Leiden for an undivided professorship, the Rijke group added, Van der Waals would have been more than welcome. But Van der Waals’s experimental work – the main issue here – was not particularly original, and served primarily to verify theoretical calculations. ‘We would not in general wish to diminish the importance of such experiments, but nonetheless feel compelled to comment that the most important discoveries of our century have been made by men who were not tied to the apron-strings of theory.’ Fresnel’s theory of ether and Faraday’s discovery of magnetic induction were cited as examples of free empirical research.

The four then directed their arrows at Kamerlingh Onnes. His dissertation, they felt, was more in the nature of mechanics than experimental physics, and the ‘unfinished experiments’ he had conducted in Delft could not be taken into account. While possessing great talent for theoretical research was not a valid reason for someone’s ‘unconditional exclusion from experimental physics’, it did call for the ‘greatest circumspection’ to be exercised:

‘Experimental physics is fraught with so many anxieties and so much grief and disappointment, and demands so much physical exertion, that one would need fortitude verging on the supernatural to make such an effort when one may acquire just as much fame by other means. Indeed, Mr Onnes himself has demonstrated this point. Serving

²⁵ Albrecht Fölsing, *Wilhelm Conrad Röntgen: Aufbruch ins Innere der Materie* (Munich 1995) 13–104.

as assistant to the physics laboratory of the Polytechnic, he must have been completely absorbed in experimental physics. Even so, he has not been able to complete a single piece of experimental research, and yet he has found time to write a major piece on a theoretical subject.’

The Rijke group concluded their letter by noting that Röntgen’s gesture of sending offprints of all his publications to Leiden provided conclusive proof of his desire to be regarded as a fellow countryman.

The initiative now passed to the Lorentz group, which hit back on 26 May with a twelve-page epistle of their own. They argued that theory and experimentation always went hand in hand, and maintained that ‘an experimental physics divorced from theoretical physics [was] utterly unthinkable’. Precise reasoning in physics relied on mathematics, they insisted: Fresnel’s discoveries had been guided by theoretical reflections, and Faraday was ‘in the higher sense of the term a theorist, indeed a mathematician, although you will not find a single formula in his work. ... Anyone who tries to penetrate the essence of things must be a theorist.’ While conceding that it was possible for those who were not fully cognizant with theory to be usefully employed in physics, the letter asserted that ‘the higher regions of physics would be closed off to them.’

After which the letter had some words of praise for Kamerlingh Onnes. ‘Mr Onnes possesses to a rare degree the combination of experimental and theoretical talent that the faculty values so greatly’, and Onnes’s dissertation displayed ‘extraordinary experimental aptitude’.

To appoint Röntgen, the letter went on, would be to send out the wrong signal, as if the Netherlands possessed no suitable candidates of its own. Furthermore, Röntgen was in no respect superior to Van der Waals or Onnes. ‘Physics is not languishing in the Netherlands,’ asserted the Lorentz group:

‘On the contrary, it is flourishing today as it has not flourished for a very long time. Its practitioners, most of whom are associated through ties of friendship, enjoy all the advantages that accrue from personal contact and debate about scientific issues; these close ties are felicitous indeed, since they mean that one may truly speak of a “Dutch physics”.’

This letter of 26 May was accompanied by two appendices. Professor Ludwig of Giessen, having been asked for his opinion, had written to Martin that his colleague Röntgen still considered himself Dutch, but that others saw him as a German and that he had become estranged from the Netherlands after having lived abroad for twenty years. Even so, he spoke Dutch to his father, who lived with him, and Ludwig believed that Röntgen would be happy to accept a chair in the Netherlands, provided certain demands were met.

The other appendix was a letter from Bosscha to Van de Sande Bakhuyzen. Bosscha wrote that Van der Waals was the better teacher and had more of a

reputation in Europe. But this would soon change. ‘... I expect Onnes to surpass him. Onnes is cleverer and thinks things through more deeply.’ Bosscha praised Onnes’s ‘fine character’ and expressed his admiration for the *General theory of liquids*. ‘No one had seen this before Onnes, not even Clausius or Van der Waals.’ He continued:

‘I witnessed Onnes’s dissertation taking shape virtually before my eyes. His ideas were confirmed within just a few weeks. It put me in mind of Ampère, who comprehended what Oerstedt had discovered but only in the form of an inexplicable fact. ... He has the capacity to attract a following, and there are few of whom this may be said. ... It would be folly to seek beyond our borders when we have physicists of this calibre here. Once Onnes has an opportunity to resume his experimental research, within a few years he will have achieved so much that they will be trying to coax him to Germany.’²⁶

On 30 May the Rijke group countered with yet another letter, claiming that Bosscha was exaggerating. He and his allies were oblivious to ‘the host of physicists who say, “theories may come and go, but the laws of nature will always remain the same; we therefore wish to devote our energies, and hope to link our names, solely to the establishment of these laws.”’ What was at issue was a chair in experimental physics. Five years earlier, wrote Rijke, no one in the faculty had objected to the split that had been introduced between experimental and mathematical physics, and it therefore made no sense to start undermining the experimental side. As for ‘sending out a signal’, Rijke ended by suggesting how the decision would be viewed by posterity: ‘an experimental physicist was needed, and in making the choice, regard was had to the just claims of a Dutchman who, though residing temporarily outside the country, had always wanted to return home.’

After this unrestrained display of dissent within the faculty, it was up to the board of governors to resolve the matter. This took another six weeks. The board too found itself unable to take one line. The majority placed Röntgen at the top of the nomination, followed by Van der Waals and Kamerlingh Onnes. But a minority rejected Röntgen altogether and chose Onnes as the leading candidate (not altogether uninfluenced, perhaps, by the fact that at an annual salary of 4,000 guilders, he would be 2,000 guilders cheaper than his rivals), followed by Van der Waals. The long delay may have had something to do with the ‘ministerial crisis’ that was going on.

²⁶ Bosscha to Van de Sande Bakhuyzen, UB Leiden, Archief Curatoren, ingekomen stukken 1882, no 342.

Did Van der Waals want the job? On 15 May, the faculty had been unable to give the board of governors an answer. The death (from tuberculosis) of his wife Anna Magdalena in December 1881 had plunged Van der Waals into a deep depression, and it was not the right time to sound him out about a possible move to Leiden. The minister was finally notified of the board's position on 13 July 1882, and on 31 July, Minister Pijnacker Hordijk asked it to clarify the situation. Within a day, Amsterdam sensed danger, and a letter was sent to Van der Waals' home address, begging him to stay.²⁷ His colleagues Gunning, Oudemans, De Vries and Van Pesch wrote that his departure would be a terrible blow to Amsterdam, that his academic stature added lustre to the still relatively new university, as the 'most outstanding ... indeed the crowning member' of the faculty, and 'earnestly entreated' him to remain faithful to the University of Amsterdam. The pleas worked. On 23 August, Van der Waals wrote to Leiden, informing the board of governors that he would not consider a position there.²⁸

Meanwhile, Onnes had to wait and see what would happen. Menso wrote encouraging words to his brother from Italy, saying that it would be 'pretty rich ... to resort to a German'. In Groningen, Professor Baerends, who came from Jena in Germany, had only recently caused a commotion by disappearing prematurely for the summer recess. This 'scarcely made one eager for a repeat performance', besides which 'Baerends' unpleasantness was legendary in Jena'. Anyway, wrote Menso, Heike's gift for eloquence gave him an enormous advantage over a German. 'Nothing has changed in Leiden', Heike replied in 28 May, emphasising that as a rival Röntgen could not be compared to Baerends, since he had a 'very solid reputation'.²⁹

By 31 August, Onnes's patience was exhausted. 'No one knows what is going on in Leiden, but one thing is sure: delaying an appointment so long is quite irresponsible.' He gave Menso some extra background information:

'Perhaps I mentioned in one of my earlier letters that my nomination had been opposed; Professor Rijke had suggested that my only support came from "friends" – and yet he had a letter of recommendation from Kirchhoff in his pocket that he carefully concealed. The German is probably out of the picture, and everything now depends on whether Van der Waals is willing to leave Amsterdam for Leiden. ... And what does all this bickering achieve other than to stir up ill-feeling?'³⁰

²⁷ N-HA, Van der Waals archives, inv. no. 12, letter of 1 August 1882.

²⁸ *Curatoren* to BZ, 23 August 1882, UB Leiden, Archief Curatoren.

²⁹ Menso to Heike, summer 1882; Heike to Menso, 28 May 1882, coll. De Knecht.

³⁰ Heike to Menso, 31 August 1882, coll. De Knecht.

What Onnes did not know was that Lorentz had taken action as soon as he had heard of the board of governors' nomination. In mid-July, letters of recommendation were pouring in on behalf of Kamerlingh Onnes. Mees called his former pupil 'a highly industrious and talented person' whom he held in high regard as both a mathematician and a physicist, and said that he would be delighted if Onnes were offered a professorship, not just for the physicist himself but 'also for the benefits to Dutch science'.³¹ A letter from Buys Ballot in Epe recalled Onnes's entry to an academic competition set in Utrecht (1871, see chapter 3): 'superb and with an astonishing depth of knowledge for one so young in addition to highly acute judgment in his command of theory'.³² Onnes, Mees's 'much-loved disciple', was more than capable of taking on the 'heavy responsibility' of the chair in Leiden, concluded Buys Ballot.

The next person to sing Onnes's praises was Ernst Schering, professor of astronomy in Göttingen, director of the 'Gaussischen Erdmagnetischer Observatorium', who was just then writing a positive review of Onnes's dissertation. 'I would be equally delighted', wrote Schering in a marvellous sentence to Lorentz, 'if I could in any way promote the appointment of a young man whose invention of new methods is both felicitous and based on firm scientific foundations to a position through which all the fruits may be plucked for science that the significant talent of Dr Kamerlingh Onnes is capable of bearing'.³³

But the truly decisive voice was that of Gustav Kirchhoff, with whom Onnes had embarked on his pendulum experiments in Heidelberg. While Robert Bunsen had written on 30 April that Onnes was gifted both in the laboratory and as a mathematician, and that Röntgen was 'a truly formidable experimental physicist',³⁴ Kirchhoff wrote to Rijke on the same date, from his new home (and position) in Berlin, that Röntgen and Kamerlingh Onnes were both excellent, but that since the former had already secured a good position, he would rather see the Leiden appointment go to Onnes. When Lorentz requested information afresh in August, it emerged that Rijke had kept back this for Onnes so crucial letter of recommendation. Kirchhoff wished once again 'to express [his] high opinion of this physicist's talent'.

'I wrote that I had formed this opinion in the period when Mr Onnes was working in my laboratory in Heidelberg, where I frequently had occasion to observe the curiosity and indefatigable persistence he displayed both in difficult experiments and

³¹ UB Leiden, Archief Curatoren, ingekomen stukken, 15 July 1882.

³² Letter from Buys Ballot, 12 July 1882.

³³ Schering to Lorentz, 18 July 1882.

³⁴ Bunsen to Rijke, 30 April 1882, UB Leiden, Archief Senaat en Faculteiten.

in the processing of his observations. ... What I learned of his work at a later stage served only to strengthen my high regard for his knowledge and skills. I wish to express to you once again my firm belief that if appointed to the chair of professor of experimental physics Mr Onnes will perform his responsibilities with honour and to the benefit of science.³⁵

On 20 July, in the middle of the summer recess, Suringar, Van der Burg, Lorentz and Van de Sande Bakhuyzen (Bierens de Haan, Van Bemmelen and Martin could not be contacted) wrote directly to The Hague (sending a copy of the letter to the board of governors) to notify Minister Pijnacker Hordijk of the new harvest of letters of recommendation.³⁶ They understandably drew particular attention to the words of Gustav Kirchhoff, 'one of the most famous physicists in Germany' and 'wholly capable of assessing [Onnes's] abilities as an *experimental physicist*'. That same week, Rijke and Sande Bakhuyzen both travelled to The Hague to speak to the minister,³⁷ who also raised Röntgen's name: did he, in fact, have Dutch nationality? This point remained unresolved: not until 1961 did it emerge that the Röntgen family had never possessed Dutch citizenship. However, after living in Apeldoorn for six years they had been given 'equivalent' status, with the same rights and obligations as those of full Dutch citizens, but without the right to vote.³⁸

On 28 July followed Schering's (late) letter to The Hague, accompanied by the remark that the Lorentz group had not leant over backwards on behalf of Van der Waals because this would have seemed insulting to such a famous scientist. On 31 August, eight days after Van der Waals had announced his resolve to stay in Amsterdam, Pijnacker Hordijk finally made his decision: the chair would go to Kamerlingh Onnes. The royal decree formalising this appointment was passed on 3 September. Onnes, who was already preparing to take over the lectures of the ailing Bosscha once again, had secured his position.

³⁵ Letter from Kirchhoff, 12 July 1882.

³⁶ Suringar et al. to board of governors (*curatoren*), 20 July 1882, UB Leiden, Archief Curatoren, ingekomen stukken.

³⁷ NA, inv. no. 2.04.26.02, no. 294 (1882), doc. 128.

³⁸ Fölsing, *Röntgen* 19-20.

10. New heights

At the end of the nineteenth century, Leiden was recovering from the deep slump in the textiles industry that had nourished its expansion back in the seventeenth century. From a population of 70,000 at the height of the Golden Age boom – surpassed only by Amsterdam – a mere 28,000 remained by 1818, after the collapse of the cloth industry, and half the townspeople were dependent on charity.¹ One could still see reminders of the city's glorious past: the grand town hall and Lakenhal (clothmakers' hall), the numerous weavers' houses flanking the network of canals, and the stately mansions along the Rapenburg, Apothekersdijk, Herengracht, and the branches of the Rhine. But the city also had miserable slums languishing in appalling filth, and as late as 1866 a cholera epidemic claimed 881 lives. In 1871 a new drinking water system was introduced, bringing clean water from the dunes, and conditions gradually improved. Johannes Kneppelhout, who satirised the city and its inhabitants under the pseudonym of A Klikspaan ("Tattle-tale"), presented a dismal picture in his *Studentenleven* (1844): 'All look on in resignation as the city crumbles and rots before their eyes, like the dead body of a criminal dumped outside the Morspoort.'²

In 1882, when Heike Kamerlingh Onnes set up home on the Oude Singel canal, the population had reached 42,000 and was climbing, although growth lagged behind the national average. The city landscape had been transformed over the past few decades. The great old Hooglandse Church and St Peter's (Pieterskerk) and the castle (De Burcht) still dominated the skyline. Two of the city gates were still standing – the Morspoort mentioned by 'Klikspaan' and the Zijlpoort – but the other six had been unceremoniously demolished in 1860. The ramparts had suffered the same fate, making room for the observatory (built in 1860), the elegant public gardens and numerous factories, including an

¹ See e.g. P.J. Blok, *Geschiedenis eener Hollandsche stad*, vol. 4 (The Hague 1918); P.C.N. Baesjou et al., *Leiden 1860-1960* (Leiden 1962); *Leidsch Jaarboekje*, published annually from 1904 onwards.

² Klikspaan, *Studentenleven* (Leiden 1844). Scholastic edition *Studentenschetsen*, Kets et al. (ed.) (The Hague 2002) 231.

ironworks, a gasworks, and a bread factory. One by one, the malodorous canals were filled in, and Leiden eased its way out of its long economic malaise. With a workforce of 854 in 1890, the Leiden Cotton Company run by the Driessen family was the largest employer. The advent of the steam engine – Krantz cloth factory was the first to introduce the new-fangled machine, in 1818 – heralded the modernisation of the cloth industry, although little energy went into opening up new markets. New on the economic scene in the 1860s were the canning factories, which generated ample seasonal employment for home workers: entire families could be found sitting around their living room – or even out in the street – shelling peas and beans, scraping carrots, or peeling onions with the tears running down their faces.

In the latter half of the nineteenth century, Leiden was a city sharply divided into the haves and have-nots, almost completely lacking an intermediate class. It was the elite – officers of the court, teachers and professors, military officers and physicians, and in some cases manufacturers – who sat on the city council and local advisory committees, who founded Toeljee skittle club and Vélocipède (a club for enthusiasts of the first rudimentary bicycles), and who met at Amicitia Society in the Breestraat. These select few also had social gatherings or ‘sandwich evenings’ at each other’s homes, according to a set formula of tea at seven, gracious compliments to the daughter of the house for her piano-playing, pleasant conversation, wine and puff pastry, a little dancing, and some sandwiches before setting off home.³ The nouveau riche were excluded from these merry events, and congregated instead at their own New Society.

Unemployed workers abounded. ‘Berne keeps bears, The Hague has storks, and Leiden has its paupers’, quipped ‘Klikspaan’.⁴ The most notorious slum was the quarter known as the ‘Camp’ between Haarlemmerstraat and Oude Vest. In alleys such as Paradijssteeg, Bouwelouwensteeg and Duizenddraadsteeg you could find the tripe butcher, the mustard seller and the fire and water shop (for coal and hot water), not to mention the brothels. A fishmonger’s cart would rattle through the filthy alleys in the evening selling dab or ‘harde-harde’ (lean herring) for one cent apiece. The ‘Camp’ was teeming with lice, and the 1857 student almanac described it as ‘home to the vilest and most revolting elements within the city walls’ – idlers and pickpockets such as Jantje van Dertienen, Jobje Veldbrief, Dr Post [legendary literary villains], ‘and whoever else may belong to that gang that are the bane of Leiden’s police force’.⁵

³ Willem Otterspeer, *Bolland: een biografie* (Leiden 1995) 217–218.

⁴ *Op cit.* note 2, 232.

⁵ *Almanak van het Leidsch Studenten Corps* 1857, quoted in Otterspeer, *Bolland*, 216.

Equally wretched conditions prevailed in the quarter bounded by Herengracht and Zijlsingel. At no. 16, Singelstraat, between Zesde Groenesteeg and Oosterkerkstraat, lived Marie Swanenburg or 'Good Mie', known for her willingness to help out in emergencies, tending the sick and taking care of the children. She was married to the factory worker Van der Linden, with whom she had six children, in addition to the three illegitimate children born to her before her marriage. Six of these nine children died before reaching the age of three. Others in her immediate surroundings, adults as well as children, also died prematurely. At length it transpired that Good Mie had poisoned them, administering orpiment (a rat poison rich in arsenic that was often mixed with plaster – so sloppily that lumps of it could be picked out) to a total of 102 victims. She put it in their coffee, their soup, their porridge or their bread rolls, causing 27 to die – after first suffering terrible agony – and another 45 to fall seriously ill. No sooner were the dead buried than Good Mie collected the proceeds – a substantial sum – from various burial funds with which she had taken out insurance policies on her victims' lives.⁶

On 15 December 1883 Good Mie was finally arrested – her insolent berating of an insurance agent for tardy payment sealed her fate. Her case was tried in The Hague in April 1885, with R.T. Bijleveld – Heike Kamerlingh Onnes's prospective father-in-law – prosecuting. Bijleveld described Good Mie as 'a creature unworthy to be called a human being' and recalled that the Romans imposed harsher sentences on poisoners than on 'ordinary' murderers. On the strength of the evidence relating to four recent deaths – the anatomist Zaaiker (Onnes's colleague at the Steenschuur physics laboratory), called as an expert witness, had exhumed almost twenty bodies and examined them for traces of arsenic – Good Mie was sentenced to life imprisonment.

Late nineteenth-century Leiden was a modern city in the making. In 1842-43 it had acquired rail links with Haarlem and The Hague (shortening the travelling time to both Amsterdam and Rotterdam to an hour and a half), and in 1879 a line was opened to the town of Woerden. A year later, a new station was completed at Rijnsburgerweg, which was then in Oegstgeest. Around the same time, the first tramways started taking passengers to Noordwijk and Katwijk. Life still proceeded at a fairly leisurely pace. The coachman of the horse-drawn tram that came to pick up train passengers from Stationsweg cracked his whip by way of warning signal when he arrived. Passengers would emerge from the station coffee-house 'Zomerzorg', a pleasant building nestling in some shrubbery, and amble over to the vehicle that stood waiting for them. At length the tram would pull out at a slow trot towards its destination, passing through the

⁶ W.K. van Leyden, *Goeie Mie of de Leidsche gifmengster* (Leiden 1936).

fashionable, cheerful Breestraat with its bluestone pavements, or the Haarlemmerstraat, where the new general stores with their eclectic merchandise enticed women from the poor neighbourhoods. Other modern means of transport – bicycles and steamboats – also made their appearance. Leiden acquired a telephone network in the 1880s. The first car passed through the city in 1896, on its way to The Hague. Three years later, the young nobleman and student J.C. Schorer acquired a Benz-Comfortable, becoming Leiden's first car owner.

Revolution never hung in the air in Leiden. Trade unions advanced their members' interests at amicable meetings with employers. The organisation 'Union Yields Strength' (once the motto of the United Provinces) was founded in 1876 with the cooperation of local manufacturers, with the stated aim of 'promoting the civilised manners and cultural refinement of factory workers'.⁷ In May 1882, eleven years after the founding of the General Dutch Workers' Union, C.H. Kouw (whose brother was Onnes's mechanic) started a branch in Leiden. It set out to elevate workers by 'orderly and lawful means', and steered well clear of the socialist movement that had recently been founded. The Workers' Union had only a few hundred members; most workers belonged to Church organisations instead.

Leiden had two groups that stood out clearly from the rest of the population: soldiers and students – two groups that often quarrelled if they met in the street. As a garrison town, Leiden had been home to the 1500-strong Fourth Infantry regiment since 1861. At the Ruin – of the gunpowder ship that had exploded in 1807 – where a statue was erected in 1884 of Pieter Adriaansz van der Werff (Leiden's heroic burgomaster at the time of the Spanish siege), platoons of soldiers were drilled 'until those living nearby were crunching the dust between their teeth'.⁸ The soldiers' regular processions to church were a wonderful spectacle: the entire garrison would sally forth from the Morspoort barracks to musical accompaniment and march towards the city centre; half-way down Breestraat the men would come to a halt and split according to their denomination, some marching on to the Hooglandse Church and others heading down Ketelboetersteeg to St Peter's. For many years it was customary for townspeople to invite soldiers to their homes for coffee and small talk after church.

As for the students themselves, with their numbers standing at six hundred in 1870 and almost a thousand by the end of the century, they were always a strong presence in the city. The students called the townspeople 'rotters' (*ploerten*) and the townspeople in their turn coined the arcane term of abuse 'bobbin dogs'

⁷ Blok, *Geschiedenis*, 152–153.

⁸ Otterspeer, *Bolland*, 216.

(*spoelbonden*) for the students. Aside from criminal offences, it was up to the principal of the university to keep the students in tow. Until the passage of the 1876 Higher Education Act, almost all students joined the fraternity as a matter of course; after this, a growing proportion of the student body (many of them commuters) declined to join, earning themselves the epithet 'nihilists'. By 1910, these outsiders outnumbered fraternity members. Meanwhile, two denominational societies had been founded (the Catholic Augustinus and the Protestant Societas Studiosorum Reformatorum Lugdunensis), and the growing group of women students had set up their own society – Leiden Society of Female Students – as had a group established to promote the interests of study (LSV 'Pergo ac Peraga'). All these new societies depleted the fraternity's membership.

The first woman to enrol at Leiden University, Fanny Berlinerblau, who came from Zürich but was of Russian origin, was immediately sent packing in 1873, since her professor considered gynaecology an inappropriate course of study for a lady. It was five years before another woman ventured to register, and then only as a non-examination student; by this time, the Netherlands' first woman student Aletta Jacobs was close to gaining her doctorate in Groningen. But by 1900 the university had 213 women students. The fraternity looked on darkly, seeing the growing number of women students largely as a threat. 'And including women in fraternity life', in the view of one Leiden student in 1898, writing in *Minerva*, 'would mean nothing less than loosening the ties of the fraternity, indeed, dissolving it altogether.'⁹

'The clubhouse', commented the satirist Klikspaan, 'represents the fraternity. Abolish the bar and you destroy the fraternity as a structured body.'¹⁰ The student club *Minerva* with its bar dated from 1814 and moved into brand-new premises on Breestraat in 1875, with the best reading table in the city and a cellar with room for 200 ankers of wine (almost 1,000 bottles). The *soirée musicale* acquired a counterpart on Breestraat in the form of the lewd *café chantant*. In 1881 the female singers from Rotterdam's club *Walhalla* performed at *Minerva*, charming ladies whose talents were not confined to singing. Gambling – also illegal – was extremely popular there.¹¹ The atmosphere at the bar in the 1890s, a kind of 'colonial manliness' with an internal hierarchy presided over by the 'untamables' – was dominated by coarse banter, drunken orgies, beer fights and brawls that would not infrequently spill into the streets.

⁹ *Minerva*, 3 November 1898.

¹⁰ *Op cit.* note 2, 332.

¹¹ Otterspeer, *Wiekslag*, 477-502.

Nonetheless, the fraternity was deemed essential to student life. To call a halt to its disintegration and relative decline, F.G. Schalkwijk and L.S. Ornstein, two of Kamerlingh Onnes's students, proposed in 1901 that non-fraternity members be given semi-membership status by way of the faculties, in the interests of academic life. 'Beware, gentlemen, lest you act as the Trojans', objected the member Kamp at the fraternity meeting. 'They brought the Trojan horse into their midst; let us not do likewise with the Leiden pigs.'¹²

One perpetual bone of contention was the initiation (or ragging) of new students. After a series of scandals, the initiation phase had been abolished in 1840 and replaced by a noviciate, which was completed with the freshmen's festive admission to the fraternity in the Lion d'Or in Breesstraat. But the excesses soon resurfaced. In 1856 four senior students made the new theology freshman W. van Roggen drunk and then dragged him to a brothel and forced him to kiss some prostitutes. During the 1871 initiation period, the senior student Spruit forced the freshman Bremond to write down and sign a string of obscenities. In 1884 the University Senate learned that two students had been driven insane during the initiation period, and that one of them had died. 'Weak constitution', said the almanac. Freshmen were frequently beaten up. In 1894 the student Pet was stripped to the waist and made to walk around like a pig, to be 'slaughtered' and hung against a door. All these incidents prompted the Senate to draft a set of regulations on initiation, which was adopted in 1894, seeking to banish such excesses entirely. It helped briefly, but in 1902 things went badly wrong again in a hotel, where Alfred Bolland, the son of the colourful and forceful philosophy professor G.J.P.J. Bolland, was compelled to act the part of a woman of easy virtue performing indecent acts with a young man.¹³

All these were symptoms of a crisis in an age of modernisation that was accompanied by growing social, political and sexual differentiation; resentment of these changes was brewing among the traditional student population, who came from the highest echelons of Dutch society. They expressed this resentment in a hardening of attitudes to initiation, in a nostalgic desire to recapture the exclusivity, unity and hierarchy of the past. And their efforts in turn provoked a reaction among the 'newcomers'.¹⁴

¹² Otterspeer, *Wiekslag*, 486.

¹³ W. Otterspeer, *De opvoedende kracht van den groentijd: het Leidse ontgroenschandaal van 1911* (Leiden 1995).

¹⁴ *Ibid.*, 40-41.

Ailing family

Oude Singel 6, Onnes's first address in Leiden, was just past Lakenhal, not far from Beestenmarkt. It was a sought-after area, even though the notorious 'Camp' slum lay just across the water, immediately beyond Oude Vest. Onnes's rent was 600 guilders a year. He had briefly considered an apartment on the shady Plantsoen, where the former ramparts had been demolished to make room for smart new mansions in the 1880s,¹⁵ but for two rooms *en suite*, a basement and cellar, an entrance hall, a small consulting room and another four upstairs rooms he would have had to fork out 200 guilders a year more. And that was beyond his means.

His financial constraints were related to the situation at the family's brickworks at Feerwerd, where his uncle Jeipe was in charge. 'It was already clear in Groningen that things were in a very bad way', Heike wrote to Menso, who was staying in Vienna at the time, in January 1882.

'In the first place, last year went worse than I had suspected, because previously only approximate figures had been given for the debts and stocks, and given Uncle's familiar tendencies, the estimates were obviously far too high. This made it clear to me that we have been draining too much of the company's resources over the past few years – and what is worse, that the business will certainly be making a very small profit in the foreseeable future.'¹⁶

Uncle Jeipe was scarcely a brilliant businessman, that much was clear, and the deep crisis in agriculture – which meant that selling the factory and the land was not an option – had brought the brickworks H.K. Onnes & Co. to the edge of bankruptcy. Jeipe and Heike's father had stood surety for each other (a common enough construction in firms), and after Harm's death, in October 1880, the heirs inherited this burden. 'Much of the company's capital has already been used up, and only great thrift can preserve the rest', wrote Heike. They would have to cut their coats according to their cloth, that was what mattered. 'Last year I spent 5,700 guilders from Groningen; if the firm is to survive, expenditure must not now exceed 3,000.'

'I am sorry that I did not reach this conclusion last year; I could then have tightened the screws of economy in various directions. You know well enough that I find this anything but pleasant. My plan, which is still a dark secret at the moment of course, is that Mother and Jenny, and possibly Adolf too, should come and live with me after the summer, once it has been decided whether I am perhaps going to Leiden or staying

¹⁵ MB, Archives of Heike Kamerlingh Onnes, inv. no. 260.

¹⁶ Heike to Menso, 7 January 1882 [erroneously reads 1881], coll. De Knecht.



Ill. 17. Menso Kamerlingh Onnes, self-portrait from 1882, watercolour painted during his stay in Italy (private collection).

in Delft. Even then, however, it will be difficult to preserve the pleasant atmosphere of prosperity that we have enjoyed up to now, and which is of great value to Jenny too.¹⁷

In Leiden, Onnes would have an annual salary of 4,000 guilders (3,200 after tax) as a new professor, whereas in Delft he received only 1,200 guilders (plus

¹⁷ *Ibid.*

a 'generous allowance' for replacing Bosscha), but if Leiden fell through, he hoped to secure the rank of 'lecturer' there, with a salary of 3,000. He anticipated that he would easily be able to make some additional earnings to compensate for the gap between Delft and Leiden. Meanwhile, he found it important to ensure that he was not the only person contributing to the family income. 'So I must ask both you and Onno to help, by making some sacrifices to alleviate the situation for Mother, Jenny, Adolf and the business.' Pierson, his friend from Heidelberg and now Onno's employer in Amsterdam, was willing to advance 500 guilders salary annually. Could Menso not earn some extra money? And would not living 'a very simple life in Florence or some other Italian city' be much cheaper than Vienna and 'highly beneficial' to his studies as well as to his health?

With these plans in mind, Onnes rented a large home in Leiden. But his mother and sister – Adolf decided to seek his fortune in America – could not move to Leiden straight away. This was because his brother Onno fell ill at the beginning of September 1882; he started to spit blood, and the doctor dispatched him post-haste to the Riviera for treatment. Heike hastened to Amsterdam to visit his brother in hospital (lodging with Korteweg for a week) and abandoned his plans for a working trip to a number of foreign laboratories. It seemed that their father's weak lungs were a hereditary condition. A week before Onno fell ill, Heike sent prescriptions to Italy, where Menso wrote that he had inflamed eyes, a malady that frequently plagued Heike too and that was related to his bronchitis. He hoped that some eye-drops and ointment would provide relief. 'But if you develop tiny abscesses on the cornea, with shooting pains and an aversion to light, you will have to take atropine', Heike wrote to Rome. 'You cannot be too careful with your eyes.'¹⁸

When he returned to Amsterdam, Heike impressed upon Menso once again – who was in Italy mainly for his health – the importance of exercising caution. Don't force your eyes, he urged him,

'I know from experience how much they suffer from any protracted malady. I have already renounced smoking altogether because of it, and third-class train carriages fill me with horror and revulsion. Aside from this, I have just had another lesson with Onno, who is now lying sick in Amsterdam from over-exertion and an exaggeratedly thrifty way of life.'¹⁹

Heike felt very guilty about Onno, a nervous young man who had responded frenetically to the exhortation that he should contribute to the family income,

¹⁸ Heike to Menso, 31 August 1882, coll. De Knegt.

¹⁹ Heike to Menso, 14 September 1882, coll. De Knegt.

with disastrous results. When his mother and Jenny arrived in Amsterdam from Hengelo, they relieved Heike of his duties in attending his sick brother. Onno travelled to Montreux and on to San Remo, accompanied by his mother; Jenny stayed with relatives and friends during her absence. Menso broke off his delightful life in Capri to keep his brother company for a while. The extra expense involved in all this compelled Heike to take an advance on the 1,000-guilder raise he would be given as a professor in five years' time. 'Pierson has rendered me this great service as an act of friendship.'²⁰ By this time, Heike had long since abandoned the idea of paying for 'scientific trips, private assistants and so forth' out of his own pocket.

The conclusion was clear: retaining 'Huize 't Waerle', the 'carefree environment' of his mother and Jenny, was not financially viable, and where 'true happiness' was at stake, 'all appearances' must be sacrificed – 'My friends here must know, of course, the reasons for my strict parsimony.' Jenny would enjoy the move to Leiden (Heike was planning the move for May): she would finally meet some people of her own age. The family budget might look as follows: Feerwerd and Heike would contribute 3,700 and 3,300 guilders, respectively, while the Leiden house (Heike, mother, Jenny) could have 4,800 guilders, leaving a total of 2,200 for Menso, Onno, and Adolf. Heike would have liked to send his sister to Italy with his mother and Onno – he was very concerned about Jenny's health – but the expense was prohibitive. Nor was there any question of buying a house with a garden, let alone a country estate. In the end, Heike, his mother, Jenny and Menso all moved into a rented house in Leiden near the inland harbour, but not until the autumn of 1883.

The delay in moving house was caused by an infection that Heike had contracted in the spring. In March 1883 he notified the board of governors of his indisposition and obtained permission to go to Hengelo to recover his health. Lorentz took over his introductory lectures, and Sissingh replaced him as overseer of the laboratory. Heike occasionally came to Leiden to see how things were, but the process of recovery was slow – 'I still don't trust my eyes', he wrote to Lorentz from 't Waerle' in May²¹ – and his physician (who had told him to keep a daily record of his body temperature and stools)²² advised him to go abroad. The board of governors did not immediately grant him leave, but at the end of May he obtained its consent to go to Germany. He broke his journey in Bonn and sought out Rudolph Clausius,²³ who received him 'very

²⁰ Heike to Menso, 4 October 1882, coll. De Knecht.

²¹ Heike Kamerlingh Onnes to Lorentz, 23 May 1883, N-HA, Lorentz archives, inv. no. 39.

²² MB, Archives of Heike Kamerlingh Onnes, inv. no. 260.

²³ Heike Kamerlingh Onnes to Lorentz, 25 August 1883, N-HA, Lorentz archives, inv. no. 39.

warmly' and invited him to dinner. Heike was put in mind of his enjoyable days in Heidelberg: 'We sat in the garden drinking Rhenish until late at night', he wrote to Lorentz.

Heike then boarded a steamboat to Wiesbaden. 'Glorious weather, if a little too hot, so that my pulse often causes me some alarm, but the thermometer constantly reassures me.' Heike spent several weeks convalescing on Lake Lucerne, enjoying the natural scenery. He was joined by Onno – their mother had returned to Hengelo with Jenny, and Menso was travelling around Italy and practising portraiture. Heike had hoped to stop off in Strasbourg, which had a gigantic, splendidly equipped new physics laboratory (a status symbol installed by Germany after its conquest of the Alsace from the French in 1870) but it became clear that this would be too tiring. Heike's health gradually improved, but his constitution remained fragile. 'My respiratory system has fortunately become far less sensitive', he wrote to Lorentz from Morschach at the end of August.

'When I am not resting I scarcely notice it at all, but when I exert myself I sometimes feel my ribs and throat. But I am completely addicted to fresh air; a room full of people makes my head feel hot. And joining in a real debate is still beyond me. So I shall unfortunately be *compelled* to take it easy this winter. ... But I am glad that I am at least making constant progress. For some time I had been unable to put on any weight, but over the past three weeks I have gained three pounds. ... My eyes are seldom red any more, my aversion to light has gone, my digestion is back to normal, and in general I feel in good health but not yet resilient.'

When Onno's physician came to visit him in Switzerland, he examined Heike too, and advised him not to resume work in Leiden too soon. But by September, at the beginning of the new academic year, Heike was back at his post: 'I believe that I am now strong enough to carefully return to work, under my mother's supervision'.²⁴ At the beginning of October, then, his mother and Jenny finally moved from Hengelo to Leiden, where they were joined later that month by Menso. The family's capital had evaporated. The four of them lived on Heike's salary, besides which his mother received an annual sum of 2,250 guilders from Feerwerd (where Jeipe's son Jan had taken over as manager of the brickworks). Onno settled in the little village of Vrijenban, near Delft. At the Yeast and Methylated Spirits Factory in Delft he rose to become general assistant to the director, Van Marken. Albert had left Surabaya and gone to Havana, where he won a prize with a design for a steel roof for a market. Adolf, who had seen quite enough of Feerwerd, decided to seek his

²⁴ *Ibid.*

fortune in America. Thus, each member of the Onnes family entered into a new phase of life. In the new family headquarters at Havendwarsstraat in Leiden, they must surely have sometimes had nostalgic memories of ‘t Waerle’ and their old home on Zoutstraat. How could they recover the prosperity they had enjoyed in Groningen? A certain savoir-faire proved to be the key: three marriages with highly eligible partners helped to restore the family’s fortunes.

Exuberant flower fantasies

In Italy, Menso’s talent as a painter became manifest. ‘I was delighted by your watercolours’, wrote Heike in April 1882, after Menso had sent some of his work from Rome. He thought the portrait of Countess De Bojani ‘highly expressive’, but felt that of their sister Jenny was ‘not entirely right’: the colourful dress behind the little bed of pansies did not create ‘a successful harmony’.²⁵ A self-portrait has survived from his Rome period in which Menso dressed himself up as a bohemian. From Capri, where he spent the summer months to escape from the heat, Menso sent another little box of studies, most of them oil paintings and watercolours ‘from nature’. At that point, and having heard LeComte’s enthusiastic response, Heike – who had suggested to Menso only a month before that he should go back to school, obtain his HBS certificate and study architecture in Leiden – resigned himself to his brother’s preference for ‘pure art’, even though it would not bring in any money. But he was decidedly lukewarm about Menso’s idea – inspired by guilt regarding the miserable situation in Feerwerd and his lack of financial independence – of asking Onno to act as his agent to market his watercolours at shops in Amsterdam, and to supply work on commission if there was enough demand for it: Onno had just fallen ill and Heike had no desire to degrade himself as a professor by hawking watercolours around Amsterdam.

Where modern art was concerned, Leiden was uninspired and uninspiring in the 1880s. On Pieterskerkgracht stood – and still stands today – the venerable institution *Ars Aemula Naturae* (Art Imitates Nature), one of the oldest academies of painting and draughtsmanship in the Netherlands, which doggedly persisted in time-honoured modes of training such as drawing from clothed models, nude models and plaster casts.²⁶ Students were taught to value skill more highly than originality, and unlike the Hague academy, its Leiden

²⁵ Heike to Menso, 30 April 1882, coll. De Knegt.

²⁶ Nancy Stoop, ‘Onder één dak. *Ars Aemula Naturae* en De Kunst om de Kunst, 1890-1940’, *Dageraad van de Moderne Kunst* (Zwolle 1999) 71-78.

counterpart was highly elitist. The conservative directors had sole control, and as an artists' association, *Ars* was worlds apart from *Arti et Amicitiae* (Amsterdam) and *Pulchri Studio* (The Hague). The municipal museum, which had opened in 1874 in the Lakenhal (the former Clothmakers' Hall), also ignored artistic developments elsewhere in its exhibitions and acquisitions. Until 1890, the few wealthy Leiden citizens with an interest in art, such as the textiles baron C.J. Leembruggen and the spirits manufacturer D. Hartevelt, eschewed modern art and confined their purchases to old masters.

This narrow-minded climate must have been dispiriting for a cosmopolitan artist such as Menso Kamerlingh Onnes, who had followed modern trends from close by in Munich, Vienna (where he had sought out the famous society painter Hans Makart) and Italy. Fortunately he soon found a kindred spirit: Floris Verster.²⁷ They met in or before 1884, when Floris made a portrait of Menso in oil on panel. A year younger than Menso, Floris came from an affluent patrician background. His father, steward of Rhineland Water Board, treasurer of *Ars*, a member of the municipal council, an avid huntsman and an administrative official at the Natural History Museum, had taken Floris to the museum and taught him to draw stuffed animals. Floris, like Menso, had left the HBS without a certificate. In the winter of 1878-1879 he attended classes in perspective drawing at *Ars* from the then unknown artist George Hendrik Breitner, whose drawings of horses, soldiers and cannons he greatly admired. Verster enrolled at the Hague Academy of Art, where Breitner too was a student, and in 1882, having acquired his diploma, he left to continue his training in Brussels. In 1883, the year in which Menso joined the rest of his family in Leiden, Floris too returned to his parental home on Rapenburg.

Menso and Floris influenced each other's art. Menso was self-taught but had travelled a great deal in Europe and moved in international artistic circles, while his friend, though more highly skilled in technique, was still in the process of developing a style of his own. Until the mid-1880s, Verster was still clearly under the influence of the Hague School (Israëls, Mauve, Mesdag, Maris, Bosboom, and Van der Maarel) and he painted predominantly landscapes. Around 1886, with the emergence of the Eighties Movement (which viewed art as the expression of individual emotions) and the shift of the avant-garde from The Hague to Amsterdam, Verster struck off along a new path with his colourful, animated still lifes. At the time he often worked in Menso's studio, and a comparison of the two painters' work from the years 1886-1891 reveals striking similarities in style and choice of subject-matter.

²⁷ Christiaan Vogelaar, *Floris Verster* (Leiden 2002).

Heike, who had been given top marks for freehand and construction drawing at the HBS, but never used his talent other than to make accurate sketches of experiments, exerted himself to promote his brother's career as an artist. 'Boldly executed, almost too much so, are the portraits of Mr Kamerlingh Onnes', wrote the reviewer 'A.' on 19 February 1886 in the *Leidsch Dagblad* in response to an 'art appreciation' show organised by *Ars* (a closed exhibition of recent work, held a few times a year, for artists and prominent citizens). 'Yet they are pleasing, and suggest the hand of a skilled artist rather than an amateur.' On 1 March the same newspaper printed a letter from one Mr X, who wrote that Mr A's 'artistic expertise had certainly not deceived him ... We can inform Mr A that Mr Kamerlingh Onnes studied for many years in Munich, Vienna and Rome, and has executed a number of estimable commissions in this city as well as in foreign parts.' We may be fairly confident that Mr X was Heike.

The use of the double-barrelled name 'Kamerlingh Onnes' is striking.²⁸ As already noted, the name originated with Heike. In 1870, the prospective student H.K. Onnes suddenly started calling himself 'H. Kamerlingh Onnes'. This promotion of his second forename to a surname was not uncommon at this time, and scarcely attracted attention since Kamerlingh was in fact a surname: his grandmother's. The innovation was not copied by anyone else until Heike's mother, brother Menso and sister Jenny had moved in with him. In the population register of Zoeterwoude, where the four moved into a house in May 1886 (in the new residential area of Vreewijk, just outside the outlying canal – today it is part of Leiden), Menso's last name 'Onnes' was conscientiously changed into 'Kamerlingh Onnes', and his second forename 'Kamerlingh' was deleted.²⁹ The same change was made to the surname of Jenny – whose forenames were now suddenly given as Jenny Gerdina. These obscure manoeuvres were evidently not of the kind to bother officials.³⁰ It was undoubtedly Heike who ensured that all the family members adopted the same double-barrelled name, to preserve the family's unity.

The studio where Menso and Floris worked was in Vreewijk, probably in the attic of the new house, or perhaps in another house nearby. In 1886, Menso painted a pensive, aristocratic Floris, with the ends of his moustache twisted jauntily upwards. Both artists started experimenting with still lifes, rather an unpopular genre at the time, and with light reflections and coloured glass. The

²⁸ Ard van Sighem, 'Heike (Kamerlingh) Onnes', *Quanta*, August 1994.

²⁹ Gemeentearchief Leiden, bevolkingsregister (population register) Zoeterwoude 1880-1895, district F.

³⁰ Only Onno, who like Adolf had not been given the name 'Kamerlingh' as an additional forename by their father Harm, took the trouble – though not until 1932 – to register the double-barrelled surname by Royal Decree. The change is recorded in his birth certificate in Groningen Archives.

more adventurous Menso urged Floris to attempt larger paintings and more audacious compositions than he had produced hitherto, such as *Dead Swan* from 1886. Verster's real breakthrough as a major exponent of avant-garde art came with his flower pieces. Menso too produced some notable work in this area, with watercolours such as *Vase with honesty and garden nasturtium* (1889), *Glass bowl with roses* (1890) and *Poppies in vase* (1892). He wanted his still lifes – 'flower fantasies' – to be interpreted lyrically, and gave them titles such as *Moonlight*, *False luxury*, *Beautiful death* and *Les Fleurs du Mal* (after Baudelaire's book of poems of the same name, inspired by the French symbolists). Menso submitted them to shows at *Arti* and *Pulchri*, to which both he and Floris belonged. His work attracted attention. 'Re-creations, transformations of flowers, lyrical outpourings, whose effervescent emotion blurs the boundaries of the observable such that it merges into a vision', wrote the *Nieuwe Rotterdamse Courant*.³¹

In the years 1888-1891 the work of the two young Leiden artists was almost indistinguishable. Menso, a year older and already acquainted with the international scene, appears to have influenced the introverted, dreamy Floris more than the other way round.³² Besides still lifes, he painted portraits, mainly of family members: in 1888, the year of Jenny's marriage to Floris, he made a life-sized painting of her as a bride, in intense colours and with rough brushstrokes. This portrait is seen as Menso's masterpiece. 'A remarkably superior example of colour without colourfulness, of style without pose, of harmony without monotony', commented Cornelis Veth.³³ 'Rather un-Dutch, at times worldly', wrote the critic Albert Plasschaert about Menso's work, which distinguished itself, in his view, by virtue of its 'verve and unusualness'.³⁴

From May until August 1890, Menso Kamerlingh Onnes and Floris Verster exhibited at the Lakenhal, in a show mounted to commemorate the opening of the Hartevelt Room. Their work was displayed alongside Hague School celebrities as well as newcomers such as Breitner, Van der Valk, Veth and Zilcken – selected by Menso and Floris themselves, who were in the exhibition committee. 'The Leiden exhibition sends up a cheer', wrote Willem du Tour in *De Amsterdammer*. Menso sold his watercolour *Flowers*.³⁵ No obstacle seemed to

³¹ *Nieuwe Rotterdamse Courant*, 7 April 1891.

³² Elsbeth R. Castelletti-Herfst, 'Floris Verster en Menso Kamerlingh Onnes: een artistieke ontmoeting in Leiden' (Leiden 1977) 12.

³³ Cornelis Veth, 'Menso Kamerlingh Onnes (1860-1925)', *Maandblad voor beeldende kunsten* 3 (1926) 197-204, esp. 201.

³⁴ Albert Plasschaert, *Floris Verster en zijn plaats te midden der schilders, geboren omstreeks 1860* (Amsterdam 1904) 12.

³⁵ Ankie de Jongh-Vermeulen, 'De presentatie van eigentijdse kunst in Leiden tussen 1890 en 1940', *Dageraad van de Moderne Kunst* (Leiden 1999) 93-116.

impede the two friends' path to a glorious career. And Verster did in fact achieve fame around this time; the monumental flower pieces he produced then have a 'melancholy beauty' that can still move us today.³⁶ That Menso has remained relatively unknown as a painter, in spite of his talents and command of technique, is largely attributable to his modest output after 1894. His weak health (which explains why he rarely produced landscapes) and his sudden affluence were contributory factors here, besides which much of his work remained within the family.

Menso's affluence came about through his marriage. Heike and Jenny also made advantageous unions. Heike was the first to marry: in September 1887 he was joined to Betsy Bijleveld, the eldest daughter of the procurator-general in The Hague. Betsy, eight years younger than Heike, had spent her childhood in Leiden, where her father had been a judge. When the district court was moved to The Hague in 1877, the Bijlevelds followed it. It was a prominent family³⁷ – Betsy's grandfather had also been a judge, and her mother grew up near Noordeinde Palace and played with the children of King William II.³⁸ Heike had met Betsy at the silver wedding of Samuel Rosenstein,³⁹ professor of medicine and pathology and a man of very outspoken opinions.⁴⁰ Heike knew Rosenstein from his student days in Groningen (Rosenstein had transferred to Leiden in 1873) and had consulted him at length in September 1882 concerning his brother Onno's illness and his trip to the Riviera.⁴¹ 'We danced together at Rosenstein's silver anniversary', Heike recalled his early acquaintance with Betsy or 'Bé': 'I happened to stop by to see Van Bemmelen when she was drinking tea there.' Van Bemmelen was Heike's neighbour when he first moved to Vreewijk.

The marriage was consecrated at the Kloosterkerk in The Hague by the Dutch Reformed minister Van den Kemp from the village of Spankeren, not far from the Onnes family's old home, 't Waerle'. The engaged couple had already travelled to Germany in the summers of 1886 and 1887; they had visited the Moselle and the Weimar of Goethe and Schiller. In a letter written to Van Bemmelen shortly before his marriage, Heike lost himself in rapt contemplation of his state: 'The pleasure of tasting an engagement is a privilege from which I had scarcely hoped to derive such enjoyment.' But wallowing in romance must not, of course, be allowed to get out of hand: 'I hope to be back

³⁶ Lien Heyting, 'Uitzinnige, wilde bloembossen', *NRC Handelsblad*, 13 December 2002, 8.

³⁷ Patriciaatsboekje 45 (1959).

³⁸ Information provided personally by Baroness G.A. Kamerlingh Onnes-Van Dedem.

³⁹ Van Itallie-Van Embden, 45.

⁴⁰ Otterspeer, *Wiekslag*, 285-288.

⁴¹ MB, Archives of Heike Kamerlingh Onnes, inv. no. 260.



Ill. 18. Heike and his bride Betsy Bijleveld, September 1887 (collection of Baroness Kamerlingh Onnes-Van Dedem).

in Leiden soon, then I'll be busy with my pumps from dusk to dawn; I am beginning to look forward to it.⁴²

Betsy's father had opposed the marriage, possibly because Heike was not well off. Over the first few years, Mother Bijleveld-Hartman would occasionally smuggle something extra to Leiden – Heike later built up cordial relations with his in-laws. On 5 July 1888 Betsy and Heike had a son, Albert Harm. It was a difficult delivery, and Betsy later had an ectopic pregnancy from which complications arose that prevented her from giving birth to any more children.

⁴² Heike Kamerlingh Onnes to Van Bemmelen, 27 July 1887, MB, archive 99.

Menso and Jenny had moved to a house in Herenstraat, on the outskirts of Vreewijk, before the wedding,⁴³ and it was probably in the attic of this new home that Menso and Floris produced their sparkling still lifes: here Menso painted his self-assured *Self-portrait with red beret*, and made portraits of Albert Harm, his mother and Jenny. And in the back garden, Floris painted his *View of Vreewijk*.

In 1891 Menso and Floris went their separate ways. For Menso, it was the year of his marriage. He too had won the heart of a highly eligible partner: Kitty Tutein Nolthenius, who came from a wealthy patrician family in Amsterdam. Her brothers Hugo and Jan knew Heike from his time in Delft, where both now had high positions at the Dutch Oil Factory (today's Calvé) owned by Van Marken. It was Onno, who also worked for Van Marken, who introduced Menso to the Tutein Nolthenius family. Julie, the eldest sister of Hugo and Jan, wanted a painting of her little daughter, and while Menso was making this portrait at the country estate of Adelsberg, he met Kitty.⁴⁴ The couple went to Tunis for their honeymoon, after which they moved into a mansion on Haagweg, which now lies within Leiden.

The last to marry was Jenny. She and Floris Verster married in 1892, and went to live at Groenoord, a country house at an idyllic location overlooking the canal Haarlemmer Trekvaart. They led a rather secluded life, associating only with relatives and with Albert Verwey in Noordwijk. Jenny made the arrangements for her husband's still life paintings – a task she had taken over from Menso – and devoted her creative energy to needlework: she designed and made doll's clothes and fashionable garments. After Floris had stopped working with Menso, he had abandoned watercolours. With increasingly exuberant flower still lifes, which had earned him a place among the leading ranks of the Dutch avant-garde, he had reached the limits of his artistic capabilities. He found himself in an impasse, and in 1891 Jenny wrote: 'He has a strong sense that something new is called for and he is desperately seeking it'.⁴⁵ At length, in 1893, Verster would surprise friend and foe with his symbolist, finely detailed pastel drawings.

As for Heike's mother, she moved in with Heike and Menso, her two sons in Leiden, spending six months of the year with each. Heike had been the last to leave Vreewijk, after Jenny's wedding, and moved his family to Stationsstraat, then in Oegstgeest – little Albert suffered from a serious disease that

⁴³ *Op. cit.* note 29.

⁴⁴ J. Nypels-Kamerlingh Onnes, *Jeugdberinneringen en familie verhalen* 28.

⁴⁵ Aleid Montens, 'Aantekeningen van Jenny Kamerlingh Onnes over Floris Verster', *Jong Holland* 2 (1986) 42–54, esp. 51.

made it essential to find a house that was less damp. Ten years after their relatively impoverished arrival in Leiden, the Kamerlingh Onnes family had little reason to complain. Even so, one dark shadow dimmed the matrimonial happiness and prosperity. On 12 December 1887, Heike's eldest brother, the inventor, suddenly fell ill while descending a mine in Aguas Calientes, Mexico, and died of heart failure. Six months later, when Heike's son was born, he was named Albert after his adventurous uncle.

11. ‘Door meten tot weten’: knowledge through measurement

‘The manifesto of modern experimental physics in the Netherlands’ – that is how one recent author has described the inaugural address with which Heike Kamerlingh Onnes, at just 29 years of age, accepted his first professorship at the University of Leiden on 11 November 1882.¹ Under the general heading of *The significance of quantitative research in physics*, he expounded on his vision of the field as a whole, the challenges he envisaged, and the programme he planned to pursue.

The period leading up to the inaugural address was very hectic. On 7 September, Onnes went to Leiden to discuss the transition with Rijke. His predecessor, who had recently been appointed to the Council of State, made no attempt to conceal his anger about the way his succession had been resolved. While courteously professing his high regard for Onnes’s character, he held that a ‘flagrant injustice’ had been perpetrated. Nonetheless, the two men got down to business: Rijke would clear his desk on 19 September, and 600 guilders remained of the physics laboratory’s 2,250 annual budget to get through the final quarter of the year. ‘I can’t say he was amicable’, replied Onnes when interior minister Pijnacker Hordijk asked him later that month how Rijke had received him. The rift was never healed. On Bosscha’s express advice, Onnes kept his predecessor in the dark about his plans with the laboratory, and the embittered Rijke did not even come to hear his successor’s inaugural address. In fact he never set foot in the physics laboratory again.² Onnes did visit Rijke at home once, in 1894, with a Dewar vessel of liquid oxygen under his arm.

Before looking at the Onnes’s address, some context will be helpful, regarding the status of physics at the time and its foundations. A good place to start is with the ideas of the physiologist and physicist Hermann von Helmholtz, who was appointed as professor of physics in Berlin in 1871 and who had previously worked alongside Kirchhoff and Bunsen in Heidelberg. Helmholtz

¹ Frans van Lunteren, ‘Van meten tot weten’, 126.

² P. van Geer, *De Nederlandsche Spectator* 49 (1904).

played a key role in the cultural life of Germany (and indeed Europe) in the latter half of the nineteenth century, not only with his countless academic discoveries – in fields as diverse as mathematics, medicine, psychology, physicochemistry and meteorology, and even painting and music – but also, and more importantly, through his dozens of popular lectures, which were published in book form. In these he expounded to a large public ranging from dignitaries to representatives of the German middle classes (both *Besitzbürgertum* and *Bildungsbürgertum*) the blessings of science and technology for modern society.³ Onnes was familiar with these lectures, and had quoted Helmholtz approvingly, on the importance of combining theory and experimental work, in the introduction to his dissertation.

In Helmholtz's view, physics revolved around the painstaking collection of experimental observations in conjunction with theory. Using the inductive method (arguing from the specific to the general), this could yield the immutable, objective laws of nature. Helmholtz wholly rejected the deductive approach pursued by Romantic natural philosophers such as Schelling, Goethe and Hegel, who saw the world not in mechanical terms but as a living, pulsating organic whole, and who hoped to restore the lost unity of mind and nature by purely intuitive, speculative means.⁴ He believed that actual laws of nature such as the law of conservation of energy and Darwin's theory of evolution (1859) held out the prospect of clarifying the all-embracing structure of the natural world and the deep causes of natural phenomena.⁵ Like Gustav Kirchhoff, Helmholtz set himself the task of 'describing the movements in the natural world, and doing so in full and in the simplest possible way'.⁶

Helmholtz was driven by the desire to expand and apply scientific knowledge. Science was also seen as an instrument to be used for the benefit of the state. As the first director of the Physicotechnical Institute, founded in Charlottenburg (near Berlin) in 1888 in collaboration with German industry, he was involved in the development of high-precision instruments and establishing electrical standards. Still, Helmholtz was no technocrat: the further development of political, legal and ethical knowledge, and in their wake historiography

³ Hermann von Helmholtz, *Vorträge und Rede* (Braunschweig 1903). An English translation of these lectures, with an introduction by the American science historian David Cahan, was published in 1995 as *Science and Culture: Popular and Philosophical Essays* (Chicago 1995).

⁴ H.A.M. Snelders, *Wetenschap en intuïtie: het Duitse romantisch-speculatief natuuronderzoek rond 1800* (Baarn 1994) provides a good introduction (in Dutch) to the 'natural philosophy' of the German Romantics.

⁵ David Cahan, 'Helmholtz and the civilizing power of science', *Hermann von Helmholtz and the foundations of nineteenth-century science* (Berkeley 1993) 559-601.

⁶ G. Kirchhoff, *Vorlesungen über mathematischen Physik. Mechanik* (Leipzig 1876), Preface.

and philology, were also essential in his view. All such learning could help build up the still young German nation.

Helmholtz considered the emphasis on research in the German academic system superior to the French and British reliance on teaching. State grants for well-equipped laboratories helped German research to flourish, without restricting the intellectual freedom of those concerned. One disadvantage of this system, however, was the risk that specialist researchers might lose contact with their neo-humanist colleagues within academia, a risk that Helmholtz hoped to diminish with his popular lectures. He gave these lectures with a view to educating society's elite, which, if receptive to the glad tidings of science, could bring prosperity, social harmony and political unity to German society. That science might also encounter intolerance and socio-cultural narrow-mindedness in the hierarchical, authoritarian German academic system did not occur to Helmholtz.⁷

As for attitudes among the general public, a certain aversion to science was not uncommon in this period, according to the British writer and critic George Henry Lewes, the partner of George Eliot (Mary Ann Evans). In his essay, 'On the dread and dislike of science' which appeared in the *Fortnightly Review* of 1 June 1878, Lewes delivered a stinging attack on the public's failure to appreciate the importance of science – an article that so impressed Onnes that he made and kept a summary of it.⁸ Lewes, an adherent of the positivism of the French philosopher Auguste Comte (who held that speculation and metaphysics were obsolete in science, and that knowledge arose from observations, hypotheses and experiments), made no bones about his position:

'In the struggle of life with the facts of existence, Science is a bringer of aid; in the struggle of the soul with the mystery of existence, Science is a bringer of light. As doctrine and discipline its beneficence is far-reaching. Yet this latest-born of the three great agents of civilisation – Religion, Common-Sense, and Science – is so little appreciated by the world at large that even men of culture may still be found who boast of their indifference to it, while others regard it with a vague dread which expresses itself in a dislike, sometimes sharpened into hatred.'⁹

While science was more popular among the general public than ever before, wrote Lewes, it was also subject to prejudice and misapprehensions. And why? Because the public completely failed to grasp what science involved:

⁷ *Op. cit.* note 5, 600-601.

⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 287.

⁹ George Henry Lewes, 'On the dread and dislike of science', *The Fortnightly Review* 23 (1878) 805.

‘No rational being dreads and dislikes Knowledge. No one proclaims the superiority of Ignorance as a guide of conduct. Yet Science is simply Knowledge classified, systematised, made orderly, impersonal and exact, instead of being left unclassified, fragmentary, personal and inexact. Auguste Comte calls it “Common-Sense methodised and extended.”’

Inexact knowledge existed in abundance, Lewes continued, and much exact knowledge was non-methodical.

‘There is plenty of experience, which is personal and incapable of being communicated to others. Wanting the illumination of many minds, this store cannot do the work of Science, which is the experience of many enlarging the experience of each. If there is immense benefit in knowing what are the facts and the order of the physical world in which we live, and of the social world in which our higher life is lived, there is clearly a great advantage that this knowledge should be made orderly and communicable; and the dread of such an arrangement of knowledge is obviously irrational. Thus enlightened, we recognise in Science the deliberate effort to reduce the chaos of sensible experiences within the orderliness of ideal constructions, condensing multitudes of facts into simple laws – an effort which the Intellect acknowledges as a supreme duty, and which Conduct acknowledges as a guide.’¹⁰

Human beings have an inbuilt tendency to rebel against science, Lewes observed. Science is abstract, impersonal and systematic, while people naturally incline to what is concrete and personal; they would rather guess at something than make accurate observations. Precision arouses irritation. Science is all very well as long as one does not start claiming that the results achieved on one occasion will be valid elsewhere. Chemists who start talking about art and physicists who pronounce on moral issues are exceeding their authority. The notion that everything can be explained from mechanical principles must be rejected. ‘Nature is not mechanical only.’ Scientists might say that nature always punishes the weak (the impact of Darwin’s ‘survival of the fittest’ had been enormous), but anyone who tried to apply such views to society, without taking ethical considerations into account, could be sure of encountering fierce opposition. Rightly so, added Lewes, but that did not alter the fact that science was first and foremost a method – a method applicable to all kinds of knowledge.

Where the relationship between science and religion was concerned – another thorny issue – Lewes was convinced that as science advanced and the reservoir of exact knowledge grew larger, supernatural explanations would gradually lose ground. Some endured for the time being – but only in those areas in which scientific research was still in its infancy.

¹⁰ *Ibid.*, 806-807.

‘When Science has fairly mastered the principles of moral relations, all Knowledge will be incorporated in a homogeneous doctrine rivalling that of the old theologies in its comprehensiveness, and surpassing it in the authority of its credentials. “Christian Ethics” will then no longer mean Ethics founded on the principles of Christian Theology, but on the principles expressing the social relations and duties of man in Christianised society. Then, and not till then, will the conflict between Theology and Science finally cease; then, and not till then, will the dread and dislike of Science disappear.’¹¹

In mid-September 1882, against this background of Helmholtz’s optimistic public education campaign and Lewes’s self-assured admonitions – but without explicitly mentioning any of these ideas – Heike Kamerlingh Onnes set about writing his inaugural address. He planned to give it on or around 1 November. In the meantime, he planned to make a tour of the physics laboratories of Berlin, Würzburg and Strasbourg to gain some ideas for Leiden. This plan fell through, however, when his brother Onno suddenly developed a lung disease and had to be rushed abroad to a more wholesome climate; as head of the family, Heike spent the entire month of September making the necessary arrangements. ‘I am toiling over my speech’, he wrote to Menso on 4 October. ‘It is a dismal task having to knock together a piece like this, and all the worrying business with Onno has scarcely increased my capacity for work, so that I’m now actually rather pressed for time.’¹² On 9 October Onnes read out his first draft to Bosscha. Two days later he read it to Lorentz, and a week later to Van Bemmelen, who said that he could not follow the train of thought. By Saturday 11 November, after he and Lorentz had ‘tidied up’ the text, the newly-appointed professor of experimental physics finally presented himself at the university building on Rapenburg – if a little nervous – to give his address. It had been a long time coming, but the text was well-structured and impressed the audience.

‘Esteemed listeners!’ began Onnes in the Great Hall at 2 p.m.,¹³ before launching into a public profession of his core beliefs by way of a preface to his address on the significance of quantitative research:

‘Physics owes its success in the production of means to foster material well-being and its powerful influence on our world view to the pure spirit of experimental

¹¹ *Ibid.*, 815.

¹² Heike to Menso, 4 October 1882, coll. De Knecht.

¹³ Heike Kamerlingh Onnes, *De betekenis van het quantitatief onderzoek in de natuurkunde* (Leiden 1882). For an English translation see: Arno Laesecke, ‘Through Measurement to knowledge: the inaugural lecture of Heike Kamerlingh Onnes (1882)’. *Journal of Research of the National Bureau of Standards and Technology* 107 (2002): 261–277.

philosophy. It can only retain its significant role in the work and thought of present-day society if it continues, by observation and experiment, steadily to win ground from the unknown.¹⁴

Onnes then recited a refrain that he would repeat at intervals for over forty years: a lament on the lack of resources.

‘The number of institutions – and more to the point the sum of their resources – that provide it [physics] with the opportunities it needs [to win ground from the unknown], however, in no way reflects the great importance of these institutions to the public interest that they serve. Anyone who takes upon himself the momentous task of educating students to practise physics, and of overseeing one of these institutions, must therefore examine with redoubled seriousness his views on the demands of empirical research in our times.’¹⁵

After which Onnes came to the crux of his address, compressed into the most famous maxim in the history of Dutch physics:

‘In his labours and efforts, he may be driven by no other incentive than a poetic thirst for truth; his goal may be to fathom the nature of things; yet he cannot derive the courage to accept an office that will provide him with an opportunity to do so from anything other than the firm belief that he can make himself useful by holding to certain principles.’

It is my view that in the practice of experimental physics, an emphasis on *quantitative research*, that is, the quest for quantitative relationships between phenomena, must stand in the foreground.

“Knowledge through measurement” is the maxim I would wish to write on the wall of every physics laboratory.¹⁶

‘The paths that have led great minds to truth are frequently inscrutable’, Onnes continued. ‘They behold its light with the inspiration of an artist, create the questions that entire generations of observers and mathematicians can labour to solve, and design the foundations from which the edifice of science will rise.’ Not everyone can be an architect, he added, but it would be a great thing if many could help to consolidate the structure. ‘And for one who has developed sound judgment, a practised hand and a mature character, there remains the satisfaction of helping to complete the grand creation of the likes of Newton and Huygens, Volta and Fresnel, Faraday and Kirchhoff’ – men who had set an example with their quantitative research, choosing a path ‘far from jack’o-lanterns, where labour is certainly not lost’.

¹⁴ *Ibid.*, 5.

¹⁵ *Ibid.*, 5.

¹⁶ *Ibid.*, 6-7.

Onnes set out three ways in which quantitative research could prove useful. The first was exemplified by experiments with free fall, for instance, which had resulted in a law giving the relationship between movement and time. Observed numerical values could be used to demonstrate connections between different phenomena, revealing an unexpected cohesiveness. An experiment could reveal how one variable was converted into another: by drilling through a cannon barrel, Count Rumford had discovered that the work done was equal to the heat generated. Numbers were important. Had not Mayer, who had failed to provide any quantitative corroboration for his reflections on the First Law of Thermodynamics, long been reviled?

Presenting phenomena in a measurable form – that was what experimental physics was about. Sometimes this was childishly simple, and sometimes it was a hellish conundrum. ‘However, our ingenuity should never abandon a phenomenon until it has been purified, simplified and combined with others to such an extent that the link between cause and effect has been illuminated in measurable quantities.’ As examples, Onnes cited the work of Volta and Coulomb in electricity, while the mathematicians Gauss, Poisson and Green had formulated the concept of potential, a ‘tangible variable’ that then proved susceptible to measurement, thanks to Thomson’s sensitive electrometer.

And this brought Onnes to the nature of the fertile relationship between physics and mathematics. ‘They support and nourish each other’, he emphasised. ‘So intimately are they entwined that it would be pointless to ask which one takes precedence.’ This was a commonplace among modern German physicists – and a view that Rijke abhorred.

But the importance of quantitative experiments went beyond the measurements themselves. The second benefit to be gained from quantitative research was that its results served as the basis for developing new instruments, that could in turn help to explain other effects. Here Onnes mentioned the example of the discovery of thermoelectricity: the phenomenon that when a temperature difference exists between two different metals, contact between them generates an electric current. The Italian Macedonio Melloni subsequently invented the differential thermopile, an instrument that enabled him to demonstrate that thermal radiation, like light, consists of electromagnetic waves. And in his measurements of geomagnetism, Carl Friedrich Gauss hit upon the brilliant idea of fitting a little mirror to the magnet and measuring its rotation accurately by following the movements of the mirror image through a viewer.

Thirdly, quantitative research guided the choice of a practical system of units. At a Paris conference held a few weeks before Onnes’s inaugural address, Wilhelm Weber had presided over the introduction of the ‘absolute electromagnetic measurement system’, which added the ohm (unit of resistance) and farad (unit of capacitance) to the meter, second and kilogram. The

establishment of international standards relied on accurate measurements, with the work being divided among different laboratories. Onnes's measurements of resistance in Delft may have had something to do with Bosscha's position as the Netherlands' primary exponent at international metrological conferences.

Quantitative research in physics thus bore fruit in three different ways: in the form of laws, instruments, and standards. But would this great significance, Onnes asked himself, continue to apply in the foreseeable future? After posing this clearly rhetorical question, the new professor went on to unfold his ambitious programme for the future. He would tackle 'the only new direction in physics research that can be identified at this moment in time': fathoming the essence of molecules and explaining physical properties in terms of the structure, combination and movement of molecules.

'Solving this problem involves numerous difficulties, because we cannot penetrate the molecule itself. But given the composite nature of the laws that determine the relationship between physical properties and the nature and movement of molecules, we may call it a significant advance if we succeed in formulating laws of approximation.'¹⁷

It was the measurement in diverse conditions of the properties of substances, such as their density, coefficient of expansion, coefficient of friction, refractive index, conductivity, and so on, that must pave the way to these laws of approximation, whereby 'molecular physics' had the specific task of examining the resulting laws of approximation in the light of increasingly accurate findings. Just as Kepler's law had approximated the elliptical orbits described by the planets, and the determination of deviations in the orbit of Uranus had been used to predict the existence of Neptune, in molecular physics too, the study of deviations from successive laws of approximation could prove to be a source of new discoveries.

Onnes illustrated this argument with Van der Waals's equation of state and law of corresponding states. The former was based on the volume of molecules and the mutual attraction between them, while the latter derived from the 'equivalence' of their movements – as Onnes himself had demonstrated in his *General theory of liquids* (1881). Physicists should be pleased with laws of approximation such as that of Van der Waals: they gave a 'fresh impulse to quantitative research'. And the law of corresponding states would produce a complete reversal in relation to the determination of physical constants, resulting in more widely applicable laws of approximation, with the added detail that

¹⁷ *Ibid.*, 25.

every deviation yielded a 'hint' that advanced the research into the essence of molecules. Since every improvement in the laws of approximation would make these deviations smaller, the measuring apparatus would have to be more and more accurate. At this point, Onnes gave his audience a prophetic insight into the part his physics laboratory would play in all these developments:

'On the one hand, this will make the pumps designed by Cailletet and Pictet [two pioneers in the field of low temperatures] indispensable, and on the other hand, part of the laboratory [relating to the emphasis on accurate measurement] will be equipped, just as an observatory, with instruments whose properties are known and recorded in registers down to the smallest detail, and rooms in which such equipment may be used to best effect.'¹⁸

Then, after briefly emphasising the importance of cooperation between physics and chemistry, Onnes sounded the final chord of his address. Quantitative research, he stated boldly, deserved to be given pride of place in the laboratory, since he believed 'processing the findings arising from experiments conducted with superlative accuracy to be the best training for those who aspire to be physicists in the true sense of the word.' The 'mere observation of a phenomena in accordance with certain precepts', he added, had something 'unsatisfying' about it.

'In the accuracy of the findings, quantitative research holds out the possibility of verification, so that one may regard the fruits of one's labours with satisfaction. What it calls for, more than anything else, is a clear notion of the variables one wishes to measure. The desire to achieve the utmost accuracy with the equipment at one's disposal inculcates a sense of efficiency and compels researchers to be meticulous and tenacious. Only by applying self-criticism and method can results be achieved that one may view with confidence. And through the comprehensiveness with which one must take account of every phenomenon in conducting quantitative research, many will develop an eye for observing *new* phenomena.'¹⁹

Hendrik Casimir, who went to Leiden to study physics in 1926, shortly after Onnes's death, would later write in his autobiography, *Haphazard Reality*, that the maxim 'knowledge through measurement' did a great deal of harm. 'Qualitative observation has to precede quantitative measurement', wrote Casimir, and: 'by making experimental arrangements for quantitative measurements we may even eliminate the possibility of new phenomena appearing.'²⁰ Onnes

¹⁸ *Ibid.*, 32.

¹⁹ *Ibid.*, 35.

²⁰ H.B.G. Casimir, *Haphazard reality* (New York 1983), 161.

(whom Casimir described, for the rest, as ‘too good a physicist to adhere rigorously to his own narrow-minded precepts,²¹) clearly thought otherwise.

Onnes concluded his address by paying tribute to the ‘great masters’:

‘But research must excel in thoroughness just as much as in originality. And this thoroughness will be fostered if the great masters are studied as much as is necessary to successfully duplicate their findings. Thus physics too has its great masters, the study of whose work is an ever-fresh source of new insight and inspiration for scholarly work. They teach us that we must follow phenomena to the outermost limits of science. In contrast to the trend that is discernible in a good many contemporary scientific essays, whose authors seem eager to link their names to as many phenomena as possible, I would thus wish to develop a sense of scientific obligation, based on that of the “great masters”, that calls for thorough, comprehensive research.’²²

Onnes then expressed the customary words of gratitude. He thanked the board of governors for having vested confidence in him. But he did not expect this body to support him in procuring his ideal, namely of ensuring that the Netherlands had ‘at least one first-rate physics laboratory’, which Onnes wished to name after Huygens, ‘as a long overdue tribute from the people who may number him, Newton’s peer, among its greatest sons’. Instead, Onnes hoped to extract such support from a private sponsor, someone like Johns Hopkins in Baltimore or the Duke of Devonshire in Cambridge; the possibility of obtaining state support on the scale provided in Germany never even occurred to him. But first, the scientific standard of physics at Leiden would have to be improved, and in the meantime the board of governors’ financial support was crucial. ‘I would ask the board not to deny me that support.’

Finally, Onnes turned to the students, and told them what he hoped to achieve with his teaching.

‘Universities should be the breeding-grounds of efforts to attain the ideal. The youth who are the hopes of the nation are entrusted to it, not merely to be equipped with the kind of knowledge that any social organism needs to exist and to work, but more importantly to ensure that they will disseminate among the people that spirited enthusiasm for noble pursuits that is the vital basis of a strong national consciousness. Do not withhold your cooperation, when, in nurturing zeal for scientific research more than in presenting findings, I endeavour to play my part in making the advancement of science a matter of public concern.’²³

²¹ *Ibid.*, 161.

²² Kamerlingh Onnes, *De beteeckenis*, 35–36.

²³ *Ibid.*, 40.

Looking at Onnes's address as a whole, the key position he accorded to physics research is noteworthy. This was quite new. Anyone who peruses the inaugural speeches of Dutch physics professors before Kamerlingh Onnes will be struck by the fact that they scarcely ever focus narrowly on physics research.²⁴ Van Rees (Utrecht, 1838) presented a portrait of the physician Bleuland, Rijke (Leiden, 1845) discussed his predecessor Uijlenbroek, Buys Ballot (Utrecht, 1846) spoke on 'the need for the versatile pursuit of science' and Mees (Groningen, 1868) entitled his inaugural address, 'science education as an essential part of civilised education'. Physics was always identified with science in general and its educational value. Onnes's predecessors felt themselves to be not so much physicists as professors, who had been entrusted with the task of educating students to be the guardians of the nation's well-being. From this point of view, conducting independent research was not a priority; what mattered was teaching.²⁵

Thus science, in the view of Onnes's predecessors, stood for enlightenment and civilisation. Truth was equal to good; scientific knowledge possessed moral value, and led to a civilised social order. The Utrecht zoologist Pieter Harting, who retired in 1882, had nothing good to say about the specialists being turned out by the German universities. 'They remain masons and never become architects', he wrote in 1858, and twenty-five years later he still felt the same way.²⁶

The emergence of a research ethos in the Netherlands took place in the last quarter of the nineteenth century. Lorentz was the first to dwell at length on specialised physics research when he gave his inaugural address *The molecular theories in physics* in January 1878, having been appointed professor of mathematical physics at Leiden. He too would 'consider himself fortunate' if he could offer his students an opportunity to perform 'their own scientific work'.²⁷ Lorentz saw it as his task to deliver physicists who had specialised in research, not men to lead the nation. This research was not an exercise in *l'art pour l'art*; rather, it provided knowledge to drive the engine of social progress. In Lorentz's view, the benefits of science were not so much moral as practical – although the road to concrete applications was sometimes very long. With Lorentz a generation of physicists arrived at the front who had been educated at the new HBS type of secondary school. This led to a shift in social background among the

²⁴ *Op. cit.* note 1, 114–115.

²⁵ Bert Theunissen, '*Nut en nog eens nut*'; *Wetenschapsbeelden van Nederlandse natuuronderzoekers 1800-1900* (Hilversum 2000).

²⁶ *Ibid.*, 57–79.

²⁷ H.A. Lorentz, 'De moleculaire theorieën in de natuurkunde', *Collected papers* 9 (The Hague 1939) 21.

body of professors: it was no longer the established intelligentsia (the ‘scholarly class’) but the middle classes that set the tone. It may be this, combined with the superbly equipped laboratories that had nourished the HBS students’ scientific curiosity, that gave rise to their different view of science.²⁸

The rise of the middle classes, engendered by the changing economy, influenced the intellectual climate. Belief in scientism – the notion that scientific methods should be applied freely in other areas of life – was widespread (although there were also groups opposing it) and the appearances and conventions of an immobile society of estates were vanishing in favour of a highly dynamic, achievement-oriented society.²⁹ In this climate, pioneers such as Lorentz, Kapteyn, Van der Waals, Van ’t Hoff, De Vries and Kamerlingh Onnes seized their opportunity. They had little in common with their predecessors, who had been idealistic ‘educators of the people’ and purveyors of general culture. Their favourite place was on the cutting edge of research, a place unattainable for the uninitiated, which constantly shifted according to its own autonomous developments. The modern researcher was both a professional and a specialist.

Drinks were served in the Senate chamber after the inaugural address, and Lorentz proposed a ‘hearty, heartfelt toast’ to Heike’s advocacy of ‘other principles besides knowledge through measurement’. The friends who came to congratulate the new professor included Mr and Mrs Bosscha, Haga, Legebeke, Snijders, Kerckhoff (all from Delft), Onnes’s student friend Mensinga, Korteweg, Van de Sande Bakhuyzen, Lorentz, and Mr and Mrs Van Bemmelen.³⁰ His family was represented only by his sister Jenny: his mother, Onno and Menso were in Italy, Albert was in the East Indies, and Adolf was in Groningen. This was regrettable, but it did not spoil the atmosphere. Onnes had given a splendid address; he had taken the plunge. On Tuesday, he would start lecturing to advanced students on practical laboratory work. For the time being, his duties would be confined to teaching.

²⁸ *Op. cit.* note 1, 134–135.

²⁹ A.J.P. Maas, *Atomisme en individualisme. De Amsterdamse natuurkunde tussen 1877 en 1940* (Hilversum 2001) 13–24; Bastiaan Willink, *Burgerlijke sciëntisme en wetenschappelijk toponderzoek. Sociale grondslagen van nationale bloeiperioden in de negentiende-eeuwse bètawetenschappen* (Rotterdam 1988).

³⁰ MB, archives of Heike Kamerlingh Onnes, inv. no. 260.

12. Monstrosity gets a face-lift

A ‘monstrum horribile visu’ was the chronicler’s verdict of Leiden’s 1860 Student Almanac on the brand-new building for the chemistry, physics, anatomy and physiology departments. At the Steenschuur site known as the ‘Kleine Ruïne’ (Small Ruin) which had remained an open wound since the calamitous explosion of a gunpowder ship there in 1807, a laboratory had been built for 115,767 guilders (the minister having vetoed the initial budget proposal of 200,000 guilders) in an eclectic style based on a design by the king’s architect, Henri Camp.¹ Its festive opening on 20 October 1859 prompted a wide range of opinions on the new building’s aesthetic qualities. A book on the city published in instalments in this period (*De Stad Leiden*) commended its wide corridors and elegant staircases and wrote that everything had been built solidly and on a grand scale, paying special attention to light and air. It also admired the ‘beautiful’ fence around the building.²

The students took a different view. ‘Monstrously ugly’ was the Almanac’s view of the ‘humble façade and... the absurd, hybrid, bulbous rear section’.³ And ‘hardly intelligent – renovations had to be carried out even before the building was finished to protect the physics apparatus from the draught.’ Nonetheless, the chronicler for the academic year 1858-1859 was ready to accept that the building fulfilled the requirements: ‘After all the words of praise that the board of governors, professors and even students have lavished on this new facility, we are obliged to conclude that it is efficient and meets a great need’⁴. The following year, the Almanac revised this assessment too. ‘Has the [physics] building fulfilled in all respects the expectations that were cherished at its inauguration? The majority view is that it has not.’⁵ While the new laboratory

¹ Otterspeer, *Wiekslag*, 122.

² W.P. Jorissen, *Het chemisch (thans anorganisch chemisch) laboratorium der universiteit te Leiden van 1859-1909* (Leiden 1909) 3-4.

³ *Leidsche Studenten-Almanak* 1860, 163.

⁴ *Ibid.*

⁵ *Leidsche Studenten-Almanak* 1861, 239.



Ill. 19. The Steenschuur laboratory shortly after its completion in 1859. The physics department occupied the right wing, chemistry the left, and anatomy the rear section (Academisch Historisch Museum, Leiden).

contained more space, the arrangements for practical laboratory work were wholly unsatisfactory.

The building soon proved to be too small. The situation was improved in 1867, when physiology acquired separate premises on Zonneveldsteeg, immediately behind the Steenschuur complex. After this, a new wing was built for anatomy at right angles to the back section – putting paid to the ‘bulbous’ rear façade. From then on, only physics and chemistry had to share the main building. In the immediate surroundings, on the corner of Nieuwsteeg and Zonneveldsteeg, was an ice cellar administered by the physics department.

Leiden had acquired its first physics laboratory in 1675, when the philosophy professor Burchard de Volder (1643-1709) gained the board of governors’ consent to equip a small building in Nonnensteeg, next to the Botanical Gardens, as a *Theatrum Physicum* or ‘physics theatre’.⁶ De Volder had visited

⁶ Peter de Clercq, *The Leiden Cabinet of Physics* (Leiden 1989).

the Royal Society in London the year before, and had been so impressed by Robert Boyle's vacuum pump experiments that he decided to introduce the empirical method as part of the curriculum in Leiden – the first to do so in the Netherlands (a few universities elsewhere in Europe had already taken this step).⁷ In the first five years, De Volder spent 2,500 guilders on instruments for experiments to demonstrate 'the truth and certainty of the propositions and doctrines that were presented to the students'. He was fortunate enough to find an extremely able instrument-maker in the Leiden brass-founder Samuel van Musschenbroek (1648-1681).

In 1742 the Physics Laboratory in Leiden suddenly became the repository of the largest collection of instruments in the world when the board of governors purchased the magnificent private collection of Willem Jacob 's Gravesande, who had died earlier that year. Professor 's Gravesande had taught classes for years at his own home on Rapenburg – Voltaire was among those who attended them – where he propagated Newtonian theory on the basis of experiments. He included reports of many of these experiments in his textbook *Mathematical Elements of Natural Philosophy, Confirm'd by Experiments, or Introduction to Newtonian Philosophy*, which achieved international success, bringing the instrument-maker Jan van Musschenbroek (a cousin of Samuel's) a mountain of work. When the 's Gravesande collection was transferred to the Physics Laboratory, it caused a severe lack of space. To give the larger collection the decent storage space it deserved, the 'cramped and musty little instrument room' in Nonnensteeg was expanded with the addition of the small house nest door.

As the nineteenth century drew on, Leiden's physics laboratory failed to keep up with the latest developments. No outstanding professors had been appointed since 's Gravesande and Petrus van Musschenbroek (Jan's brother). And the main arena of scientific progress had shifted away from the universities in the latter half of the eighteenth century to societies such as the Holland Society of Sciences and the Teylers Foundation (both in Haarlem) and the Batavian Society for Experimental Philosophy in Rotterdam.

In 1824 the Physics Instruments Collection, as it was now called, had been moved to new premises on the corner of Papengracht and Houtstraat (now part of the National Museum of Antiquities). This location too was far from ideal. When Rijke had been making do there for a year in 1846, he complained to the Board of Governors that even second-rate institutes had better facilities.⁸ 'Much of the time', said Rijke, 'lecturers are unable to see the movements

⁷ Gerhard Wiesenfeldt, *Leerer Raum in Minervas Haus. Experimentelle Naturlehre an der Universität Leiden, 1675-1715* (Amsterdam 2002) 66-67.

⁸ Otterspeer, *Wiekslag*, 121.

taking place in the apparatus, and have to find out what is happening by asking their students, who can only give a sufficiently precise answer in clear weather.’

‘When dealing with the subject of heat, material frequently has to be heated over a naked flame. But the lack of a chimney-piece renders this almost impossible. This past winter I was compelled on a number of occasions to teach with the windows open, and even this was not a solution when the combustion of charcoal needed to be sustained for a considerable time, since although I took the added precaution of standing in a draught between windows on opposite sides of the room both before and after the lecture, the fumes greatly undermined my health. The hazards attached to working with electricity will be apparent to anyone who is acquainted with the size of the instruments required and the limitations of the space.’⁹

But it was the complaints made about Van der Boon Mesch’s chemistry laboratory that finally spurred the board of governors into action.¹⁰ On 13 February 1851, twenty-one residents of Leiden, including several manufacturers, complained that the space was far too small for those wishing to attend the chemist’s lectures. ‘A great many of those present’, they wrote, ‘are hemmed in by the crowd or so far away that they are unable to see the experiments and examples that help so greatly to clarify what has been said, so that the applications are quite lost on them.’¹¹ Students too protested: they considered the chemistry laboratory unsuitable for conducting practical experiments, and made their views known in two separate letters.¹² These students included the later professors A.C. Oudemans, J.M. van Bemmelen, J. Bosscha and R.S.T. Modderman. The board of governors could hardly turn a deaf ear to such protests, and in response they commissioned the new Steenschuur complex.

Rigorous renovation

When Heike Kamerlingh Onnes took over the physics laboratory from Rijke on 19 September 1882, it had scarcely changed since its opening in 1859. Entering the building through the side entrance of the north wing, opposite the premises of the Society for the Promotion of the Public Good, one arrived in a small hall with stairwell (see floor plan).¹³ The first floor accommodated the collection of precious instruments – Rijke remarked proudly in 1879 that his

⁹ Rijke to *curatoren*, 14 April 1846, UB Leiden, Archief Curatoren II, inv. no. 105, appendix 78.

¹⁰ Otterspeer, *Wiekslag*, 121-122.

¹¹ UB Leiden, Archief Curatoren II, inv. no. 115, appendix 26, 13 February 1851.

¹² UB Leiden, Archief Curatoren II, inv. No. 115, appendix 27 and inv. no. 116, appendix 20.

¹³ *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de jaren 1882-1904* (Leiden 1904) 11-12.

old things 'are just as serviceable now as when 's Gravesande first gained possession of them a century and a half ago.'¹⁴ Fuel was stored in the basement, which also contained a small workshop. To the left of the hall was the professors' staffroom (A) and to its right the weighing room. Behind these were two workrooms each measuring 8 × 6 metres (C/D and E) for students who performed experiments under the supervision of laboratory assistant Sissingh, the lecture hall (F/G), which was twice that size, and the professor's private study (H).

As soon as Onnes had taken stock of the laboratory, he realised that only a rigorous renovation could salvage his plans. The building might well have been adequate when Rijke moved in, but by now everything was hopelessly out of date. 'Since then ... stagnation has meant decline,' Onnes declared to the board of governors on 1 April 1884 when he came to justify his renovation plans, 'to such an extent that the laboratory now actually lags far behind those of Delft's Polytechnic and the Municipal University of Amsterdam.'

A month after his arrival, in November 1882, Onnes had asked Van der Waals to send him his plans for a new laboratory in Amsterdam, to increase the pressure on the board of governors.¹⁵ After a strenuous tug-of-war with a recalcitrant city council,¹⁶ Van der Waals was at length able to move into new premises on Plantage Muidergracht, in 1883 (price ticket: 90,000 guilders). The building had separate laboratories for research on magnetism, static and galvanic electricity (direct current), light, sound and heat.¹⁷ Nothing even remotely resembling such facilities existed in Leiden. Anyone comparing the Steenschuur building with comparable foreign institutes, Onnes summarised, would be forced to conclude that it was in a 'dilapidated state'.¹⁸

Still, Onnes was not one to give in to despondency; instead, in anticipation of the renovation work, he set about planning an internal reorganisation. The first people to discover that the new professor – and laboratory director – had views radically different from those of his predecessor were the staff. On 13 November 1882, the Monday after Onnes's inaugural address, the mechanic C.W. Kouw (whose previous job title had been 'custodian') and laboratory assistant G. Veere were informed that they would henceforth be working a ten-hour day. What is more, Kouw and his helper Sissingh would keep records of all their activities in a logbook.¹⁹ On the Sunday after this, Onnes notified

¹⁴ P.L. Rijke, 'Levensschets van Willem Jacob 's Gravesande', *Album der Natuur*, 1879, 76.

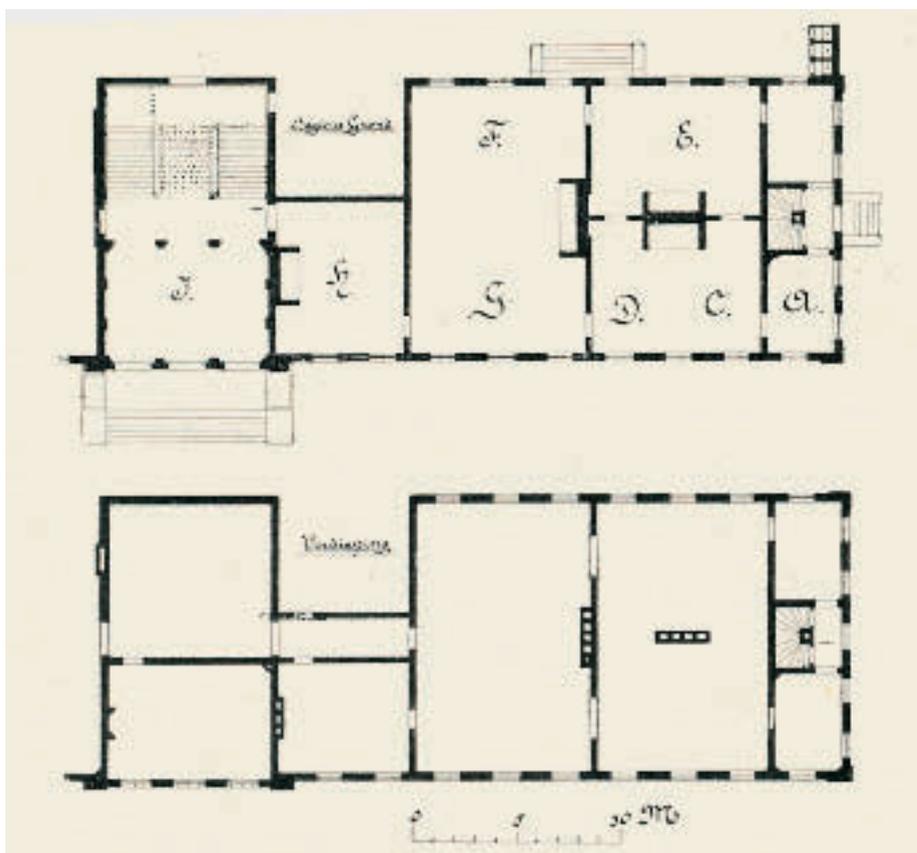
¹⁵ Heike Kamerlingh Onnes to Van der Waals, 6 December 1882 (draft), UB Leiden, archives Stationsweg.

¹⁶ Maas, *Atomisme en individualisme*, 40–42.

¹⁷ *Ibid.*, 47.

¹⁸ Heike Kamerlingh Onnes to *curatoren*, 1 April 1884, UB Leiden, Archief Curatoren, inv. no. 36.

¹⁹ MB, archives of Heike Kamerlingh Onnes, inv. no. 260.



Ill. 20. Plan of the Physics Laboratory at the beginning of Heike's professorship in 1882. The first stage of conversion into a research laboratory started in 1883.

the board of governors that he would be needing a 'special grant' of 1,724 guilders to equip Kouw with a fine and a coarse lathe as well as diverse other instruments and devices.²⁰ It was customary to submit petitions of this kind in the annual budget, presented on 1 May, but Onnes considered this request to be of such 'fundamental importance' that it could not wait.

Without pausing in his stride, Onnes went on to request an increase in the sum allocated for the purchase and maintenance of instruments and other equipment in 1883 from 1,340 (the sum requested by Rijke himself) to 2,500 guilders.

²⁰ Heike Kamerlingh Onnes to *curatoren*, Museum Boerhaave, 19 November 1882, UB Leiden, Archief Curatoren, inv. no. 1655.

Only then could Leiden's physics laboratory maintain its current 'modest position': that of 'meeting the moderate demands of a lesser university'. As things stood, the total subsidy was far less than that allocated to chemistry, where the inorganic chemist Van Bemmelen received 3,000 guilders and the organic chemist Franchimont 5,000. And this discrepancy had persisted even though recent advances in physics had been 'every bit as noteworthy' as those in chemistry. 'As a result, even under the meticulous management of Professor Rijke,' wrote Onnes diplomatically, 'highly important lines of research were perforce neglected.'

The case of Kouw – who had assisted Rijke in his research and in preparing experiments for lectures – was in itself remarkable. When Onnes asked him what instruments he had made in the seven years that he had been working there, all he had to show for himself was 'a fairly unremarkable commutator and a few stands'. But as soon as Onnes set his mechanic to work (with the consent of his colleague Van de Sande Bakhuyzen) in the astronomy workshop, where Kouw's brother worked as an instrument-maker, he produced – within just a few days – an adjustable table on which to set up experiments. If the man were given good tools to work with, it would boost his value to the laboratory enormously.

The governors demurred. It was not unexpected for the new professor to present a list of demands, but this was all 'rather precipitous'. Rijke had never asked for those two lathes, complained one of the governors (Kist) in an internal memorandum, and besides, 6,000 guilders would shortly be requested for the observatory, just when parliament wanted to make cuts. The official reaction was that the board of governors looked favourably on Onnes's requests, but since the Minister would not increase a budget when it had already been put to parliament, the matter should be deferred until the 1884 budget.²¹

Onnes did not give in. On the contrary, he submitted a revised, expanded list of demands. Besides the additional 1,160 guilders he needed for instruments, he now wanted 200 guilders because of the longer working days ('heat, water, light, maintenance etc.'). 600 for experiments and studies, and 40 to make 'charts, tables, working plans etc.'. In addition, the laboratory assistant's annual salary of 400 guilders was far too low in view of the new longer working hours; at least 200 guilders more would be reasonable.²² Unsurprisingly, in January 1883 Onnes came away empty-handed once again²³ – the governor

²¹ *Curatoren* to Heike Kamerlingh Onnes, 6 December 1882, UB Leiden, Archief Curatoren, inv. no. 1655.

²² Heike Kamerlingh Onnes to *curatoren*, 12 December 1882, UB Leiden, Archief Curatoren, inv. no. 1655.

²³ Minister of the Interior to *curatoren*, 22 January 1883, UB Leiden, Archief Curatoren, inv. no. 30.

Baron Sloet van den Beele made a special journey to the Steenschuur to impress upon the new professor that he should stop ‘racing forward’ (after which the two men spoke at length on Rijke’s opposition to Onnes’s appointment and the great expense of the Aceh conflict²⁴) – but governors and politicians alike had by now taken on board that Onnes was cast in a very different mould from Rijke.

In a memorandum entitled ‘Urgent demands for physics teaching’, Onnes outlined his plans.²⁵ The medical students needed a lecture hall with 60 seats, a room in which to perform practical exercises, and a dark room. First-year students of the ‘philosophy’ department also needed a room for practical work that could double as a lecture hall and be used for the *investigationes selectae* (lectures on demonstration experiments). In addition, Onnes asked for another room with ready-made laboratory experiments and a lecture hall for Lorentz. Advanced physicists (two undergraduates and a PhD student came to mind) could each be given their own room to perform experiments without being disturbed. For himself he wanted a private laboratory for research and a ‘consulting room’. He also explained that he needed two rooms in which to set up ‘high-precision instruments’ – one for scales, a clock, and a barometer, and a second room, without iron surfaces, for devices to make electrical and magnetic measurements. Finally, Onnes wanted a workshop, a space for a gas engine, and somewhere to park Rijke’s collection of old physics instruments.

Among the ‘further requirements and desiderata’ that Onnes omitted from his final building plans were a room for his research assistant Sissingh, an apartment for the laboratory assistant Veere, and a ‘private laboratory’ for Professor Lorentz. In an earlier version of the plans, the latter space had been planned for the first floor,²⁶ but it now became clear that there was no room for it there.

Why did Onnes not ask for a new laboratory? Quite aside from the years of delay his programme would have suffered, he was well aware that the chemistry department had already received several promises of a new laboratory. The Minister had already considered giving Leiden a second chemistry laboratory – specially for organic chemistry – back in 1873, when Van Bemmelen and Franchimont were appointed to succeed the sick Van der Boon Mesch, but the facility was not actually built until 1901. Inorganic chemistry too had been promised a new laboratory. Various plans were energetically put forward amid

²⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 260. The suppression of the uprising in Aceh was draining the national budget.

²⁵ *Op. cit.* note 18.

²⁶ UB Leiden, Stationsweg archives, inv. no. 103.

the rest of the budgetary proposals and just as quickly scrapped. Not until 1917 was inorganic chemistry too finally relocated in *Jugendstil* premises in Vreewijk (now Hugo de Grootstraat), opposite their colleagues from organic chemistry.

Meanwhile, Kamerlingh Onnes waited impatiently for the day on which he would finally have the Steenschuur all to himself. He included the reallocation of the chemistry wing in his plans for the internal renovation and expansion of the physics laboratory, but was wise enough not to take it wholly for granted. One minute he would be fantasising with Bosscha about how he would use the additional wing, and the next he would be sighing that the plans for the new chemistry building were bound to misfire.²⁷ Sometimes the government took advantage of this uncertainty, blocking his proposals for the expansion of the physics laboratory with the argument that he would soon be acquiring the extra space he needed.²⁸

The upshot of all this was that only internal rearrangements and renovation work took place between 1883 and 1885. The instrument collection was unceremoniously banished to the attic. In an explanatory memorandum to the board of governors, whom he gave a guided tour of his upgraded laboratory on 1 November 1886, Onnes gave assurances that the precious collection had been relocated to 'suitable, if modest' surroundings.²⁹ Heaters had been installed in the attic to ward off damp, and new windows had been inserted to admit sufficient light. In addition, the attic was being plastered and painted to improve its appearance. Display cases had been ordered in which to place 'Gravesande's 'historically so valuable collection'.

Early in 1887 some of the optical instruments – lenses cut by Constantijn and Christiaan Huygens, one of the earliest cycloidal pendulums (guaranteeing a constant oscillation time), an orrery and some old globes – were moved to the observatory. 'It was not without a certain wistfulness', wrote Onnes in his annual report, in October 1887, 'that I parted with the objects handed down from our great countryman Huygens.' He said that he would have liked to emulate foreign laboratories by proudly exhibiting his collection in the attic, but felt that it was inappropriate, in the absence of support, 'to consider the fulfilment of such a remote wish.'³⁰ For years the glorious old instruments slumbered in a rather ignominious existence in the attic, until the 1930s, when C.A. Crommelin took their fate to heart and made them the centrepiece of the Dutch Historical Science Museum (the precursor of Museum Boerhaave).

²⁷ *Op. cit.* note 24.

²⁸ *Curatoren* to Heike Kamerlingh Onnes, 13 December 1889, UB Leiden, Stationsweg archives.

²⁹ UB Leiden, Archief Curatoren, ingekomen stukken 1886, no. 195.

³⁰ Annual report for 1886-1887, UB Leiden, Archief Curatoren, inv. no. 1554.

The renovation had been scheduled for the summers of 1884 and 1885 to avoid disrupting classes. A central corridor was constructed through the entire length of the ground floor of the physics wing, on either side of which were five spacious rooms in which advanced students could conduct practical exercises and research. This design was inspired by the Würzburg laboratory of Friedrich Kohlrausch, the German champion of precision measurement, which had opened in 1879.³¹ Onnes had asked Kohlrausch for the plans.³² The Leiden corridor led to the central hall (room I), which Onnes had allocated to magnetic measurements,³³ – his first annexation, approved by Professor T. Zaaijer, director of the anatomy laboratory,³⁴ and his chemistry colleagues. The central corridor had the added advantage that their walls could support a number of heavy stone plates installed on the first floor, enabling researchers upstairs to perform their experiments without any bothersome vibrations.

Onnes had submitted the renovation plans to the board of governors on 1 April 1884,³⁵ with an estimated budget of 8,000 guilders. A sum of 3,800 guilders was available for special grants that year, 2,000 of which was intended for the purchase of a gas turbine (stationed in a separate little building in the garden at the corner of Langebrug and Zonneveldsteeg). This left just 1,800 guilders, which the government architect judged to be enough for the new lecture hall. Onnes thought this sum ‘not to be spurned in these times’, but all the same it was ‘just a drop in the bucket when it comes to bringing the resources of experimental physics up to the same level as those of lower-ranking universities abroad’.

‘But something at least can be done to prevent my having to advise talented youngsters who want to be financially independent to abandon a laboratory as poorly equipped as that in Leiden as swiftly as possible in favour of a superior one abroad.’

There was hence a shortfall of 6,200 guilders. But Onnes was a shrewd tactician: he knew that the annual maintenance of the university buildings had cost 3,000 guilders less than the estimate, and what would be more splendid than to spend this money on his renovation? Indeed, if this was not done,

‘I should probably be obliged to choose, in the coming academic year, between denying Sissingh an opportunity to prepare a dissertation on an experimental topic, or

³¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 260.

³² Kohlrausch to Heike Kamerlingh Onnes, 29 November 1882, MB, archives of Heike Kamerlingh Onnes, inv. no. 301.

³³ *Natuurkundig Laboratorium 1882-1904*, 16.

³⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 260.

³⁵ Heike Kamerlingh Onnes to *curatoren*, 1 April 1884, UB Leiden, Archief Curatoren, inv. no. 36.

withholding from the advanced students the practical exercises that they so greatly appreciate.⁷

The board of governors was impressed with his arguments, and sent the building plans and Onnes's two explanatory memoranda to the Minister with a positive advice.³⁶ To no avail: Onnes had to make do with the 1,800.³⁷ His wishes were eventually granted a year later, a success marred by the death of a bricklayer carrying out renovation work in the laboratory in August 1885; he was killed by falling masonry when a vault caved in.³⁸ The corridor was also used as a storage space for apparatus, chemicals and glass, and the glass-blowing table was also kept there. By this time, some first-floor space had been found for the practical exercises for 'beginners', including dozens of medical students. The advanced students worked downstairs – including Sissingh, who obtained his doctorate in 1885.

New rooms are excellent, but well-equipped new rooms are better still. To provide electricity, which was needed for lecture demonstrations and laboratory work, Bunsen elements (batteries) and a dynamo, driven by the new gas turbine engine, were installed. Many years later, in 1904, Onnes recalled this situation in his rectorial address:

'Astonishing to think of everything that has improved in Leiden over the past 20 years! Some may recall the battery of 60 Bunsen elements we had to use before we had a single generator – needing personal supervision lest they broke down and left us without electric light – which had to be assembled and dismantled every day. And then there was the first gas turbine engine, which needed the director and his staff to strain until they were quite out of breath before the flywheel would start moving.'³⁹

Among the early acquisitions were a bifilar (wound around with wire folded double) magnetometer, a mercury air pump, a rheostat ('collector' of sunlight) and a Nicol prism to produce polarised light (1883-84); two lathes, a variometer, a Kohlrausch-type magnetometer, a Gramm machine (dynamo) and a Cailletet pump (1884-85); a bifilar galvanometer, a Wroblewski vessel (in which to collect liquid gases) and a Cailletet tube for condensed gases (1885-86) – the molecular field had not been forgotten. To equip the lecture hall, the medics' laboratory, the three laboratories for advanced students, the magnetism laboratory and the engine room, Onnes put 5,400 guilders on the 1886 budget – and received it without a hitch. After the appointment of a second assistant

³⁶ *Curatoren* to BZ, 10 April 1884, UB Leiden, Archief Curatoren, inv. no. 36.

³⁷ BZ to *curatoren*, 19 May 1884, UB Leiden, Archief Curatoren, inv. no. 36.

³⁸ Heike Kamerlingh Onnes to Van Bemmelen, 6 August 1885, MB, archive 99.

³⁹ H. Kamerlingh Onnes, *De beteekenis van nauwkeurige metingen bij zeer lage temperaturen* (Leiden 1904) 17.

(P.H. Doyes)⁴⁰ and an instrument maker (J.J. Curvers), a 15 hp Westinghouse steam turbine with vertical boiler had been put into use, the building had been given a fresh coat of paint, and the Physics Instruments Collection had been renamed the Physics Laboratory and Collection, Onnes could look back on a successful start-up phase.

Not that everything was ideal; Onnes always had something to complain about. In the 1887-88 annual report he lamented, “There is too little space in which to work; the health of the staff is constantly under threat, and too few safety precautions are in place for fire and explosions.’ And two years later: ‘Even an impoverished factory-owner would find the ramshackle state of the boilerhouse unacceptable. A solid engine building is indispensable; in its present state, the steam turbine is being damaged.’ In 1891 his litany of woes continued: ‘To go up onto the roof now is to place your life in jeopardy. Having remonstrated with you so many times about the dangerous state of the roof, I can now place the responsibility for its condition and any possible consequences squarely on the Government’s shoulders.’ Onnes went on harrying the Government until his protests were heeded. The 1892-93 annual account states: ‘We can now expect the matter to be properly resolved.’

By 1886 the classes for ‘beginners’, including medical students, had been set up satisfactorily, and it was time to turn to the advanced students. With unflagging energy and supreme willpower, Onnes continued to bombard the board of governors and the Ministry with requests for support in a steady stream of letters, memoranda, pleas and explanatory notes. His old friend Tellegen from Groningen University, to whom Onnes had sent some of these documents to peruse, was impressed: ‘I admire the tenacity ... with which you have reacted, and with which you have succeeded in attaining so much. But how much correspondence it took!’⁴¹ The board of governors sometimes found all this persistence rather wearying. When Onnes wrote in December 1886 asking for 3,200 guilders in excess of the regular budget to buy a steam turbine (already hired) and to install gas and water in the laboratories, the governors exchanged irritable responses. ‘Our demanding Professor will have to cut his coat according to his cloth’, grumbled Kist. Fellow-governor Fock thought Onnes’s request ‘ill-timed’, but mused ‘perhaps he is acting in consultation with Ministry officials and has already talked them round.’⁴²

⁴⁰ Onnes tried in vain to procure an assistant through the mediation of Kohlrausch; Kohlrausch to Heike Kamerlingh Onnes, 6 January 1886, MB, archives of Heike Kamerlingh Onnes, inv. no. 301.

⁴¹ Tellegen to Heike Kamerlingh Onnes, 22 March 1890, archives Huygens Laboratory.

⁴² Heike Kamerlingh Onnes to *curatoren*, 10 December 1886, UB Leiden, Archief Curatoren, inv. no. 48.

Onnes's wish-list included a third assistant, the purchase of instruments and apparatus for courses in 'molecular forces' and 'electromagnetic measurement' (corresponding to the laboratory's two lines of research, as detailed in chapters 15, 16, and 18), a supply room, a supervisor, and more space. He secured it all, although the investments were substantial, and The Hague was sometimes slow to disburse the funds. In effect, Onnes was already busy building up a cryogenic research laboratory. But for tactical reasons he played down this aspect of his work and continued to stress the need for good education to the board of governors and the Ministry. It was his repeated, explicit emphasis on education – Van der Waals had used similar tactics in Amsterdam to get approval for his new laboratory on Plantage Muidergracht, which was taken into use in 1883⁴³ – that enabled Onnes to extract from the government the money he needed for his cryogenic laboratory.

In the new design, every advanced student was allocated a separate space in which to 'leave his apparatus as he wanted it, and continue his work whenever he had time to do so in between lectures'.⁴⁴ Even so, Onnes had to provide help 'almost continuously', since the two assistants (in 1886, after three years of nagging, Sissingh had finally been joined by Doyer) were already stretched to the limit supervising the experiments on the first floor. 'There are usually people waiting for him in one room while he is still providing information in the next', wrote Onnes in defence of his request for a third assistant in the physics department, in his explanatory memorandum to the 1890 national budget.

'Notwithstanding the fact that Professor Kamerlingh Onnes devotes all his time to the laboratory, he has not yet had time to complete any research of his own, which would surely boost the development he has set out to achieve with his students, and which for this reason is indeed the primary task of a professor of experimental physics. The appointment of a third assistant would therefore significantly improve the training of advanced physics students.'⁴⁵

Parliament remained unconvinced, concluding 'that Professor Kamerlingh Onnes, who, according to the academic report for 1887-1888 only teaches two hours' elementary mechanics a week, and whose assistant supervises the practical work of first-year students, has ample time to supervise the experiments of the few more advanced students,' according to the Preliminary Report. The Minister asked Onnes to suggest how he should respond to this criticism. The

⁴³ Maas, *Atomisme en individualisme*, 40-42.

⁴⁴ *Op. cit.* note 18.

⁴⁵ 1890 Rijksbegroting, Memorie van Toelichting, chapter V, no. 2.

professor of experimental physics evidently had a reputation for extravagance. 'In general, there are doubts as to whether the funds allocated to physics teaching are being deployed with the necessary good husbandry', the Minister wrote to Onnes. 'It is claimed that very costly instruments have sometimes been purchased, whose expense is out of all proportion to their usefulness.'⁴⁶

Onnes hastened to clear up all such misunderstandings in a long and detailed letter. He continued working with the advanced students even during the holidays, he said in his defence, and they frequently came to his house in the evenings to discuss points of theory. And a laboratory that had to meet so many educational requirements was necessarily expensive. 'It is surely curious' wrote Onnes, 'that the importance of the study of molecular forces could be questioned in a country that has produced a man such as Van der Waals.' Without money, no course could be provided in this subject, nor in electromagnetic measurement.⁴⁷ The Minister duly incorporated all these arguments into his Memorandum of Reply, but Onnes's worries were not assuaged. Through his student Kuenen, whose father (the liberal professor of theology Abraham Kuenen) had acquaintances in political circles, he sought contact with parliamentarians who would be willing to speak on his behalf when Parliament debated the budget.⁴⁸ He had planned to show the Leiden liberal Bool round his laboratory, 'so that you can best judge the correctness of the Government's arguments', but had to cancel because of a mild case of bronchitis.⁴⁹ In the event, however, all the budgetary proposals were approved, and Bool kindly telegraphed Onnes immediately to tell him the good news.⁵⁰

This meant that Onnes acquired his third assistant, a stock of supplies (copper rods, zinc wires, ebonite rods, working steel, india-rubber corks, glass-work, household items, chemicals and so forth, to a value of 2,000 guilders)⁵¹ and a series of appliances to produce artificial cold. He had 3,000 guilders to purchase equipment, with the prospect of another 5,000 in the near future. By then the laboratory had already been fitted with electrical equipment to the tune of some 5,000 guilders – after shrewd negotiations with potential suppliers, Onnes (who studied every detail) had signed a contract with the Dutch Electricity and Metallurgy Company, which was based in The Hague.⁵² The

⁴⁶ BZ to Heike Kamerlingh Onnes, 30 October 1889, archives Huygens Laboratory.

⁴⁷ Heike Kamerlingh Onnes to BZ, 3 November 1889, archives Huygens Laboratory.

⁴⁸ Kuenen to Heike Kamerlingh Onnes, 12 December 1889, archives Huygens Laboratory.

⁴⁹ Heike Kamerlingh Onnes to Bool, 13 December 1889, archives Huygens Laboratory.

⁵⁰ Bool to Heike Kamerlingh Onnes, 14 December 1889, archives Huygens Laboratory.

⁵¹ UB Leiden, Archief Curatoren, begroting natuurkunde 1890.

⁵² Archives Huygens Laboratory, 'electrische installatie' file.

equipment could be called ‘robust in every respect’, with a modern control desk, a Siemens dynamo that could supply 70 ampères at 75 volts, and 31 storage batteries.⁵³ Now, finally, Onnes and his students were in a position to carry out the academic programme he had set out in his inaugural address.

In three successive years, the course on molecular forces had been removed from the budget. This put Onnes in an awkward position. In 1887 the first students who had attended his course for first-year ‘philosophers’ presented themselves at the laboratory. The rejection of his applications for funds in 1887 and 1888 crippled his teaching of advanced undergraduates. And not until this problem was solved would Onnes feel able to give those with doctorates and PhD students total freedom to conduct their own research. ‘Even so, I can already say what is going through my mind’, he wrote when submitting his budget in May 1887. He went on to argue strongly in favour of specialisation. ‘It seems to me that our academic institutions can only compete with the giant laboratories abroad, with only three national universities ... if each of the laboratories focuses more narrowly on one branch of physics research.’⁵⁴ By then, Leiden had already chosen its special field: research into Van der Waals’s molecular theories, in particular the law of corresponding states.

For this research, they would need apparatus for artificial cold and condensed gases, including a large and small Pictet pump, a small compressor, a drum of methyl chloride, manometers, vacuum meters, condensers for ethylene and oxygen, a heater for the preparation of ethylene, Wroblewski apparatus, and two cubic metres of ethylene gas.⁵⁵ The molecular physics course for advanced students had been devised so as to enable a cryogenic laboratory to be built. On 7 June 1892, the first 20 cc of liquid oxygen were poured into a container. The genesis of that cryogenic work is dealt with in a separate chapter (chapter 14).

A dynamic laboratory

At the beginning of 1893, with the advent of a supervisor – officially responsible for administering the instrument collection, but in practice a kind of assistant director who watched over the everyday activities at the Steenschuur and made sure that everything was working – the staff were as follows: Professor H. Kamerlingh Onnes (director), Professor H.A. Lorentz (supervision of medical students’ laboratory work), Dr J.P. Kuenen (supervisor), Dr P. Zeeman

⁵³ *De Ingenieur*, 28 March 1891.

⁵⁴ UB Leiden, Archief Curatoren, inv. no. 1655, begroting natuurkunde 1888.

⁵⁵ *Ibid.*

(assistant), Dr L.H. Siertsema (assistant), Dr M. de Haas (assistant), C.W. Kouw (mechanic), J.J. Curvers (mechanic) and G. Veere (laboratory technician). In addition, half a dozen apprentices worked in the laboratory, trainee instrument-makers – a form of training that Onnes had launched in 1885, which constantly expanded and yielded enormous benefits for him (see chapter 20). Within ten years, the sleepy physics laboratory had been transformed into a dynamic institute with unique facilities, which was awarding one doctorate after another and stood on the threshold of a series of major discoveries.

Was Kamerlingh Onnes content with what he had achieved? The annual procurement grant rose from 2,250 guilders in 1883 (requested by Rijke) to 6,486 ten years later, in addition to which extra grants amounting to several thousand guilders were often allocated. In comparison, inorganic chemistry (Van Bemmelen) rose in the same period from 3,000 to 3,500 guilders, and organic chemistry (Franchimont) from 5,000 to 5,450. While Rijke had enclosed just a few lines of explanation with his budget requests, Onnes covered four densely written sheets or more. Comparison with physics in other parts of the Netherlands shows that Leiden surged ahead in the 1880s, though it lost part of this lead by 1890. Utrecht and Groningen started with 1,500 and 1,000 respectively, raised in 1890 to 2,500 and 1,500 (Utrecht, where the new professor V.A. Julius set up a laboratory, was given a special grant of 4,000 guilders). A year later, when Haga was about to move into a new laboratory in Groningen, the regular grant there was increased to 4,000 guilders. And twelve months after this, Utrecht climbed to 4,500. It then remained constant at this level for some time, as did the 4,000 guilders in regular grant that was awarded to Groningen. Finally, Amsterdam, which was subsidised not by the state but by the municipality, had an annual procurement grant of just over 2,000 guilders in the period 1883-1893.⁵⁶

Given these figures, Onnes had every reason to be satisfied. But he was too astute to show it. Putting pressure on the board of governors – that was evidently the most effective tactic. In October 1891, around the time he was equipping his cryogenic laboratory, he complained in his annual report about the fact that his main building, in spite of the many letters he had sent, contained far too few ‘spacious and efficiently equipped rooms’. Onnes: ‘The tale of woe that is the consequence of failure to respond in good time to the urgent and extremely modest requests I have submitted in this connection is more constraining and oppressive for my deserving students on each day that passes.’⁵⁷

⁵⁶ Maas, *Atomisme en individualisme*, 46.

⁵⁷ UB Leiden, Archief Curatoren, inv. no. 1556, jaarverslag natuurkunde 1890-1891.

In contrast, the board of governors, who had come to take another look round the premises in May 1891, expressed great satisfaction. ‘We had the impression’, stated Star Numan’s report, ‘that science is serving education superbly at this institution.’ On their guided tour of the laboratories, the governors were very impressed by the way in which Onnes involved his advanced students in the research. They also saw for themselves that the boilerhouse was indeed in a perilous state, and that new working areas were urgently required. As things stood, Kuenen and De Vries were having to share a room, and could not work on their dissertations at the same time. And if Zeeman was experimenting with light in room H, there was no room for anyone else. ‘While Mr Onnes acknowledges that he is an expensive professor’, wrote Star Numan, ‘he suggests that he himself is not to blame for it.’ Instruments were expensive, and physics experiments needed ‘a large space’. In Lorentz and Kamerlingh Onnes, the university had two ‘capable men who ... possess the organisational talent needed to distribute the work among assistants and students, while they themselves are the soul of the endeavour. ... They urgently request more vigorous support. Hora ruit.’

‘Is it not a sad thought (Professor Onnes asked us), that the best years of my life are rushing by without my being to the university what I have the energy to be, simply because I lack the space in which to develop my powers to the fullest extent?’⁵⁸

The necessary changes would be made. And Onnes’s gift for winning people high and low over to his point of view would earn him a great deal of support. ‘Onnes was a brilliant man’, wrote his pupil Pieter Zeeman in the *Algemeen Handelsblad* after Onnes’s death. ‘He could buoy up the feelings of his staff, as the wind propels the clouds. He could work miracles with a little flattery, or with witty (sometimes sardonic) irony. He knew how to charm even those who were above him in the hierarchical order ... and decisions were sometimes turned in Onnes’s favour at the last minute.’⁵⁹

⁵⁸ UB Leiden, Archief Curatoren, inv. no. 71, doc. 448, 8 May 1891.

⁵⁹ P. Zeeman, ‘Prof. Dr. H. Kamerlingh Onnes †’, *Algemeen Handelsblad*, 22 February 1926.

13. The fullness of wisdom

On 12 April 1892, Johannes Petrus Kuenen, the son of a Leiden theologian, gained a doctorate under the supervision of Professor Heike Kamerlingh Onnes for his dissertation on measurements relating to the Van der Waals surface for mixtures of carbonic acid and methyl chloride. Kuenen was not the first PhD student whose dissertation was supervised by Onnes, but he was the first to have been trained entirely by him. It was then ten years since Onnes had taken over from Rijke at the helm of the laboratory, during which time physics teaching at Leiden had been utterly transformed.

This teaching focused on two groups. First, there were the institute's 'own' mathematics and physics students – very few at the beginning. In 1882, when Onnes took up his post, the entire 'philosophy' faculty (mathematics, physics, astronomy, chemistry, pharmaceuticals, biology and geology) contained only one full-time first-year student – who was studying pharmaceuticals. The student almanac painted a sombre picture. 'Some lectures have audiences of one or two; in fact two lectures – algebraic analysis and higher algebra by Professor Bierens de Haan – were cancelled since there were no students at all to attend them.'¹ The moment was approaching at which 'the last philosopher would be wandering alone through the streets of Leiden'.

The 1876 Higher Education Act was blamed for this malaise. It had lengthened *gymnasium* school from five to six years, creating a dip in all university admissions around 1882. Far more important than this temporary effect, however, was the barrier for HBS school-leavers seeking university places: the exemptions previously granted for Greek and Latin had been virtually abolished. And these were the very people the mathematics and physics departments needed to attract. In education reports, Onnes repeatedly observed that HBS pupils were better prepared in these subjects than their fellows who had attended a classics-based *gymnasium*, and he was not alone in this view. 'The

¹ *Almanak van het Leidsche Studentencorps* 1884, 320.

knowledge of students who have attended *gymnasium* is on the whole poor', read the report for 1887-1888.²

Given the absence of mathematics and physics majors, the physics department was mainly occupied with teaching first-year medical students – thirty to seventy a year – whose compulsory examinations included elementary physics. This introductory lecture series, larded with carefully prepared experiments, had made Rijke enormously popular with the students. It was up to Kamerlingh Onnes to craft what he considered to be the essential reform of physics education in Leiden without triggering a collective surge of nostalgia for his predecessor.

Three days after his inaugural address, on 14 November 1882, Onnes had a discussion with advanced students in his Steenschuur laboratory about experimental exercises.³ Bosscha had tried to boost laboratory work when he had been Rijke's assistant – the matter had been allowed to slide after he left – and since 1881 the Delfzijl man Rimmelt Sissingh supervised students in this area. 'Always helped the young people that Rijke neglected', Onnes wrote in his notebook in September 1882.⁴ Sissingh was eager to continue as assistant under the new professor/director. Half a dozen students started work in the two ground-floor laboratories under his leadership in November.

After the interior rearrangements were completed in 1885, this laboratory work evolved into a comprehensive introduction to the instruments used in physics. Students performed about fifty experiments, ranging from the determination of the radius of curvature of lenses and the latent heat for melting ice to measurements of Fresnel interference phenomena and chromatic polarisation, studying the horizontal component of geomagnetism, and determining the density of gases.⁵ The influence of Gustav Kirchhoff's seminars, including the compulsory reports, is unmistakable. Before each experiment, students were given a list of guidelines, probably modelled on those in Kohlrausch's famous *Leitfaden der praktischen Physik*, the first edition of which was published in 1870, and which contained an error analysis as well as countless experiments.

Even new first-year students performed experiments and 'limited studies'. They were far from superficial: 'The classes focus precisely on the difficulties that arise during each experiment and the points that remain blank in the report,' the board of governors quoted Onnes as saying, when they came to look

² UB Leiden, Archief Curatoren, inv. no. 1555.

³ MB, archives of Heike Kamerlingh Onnes, inv. no. 260.

⁴ *Ibid.*

⁵ Cahier (notebook) of F.M. Jaegers, 'Physisch Practicum' 1895-1898, MB.

round the laboratory in November 1886.⁶ Finally, the medical students had their own laboratory classes, with demonstrations and exercises in the use of instruments, which Onnes called ‘a primary prerequisite for the sound practice of present-day medicine’.⁷

In his first lecture to first-year medical students, Onnes discussed his broad approach to physics, the attitude he expected his students to adopt, and the way in which he envisaged their mutual joint endeavours. Besides the ‘knowledge through measurement’ creed first proclaimed in his inaugural address, this is one of the rare testimonies to Onnes’s philosophy of science. Physics, preached the new professor – echoing Helmholtz – sets out ‘to describe the laws that govern the material world as fully and simply as possible by reasoning based on observation and experiment’.⁸

‘This [inductive] method proceeds from the basic premise that cause and effect are always related in the same way; in other words, that this relationship is expressed by natural laws. In its quest for these laws, physics strives to achieve not only *completeness and accuracy* but also, and above all, *simplicity*. The bringing together of several natural laws into a single higher law, from which these follow, is an *explanation*. When one speaks of an explanation, one must bear in mind that it is nothing more than reducing [the relationship] to fundamental principles which provide an easier or wider overview of phenomena, but which always remain as inscrutable as the basis of causality itself.’

This approach revolved around ‘the art of altering and calling forth natural phenomena’ – *experimental research*. ‘I shall endeavour to allow nature to speak through experiments’, said Onnes. ‘My own lectures are merely intended to explain the experiments.’ Instead of approaching natural phenomena – as a ‘delirious patient’ – with book learning, Onnes considered it crucial that one should ‘experiment oneself, not just look at apparatus from a distance but handle it and repeat the experiments.’

‘I shall therefore leave the apparatus I have used in place for the rest of the day after each lecture and during the following day, so that anyone wishing to repeat the experiments or to inspect the internal mechanisms can do so. I myself shall be present throughout, and shall be entirely at your disposal to provide any help or information you may require. There is no better way for me to use my time than to contribute in this way to instilling pure insight. Seek to attain not the fullness of knowledge but *the fullness of wisdom* – that is my motto where education is concerned. Hence in my lectures I shall set out primarily to shed light on the fundamental concepts of physics.’

⁶ UB Leiden, Archief Curatoren, ingekomen stukken, 1 November 1886.

⁷ Begroting natuurfunde 1885, UB Leiden, Archief Curatoren, inv. no. 1654.

⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 4.

Gone were the days when a student was expected to ‘write down the textbooks from the professor’s lips’, said Onnes: ‘the availability of excellent textbooks means that the primary significance of lectures is to stimulate students’ interest in their studies’. He himself swore by Bosscha’s *Leerboek der Natuurkunde*, ‘every chapter of which is a masterpiece of reasoned experiment’, and was greatly superior in cultivating insight (rather than presenting facts) to more voluminous German textbooks. Students were expected to study this book independently as a supplement to the lectures.

Onnes wound up his words of welcome by urging his audience to ‘accept the friendship that I offer you in all sincerity, so that the bond between professor and students may be of a higher order than that glorified in stirring speeches or impassioned treatises’. To demonstrate this friendship, Onnes hoped that they would inform him frankly of their wishes and ‘perhaps even’ grievances regarding his teaching. In conclusion he briefly reiterated his mission:

‘My primary aim will be to arouse in you a love of research, of the logical whole of experiment and reasoning that gives physics its influence on society and its sister sciences, by virtue of which it may rightly be called one of the finest branches of learning.’

This emphasis on research and experiment signalled a break with Rijke’s approach, and made the renovation of the Steenschuur laboratory Onnes’s top priority.

Onnes also wrote a short speech about the role of physics in society. Since it is preserved in the same file as the above words of welcome,⁹ we may assume that Onnes also drove home to his new students the value of physics when he embarked on his professorship. Such boons it had to offer! It was physics that ‘pointed the way for navigators, through night and storm, to a new world, and that forged the rod that wrenches lightning from an ominous welkin’. After which Onnes, in no less florid prose and with a characteristically sanguine turn of phrase, depicted a veritable vision of progress:

‘And now that the age of electricity is upon us, and the dawn of this new era is already illuminating us with its rays, [physics] is pointing the way to a future in which the riches of beds of coals will have served only to buttress the first steps of humanity in its infancy, and the glaciers, melted to mountain streams, will disseminate their energy through joyous fields in a system of endlessly ramified copper veins; a future in which the chains of the slavery of industry will be cast off, and the predicament of the millions whose lives are now submerged in dust and sweat amid a feverish hunt for prosperity and their children’s freedom will be consigned to the past.’

⁹ The file ‘warmte, cursus ‘82-‘83’, archives MB.

After which Onnes added a philosophical footnote:

‘Thinkers have frequently bathed in the refreshing stream of physics – thinkers who have crushed the bonds with which dogmas and superstition seek to constrain the expression of the eternally free spirit. And now that physics, since the discovery of the great law of conservation of energy, is forging with its sister sciences one great history of the origin of worlds, now that it is turning its gaze towards the innermost part of nature and beholds everywhere a fabric of dynamic phenomena in the simple description of which it strives to create the most exalted poetry – it has aroused a powerful and irreversible stream of thought which, if unchecked, can become idolatry of the material world, but which eventually, purified by cognitive criticism, will prepare the triumph of idealism.’

The word ‘idealism’ refers here to empirical criticism, an approach that was opposed to scientific materialism, a form of realism that reached its heyday around 1870 and in its descriptions of nature accepted only mechanistic explanations.¹⁰ But banishing theories that reached beyond empirical facts, as the positivist J.B. Stallo had done in his 1882 book *The Concepts and Theories of Modern Physics* – acclaimed by the great philosopher of science Ernst Mach – was a bridge too far for Onnes. It was incompatible with his love of atoms.

It was rare for Onnes to express his views on the philosophy of science. When the physicist and philosopher Jacob Clay, who had gained his doctorate in Leiden in 1905 on the strength of his dissertation on the calibration of thermometers, won an academic contest in 1915 with his ‘Sketch of a critical history of the concept of laws of nature in modern philosophy’,¹¹ Heike wrote a letter of congratulations in which he recalled the philosophy that he had taught in his mechanics classes when Clay was a student.

‘Your chapter on Galileo put me in mind of the days when I taught mechanics as part of the *capita selecta* and used to take Galileo’s book [*Discorsi*] to class, or in any case sections of the discourses, and recited that striking passage [on falling motion] that you quote yourself. My intention was primarily to impress upon the young people the way in which the concept of acceleration was introduced, by an intuitive leap prompted by experimental work. The question of why it is that when one, following an intuition, focuses on a particular line of thought in physics, one is automatically led towards a new intuition that opens up a wider field of action – lies behind the picture that Galileo’s work unfolds for us. For the time being, we can affirm that intuition is of great significance to physics, and the way to reach it is by hard work in one direction.’¹²

¹⁰ Brush, *The Kind of Motion we call Heat*, 51-67.

¹¹ ‘Schets eener kritische geschiedenis van het begrip natuurwet in de nieuwere wijsbegeerte’.

¹² Heike Kamerlingh Onnes to Clay, 25 November 1915, coll. Frieling-Van Osselen.

This passage gives us a wonderful insight into Heike's philosophy of research, including a justification of the narrow programme he pursued in Leiden.

Lorentz comes to Onnes's aid

Let us look briefly at Onnes's initial teaching load. At the students' request, Rijke had split up the introductory lecture in the academic year 1879-1880. The first-year 'philosophers' and medical students now had four hours, while those majoring in mathematics or physics attended one or two additional hours to allow for more in-depth discussions. This lightened the load of the medical students, to their considerable relief. Rijke also taught a one-hour meteorology class, although this was regularly cancelled in the absence of any audience. Lorentz taught three or four hours of mathematical physics to graduates, three hours of mathematics to medical students, and an hour's mathematics to chemists. Lorentz too was popular among his students. 'Each year afresh Professor Lorentz elicits our praise and gratitude', was the verdict recorded in the 1882 almanac.¹³

In the *Series Lectiones* of 1882-1883, the Latin overview of the lectures at the University of Leiden, Kamerlingh Onnes's name was not mentioned at all, because of the long delay caused by the wrangling over his appointment. Still, he did teach that year, although only briefly. November was a late start for the students, and at the end of February a debilitating eye infection forced Onnes to take sick leave for the rest of the year; Lorentz took over his introductory lectures.

Onnes's classes for medical students could scarcely be called a break with Rijke's approach. Shortly after his appointment, the new professor and laboratory director decided, after consulting his friend Lorentz, to give a series of introductory lectures taking up three or four hours a week. In the autumn term he would provide an introduction to mechanics, and in the spring term he would teach heat, with abundant demonstrations: galvanometers, thermoelements, vacuum pumps, the boiling of ether, the 's Gravesande experiment, the compression of carbonic acid, and so forth. For graduate students, the records list an hour with 'special subjects, to be treated exhaustively',¹⁴ which might have included meteorology. Then there was a series of lectures in experimental physics for first-year students, focusing on the use of instruments (cancelled in 1883 because there was no suitable space for it). And in December the idea was born of organising regular evening seminars at the laboratory, together

¹³ *Almanak van het Leidsche Studentencorps* 1882, 273.

¹⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 260.

with Lorentz. At these seminars, advanced experimental and theoretical physics students could discuss (and perhaps demonstrate) their research with professors and fellow students – a truly innovative plan. Since there were few students working at this level at the beginning, Kamerlingh Onnes and Lorentz sometimes did presentations instead.

After his illness incapacitated him, Onnes puzzled over the lectures for medical students. On 23 May 1883, while still in the early stages of convalescence, he wrote to Lorentz from his sickbed at the house ‘t Waelre’ in Hengelo, where his mother was taking excellent care of him, asking if his colleague would be ‘willing and able’ to take over the medics’ course for the rest of the year.¹⁵ Lorentz wrote back offering to share responsibility for the course with him. In June, when Onnes had finally obtained the governors’ consent to travel to more wholesome foreign parts to recover his health, Onnes wrote to Lorentz again from the beautifully situated Oberweilen – ‘babbling brooks beneath tall pine trees’ – to express his heartfelt thanks. He would be delighted to accept the offer. ‘I would not do so, had I not heard of the ease and success with which you give these lectures, and that you also find the time to make suggestions to the students in the laboratory, helping them to press ahead [with their optional experiments].’¹⁶

In the event, his colleague’s fragile state of health – Onnes’s lectures were frequently cancelled because of illness during his first few years in Leiden – meant that Lorentz took over the introductory lectures for medical students permanently. Combined with supervising the laboratory work (four afternoons a week; Sissingh was fully occupied with the laboratory sessions for new ‘philosophy’ students) this meant a weekly teaching load of 12 to 15 hours. Lorentz bore this burden for many years, although the strain was somewhat alleviated in 1887 by the advent of a second assistant alongside Sissingh. He even published his own physics textbook (*Beginnselen der natuurkunde*) in 1891. For years Onnes tried in vain to obtain approval to appoint assistants and/or *lectors* to help Lorentz. Not until Lorentz seriously considered moving to Munich, in 1905, did the Minister realise that something had to be done, and the arrival of J.P. Kuenen as a second professor of experimental physics brought some relief. Lorentz was finally rid of the medical students.

From 1883 onwards, Onnes’s teaching task was mainly confined to three lecture series: mechanics for advanced students (two hours a week; changed to ‘energetics’ in 1892), experimental physics for beginners (two hours, including a theoretical component) and scientific instruments (one hour). He

¹⁵ Heike Kamerlingh Onnes to Lorentz, 23 May 1883, RANH, Lorentz archives, inv. no. 39.

¹⁶ Heike Kamerlingh Onnes to Lorentz, 21 June 1883, RANH, Lorentz archives, inv. no. 39.

also covered special topics such as electricity, thermodynamics, thermodynamic potential, chemical equilibrium and mixtures. Attendance at these lectures improved slightly, according to the annual reports that Onnes sent to the board of governors,¹⁷ but numbers remained low: the maximum was the twelve students who attended the energetics lectures in 1901-1902. Onnes spent most of his time supervising the research of the more advanced students. These home-bred scientists, the first four of whom entered the scene in the education report for 1887-1888, numbered three students on average until 1900. After this the numbers doubled, and after a dip around 1909, there were again six by 1920.

Let us turn to the students' assessment of their new teacher. In the report of the 1882-1883 academic year, the almanac refrained from passing judgment on the main lecture: its late start and Onnes's indisposition meant that there was too little to go by. However, the chronicler did note that his arrival had introduced 'an uncommon amount of activity' in the laboratory. 'He shows us practical physics from a fresh vantage point, and true to his motto "knowledge through measurement" he teaches us, with his unbounded willingness to help, courageously to embark on a piece of research and bring it to fruition.'¹⁸ The joint seminar launched by Onnes and Lorentz, 'at the same time forging a bond between teachers and students', also met with an appreciative response. The chronicler expressed the hope that it would endure for many years.

Even when another year had passed, the almanac chronicler still deferred judgment: Onnes had again been off sick for much of the year. But the academic year 1884-1885 – in which Onnes had again been compelled to cancel some of his lectures – his teaching was given a positive evaluation: the professor had given students a clear understanding of the basic principles of mechanics, and the lecture on light, in which students made their own observations, was original and highly enjoyable.¹⁹

Then came the criticism. In the 1887 almanac the mechanics lectures were described as sometimes difficult to follow, 'possibly because the subjects are treated in rather too much depth, perhaps, for a course in *elementary* mechanics'.²⁰

Five years later, the verdict on this lecture series was that its 'high-flown reflections demanded a great deal from its audience'.²¹ A year after that, the lectures were described as 'not always clear to all those who attended'.²² And

¹⁷ UB Leiden, Archief Curatoren, inv. no. 1553-1563.

¹⁸ *Almanak van het Leidsche Studentencorps* 1884, 327.

¹⁹ *Almanak van het Leidsche Studentencorps* 1886, 305.

²⁰ *Almanak van het Leidsche Studentencorps* 1887, 293.

²¹ *Almanak van het Leidsche Studentencorps* 1892, 284.

²² *Almanak van het Leidsche Studentencorps* 1893, 312.

in 1894, elementary mechanics elicited the following verdict: ‘Much as we appreciate the Professor’s earnest desire for clarity, we nonetheless believe that a less circuitous exposition would in fact benefit clarity, which is much to be desired, since the purely philosophical treatment of this subject presents a good many difficulties.’²³

As the years passed, Onnes developed an ever greater aversion to lecturing. The mathematician and historian Dirk Struik, who had attended Onnes’s lectures in 1913 as a first-year student, wrote in his memoirs that the professor presented his material in as dull a manner as possible.²⁴ C.A. Crommelin, who had been trained by Onnes and was supervisor (from 1907) and assistant director (from 1924) of the laboratory, considered that the professor was ‘far more gifted as a researcher than as a teacher’.

‘His lectures were frequently difficult to follow, and the same applied even in a private discourse. Onnes did not like lecturing, and he liked popular presentations even less. His mind focused entirely on scientific research and on guiding students and assistants in this direction; he unquestionably underestimated the importance of good teaching and popularising science in a fruitful way, of communicating science to students and the public at large.’²⁵

Onnes certainly did not underestimate the importance of thoroughly reorganising the teaching of laboratory skills. Without for a minute losing sight of his goal – performing research into the molecular theories of Van der Waals – he nonetheless prioritised teaching in the first few years of his professorship. All his efforts focused on training a group of experimental scientists who, once proficient in precision measurement, could tackle a wide range of research questions. Creating a school of science, that was Onnes’s initial focus. The first to benefit from his newly equipped laboratory were PhD students; he himself had no time for research in this start-up phase. Not until 1894, twelve years after his appointment, did he publish something of his own. By then, the laboratory in Leiden had a unique infrastructure for creating low temperatures. And when he was moving around between the pumps and the boiling flasks, Onnes had more to offer students than in a lecture hall.

²³ *Almanak van het Leidsche Studentencorps* 1894, 202–203.

²⁴ Dirk Struik, *Memoires*, chapter 5, 12.

²⁵ Dr. C.A. Crommelin, ‘Heike Kamerlingh Onnes’, in T.P. Sevensma (ed.), *Nederlandsche helden der wetenschap* (Amsterdam 1946) 234.

14. Cold war (1)

‘The polar regions of physics have the same effect on experimentalists as the extreme North and South poles on discoverers; they rouse them to join battle’, pronounced Kamerlingh Onnes in 1904 in his foundation day address as rector of Leiden University Senate.¹ He created these polar regions in room E of the newly built laboratory. Until 1898 it was there, opposite his study, that all the department’s cryogenic activities were concentrated. In his 1882 inaugural address (see chapter 11), Onnes had included Cailletet and Pictet pumps in his list of ‘indispensable laboratory instruments’, and within a few years he had secured them. With iron discipline and tremendous energy he gradually built up his cryogenic facility, on the basis of a carefully delineated plan. The aim was to perform physics experiments in liquid baths at extremely low temperatures.²

Cailletet and Pictet had created a sensation in 1877 – working quite independently of one another – by producing liquid oxygen, if only very briefly. This was acclaimed as the conquest of the first of the ‘permanent gases’ that Michael Faraday had been unable to condense in his experiments of 1823 and 1845. The others were nitrogen, carbon monoxide, nitric oxide, methane and hydrogen; the noble gases (including helium) had not yet been discovered. Cailletet and Pictet had set up their experiments in a totally different way, but they had one thing in common – a construction enabling highly compressed gas to escape suddenly from the chamber in which it had been enclosed.

Before Cailletet and Pictet, most efforts had focused on compression. This proved an effective approach provided the temperature was below the critical value. Faraday produced a mixture of solid carbonic acid and ether in a basement of the Royal Institution in London, lowered the pressure as much as possible, and at the temperature thus acquired, namely -110°C , he compressed the

¹ H. Kamerlingh Onnes, *De beteekenis van nauwkeurige metingen bij zeer lage temperaturen* (Leiden 1904) 5.

² Verslagen zittingen KAW, afd. wis- en natuurkunde, 3 (29 December 1894) 164. *Comm.* 14.

gases he was using to about 50 atmospheres. Half a century earlier, Martinus van Marum, curator of the physics laboratory of the Teylers Foundation, had also experimented with compression, but at room temperature – and he had successfully condensed ammonia in 1787. The claim – which Bosscha stoutly defended (and Onnes repeated) in his speech to the first Dutch Physical and Medical Science Conference in 1887 – that Van Marum was the first scientist to have successfully condensed a gas, flattered Dutch national pride but proved untenable.³ The credit should possibly go to the French scientists Gaspard Monge and Louis Clouet, who taught at the military academy in Mézières. They liquefied sulphur dioxide before 1780.

In 1877, when there was still a brisk trade in Norwegian and Canadian natural ice, and the Scottish butchers Bell and Coleman shrewdly patented a cooling machine using air expansion,⁴ the scientific battle surrounding cold erupted in earnest. On 24 December, Louis-Paul Cailletet, a mining engineer from the little town of Chatillon-sur-Seine, who was employed at his father's metalworks, sent a message to the Académie des Sciences in Paris. That same day, the letter was read out at the Académie's weekly meeting, in a former chapel opposite the Louvre.⁵ The letter was about the liquefaction of oxygen. The Académie's Permanent Secretary, Dumas, thought the news so momentous that he prefaced it with a quotation from Lavoisier. The father of oxygen theory, guillotined in 1794, imagined what would happen if the earth were moved to the cold of Jupiter or Saturn. 'The water that fills our rivers and lakes, and probably the vast majority of the fluids known to us, would change into solid mountains', posited Lavoisier. And at least some of the substances making up air, he continued, would no longer be invisible gas but would condense into 'new liquids ... of which we are now wholly ignorant.'

Cailletet experimented with gases that he placed under very high pressure in a thick-walled glass tube, in the hope of condensing them into liquid.⁶ There was relatively little risk of explosion in his construction, which was copied by numerous others. Gas was compressed in a steel pipe. The pressure was transferred to the chosen gas by hydraulic means, using water and mercury. Cailletet insisted on precise results and accurate methods, and had spent years on end tinkering with metal manometers and alcohol thermometers, building on the work of experimentalists such as Berthelot and Regnault. To compress his

³ Ernst Cohen, *Van Boerhaave tot Kamerlingh Onnes* (Utrecht 1922) 12–20.

⁴ Ralph G. Scurlock (ed.), *History and Origins of Cryogenics* (Oxford 1992) 9–11.

⁵ *Comptes Rendus*, 20 (1877) 1213–1214.

⁶ Kurt Mendelssohn, *De jacht naar het absolute nulpunt* (Dutch translation of *The quest for absolute zero*) (Amsterdam 1966) 7–10.

gases he designed a mercury pump that had far fewer disadvantages than ordinary compressors,⁷ and which greatly appealed to Onnes.

At the beginning of November 1877, Cailletet had started on a series of experiments with acetylene in his private laboratory in Châtillon-sur-Seine. He expected 60 atmospheres to be enough to condense the gas.⁸ But before this pressure was reached, a leak arose in the tube and gas escaped with great force. The observant Cailletet noticed that at that precise moment, a thin haze arose in the tube, which then immediately evaporated again. The sudden release of pressure evidently caused the acetylene to cool down so quickly that condensation arose. The escaping gas had to push away the air outside – so rapidly that the energy this required detracted from the gas's own 'internal' energy, resulting in a fall in temperature. To make sure that what he had seen was not just steam, Cailletet repeated his experiments with pure acetylene from Berthelot's laboratory in Paris. Haze again. Through serendipity – as so often happens in science – Cailletet had stumbled on a new technique for liquefying gases.

After the success with acetylene, it was time to study the various elements that make up air. To lower the initial temperature – and hence to go below the critical temperatures – Cailletet had placed his tube of gas in a bath containing liquid sulphurous acid, which boiled at -29°C . Carbon monoxide and both nitric and nitrous oxide (NO and N_2O) obligingly exhibited a haze after sudden expansion; moreover – spectacularly – so did oxygen. Hydrogen did not react, and nitrogen had not yet been studied. Cailletet hoped to establish whether he had seen liquid or solid oxygen after he had measured the light scattering. He was also preparing a chemical experiment that he hoped would rule out the presence of ozone.

Was Louis-Paul Cailletet heading for eternal glory? That was not yet clear. Following the report from Châtillon-sur-Seine, *another* treatise about the liquefaction of oxygen was presented at that memorable meeting of the Académie, just before Christmas. Raoul-Pierre Pictet, a physicist from Geneva and the inventor of a refrigerator, had apparently produced the same result by following an entirely different path. On 22 December – in other words before Cailletet – he had notified the French Académie by telegram: 'Oxygen liquefied today at 320 atmospheres and minus 140 degrees by using a combination of sulphurous acid and carbonic acid. Raoul Pictet.' Within a few days, Pictet, who had been assisted by Regnault, despatched a letter clarifying his method. He used a cascade of two closed circulatory systems, whereby the final temperature in the first

⁷ Louis Cailletet, 'Nouvel appareil pour la liquefaction des gaz. Emploi des gaz liquéfiés pour la production des basses températures', *Annales de Chimie et de Physique* 29 (June 1883) 153-164.

⁸ *Comptes Rendus* 20 (1877) 851.

was the initial temperature in the second – a principle that Onnes would eagerly adopt.

Pictet's cascade worked like this. In the first system, a bath of sulphurous acid was kept at low pressure using two pumps driven by a 15 hp steam turbine engine. This brought the temperature down from -29°C to -65°C (whereas the cooking temperature in a pressure cooker is higher than normal because of the high pressure, pumping to reduce pressure brings the temperature down). The sulphurous acid that had been pumped out was fed through a water-cooled condenser, where it condensed at a pressure of 2.75 atmospheres at -25°C , after which the liquid was again passed to the pumping bath, and so on. This is the closed-cycle principle used in a refrigerator.

The pumped-out bath from the first cycle provided the cooling for the second. There, carbonic acid circulated, which was reduced in temperature – using two other pumps – to -140°C . In this way, a 1-metre long glass tube (with an internal diameter of 1 cm) with oxygen gas was cooled. This oxygen was released with the decomposition of potassium chlorate in a vessel connected to the tube. In this way, an oxygen pressure of 320 atmospheres was gradually built up, in a process lasting several hours. After this, Pictet, like Cailletet, suddenly released the oxygen through a narrow opening. This increased the cooling effect, attaining a temperature that he estimated at -200°C ,⁹ so that some of the gas was condensed and liquid oxygen sprayed out of the opening. Here too, the effect was very brief: all the liquid evaporated again almost instantaneously. 'We consider the results of these experiments to be so important', stated Pictet, concluding his explanation, 'that we saw fit to inform the Académie of them immediately.'¹⁰

So it seemed that Cailletet had been beaten to the finish. That was a bitter pill to swallow, since he had demonstrated his experiment at the École Normale in Paris on Sunday 16 December, with a number of Académie members in the audience. Cailletet had waited until 24 December to notify the Académie because of his forthcoming election as corresponding member. Afraid that presenting his spectacular results immediately before the vote at the meeting of 17 December might have a negative impact, he had kept his report of the liquefaction of oxygen under his hat. Still, Cailletet had taken the precaution of recording his results, sending an account of his experiments to his friend Henri Sainte-Claire Deville, a member of the Académie, on 2 December. Deville was so impressed that he forwarded the letter a day later to the secretary Dumas, who signed it and added a date stamp – a shrewd procedure that

⁹ *Ibid.*, 10.

¹⁰ *Ibid.*, 1214–1216.

prevented a great deal of trouble. As soon as Pictet's communication had been discussed at the meeting of 24 December, the letter was opened and read out to those present, thus establishing Cailletet's priority. On 31 December the newly elected corresponding member reported to the Académie that in the week after Christmas he had also succeeded in condensing nitrogen and air. Even hydrogen exhibited a gossamer-thin haze following sudden expansion, but given the very low critical temperature of that gas (33K), it seems clear that this was attributable to contaminants.¹¹

The experiments of Cailletet and Pictet had produced spectacular results. Yet something was missing. At the Académie meeting of 24 December, Jamin had already noted that to have observed a spray of oxygen or an oxygen haze, however splendid, could not be regarded as anything more than an interim result. The conclusive experiment, which had not yet been conducted, would be one that produced liquid oxygen that would boil away steadily at one atmosphere (that is, air pressure) for a longer period. 'Let us hope that both these capable experimental scientists, each working in his own way, will achieve this conclusive result', said Jamin.¹²

Over five years elapsed before this conclusive result was achieved, and then it was neither Cailletet nor Pictet who fulfilled Jamin's hopes, but – to the great chagrin of the French – two Poles. On 9 April 1883, the Académie member Debray, who was attached to the École Normale Supérieure in Paris, received the following telegram from Cracow: 'Liquid oxygen produced, totally liquid, as colourless as carbonic acid. Expect a report within a few days.'¹³ The telegram was from Zygmunt Wroblewski and Karol Olszewski.

Wroblewski had met Debray in 1882, when he had done some experiments with dissolving carbonic acid in water at high pressure in Debray's laboratory in Paris. He was 37 years old at the time – Wroblewski was a late developer. Born in Grodno as the son of a lawyer, he had been admitted to the University of Kiev in 1862. The following year he had taken part in the uprising against the Russians, who were conscripting Polish students into their army. Wroblewski was arrested and sent to do forced labour in Siberia. In 1869 he benefited from a universal amnesty, but his health was poor, and but for two eye operations he would have lost his sight.

While Wroblewski was recuperating in the Swiss Alps, he met Clausius, who encouraged him to focus on thermodynamics. He resumed his studies in Heidelberg, where he met Kamerlingh Onnes, and gained his doctorate in

¹¹ *Ibid.*, 1270–1272.

¹² *Ibid.*, 1218.

¹³ *Comptes Rendus* 96 (1883) 1140.

Munich in 1874. In exchange for accepting a position at the Jagiellonian University in Cracow (then in Austrian territory) he was granted a scholarship to widen his horizons abroad. He visited London, Oxford and Cambridge, and worked for some time in the laboratory of the *École Normale* in Paris, where he saw Cailletet's apparatus for pressurising and expanding gases. He devised his own specifications for a modified version, and enlisted the services of the famous Parisian instrument-maker Ducretet to build it. At the end of 1882 Wroblewski returned to Cracow as the newly appointed professor of physics, taking his new device with him. It would prove highly serviceable in the assault on oxygen and other 'permanent' gases.

In Cracow, Wroblewski initially collaborated with Karol Olszewski, the son of a landowner from Broniszow in the region of Galicia. Olszewski too had studied in Heidelberg while Onnes was working on his pendulum there, and had gained his doctorate in 1872 under the supervision of Bunsen. In 1876 he was appointed associate professor of chemistry, becoming a full professor in 1891. Olszewski led a reclusive bachelor's existence, living in his institute and sometimes not venturing outside for months on end. The Jagiellonian University (alma mater of Copernicus and Pope John Paul II) suffered from a lack of resources, and he had to make do with old equipment. Frustrating though this was, it also helped to make him an extremely dexterous and inventive scientist.

The theoretically minded Wroblewski and the dyed-in-the-wool experimentalist Olszewski made a perfect partnership. Armed with the Cailletet apparatus from Paris, they achieved in a few months what had eluded Cailletet for five years: making oxygen and other 'permanent' gases liquid, and keeping them liquid for some time. The decisive innovation in comparison to Cailletet's approach was that the two Poles suspended the capillary tube containing the chosen gas in a cylinder with liquid ethylene in which a vacuum was created using a pump. Cailletet himself had been the first to suggest using liquid ethylene as a coolant.¹⁴ But whereas the Frenchman had the ethylene vaporise at 1 atmosphere (i.e. air pressure), thus attaining a temperature slightly below -100°C , Wroblewski and Olszewski had the brilliant idea of pumping out the vapour above the ethylene, a principle that Pictet had applied with his cascade in Geneva, but using sulphurous acid and carbonic acid instead.

By pumping out the vapour, the Poles in Cracow attained the far lower temperature of -139°C , which made all the difference. Whereas Cailletet noticed no change in the oxygen at 150 atmospheres, after which rapid expansion produced very brief and unruly ebullition without any perceptible meniscus, in

¹⁴ *Comptes Rendus* 94 (1882) 1224-1226.

the lower temperature attained in Cracow, 20 atmospheres sufficed to condense the oxygen, without expansion. Oxygen, wrote Wroblewski and Olszewski in *Annalen der Physik und Chemie*, 'is a translucent, highly volatile and colourless liquid with a clear-cut meniscus far flatter than that of carbonic acid. When the pressure is reduced, a foam appears and the liquid becomes thinner towards the surface; at even lower pressure, the liquid vaporises throughout.'¹⁵ Nitrogen and carbon monoxide had also been conquered, but only after a phase of expansion. The vaporisation was so rapid that the Poles could maintain them in a static liquid state for only a few seconds.

Shortly after their successful results of 9 April, Wroblewski and Olszewski parted company; incompatibility of temperament rendered the collaboration unworkable. Wroblewski was a vigorous, energetic man, whose domineering nature was bound to grate on the stolid, patient Olszewski.¹⁶ They each went their own way in cryogenic research, and both claimed to have proposed the decisive idea for producing liquid oxygen; the non-alphabetical order of authors in the article published in the *Annalen* may be an indication that Wroblewski was closer to the truth. It may be added that Wroblewski was the first who saw liquid oxygen not only as a goal in itself, but also as a means to measure physical properties at extremely low temperatures: for this he poured liquid oxygen into a separate glass into which preparations and instruments could be inserted, a procedure whereby he established that electrical conductivity in copper increased at lower temperatures.

The irritations spilled over beyond the Polish duo. In 1884, Cailletet complained that although Wroblewski was meticulous in his reports to the *Comptes Rendus*, as soon as he started writing in Polish he exaggerated the Poles' achievements relative to the French.¹⁷ By way of illustration, Cailletet cited Wroblewski's assertion that all previous attempts to liquefy oxygen had foundered on the impossibility of cooling it to a low enough temperature. In his report to the Cracow academy, the Pole wrote that Cailletet had withdrawn the claim he had made in 1877 to have seen a subtle hydrogen haze. Nothing could be further from the truth, fulminated an incensed Cailletet. On top of this, Wroblewski's claim to have been the first to propose using liquid methane as a coolant, published in the *Comptes Rendus* of 21 July 1883, was also wide of the mark. Cailletet had experimented with methane as far back as

¹⁵ Sigmund von Wroblewski and Karl Olszewski, 'Über die Verflüssigung des Sauerstoffs, Stickstoffs und Kohlenoxyds', *Annalen der Physik und Chemie* 20 (1883) 243-257.

¹⁶ Smoluchowski to Heike Kamerlingh Onnes, 6 May 1915, MB, archives of Heike Kamerlingh Onnes, inv. no. 309.

¹⁷ *Comptes Rendus* 99 (1884) 213-215.

1881, and had deposited a sealed envelope with the Académie establishing priority when it became clear that he would be unable to issue a publication or communication for some time.

A few months after severing their working relationship, Wroblewski and Olszewski each individually picked up the thread of their research into low temperatures. Now that oxygen had been liquefied – although without making it ‘static’ and producing steady boiling at one atmosphere (that is, in contact with the air)¹⁸ – it was the turn of hydrogen. The breakthrough came in January 1884: ‘hydrogen cooled by boiling oxygen liquefied by reducing pressure’, read Wroblewski’s telegram to his Parisian mentor Debray.¹⁹ The Pole had constructed a new device for the purpose, in which he compressed hydrogen in a glass capillary tube to 100 atmospheres. The advantage over Cailletet’s structure was that the expansion was far more rapid, making lower temperatures possible. As in the case of oxygen the previous year, the hydrogen exhibited a haze and an extremely brief and tumultuous ebullition. In his report to the Académie, Wroblewski predicted that static liquid hydrogen could be attained at temperatures not much lower than that of boiling oxygen at low pressure.²⁰

This spurred Olszewski to respond in kind. Within a few weeks he had written to Paris, claiming that he too had conquered hydrogen. In his own experiment, Olszewski allowed the hydrogen, which was cooled with liquid oxygen at a pressure of 6mm Hg, to expand at 190 atmospheres.²¹ Neither he nor his rival Wroblewski was able to reduce the hydrogen to the form of a static liquid, however; the critical temperature of hydrogen was evidently too low. To determine this temperature, Wroblewski conducted a series of experiments in which he measured isotherms of the gas at low temperatures. Tragically, he suffered a fatal accident before achieving any conclusive results. Almost blind, he was working in his laboratory late one night in March 1888 when he overturned a kerosene lamp and suffered severe burns. He lay in hospital for three weeks before finally succumbing to his injuries.

The Leiden cascade

In Leiden, Kamerlingh Onnes was not yet ready to tackle hydrogen. He could not start setting up his cryogenic installations until the academic year 1885-1886,²²

¹⁸ *Comptes Rendus* 97 (1883) 1553-1555.

¹⁹ *Comptes Rendus* 98 (1884) 149.

²⁰ *Ibid.*, 304-305.

²¹ *Ibid.*, 365-366.

²² For the construction of the cryogenic laboratory, see H. Kamerlingh Onnes, ‘Over het Kryogeen Laboratorium te Leiden en over het verkrijgen van zeer lage temperaturen’. *Verslagen* 3 (29 December

after the internal renovations of the laboratory had been completed. In the meantime, Wroblewski and Olszewski had appeared on the scene, and their ‘fine research’ inspired Onnes to adopt the following approach: ‘allow the oxygen to circulate according to Pictet’s method and use it for experiments, in the same way that Wroblewski and Olszewski, following in Cailletet’s footsteps, had learnt to use ethylene.’²³

Onnes had little help at the beginning and the work scarcely progressed. The instrument-maker Kouw duly assembled all the pieces of equipment that Onnes had designed, but maintenance work on the existing instruments took up much of his time, added to which he was regularly called upon to help operate the apparatus. ‘The research could therefore not progress otherwise than at intervals that were sometimes very deleterious’, wrote Onnes. In 1884 the then 20-year-old Karel Bosscha, the youngest son of Onnes’s superior in Delft, had lent a helping hand in setting up the instruments,²⁴ and the apprentice instrument-makers who worked at the laboratory could perform some of the simplest tasks, but Onnes badly needed a second instrument-maker, and had to wait until 1889 before one could be appointed.

Despite these delays, cold was the one thing that occupied Onnes’s thoughts all the time. In Châtillon he ordered the mercury compressor that Cailletet had described in 1883. The pump for compressing pure gases was delivered in the academic year 1884-85, but years of modifications were required before it met Onnes’s stringent demands. The unique feature of the compressor was that a layer of mercury rested on the piston which, by constantly adapting to the shape of the cylinder, prevented some of the gas remaining behind after each compression stroke, which increased the device’s efficiency. Onnes was so enthusiastic about this principle that, even when the compressor turned out to be ‘wholly inadequate’, he said that he would gladly spend a few years improving Cailletet’s design.²⁵

The problem was that the mercury was in contact with the glycerine that lubricated the piston. Since mercury is heavier than glycerine, the latter floated on top, disrupting the operation of the pump. Onnes addressed this problem by mounting a mercury-filled U-shaped tube beneath the cylinder (see fig. 22).

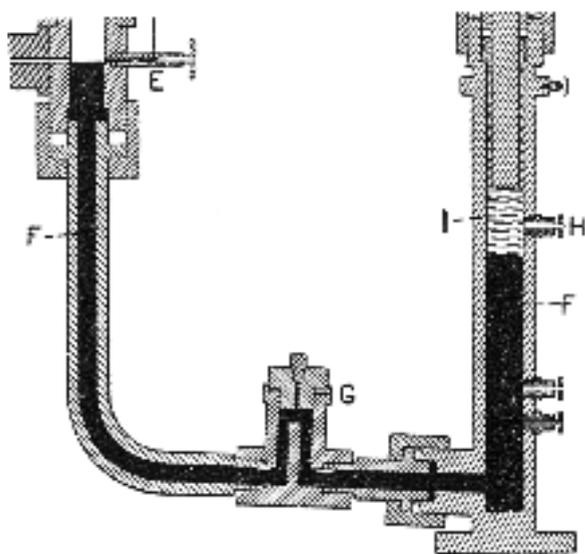
1894) 164-181. *Comm.* 14; *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904*, 9-60.

W.H. Keesom, ‘Prof. Dr. H. Kamerlingh Onnes †; Zijn Levenswerk, de Stichting van het Cryogeen Laboratorium’. *Physica* 6 (1926), pp 81-98; Anne C. van Helden, *De koudste plek op aarde; Kamerlingh Onnes en het lage-temperatuuronderzoek 1882-1923* (Leiden 1989). Translated as: *The coldest spot on earth* (Leiden 1989).

²³ *Op. cit.* note 2, 169.

²⁴ K.A.R. Bosscha to Lorentz, 1 October 1926, N-HA, Lorentz archives, inv. no. 9.

²⁵ *Op. cit.* note 2, 167.



Ill. 22. U-shaped tube with mercury for the Cailletet pump. The glycerine I in front of the piston (on the right) was used as a lubricant. The gas was compressed on the left using the U-shaped tube of mercury (F), a procedure that did not admit impurities.

A second cylinder, containing the piston, was placed above the other end of the U. The piston's up-and-down motion was transmitted through the mercury (communicating vessels) to the original cylinder containing the gas, and in this new construction there was no contact whatsoever between this gas and the glycerine.

Figuring out and testing this modification, and numerous smaller improvements, took Onnes oceans of time. In April 1889 a new 'suction tube safety valve' burst at a pressure of 20 atmospheres. 'Glass all over the room, enormous shock', noted Onnes in his logbook. 'The copper casing was ripped open savagely.'²⁶ He took the barrel of a rifle as the model for his new safety device. Not until 1890 was the pump working satisfactorily. But then he had an instrument on which he could place absolute reliance, which would always be ready for immediate use even if it had remained idle for long periods of time. In 1891, Onnes – to whom maintaining secrecy went against the grain – announced that a publication was forthcoming. In fact the promised article did

²⁶ MB, archives of Heike Kamerlingh Onnes, inv. no. 46.

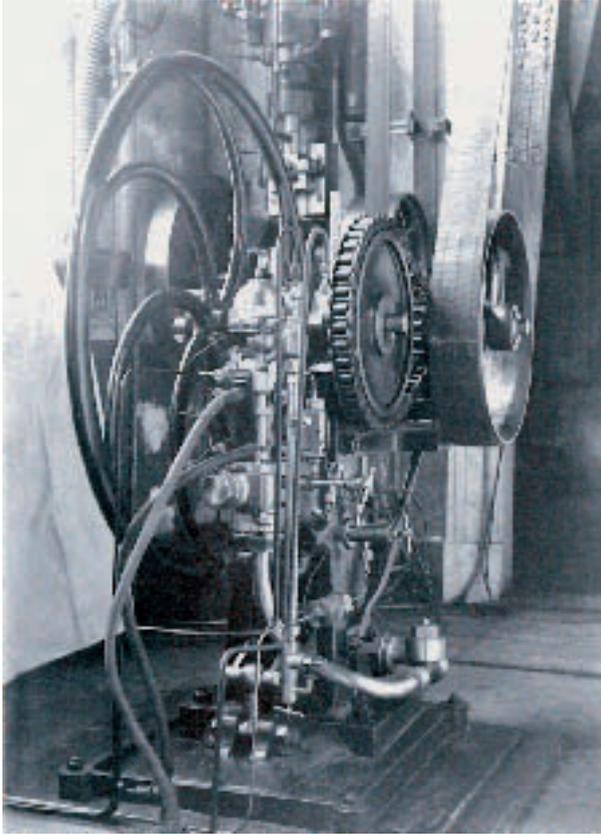
not appear until 1900, when Onnes explained, down to the smallest detail, all the improvements he had made to the pump.²⁷ The Cailletet compressor, which, in combination with a booster, could attain 100 atmospheres, and which was particularly useful in the compression of pure, expensive gases, was a wonderful boon for the Leiden laboratory.

The meticulous design, building, testing and improvement of a cascade to produce liquid oxygen was a hugely taxing project. Onnes had to overcome innumerable technical problems, and besides ensuring that the physics laboratory was running smoothly and supervising PhD students, he spent almost all his time tinkering, soldering and adjusting. He scarcely had any time to do any research of his own. Not until 1894, thirteen years after his *General Theory of Liquids*, did he pick up the thread of his research with two modest articles on the coefficient of viscosity of fluids in corresponding states – an experimental subject on which his PhD student M. de Haas was preparing his dissertation. By then, Onnes was forty years old. In the next six years he published seven articles on the construction of the cryogenic laboratory (all of them in the Academy's *Verslagen*, after which English translations appeared in the *Communications*), and one discussing – before the fact – the liquefaction of hydrogen in the light of the law of corresponding states.

In building his cascade, Onnes took Pictet's experiments as his point of departure. In 1885 he ordered two dual-action pumps from the company that had built Pictet's apparatus, the Société Genevoise pour la construction des instruments physique. In this type of pump, two pistons were mounted on a single piston rod, one behind the other. One of the cylinders created a vacuum, while the other compressed the gas. The devices were intended for the market, and months went by before Onnes had honed their performance and reliability to laboratory level. The pumps had to be ready for action instantly even after a long period of standing idle, and besides Onnes, the laboratory staff also had to be capable of operating and maintaining them. In his article on the building of the cascade, published at the end of 1894 at a time when Leiden had only just mastered the technique of producing liquid oxygen, Onnes described his struggle with the pumps.

'Ensuring that every piece was free of leaks or flaws of any size; applying gaskets that were a perfect fit; choosing the right kind of pipes; making taps with cork gaskets, which did not jam because of the cold, gauge glasses that constantly indicate the level of the condensed gas, and filtering devices to protect the taps – it all took a great deal

²⁷ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory. II: Mercury pump for compressing pure and costly gases under high pressure', in KNAW, Proceedings, 2, 1899-1900, Amsterdam, 1900, pp. 437-458. *Comm* 54.



Ill. 23. Cailletet pump, which Onnes equipped with reverse pistons with mercury on top, to keep the gas being pumped round free from impurities.

of time. Much of what is available today was unknown at that time and therefore had to be constructed in time-consuming ways. Practice had to be gained in a variety of unusual kinds of work.²⁸

What is more, explained Onnes, working with gases such as sulphurous acid, methyl chloride and ethylene posed certain risks; extra safety devices had to be fitted to minimise these hazards in an educational context.

Besides dual-action pumps, the Société Genevoise also supplied components for the cascade's first cycle. In 1887 he had assembled the system. A Pictet pump compressed gaseous sulphurous acid in a condenser (which also

²⁸ *Op. cit.* note 2, 169-170.

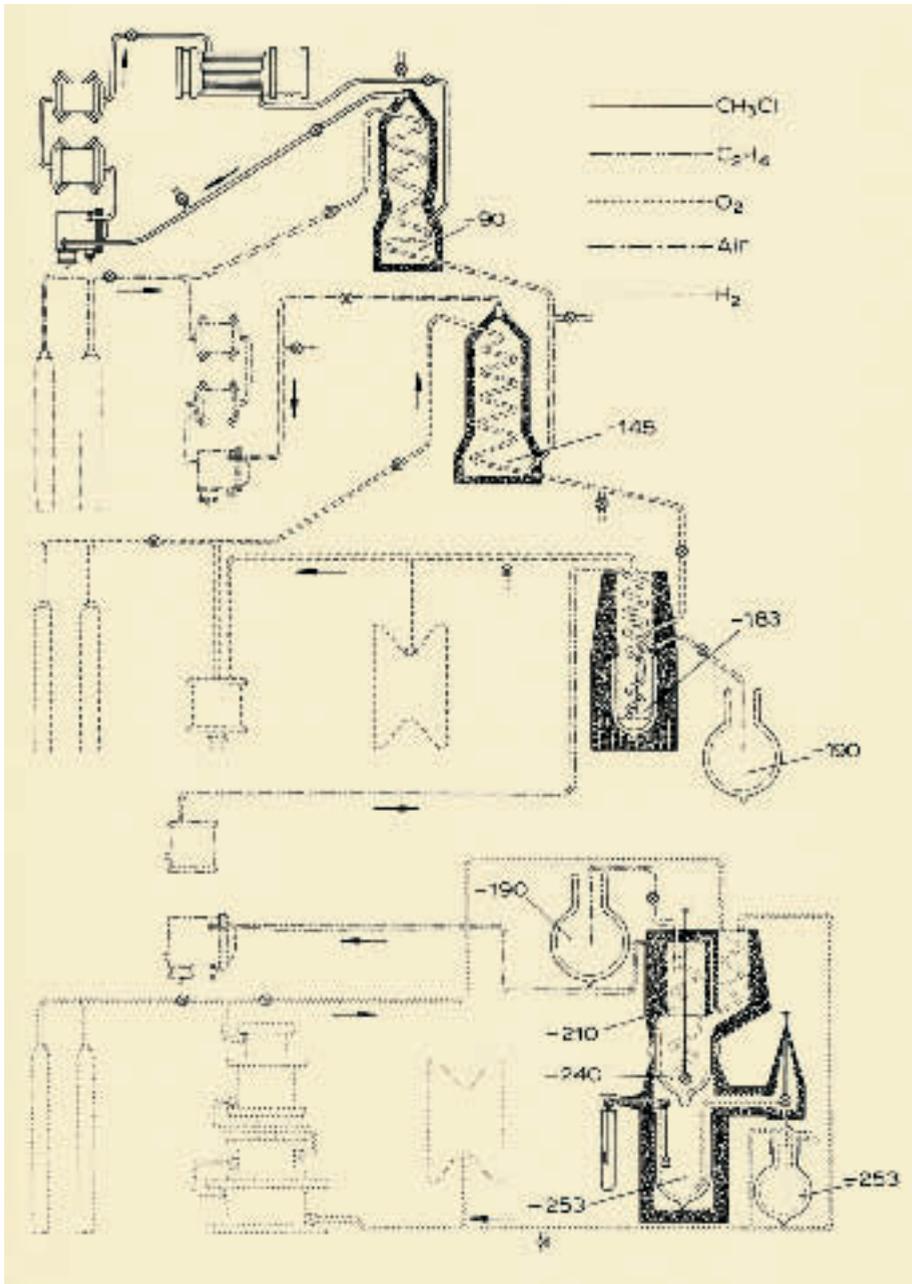
served as storage vessel); a few atmospheres proved sufficient to obtain liquid of approximately -30°C . A cooling circuit of tap water removed the condensation heat that was released. Part of the liquid sulphurous acid was pumped into the 'boiling flask', which also served as condenser for the second cycle with ethylene. Using the Pictet pump to create a vacuum lowered the temperature in this flask to about -70°C , all of which was similar to what Raoul Pictet had achieved ten years earlier. The cycle constituted a metallic system that could easily withstand the pressure generated by liquid sulphurous acid at room temperature. Parts of the cycle that were to reach extremely low temperatures were made of copper.

Onnes soon grew dissatisfied with the Pictet design. His lab logbook records that in 1888 he replaced the toxic sulphurous acid, which was corroding the insides of the system, with methyl chloride.²⁹ The use of the latter as a coolant had been suggested in 1885 by Louis Cailletet, 'to whose genius we are so indebted in this area', wrote Onnes. Not only did Pictet's sulphurous acid cause 'an extraordinary amount of trouble and unpleasantness', but Onnes was also rather unhappy about the construction of the first cycle. It proved to be 'even more inconvenient to use than appeared from the drawing'. To increase efficiency, Onnes fitted the methyl chloride boiling flask with a regenerator spiral: the ethylene from the second cycle passed through a long, thin-walled spiral tube to the methyl chloride boiling flask (where it was condensed at eight atmospheres). Methyl chloride vapour pumped out in the opposite direction imparted some of its cold to the spiral, thus pre-cooling the ethylene. It took about three-quarters of an hour for the boiling flask of the first cycle to fill with liquid methyl chloride at -70°C .

The second cycle contained ethylene. This was an excellent coolant, but it too had certain disadvantages. For instance, ethylene and air constituted a 'highly explosive' mixture, which compelled Onnes to take a variety of safety precautions: the use of steam heating in lab E, electric lighting rather than gas lamps (also installed in 1883),³⁰ and a powerful ventilator to dispel whatever ethylene or methyl chloride gas escaped from the system. Another difficulty was obtaining pure ethylene. When Onnes started on his ethylene cycle in 1887, the gas was not yet commercially available; when it did come onto the market in 1892, Onnes ordered it from Orchard in London. He still had to wait six months for delivery, and when the gas arrived the level of contaminants was found to be 3% – 2% more than the maximum acceptable for Onnes. Contaminated ethylene condensed at a higher pressure, increasing the risk of explosion.

²⁹ MB, archives of Heike Kamerlingh Onnes, inv. no. 46.

³⁰ Heike Kamerlingh Onnes to Zeeman, 22 September 1893, N-HA, Zeeman archives, inv. no. 82.



Ill. 24. Scheme of the cascade with which liquid air was produced in three cycles (methyl chloride, ethylene and oxygen). This liquid air served as a pre-coolant in the hydrogen liquefier (1905), while the helium liquefier (1908) was pre-cooled using liquid hydrogen.

Onnes therefore found himself compelled to prepare pure ethylene himself. In lab F (adjacent to the cryogenic area in lab E), he set up a time-consuming and expensive heating process, which had to be performed at exactly the right temperature. Alcohol vapour was passed through flasks with sulphuric acid, whereby the purification and dehydration apparatus was prepared for continuous use and fitted with the necessary automatic safety and regulatory mechanisms. By 1890, Onnes had perfected this technique such that the ethylene gas produced in Leiden – in portions of one and a half cubic metres – had a purity of 99%. But at low pressure it was impossible to prevent air seeping into the system, and experiments sometimes had to be suspended for this reason. In addition, ethylene would sometimes be lost. The heating system was therefore kept ready for use at all times.

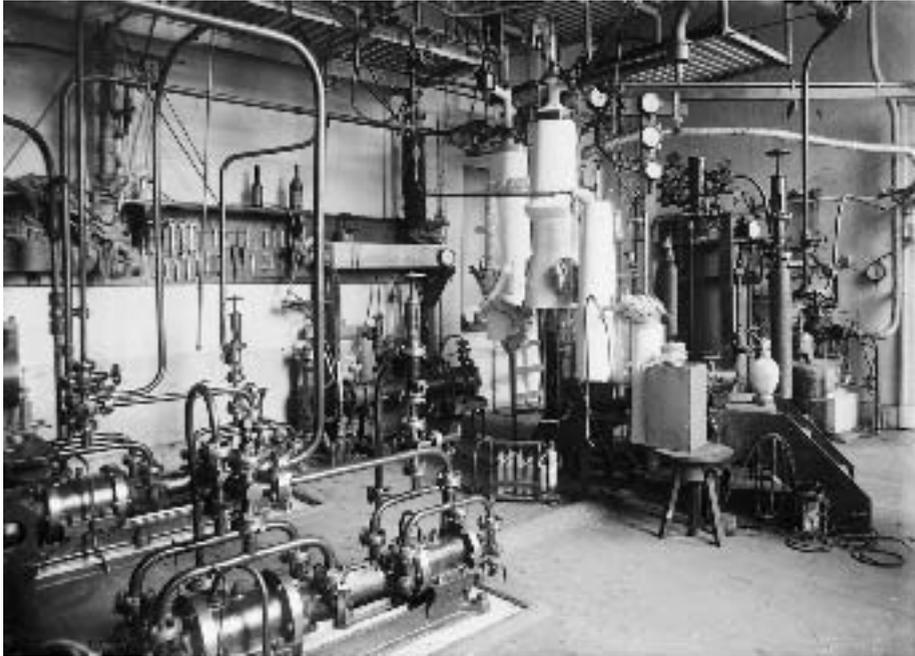
In his design for the ethylene boiling flask (the drawings had been given to Curvers in June 1890; testing and modification started in January 1891), Onnes had integrated the regenerator spiral/heat exchanger (for oxygen from the third cycle) into the apparatus. Onnes had spent many hours racking his brains over this boiling flask, which later served as the model for other boiling flasks and liquefiers in the cryogenic laboratory. Given all the difficulties involved in preparing ethylene, he wanted to minimise its use in the second cycle. In practice, he found that one and a half kilos sufficed – Dewar in London had been working with 50 kilos! The circulation system was entirely made of metal, as in the first cycle, but this time only copper was used. The thin walls were reinforced by ribs to withstand vacuum and overpressure. At the bottom of the boiling flask, liquid ethylene washed around about ten winds of the spiral (volume: 300 cm³; cooling surface: 1,500 cm²) in which oxygen was to be condensed. The required pressure of 60 atmospheres was provided by the Cailletet compressor.

The boiling flask, which was 22 cm in diameter at the base and tapered towards the top, had been constructed to attain the best possible balance between the quantities of condensing surface, the metal to be cooled, the ethylene required, the oxygen produced, and the leakage of heat to the surroundings. For thermal insulation, Onnes had wrapped the apparatus in layers of sheep's wool – to achieve the best result, according to an expert, the wool had to be washed, degreased in warm water, cleaned and combed into the shape of 'French loaves or blanket-like slabs'. The layers of wool, divided into sections by pieces of felt, were separated by cotton and varnished paper. All this served to suppress thermal convection, conduction and radiation. The apparatus worked excellently: in the space of a few hours – without the outside becoming damp (let alone freezing) – the boiling flask contained a litre of liquid ethylene, boiling at a pressure of 2 to 3 cm Hg. The equipment had been designed such that the ethylene gas pumped out of it, which was pre-cooled by

the oxygen gas flowing through the regenerator spiral, left the boiling flask at about room temperature. All the cold in the system was utilised.

As a safety precaution, a 600-litre metal boiler was included in the ethylene cycle, in which the liquid ethylene could expand rapidly in an emergency without the pressure rising dangerously high. Onnes kept surplus ethylene in gaseous form in a welded boiler at a maximum of 15 atmospheres. The cycle included an oil catcher and dehydrator to prevent taps freezing fast as a result of contaminants in the water vapour. It was another year and a half before everything was working.

By then, the oxygen cycle was also ready for use. Onnes wanted to emulate Wroblewski's 1885 procedure by tapping liquid oxygen from the bottom of the regenerator spiral and transferring it to a glass vessel (boiling beaker or cryostat) in which it could boil away gradually, whether or not at lower pressure. Thermometers and preparations to be studied could be immersed in this vessel. Later on it also became possible to transfer liquid oxygen from this vessel to a Dewar flask – a kind of thermos flask. The boiling beaker was encased in a thin-walled air-tight copper casing, which had a layer of felt glued to the interior, around which was nickel paper to prevent thermal radiation. The casing



Ill. 25. The cryogenic laboratory of Kamerlingh Onnes in lab E, 1900.

had two pairs of mica windows on opposite sides, to admit light and to allow an observer to see what was happening inside.

In the first few years of the cascade, there was a shortage of pumps. In the oxygen cycle, the Cailletet compressor plus booster compressed the oxygen, while the two dual-action Pictet pumps were used in the methyl chloride and ethylene cycles. But to cool the oxygen below -182°C (the boiling point at atmospheric pressure) called for an additional vacuum pump. Since Onnes did not have an extra pump in 1892, he decided to temporarily shift the Pictet pump from the first to the third cycle and to place the ethylene spiral tube in a tank containing solid carbonic acid. Tapping substantial quantities of carbonic acid from the cylinders available on the market caused constant problems, since the taps kept freezing. To eliminate the problem of water vapour in the carbonic acid, Onnes asked the Rotterdam company from which he purchased it (the *Nederlandsche Kaenoliet en Koolzuur-Maatschappij*) to pass their product over quicklime before bottling it. In 1893, Onnes borrowed from the navy a Brotherhood compressor pump³¹ – designed for the launching of torpedoes – that he deployed in an extra cycle with methane and, later, in one with nitrogen or liquid air.

After tinkering with the ethylene boiling flask and oxygen boiling chamber, sealing countless leaks, and heating hectolitres of ethylene, on 23 June 1892 it was time to celebrate: Onnes collected his first liquid oxygen in the ‘Wroblewski glass’. It had fragments of dirt floating on the surface, and at 20 cc, it was a modest quantity. ‘Cold is awe-inspiring’ wrote the otherwise so down-to-earth scientist in his lab logbook. The celebrations were short-lived. During the first liquefaction, the oxygen boiling chamber developed a malfunction. Repairs and improvements, including a longer ethylene spiral and a larger oxygen boiling chamber, lasted until December 1893. With these changes, Onnes now possessed a superb installation. Just before Christmas, he made a quarter of a litre of liquid oxygen with his cascade, caused it to boil at low pressure, and showed the bluish fluid to ‘a number of scientific friends’ over the next few hours. In May 1894, Onnes took a Dewar glass of liquid oxygen to the Academy’s meeting in Amsterdam, where his audience was suitably impressed. What was remarkable was not the liquefaction of oxygen – that had been achieved in Poland ten years earlier (and repeated in diverse other laboratories) – but the possibility of doing research at various low temperatures, which Onnes was capable of keeping constant to a hundredth of a degree.

It is interesting to note that the first description of the Leiden cascade, including a selection of detailed drawings, was published in *Revue générale des*

³¹ Correspondence with the navy is preserved in the archives of the Huygens Laboratory.

sciences pures et appliquées. In April 1896, E. Mathias, a professor in Toulouse, published an article in this French journal expressing his enthusiastic admiration for Onnes's cryogenic laboratory.³² A year earlier, in the same publication, Mathias had discussed the cryogenic laboratories in different parts of Europe, not long after Onnes had presented a brief account of his installation in Leiden.³³ James Dewar too had recently been discussed in the *Revue générale*. Mathias had gone to look round the Steenschuur laboratory, and Onnes gave him some splendid construction drawings (on a scale of 1:30, partly in colour), intended for a Leiden publication (a guidebook published a schematic drawing of the cascade on 22 April 1897 on the occasion of the large workshop given for secondary school teachers – 'teachers' day';³⁴ it was not until 1904 that this new invention was communicated to the general public, when the commemorative volume appeared marking the 25th anniversary of Onnes's doctorate).

At the end of his article, which was awash with technical detail, Mathias provided the timeframe for the liquefaction of oxygen in Leiden on 22 May 1894. According to the French report, at 9.15 Onnes began by starting up the methyl chloride cycle; at 10.00 it was time for the ethyl condensation; at 10.37 the first liquid ethylene appeared; at 11.50 the ethylene boiling flask was filled, and the pump was started up; by 12.09 the ethylene pressure had fallen to 7 cm Hg and it was cold enough to pass oxygen through the spiral at high pressure; at 12.44 the oxygen boiling flask started to fill with liquid; at 13.32 the glass was full of liquid oxygen (a quarter of a litre), all at atmospheric pressure; at 14.10 it was possible to experiment with the oxygen bath, and at 16.45 the experiment was concluded.³⁵

The cold produced in Leiden attracted widespread international publicity. The August 1896 issue of the magazine *Nature* showered praise on Onnes's cryogenic installations.³⁶ The article emphasised that Leiden had devised its own, unique approach. Ideas borrowed from Pictet (the cascade), Cailletet (the use of methyl chloride and ethylene) and Wroblewski (the construction used for collecting liquid oxygen) had been integrated into an installation that produced a permanent bath of half a litre of liquid oxygen. Furthermore, *Nature*

³² E. Mathias, 'Le laboratoire cryogène de Leyde'. *Revue générale des sciences pures et appliquées*, 30 April 1896, 381-390.

³³ *Revue générale*, 1895, 86.

³⁴ 'Gids bij het bezoek van heeren leeraren aan hogere burgerscholen en Gymnasia aan het Natuurkundig Laboratorium der Rijksuniversiteit te Leiden op donderdag 22 april 1897', MB, archives of Heike Kamerlingh Onnes, inv. no. 238.

³⁵ See also MB, archives of Heike Kamerlingh Onnes, inv. no. 52.

³⁶ 'The physical laboratory at Leiden (Holland)', *Nature* 54 (13 August 1896) 345-347.

felt that the close attention paid in Leiden to safety and efficiency – the cascade was an extremely high performance apparatus – made it a ‘model cryogenic laboratory’. The magazine presented some figures to illustrate its point. For every 1.5 kilos of ethylene that Onnes used in his installation, Dewar needed 40. And whereas Pictet had driven his cascade with 30 to 40 horsepower, Leiden could manage with 6 to 8 hp. Olszewski needed even less, but he worked with less than 70 cc of liquid oxygen, and did not have a permanent bath. ‘[O]ne cannot but admire the perseverance and skill which the development of this system reveals’, marvelled *Nature*. The author was also extremely impressed with the experiments currently in progress as part of the Lorentz and Van der Waals series. ‘In short, the place is rich in apparatus of all kinds, and possesses numeral appliances; so much so, that one would rank it amongst the best provided (and, one may add, most productive) research laboratories.’

While Onnes was demonstrating his liquid oxygen in the Trippenhuis building in May 1894, Leiden was already engaged in a race with London, Cracow and Berlin to liquefy the next ‘permanent’ gas: hydrogen. Calling it a ‘race’ is not a retrospective description; Onnes himself referred in 1895 to the ‘constant international competition’ in which he was caught up.³⁷ Before discussing this competition, and making the acquaintance of the irascible James Dewar and his secret refrigerators in the Royal Institution, let us first review the other activities taking place at the Steenschuur laboratory.

³⁷ Heike Kamerlingh Onnes to *curatoren*, 5 April 1895, UB Leiden, Archief *curatoren*.

15. The Lorentz series

On 22 April 1897, almost a hundred gymnasium and HBS teachers gathered at the university physics laboratory in Leiden for what we would call today a workshop. The programme included a lecture by Lorentz on ‘the principles of electricity’, a theory of electromagnetism based on the interaction between charged particles and ether, and demonstrations (with explanations) of various experiments in the laboratory. In his introductory speech to the overcrowded lecture-hall,¹ Onnes singled out the laboratory’s two main lines of experimental research. ‘Do I need to name the driving forces behind them?’ he asked,

‘Or have you not already connected these lines of research to the names of two countrymen? – [thus noting] that the activities of this laboratory are concerned on the one hand with the molecular theory developed by Van der Waals, and on the other with the electromagnetic theories in the development of which Lorentz played such an important part.’²

The Lorentz series, the magneto-optical research conducted in Leiden between 1882 and 1904 (culminating in the discovery of the ‘Zeeman effect’ in 1896), has always received less attention than it deserves. The physics laboratory run by Kamerlingh Onnes is primarily associated with liquid helium and superconductivity, and not with magneto-optical research. Yet it was the latter that took precedence until the turn of the century. The magneto-optical research at the Steenschuur laboratory was closely aligned with Lorentz’s micro-approach, in which the protagonists were charged particles in motion known initially as ‘ions’ – in 1897 it became clear that they were electrons. Lorentz led the way in this field. Most other scientists, in particular those working in Britain (with the exception of Joseph Larmor), persisted in adopting a macroscopic approach,

¹ H. Kamerlingh Onnes, *Inleidende toespraak bij het bezoek van HH. Leeraren aan H.B.S. en Gymnasia, aan het Natuurkundig laboratorium der Rijks-Universiteit te Leiden op 22 April 1897* (Leiden 1897).

² *Ibid.*, 8–9.

in which there was no place for molecules, atoms or ions when calculating electromagnetic effects.³

The initial precedence of the Lorentz series is very clear from the *Communications from the Laboratory of Physics at the University of Leiden* – largely English translations of communications that Onnes had made on his students' behalf to the national Academy of Sciences (of which he became a member in 1883; see chapter 22). Onnes launched the *Communications* to make the experimental work being done in Leiden accessible to an international readership. The *Archives Néerlandaises des Sciences Exactes et Naturelles*, published annually since 1868 by the (provincial) Holland Society of Sciences and Humanities, contained primarily surveys, not experimental communications that needed rapid international dissemination. Given that German was still the most important language of communication in physics (the *Annalen der Physik und Chemie*, which from 1876 onwards included appendices with brief summaries, was the most prestigious journal in this period) Onnes's decision to publish in English testified to his foresightedness.

The first issue of the *Communications*, with an account of the PhD research of R Emmelt Sissingh, appeared in 1885. The journal appeared at irregular intervals, from 1899 onwards including *Supplements* containing special articles and pieces with a broader scope. Onnes sent specific issues to fellow physicists who expressed an interest, and set up exchange subscriptions with foreign institutes and libraries. The issues were collected in volumes, the first of which (containing numbers 1 to 12) was published in 1894. Onnes's final contribution (in 1926) was no. 183.

As already noted, for many years most of the research done in Leiden fell under the heading of the 'Lorentz series'. When *Communication* 60 rolled off the presses of IJdo printers in the summer of 1900, 31 of the reports had been concerned with this series – considerably more than the 20 communications related to the theories of Van der Waals (to be discussed in chapter 18). For the rest, the experimental work performed at the physics laboratory related mainly to research methods and techniques.

Lorentz as an experimentalist

When Kamerlingh Onnes first entered the Steenschuur building in September 1882, he had already known Lorentz for ten years. In April 1871, Van Bemelen – with whom Onnes had once stayed for a week as a first-year student

³ For an in-depth technical study of this subject, see Jed Z. Buchwald, *From Maxwell to microphysics: aspects of electromagnetic theory in the last quarter of the nineteenth century* (Chicago 1985).

to revive his pleasure in chemistry experiments (see chapter 3) – had put his former pupil in touch with Lorentz (and Haga). Walking in the woods around Arnhem the boys had discussed ‘the beauty of physics’⁴ and forged a lifelong friendship. In the summer of 1880, Onnes sent a note to Lorentz from his family home ‘t Waelre’ congratulating him on his engagement to Aletta Kaiser (a niece of the famous astronomer), in which he allowed his imagination to conjure up another such walk: ‘Without a doubt we would have woven love and science together in our conversation – in theory; only you are now doing it in practice, and better.’ And by way of preface to a few lines by Emanuel von Geibel (‘Ich bin der dunkle Edelstein / Aus tiefen Schacht gewöhlet / Du aber bist der Sonnenschein / Darin er Farben spielet’):⁵ ‘Perhaps we might have discussed the way in which satisfying our desire for intimacy increases our capacity for work.’⁶ In other words, desire was presented as a catalyst in science.

Hendrik Antoon Lorentz was the son of a prosperous market gardener in Arnhem.⁷ ‘Hentje’ was a quiet, cheerful boy who was quite slow in learning to speak. Even so, he soon displayed unusual aptitude: at ten years of age he used his pocket money to buy a table of logarithms, and he soon learned to use it. At the HBS, where Herman Haga was one of his classmates, the teacher H. van der Stadt bred in him a love of physics. Van der Stadt sent his brilliant pupil to run around inside a concert hall with an anemometer attached to a piece of wood, to ascertain the relationship between velocity and the reading on the anemometer. Although Lorentz was by inclination a theorist, he never lost his interest in experimental physics.

As a student in Leiden he made a great impression on those around him. Kaiser decided to resume a series of lectures in theoretical astronomy that he had abandoned for lack of students just for Lorentz, (‘They don’t understand a word I’m saying, except for that boy with the dark eyes’).⁸ After Lorentz had gained his Bachelor’s degree (in 1871) he continued his studies in Arnhem, where he taught at evening school. He studied for his PhD under the supervision of Rijke, and in December 1875 he gained it *magna cum laude* on the strength of his dissertation *On the theory of the reflection and diffraction of light*.⁹

⁴ H. Kamerlingh Onnes, ‘Huldiging van professor Lorentz bij de herdenking van zijn 50-jarig doctoraat 11 December 1925’. *Physica* 6 (January 1926) 5.

⁵ ‘I am the dark gem / Quarried from deepest shaft / But you are the sunshine / In which the colours play’.

⁶ Heike Kamerlingh Onnes to Lorentz, 27 July 1880, N-HA, Lorentz archives, no. 39.

⁷ On Lorentz, see A.J. Kox, ‘Hendrik A. Lorentz 1853-1928’, *Van Stevin tot Lorentz: portretten van achttien Nederlandse natuurwetenschappers* (Amsterdam 1990) 226-242; A.D. Fokker, ‘Hendrik Antoon Lorentz’, in T.P. Sevensma (ed.), *Nederlandsche beelden der wetenschap* (Amsterdam 1946) 51-94.

⁸ *Op. cit.* note 4, 8.

⁹ *Over de theorie der terugkaatsing en breking van het licht* (Leiden 1875).



Ill.26. Hendrik Antoon Lorentz, professor of theoretical physics in Leiden, around 1895; drawing by Jan Veth.

This work built on the theory developed by James Clerk Maxwell (as formulated by Helmholtz), who had defined light, in 1865, as an electromagnetic vibration in the ether, and set out the programme on which Lorentz embarked in 1878, as professor of mathematical physics. ‘According to Lorentz’s theory of electricity’, Kamerlingh Onnes explained to the assembled secondary school teachers in 1897, ‘light oscillations are caused by small charged particles, light ions, which, through their movements, or electrical oscillations, transmit electrical waves in the world ether.’¹⁰

In 1892 Lorentz published a long article in the *Archives Néerlandaises*,¹¹ which can be viewed as an intermediate step towards what was later called his ‘electron

¹⁰ *Op. cit.* note 1, 18.

¹¹ H.A. Lorentz, ‘La théorie électromagnétique de Maxwell et son application aux corps mouvants’, *Archives Néerlandaises* 25 (1892) 363–552.

theory'. In 1895, two years before the teachers' workshop, Lorentz had written a monograph setting out his views on magneto-optical phenomena, *Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Körpern*.

Onnes, who had immediately informed Lorentz of his application for the professorship of experimental physics at Leiden, went to see his new colleague at his home on Hooigracht two days after his appointment, on 5 September 1882. The two men discussed the large lecture for medical students and 'beginners' that Onnes was to take over from Rijke, and their discussion also touched on Lorentz's need of a 'room' in which to conduct experiments. This was evidently a sensitive issue, since on 25 September, Onnes noted in the diary he kept during his early months in Leiden: 'Lorentz: Won't immediately accept offer of room because gossip here has already spread its nets over promise of allocation of laboratory rooms.' This gossip was probably fuelled by the plan to banish the instrument collection, Rijke's pride and joy, to the attic, to create more laboratory space downstairs. Onnes discussed the question of space with Bosscha, and they conceived the idea of allocating one of the ground-floor rooms to 'the assistant' (Sissingh) and Lorentz. In mid-November, when Onnes's inaugural address was behind him and the new professor took up his task in the physics laboratory, Lorentz agreed to this plan.¹²

What kind of experiments was Lorentz planning to conduct? At this time, he was doing theoretical research on the 'Hall effect' and the related rotation of the plane of polarisation of light. The 'Hall effect', identified in 1879 by Edwin Hall in Baltimore, is the phenomenon whereby if an electric current passes through a thin sheet of metal (Hall used gold) and a magnetic field is applied perpendicular to the current, a potential difference arises between the two sides of the metal. A moving charge, we would say now, is subject to a Lorentz force perpendicular to the plane of the current and the magnetic field; the electrical and magnetic forces on the moving electron are in equilibrium. The Hall effect was related to the 'Kerr effect' identified three years earlier: when polarised light is reflected by a magnetised mirror, the plane of polarisation is rotated. With his theory, Lorentz, who published his findings in the *Verslagen* of the Dutch Academy in June 1883 – later that year his PhD student W. van Loghem elaborated it in more detail¹³ – was able to calculate the size of the Kerr effect accurately.¹⁴

¹² 'Aanvraag Lorentz om praktisch te werken', MB, archives of Heike Kamerlingh Onnes, inv. no. 260.

¹³ W. van Loghem, *Theorie der terugkaatsing van het licht door magneten* (Leiden 1883).

¹⁴ H.A. Lorentz, 'De door Hall ontdekte werking van een magneet op een electrischen stroom en de electromagnetische draaiing van het polarisatievlak van het licht', *Verslagen en Mededelingen KAW*, second series, 19 (June 1883) 217-248.

The first thing Lorentz did in room G of the physics laboratory (regularly assisted by Onnes) was to make a routine study of the operational capacity of the Jamin-type spectrometer. When this was finished at the beginning of 1883, he embarked on a piece of ‘original research’: he conducted Kerr’s experiment with mirrors made of silver, soft iron, and steel. The idea was to determine the intensity of the Kerr effect by allowing polarised light to be reflected back and forth several times between two parallel magnetised steel mirrors. In the article he wrote for the Academy in June 1883, Lorentz said the measurements he had obtained were ‘rough’ and hoped that he would soon have something further to report.

No publication was forthcoming, however, and the evidence suggests that Lorentz’s excursion into experimental physics was brief. In March 1883 Onnes fell ill, and the responsibility for teaching the large lecture shifted to Lorentz – an arrangement that became permanent when Onnes’s health proved to be fragile. Lorentz no longer had time to conduct experiments, and Sissingh took over the work on Kerr’s experiment. Lorentz did continue to follow closely the optical research done in Leiden, and in the commemorative volume published to mark the 25th anniversary of Onnes’s doctorate (in 1904) he wrote a chapter on ‘Optical and Magneto-Optical Research’ summing up the advances that the laboratory had achieved in this field.¹⁵

The Sissingh phase difference

Before Sissingh could get down to studying the Kerr effect, he had to finish his doctorate. Whereas under Rijke he had done little more than assist during lecture demonstrations and the advanced students’ laboratory work, when Onnes took over Sissingh immediately started setting up his own research. As his subject he took the reflection of polarised light by a metal mirror: this was where the Lorentz series began. After he had built up and tested the experimental setup, work on the measurements started in the winter of 1883–1884. In March 1885, Sissingh gained his doctorate on the strength of his dissertation on the measurement of the elliptical polarisation of light.¹⁶

Let us take a closer look at this research, and Onnes role in it. To start with, Sissingh replaced the Jamin-type spectroscopy used by Lorentz with the more robust Meyerstein type, which Bosscha had supplied on loan. The light that struck the mirror was of a single colour, ‘plucked’ from the spectrum that a

¹⁵ H.A. Lorentz, ‘Optische en magneto-optische onderzoekingen’. *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904) 181–259.

¹⁶ *Metingen over de elliptische polarisatie van het licht* (Leiden 1885).

flint prism casts from a carbon lamp (in winter) or from sunlight striking a heliostat (in the summer). The spectroscope was equipped with two Nicol prisms, composite plates of calcite (Iceland spar) with the special property that they admit light oscillating in only one direction. One of the Nicol prisms served to polarise light that was unpolarised. The other served to analyse the light reflected by the mirror. For if the directions that two Nicol prisms will admit are placed perpendicular to one another, no light is admitted at all. Any change in the plane of polarisation as a result of reflection by a metal mirror would immediately become apparent, since in that situation light *would* penetrate the ‘analyser’ prism, which would have to be rotated through a certain angle in order to restore the light’s ‘extinction’.

Metals have the property that when reflecting light (provided the plane of oscillation is neither in or perpendicular to the plane of incidence) they convert linearly polarised light into *elliptically* polarised light. The former is comparable to the wave that forms in a rope when the end moves up and down (or back and forth), while the latter resembles the wave that forms when the end describes an ellipse perpendicular to the direction of the rope. This ellipse (which can be construed as a combination of two linear oscillations of different amplitudes and with a phase difference) was measured using a Babinet compensator. This is a precision instrument consisting of two parallel wedge-shaped quartz plates, one of which can be adjusted precisely using a micrometer screw, thus allowing the total thickness to be varied. Since the two components of the elliptically polarised ray of light penetrated the quartz at different velocities, the phase difference could be cancelled out by adjusting the thickness of the quartz combination: if the compensator was adjusted appropriately, it would restore linearly polarised oscillation, the orientation of which was an axis of the ellipse.

In November 1882, Sissingh started adjusting and improving the Babinet compensator, with Onnes adopting a supervisory role. ‘I am extremely sorry to hear that the compensator is still giving you so much trouble’, wrote Onnes in July 1883 from Switzerland, where he was convalescing,¹⁷ advising Sissingh to look for better Nicol prisms. Finding examples that would not bend the rays of light was a taxing assignment, but the result was an experimental setup in room G of the physics laboratory, including a collimator and a viewer, that was far more accurate than those of Jamin in Paris or Quincke in Heidelberg.

Sissingh’s measuring results with silver mirrors (including an underwater setup) and soft iron were in perfect accord with Cauchy’s theory, published in 1839. ‘The correspondence with the formula is truly admirable’, rejoiced

¹⁷ Heike Kamerlingh Onnes to Sissingh, 22 July 1883, MB, archive 8.

Onnes one summer holiday later, from Soden, ‘and provides fresh evidence that the Babinet compensator is one of the most refined measuring instruments available.’¹⁸ In Onnes’s absence, Sissingh received Gustav Wiedemann, editor-in-chief of the *Annalen*. The visit presented a fine opportunity to draw the attention of someone with an international reputation to Leiden’s new physicist. ‘It must have been delightful for you’, wrote Onnes, ‘to display the soundness of your work by showing him the device. This will also ensure that your results receive the publicity they deserve.’¹⁹

Lorentz followed Sissingh’s activities closely and sometimes made practical suggestions.²⁰ But Sissingh was unable to demonstrate the temperature effect he had predicted in the ‘ellipticity’ of the reflected light rays. The method he used to heat the mirror (to 125 °C) derived from Onnes, and the entire methodology bore the unmistakable stamp of the ‘knowledge through measurement’ philosophy: first designing a measurement method, constructing the separate pieces of equipment with the utmost care, tracking down and eliminating sources of errors, and hence maximising the accuracy of measurements. Sissingh’s dissertation exhibited very thorough workmanship, but could scarcely be called spectacular, since he was concerned with verifying a theory postulated in 1839.

From 1885 onwards, the research in the Lorentz series concentrated on the influence of magnetism on light. In 1895 the work was expanded to include the Hall effect. In this magneto-optical work, three separate effects were studied. In lab G, Sissingh, Zeeman and Wind performed experiments with the Kerr effect: the rotation of the plane of polarisation when light rays were reflected in a magnetised mirror. Meanwhile, in lab C, Siertsema was investigating the Faraday effect: the rotation of the plane of polarisation in a column of compressed gas or liquid subject to a magnetic field. And in lab I, Zeeman was studying the reactions of a light source to a magnetic field – what came to be known as the Zeeman effect (see chapter 16). Of these four physicists, Siertsema, who became curator of the Physics Laboratory in 1894, stayed at his post the longest. His appointment as professor at Delft’s Polytechnic (renamed ‘Technische Hogeschool’ or Institute of Technology a year later) on 1 August 1904 marks the end of the Lorentz series.

After gaining his doctorate, Sissingh switched to researching the Kerr effect – a study that would conclusively influence magneto-optical theory-forming in favour of a micro-approach. After Lorentz and Van Loghem had formulated

¹⁸ *Ibid.*, 12 August 1884.

¹⁹ *Ibid.*, 7 September 1884.

²⁰ *Ibid.*, 23 September 1884.

and elaborated their Kerr theory in 1883, so that they could perform calculations with it, a number of experimental physicists took the research further. Initially the researchers also looked at the refracted light rays that penetrated *into* the magnetic mirror. This called for an experimental tour-de-force: making a magnetised mirror that was so thin that it reflected some of the light while allowing some through. In 1884, Kundt – a scientist working in Strasbourg – managed to precipitate transparent layers of iron, cobalt and nickel on platinised glass and to measure the Kerr effect in the refracted as well as the reflected light rays.²¹ Lorentz believed that this was unnecessary, however; it sufficed to measure it in the reflected rays.

Sissingh's work on the Kerr effect followed on from the research done by P. Kaz (working under Van der Waals in Amsterdam), whose 1884 doctoral dissertation – an isolated study unrelated to any research programme – discussed the reflection of light by magnets. The Italian physicist Auguste Righi also published on this subject in 1887.²² But the accuracy of this work fell very far short of the measurements made in Leiden.

Since Kaz's Amsterdam study had focused on *polar* reflection, in which the magnetic field was perpendicular to the metal mirror, Sissingh initially concentrated on *equatorial* reflection, in which the magnetisation is parallel to the mirror, in the plane of incidence. In this experiment, light, either polarised in the plane of incidence or perpendicular to it, struck an iron mirror.²³ This mirror was a section – ground smooth – of an iron ring (diameter 10 cm; 6 mm thick) wound around with seven layers of copper wire through which a 15-ampère electric current was passed, using a battery. The magnetic field lines, caught in the iron, ran parallel to the reflective surface. The rotation of the plane of polarisation was very minor: in the case of equatorial reflection the Kerr effect brought about an extra component in the reflected light oscillations with an amplitude of less than 0.1 per cent of the original oscillation (in the case of polar reflection, this figure was about 0.6 per cent). In order to be able to measure this weak component through the rotation of the Nicol prisms (accuracy of readings was 0.33 minute of arc), white light was needed, which ruled out the use of the Babinet compensator.

The amplitude of the magnetic component in the reflected light and the phase difference with the primary component was determined at various

²¹ A. Kundt, 'Die electro-magnetische Drehung der Polarisationsebene des Lichtes durch Eisen, Cobalt und Nickel', *Annalen der Physik und Chemie* 23 (1884).

²² A. Righi, 'Recherches expérimentales sur la lumière polarisée réfléchie par la surface équatoriale d'un aimant. *Annales de Chimie et de Physique*, serie 6, 10 (1885).

²³ R. Sissingh, 'Metingen over Kerr's verschijnsel bij magnetisatie evenwijdig aan het spiegelend oppervlak', *Verhandelingen van de KAW*, tweede serie, 28 (1890) 1-65. *Comm.* 3.

angles. The Nicol prisms were placed according to both a 'minimum method' and a 'null method' (the latter having been suggested by Van der Waals in 1884). The two methods were complementary. To improve accuracy, the average was taken of 200 to 300 individual observations, with rotations measuring only a few minutes. Sissingh toiled away at these measurements for four years, in addition to his work as laboratory assistant. It was sheer drudgery, but the results were significant.

Comparison with the theory of Lorentz and Van Loghem showed that the amplitudes measured were correct, but the phase constantly differed by 85° , regardless of the angle of incidence. Zeeman (whose background is discussed below) helped to record measurements from 1889 onwards and took over the research on the Kerr effect in 1890 when Sissingh took a teaching job at the Polytechnic. He too found a 'Sissingh phase difference' when he studied polarised light undergoing polar reflection in iron and cobalt, irrespective of the angle of incidence, the difference varying from one metal to the next.²⁴ The non-ferromagnetic tellurium, silver, palladium and platinum exhibited no effect.

For much of 1893, Zeeman, who was conducting research on the propagation of electrical oscillations in liquids with Professor Emil Cohn in Strasbourg, was replaced by Cornelis Harm Wind. A graduate of Groningen University, Wind started out in Leiden as Onnes's and then Lorentz's assistant. Following on from Zeeman's work, he investigated polar reflection in nickel, and here too he discovered a 'Sissingh phase difference'.²⁵ After Zeeman's return from Strasbourg, Wind went back to Groningen. At the beginning of 1894 he was awarded his doctorate (with Professor Haga as supervisor) for his dissertation on the determination of local variations in geomagnetism in the brand-new physics laboratory in Groningen, which was specially equipped to measure magnetic phenomena.

How could this phase difference be reconciled with the theory of Lorentz and Van Loghem? The theory had failed, Lorentz himself concluded bluntly, but he was nonetheless 'encouraged' by the consistency of the deviation. In

²⁴ P. Zeeman, 'Over metingen over het verschijnsel van Kerr bij polaire reflectie op ijzer, kobalt en nikkel', *Verslagen* 1 (June 1892) 19-22. *Comm.* 5; P. Zeeman, 'Over metingen over het verschijnsel van Kerr bij polaire reflectie op kobalt bij verschillende invalshoeken' 1 (October 1892) 58-60. *Comm.* 5; P. Zeeman, 'Vergelijking van metingen over polaire terugkaatsing op magneten met de theorieën van Goldhammer en Drude' 2 (October 1893) 82-86. *Comm.* 8; P. Zeeman, 'Het verloop der phase bij polaire terugkaatsing op kobalt en nikkel en de hoek van teekeningkeering der nuldraaiing ψ_{ip}° volgens theorie van waarneming' 2 (April 1894) 175-179. *Comm.* 10.

²⁵ C.H. Wind, 'Meting over Sissingh's magneto-optisch phaseverschil bij polaire reflexie op nikkel', *Verslagen* 2 (January 1894) 116-123. *Comm.* 9.

1892 and 1893, David Goldhammer (Kazan, Russia) and Paul Drude (Göttingen) set out to repair the theory of the Kerr effect – by this time the Sissingh phase difference, which foreigners were initially inclined to disbelieve or play down, according to Onnes,²⁶ had been established beyond all doubt. Onnes wrote to Sissingh that he was delighted with Goldhammer's involvement: 'This certainly livens things up.'²⁷ J.J. Thomson was also studying the phenomenon in Cambridge, and reached conclusions similar to Drude's. The Leiden findings showed that Goldhammer was right, although Drude, who still held firm to a macroscopic approach, refused to accept this at first. Both aggressively claimed victory. 'It is very strange that Drude will not admit that his theory constitutes a special case of mine', Goldhammer wrote at the beginning of 1893 to Onnes²⁸ – who was keeping him informed of the latest results achieved in Leiden with letters and the *Communications*. Onnes made no bones about his opinion in a letter to Sissingh: 'I think that Drude needs a dressing down!'²⁹ The disadvantage of Goldhammer's micro-theory was that its relation to the Maxwell equations was rather unclear, besides which it was based on a 'purely mathematical hypothesis',³⁰ without any clear physical interpretation.

It was Wind, a gifted theorist as well as an experimentalist, who – encouraged by Lorentz – was the first to propose a physical theory that could explain the experimental findings. He sought the explanation for the Sissingh phase difference in the coexistence of a 'displacement current' and a 'conductive current', each of which was influenced by the magnetic field in its own way. His first theoretical communication was submitted to the Academy's meeting of September 1894 by Lorentz.³¹ In January that year he had published his observations with nickel through the mediation of Onnes.³² Wind insisted in publishing a piece under his own name instead of 'surrendering' it for inclusion in a more general article being prepared by Sissingh. Onnes thought this understandable: Wind still had to make a name for himself in Groningen. Onnes also had no objection to Wind introducing the term 'Sissingh phase difference'. This heading, he told his associate Sissingh (who had by then been

²⁶ *Op. cit.* note 1, 25.

²⁷ Heike Kamerlingh Onnes to Sissingh, 31 May 1892, MB, archive 8.

²⁸ Goldhammer to Heike Kamerlingh Onnes, 29 January / 8 February 1893, MB, archives of Heike Kamerlingh Onnes, inv. no. 297.

²⁹ Heike Kamerlingh Onnes to Sissingh, 19 September 1893, MB, archive 8.

³⁰ C.H. Wind, 'Eene Studie over de theorie der magneto-optische verschijnselen in verband met het Hall effect', *Verhandelingen*, vol. 5, no. 3 (December 1896) 1-91.

³¹ C.H. Wind, 'Beschouwingen over het magneto-optisch verschijnsel van Kerr', *Verslagen* 3 (September 1894) 82-89.

³² *Op. cit.* note 25.

appointed in Delft,³³ would absolutely not deprive the discoverer of this effect of his priority in this connection.³⁴

In December 1896, by which time Wind had been appointed *lector* of mathematical physics and physical chemistry in Groningen – a second, more probing treatise appeared.³⁵ Besides providing a conclusive explanation for the Hall and Kerr effects and the rotation of the polarisation plane in a magnetic field, Wind surprised the scientific world with an effect hitherto deemed impossible – which would become known as the ‘Wind effect’. If a polarised beam of light struck a metal mirror, with the magnetisation perpendicular to the plane of incidence, Wind maintained that there would, after all, be a perceptible rotation. At his request, Zeeman immediately set to work in Leiden to demonstrate this; and the – minuscule – effect was indeed recorded.³⁶

Wind’s two theoretical articles about the Kerr effect, which he wrote under Lorentz’s supervision, were not published in the *Communications*. Translated summaries appeared in the *Beiblätter* (1895), the *Physical Review* (1898) and the *Archives* (1899), but these made little impact. Although the empirical Sissingh phase difference had served as a catalyst in the shift from macroscopic to microscopic electromagnetism, Wind and Lorentz had negligible influence in the 1890s. The success of Lorentz’s ‘ion’ theory in explaining the Zeeman effect (see chapter 16) initially made little difference. In 1900, when Drude had been ‘converted’ and introduced ‘ions’ in his influential textbook *Lehrbuch der Optik*, his derivation of the ‘Wind effect’ mentioned neither Wind nor Lorentz.³⁷ In consequence, Joseph John Thomson, who discussed the Kerr effect in his *Notes on recent researches in electricity and magnetism* (1893), completely ignored Wind in his article on magneto-optics for the famous 1911 edition of *Encyclopaedia Britannica*.³⁸ True, the Groningen physicist had had the temerity to comment, in his 1894 Academy article, that Thomson had based his conclusion on the displacement current in relation to the Kerr effect on ‘a flawed correspondence of the theory with observation’, but this is surely not the sole reason for Thomson’s omission.

³³ Heike Kamerlingh Onnes to Sissingh, 17 September 1890, MB, archive 8.

³⁴ *Ibid.*, 19 September 1893.

³⁵ *Op. cit.* note 30.

³⁶ P. Zeeman, ‘Metingen over den invloed eener magnetisatie, loodrecht op het invalsvlak op het door een ijzerspiegel teruggekaatste licht’, *Verslagen* 5 (June 1896) 103–110. *Comm.* 29.

³⁷ Jed Z. Buchwald, *From Maxwell to Microphysics* (Chicago 1985) 257.

³⁸ J.J. Thomson, ‘Magneto-optics’, *Encyclopaedia Britannica*, 1911, vol. 17, 388–391.

The first to discover that magnetism affects light, in 1845, was Michael Faraday. In the Royal Institution, London, Faraday passed polarised light through a perforated pole shoe of a powerful electromagnet. When he placed a piece of glass with borate of lead in the magnetic field and passed light through it, he found that the polarisation direction had rotated.

This rotation was further studied in Leiden by Lodewijk Hendrik Siertsema, who had gained his doctorate in Groningen in 1890 (supervised by Haga) with a dissertation on the determination of refractive indices. In 1893 he came to Leiden, where he initially succeeded Kuenen as a teaching assistant, becoming curator two years later. Instead of a perforated pole shoe, Siertsema used two reels of wire placed one behind the other, with a total length of two metres (3,650 winds; internal diameter 6 cm; reels fed with 60 ampères from a dynamo), in which the copper test tube with the chosen gas or fluid was inserted. To neutralise the temperature increase in the electromagnet, and thus to prevent convection flows arising from temperature differences in the test tube, the tube was placed in a second, larger tube through which water flowed. In the winter, when tap water was a good deal colder than room temperature, the ends of the tube were wrapped in cotton wool providing thermal insulation. Attached to these ends were brass extension pieces containing the 'polariser' and 'analyser' Nicol prisms. The holders could not be made of iron, because this would complicate the calculation of the strength of the magnetic field. To make them tough enough to withstand the high pressure, Onnes had them produced at the artillery foundry in The Hague from homogeneous bronze used in the manufacture of cannons. The light in Siertsema's experiment came from a carbon lamp of the type used for navy searchlights, placed in an iron case.

Siertsema started with gases: oxygen, air, nitrogen, hydrogen, nitric oxide and carbonic acid. To magnify the Faraday effect, he compressed them in the test tube to a maximum of 100 atmospheres. Pure oxygen was unavailable commercially and had to be prepared in the laboratory: diluted sulphuric acid was electrolysed in ten basins at a time. The Cailletet pump compressed it in the test tube without any contaminants becoming mixed in – the first link between the Lorentz series and the cryogenic laboratory. The recorded measurements were compared with the numerous formulas for 'magnetic rotation dispersion' that were in circulation at the time.³⁹ Mascart's yielded the best correspondence, but Siertsema did not venture to propose a theoretical physical explanation.

³⁹ L.H. Siertsema, 'Over de dispersie bij de magnetische draaiing in zuurstof', *Verslagen* 3 (January 1895) 230-238. *Comm.* 15c.

After the gases, Siertsema turned to liquids: sugar solutions of varying concentration and pressure, water, red prussiate of potash and liquid methyl chloride and nitric oxide ($-90\text{ }^{\circ}\text{C}$ at atmospheric pressure). Liquid air and liquid oxygen were also on the list, as Onnes told the visiting teachers, but they were never used. Both could be tapped in Dewar vessels in the cryogenic laboratory (lab E), and a compressor could be used to transfer it to the test tube in lab C on the other side of the corridor. This time the test tube was made of glass and ebonite, it was shorter and thicker, and had insulation to prevent turbulent boiling. But to obtain a ‘completely calm liquid, entirely free of rising bubbles’ was not easy, and adjusting the Nicol prisms also posed difficulties.⁴⁰

Siertsema determined the rotation of the plane of polarisation by regulating the analyser prism until the ‘extinction’ of the light had been restored. Here too, Leiden’s research was far more accurate than that previously conducted by Kundt, Röntgen and Becquerel. Since the Nicol prisms were attached to the test tube, it was hoisted in its entirety. Up to 4^{-} , the maximum rotation in these experiments, this was not a problem. For each colour of light, the rotation of the polarisation plane was measured by mirror reading, resulting in a dispersal graph. Violet light exhibited a greater rotation than red.

Onnes presented the results of these experiments to the Academy from January 1895 onwards in a series of brief reports, after which they were published in translation in the *Communications*. A longer general account of Siertsema’s work appeared in 1899 in the *Archives Néerlandaises*.⁴¹ This too provided little more than an account of the apparatus used and a bloodless enumeration of the recorded measurements. This branch of the Lorentz series did not provide any new insights and apparently foundered prematurely because of technical cryogenic problems. In August 1904, Onnes’s right-hand man took a post in Delft and the experimental setup was dismantled.

Finally, there was the Hall effect. After all the research into the closely related Kerr effect, it was only logical that the Leiden laboratory should look at the Hall effect too. Two of Onnes’s students took on the task. Adriaan Lebrecht (Zeeman’s brother-in-law) gained his doctorate in 1895 for a dissertation on ‘Measurements of the Hall effect in bismuth’, followed two years later by Ewoud van Everdingen Jr, whose work dealt with ‘Measurements of the Hall effect and the increase of resistance in a magnetic field’ – any dissertation

⁴⁰ L.H. Siertsema, ‘Measurements on the magnetic rotation of the plane of polarisation in liquefied gases under atmospheric pressure. II. Measurements with methyl chloride’, in KNAW, Proceedings, 5, 1902-1903, Amsterdam, 1902, pp. 243-247. *Comm.* 80.

⁴¹ L.H. Siertsema, ‘Mesures de la polarisation rotatoire de l’oxygène et de l’autres gaz, dans divers parties du spectre visible, et détermination de la constante de rotation magnétique de l’eau pour la raie D du sodium’, *Archives Néerlandaises*, Series II, vol II (1899) 291-380.

from the physics laboratory in Leiden was almost certain to have a title beginning with 'Measurements'. After gaining his PhD, Lebret found employment at an ozone factory in Schiedam. Van Everdingen stayed in Leiden for a few years, eventually accepting a post at the Royal Dutch Meteorological Institute (KNMI) in De Bilt in 1902.

The Hall effect, in effect a rotation of the equipotential lines in a metal sheet in a magnetic field, was most marked in bismuth – the lower the temperature, the stronger the effect – and the research in Leiden therefore concentrated on this metal. In order to measure the phenomenon accurately and to avoid disruptive thermal effects, Lebret used a compensation method that was also applied by Van Everdingen. The idea was to bring the result of a differential galvanometer, which measured the difference between the Hall current and an adjustable current derived from the main current, down to zero. Since Hall current and compensation current had the same basis, the main current was irrelevant. Furthermore, the main current only needed to be switched on briefly, so that no significant development of heat occurred. Only the increase in resistance in a magnetic field persisted as a disruptive factor in this method of measurement.

To Lebret's surprise, there was a quantitative change in the compensation resistance when the direction of the main current was reversed. 'We gladly recall', wrote Zeeman in the commemorative volume of 1904, 'how Professor Onnes immediately came to our assistance at such moments and with a critical observation, a word of encouragement, an idea, sometimes simply exerting a suggestive influence by his mere presence, breathed new life into the research'.⁴² Nothing Lebret tried made any difference; the asymmetry persisted. The cause was eventually traced to the changed orientation of the bismuth crystal. Obtaining a suitable bismuth crystal from which to cut sheets was quite a feat in itself. When neither the crystals produced in Leiden nor those obtained from the Königliches Blaufarbenwerk in the town of Oberschlema proved adequate, Onnes, who was 'in constant contact with the outside world by mail and telegraph', managed to secure better specimens from his associate Perrot in Paris, who had succeeded in making homogeneous bismuth crystals through slow cooling.

Van Everdingen measured the Hall effect as a function of temperature in varying strengths of the magnetic field. He borrowed the electromagnet he needed from the Teylers Museum in Haarlem. He had not been able to deal with the low temperature work in his dissertation, because Onnes was embroiled in

⁴² P. Zeeman, 'Elektrische onderzoekingen', *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904) 269.

a struggle for a licence under the Nuisance Act in the period 1895-98 (see chapter 17), and pending these proceedings the cryogenic laboratory was at a standstill. When the case was finally won, liquid methyl chloride (-23°C), liquid nitric oxide (-90°C) and oxygen (-182°C) were available again, and Van Everdingen was finally able to record his measurements.

In his 1897 address to secondary school teachers, Onnes left his audience in no doubt that the experiments in the Lorentz line would increasingly be determined by the cold from Leiden's cryogenic laboratory.

‘That as the electromagnetic group of experiments continue, more and more connections will be found with the molecular theory research line is clear from the research I have just discussed [on the Hall effect], in which temperature exercises a strong controlling influence.’⁴³

But seven years later, the advances on the cryogenic front brought the magneto-optical research to a halt, and the departures of Van Everdingen and Siertsema meant the end of the Lorentz series in 1904. The net result was that the Leiden laboratory had forged an international name for itself by making measurements of an unprecedented accuracy, and that the microscopic theory was now on much firmer ground, because of Sissingh's phase difference and because of another discovery, to be described in the next chapter – the Zeeman effect.

⁴³ *Op. cit.* note 1, 28.

16. The Zeeman effect

The Zeeman effect was discovered in the autumn of 1896,¹ while Onnes was on holiday. Were these two things at all related? Zeeman's switch to the experiment that would earn him and Lorentz the Nobel Prize for physics in 1902 was strikingly abrupt. Immediately before the first note on the Zeeman effect of Wednesday 2 September, his laboratory logbook records: 'seal off basin / try bridge at the front of the basin / also close to oscillator'.² These notes relate to experiments on the absorption of electrical oscillations in electrolytes, which had occupied Zeeman's attention in Leiden since October 1895. On 20 August 1896 Onnes wrote an enthusiastic letter from Bad Reichenhall, Bavaria, where he was on holiday, in response to Zeeman's latest findings: 'I read your reports of the experiments with electrical oscillations with great interest. Perhaps they could be expanded into a piece for the [Academy's] December meeting. That would be very important.'³ The piece was duly written.⁴

In the meantime, however, Zeeman had become preoccupied with an effect that had interested him for years: the influence of a magnetic field on a light spectrum. In July 1891 he conducted his first experiment in this area. 'Using an improvised setup, the spectrum of a sodium flame was examined between the poles of a Rühmkorff electromagnet. The result was negative', wrote Zeeman in his first communication to the Academy when the experiment had finally succeeded.⁵ Zeeman had reported his findings in a letter to

¹ For the discovery of the Zeeman effect, see W.P. Troelstra, *De ontdekking van het Zeeman-effect* (Master's thesis, University of Amsterdam 1992) 1-71; A.J. Kox and W.P. Troelstra, 'Uit het Zeeman-archief: de ontdekking van het Zeeman-effect', *Gevina* 19 (1996) 153-166; Theodore Arabatzis, 'The discovery of the Zeeman effect: a case study of the interplay between theory and experiment', *Studies in History and Philosophy of Science* 23 (1992) 365-388.

² N-HA, Zeeman archives, inv. no. 506, 24.

³ Heike Kamerlingh Onnes to Zeeman, 20 August 1896, N-HA, Zeeman archives, inv. no. 82.

⁴ P. Zeeman, 'Metingen over de absorptie van elektrische trillingen van verschillende trillingstijd in verschillend geconcentreerde electrolyten', *Verslagen* 5 (September 1896) 133-140. *Comm.* 30.

⁵ Pieter Zeeman, 'Over den invloed eener magnetisatie op den aard van het door een stof uitgezonden licht', *Verslagen* 5 (October and November 1896) 181-184, 242-248. *Comm.* 33.

Onnes on 31 July 1891 – again during the holidays! – the rest of which was devoted to the latest measurements of the Kerr effect. ‘I also studied the iron spectrum in a magnetic field but was unable to clearly detect any displacement of the lines.’ Zeeman, who was then 26 years of age, seems to have felt somewhat awkward about his youthful rashness at the time, and defended himself against any criticism his actions might incur:

‘This case pre-eminently provides the greater satisfaction I derive from quantitative research, and should I ever forget your motto of “knowledge through measurement”, my memories of this research [on the iron spectrum] would certainly suffice to remind me not to resume work on it before having first considered thoroughly what is to be expected.’⁶

Trying something out on impulse was not the done thing at the physics laboratory under Onnes. In an article in *Physica* commemorating the 25th anniversary of the identification of the Zeeman effect, the professor/laboratory director left his readers in no doubt about this. Recalling that first attempt of July 1891, he wrote:

‘He surprised me with that question [concerning the possibility that magnetism might influence the colour of light] one morning when we were standing around the spectrometer with polarisation apparatus – with which he had been working on the “Lorentz series” of Leiden measurements together with Sissingh and Wind in the same room – discussing some matter concerning the measurements. Zeeman’s sudden decision to conduct a spectroscopic study of a sodium flame in a magnetic field had yielded a negative result. He then let the matter rest for a while. Although the possibility that the postulated change in the D-lines might have been detected with a more sensitive spectroscope than his must have caused him to waver, he nonetheless allowed himself to be guided by the principle that nothing could be predicted regarding the nature or measure of the phenomenon, and that identifying it would thus call for a new, ill-defined research project that would jeopardise completion of the measurements in which he was engaged. He had not departed from the line of his work further than appropriate with a reasonable sacrifice of time using apparatus that was already to hand, and held firm to the well-founded research on which he had already embarked, which also yielded positive answers to certain questions, albeit of a more modest nature.’⁷

In 1898, when Zeeman was a *lector* in Amsterdam and the professor and his former assistant were on terms of friendship, Onnes reminisced, in a note

⁶ Zeeman to Heike Kamerlingh Onnes, 31 July 1891, N-HA, Zeeman archives, inv. no. 82.

⁷ H. Kamerlingh Onnes, ‘Zeemans ontdekking van het naar hem genoemde effect’, *Physica* 1 (1921) 242.

marking Zeeman's election as a member of the Academy, about the self-willed man from Zeeland who had had the temerity to set up experiments on his own initiative:

'I recall with great pleasure our first meeting, which held out so much promise; I also recall that my confidence in your future was proof against the opposition that my decisions sometimes encountered.'⁸

Pieter Zeeman was the son of a Protestant minister.⁹ Born in 1865 in Zonnemaire, a village on the island of Schouwen in Zeeland, he had attended the HBS in Zierikzee. After leaving school in 1882, with outstanding results for physics, he set about conquering Greek and Latin to the required standard so as to gain admission to university. He was tutored by the classicist J.W. Lely, deputy principal of the Delft *gymnasium*, and even boarded with him. But the attractions of physics and astronomy were stronger than those of Latin and Greek, and it took Zeeman three years to secure the papers he needed. Meanwhile, he succeeded in getting his report of a shower of meteorites observed on 17 November 1882 accepted by the weekly *Nature*,¹⁰ after which the *Philosophical Magazine* (another British periodical) referred to him in an article on the subject as 'Professor Zeeman' of Zonnemaire.¹¹

It was in Delft that Kamerlingh Onnes and Zeeman first met, on a walk around the Raaphorst estate in Wassenaar where Lely had taken up temporary residence.¹² Onnes, who will undoubtedly have told Zeeman about the time that his Groningen HBS school friend Gratama had observed a shower of meteorites in 1870, was highly impressed by the knowledge displayed by his eighteen-year-old 'guide'. 'Before long,' Onnes continued in his 1921 article for *Physica*, 'the talk turned from the diverse fine aspects of the natural scenery in the outskirts of Leiden to our scientific field.'

'I was astonished to discover that Zeeman was already acquainted with works such as Maxwell's *Heat*, and had assimilated numerous other works of this kind. His greatest desire was to conduct experiments. Delighted by the prospect of guiding a pupil such as this, I felt it my responsibility to encourage him most emphatically to follow his

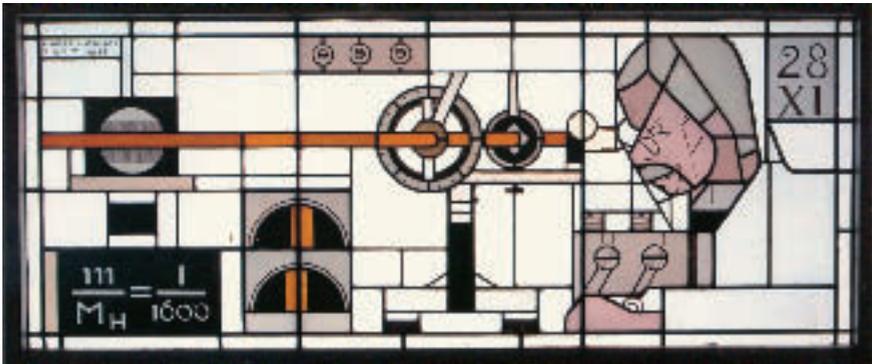
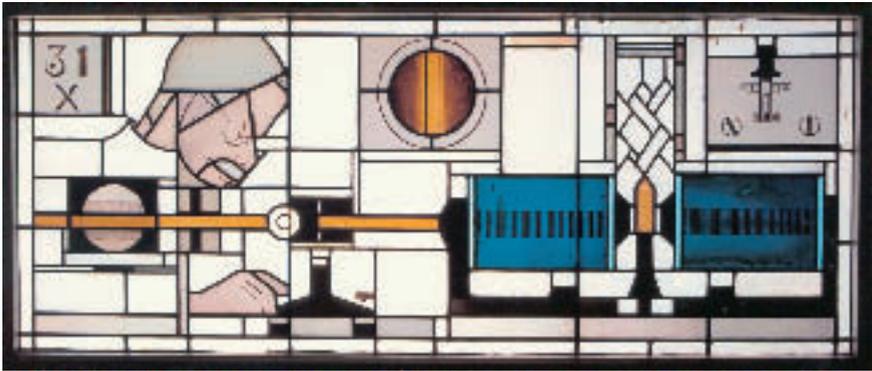
⁸ Heike Kamerlingh Onnes to Zeeman, 24 April 1898, N-HA, Zeeman archives, inv. no. 82.

⁹ For biographical information on Pieter Zeeman, see A.J. Kox, 'Pieter Zeeman (1865-1943), Meester van het experiment', in J.C. H.Blom (ed.), *Een brandpunt van geleerdheid in de hoofdstad. De Universiteit van Amsterdam rond 1900 in vijftien portretten* (Hilversum 1992) 213-228.

¹⁰ H.J.H. Groneman, 'Remarks on and observations of the meteoric auroral phenomena of November 17, 1882'. *Nature* 27 (25 January 1883) 296-298.

¹¹ N-HA, Zeeman archives, inv. no. 245.

¹² Zeeman to Betsy Kamerlingh Onnes, 23 February 1926, MB, archives of Heike Kamerlingh Onnes, inv. no. 93.



Ill. 27. The stained-glass Zeeman windows, after a design by Harm Kamerlingh Onnes. In 1922 they were installed in the inside wall of lab I, where Zeeman conducted his experiment in 1896. In the left window, at the top, we see Zeeman looking through a spectroscope at sodium light emitted by kitchen salt in a burner. When the electromagnet is switched on, the yellow sodium line widens (or splits). This has become known as the Zeeman effect. The middle window depicts Lorentz's explanation, while in the picture on the right-hand window, Zeeman is searching for the polarisation of the edges of the sodium line, as predicted by Lorentz. In 1902 Lorentz and Zeeman shared the Nobel Prize for Physics.

vocation. I felt confident in predicting that a life of dedication to science would bring him happiness.¹³

Zeeman registered as a student in Leiden in 1885. In March 1889 he set to work helping Sissingh with his time-consuming and taxing experiments on the Kerr effect. ‘Instructive’, he wrote in his diary, ‘inasmuch as it has taught me greater accuracy of observation, more insight into research, and greater perseverance in working my way through a single subject.’¹⁴ In 1890, even before he had been awarded his Master’s degree, Onnes and Lorentz hired him as an assistant (Zeeman helped Lorentz with the demonstrations in the large lecture and in the related laboratory classes for medical students). Zeeman was full of admiration for his teacher Onnes. ‘This week I happened to see a letter that Clausius wrote to O. in Dec. 1874’, he wrote in his diary on 20 February 1891,

‘In which he C[lausius] tells him, in response to some remarks by Onnes, that fellow workers who delve as deeply as O. are naturally very welcome in molecular physics. When one recalls that O. (born in 1853) was 21 years old at the time, this could only fill one with admiration for his precocious development, which was evidently bolstered at the time by an exceptional capacity for work, to which his extracts from Boltzmann and Clausius [...] bear witness [...]. It is always good for us to contemplate the characteristics of outstanding people, especially when we live in close proximity to them and are so remote from such qualities ourselves.’¹⁵

Michael Faraday was one of Zeeman’s great role models. On 19 April 1890, having read a book on Faraday by Bence Jones, Zeeman wrote in his diary: ‘Would it be possible to obtain light through magnetism or electricity? This idea occurred to me after studying Faraday.’ On 20 September Zeeman obtained the same findings as Faraday after the Englishman had held a flame between the poles of a magnet: ‘not the slightest effect in the lines of the spectrum was observed’. Zeeman marked this quotation with a double line in the margins of his diary. On 20 June 1891, Zeeman noted that he was reading Gladstone’s *Life of Faraday*, but the diary tells us nothing about the summer when he made his first attempt to form a picture of what would become known as the ‘Zeeman effect’, since the pages concerned have been removed.

In 1892 Zeeman was awarded a gold medal by the Holland Society of Sciences and Humanities for his measurements of the Kerr effect – the competition having been set by the members Lorentz and Onnes. The entry also served as the basis for Zeeman’s dissertation.¹⁶ In February 1893 he left for

¹³ *Op. cit.* note 7, 244.

¹⁴ N-HA, Zeeman archives, inv. no. 313, 25 January 1890.

¹⁵ *Ibid.*, 20 February 1891.

¹⁶ P. Zeeman, *Metingen over het verschijnsel van Kerr* (Leiden 1893).

a six-month stay in Strasbourg, to join Emil Cohn in a research project on the propagation of electric waves in water. On his return he continued this research in Leiden, while lecturing (unsalaried) on topics with an experimental slant. After the discovery of the Zeeman effect, which Onnes described in 1897 to visiting secondary school teachers as ‘without a doubt ... one of the finest discoveries of recent times’, Van der Waals secured Zeeman for Amsterdam as a *lector* at the end of November 1896. Onnes had wanted to offer his pupil a similar post in Leiden but was unable to do so. Since the departure of laboratory supervisor Johan Kuenen for England the year before, Onnes once again failed to obtain the necessary approval, despite his strenuous efforts, to appoint a *lector* to lighten Lorentz’s teaching load.¹⁷

Zeeman as his own sceptical critic

What made Zeeman decide to repeat the experiment that had failed in 1891? To start with, he had read Maxwell’s biographical sketch of Faraday in the *Encyclopaedia Britannica* since then. This reminded him that in 1862, the great experimental physicist, in his last experiment, had tried in vain to detect a colour displacement in the light of a flame held in a magnetic field. ‘If a Faraday conceived of the possibility of such a relationship,’ reasoned Zeeman in the introductory paragraph of his first article for the Academy on the effect that was to be named after him, ‘it must be worthwhile repeating the experiment, given the excellent resources now at our disposal in the realm of spectral analysis’.

It is generally assumed that the primary ‘excellent resource’ was Leiden’s new Rowland grating. This was a concave metal mirror (10-ft radius of curvature) with a 14,438 line per inch diffraction grating. The instrument – developed in the early 1880s by the physicist Henry Rowland in Baltimore, Maryland, after which over a hundred were supplied at cost price to European laboratories – permitted the analysis of a spectrum such as that of a sodium flame into its separate colours with an unprecedentedly high resolution. What is more, the instrument’s concave shape rendered the use of other lenses unnecessary. The Rowland grating was extremely useful to Michelson and Morley in their determination of the constant speed of light in 1887, as it was in the measurement in 1900 – plotting intensity against wavelength – of the spectrum of a ‘black body’, an object that absorbs all electromagnetic radiation that falls onto it.

But the Rowland grating cannot have made all the difference between Zeeman’s failed attempt in 1891 and his later success. Onnes was not the first to

¹⁷ UB Leiden, archief Senaat en Faculteiten, wis- en natuurkunde, 1895-1896.

acquire the grating; it was expensive, but he had obtained one in the course of 1890.¹⁸ Instead, the decisive factor seems to have been the newly-made screen with a linear slit that could be very finely adjusted. Whatever the case may be, the combination of the grating and the slit enabled the headstrong Zeeman to score a triumph that for some considerable time placed the cryogenic work – already in limbo because of the endless bureaucratic fuss about the licence under the Nuisance Act (see chapter 17) – in the shadows.

Let us turn to the way in which the Zeeman effect was observed. In his 1921 *Physica* article, Kamerlingh Onnes describes the initial situation in lab I – once the entrance hall. ‘Let us picture him [Zeeman] working there’:

‘He had not had to make many special preparations. A screen with an exceedingly well-crafted slit, which could be adjusted finely enough to do justice to the Rowland grating’s high resolution, had been prepared by one of the laboratory instrument makers as an assessment sample of his workmanship. Zeeman also had a Fresnel lens to view the image of the grating through the slit. The vibration-free connection between the different parts of the spectroscope was achieved by setting them up on the large monolith, built on separate foundations resting on piles, that was constructed when the former entrance hall of the building at the ‘Small Ruin’ was converted into a laboratory, and which extends beneath the entire floor. The room could easily be darkened using a few hinged screens. The spectroscope could be placed in the area at the front on the left. A sodium lamp was placed in front of the slit, in the strong field (approx. 10 Kilogauss) of the regular Rühmkorff electromagnet. The sodium flame was obtained by inserting a piece of asbestos drenched in a solution of household salt in a flame – initially an ordinary Bunsen flame, and later a flame fuelled with a mixture of coal gas and oxygen.’¹⁹

It is unclear what Zeeman did in connection with his ‘effect’ at the end of August 1896. It cannot have amounted to much more than setting up and testing the apparatus in lab I. In this vibration-free lab, where Onnes had set up apparatus from Delft for the verification of Ohm’s law in 1883, at Bosscha’s request,²⁰ stood the sensitive galvanometers that had been included in the electric circuit of experimental setups in other parts of the laboratory – a researcher in the room concerned would use a speaking tube to instruct his assistant in lab I to perform the desired measurement. In August 1896, galvanometers were in use mainly in Van Everdingen’s Hall setup. But his measurement plans were frustrated by the ongoing problems of obtaining a licence under the

¹⁸ ‘Aanvullingslijst bij den catalogus van 1882 van het natuurkundig laboratorium en kabinet’, 21 April 1892, UB Leiden, Stationsweg archives.

¹⁹ *Op. cit.* note 7, 245.

²⁰ MB, archives of Heike Kamerlingh Onnes, inv. nos. 58 and 260.

Nuisance Act, which brought work at the cryogenic laboratory to a standstill until mid-1898. Perhaps it was precisely the cryogenic malaise that enabled Zeeman to set up his experiment in lab I.

The first note that Zeeman entered in his notebook concerning his ‘effect’, on 2 September 1896, states that both yellow D-lines of sodium light, which could be seen ‘very sharply’, became two to three times wider when the magnet (drawing a current of 30 ampères) was switched on.²¹ Zeeman must have observed this with a rising sense of excitement, but as a pupil of Kamerlingh Onnes he was wise enough to check that he was not being misled by some error or side-effect before broadcasting his news. On 4 September he wrote down a possible alternative explanation in his notebook: perhaps the widening of the D-lines was attributable to the higher pressure caused by a temperature increase in the flame, due to its transformation in a magnetic field. But it was not until October that Zeeman conducted a systematic error study: Onnes, back from his holiday, will have insisted that his assistant first complete his absorption experiments with electrolytes and process his findings into a communication for the Academy before doing anything else. No better reason for the ‘opposition’ that Onnes mentions in his 1921 anniversary article than this delay imposed from above.

On 9 October Zeeman resumed work on his sodium spectrum. In a series of tricky experiments with glass and porcelain tubes, fraught by numerous problems, he managed to rule out the possibility that the effect was attributable to a change of temperature or pressure by demonstrating that it occurred *immediately* after the magnet was switched on. J.D. van der Waals Jr., later Zeeman’s colleague in Amsterdam, said in a speech to celebrate Zeeman’s seventieth birthday in 1935: ‘Anyone reading your first treatises on the magnetic splitting [initially widening] of spectral lines will receive the impression that the author is not the experimentalist himself but a rather sceptical critic, who is concerned not so much to evaluate the true value of the experiments and to ascertain their consequences, as he is to rule out any possibility that he may be misled.’²² Kamerlingh Onnes, who in 1921 recalled Zeeman’s ‘exciting efforts to resolve this question’ and spoke of his fond memories of having followed it all at such close range, would have nodded approvingly.

The first report of the Zeeman effect to the Academy was made by Onnes at the meeting of Saturday 31 October 1896.²³ Zeeman had demonstrated the

²¹ *Op. cit.* note 2.

²² J.D. van der Waals Jr., ‘Toespraak tot Professor Doctor Pieter Zeeman op den 25sten Mei 1935, Pieter Zeeman 1865-25 Mei 1935. *Verhandelingen op 25 Mei 1935 aangeboden aan Prof. Dr. P. Zeeman* (The Hague 1935) 2.

²³ *Op. cit.* note 5.

effect to his superior again the day before.²⁴ Lorentz, who was at the Academy meeting, studied the phenomenon that same weekend, and after Monday's laboratory session he summoned Zeeman and proceeded to elucidate the underlying theory in a brief sketch on the blackboard.²⁵ In a magnetic field, said Lorentz, the oscillating charged particle in every atom ('ion') was subject to a force perpendicular to both the direction of oscillation and the direction of the field. Lorentz illustrated this effect by analysing the direction of oscillation of the 'ion' into two components: one perpendicular to the magnetic field and one parallel to it. He then divided the perpendicular component into two circular oscillations (perpendicular to the parallel component) rotating in opposite directions. Of these three components, the parallel one is not influenced by the magnetic field. But both circular oscillations are influenced: one starts oscillating at a slightly higher frequency and the other at a slightly lower frequency. In consequence, in a magnetic field the sharp line in the middle of the spectrum of a light source *splits* into three lines, the outer two undergoing circular polarisation. In non-ideal conditions these lines overlap, and the observer sees only a widening of the original line, the edges of which exhibit a polarisation effect.

On 10 November, Zeeman tried to observe the circular polarisation of the edges of the D-lines that Lorentz had predicted. He still had a suitable *analyser* prism left over from the Kerr research project he had done at Wind's request earlier that year. The attempt failed, because the observations were made perpendicular to the magnetic field instead of parallel to it. On 20 November, Zeeman realised his mistake, and switched to a magnet with perforated pole shoes, so that he could make his observations parallel to the field. Three days later he could celebrate: 'Demonstrated, with Lorentz's help, that the explanation for the change in the 'movement of the "ions"' is correct, or at any rate probable', wrote Zeeman in his diary. The next day he repeated the experiment in the presence of Lorentz, who called it 'a stroke of good fortune' providing direct evidence for the existence of ions, with Faraday's rotation and the Kerr effect'.²⁶ Interestingly, Lord Raleigh (John Strutt) stated in his obituary of Zeeman for the Royal Society in 1944 that Lorentz had 'failed to notice' the effect at the time.²⁷

Lorentz had referred earlier to 'something bad',²⁸ in relation to the value of the ratio between the charge and the mass of 'ions' that determined the widen-

²⁴ N-HA, Zeeman archives, inv. no. 506,101.

²⁵ P. Zeeman, 'Hendrik Antoon Lorentz, in memoriam', *De Gids* 22 II (1928) 111.

²⁶ N-HA, Zeeman archives, inv. no. 313, 61.

²⁷ Arabatzis, 'The discovery of the Zeeman effect', 378-379.

²⁸ *Op. cit.* note 25.

ing of the lines in combination with Lorentz's theory. On the premise that ions had a unitary charge, this led to a mass that was approximately a thousand times lighter than that of a hydrogen atom. In his second article for the Academy, Zeeman presented this noteworthy result without any comment at all.²⁹ Did neither he nor Lorentz know what to make of it? Not long afterwards, it became clear that 'light ions', like cathode rays, consisted of electrons: very light, negatively charged particles. J.J. Thomson is generally credited with the discovery of the electron, in 1897, but some science historians have questioned this attribution.³⁰ While Zeeman determined the value of the charge divided by the mass, he did not determine the mass separately. A.J. Kox has conjectured that Lorentz considered Zeeman's result so bizarre that he did not wish his name to be associated with the article, and also left it to Onnes to present the result to the Academy.³¹

Theory played a totally different role in successive phases of the discovery of the Zeeman effect. If Zeeman had been apprised of Lorentz's theory before starting his experiments in August/September, and if he had equated the mass of the 'ion' with that of a hydrogen atom – the customary assumption at the time – he would quickly have concluded that the expected splitting (or widening) of the D-lines would be so minuscule that the experiment was not worth the trouble. Theoretical 'foreknowledge' can sometimes be a real handicap! Lacking it, Zeeman followed his intuition freely – guided by Faraday, it is true, but without having a clear idea of what to expect. The Zeeman effect played an important part in the discovery of the electron. On this noteworthy interaction between experiment and theory, Onnes wrote in 1921:

'While the theory clarified the significance of the experimental findings that could be obtained in the immense new field that had been opened up, the Zeeman effect, through the explanation provided by Lorentz's theory, revealed their power. That was the beginning of the accelerated development of electron theory, which has now permeated most areas of physics. [...] The difficulty of formulating a theory that corresponds closely to what is already known is analogous to the difficulty of obtaining an accurate and complete picture of a phenomenon in experiments. It is as if the struggle against the difficulties that lie along both these paths causes the human mind to resonate with nature, as it were, thus enabling new phenomena to be discovered and accurate pictures to be created.'³²

²⁹ *Op. cit.* note 5.

³⁰ For a series of articles on the discovery of the electron, see Jed Z. Buchwald and Andrew Warwick (ed.), *Histories of the electron: the birth of microphysics* (Cambridge MA, 2001).

³¹ A.J. Kox, personal communication.

³² *Op. cit.* note 7, 248-249.

Onnes could not help remarking that Zeeman's sense of satisfaction with what he had set in motion was tempered during his first few years in Amsterdam by the 'poor working conditions' at Plantage Muidergracht. For many years Zeeman lacked a suitable permanent laboratory setup.³³ Even so, he was able to record the *splitting* of the spectral lines in Amsterdam in 1897, using cadmium, rather than the mere widening he had observed in Leiden with sodium. Soon afterwards, it became clear from numerous follow-up experiments conducted in various parts of the world that the Zeeman effect was more complicated than Lorentz's theory had made it appear. Not until the discovery in 1925 of *electron spin*, by Sam Goudsmit and George Uhlenbeck, could it be incorporated usefully into quantum theory.

Assaults on Zeeman's priority

The clearest sign of a momentous discovery is when the discoverer's priority is disputed. This happened to Zeeman twice. In January 1897, Kamerlingh Onnes and Henri du Bois, a Dutch physicist working in Berlin, received a letter from Edmond van Aubel, professor of experimental physics in Ghent. Van Aubel, a former assistant of the (by then deceased) Charles Fievez, decided to champion his late superior's rights. He claimed that Fievez had studied the influence of a magnetic field on a spectrum ten years earlier than Zeeman, when working as astronomer at the Brussels observatory, and had found that spectral lines undergo a similar widening in a magnetic field to the widening seen in the case of a temperature increase. For further details, Van Aubel referred to two publications by Fievez.³⁴ The letter was addressed to Du Bois in his capacity as an external member of the Berlin-based *Physikalische Gesellschaft*, which position made him the logical intermediary in Van Aubel's eyes.

Du Bois told Zeeman that it was up to him whether or not to react, and that Van Aubel was known as a 'difficult character'. Du Bois had rejected the Belgian's request to read out the letter to the *Physikalische Gesellschaft*, explaining that this was not the custom in Berlin.³⁵

Kamerlingh Onnes had expressed himself rather more bluntly three days earlier, with memories of De Heen's poor performance in measurements at critical temperatures (see chapter 19) still fresh in his memory:

³³ *Ibid.*, 250.

³⁴ C. Fievez, 'De l'influence du magnétisme sur les caractères des raies spectrales', *Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique* 9 (1885) 381-384; C. Fievez, 'Essai sur l'origine des raies de Fraunhofer, en rapport avec la constitution du soleil', *Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique* 12 (1886) 25-32.

³⁵ Du Bois to Zeeman, 1 February 1897, N-HA, Zeeman archives, inv. no. 17.

‘Enclose urgent letter from Aubel for your information. It is probably about nothing! The Belgians are such botchers and I would be amazed if he’s set up a Rowland grating with a fine slit! Still, it will have to be checked whether the phenomena observed are at all relevant.’³⁶

In spite of this arrogant tone, Onnes took the Fievez issue very seriously, and he *did* read Van Aubel’s letter to the Academy at its meeting of 30 January, adding:

‘That Fievez conceived the idea of conducting these experiments is noteworthy and should certainly be mentioned; his findings must be taken into careful consideration.’

Onnes also told the Academy that Zeeman had been entirely ignorant of Van Aubel’s experiments and had therefore – ‘to his regret’ – not mentioned them in either of his two reports to the Academy of October and November 1896. To include the outcome of his ‘considerations’ in the report of the meeting, Onnes invited Zeeman to come to Leiden at his earliest convenience to discuss the matter in detail. Onnes also wanted Zeeman to check, in lab I, ‘whether Fievez’s divided stripes were truly polarised or not’, something that could not be done in Amsterdam. The findings would reveal ‘whether his experiments had been humbug or highly significant’.³⁷ It is unclear whether Zeeman actually performed these experiments: the report of the meeting says nothing about it. Nonetheless, Onnes questioned the magnetic origin of the widening of the lines observed by Fievez:

‘We may summarise as follows. The experiments performed by Mr Fievez could have prompted Zeeman to embark on his further research, but they could not have established the specific influence of the magnetic field on the period of oscillation of the transmitted light, and it is even questionable – for the time being, at any rate – whether the phenomenon observed by Fievez *with a magnetised flame* must indeed be ascribed to the *specific influence of a magnetic field on the period of oscillation of the light* as discovered by Zeeman, which Mr Lorentz has confirmed beyond all doubt.’³⁸

Zeeman himself raised the matter again in an appendix to the translation of his two reports to the Academy for the *Philosophical Magazine*; in Communications 33, the English version of these reports, he had already inserted a correction asserting that the ‘light ions’ were negatively charged, and not positively, as he had previously concluded. According to this postscript, Fievez had said nothing about polarisation, while some of his observations were substantively

³⁶ Heike Kamerlingh Onnes to Zeeman, 28 January 1897, N-HA, Zeeman archives, inv. no. 82.

³⁷ Heike Kamerlingh Onnes to Zeeman, 4 February 1897, N-HA, Zeeman archives, inv. no. 82.

³⁸ *Verslagen* 5 (January 1897), 356–359.

at odds with Zeeman's. All in all, the evidence strongly suggested that Fievez had observed an effect caused by temperature, even though he emphasised that it took effect *immediately* upon activating the magnetic field. The Belgians had not supplied any kind of theoretical explanation. In conclusion, Zeeman said that experiments currently in progress would resolve the matter. But the findings of these experiments are unknown, and if they had established conclusively that Fievez's observations in 1885 concerned something quite different from those of Zeeman in 1896, we would certainly have heard about it.³⁹

Then there was the case of the Greifswald professor Franz Richarz, in which Du Bois and Onnes were also involved. 'He needs to be taken a good deal more seriously than the Belgian', wrote Du Bois, three weeks after his letter to Zeeman about Fievez.⁴⁰ Richarz claimed that Zeeman should have cited his work, and Du Bois agreed. Onnes drafted a letter to Richarz and sent it to Zeeman on 22 February. He also pointed out the positive aspects of the affair: 'It's a good sign that everyone is so eager to be mentioned in connection with your work.'⁴¹ The reply from Greifswald arrived on 10 March. After complimenting Zeeman on his discovery, Richarz pointed out the connection with his own work. The Zeeman effect, he wrote, was based on 'molecular magnetism', a subject about which he himself had published an article.⁴² Since in reality an external magnetic field is needed to obtain the effect, Richarz's work does not appear particularly relevant. Nonetheless, the German wished – without in any way wishing to detract from the significance of Zeeman's achievement – for a citation. Onnes forwarded Richarz's letter to Zeeman, adding, 'I feel more uneasy about this one than about Van Aubel's ... he seems entirely unconvinced.'⁴³

Zeeman's supplement to the appendix for the *Philosophical Magazine* (concerning the Fievez case) was submitted too late for inclusion. 'Pity that the lightning conductor ... for the thunderclouds of Richarz, Chattock etc. arrived too late', wrote Onnes.⁴⁴ Zeeman tried to placate Richarz in the next issue of *Philosophical Magazine*.⁴⁵ But since he referred only *en passant* to one of

³⁹ For a balanced discussion of this subject, see Troelstra's thesis (*op. cit.* note 1) 24-27 and Kox and Troelstra (*op. cit.* note 1) 161-162.

⁴⁰ Du Bois to Zeeman, 22 February 1897, N-HA, Zeeman archives, inv. no. 41.

⁴¹ Heike Kamerlingh Onnes to Zeeman, 22 February 1897, N-HA, Zeeman archives, inv. no. 82.

⁴² *Annalen der Physik*, 53 (1894). See also Troelstra (*op. cit.* note 1) 27-30.

⁴³ Heike Kamerlingh Onnes to Zeeman, 15 March 1897, N-HA, Zeeman archives, inv. no. 82.

⁴⁴ A.P. Chattock was professor of physics at Bristol and had performed research obliquely related to the Zeeman effect.

⁴⁵ P. Zeeman, 'Doublets and triplets in the spectrum, produced by external magnetic forces', *Philosophical Magazine* 44 (July 1897) 55-60.

the German's articles and immediately added that the 'light ions' of the Zeeman effect were entirely different from the electrolytic ions in Richarz's article, this attempt misfired: 'The nature and manner of your citations of my work are still misconceived', came the response from Greifswald.⁴⁶

Onnes told Zeeman that he supported him, but that a friendlier approach might not have done any harm. 'I seem to recall that the original sentence about Richarz was warmer in tone', he wrote on 23 August from his holiday address in Schuls (Switzerland). 'The lack of cordiality offended him.'⁴⁷ He suggested that Zeeman should give the German credit for his research into the relationship between the motion of ions and light as soon as the opportunity presented itself.

Aside from Van Aubel and Richarz's protests, Zeeman received nothing but praise from home and abroad for his discovery. Haga's letter described it as 'a worthy conclusion to your experiments in Leiden'.⁴⁸ At a major international physics conference in Düsseldorf, in December 1898, the Göttingen professor Waldemar Voigt welcomed his colleague (and later friend) with the words: 'You have found a veritable pearl.' Onnes himself emphasised above all the cooperation between theory and experiment and the 'rare beauty' of the result.⁴⁹

He was not alone in this verdict. In their letter recommending Zeeman for membership of the Academy of Sciences in 1898, Van der Waals, Kamerlingh Onnes, Lorentz, V.A. Julius, W.H. Julius and Haga all stated unequivocally that the Zeeman effect was a unique discovery. After first enumerating the candidate's other achievements, they remarked that these were 'entirely eclipsed [by the] magnificent discovery' of the Zeeman effect, adding: 'It has elevated Zeeman above the ranks of ordinary researchers and defined him as a discoverer.'

'And Zeeman did not make this discovery by chance, but by directly looking for it. That he succeeded in finding it, with instruments that many described *a posteriori* as completely inadequate, shows that he possesses a quality that cannot be learned but only developed – the ability to feel instinctively which path must be chosen, to put in place a combination of physical conditions that produce the greatest effect. As a result, everything he does is in a sense "perfect".'⁵⁰

In conclusion, let us think back briefly to that memorable autumn of 1896. Why did Zeeman choose that precise moment to perform his experiment? Besides the explanations already suggested – Onnes being away on holiday, the

⁴⁶ Richarz to Zeeman, 25 July 1897, N-HA, Zeeman archives, inv. no. 128.

⁴⁷ Heike Kamerlingh Onnes to Zeeman, 23 August 1897, N-HA, Zeeman archives, inv. no. 82.

⁴⁸ Haga to Zeeman, 5 December 1896, N-HA, Zeeman archives, inv. no. 63.

⁴⁹ *Op. cit.* note 7, 247.

⁵⁰ N-HA, Akademiearchief, inv. no. 561, 1898.

inspiration he derived from accounts of Faraday's failed attempt, the availability of a minutely adjustable slit – there is one other possible reason that has not yet been mentioned. Shortly before the discovery at the beginning of September, Zeeman had consulted Onnes about a vacancy that had arisen under Van der Waals. The experimental physicist W.H. Julius, who had been an associate professor in Amsterdam since 1891, had been appointed to a full professorship in Utrecht on 8 August 1896. Zeeman wrote to Bad Reichenberg that he was interested in the position. Onnes informed his assistant that he would answer Van der Waals's questions honestly as soon as he saw him after the holiday, but that all his 'children' were dear to him. Sissingh and Du Bois were also 'fine candidates', and the laboratory administrator Siertsema was also eligible. It all depended on what kind of person Van der Waals wanted as a *lector* working alongside him. That Zeeman had chosen to work on the Lorentz series would not count in his favour, in Onnes's view. 'Had you ended up in cryogenics, as Kuenen did in his day, v.d.W. would have been more impressed by your candidacy'.⁵¹

It is conceivable that Zeeman wanted to repeat his experiment in an all-or-nothing attempt in August 1896, in the hope of boosting his chances for the Amsterdam position if it succeeded and he became the discoverer of a new, spectacular effect. After all, it would not be much trouble. But he would have to do it quickly, or there would be no point. Whether his success influenced Van der Waals's decision is unclear, but in any case Zeeman secured the position and was able to start work in Amsterdam that autumn.

⁵¹ *Op. cit.* note 3.

17. A collection of explosive devices

Inserted in the embankment of the Steenschuur, directly in front of the laboratory where Heike Kamerlingh Onnes was pursuing extreme cold, is a grey memorial stone. Its gold capitals read 'Here lay the gunpowder ship that exploded on 12 January 1807', a plain notice commemorating one of the greatest calamities ever suffered by the city of Leiden. A calamity that unmistakably reverberated through the crisis in which Kamerlingh Onnes became embroiled in 1895, leaving him to flounder in a bureaucratic swamp for three years. The bone of contention was the continued existence of the cryogenic laboratory in the heart of the city.

Let us start by recalling the disaster of 1807. On 12 January a single-masted ship carrying gunpowder had sailed through the Mare into Leiden, and at 9.30 a.m. captain Adam van Schie and his three-man crew had moored it alongside the Steenschuur quay.¹ On this bleak Monday, the air filling alternately with sleet and drizzle, neither the police nor anyone else paid any attention to the ship or its cargo – until 4.15 p.m., when it suddenly erupted skywards with a thunderous roar. In defiance of all regulations, the ship had entered the city with a cargo of 37,000 pounds of raw gunpowder. The cause of the explosion was never discovered. Witnesses had seen potato peelings being tipped overboard; someone had evidently been cooking. It was *Koppermaandag*, the traditional printers' feast held on the first Monday after Epiphany; had some crew members become drunk and recklessly roasted pork or boiled stockfish over an open fire? Had they stolen gunpowder from the hold and spilled some? If so, they did not live to tell the tale.

A fierce, dazzling light filled the sky. A mass of white smoke plummeted upwards, above the houses of Rapenburg, and spread out in a series of abrupt shudders. Then came the deafening blast, and 'houses shook, walls cracked and collapsed, transforming the most beautiful district of Leiden into a gigantic,

¹ The details of the gunpowder ship disaster derive from Prof. Dr. L. Knappert, *De Ramp van Leiden* (Schoonhoven 1906) and D.E.H. de Boer (ed.), *Hutspot, baring en wittebrood* (Leiden 1981) 79-86.

terrible heap of rubble, a hideous grave for numerous townspeople.² Doors flew open throughout the Rhineland region, people in Amsterdam thought a warship had exploded in the Zuyder Zee, and the blast was heard in Zwolle, Deventer, and even as far away as in Friesland. The anchor was later found in a meadow outside Hogewoerd city gate. Where the gunpowder ship had been moored the canal briefly lay quite dry, while further away, water gushed over the quays. Quayside and streets crumbled away right up to the façades of buildings, and in the immediate surroundings hundreds of houses were destroyed or badly damaged. Further away, thousands of windows shattered, chimneys tumbled from the roofs, cracks appeared in walls, roof tiles rained down and plates crashed from the shelves to the floor. Fires broke out here and there, fanned by a biting east wind that reached gale force in the evening.

Eye-witness reports abound. The classical scholar and university librarian Daniel Wyttenbach was eating downstairs in his house at the corner of Rapenburg and Vliet when the blast struck. He fled outside, and amid all the panic and suffering he registered that the street was littered with pages of his manuscript about Plutarch, from his study that had been demolished in an instant. After



Ill. 28. Officials visiting the ruins on Steenschuur, the day after the explosion of the gunpowder ship on 12 January 1807. It was here that the laboratory was later built that Kamerlingh Onnes moved into in 1882 (Leiden Municipal Archives).

² Knappert, *De Ramp van Leiden*, 22.

the blast, the stone-deaf wife of theology professor Jona Willem te Water, who also lived on Rapenburg, famously enquired of her husband, who was sitting opposite her, 'Did you say something, Te Water?'

The disaster claimed 151 lives and left thousands wounded. Among those who perished were the elderly master-carpenter Jan Viele, count of Randwijk, the little daughter of the notary Van Staveren, the widow Zeewold with her maidservant, schoolmaster Hagens of the Jewish School together with ten of his pupils, the partying Struyk family, and the lawyer Willem van Riebeeck with his wife and their only child. The University of Leiden lost two of its professors: historian Adriaan Kluit was buried by falling masonry and the jurist Johan Luzac, a descendant of a Huguenot family whose friends included leaders of the American Revolution such as Thomas Jefferson, John Adams and George Washington, was hurled into the Rapenburg by the force of the explosion and drowned.

Chaos ruled for the first few hours after the blast. Survivors strayed among the heaps of rubble in a dazed state, and the hundreds of people who had flocked to the scene generally got in each other's way. Thieves profited from the confusion. Later in the evening the city's armed militia sealed off the area and the rescue work was directed in an orderly fashion. Many people were pulled out of the rubble alive, and the dead were taken to the town hall. King Louis Napoleon arrived in the evening, visiting the disaster area and comforting victims. He helped with the work that needed to be done, and offered ten ducats' reward to anyone who rescued someone injured. He did not return to The Hague until 6 o'clock the next morning. He had made himself the eternal hero of the people of Leiden, especially the next day, when he donated 30,000 guilders to the city out of his own pocket.

As the fierce controversy regarding the question of whether the explosion of the gunpowder ship was God's punishment or a mere accident subsided, work started at the 'Ruin', as the site of the disaster soon became known. The debris was cleared away, the ground was covered with a layer of soil, elms and poplars were planted, and coal ash paths were laid. Louis Napoleon presented some grand plans for the site, but the Royal Academy with library, the barracks for 1,000 infantrymen and 1,000 cavalrymen and thirty town mansions he envisaged proved far too ambitious in the face of the prevailing economic malaise. Even the obelisk to commemorate the disaster, the first stone of which was laid on 18 January 1808, failed to materialise. And so it happened that the 'Small Ruin' and the 'Great Ruin' on either side of Steenschuur remained wasteland for years. In 1859, the laboratory where Heike Kamerlingh Onnes would work for so many years was erected on the 'Small Ruin' site, and in 1884 the 'Great Ruin' acquired a statue of Van der Werff, Leiden's burgomaster in the days of the Spanish siege.

The Nuisance Act and the struggle for a licence

It was the echoes of this disaster that started to dog Onnes's fortunes in 1895. On 19 January 1895 the director of the physics laboratory received a letter from Leiden municipal executive that proved to be the opening move in a long drawn-out sparring match with the authorities. Letter 'No. 72', on the subject of 'explosive substances', read as follows:

'Attention has already been drawn several times to the fact that substances are kept on the premises of the Physics Laboratory that may pose a threat to the surroundings. Further to these observations, we politely request you to specify the substances that are kept there and the quantities concerned, and to further specify whether or not a licence was obtained at the time to store them there.'³

Kamerlingh Onnes, oblivious of the woes he was unleashing, replied a week later. He explained candidly that:

'Explosive substances are never in fact kept in the laboratory or on the grounds. We do, however, store gases that have been liquefied under pressure in drums or flasks, which could of course explode if the sides of the vessel were to give way in the manner of a boiler, and which can best be compared to drums of liquid carbonic acid that are available commercially.'⁴

On the laboratory grounds, Onnes continued, he kept one drum containing 11.8 kilos of chlorine, one with 4.4 kilos of ammonia, and one with 28.8 kilos of sulphurous acid. 'All these gases are toxic if present in substantial quantities in the air.' Onnes also explained that he kept demijohns of ether and oil in the garden, as well as methane in a gas tank. For the latter the laboratory had applied for a licence in 1892, but this proved unnecessary.⁵ Onnes then cheerfully volunteered a list of items stored and used in the laboratory itself: 'a number of cylinders filled at high pressure variously with carbonic acid, oxygen, nitrogen, hydrogen, ethylene and methane, besides which it may prove desirable to store other compressed gases in this way'. Having also mentioned paraffin and alcohol, the director expressed the hope that he had given 'a comprehensive overview' of the 'dangers that might be posed to the surrounding area', and added that he was 'not in the possession of any licence other than that implicit in [his] appointment as director of the Physics Laboratory to handle, store and in part manufacture, the above-mentioned substances.' Onnes concluded by avowing that he had been 'regrettably unaware' that any

³ B&W to Heike Kamerlingh Onnes, 19 January 1895, archives Huygens Laboratory.

⁴ Heike Kamerlingh Onnes to *curatoren*, 26 January 1895, UB Leiden, Archief Curatoren.

⁵ *Curatoren* to Heike Kamerlingh Onnes, 9 June 1892, archives Huygens laboratory.

such licence was required, and would appreciate being issued with one as soon as possible.

Why had the municipal executive decided to launch an investigation in the first place? Ironically, the victim's own actions had prompted it to do so. In a police report of 20 November 1894, Onnes stated that there was a danger of the gas cylinders he had placed in the garden of the physics laboratory 'exploding' if they were handled inexpertly. He had complained to the police about rowdy youths cavorting in the garden. The vandalism was sometimes beyond the pale: on one Sunday night in May 1892, shrubs had been damaged, tarpaulins slashed, taps turned on and left running, and a window smashed. 'An expensive instrument standing immediately behind the broken window was by a stroke of good fortune preserved from destruction', Onnes wrote to the board of governors; 'otherwise we would have suffered damage amounting to many hundreds of guilders.'⁶ The problem was that there were holes in the hedge around the garden, making the site fair game for local hoodlums. Bottles were smashed, chests and lids had disappeared, and a gang of youths had even been caught pulling out electricity cables. But the board of governors shrugged off Onnes's laments, even in March 1890, when he alerted it to the dangers posed by 'explosive substances that cannot be guarded well enough',⁷ merely referring him to the police.

On 22 February 1895, Dr M.C. Dekhuijzen, a member of the municipal executive, came to look around the physics laboratory.⁸ Dekhuijzen had worked as an assistant at the physiology laboratory on Zonneveldsteeg (Onnes's rear neighbour) in the 1880s, and besides his official duties for the city he worked as an unsalaried lecturer, teaching 'the principles of animal cells'. He also served as secretary of the board of governors of the nursery school run at the headquarters of the Society for the Promotion of the Public Good (*Maatschappij tot Nut van 't Algemeen*; known popularly as the *Nut*) – a far from unimportant detail, in view of the 'explosives issue'. The *Nut* had its premises on the corner of Langebrug and Steenschuur, opposite the physics laboratory, and dated from 1850. It stood on the very site on which the former *Nut* school had been razed to the ground in January 1807, killing the schoolmaster Venker and twelve of his pupils, when the gunpowder ship exploded. That the management of the nursery school, which had a hundred children in its care in 1895, considered the presence of 'explosive materials' at the building across the street to be a sensitive issue is scarcely surprising.

⁶ Heike Kamerlingh Onnes to *curatoren*, 25 May 1892, UB Leiden, Archief Curatoren.

⁷ Heike Kamerlingh Onnes to *curatoren*, 21 March 1890, UB Leiden, Archief Curatoren.

⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 52.

On 4 March, after Dekhuijzen's visit, Onnes wrote to the municipal executive to explain that the cylinders containing compressed gases only posed a danger if exposed to 'vandalism' or 'external force' and that they belonged in an enclosed space⁹ – a shed that he had been asking the board of governors to provide for years. He also wanted gas masks, a powerful ventilator, a fire-hose, and soda lime to neutralise hazardous substances in the event of disaster. Onnes asked the authorities to kindly give him three months to put all these measures in place.

Slowly but surely the issue snowballed out of control. On 5 April the board of governors joined the fray. Three weeks earlier, Onnes had asked the board to obtain authorisation from the Chief Inspector of Government Buildings to use branches to close holes in the hedge surrounding the garden of the physics laboratory. Perhaps burgomaster F. Was, who was also a member of the board of governors, had probably brought his associates up to date at the monthly meeting. 'The Board has learned indirectly that the Municipal Council objects to the storage of explosive materials in and around the laboratory',¹⁰ stated the implicit reproach. Onnes was requested to inform the board of governors of the situation and to apply for a licence under the Nuisance Act.

Kamerlingh Onnes replied the same day, and, although there was only a slight threat hanging in the air and work at the laboratory continued as normal, his language betrayed serious alarm for the first time. Onnes noted that a recent visit by the labour inspectorate had not revealed any problems whatsoever, that the vandalism in the garden had been 'curbed sufficiently', and that Dekhuijzen from the municipal executive had come to look round. He also wrote that in applying for a licence to manufacture and keep compressed gases and to use them in experiments he had deliberately worded his application in broad, inclusive terms as a precaution. After which Onnes ended with a cry from the heart:

'Since I must endeavour with inadequate resources and insufficient staff to ensure that the teaching here remains at a sufficient standard to be competitive with foreign institutions, and frequently work in conditions that put my own life in danger to do so, it would be a very bitter pill were I to find that I had somehow fallen foul of some law or local ordinance, and I would greatly appreciate you informing me how I may best avoid doing so.'¹¹

⁹ Heike Kamerlingh Onnes to B&W, MB, archives of Heike Kamerlingh Onnes archives, inv. no. 74.

¹⁰ *Curatoren* to Heike Kamerlingh Onnes, 5 April 1895, archives Huygens Laboratory.

¹¹ Heike Kamerlingh Onnes to *curatoren*, 5 April 1895, UB Leiden, Archief Curatoren.

The board of governors forwarded the licence application to the Ministry of the Interior in accordance with the statutory procedure established in 1875, together with a recommendation that the licence be granted. The board also endorsed Onnes's request for work at the laboratory to be allowed to continue while the application was being processed. But The Hague took a different view. The cryogenic laboratory, which was close to liquefying hydrogen, was ordered to close down until the licence had been granted. What is more, Onnes was instructed to submit his application again in duplicate, since his initial application of 5 April included the steam engine he had purchased in 1886, for which no licence was needed. Versteeg, a senior civil servant at the Ministry of the Interior, made an unofficial visit to Leiden on 4 June, on which occasion Onnes urged him to summon him personally if any clarification was needed, 'to prevent making a mountain out of a molehill'.¹² On 12 June, no doubt distraught by the order from The Hague to suspend work at the cryogenic laboratory, Onnes submitted the revised application. At the same time he discussed possible safety precautions, such as the erection of a shed for hazardous substances. In a letter to the Chief Inspector of Government Buildings, he estimated that the most urgent improvements could be made for 3,000 guilders, the laboratory's entire state grant for the year 1895. But nothing was done for the present; the board of governors first wanted to see how the application fared, and blocked the funding.

Onnes realised that the question of the 'explosive substances' had to be resolved before he could continue building up his cryogenic laboratory. He requested a 'special grant' for 1896: 5,000 or 6,000 guilders, 'depending on the speed at which the municipal authorities wish things to be done', to take additional safety measures. He complained about the lack of funds that was constantly afflicting him. Now that his budget had been blocked, necessary maintenance was being seriously neglected and the laboratory might even find itself 'facing bankruptcy'.¹³

On Saturday 14 May, Onnes attended a meeting with Was and Dekhuijzen at the town hall. By then, the cryostats that had contained liquid oxygen were already empty. For the present, the once roaring compressors and suction pumps at the physics laboratory had fallen silent and the pursuit of cold had been suspended. 'Holidays', wrote Onnes on 6 July – weeks earlier than normal – in his laboratory logbook. And he did not have to think long about the issue facing him on his return: 'After the holidays: the safety issue.'¹⁴

¹² MB, archives of Heike Kamerlingh Onnes, inv. no. 74.

¹³ Heike Kamerlingh Onnes to *curatoren*, 1 May 1895, UB Leiden, Archief Curatoren.

¹⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 52.

Phase two of the 'Proceedings under the 1875 Act', a hearing before a committee of the provincial authorities, took place during the summer holidays – the Ministry of the Interior had urged a speedy resolution. Onnes decided to remain close at hand in case he was needed, holidaying at the seaside resort Domburg in Zeeland instead of going to Switzerland for a health cure. The Physics Laboratory's neighbours were invited to submit their objections, and when the hearing opened on 9 August three such statements of objection had been received.¹⁵ The chemistry and physiology laboratories had failed to respond. The former was run by Onnes's friend Van Bemmelen, and had had a fire the year before. Onnes would later fall out with Professor Einthoven, head of the physiology laboratory, though not about explosive materials but about vibrations he claimed were disrupting his electrocardiograms.

Those opposing the licence were Professor Teunis Zaaier, director of the anatomy laboratory, P. van Geer, chair of the Leiden branch of the *Nut*, and Leiden's municipal executive. Zaaier, who was also a member of the city council and had previously served on the national executive committee of the *Nut*, emphasised in his objection that the anatomy and physics laboratories shared a single building, so that any explosions in Onnes's section could have disastrous consequences for his own, resulting in 'the partial or complete loss of precious anatomical and anthropological material'. Zaaier was not only concerned about the building and his 'fine collection', but also about the threat posed to the lives of staff and students. Only if the physics laboratory took adequate safety precautions should Onnes be given his licence.

While Zaaier thus held out slight hopes of a change of position, Van Geer, professor of analytical and descriptive geometry and theoretical mechanics, who besides chair of the Leiden branch of the *Nut* was also a member of its executive committee, called unequivocally for Onnes's facility to be removed from the area. He had also been one of those who had sided with Rijke in the faculty in 1882 to oppose Onnes's appointment. Van Geer was concerned about the hundred-odd pupils of the nursery school in the *Nut* building opposite the laboratory, and found 'the close proximity of a collection of explosive devices' quite unacceptable. 'Experience gained both here and elsewhere have already provided sufficient proof of the dangers such devices pose to their immediate surroundings', he wrote in his notice of objection.

Dekhuyzen and E. Kist, town clerk and a member of the municipal executive, also wanted to see the application rejected. It was wholly unacceptable to have an institution that stores and works with gases at very high pressure in the immediate vicinity of a public school full of children (today the Haanstra

¹⁵ N-HA, Akademiearchief, inv. no. 388.

school), as well as the nursery school and music school in the *Nut* building, quite aside from the danger posed to passers-by and to the fire brigade in the event of fire. 'Any cylinder of compressed gas is explosive in the event of fire', wrote Dekhuyzen and Kist. 'A cylinder with compressed flammable gas is more dangerous still.' The two then pointed out that explosive gas mixtures could possibly arise, certainly if cylinders with different contents were placed close together, concluding that 'the present location in the midst of schools and laboratories constituting a substantial fire hazard (active in the case of the chemistry laboratory, passive in the case of the anatomy laboratory, with its preparations preserved in spirits) cannot *possibly* be deemed suitable, nor can it be made suitable, for an institution of the kind at issue.' The municipal executive's conclusion: no cryogenic laboratory within Leiden's built-up centre.

Onnes was conspicuous by his absence at the hearing of 9 August. J. Roem, inspector of university buildings, did his best to refute the objections. Roem affirmed that the most stringent safety precautions were already in place in the Physics Laboratory, and as soon as the special storage facility was ready the situation would be safer still. The inspector cannily pointed out that the railways did not object to transporting compressed gases. Dekhuyzen, who held firm to his objections, advised the provincial authority to consult expert opinion 'regarding absolute safety measures in preserving and working with liquid gases'. The two-man committee, consisting of C.J.E. Graaf van Bijlandt, who was also a member of the university's board of governors, and P.L.F. Blussé, gratefully adopted this suggestion in its recommendations to the Ministry of the Interior. For the rest it maintained a studied neutrality. The objections submitted merit serious consideration, stated its report of 10 August. 'The committee therefore considers it highly desirable to move the institution concerned to a new location outside the built-up city centre, although it cannot deny that such a move may also meet with serious objections on other grounds.'¹⁶ With recommendations like that, the Minister of the Interior could happily move in whatever way he chose.

At the end of August, Kamerlingh Onnes received notification that he should submit a statement of defence. Furthermore, the Minister of the Interior wrote to the board of governors stating that he was 'not amused' by Zaaijer's performance. 'It is surely unacceptable that while you as board of governors – according to your letter ref. No. 186 of 16 May – endorse an application by one of the university's professors, and forward this application to me to be dealt with in the customary manner, another professor, without your or my prior knowledge or authorisation, should attempt to thwart the

¹⁶ *Ibid.*

granting of said licence.¹⁷ The board of governors tried to calm the waters, but were unable to avoid issuing Zaaijer with a formal reprimand. By this point, the support for Onnes's licence application had all but evaporated: the board of governors extenuated the anatomy professor's behaviour to the Minister by mentioning the 'highly dangerous substances' that posed a threat to his collection.¹⁸

Preparing the pleading: a huge task

On his return from Domburg, Kamerlingh Onnes embarked on a vigorous counteroffensive from his paralysed laboratory. He despatched a barrage of letters, to the engineer Piepers of the steam vessel inspectorate, to First Lieutenant Guij van Pittiers of the pyrotechnic workshops in Delft, to Captain Kleynkens, a military engineer in Amsterdam, to Mr Pennink of the railway authorities, and so on. Onnes gathered his information from as many sources as possible, including foreign ones: Dampfkessel Revision Verein in Berlin, Kohlensaure Industrie in Stuttgart, the fire departments in Dantzic and Düsseldorf, and the oxygen manufacturers Oxygène in Paris and the Oxygen Company in London.¹⁹ In a letter to Bosscha, Onnes complained about the enormous effort required to accumulate all the information he needed. He would have to hurry. 'You can imagine how eager I am to send off this letter [the statement of defence],' Onnes wrote to his former teacher in Delft, 'when the most important work in the laboratory is standing idle pending the granting of the licence.'²⁰ And that is how the situation would remain for some time to come.

Onnes researched the matter in the greatest detail, and took months doing so. Burgomaster – and member of the board of governors – Was sent him a reminder on 1 December,²¹ writing that 'the case is being dragged out for too long'. The very next day, the burgomaster turned up at the Steenschuur building and informed Onnes that on second thoughts, the board of governors had decided that Zaaijer's objections to the cryogenic laboratory should be taken very seriously. 'Exchanged words, not all of them very amicable', Onnes noted after the discussion. To give the burgomaster an idea of just how much attention the Physics Laboratory devoted to safety, Onnes presented him with the 'outline of absolute safety precautions' that he had just completed – six

¹⁷ BZ to *curatoren*, 29 August 1895, UB Leiden, Archief Curatoren.

¹⁸ *Curatoren* to BZ, 6 September 1895, NA, 2.04.13, inv. no. 431.

¹⁹ UB Leiden, Stationsweg archives.

²⁰ *Op. cit.* note 12.

²¹ *Ibid.*

pages of regulations, ranging from the 10-kilo maximum content of a gas flask to the construction of a shed with ‘explosion hatches and protective bars to trap flying pieces of metal’, separate pumps, bell-jars, refrigerators and so on for gases capable of producing explosive mixtures, and steam-driven heating in areas posing a fire hazard. As far as personnel was concerned, according to this ‘sketch’, ideally a separate machinist should be appointed, as well as an assistant to supervise laboratory work in the professor’s absence and a laboratory technician to take care of the liquid gases contained in cylinders or drums.²² Burgomaster Was must have been wondering – in his role as a member of the board of governors – what all this was going to cost.

After The Hague had urged him to make haste, Kamerlingh Onnes finally sent off his notice of defence on 14 December. Not that his research at home and abroad was complete, but it would damage his case if he dragged his feet and allowed the irritations at the Ministry to grow. The notice of defence was a solidly argued paper, over thirty pages long,²³ demolishing all the objections that had been raised by Zaaijer, Van Geer and the municipal executive – although Onnes’s opponents may not have seen it as such.

Onnes began by tackling the question of the compressed flammable gases. Electric light-bulbs instead of gaslights, steam-driven heating, plans for a fire-proof storage shed: all these measures meant that the laboratory posed no danger whatsoever, held the professor-director. Any compressed gas that escaped from a gas flask was comparable to coal gas escaping from a pipe. A few cubic metres of coal gas escaping in a room that was on fire could cause a ‘very substantial’ explosion, Onnes continued, but that did not prevent gas being installed everywhere, including in private homes – his laboratory alone used forty cubic metres of it every day. No one worried about the gas tanks underneath railway carriages, and his associate James Dewar, who had a full forty cubic metres of ethylene at the Royal Institution in London, had never encountered the slightest opposition. And five cubic metres of gas, Onnes concluded in this part of his counteroffensive, had an explosive capacity roughly equal to that of twenty litres of ether, a quantity that was completely normal in industry and never gave rise to concerns of any kind.

Next, he moved on to discuss the storage of gas flasks. How was it possible, Onnes demanded, that the Physics Laboratory was in danger of being banished from the built-up city centre because of a few flasks of gas, while thousands of gas flasks were delivered to a factory in the Feyenoord district of Rotterdam every year without any fuss about licences – in fact without anyone

²² *Op. cit.* note 15.

²³ *Ibid.*

ever complaining. Breweries, hospitals and gunpowder factories kept hundreds of thousands of flasks of carbonic acid at a pressure of 50 atmospheres; whole cargoes of them were shipped from one place to another. Lectures with magic lanterns relied on oxygen flasks at a pressure of 120 atmospheres, and no one gave two hoots about it. Onnes continued: 'While the use of cylinders of this kind containing carbonic acid and oxygen is now perfectly common *in* HBS secondary school classrooms – in Leiden as elsewhere – people are suggesting that it should be prohibited in a building of the State University, partly because this building is on the other side of a wide street *opposite* a city school.' In short, the risks had been heavily exaggerated, possibly because some had confused the very real dangers to which researchers and technicians working with glass apparatus were exposed with a menace to the immediate surroundings.

As for any actual explosions, here too some matters needed to be put straight. Gas flasks or glass tanks might burst, but this was of an entirely different order from exploding gunpowder. 'Should a piece of apparatus in the laboratory burst, it might best be compared not to the explosion of a mortar but to the bursting of a small steam boiler.' Onnes had assembled a vast quantity of information about the storage of gas flasks and about explosions. Hundreds of flasks of oxygen, he had discovered, were being stored underneath houses in the middle of Stuttgart, and Berlin city centre had three separate locations with thousands of gas flasks. On two occasions a flask in one of these storage facilities had burst because of inexpert handling; on both occasions, according to the Dampfkesselrevisor Verein, the only adverse effect was that one other bottle in the vicinity had exploded. So what possible harm could there be in storing a group of at most thirty gas flasks at the Physics Laboratory? Flasks that only burst, as experiments had demonstrated, if they were violently crushed until more than half flattened, which remained intact if dropped from a height of 16 metres onto blocks of cast iron, and which easily withstood blows delivered by a fifteen-ton hammer.

Nonetheless, conceded Onnes, 'just as boilers, which are regarded as completely safe, do explode now and then, cylinders containing compressed gas, which are likewise deemed entirely safe, have also occasionally exploded.' Onnes then proceeded to give a list of accidents that was scarcely designed to spread good cheer. In Haine in the United States, a flask containing carbonic acid had burst open during a fire with such force that it was hurled against a house on the other side of the road and bored its way through two walls and a beam. In Paris, a worker had been decapitated when a flask over-filled with carbonic acid and heated by radiation had exploded. In Silesia, a worker had died when a boiler with a corroded base had exploded, spraying its contents of 1,200 litres of sulphurous acid over him. In British India, a flask of carbonic acid had exploded in the heat of the sun, propelling another flask standing

nearby into the air and over a shed. In the Netherlands, a flask with carbonic acid had pierced a ship's skin, causing one fatality. Onnes emphasised that only a few such accidents had occurred, while hundreds of thousands of flasks of gas had been circulating for decades. Such incidents bore no comparison to 'the sad tale of the numerous explosions of boilers, the horrific details of which may be found in any volume of the *Mittheilungen des Dampfkessel und Dampfmaschinenbetriebes*.'

Concluding his statement of defence, Onnes added that these rare accidents were all attributable to negligence, whereas in the Physics Laboratory, only those well versed in proper procedure worked with compressed gases. Whenever there was any question of danger, expert advice was sought from specialists at the labour inspectorate, the inspectorate of steam vessels, and the fire service, as well as from experts on pyrotechnics and engineering. Averting danger was a 'fundamental principle', and numerous safety precautions were proposed and introduced long before any complaints might arise. It would therefore only cost a few thousand guilders to satisfy the objections that had now been raised. Moving the laboratory out of the city centre would be far more expensive. What was more, it was precisely in its experiments with liquefied gases that the Leiden laboratory was building up an international reputation. Nikolai Petrovich Kasterin, a gifted Russian scientist, would be coming in the near future to gain some experience working at the cryogenic laboratory. Rejecting the licence application, Onnes concluded, would bring all this to an abrupt halt and would prevent students from 'plucking the fruits of the work to which I have dedicated over ten years of my life'.

While the board of governors mulled over their response, the laboratory director himself adopted a decidedly upbeat tone in a letter to Kasterin's teacher A.G. Stoletov, whom he knew from Heidelberg and who had visited him in Leiden the previous summer. He had run into some difficulties with the local authorities, Onnes wrote to Moscow, 'But it will all be over by the spring'.²⁴

Wishful thinking. The board of governors forwarded the statement of defence to the Ministry of the Interior on 13 January 1896, but, as Was's visit had suggested, the board's support for Onnes's application for a licence under the Nuisance Act, which it had professed to the Minister in July, had now completely evaporated.²⁵ It was wholly unimpressed by Onnes's torrent of arguments. 'Perusal of this memorandum has strengthened our conviction that this is indeed an institution where highly dangerous substances are stored and

²⁴ *Janus*, 71 (1984) 145.

²⁵ *Op. cit.* note 15, *curatoren* to BZ, 13 January 1896.

where highly dangerous experiments are performed.’ It was all very well for Onnes to maintain that there was no harm in storing compressed gases, the board observed, but preparing those gases and conducting experiments with them was a very different matter. Onnes’s request for three extra members of staff solely to supervise matters of safety demonstrated just how hazardous such activities could be. No wonder the municipal authority wanted to banish the laboratory to an ‘isolated site’ outside the city centre, despite all the safety precautions that were in place. And what about the ‘Great Ruin’ site? The university was eager to build there – the Museum of Natural History would be located there after 1900 – and a dangerous laboratory on the other side of the road would be a downright liability. Instead of presenting in detail all its objections to Onnes’s statement of defence, the board of governors decided to emulate the provincial authorities and to appoint a committee to investigate the dangers of explosion. The underlying idea was evidently that such an investigation was bound to produce a negative conclusion for Onnes and his explosive devices.

Meanwhile, the anguished professor-director went on tirelessly accumulating mountains of information about explosions. The Luftschiffer Abtheilung of the Berlin police force, the Königliches Polizei Präsidium Abteilung Feuerwehr, also in Berlin, Bremen fire service, Onnes directed his enquiries to all and sundry. What regulations were in force? Were there any known cases of explosions? What safety precautions had been taken? How many gas cylinders were stored there? His enquiries elicited a huge quantity of information that proved useful in the next round of Onnes’s battle with the authorities. ‘The safety issue is still at the same stage as before’, wrote Onnes to Gey van Pittius on 11 February. ‘The documents will soon be on their way to the Council of State. Meanwhile all we can do here is wait!’²⁶ And a week later, after the first lieutenant at the pyrotechnical workshops had suggested placing cylinders within cylinders, Onnes complained in another letter to Delft that Leiden had foolishly omitted to consult expert opinion and had therefore conceived the ‘peculiar idea’ of demanding that he move his laboratory outside the city centre.²⁷

While Onnes armed himself afresh, the Ministry of the Interior prepared its response. It was true that under the terms of the 1875 Act, the documents would have to be sent to the Ministry of Water Management, Industry and Trade and thence to the administrative disputes division of the Council of State. The latter would then hold one final hearing at which all parties would

²⁶ Heike Kamerlingh Onnes to Gey van Pittius, 11 February 1896, UB Leiden, Stationsweg archives.

²⁷ Heike Kamerlingh Onnes to Gey van Pittius, 18 February 1896, UB Leiden, Stationsweg archives.

be able to present their arguments again. After this the case would be put before the Office of the Queen, possibly but not necessarily accompanied by a draft Royal Decree, and the widowed Queen Regent Emma would decide on the application for a licence under the Nuisance Act, after first consulting the Ministry of the Interior.... or was it the Ministry of Water Management, Industry and Trade?

But that was still a long way off. To start with, the Ministry of the Interior had requested additional information. The officials in The Hague had been particularly struck by the three extra members of staff in Onnes's 'outline of absolute safety precautions', which had been appended to the statement of defence. In an unnumbered – hence unofficial – letter, Onnes was asked whether the machinist, the assistant and the laboratory technician had already started work. The Ministry also wanted more details about the small Brotherhood pumps (generally used for launching torpedoes) that Onnes had borrowed from the navy, which were being operated at Leiden's cryogenic laboratory. On 5 February Onnes put in a personal appearance at the Ministry to clear up the misunderstanding about the extra staff. Yes, he would certainly appreciate 'new officials' being appointed and assigned to his laboratory, but for the time being he could perfectly well give the safety-related tasks to existing members of staff, 'who would then have to neglect some of their other duties'. To allay fears about the Brotherhood compressors, he sent the Ministry a photograph of one. No one, wrote Onnes in an accompanying note, could seriously imagine this little instrument posing a threat to the surroundings.²⁸

In mid-February, before referring the case back to the Ministry of Water Management, Industry and Trade, the Ministry of the Interior first had a question for the Physics Division of the Academy of Sciences. What restrictions, it wanted to know, could 'reasonably' be imposed on Onnes as conditions for granting him a licence under the Nuisance Act? The Academy responded Pavlov-style, by appointing an advisory committee to look into the matter. The committee consisted of D.J. Korteweg, S. Hoogewerff and C. Lely, with J.D. van der Waals as chairman – a composition that must have brought a smile to the lips of Kamerlingh Onnes, who was himself a member of the Academy. Van der Waals's molecular theory was the beacon by which he steered his course in Leiden, and after Academy meetings, which were held in the Trippenhuys on every last Saturday of the month, he frequently accompanied Van der Waals to his home in P.C. Hoofstraat to discuss certain matters in private. Korteweg, the Amsterdam mathematician whom Onnes had met in his Delft days working under Bosscha, was also a good friend. As for

²⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 74.

the Delft chemist Hoogewerff – Onnes had only just given him a flask containing eleven kilos of chlorine in exchange for a near-empty one because he wanted to confine his stocks to ‘the absolute minimum’ while the laboratory in Leiden was under fire.²⁹ The final member of the committee was Lely, professor of civil engineering at the Polytechnic and the later brain behind the Zuiderzee Works. A quartet that is bound to advance my cause, Onnes must have thought.

Three months later, at the Academy’s May meeting, a report lay ready that Onnes could have written himself.³⁰ Several arguments from the December statement of defence made a reappearance – the storage places with thousands of gas flasks in Berlin’s city centre, the difference between compressed gases and gunpowder – and the report’s appendices included letters that Onnes had received that autumn from the Dampfkessel-Revisions-Verein in Berlin and the Kohlensäure-Industrie in Stuttgart. The committee had also consulted two theoretical treatises that Onnes had written for the occasion: one on the explosive force of a canister containing gas compressed into liquid form, and the other on the consequences of an explosion. When this theory was applied to the use of gas flasks, boiler explosions, and the bursting of a flask containing carbonic acid, it could be demonstrated – to five figures after the decimal point – that steam boilers could indeed do far more harm than gas flasks.³¹

At the request of the Academy’s committee, Onnes also researched the working conditions of his counterparts in other countries. He wrote to James Dewar at the Royal Institution in London, Raoul Pictet in his factory in Berlin, and Karl Olszewski in his laboratory in Cracow asking where their laboratories were located, what kind and quantities of compressed gases they stored on the premises, what safety precautions were in place, and if they had ever had problems with the authorities concerning safety issues. ‘I have not been able to repeat your splendid experiments’, Onnes wrote to Dewar on 6 March, ‘for since your last letter [20 July 1895] it was impossible for me to work at low temperatures and that for a reason you will be astonished to hear.’³² After which Onnes complained that the city council wanted to banish him from the city, even though his laboratory had never had an accident, and observed that he would certainly have achieved far more results had he not taken such extreme safety

²⁹ Heike Kamerlingh Onnes to Hoogewerff, 18 December 1895, MB, archives of Heike Kamerlingh Onnes, inv. no. 74; Hoogewerff to Heike Kamerlingh Onnes, 20 December 1895, UB Leiden, Stationsweg archives.

³⁰ *Verslagen*, 5 (30 May 1896) 3-18.

³¹ N-HA, archief Akademie van Wetenschappen, inv. no. 388.

³² Heike Kamerlingh Onnes to Dewar, 6 March 1896, archives of the Royal Institution.

precautions. 'Where a local authority is so extravagant [sic], it is of course not possible to continue the work.'

The passionate and irascible Scot, who had written to Onnes on 10 July 1895 telling him that he did not want people prying about his laboratory, whether from the Netherlands or from anywhere else,³³ now gladly rallied round, replying by return of post: 'It would be a great disaster to science in your country (and universal science) if the municipality of Leiden succeeded in carrying out any restrictions on your splendid cryogenic laboratory and the fine work you are doing. I cannot understand such a position. Surely the scientific man is certain to do all in his power to avoid accidents and therefore the municipality can have full confidence in him.'³⁴ After which Onnes asked on 12 May if the Academy, 'coming to the same conclusion as you', might include Dewar's letter as an appendix to the report it would presently be publishing.³⁵ 'You are quite welcome to do what you like with my letter', replied Dewar. If Onnes so desired, he would 'with the greatest possible pleasure' come to Leiden to provide assistance.³⁶ Dewar wisely glossed over the accident that had happened in his own laboratory in 1888. A disastrous error caused ethylene to come into contact with oxygen in his apparatus, causing an explosion. 'I was nearly killed and as the experiment was being performed before a number of people, several got hurt', he had previously written to Onnes.³⁷ For a whole year the pursuit of cold had been suspended in London.

Karl Olszewski also expressed his sympathy and support. Liquefying gases was at worst hazardous for the scientist himself, wrote the Pole in March, but posed no threat to neighbouring rooms or buildings. He had been doing cryogenic work for thirteen years, and never had his laboratory in Cracow, in the heart of the city, had an explosion of any significance. True, a metal manometer had once burst at quite close range, without any dire consequences, and test tubes exploded now and then, but reinforced glass provided sufficient protection in such cases. Even the fact that he occasionally found it convenient to allow 400 grams of ethylene (which is flammable in air) to escape from the apparatus had never led to an explosion. And no one in Cracow had ever complained. Olszewski concluded his letter of support by expressing the hope that

³³ Dewar to Heike Kamerlingh Onnes, 20 July 1895, MB, archives of Heike Kamerlingh Onnes, inv. no. 294.

³⁴ Dewar to Heike Kamerlingh Onnes, 8 March 1896, MB, Heike Kamerlingh Onnes archives, inv. no. 294.

³⁵ Heike Kamerlingh Onnes to Dewar, 12 May 1896, archives of the Royal Institution.

³⁶ Dewar to Heike Kamerlingh Onnes, 14 May 1896, MB, archives of Heike Kamerlingh Onnes, inv. no. 74.

³⁷ Dewar to Heike Kamerlingh Onnes, 20 July 1895, MB, archives of Heike Kamerlingh Onnes, inv. no. 294.

his account would help to dispel Leiden city council's unfounded fears, and that Onnes would soon be able to resume his 'splendid experiments' without hindrance.³⁸

The letters from Dewar and Olszewski can be found among the appendices to the Academy's report. It may be added that Van der Waals had visited the Royal Institution in 1891 – as a newly elected honorary member of the Academy – at a stone's throw from Piccadilly Circus, and seen with his own eyes that Dewar's laboratory, including its gas flasks and a 100 hp gas engine, was beneath the Lecture Room. This was the venue of the famous Friday evening lectures held since the days of Michael Faraday, with many dignitaries among the audience. The Prince of Wales frequently attended, and members of the Dutch Royal Family also put in an occasional appearance.

The conclusions of the Royal Academy – unsurprisingly for Onnes, who had corrected the proofs himself –³⁹ could scarcely have been clearer: 'We believe that the Academy may safely advise the Minister to grant the said licence, and to do so without imposing any restrictions.' To refuse the licence would be disastrous, 'not only for Dutch science but for science in general.' Were there no factories in densely-populated city centres that were a great deal more dangerous than a cryogenic laboratory? The Academy praised Onnes for the considerable attention he paid to safety, and felt that the Minister would be well advised to give him the wherewithal to make the suggested improvements.

There were a few provisos, however. To prevent fire hazard, the Academy recommended: a) that a storage facility for gas cylinders be built, to be isolated from the main building of the Physics Laboratory; b) that the steam boiler be separated from the rest of the building by a fireproof partition; c) that the laboratory cease to use rubber bags to store ethylene and switch to more robust metal containers; and d) that the dangerous (since explosive in air) ethylene be prepared in a separate, fireproof annex. 'If all these measures are taken', wrote the Committee, 'they will meet in full the objections of the director of the Anatomy Laboratory, who in our view has far more reason to fear the fire hazard posed by the chemistry than the physics laboratory.'

So much for Zaaier. But the anatomist remained unconvinced. At the Academy meeting that had adopted the report, according to the Report of 30 May 1896, he declared that he had 'not participated in the vote'.⁴⁰

³⁸ Olszewski to Heike Kamerlingh Onnes, 23 March 1896, UB Leiden, Stationsweg archives.

³⁹ *Op. cit.* note 12.

⁴⁰ *Op. cit.* note 30.

By this time, the cryogenic laboratory had lain idle for a year. It was the Ministry of the Interior's turn to respond; it did so by passing the case on, in accordance with the 1875 Act, to the Ministry of Water Management, Industry and Trade. There was no objection to the 'substantial measures' proposed in the Academy's report, Minister Van Houten wrote to his fellow Minister, 'so that I have decided to recommend issue [of the licence for which Onnes had applied] after obtaining royal assent.'⁴¹ An internal report summarised the Onnes case – which had by now become a long story. The case proved to be a precedent: never before had complaints of this kind been submitted. The administrative disputes division of the Council of State would now have to review the matter. The Ministry of the Interior further notified the Ministry of Water Management, Industry and Trade – where the case was being dealt with by the Labour and Factory Inspectorate – that the board of governors in Leiden was primarily alarmed by the expense of all the proposed new safety precautions.

A second hearing was held, this time in The Hague on 25 November 1896. The Ministry of the Interior, Zaaijer, and the board of governors all sent advance notice that they would not be submitting any further communications. The board of governors did consider, however, that the safety measures proposed by the Academy should be made compulsory.⁴² Zaaijer, the reprimand from The Hague still fresh in his memory, had little desire to attract any further rebukes and lay low, even after the secretary of the board of governors had encouraged him to submit any remaining objections.⁴³ When the board of governors of the teacher training college also withdrew its objections, it became clear that Onnes's antagonists at the final hearing would be the municipal executive and the *Nut*.

The *Nut* had little to add to the arguments it had advanced at the hearing before the provincial authority in August 1895. Responding, Onnes triumphantly brandished the Academy's report, and called on Van Geer *cum suis* to accept the verdict of the 'committee of experts'. The professor-director reacted angrily when Van Geer related that a fanlight had broken in the lecture hall of the Leiden laboratory as a result of activities with compressed gases. In fact, the accident had been caused by bags of non-compressed oxygen, and a few students who had been sitting under the window had received some minor injuries from falling glass. Compressed gases had not been involved in any way in this accident, Onnes insisted.⁴⁴

⁴¹ BZ to Waterstaat, Verkeer en Nijverheid, 24 August 1896, NA, no 2.04.13, inv. no. 213.

⁴² *Curatoren* to BZ, 12 October 1896; see note 41.

⁴³ *Notulen curatorenvergadering* 7 October 1896, UB Leiden, Archief Curatorenno.

⁴⁴ Heike Kamerlingh Onnes to Raad van State, 28 October 1896, MB, archive 74.

The municipal executive's communication too must have infuriated Onnes. Signatories Was and Dekhuijzen concluded that the Academy of Sciences, in the light of its report, also regarded the presence of a cryogenic laboratory as posing a threat to the surrounding area. For had the Academy's experts not written that factories in large cities are 'a great deal more dangerous', implying that a cryogenic laboratory evidently posed a threat. Dewar's words 'dangers of no ordinary kind' corroborated that inference. Furthermore, continued the municipal executive, Onnes's own statement of defence at the end of 1895 had presented a litany of accidents that only served to emphasise the hazards of working with cylinders of compressed gas. The municipal executive, invoking its obligation the townspeople *as well as* science, considered the 'optimistic tone' of the Academy's report 'somewhat inexplicable'. Conclusion: only if the Academy's four recommendations were made mandatory and a fireproof partition were erected between physics and chemistry could the authority yield.⁴⁵

Onnes refused to let this go, and sent the Council of State a strongly worded statement of defence.⁴⁶ He flayed the executive for first seeking expert advice and then refusing to accept the experts' conclusions, 'when the experts heard were none other than a committee of members of the Royal Academy of Sciences'. Having reiterated some of his own earlier arguments in rebuttal, Onnes ended by observing that the demand that his work be suspended until all the demands had been met meant that physics, 'which had already suffered so greatly' would be dealt another blow. The bitterness of the quarrel with the municipal authorities was reflected by the professor-director's rather crass refusal to allow the balcony of his laboratory to be used by the choir as usual in the annual celebrations of the Relief of Leiden on 3 October 1896.⁴⁷ Even the waffle stall stationed on the bridge diagonally opposite the laboratory had to be moved elsewhere.⁴⁸

At the hearing,⁴⁹ Dekhuijzen withdrew the demand for a fireproof wall between the physics and chemistry laboratories. He described the Academy's report as an *oratio pro amici*. However, he no longer sought to banish the Physics Laboratory from the city. For his part, Onnes conceded that he had possibly exaggerated the extent of the calamity hanging over his head. He acknowledged that the safety precautions suggested by the Academy – all of which he

⁴⁵ Raad van State to Heike Kamerlingh Onnes, 29 October 1896, MB, archive 74.

⁴⁶ Heike Kamerlingh Onnes to Raad van State, 19 November 1896, NA, 2.02.06-1314, inv. no. 123.

⁴⁷ Heike Kamerlingh Onnes to 3 oktobervereniging, 22 September 1896, archives Huygens Laboratory.

⁴⁸ Archives Huygens Laboratory.

⁴⁹ See note 41, rapport hoorzitting 23 December 1896.

had wanted for some time – would remove the danger associated with the production of ethylene, but feared that another year might pass before the necessary funds were released. His plea to be permitted to resume at least part of his cryogenic work in the meantime fell on deaf ears. The Council of State noted that there were no objections to granting the licence provided that ‘certain safety precautions’ were taken. A supplementary pleading,⁵⁰ in which the municipal executive observed at the beginning of December that it had been Onnes himself, after all, who had pointed out the ‘explosive nature of the metal cylinders’ in the police report he had written at the end of 1894, and that his list of ‘desirable improvements’ and his outline of ‘absolute safety precautions’ demonstrated that his laboratory was not as safe as he made out, was a superfluous parting shot.

The matter was resolved: the Council of State sent a draft Royal Decree to the Office of the Queen, and asked the Ministry of the Interior to provide Her Majesty with the requisite ‘considerations and recommendations’.⁵¹ The Ministry of Water Management, Industry and Trade suddenly noticed in April that it had been bypassed, and complained that it and not the Ministry of the Interior should have ‘elicited’ the Royal Decree under the terms of the 1875 Act. In response, its sister Ministry immediately sent it copies of all documents received from the Council of State. But even before this bureaucratic squabble had erupted, Queen Regent Emma had already signed the royal assent. To Onnes’s disappointment, the Royal Decree of 21 January 1897 included all four of the Academy’s recommendations. He received notification in April, in a letter, to which Onnes responded on 4 May, ‘to my great joy [it] opens up the prospect that providing we have sufficient support from the Government, we shall be able to resume teaching at the Physics Laboratory on the same basis as we would have continued two years ago if no objections had been raised.’ The letter went on:

‘I do not therefore wish to imprint on your minds this series of events surrounding the objections, which has had such a grievous effect on education and on the advancement of science, other than to draw your attention to the fact that my teaching, precisely at a time when it was starting to attract warm interest from many quarters and was on the point of yielding the best returns, suffered a blow from which all my work and care will be unable to help it to recover without immensely robust support from the Government.’⁵²

⁵⁰ See note 41, B&W to Raad van State, 2 December 1896.

⁵¹ See note 41, BZ to Koningin-Weduwe Regentes, 19 January 1897.

⁵² Heike Kamerlingh Onnes to *curatoren*, 4 May 1897, *Archief Curatoren*.

Then followed Onnes's list of financial demands: he wished the 3,000 guilders that had been blocked in 1895 and had long since been returned to the public purse to be used for safety measures, to which a supplementary credit of 3,200 should be added and another 19,000 guilders spent on 'further safety precautions'. In the budget proposals for 1898, which were also posted on 4 May 1897, Onnes wrote that he profoundly hoped to be delivered at last from the safety issue that had paralysed his teaching for two years. The board of governors sent it all to The Hague, but informed the Ministry of the Interior that no consent would be forthcoming for the resumption of experiments at the cryogenic laboratory until all the precautionary measures were in place. 'However much we have Dr HKO's teaching at heart, the implementation of the Royal Decree of 21 January may not, in our view, be subordinated to it.' The board asked the Minister to convey this message to Kamerlingh Onnes.⁵³

This meant, of course, that it was some time before the cryogenic research could be resumed. While Lorentz had written to Zeeman on 1 February 1897, when the Royal Decree had just been signed, that it was difficult to say whether the apparatus would be working by the Easter holidays,⁵⁴ it soon became clear that even Easter 1898 was too optimistic. On 1 May 1898, when submitting the budget for 1899, Onnes wrote that he expected to be able to resume the full range of activities in the cryogenic laboratory in the very near future.⁵⁵ He again raised the matter of the shed for the safe storage of gases, and he also planned to purchase canisters, gas clocks, duplicate pumps and gas pipes – all of which related to the total plan for the gradual expansion of his laboratory that Onnes had prepared in 1886.⁵⁶ Once more the bundle of papers went off to The Hague, and once more the board of governors enclosed a letter expressing dissatisfaction with the state of affairs. It again drew the Minister's attention to the 'extremely hazardous processes' conducted in Onnes's laboratory and strongly advised against installing all this equipment because of the extent of the danger. It also had insuperable objections to the licence Onnes was requesting for a new 40 hp gas engine.⁵⁷ In short, the board of governors remained faithful to the position it had adopted on 11 January 1896 – Onnes should be banished from the city. At the same time, it strongly supported Onnes's request for a special laboratory technician for safety.

The Minister, who, in contrast to the board of governors, had never changed his position in over three years of cryogenic crisis, remained well-disposed to

⁵³ See note 41, *curatoren* to the Ministry of the Interior, 8 May 1897.

⁵⁴ Lorentz to Zeeman, 1 February 1897, N-HA, Zeeman archives, inv. no. 103.

⁵⁵ UB Leiden, Archief Curatoren, ingekomen stukken 1898.

⁵⁶ UB Leiden, Archief Curatoren, ingekomen stukken 1886.

⁵⁷ See note 41. *Curatoren* to BZ, 14 May 1898.

Onnes, and in July 1898 the Government Architect was allocated 17,200 guilders to put the remaining safety measures in place.⁵⁸ By then, Onnes was already busily preparing to resume operations at his cold factory. On 2 May he wrote in his laboratory logbook: ‘assembled methyl chloride circulation system’⁵⁹. On 4 June, the laboratory manager Flim started taking stock of the ethylene.⁶⁰ As soon as the leaking manometers and test tubes had been sealed, and the pumps, boiling flasks and piezometers were all working properly, research at low temperatures could be resumed. The first to profit from the newly manufactured cold was the Austrian Fritz Hasenöhr, a pupil of Ludwig Boltzmann’s. In November 1898 he embarked on a study of dielectric constants, and when Onnes submitted the results of his research to the Academy on 30 September the following year, it marked the end of the cryogenic intermission.⁶¹ After a protracted struggle, the most serious crisis in Onnes’s career had finally been laid to rest.

Making up the balance of the coldless years

When we review the sequence of events surrounding the ‘explosive devices’, it is striking that the Ministry of the Interior never seriously placed any obstacle in Onnes’s path – the fact that he was required, while the outcome of proceedings was pending, to refrain from the very activities that were at the heart of the proceedings does not seem very strange from an administrative point of view. However strongly the municipal executive and the board of governors may have recommended banishing the cryogenic laboratory from the city centre, in The Hague, where the decisions were made, this option appears scarcely to have been considered. Why not? First of all there was the financial argument: it was far less expensive to have Onnes put some additional safety measures in place than to move the entire laboratory somewhere else. Besides, plans had existed for years to offer the chemists a new building and to reallocate their current space to the physics department. In addition, from 1894 to 1897, the period of the cryogenic crisis, the liberal Samuel van Houten was Minister of the Interior in the Röell Government, and the fact that this politician had his roots in Groningen cannot have done Onnes’s case any harm.

Van Houten had first-hand knowledge of the situation: he had visited the Steenschuur laboratory on 12 November 1894. Onnes had planned to take

⁵⁸ BZ to Rijksbouwkundige, 4 July 1898, NA, 2.04.13, inv. no. 432.

⁵⁹ MB, Heike Kamerlingh Onnes archives, inv. no. 53.

⁶⁰ MB, archive 444, aantekenboekje (notebook) 1.

⁶¹ Fritz Hasenöhr, ‘The dielectric-coefficients of liquid nitrous oxyde and nitrogen’, KNAW, Proceedings, 2, 1899-1900, 211-228. *Comm.* 52.

him on a guided tour, but was given very little time to highlight any pressing needs: Van Houten was in a hurry, and said, at least according to Onnes's notes, that he had not come to learn anything about Onnes's activities but 'simply to see whether one or two new chemistry laboratories will be needed'. Even so, Onnes was able to draw the Minister's attention to a few things such as the laboratory work for medical students, the apprenticeship system in the workshops, and the new rooms. When he explained that the laboratory's electrical system had been installed by Siemens and by Haneveld of Groningen, the Minister said: 'I see you take on a good many Groningen people here' – Sissingh, Siertsema and Wind all came from Groningen. When asked if he was pleased with the space, the professor-director replied that he was 'grateful but not satisfied', and described the laboratory space he had been allocated as 'a drop in the ocean of what it should be'. And when Onnes went on to say that he wanted the entire chemistry wing, Van Houten snorted 'Ha! Such greed! ... but on the other hand, it is splendid to see a man who is so passionate about his work.'⁶²

While Leiden city council's objections were perhaps not unexpected, given the terrible history of the gunpowder ship, the attitude of the board of governors must have been a bad shock to Onnes. One explanation was that the board – which in practice served as a conduit to The Hague – was composed primarily of jurists who had no affinity with the world of science. The advent in 1899 of the physicist J. Bosscha as a member of the university's board of governors – succeeded in 1908 by fellow physicist J.D. van der Waals – helped to remedy this lamentable situation. In his subsequent 'war' with Einthoven, Onnes would gratefully exploit the presence of kindred spirits among the Leiden board of governors.

How badly did the enforced break affect Onnes's progress? In 1898, James Dewar became the first scientist to liquefy hydrogen. 'Liquefied Hydrogen and Helium', read the Scot's telegram to Leiden on 12 May – but only the former was true. Could Onnes have beaten his rival to the prize had it not been for the battle of the licence? Probably not. Dewar was interested in liquefaction as an end in itself, whereas for Onnes it was just part of his Great Plan: to test the theories of Van der Waals at temperatures that were as low as possible. That is why Onnes was determined to have a construction that could produce several litres an hour of liquid hydrogen. That called for a systematic, time-consuming method in which everything was thought through, down to the smallest detail. It may be added that the development of a hydrogen liquefier did in fact continue in Leiden, in a kind of dry run, while the cryogenic

⁶² Notitie (memorandum) of 12 November 1894, archives Huygens laboratory.

laboratory was largely standing idle. Meanwhile, in 1896 Onnes purchased a Burckhardt pump (three years later he would buy another one); he also published an article that year, explaining the theoretical principles and experimental premises underlying his anticipated liquefaction of hydrogen – empirical success did not follow until 1905.

The cryogenic crisis certainly occupied much of Onnes's time in the years 1895 to 1898, but he had plenty of other things to attend to as well. To start with, he had his regular teaching load and the supervision of his undergraduates, PhD students, and assistants. After the discovery of the Zeeman effect, Onnes exerted himself vigorously in the ensuing controversy about primacy. In 1897 about one hundred secondary school teachers (at HBS as well as *gymnasium* schools) descended on the laboratory to be shown around and to attend special lectures in the Easter holiday, an initiative that other institutions later emulated. As vice-chairman of the Dutch Electrical Engineering Society, founded in 1895, Onnes also devoted considerable energy to setting up a training course for electrical engineers. And it was in this period that Onnes started professionalising the training system for instrument-makers that was to prove such a boon for the laboratory (see Chapter 20). Finally, in the years 1896-1898 he served as secretary of an Academy committee that conducted a time-consuming study of noise levels in 'cellular prisons' – a piece of research commissioned by the government (see Chapter 22).

Onnes's study of Russian deserves a separate mention. Nikolai Kasterin finally arrived from Moscow in November 1897, after his visit had been repeatedly postponed, and worked at the Leiden laboratory until the summer of 1898, studying the refractive index of gases. His presence inspired Onnes to attempt to master his guest's language, and increasingly his letters and cards to Kasterin were written in Russian. Onnes noted that in the summer of 1898, in particular, he devoted a great deal of time to studying Russian.⁶³

It is striking that Onnes rarely referred, later in life, to the unfortunate episode of the 'explosive devices' that had held up his quest for absolute zero. The guidebook used for the teachers' visit in April 1897 does not mention it – he borrowed the methyl chloride he needed for the demonstrations from Delft, since his laboratory was forbidden to produce it at the time.⁶⁴ The commemorative volume published in 1904 to mark the 25th anniversary of Onnes's doctorate contains not a word about the interruption in the cryogenic work, let alone any attribution of blame. Perhaps Onnes wanted to avoid the city council and/or the board of governors parrying any lamentations on his side by

⁶³ *Janus* 73 (1986-1990) 43-45.

⁶⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 52.

observing that it was precisely their opposition to the cryogenic installations in Leiden that had made it possible for the Zeeman effect to be discovered in 1896 – crowned with a Nobel Prize in 1902.⁶⁵ (In the previous chapter we saw that the vibration-free laboratory I, where Zeeman conducted his experiment, may well have been available only because Van Everdingen's plans had to be abandoned in the absence of the required cold conditions.) Not until after Onnes's death in 1926 did his pupil and successor W.H. Keesom refer in an obituary to 'a very serious crisis ... that might have been fatal to the cryogenic laboratory'.⁶⁶

While the Leiden laboratory fortunately had no accident worth mentioning in the Onnes era, a bang of sorts did occur much later. On Friday 2 November 1956, at 10.55 a.m., an experimental hydrogen liquefier exploded in the new cryogenic hall, immediately behind the former anatomy building that had been erected courtesy of the Bataafsche Petroleum Maatschappij. The lid and heat exchanger bored a hole straight through the roof, shot twenty metres into the sky, and landed in the courtyard. 'Four sustain light injuries from flying glass splinters', reported the *Leidsch Dagblad* that afternoon, adding that prompt action taken by technical staff 'had prevented the fire from spreading'.⁶⁷ The newspaper reported that dozens of windows had shattered in the laboratory and the immediate surroundings; eye-witness reports, on the other hand, mentioned only a few broken windows in the cryogenic hall itself. There was certainly a huge cloud of dust after the explosion, and some technicians had red manometer oil on their faces – which the journalist from the *Leidsch Dagblad* mistook for blood.⁶⁸

Spectacular, but not a gunpowder ship. A crack probably developed in the heat exchanger, causing hydrogen to come into contact with liquid oxygen, after which an electrostatic charge triggered the explosion. That was possible because liquid air had been used as the pre-coolant. This evaporated partially, so that the oxygen was left over from the oxygen-nitrogen mixture, with dramatic consequences. The incident did not have any direct consequences for the laboratory's location. And Russia's invasion of Hungary, two days later, soon pushed the modest explosion at the Steenschuur out of the newspapers and people's minds.

⁶⁵ H.N. de Lang, 'Heike Kamerlingh Onnes 1853-1926', in A.J. Kox (ed.), *Van Stevin tot Lorentz* (Amsterdam 1990) 220.

⁶⁶ W.H. Keesom, 'Prof. Dr. H. Kamerlingh Onnes; Zijn Levenswerk, de stichting van het Cryogeen Laboratorium', *Physica* 6 (1926) 81.

⁶⁷ *Leidsch Dagblad*, 2 November 1956.

⁶⁸ Personal communication by R. de Bruyn Ouboter.

18. Retrograde condensation

Let us take a step back in time. In the summer of 1887, shortly after gaining his Bachelor's degree, the physics student Johannes Petrus Kuenen was summoned to the office of Professor-director Kamerlingh Onnes for an interview. In that 'probably least ostentatious room in the entire building' he was asked whether he wished to pursue his studies in the 'mathematical or experimental direction'. Students were scarce at the time, and Onnes later recalled that he and Lorentz 'had kept their spirits up by counting someone with two names twice'.¹ Kuenen, pleasantly surprised that there, on the ground floor of the Steenschuur building, 'on the other side of the glass door', he was being offered the possibility of an academic career, did not have to think long. He thought it 'a revelation' that he might be 'entrusted with the immediate, independent research of natural phenomena' and be able to 'contribute something to the knowledge of such phenomena'.²

Once he had opted for experimental physics, the next thing was to choose his subject. In 1904 Kuenen recalled:

'I still see before me the list of possible research projects for me that Professor Onnes had drawn up and from which a choice now had to be made in mutual consultation. Perhaps that list still exists today; the two subjects that topped the list and between which I would eventually have to choose were "the behaviour of mixtures" and the "causes of the slow loss of electricity in electrostatic experiments".'³

He opted for mixtures of two substances. The underlying theory, though developed by Van der Waals, had not yet been published in 1887. The Amsterdam professor had slumped into a deep depression after his wife's death, six years earlier, and hardly published anything any more. Even so, he had continued to concern himself with theoretical research. Onnes was aware of this. He

¹ *Physica* 6 (January 1926) 10.

² J.P. Kuenen, 'Condensatie en kritische verschijnselen van mengsels', *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904) 88-89.

³ *Ibid.*, 90.

often went to Van der Waals's home in P.C. Hoofstraat after the Academy's monthly meetings in Amsterdam on Saturday afternoons, and in the study, where a portrait of Anna Magdalena stood on the armchair in front of the paper-strewn desk, the master would discuss his latest ideas. It became clear to Onnes that, building on the equation of state for simple substances, published in 1873, Van der Waals had now plunged into the theory of binary mixtures. Many years later, in the same commemorative volume as that in which Kuenen recorded his memories, the author of the ground-breaking *Continuity* wrote:

'I am now revisited by a whole series of personal recollections, now that I come to Onnes's part in the research on binary mixtures. How many talks did this subject not provoke? The one I remember most clearly is perhaps the first, because it would eventually lead me to publish my molecular theory for mixtures. Onnes told me about his plan to launch a research project on mixtures in his laboratory. For single substances it was known what could be researched, but where mixtures were concerned, one was truly in the dark. What were the problems in this connection? There was not only a lack of any theory to provide indications and guidance, but the field seemed so chaotic that one did not know where to begin or how to continue. I was surprised to hear of these plans, and was able to tell him – doubtless to his surprise too – that I had not only been working on developing a theory of binary mixtures for some time, but that I had indeed completed it in broad outline. That I was confident concerning the basic principles; only the details remained to be elaborated.'⁴

Onnes must have been flabbergasted. 'Plaitpoint', 'critical point of contact', 'rule governing coexisting phases': all manner of details were touched on at this first meeting. Since there was no time to discuss the theory in depth, his guest was rather sceptical, Van der Waals recalled.

'He blurted out, "Do you dare to assert all this on the basis of a single formula?" ... And when I told him that if I had shown him the foundations on which my entire line of reasoning was based, it would certainly allay his doubts, he insisted that I publish this theory. I had lost interest in publishing my results at that time, and I would certainly not have done so. But Onnes advanced the one argument in favour of publication to which I was sensitive. He refused to conduct any research based on this theory if he could not include an acknowledgment.'⁵

In developing his theory of mixtures,⁶ Van der Waals made good use of the ideas of J. Willard Gibbs. This American physicist, working completely alone

⁴ J.D. van der Waals, 'De arbeid van Kamerlingh Onnes voor de Vaderlandsche Natuurkunde', *Het Natuurkundig Laboratorium* (1904) 82.

⁵ *Ibid.*, 83.

⁶ For a detailed survey, see J. Levelt Sengers, *How Fluids Unmix: Discoveries by the School of Van der Waals and Kamerlingh Onnes* (Amsterdam 2002) 87-106. I wish to thank Anneke Levelt Sengers for

at Yale, had produced two formidable articles in 1876 and 1878 on phase equilibria, including mixtures with fluid and solid components, offprints of which he sent to Amsterdam.⁷ On the basis of Gibbs's *phase rule*, which laid down a simple relationship between the number of components in a system, the number of phases, and the number of degrees of freedom (such as pressure and temperature), Van der Waals was able to explain Hendrik Willem Bakhuis Roozeboom's surprising observations using hydrates of hydrogen bromide. This chemist had gained his doctorate at Leiden in 1884 (with Van Bemmelen as supervising professor) and had conducted part of his research at Onnes's physics laboratory.

In mid-1886, Van der Waals gave a sensational presentation at the Steenschuur building on phase equilibria according to Gibbs's new thermodynamics, his audience consisting of Van Bemmelen, Lorentz, Kamerlingh Onnes and Bakhuis Roozeboom. It must have been crucial to Onnes in helping him to map out the direction of his research and in elevating thermodynamic research at Leiden to a higher plane. In 1873 Gibbs had introduced a graphic method: three-dimensional surfaces expressing free energy as a function of entropy and volume. Other thermodynamic quantities followed from the gradient (steepness) of the surface. Kamerlingh Onnes now followed Maxwell in actually constructing such Gibbs surfaces for water and carbonic acid, on the basis of French experimental data.

At the end of 1886, Bakhuis Roozeboom published an article on conditions for equilibrium, using a formula that Van der Waals had derived in his presentation. In his introduction, Bakhuis Roozeboom wrote that it was regrettable that Van der Waals had not yet been willing to publish the ideas referred to in his letters.⁸ At Onnes's insistence, Van der Waals finally decided to do so in 1889. At the Academy's February meeting, he presented 'certain findings obtained in seeking to develop a molecular theory for a binary mixture'.

This article, brief though it was, dealt with all the essential points in condensed form: the extension of the equation of state for single substances to one for mixtures, the central role accorded to free energy in the system (which attains a minimum in the state of equilibrium) and the geometrical method indicating what state of equilibrium the mixture will attain and how the co-existing phases will 'work out'. The latter relied on the so-called Ψ -surface, a

making available her transcripts of correspondence between the protagonists in the research on mixtures.

⁷ J.W. Gibbs, 'On the equilibrium of heterogeneous substances', *The scientific papers of J. Willard Gibbs*, vol. I (London 1906) 55-353.

⁸ A.Y. Kipnis, B.E. Yavelov and J.S. Rowlinson, *Van der Waals and Molecular Science* (Oxford 1996) 157-159.

three-dimensional figure plotting volume against the relationship between the two components along the two horizontal axes, so that the free energy is indicated along the vertical axis. This produced a ‘landscape’ with dents or folds, and by rolling a flat surface (an inked glass plate) over that landscape and recording the contact graphs, Van der Waals obtained a graphic representation showing which coexisting phases were possible.

After the concise communication of February – possibly intended merely to establish precedence – Van der Waals elaborated his ideas in detail in a major article. He wrote in Dutch, with a view to publication in the Academy’s *Verhandelingen* (Proceedings), but on Bosscha’s advice he decided to submit it to the *Archives Néerlandaises* instead. Bosscha himself translated the article into French – no easy task, since Van der Waals had the habit of keeping his explanations of formulas to an absolute minimum – or less.⁹ The 56-page ‘Théorie moléculaire d’une substance composée de deux matières différentes’ appeared in 1891.¹⁰

The article printed immediately after Van der Waals’s contribution in the *Archives* was a treatise on plaitpoints by the mathematician Diederik Johannes Korteweg,¹¹ a colleague of Van der Waals’s at the University of Amsterdam who had been his first PhD student (gaining his doctorate in 1878), and who knew Onnes from his days in Delft. Korteweg had made an in-depth study of Gibbs-type surfaces (expressing free energy as a function of entropy and volume; the Ψ -surface is a derivative of the Gibbs surface) and had published on the subject in 1889 – in other words, before the mixtures – in the Vienna Academy’s *Sitzungsberichte* (the piece in the *Archives* was a translation). In his Nobel Prize acceptance speech, Van der Waals said that he had derived great benefit from Korteweg’s studies in mathematical physics (a second article by Korteweg with an exhaustive classification of possible plaitpoint constructions was published at the back of the same issue of the *Archives*¹²), but the article contained no acknowledgements of this work. Bosscha, in his capacity as translator, kindly added a footnote reference to Korteweg.¹³

No sooner did the theory of binary mixtures see the light of day than Kuenen, who had gained his Master’s degree in 1889 and had been appointed

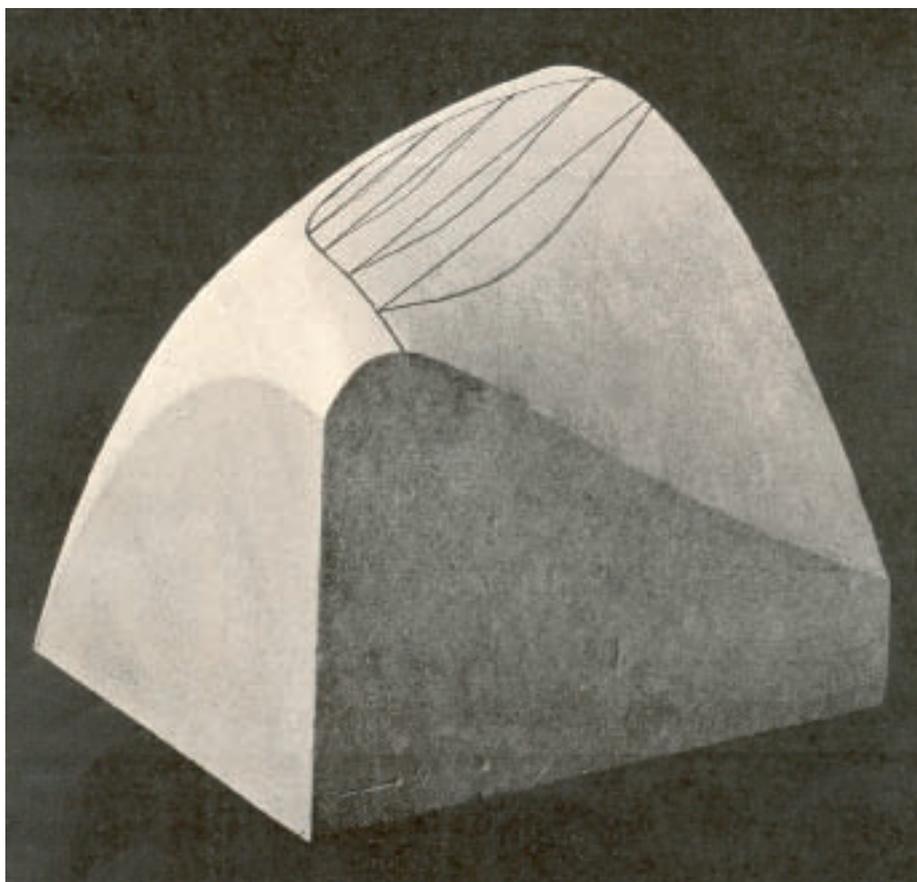
⁹ *Ibid.*, 262.

¹⁰ J.D. van der Waals, ‘Théorie moléculaire d’une substance composée de deux matières différentes’, *Archives Néerlandaises* 24 (1891) 1–56.

¹¹ D.J. Korteweg, ‘Sur les points de plissement’, *Archives Néerlandaises* 24 (1891) 57–98.

¹² D.J. Korteweg, ‘La théorie générale des plis et la surface psi de van der Waals dans le cas de symétrie’, *Archives Néerlandaises* 24 (1891) 295–368.

¹³ Johanna Levelt Sengers and Antonius H.M. Levelt, ‘Diederik Korteweg, pioneer of criticality’, *Physics Today*, December 2002, 47–53.



Ill. 29. Three-dimensional model of a Ψ' -surface of a mixture of two substances. Free energy is plotted vertically, while the two horizontal axes indicate the composition of the mixture and volume. Rolling an inked glass plate over the surface yielded information on the possible phases of the mixture.

as Onnes's assistant six months later, started working with it in Leiden. By way of encouragement, Onnes had set a competition on behalf of the mathematics and physics faculty in the spring of 1891: 'The Faculty invites observations that are suitable for testing the theory of Van der Waals (Archives Néerl. T. XXIV) in respect of mixtures of two substances.'¹⁴ Onnes was particularly hoping that Kuenen would construct a Ψ' -surface on the basis of measurements.

¹⁴ *Almanak van het Leidsche Studentencorps* 1891, 135.

As the components of his mixture, Kuenen took carbonic acid and methyl chloride, with critical temperatures of 31°C and 123°C , respectively. Both were available in abundance in the cryogenic laboratory. Nonetheless, numerous problems had to be overcome. The required purity was obtained through distillation and drying processes, and a glass apparatus with mercury bulbs was used to make a mixture with a predetermined composition. To keep the temperature constant, the Cailletet tube in which the mixture was enclosed was placed in liquid around which was a vapour bath of methyl or ethyl alcohol, water, amyl alcohol, turpentine or aniline, depending on the desired temperature. In this way, isotherms were measured at temperatures ranging from 23°C to 170°C . Both the accurate determination of the condensation point, the moment at which liquid starts to form in a mixture of vapours, and the actual course of the condensation process were impeded by the snail's pace at which the system reached equilibrium. In the narrow test-tube, diffusion processes, especially those involving two liquids, proceeded extremely slowly. To solve the problem, Kuenen inserted a stirrer into his test-tube, made of iron wire with studs, that could be moved up and down from outside using a magnet. Leiden would derive enormous benefit from this simple but highly effective aid in future years.

At the same time, however, this stirring had a disruptive effect in situations close to the critical point, because it generated heat. Kuenen initially failed to notice this, and his observations baffled him. 'I recall one morning', he wrote in the 1904 commemorative volume, 'when Professor Onnes himself participated in the observations for several hours, which was not his custom; as a rule, his almost daily visits were taken up entirely by consultations and planning.'¹⁵

On 8 February 1892, during the Foundation Day celebrations of the University of Leiden, Kuenen was awarded a gold medal for his 'highly compactly worded answer' – the competition had elicited a single entry. The jury report, written by Onnes in consultation with Van der Waals, referred to 'diverse experiments that shed more light on the qualitative link with the theory of binary mixtures', according a key role to observations of condensation phenomena and the vanishing of the meniscus under compression, entirely in the context of the folds in the Van der Waals surface.¹⁶ A detailed version of the prize-winning entry, with theoretical considerations besides measurements and graphs, was presented in April 1892 as Kuenen's doctoral dissertation: *Measurements concerning the surface of Van der Waals for mixtures of carbonic acid and methyl chloride*.¹⁷

¹⁵ *Op. cit.* note 2, 117.

¹⁶ *Almanak van het Leidsche Studentencorps* 1892, 112.

¹⁷ Johannes Petrus Kuenen, *Metingen betreffende het oppervlak van Van der Waals voor mengsels van koolzuur en chloormethyl* (Leiden 1892). No. 18 of the traditional 'propositions' accompanying the dissertation was 'Our space is an innate form of observation'.

Van der Waals, who was very interested in the results achieved with his theory, was always the first to hear the findings of the experiments in Leiden, either from Onnes during one of his visits, or in letters to his home. Although only 'a spectator at a distance', he knew exactly what experiments were being conducted at the Steenschuur, as was clear from his contribution to the 1904 commemorative volume:

'For although I was seldom present at any of these experiments, and only sporadically saw any of them with my own eyes, they were not unknown to me. In many cases I not only knew what research was being conducted, but also the envisaged objective. I knew the questions to which Onnes sought experimental answers. The practical difficulties encountered at the beginning, the path that had first achieved successful results, the points of view that gradually opened up, and finally the results that had been obtained – I was fully acquainted with all of this, either in conversation or detailed letters, or sometimes through detailed communications that stretched to the length of treatises and were illustrated with drawings and slides. Moreover, ... these experiments were closely linked to questions that I myself was seeking to answer, or believed I had already answered. In many cases Onnes took results I had obtained theoretically and subjected them to the verdict of experiment, and I awaited the verdict with no less excitement than the observer himself. And that I would be obliged to accept this verdict as the correct one – about that I was in no doubt. In many of the research projects conducted at the Leiden laboratory I was an interested party, and almost felt like a participant.'¹⁸

Onnes derived great benefit from his monthly visits to Van der Waals's home on P.C. Hoofstraat. Van der Waals's desk was covered with unpublished calculations containing 'many valuable comments' in relation to Kuenen's 'splendid work'. 'On the basis of such calculations, made long beforehand', Onnes observed in the daily newspaper *De Telegraaf* in March 1923, 'Van der Waals could often form an opinion on peculiarities in one of the graphs representing the results of the ongoing work in Leiden', adding that subsequent measurements generally confirmed Van der Waals's distrust of such peculiarities.¹⁹

The Ψ -surface that Onnes wanted Kuenen to produce initially proved to be overambitious. Van der Waals's equation of state was not able to reproduce Kuenen's measurements using pure methyl chloride and pure carbonic acid with sufficient accuracy, which meant that calculations of the free energy in cases of mixtures of these two substances were of little value. Not until 1900 did Onnes succeed, in collaboration with Max Reinganum, a colleague from Göttingen who was a guest at the physics laboratory in 1899 and 1900, in calculating the

¹⁸ *Op. cit.* note 4, 72-73.

¹⁹ H. Kamerlingh Onnes, 'Ter herinnering aan Prof.Dr. I.D. van der Waals'. *De Telegraaf*, 11 March 1923.

Ψ -surface himself on the basis of a modified equation of state, after which the services of a local modeller (Zaalberg) were enlisted to make plaster scale models. A trial specimen measuring 30 by 20 by 40 centimetres proved to be too small, after which the measurements were doubled. Even hollowed out, the models still weighed over 80 kilos.

In 1898, Onnes distributed photographs at the *Naturforscherversammlung* in Düsseldorf, and to those who were interested he also sent casts of the small model and of part of the large one.²⁰ By rolling an inked glass plate over this ‘mountain landscape’, he was able to trace Korteweg’s ‘binodal curves’ that form the boundaries of the folds. Almost thirty of these plaster models have been preserved, and can be found in the collection of Museum Boerhaave.²¹

Although producing a truly accurate Ψ -surface had proved overly ambitious in 1891, the idea of such a surface nonetheless set Kuenen thinking. Van der Waals’s article on binary mixtures in that year’s *Archives* was accompanied by an engraving depicting the shape that this free energy landscape might assume.²² In the case of two folds, this held out the prospect of a binary system of a vapour and a liquid, in which one would expect increasing pressure to cause that liquid to separate into two different components. To his disappointment, Kuenen did not succeed in achieving such a mixture with *three* coexisting phases (one vapour and two liquids) using a mixture of methyl chloride and carbonic acid. The putative successes of Wroblewski and Cailletet in this area proved to be artefacts of a system that was not yet in equilibrium. When Kuenen repeated the Polish and French experiments, he also saw the liquid dividing – but when the mixture was stirred this division immediately vanished. Similarly, Dewar’s observation of liquid dividing in a mixture of carbonic acid and carbon disulphide was invalidated by Kuenen’s rigorous stirrer.²³

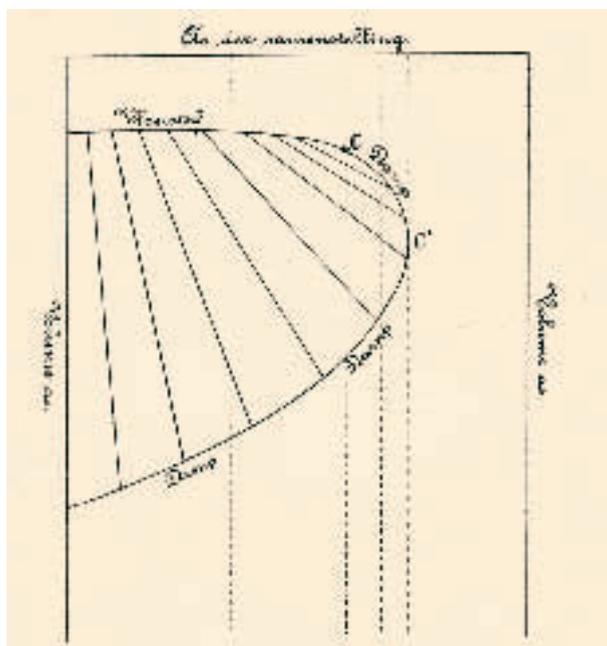
Kuenen’s great triumph was his discovery in 1892 of *retrograde condensation* – the phenomenon that in a mixture continuing a liquid and a vapour, the conditions are such that while compression (reducing volume) initially leads, as

²⁰ H. Kamerlingh Onnes, ‘Contributions to the knowledge of Van der Waals’ psi-surface. I. Graphical treatment of the transverse plait’, in KNAW, Proceedings, 3, 1900-1901, Amsterdam, 1901, pp. 275-288. *Comm.* 59a; H. Kamerlingh Onnes and M. Reinganum, ‘Contributions to the knowledge of Van der Waals’ psi-surface. II. The part of the transverse plait in the neighbourhood of the plait-point in Kuenen’s experiments on retrograde condensation’, in KNAW, Proceedings, 3, 1900-1901, Amsterdam, 1901, pp. 289-298. *Comm.* 59b.

²¹ Anne C. van Helden, ‘Kamerlingh Onnes’ three-dimensional graphic method’, in K. Martinós (ed.), *Thermodynamics: history and philosophy; facts, trends, debates* (Singapore 1991) 455-461.

²² *Op. cit.* note 10, 28.

²³ J.P. Kuenen, ‘Eenige proeven over het verband van de twee plooiën in het oppervlak van Van der Waals voor mengsels’, *Verslagen*, 2 (June 1893) 28-31. *Comm.* 7.



Ill. 30. Projection of the Ψ -surface of a mixture onto the base. The curved line indicates the edges of the fold that appears in the surface under certain specific conditions. Corresponding points in the liquid and vapour branches of the mixture are connected by straight lines. C is the critical point. Under compression, mixtures between C and C' display a phenomenon (discovered in 1892 by Johan Kuenen) known as retrograde condensation: the quantity of liquid in the test tube with the mixture initially increases, but if the mixture is compressed further, the liquid vanishes.

expected, to more liquid, through condensation, if pressure is increased further, the liquid level actually starts to *fall*. 'I still hold in vivid remembrance', wrote Kamerlingh Onnes in 1922 in *Nature*, 'how Kuenen, putting in action his magnetic stirrer, the simple but fundamental contrivance by which he succeeded in eliminating retardation, had the satisfaction of demonstrating to van der Waals the retrograde condensation, and of seeing van der Waals looking in deep reflection at the beautiful phenomenon, which at once put his theory beyond any doubt. An admirable interaction of Kuenen's experiments and van der Waals deductions followed.'²⁴

²⁴ H. Kamerlingh Onnes, 'Prof J.P. Kuenen', *Nature* 110 (1922) 673-674.

The discovery was made not long after Kuenen gained his doctorate. On 16 June 1892, Onnes wrote to his Amsterdam friend, inviting him to allow Kuenen personally to demonstrate to him the retrograde condensation he had just observed, ‘preferably on Monday, which day you will certainly want to spend with me’.²⁵ Van der Waals, deeply impressed, later referred to ‘Kuenen’s brilliant piece of research’ and to the ‘acid test’ of his theory.²⁶ A lengthy correspondence ensued between Leiden and Amsterdam regarding the exact conditions in which retrograde condensation (the term coined by Kuenen) occurred, the underlying theory, and the possibility of three coexisting phases. Van der Waals eagerly awaited the last observations, in exchange for which he sent Kuenen and Onnes his latest theoretical writings.

Onnes presented Kuenen’s retrograde condensation to the Academy at the end of June. The phenomenon had been observed at between 103°C and 106°C in a mixture that was 40 per cent carbonic acid. His communication dismissed earlier observations by Cailletet (1880), Andrews (1875) and Van der Waals (1880), in particular of a gradually flattening and then vanishing meniscus under increased pressure, as phenomena attributable to retardation – caused by slow diffusion. Kuenen too had observed similar pseudo-effects – he mentioned them in his competition entry – but his magnetic stirrer put paid to them. At the end of his article, he had some stern words for Andrews: ‘Finally, the theory expounded may be used with complete success to explain the observations of Andrews, who has described the condensation of his mixtures in the greatest detail. That an experimental physicist such as Andrews failed to see what was actually happening is completely understandable given his ignorance of Van der Waals’s theory, without which retrograde condensation could not easily be discovered.’²⁷ The final sentence – scarcely fair and distinctly tactless – was deleted from an English translation of the article in *Communications* 4.

Dual precedence: a new conflict

Kuenen had not only discovered retrograde condensation empirically, he had also *predicted* it. The idea had occurred to him in March 1892, while he was expanding his prize-winning entry with its abundant ‘observations suitable for testing the theory of Van der Waals for mixtures in respect of mixtures of two substances’ into a fully-fledged dissertation, with the addition of some

²⁵ Heike Kamerlingh Onnes to Van der Waals, 16 June 1892, N-HA, Van der Waals archives.

²⁶ *Op. cit.* note 4, 83–84.

²⁷ J.P. Kuenen, ‘Over retrograde condensatie’, *Verslagen* 1 (June 1892) 19. *Comm.* 4.

theoretical chapters. In the absence of a good equation of state, he had dropped the idea of constructing a Ψ -surface for his mixture of methyl chloride and carbonic acid, but that did not alter the fact that he could certainly say approximately what such a surface would look like. And this shape told him that retrograde condensation could be expected in mixtures occupying a very special position in the Ψ -surface: between the plaitpoint and the point of contact of the binodal curve. It may be added that Kuenen acknowledged all his sources entirely properly in his dissertation: 'the application of the theory of Van der Waals ... suggests a solution, however, for which he himself had already paved the way'.²⁸ He then quoted a passage from Van der Waals's article in the *Archives*.

Even so, Van der Waals was very unhappy about Kuenen's claim to dual precedence in respect of this discovery. Initially he kept his disgruntlement to himself, but in October 1894 he vented his fury. His outburst was triggered by a communication that Onnes had delivered to the Academy the month before on Kuenen's behalf.²⁹ In this piece, Kuenen demolished a paper by Pierre Duhem, entitled 'Les Mélanges doubles'. 'It is my intention to make Duhem's graphic representation more complete and to divest it of certain inaccuracies', Kuenen prefaced his punitive expedition against the French physicist. Duhem's most egregious error had been to allege that the main outlines of his theory, including the possibility of retrograde condensation, had been drawn back in 1888. Kuenen, 'without wishing to refute this fairly indeterminate assertion', wiped the floor with Duhem's claim with persuasive arguments, before continuing:

'I therefore think it justified to continue to assert in full my precedence concerning both the prediction and the empirical confirmation of retrograde condensation as well as the explanation of critical phenomena of mixtures.'³⁰

In a letter to Van der Waals, dated 9 October 1894, Onnes denied that he and Kuenen had expressed themselves 'too arrogantly' regarding Duhem. By then, a 'review' of the said French treatise in proofs of the *Beiblätter* had come to the attention of the Leiden scientists, containing the remark that Duhem dwelt particularly on the subject of retrograde condensation, 'for which he had previously ('88) supplied the explanation'. Kuenen, according to Onnes, had immediately sought to rectify the matter. In his letter Onnes wished to convey to Van der Waals, who saw little harm in Duhem's claims, that the matter was less innocent than was assumed in Amsterdam. But Leiden too did not wish to

²⁸ *Op. cit.* note 17, 21.

²⁹ J.P. Kuenen, 'Over de condensatie van een gasmengsel', *Verslagen* 3 (September 1894) 90-99. *Comm.* 13.

³⁰ *Ibid.*, 92.

overstate the case. ‘Anyway, I should stop pestering you about the depravity of our prolific Duhem’, Onnes ended his letter. ‘I only wished to elicit a smile.’³¹

But Van der Waals saw absolutely nothing to smile about. Ten days later, he sent Onnes a letter in which he again remarked that he did not begrudge Duhem having his ‘bias’, like anyone else. He then went on to convey his ‘disenchantment’ with Kuenen’s claim to precedence in the prediction of retrograde condensation. In his view, the empirical research of Onnes’s pupil had merely confirmed the conclusions of his own theory of binary mixtures – as was stated in a footnote to the French edition of *Continuity*, which had just been published.

‘For anyone who is able to read, the whole thing was explained in my *théorie moléculaire* pag 54-56 ... In that purely mathematical piece – I dealt briefly (perhaps too briefly) (but the introduction warns of this brevity) with all the various points, only inasmuch as necessary for a good reader. ... Yet it hurts me that Kuenen lays claim to precedence regarding the prediction. I would have had to be very blind to the significance of my own results ... if I had not seen retrograde condensation (as Kuenen has felicitously named it). I frequently discussed the point of contact and the plaitpoint in oral exchanges. That I had not spoken to either you or Kuenen about this matter before is because Kuenen was not then making such bold claims. ... Truly, if Kuenen deduced it [the phenomenon of retrograde condensation] from the theory, do you really think that I had not?’³²

After which Van der Waals ended by stating that he did not wish the slightest ‘shadow of a misunderstanding’ to remain. ‘If you can convince me that I am mistaken, or rather that Kuenen should as a matter of course look upon himself as the predictor, I will never mention the matter again.’

He did not have long to wait for Kamerlingh Onnes’s reply. ‘I hasten to reply to the letter I received from you this morning’, he began his defence on 20 October, in a letter full of deletions and marginal additions – a sign that the complaint had distressed him. First and foremost, Onnes impressed upon Van der Waals, the matter had ‘nothing to do with’ Kuenen. ‘Everything of a personal nature that appears in the documents and communications is always, I should almost say entirely, my own responsibility.’ Not a single text went out without Onnes editing it, ‘to ensure absolute fairness and that preferably rather less, and certainly never more, is claimed, than what may in all good faith be regarded as one’s own work’.³³

³¹ Heike Kamerlingh Onnes to Van der Waals, 9 October 1894, N-HA, Van der Waals archives.

³² Van der Waals to Heike Kamerlingh Onnes, 19 October 1894, MB, archives of Heike Kamerlingh Onnes, inv. no. 312.

³³ Heike Kamerlingh Onnes to Van der Waals, 20 October 1894, MB, archives of Heike Kamerlingh Onnes, inv. no. 312.

Kuenen, Onnes stressed, had ‘always underscored’ the fact that almost all his work was related to the Gibbs surface and the theory of Van der Waals. ‘Every reader will find in his work the strong expression of the conviction that your theory provided the groundbreaking principles for the research of mixtures.’ In Kuenen’s ‘derivation’ of retrograde condensation, both in his dissertation and in his articles for the Academy, he had always acknowledged Van der Waals’s work in the correct way. The phenomenon itself was truly something new, Onnes went on:

‘When Kuenen first told me about his ideas, I was extremely surprised, even though I had studied your “théorie moléc.” with the greatest of interest.’³⁴

Although Kuenen had assured Onnes that it was ‘easily inferred from the theory’ and had used Van der Waals’s own diagram from the *Archives* ‘with an explicit acknowledgement’, that did not alter the fact that he had found something new. Indeed, Onnes impressed upon his pupil that although Van der Waals had pointed out the gradually flattening and vanishing meniscus, his friend had either failed to notice that in certain circumstances a ‘totally different phenomenon’ occurs or he had not thought it worth the trouble of drawing this point to the attention of others. ‘It is my sincere belief’, wrote Onnes, ‘that Kuenen was the first to say: “But take note that in the neighbourhood [of that point] something very unusual happens, something that one might call retrograde condensation” and who thus *predicted* retrograde condensation.’

Van der Waals had never mentioned that he had known about the phenomenon before, wrote Onnes, and his letter provided the first indication of it. And referring to the closing words of that letter: ‘I therefore believe that Kuenen should as a matter of course assert his primacy as predictor vis-à-vis Duhem, and that it would have been incorrect if he had put your name forward instead of his own.’ In short, it was Van der Waals who had provided ‘insight into this phenomenon’, but Kuenen had predicted it. Besides, the theory probably harboured still more wonderful facets that would yield other surprising phenomena that had not yet been identified as such by Van der Waals. Having got all this off his chest, in a good many pages, Onnes closed his lengthy epistle by expressing his conviction that Kuenen’s claim to precedence regarding the prediction of retrograde condensation had by no means been ‘too bold’ and by affirming that ‘I have sufficient confidence in your friendship as to believe that you will rather appreciate than deprecate the outspokenness with which I have set forth my views’.

³⁴ *Ibid.*

Van der Waals did not find this line of argument persuasive. On 21 October – how superbly the postal service functioned in those days! – Onnes found his rejoinder on the doormat.³⁵ The heart of the matter, sighed Van der Waals, was that ‘I see once again how wrong I am, when writing about what I see as the main point, to omit mention of what appear to me at such moments to be minor matters, from a desire for brevity’. And after a few words of clarification: ‘I shall therefore have to bear the consequences of all these lapses in this case.’

‘Still, there is one point that I find somewhat hurtful. As soon as you told me that you were looking for a theory to guide your research on mixtures, I freely, and in the fullest confidence, poured forth everything I had found in that connection. I talked a great deal about it, pointed out to you the significance of the point of contact and the plait-point. Of course a great deal was dealt with only cursorily and – I acknowledge – too much from the mathematical angle, because it simply could not have been discovered in any other way. Now what would have been more natural than for Kuenen to have asked me, when he believed he had been the first to notice retrograde condensation, whether I had noticed it or not. Especially since it concerns a matter that is as obvious as this. I would have answered truthfully and correctly. ... There is no *legal* obligation to proceed in this way – but since I had poured everything out – even before I was planning to write something about it ... it would merely have been repaying a confidence with a confidence.’³⁶

Van der Waals added that he had ‘various notes’ in his possession about retrograde condensation. But he was ‘reluctant’ to publish them because of his desire to say ‘what is for me the whole truth’ and the fear of ‘becoming entwined in unpleasantness of a personal nature’. And having summarised his position once again: ‘You say it is your sincere belief that Kuenen was the first to predict retrograde condensation. Did it then really not strike you as odd, on seeing that Kuenen had achieved it in practice, that I did not show the least astonishment?’ Van der Waals added that one of his reasons in explaining his side of things was to ensure that Onnes and Kuenen ‘are not too much taken aback if, in writing about the matter again, I remain faithful to the truth and am obliged to present a different version of events – since you have not yet convinced me.’

But the friendship was not in danger. Van der Waals concluded his letter by expressing the hope that an ‘oral exchange’ the following Saturday, when

³⁵ Van der Waals to Heike Kamerlingh Onnes, 21 October 1894, MB, archives of Heike Kamerlingh Onnes, inv. no. 312.

³⁶ *Ibid.*

Onnes came to dinner after the Academy meeting, would lead to a ‘better conclusion’. And ‘Should you take offence at anything I have written in this letter, please forgive me, since that was far from my intention. In a polemic, I feel the desire to formulate things sharply. But “sharp” in the sense of “precise” can easily degenerate into the sense of “hurtful”.’

Onnes did start on a reply, but most probably had second thoughts and decided to wait until Saturday, when the two men could talk at Van der Waals’s home. In that draft letter,³⁷ Onnes regretted that Van der Waals had not published ‘the many writings in your portfolio’, even after friends had urged him to do so. ‘The fact that you have such difficulty doing so will often result in others discovering independently things that you already knew, and even if they study what you have written, they may find that you have not mentioned [a particular matter] at all, and they are then completely entitled to claim that they were the first to make this discovery on the basis of your theories.’ Onnes also felt ‘compelled to note’ that Van der Waals had not in fact entrusted to him orally any more than had later been published in the *Archives*, so that Kuenen, who in any case started his work on retrograde condensation much later, did not hear anything “by some indirect route”. As for Van der Waals’s ‘lack of astonishment’ at Kuenen’s demonstration of retrograde condensation, Onnes, who had also been present, remembered things rather differently: ‘When you came to Leiden, you examined the phenomenon so critically that we said afterwards: “When Prof. v.d.Waals came to look, he was not yet able to believe it.”’

But Onnes left the letter unposted and went to Amsterdam the following Saturday. The notes he made on his discussion with Van der Waals reveal that the two belligerents did not achieve much of a *rapprochement* at the dining table in P.C. Hooftstraat. ‘I said there was nothing to prevent him writing, “I was unaware of the facts of the matter”. And that irritates v.d.W.’ Onnes displays a revealing pragmatism: ‘I did *not* offer to encourage Kuenen to say that vdW already knew about it; that could always be done later.’³⁸

The quarrel was patched up later on. In the second volume of his *Continuity*, published in German in 1900, Van der Waals discussed Kuenen’s research on retrograde condensation in binary mixtures at length. He noted that Kuenen ‘was the first to concern himself with the phenomenon and to have confirmed it empirically, and coined the term “retrograde condensation” for it.’³⁹

³⁷ Draft of a letter from Heike Kamerlingh Onnes to Van der Waals, 22 October 1894, MB, archives of Heike Kamerlingh Onnes, inv. no. 312.

³⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 281.

³⁹ J.D. van der Waals, *Die Continuität des gasförmigen und flüssigen Zustandes, T.2., Binäre Gemische* (Leipzig 1900) 128.

He dedicated this new volume to Kamerlingh Onnes: ‘The felicitous cooperation between theory and experiment that is presented in the following pages is primarily thanks to you. The condensed version of my *Théorie Moléculaire* was published in 1889 at your insistence. From that day to this, you have devoted your abundant talent ceaselessly to experimental research, with the aim of achieving results that are of vital importance to theory.’ Onnes took a childlike delight in this dedication, judging by the letter of thanks he wrote when the book appeared:

“I can’t grasp it, can’t believe it”, something of the kind thrilled inside me when the 2nd volume of the Continuity actually lay before me, and when opening it, I read what I knew I would read, but which will now be read everywhere where people are interested in physics, long after I have ceased to work.⁴⁰

After which Onnes, startled perhaps by his own excitement, quickly changed the subject to more familiar matters: folds in the Gibbs surface that his students Hartman, Verschaffelt and Keesom had observed in Leiden.

Kuenen’s response to the sequel to Van der Waals’s dissertation was rather less enthusiastic. ‘Although v.d.W.’s book (Cont. II) contains a wealth of significant material, even for us veterans’, he wrote to Kamerlingh Onnes from Dundee, ‘it is unfortunate that there was no Lorentz at hand to clarify it all systematically and consistently for scientific readers.’⁴¹ Kuenen had not forgotten the squabble about retrograde condensation. ‘If everything that follows from a theory (especially if this is purely thermodynamic) were to be the property of the theorist, Van der Waals would not be able to claim anything at all for himself and everything would belong to Clausius or heaven knows who.’ But Kuenen too eventually managed a gesture of reconciliation. In the 1904 commemorative volume, he wrote that a ‘consistent application’ of Van der Waals’s graphic representation had led him to retrograde condensation.⁴² ‘So the solution was potentially already encapsulated in this diagram’ – a concession that was not far off Van der Waals’s own position during the conflict of 1894.

In 1895 Kuenen moved to Britain, the country of his bride. He continued his research on critical phenomena in London, as the assistant of the chemist William Ramsay (who became the first to isolate helium gas in this period). Only a few months later, Kuenen was appointed as professor of physics in Dundee, Scotland, where he discovered various new types of phase behaviour

⁴⁰ Heike Kamerlingh Onnes to Van der Waals, 18 October 1900, N-HA, Van der Waals archives.

⁴¹ Kuenen to Heike Kamerlingh Onnes, 29 April 1901, MB, archives of Heike Kamerlingh Onnes, inv. no. 301.

⁴² *Op. cit.* note 2, 118.

in mixtures with liquid components that mixed poorly, such as water and ether. In 1907 he returned to Leiden, where he was appointed as the second professor of experimental physics, working alongside (or under) Kamerlingh Onnes.

Meanwhile, the research on mixtures had been continued there by the Delft scientist Charles Hartman, Jules-Émile Verschaffelt, who had trained in Ghent, and Willem Keesom, the son of a livestock farmer from the island of Texel. Verschaffelt worked on the combination carbonic acid and hydrogen, in which he also recorded retrograde condensation.⁴³ He also verified the law of corresponding states in mixtures. Hartman, who studied the transverse fold in the Ψ -surface of the mixture methyl chloride and carbonic acid,⁴⁴ would cross swords with Duhem in a second dispute in 1900.⁴⁵ Keesom, tackling mixtures of oxygen and carbonic acid, also observed retrograde condensation.⁴⁶ Onnes would have liked to place the Van der Waals series on a more systematic footing by starting off with mixtures of single-atom gases, such as the recently discovered argon and helium, or mixtures of metal vapours. But this was not feasible. Pure argon and helium were as yet unavailable, and working with metal vapours called for temperatures too high for the safety of the apparatus. Even mixtures of diatomic gases were initially rejected, since the critical temperatures of hydrogen, oxygen and nitrogen were so low that they could not be considered until the cryogenic apparatus was working optimally.

An overview of international work on mixtures was provided in Hartman's doctoral dissertation.⁴⁷ Aside from the work done in Leiden, that list, with its dozens of names and combinations of substances, featured exclusively foreign researchers, with the exception of one of Van der Waals's students from Amsterdam.

⁴³ J.E. Verschaffelt, 'Measurements on the system of isothermal lines near the plaitpoint and especially on the process of the retrograde condensation of a mixture of carbonic acid and hydrogen', in KNAW, Proceedings, 1, 1898-1899, Amsterdam, 1899, pp. 288-295 and pp. 323-328. *Comm.* 45 and 47.

⁴⁴ C.M.A. Hartman, 'The composition and the volume of the coexisting vapour and liquid phases of mixtures of methyl chloride and carbonic acid', in KNAW, Proceedings, 1, 1898-1899, Amsterdam, 1899, pp. 83-90. *Comm.* 43.

⁴⁵ C.M.A. Hartman, 'On the phenomena of condensation in mixtures in the neighbourhood of the critical state', in KNAW, Proceedings, 3, 1900-1901, Amsterdam, 1901, pp. 66-70. *Comm.* 56.

⁴⁶ W.H. Keesom, 'Contributions to the knowledge of Van der Waals' ψ -surface. V. The dependence of the plaitpoint constants on the composition in binary mixtures with a small proportion of one of the components', in KNAW, Proceedings, 4, 1901-1902, Amsterdam, 1902, pp. 293-307. *Comm.* 75.

⁴⁷ C.M.A. Hartman, *Metingen omtrent de dwarsplooi op het Ψ -vlak van Van der Waals bij mengsels van chloormethyl en koolzuur* (Leiden 1899).

Retrograde condensation was Onnes's supreme success story in the Van der Waals line before the turn of the century. Even so, the phenomenon sank into oblivion in the twentieth century. In a mixture there is almost always a range of temperatures and pressures in which retrograde condensation occurs, but conditions are frequently so volatile that it is difficult to actually observe the effect. This does not apply in the case of natural gas, however, a mixture that includes non-volatile compounds (such as alkanes with long carbon chains). When deep-well gas drilling began in the United States in the 1930s, crews were taken by surprise to discover that the gas liquefied, or worse still, froze, as the pressure was released. It is said that the physics professor George Uhlenbeck, who was attached to the University of Michigan at the time but had been trained in Leiden (in Onnes's declining years), had to remind the astonished engineers of Kuenen's discovery forty years earlier. History repeated itself in the 1960s during drilling off the coast of England in the North Sea. At the English coastal pumping station of Bacton, the gas pipes froze as soon as the pressure on the gas was reduced. This time it was John Rowlinson, professor at Imperial College, London, and the author of historical studies of mixtures in the 1950s, who solved the riddle.⁴⁸

⁴⁸ Levelt Sengers, *How fluids unmix*, 100-101; 264-265.

19. Into the breach for Van der Waals

The continuity between the liquid and vapour phases, which Andrews had established experimentally for carbonic acid in 1869 and which acquired a firm theoretical basis four years later in Van der Waals's equation of state, was far from uncontroversial in the final quarter of the nineteenth century.¹ To be sure, in 1822 Cagniard de la Tour had heated a closed tube containing liquid and vapour, until at a certain point he had observed the meniscus vanishing. But researchers were vexed by the question of what happened to the liquid *above* that critical temperature. Mendeleev and Faraday suggested that it dissolved into the vapour and retained its identity, a view that was widely endorsed. The idea that vapour and liquid molecules were simply different, one consisting of fragments of the other, was propounded well into the twentieth century, albeit more sporadically as time went on. Dissenting voices were heard, however – most notably from Leiden. From 1893 to 1907, the Physics Laboratory did battle with the critics of continuity, and if arguments failed to convince, Onnes sometimes repeated experiments that supposedly refuted Van der Waals's principle to show where they had gone wrong; time and again the foreign physicists proved to have been misled by factors that the Leiden experimentalists were better able to control.

Before we turn to this polemic, two other lines of research in the Van der Waals series should be mentioned: internal friction and capillary rise.² In February 1891, Onnes's assistant Stoel gained his doctorate on the strength of a dissertation on the temperature dependence of internal friction in liquid methyl chloride between its boiling point (-23°C) and its critical temperature (143°C).³ Liquid flowing through a tube consists of concentric 'cylinders' rubbing past each other, as it were, the outermost cylinder 'adhering' to the wall

¹ For an overview of objections that were raised to the continuity doctrine and the arguments used to refute them, see Levelt Sengers, *How fluids unmix*, 189-222.

² *Het Natuurkundig Laboratorium 1882-1904*, 154-177.

³ L.M.J. Stoel, *Metingen over den invloed van de temperatuur op de invendige wrijving van vloeistoffen tusschen het kookpunt en den kritischen toestand* (Leiden 1891).

of the tube. One measure for internal friction is the speed with which the liquid flows through a thin tube that is subject to a pressure difference (a tube protruding from the side of a water butt, for instance). The Paris physician Poiseuille had posited an empirical formula for this flow velocity in the mid-nineteenth century, a formula incorporating the pressure difference, the tube's dimensions, and the properties of the liquid.

It was Stoel's task to find out how the coefficient of friction or 'viscosity' varied with temperature. This would provide a test of the Van der Waals theory. In his *General Theory of Liquids* (1881), Onnes had derived the relationship between the coefficients for two liquids in corresponding states near the critical temperature.⁴ The experiment was not easy to set up. Since the critical pressure of methyl chloride is 65 atmospheres, the two-metres-tall glass measuring instrument had to be extremely robust. Cleaning was especially difficult: the capillary was constantly breaking. But when the tube, having been filled with methyl chloride, was sealed by melting in March 1890, the apparatus proved so durable that nine months (and a hundred readings) later, not a speck of dust had intruded to impede measurement. The temperature was regulated by suspending the glass tube in a liquid bath of water or glycerine.

Stoel was very disappointed to discover that he could only make *relative* determinations of the coefficient of viscosity: he was unable to trace any systematic error. Absolute values were eventually determined in 1894 with the improved measurement setup devised by Marc de Haas, who took over the project.⁵ Comparison of carbonic acid (using results obtained in Germany) with methyl chloride demonstrated that the law of corresponding states was 'sufficiently accurate', that is to say, 'not substantially less so' than in other applications.⁶

The other line of research was capillarity. This is the phenomenon that in a slender, open glass tube (capillary) immersed in a basin containing liquid, where the liquid 'sticks' to the glass (as in the case of water), its surface or 'meniscus' is concave and higher than the level in the basin, whereas in the case of a liquid that does not stick (such as mercury) the meniscus is convex, and the liquid level in the capillary sinks below that in the basin.

⁴ H. Kamerlingh Onnes, 'Algemeene theorie der vloeistoffen', *Verhandelingen* 1881, second paper, 8.

⁵ M. de Haas, 'Metingen over de wrijvingscoëfficiënt van chloormethyl in absolute maat tusschen het kookpunt en de kritische toestand', *Verslagen*, 2 (January 1894) 123-126; 3 (June 1894), 62-64. *Comm.* 12a,b; Marc de Haas, *Metingen in absolute maat van wrijvingscoëfficiënten van vloeistoffen tusschen het kookpunt en den kritischen toestand* (Leiden 1894).

⁶ H. Kamerlingh Onnes, 'De coëfficiënten van inwendige wrijving bij vloeistoffen in overeenstemmende toestanden', *Verslagen* 2 (January 1894) 128. *Comm.* 12c.



Ill. 31. The Belgian physicist Jules-Émile Verschaffelt worked as Onnes's assistant, researching capillarity and mixtures of gases.

In January 1893, Van der Waals presented to the Academy his *Thermodynamic Theory of Capillarity*.⁷ Continuity again played a key role – in this case of the density at the liquid-vapour interface. Five years earlier, a brief communication on the theory had aroused Onnes's interest. Also in January 1893, the Amsterdam-trained scientist E.C. de Vries gained his doctorate, under Onnes as supervisor, with a dissertation on capillary rises in ether (to an accuracy of 0.01 mm, determined with a cathetometer). Stable temperatures were essential: as soon as drops of liquid or vapour bubbles formed in the capillary, taking measurements was a waste of time. As always, corrections (allowing for the fact that the meniscus was not flat, for instance) were indispensable and crucial to the quality of the results. These showed a linear fall in capillary rise when plotted against temperature. But deviations occurred above 160°C, and when the temperature approached the critical point (194°C) the graph curved towards the horizontal. At this point De Vries gave up the project; like Stoel, he became a HBS teacher.

Onnes presented the findings at the Academy's meeting of February 1892.⁸ This finally drove Van der Waals to publish his theory of capillarity in detail. In the comments he submitted for inclusion in the Academy's *Verslagen* alongside the communication from Leiden, he described his search to determine whether his (concise) theory from 1888 corresponded to De Vries's readings. As the critical temperature approached, Van der Waals had deduced, the capillary rise no longer followed a linear graph (as predicted by the theories of Laplace and Gibbs), rising instead by an exponent of 1.5. De Vries's six data points, according to his calculations, produced an exponent of 1.23. 'However,' concluded Van der Waals's comments, 'the values rise as one approaches the critical temperature, and appear to confirm the hypothesis that the limiting value may be set at 1.5.' This appeared to be a case of wishful thinking.

In London, the chemist William Ramsay also published measurements of capillarity in the autumn of 1893.⁹ The British research project was impressive in its scope. Whereas De Vries had only managed to scrape together six data points for a single substance (ether), Ramsay produced series averaging twenty values for nine organic compounds. Onnes responded rather sullenly to this barrage of figures. Writing to Van der Waals, he noted that Ramsay had been

⁷ J.D. van der Waals, 'Thermodynamische theorie der capillariteit onder de hypothese van een continue verandering van dichtheid', *Verhandelingen* 1893, 1-56.

⁸ E.C. de Vries, 'Metingen over den invloed van de temperatuur op de capillaire stijghoogte bij aether, tussen den kritischen toestand en het kookpunt van aethyleen', *Verslagen*, 1 (1892) 156-158. *Comm.* 6.

⁹ W. Ramsay and J. Shields, 'Über die Molekulargewichte der Flüssigkeiten', *Zeitschrift für Physikalische Chemie* 12 (1893) 433-475.

disparaging of the approach taken in Leiden – dismissing De Vries’s observations as ‘too few in number’¹⁰ – and that he had neglected to give Van der Waals and Onnes due credit for a theoretical formula they had derived.¹¹

Van der Waals immediately turned out fresh calculations on the basis of the readings taken in London, arriving at an exponent of 1.27 for ether and 1.23 for benzol and acetic acid. These were close to the 1.23 found by De Vries for ether, but bore little relation to 1.5. Even so, in his reply to Onnes, he reiterated his firm belief that the exponent must be 1.5 in the absolute proximity of the critical temperature.¹² In an appendix to the German translation of his article on capillarity, he incorporated Ramsay’s readings for chlorobenzene and carbon tetrachloride. Van der Waals was honest enough to remark that the exponent sometimes rose as the critical temperature approached, but sometimes did not. ‘Whether the limiting value [...] truly equals 1.5 cannot be decided on the basis of these observations.’¹³

By then, Onnes had entrusted the research on capillary rises to the Belgian physicist Jules-Émile Verschaffelt. Having gained his doctorate in Ghent in 1893, Verschaffelt had spent a year in Amsterdam before transferring to Leiden. Verschaffelt focused on carbonic acid and nitrous oxide (N₂O; laughing gas) instead of ether. Like De Vries, he kept the measuring tube with capillary at the desired temperature using a basin of liquid, variously using simple tap water or methyl chloride. This basin was in turn immersed in a series of glass vessels which preserved heat insulation and helped to guard against the measuring tube bursting. The tube itself was made of such thick glass that temperature equilibrium sometimes took hours to achieve.

In his first publication, which Onnes presented at the Academy’s meeting of June 1895, Verschaffelt presented four data points for carbonic acid and three for nitrous oxide.¹⁴ The exponents he recorded were 1.311 for carbonic acid and 1.333 for nitrous oxide – as an experimentalist, Verschaffelt was a class above De Vries. One year later, he produced a fresh series of data points for carbonic acid, this time very close to the critical temperature. Since the capillary rises fell to less than 1 mm in this situation, and the convex meniscus

¹⁰ *Ibid.*, 438.

¹¹ Heike Kamerlingh Onnes to Van der Waals, 3 November 1893, N-HA, Van der Waals archives.

¹² Van der Waals to Heike Kamerlingh Onnes, 6 November 1893, MB, archives of Heike Kamerlingh Onnes, inv. no. 312.

¹³ J.D. van der Waals, ‘Thermodynamische Theorie der Kapillarität unter Voraussetzung Stetiger Dichteänderung’. *Zeitschrift für Physikalische Chemie* 13 (1894) 657–725.

¹⁴ J. Verschaffelt, ‘Metingen omtrent capillaire stijhoogten van vloeibare gassen’, *Verslagen* 4 (29 June 1895) 74–82. *Comm.* 18.

in the capillary (a prerequisite for determining corrections accurately) is preserved only if the rise is at least ten times the interior diameter, the Belgian used an exceedingly thin capillary (diam. 0.0882 mm). In small steps he gradually approached the critical temperature (31°C). Eventually, the Van der Waals exponent did indeed approximate 1.5. 'This result may therefore be deemed highly satisfactory', concluded Kuenen in the 1904 commemorative volume.¹⁵ Verschaffelt himself expressed himself a good deal more cautiously in 1896: he had been compelled to read the necessary densities from a French graph, which had probably influenced his findings.¹⁶

In 1900, a year after publishing his doctoral dissertation on mixtures of carbonic acid and hydrogen, Verschaffelt published a definitive paper on fluid critical exponents. Sidney Young, one of Ramsay's students, had published some superior data on isopentane in 1894, to which the Belgian, who was by then working as a teacher in Dordrecht, applied the same method of analysis as four years earlier with his measurements of carbonic acid. Once again, the exponent was well below the 1.5 proposed by Van der Waals – nor did the value appear to rise at all in the immediate proximity of the critical temperature. This meant that the classical theory was defective.¹⁷ Onnes, who was preoccupied with mixtures and with parrying assaults on continuity, did not lose any sleep about it. After ten years of experimental work in Leiden, he knew more than anyone else about the flaws in Van der Waals's equation of state. He probably thought Verschaffelt was flogging a dead horse. It was not until the 1960s that physicists realised that classical equations of state are fundamentally inadequate in the region of critical values.¹⁸

On 'molécules gasogéniques et liquidogéniques'

It was William Ramsay, in 1880, who opened fire on the doctrine of continuity, according to which there is no essential difference between a liquid and its vapour.¹⁹ Ramsay, who was by then professor of chemistry at University College, Bristol, studied a number of organic liquids with critical temperatures in the neighbourhood of 200°C and observed that as soon as he filled the closed

¹⁵ *Het Natuurkundige Laboratorium 1882-1904*, 167.

¹⁶ J. Verschaffelt, 'Metingen van capillaire stijghoogten van vloeibaar koolzuur in de nabijheid der critische temperatuur', *Verslagen* 5 (27 June 1896) 94-103. *Comm.* 28.

¹⁷ J. Verschaffelt, 'On the critical isothermal line and the densities of saturated vapour and liquid in isopentane and carbon dioxide', in KNAW, Proceedings, 2, 1899-1900, Amsterdam, 1900, pp. 588-592. *Comm.* 55.

¹⁸ J.M.H. Levelt Sengers, 'Critical exponents at the turn of the century', *Physica* 82A (1976) 334.

¹⁹ Sengers, *How fluids unmix*, 189-222.

glass tube with more liquid, the temperature at which the meniscus vanished fell, sometimes by as much as thirteen degrees. On the basis of this and other experiments, he concluded (and was the first to do so) that vaporisation was accompanied by the splitting up (dissociation) of molecules into smaller fragments. Below the critical temperature, Ramsay maintained, the two types of molecules did not mix, while above it they did.

While Kuenen was embarking on experiments with mixtures in Leiden, Louis Cailletet and his assistant Collardeau in Paris were performing a no less influential experiment in Paris to disprove the proposition that the densities of liquid and vapour coincided at the critical point. Carbonic acid was forced into an O-shaped glass tube with a little sulphuric acid at the bottom. The left side was cooled, so that condensation occurred only there. Because of the difference in density between liquid and vapour, the sulphuric acid level was different in the two vertical sections. If the entire piece of apparatus was then heated up to the critical temperature of carbonic acid, the difference in levels diminished, but it did not disappear, not even several degrees above the critical temperature. The Frenchmen concluded that the liquid had not completely evaporated at the moment when the meniscus vanished – again contrary to the theory of Van der Waals. The Italian scientist Zambiasi repeated this experiment in 1892, reaching the same conclusion.

Thus, in 1893, the year in which Leiden launched its counter-offensive, a motley array of observations had been published, some of them inconsistent with each other but all appearing to disprove the continuity posited by Andrews and Van der Waals. In 1892, the physicist Pierre de Heen had found in Liège that in ether, the temperature at which the meniscus vanished actually rose if there was more liquid in the tube (Ramsay had reported a fall in 1880). The Belgian also calculated that the density of saturated vapour could assume a range of values – differing by up to 50 per cent – at one and the same temperature. And in 1893 Boris Golitsyn, a scientist from a noble St Petersburg family who wrote under the name of ‘Galitzine’, published an article in Moscow confirming De Heen’s differences in density, which he attributed to Ramsay’s splitting molecules.

The experiments conducted by all these critics, however, were marred in various ways. The presence of impurities, the sometimes extremely slow attainment of equilibrium in the narrow tubes, and the role of gravity were among the factors overlooked. Besides this, the experimentalists had little understanding of the theory of binary mixtures, which had only been published in 1891. Louis-Georges Gouy, professor of physics in Lyon, did shine a single ray of light into this darkness: in 1892 he pointed out the strong influence of gravity in the immediate proximity of the critical point, caused by the high degree of compression in this situation.

Ramsay, whose 1880 work was constantly being cited by the anti-continuity camp, realised in 1894, by which time he had spent years experimenting with critical substances, that he had been misled by impurities. In the *Zeitschrift für Physische Chemie* he openly repudiated his former position that liquids also possess a distinct identity above the critical temperature: 'I feel compelled to do penance once again by seizing the present occasion to declare that I no longer believe in that nonsense; and to set forth the grounds on which one, in experiments appearing to corroborate these ideas, may easily be misled.'²⁰ After which he proceeded to demolish the research of Zambiasi, Galitzine and De Heen.

Kuenen had done the same the year before. In his research on mixtures of carbonic acid and methyl chloride, the crowning achievement of which was his discovery in 1892 of retrograde condensation, he had discovered in practice how slowly temperature equilibria are achieved without stirring. As a rule, this sluggishness was attributable to the presence of impurities, such as air. 'New theories concerning pure substances therefore seem to me to be superfluous for the present as purporting to explain the critical phenomena of substances', he concluded in October 1893, having studied all the divergent experiments.²¹ Seven months later, he reported his version of Galitzine's experiment, performed in Leiden. Once the U-shaped tube had been treated according to Leiden standards, the variations in density reported by the Russian at the same supercritical temperature simply melted away. *En passant* Kuenen also discussed the theoretical implications of the premise of separate vapour and liquid molecules. Whether or not these could change into one another, positing their existence led to incongruities and even absurdities.²²

Kamerlingh Onnes was delighted with the results of this 'difficult and highly time-consuming research' and hoped that they would have the desired effect.²³ But De Heen shrugged off the deluge of criticism meted out to him by Ramsay and Kuenen. In 1896 he decided to build an apparatus to separate

²⁰ W. Ramsay, 'Über den kritische Zustand'. *Zeitschrift für Physikalische Chemie* 14 (1894) 486. 'Unglücklicherweise wird mein Name oftmals als Anhänger, ja sogar als Ursprung solcher Ideen citiert; und ich fühle mich gezwungen nochmals Busse zu thun, indem ich diese Gelegenheit nehme zu erklären, dass ich an solchen Unsinn nicht mehr glaube; und auch die Gründe auseinanderzulegen, warum man bei Versuchen, welche diese Ideen zu bestätigen scheinen, sich leicht täuschen kann.'

²¹ J.P. Kuenen, 'Over de abnormale verschijnselen bij het kritisch punt', *Verslagen* 2 (October 1893) 89. *Comm.* 8b.

²² J.P. Kuenen, 'Eenige proeven over de abnormale verschijnselen bij het kritisch punt', *Verslagen* 3 (May and June 1894) 19-34 and 57-62. *Comm.* 11.

²³ H. Kamerlingh Onnes, 'On De Heen's experiments about the critical state', in KNAW, Proceedings, 3, 1900-1901, Amsterdam, 1901, pp. 628-643. *Comm.* 68.

molécules gasogéniques et liquidogéniques. Two cylindrical vessels, with pistons moving in tandem (keeping the total volume constant), were filled with liquid carbonic acid. The two vessels were connected by a thin tube with a spigot. When the upper vessel was empty, the spigot was opened, the entire apparatus heated to above the critical temperature and the spigot closed again. From the differences of density that De Heen observed, he concluded that the upper vessel contained gas molecules and the lower one the liquid kind.

With an earnestness worthy of a better cause, Onnes set about exposing the errors in this botched job.²⁴ Shortly after publication De Heen visited the laboratory in Leiden,²⁵ and Onnes seized the opportunity to impress upon the Belgian that minute deviations in temperature, pressure and composition in the neighbourhood of the critical state could cause great changes in density. Onnes had a strong suspicion that De Heen's carbonic acid contained impurities, something to which the latter, to his irritation, attached little importance. He was able to persuade De Heen to send his apparatus to Leiden, however, where the experiment would be repeated using carbonic acid guaranteed free of impurities, and putting in place certain precautions. It fell to Verschaffelt (a fellow countryman of De Heen's) to test this *analysateur de l'état critique*. The apparatus looked suspect from the start. When it was unpacked, the gaskets used for the pistons proved to be made of leather drenched in wax or grease – substances that are so soluble in carbonic acid as to make purity unattainable. 'Thus the only advantage of the presence of the apparatus in Leiden was to enable certain of its peculiarities to be studied; aside from this the matter was set to one side.'

A year later, De Heen repeated his claim to have identified two critical densities. The Belgian expressed the hope that experiments with his analyser would be repeated all over the world. The outcome of such experiments was easy enough to predict, sighed Onnes. After which he indicated how Leiden tackled such things: 'Anyone who wishes to repeat De Heen's determinations of density must in any case seek to set up these experiments such as to establish convincingly the homogeneity of each phase, and to measure accurately small differences in temperature, pressure and composition of the phases to be compared, to make it possible to calculate the corrections arising from them.'²⁶

Verschaffelt and Onnes were convinced that if the necessary corrections were applied to De Heen's data, the results would be reconcilable with Van der Waals's theory. After which they suited the action to the word, and assembled

²⁴ *Ibid.* p. 628

²⁵ De Heen to Heike Kamerlingh Onnes, 14 July 1897, MB, archives of Heike Kamerlingh Onnes, inv. no. 298.

²⁶ *Op cit.* note 23, p. 630.

a piece of apparatus 'from diverse appliances present in the laboratory' to check De Heen's claim. Since Verschaffelt had left for Dordrecht by then, Onnes decided to perform the experiment himself. He also felt that De Heen's experiment did not add anything to Galitzine's, the validity of which had already been disproved in Leiden. 'So if it came down to arguing De Heen's propositions', said Onnes, 'we could point out that everything De Heen infers from his experiments with the analyser has already been comprehensively refuted in Kuenen's rebuttal of Galitzine.'²⁷

In spite of all this, Onnes followed through. The Leiden analyser, a simplified version of the one used in Liège, was filled with pure carbonic acid, and after De Heen had supplied some information concerning the way the spigots were to be operated,²⁸ his experiments were repeated. The net result was that the densities in the two cylinders were virtually identical. As Onnes reported: 'A minute deviation is found, in contrast to De Heen's results, which outcome, taking into account the limits of observational error, may be formulated, in De Heen's terms, as "the *liquidogène* and *gazogène* molecules are the same.'" Onnes then proceeded to dissect the sources of error that had produced the difference in density in Liège: temperature differences between the two vessels, impurities in the carbonic acid, and the failure to apply essential corrections in calculating densities. Summarising, he asserted that it was justifiable to conclude that De Heen's experiments did not provide any reason to question the correctness and comprehensiveness of the existence of a single critical point and of continuity, as prescribed by the theory of Van der Waals.

Sydney Young, to whom Onnes had sent a copy of the relevant *Communication*, was delighted with these results: 'I think that physicists owe you a debt of gratitude for having undertaken the laborious and somewhat thankless task of so carefully examining and, when necessary, repeating Prof. de Heen's work. I do not see how any further doubt can now be felt on the matter.'²⁹

De Heen too thanked Onnes for sending him the copy of the *Communication* with his results, but remained unconvinced. He cited Galitzine's contribution to the previous year's Congrès International de Physique, where the Russian had presented measurements of the refractive index close to the critical temperature that indicated substantial differences in density, thus corroborating De Heen's own results. To resolve the matter once and for all, the Belgian suggested appointing a committee composed of Onnes, Verschaffelt,

²⁷ *Ibid.*, p. 633.

²⁸ De Heen to Heike Kamerlingh Onnes, 7 October 1898, MB, archives of Heike Kamerlingh Onnes, inv. no. 298.

²⁹ Sydney Young to Heike Kamerlingh Onnes, 27 June 1901, MB, archives of Heike Kamerlingh Onnes, inv. no. 313.

Mathias, Galitzine and himself, each of whom would repeat the same experiment using the same apparatus. Onnes, as the leading researcher in the area of critical phenomena, should chair the committee. This plan never materialised. Happily, the polemic had not undermined the good relations between those involved. Onnes was invited to stop off in Liège on the way to his holiday destination in the Alps, and De Heen sent cordial greetings to Mrs Onnes and little Albert.³⁰

De Heen was by no means the last of the Mohicans; he was followed by Traube and Teichner. In 1902, J. Traube, professor of physics in Charlottenburg, launched the theory that upon vaporisation, *fluidons* (liquid molecules) expand into *gasons*. Two years later he instructed his student Teichner to perform an ingenious experiment to chart the behaviour of supercritical carbon tetrachloride (CCl₄). In a glass tube half filled with this liquid, Teichner placed hollow glass spheres only a few millimetres in diameter, with densities approximating that of critical carbon tetrachloride. The little balls settled at the level corresponding to their density, which revealed the distribution of density in the tube at a glance. When the tube was then slowly heated to above the critical temperature (282.2°C), the distribution of the little balls showed that the density above was about 25 per cent lower than below. Stirring reduced the difference, but this did not prevent Teichner from concluding that his experiments corroborated the findings of De Heen and Galitzine.

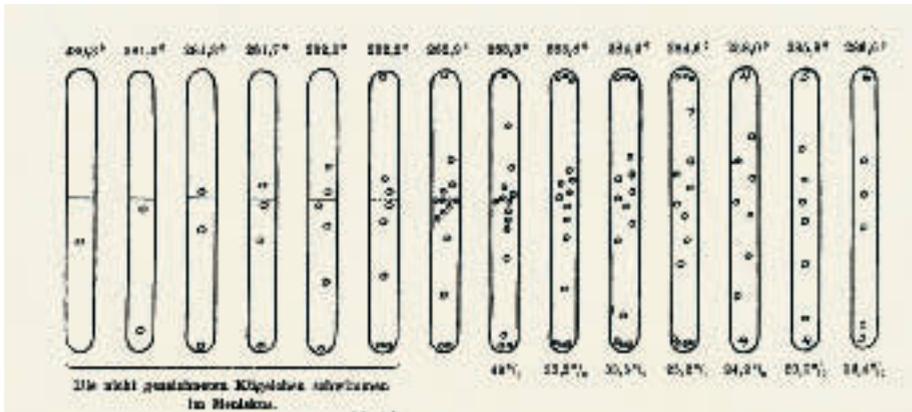
Elegant though this experiment may have been, it was seriously flawed. In 1903, Teichner had sent one of his test tubes to Sidney Young. When Young heated it in his Bristol laboratory, he noticed that the contents gradually took on a brownish colour (signifying decomposition), and the gas too proved to be contaminated with a substantial quantity of air. When he repeated the experiment with pure carbon tetrachloride, he found no change in density whatsoever. Young returned the apparatus to Charlottenburg, enclosing an explanation of his method of filling the tubes.³¹

In Leiden, Teichner's experiment was initially rebutted on theoretical grounds. Abundant research on mixtures had been conducted at the Physics Laboratory since 1897, partly to test Van der Waals's theory and partly to ascertain the quantitative effect of impurities. Verschaffelt had studied the combination of carbonic acid and hydrogen,³² and a few years later Keesom had

³⁰ De Heen to Heike Kamerlingh Onnes, 30 May 1901, MB, archives of Heike Kamerlingh Onnes, inv. no. 298.

³¹ Young to Verschaffelt, 8 March 1905, MB, archives of Heike Kamerlingh Onnes, inv. no. 313.

³² J.E. Verschaffelt, 'Measurements on the system of isothermal lines near the plaitpoint and especially on the process of the retrograde condensation of a mixture of carbonic acid and hydrogen', in KNAW, Proceedings, 1, 1898-1899, Amsterdam, 1899, pp. 288-295 and pp. 323-328. *Comm.* 45 and 47.



Ill. 32. Teichner's experiment (1904). Hollow glass spheres of slightly differing densities are placed in a glass tube containing liquid. Since the little balls settle at the level corresponding to their density, their distribution reveals the different densities of the liquid in the tube.

tackled carbonic acid and oxygen.³³ The two men had also concerned themselves with the theory underlying the effects of impurities.³⁴ So Verschaffelt was very well prepared when he subjected Teichner's experiment to critical analysis in 1905.³⁵ He knew, for instance, that carbonic acid contaminated by only 0.001 per cent of oxygen produced differences in density in the order of those observed by De Heen. He therefore emphatically denied that Teichner's observations disproved the continuity posited by Van der Waals and Andrews: 'These phenomena may be explained, down to particularities, by the presence

³³ W.H. Keesom, 'Isothermals of mixtures of oxygen and carbon dioxide' I-VI, in KNAW, Proceedings, 6, 1903-1904, Amsterdam, 1904, pp. 532-554; 554-565; 565-577; 577-588; 588-593; 593-597. *Comm.* 88.

³⁴ W.H. Keesom, 'Contributions to the knowledge of Van der Waals' psi-surface. V. The dependence of the plaitpoint constants on the composition in binary mixtures with a small proportion of one of the components', in KNAW, Proceedings, 4, 1901-1902, Amsterdam, 1902, pp. 293-307. *Comm.* 75; 'VI. The increase of pressure at condensation of a substance with small admixtures', *ibid.*, pp. 659-668. *Comm.* 79.

J.E. Verschaffelt, 'Contributions to the knowledge of Van der Waals' psi-surface VII. The equation of state and the psi-surface in the immediate neighbourhood of the critical state for binary mixtures with a small proportion of one of the components', in KNAW, Proceedings, 5, 1902-1903, Amsterdam, 1902, pp. 336-350. *Comm.* 75, 79, 81 and *Supplement* 6.

³⁵ J.E. Verschaffelt, 'The influence of admixtures on the critical phenomena of simple substances and the explanation of Teichner's experiments', in KNAW, Proceedings, 7, 1904-1905, Amsterdam, 1905, pp. 474-482. *Supplement* 10.

of impurities which gradually pervade the substance, and calculations based on the existing data have demonstrated that to obtain quantitative agreement, a degree of contamination must be presupposed of the same order as that which certainly existed in other experiments with supposedly pure substances.³⁶

Sidney Young was delighted with Verschaffelt's findings.³⁷ The content of his letter to Dordrecht was passed on to Onnes. 'How very kind of your wife to copy it for me', the latter hastened to reply, 'It gave me great pleasure.' That 'such a proven authority as Young' squarely supported Verschaffelt was worth celebrating. At the end of his letter, Onnes told his ally that the 'little floats' for carbonic acid were as good as ready for use. Leiden had decided to repeat Teichner's experiment, but using carbonic acid, which was easier to handle. 'The De Heen series is finished,' Onnes added, 'and sufficiently for a comprehensive refutation.'³⁸

Indefatigable in his crusade against the opponents of Van der Waals, the beacon of the Leiden laboratory, Onnes showed one more time, in April 1907, with liquid helium in sight, that without the presence of impurities, the experiments concerned were all perfectly compatible with continuity.³⁹ His student G.H. Fabius was given the task of repeating the experiments of De Heen and Teichner with the necessary precautions. For De Heen it was the second time that Leiden had attacked him on this count. The reason was that in 1901, the thermo-element in one of the vessels of the Leiden analyser had developed a defect, rendering the temperature correction unreliable. When the defect was fixed, numerous accurate measurements were recorded, which demolished De Heen's density differences even more thoroughly than the first series.

The Leiden version of Teichner's experiment benefited enormously from the golden hands of Onnes's master glassblower, Kesselring. This wizard succeeded in melting a thermo-element into the top and bottom of the tube without creating any weaknesses in the glass (which had to withstand up to 150 atmospheres) and in making the lighter glass balls ('floats') corresponding to the density of carbonic acid. He was equally painstaking in making the liquid bath. It consisted of a non-silvered vacuum glass with a stirrer, which was in turn immersed in a bath with vacuum glass. This made it possible to stabilise the temperature up to 0.002 degrees. While the temperature passed the critical value extremely slowly (the experiment took from 11 a.m. until 9 p.m.), the

³⁶ *Ibid.*

³⁷ Young to Verschaffelt, 8 March 1905, MB, archives of Heike Kamerlingh Onnes, inv. no. 311.

³⁸ Heike Kamerlingh Onnes to Verschaffelt, 12 March 1905, MB, archives of Heike Kamerlingh Onnes, inv. no. 311.

³⁹ H. Kamerlingh Onnes and G.H. Fabius, 'Repetition of De Heen's and Teichner's experiments on the critical state', in KNAW, Proceedings, 10 I, 1907, Amsterdam, 1907, pp. 215-230. *Comm.* 98.

behaviour of the floats (divided into nine density categories) was followed meticulously. As expected, Teichner's density differences vanished almost completely. 'We believe that we have recorded a smaller difference in density than observers before us', Fabius and Onnes wrote with a combination of pride and modesty in their Academy article.

Did it help? Many scientists from the anti-Van der Waals camp must have been convinced by the rebuttals from Leiden. Not so Traube (Teichner's superior) or De Heen, however. In 1908 the latter wrote to Verschaffelt, who was by then professor experimental physics at the Free University in Brussels, that he still did not believe in the continuity between the liquid and gaseous phases.⁴⁰ And in 1914, Traube instructed his student Hein to repeat Teichner's experiments. Presently, the dissident from Charlottenburg conceded grudgingly that Hein's results accorded better with those of Fabius and Onnes than with Teichner's. Even so, he refused to jettison his *fluidons* and *gasons*. By then, Onnes must have been supremely unconcerned. Helium had been conquered in Leiden, superconductivity had been discovered, and both he and Van der Waals had seen their work crowned with Nobel Prizes. Traube no longer mattered.

⁴⁰ De Heen to Verschaffelt, 11 August 1908, MB, archives of Heike Kamerlingh Onnes, inv. no. 311.

20. The blue-collar boys

The cryogenic laboratory and the launch of the Lorentz and Van der Waals series both sprang from the vision, determination, and organisational talent of Kamerlingh Onnes. But to put his plans into practice, the professor-director was reliant on the assistance of able technicians. The bedrock of this technical support was the instrument-makers' school in Leiden. This in-house training course, which made a cautious start in 1885 and assumed its definite form around the turn of the century, turned out skilled and semi-skilled assistants ranging from errand boys to competent technicians, from 'measuring drudges' to glass artists, without whom the precision and large scale of the Physics Laboratory would have been unthinkable. This chapter will look at the origins of this unique vocational training course, at the way it was set up, and the factors that helped it grow into such a resounding success.

When Onnes first took up his new position in Leiden, in November 1882, the quality of technical assistance left much to be desired. In the basement of the Physics Laboratory, the mechanic, C.W. Kouw, had a small, dark workshop next to the fuel storage area.¹ Appointed in 1876 when the new Higher Education Act entered into force, Kouw initially worked alone, but after Onnes's arrival – ushering in an era of tinkering with compressors, methyl chloride condensers and Bunsen elements, the start of Sissingh's optical research and the Leiden laboratory's first drastic renovation – he was given a single assistant. This initiated a training system that Onnes continually expanded and professionalised over the years and that played a key role in Leiden's cryogenic success story.

Kouw's first assistant was Cornelis van Heusden, who started work at thirteen in December 1885, for a weekly wage of 50 cents. He would remain at the Physics Laboratory until July 1892, by which time he was earning 4 guilders 50, and would go on to pursue a career as a draughtsman at Leiden's ironworks. Within twelve months Van Heusden was joined by G. Kouw, the mechanic's

¹ *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904) 13.

son, and by G. Metselaar, the son of a local tailor. Both had probably first attended the three-year 'practical technical school' that had been founded in Leiden in 1883. In the new workshop on the first floor of the newly built laboratory, they learned how to make instruments as part of everyday laboratory practice.

Aside from a few thirteen and fourteen-year-olds at the beginning of their apprenticeships, most of the boys who enrolled at the Steenschuur laboratory were aged between sixteen and eighteen. Besides working at the laboratory they were required to attend evening classes in theory at the society *Mathesis Scientiarum Genitrix* (MSG; 'Mathematics is the Mother of Sciences'), founded in 1785. This had been housed since 1867 in the premises of the HBS secondary school on *Pieterskerkgracht*. The director was P. Dikshoorn, while the executive committee of the mathematics society was chaired by the chemistry professor J.M. van Bemmelen, who had been Onnes's chemistry teacher and dedicated mentor in his high school days in Groningen. So cordial were the relations between MSG and the physics laboratory that in 1891 Onnes arranged for two of his advanced students to teach mathematics, physics and mechanics classes free of charge to students who had completed the MSG course.

By 1889 the laboratory had six trainee instrument-makers at its disposal. These 'blue-collar boys' (so called because of their blue overalls) were of enormous help in helping to set up the cryogenic laboratory. Equipment and instruments frequently had to be made on site, and the pumps purchased commercially were completely overhauled because industrial standards were inadequate in a laboratory that aspired to measurements of the utmost accuracy. There was no shortage of work, and in 1890, when Onnes received permission to build a second workshop, a shed was built beside the cryogenic laboratory. J.J. Curvers was placed in charge of the new workshop, while Kouw held sway upstairs in the main building.

The laboratory continued to expand along the *Langebrug*, and in 1897 Curver's workshop acquired better, more spacious accommodation with an adjoining drawing office in a new annex. By this time the laboratory also had its own glassworks. This was initially led by G.J. Flim, a baker's son from *Hellendoorn* who had been taken on as a trainee at seventeen in April 1893 and would end up as cryogenic manager and Onnes's right-hand man. On many occasions, including his Nobel Prize acceptance speech in 1913, Onnes expressed heartfelt thanks to Flim the 'wizard' for his part in the successful work in Leiden.

Under these greatly improved circumstances the school steadily gained in popularity: from 16 students in 1898 it grew to 27 three years later and 32 by 1904. After that the student population remained fairly constant; it did not

pass the 40 mark until after the First World War.² There was never a shortage of candidates, and after aspiring pupils – most of whom were soon being drawn from places other than Leiden – had worked on a trial basis in one of the laboratory's workshops for a week, the best were allowed to stay on. Only a handful were removed prematurely, 'dismissed on grounds of unsuitability' or 'sent packing after theft'.³ In a speech to the Dutch Electrical Engineering Society in 1898, Onnes observed that his custodian and mechanic Kouw had endured 'many disappointments' when taking on pupils in the preparatory stages of the new system, and that had it not been for Kouw's 'perseverance and love', he himself, as director, would have succumbed to discouragement.⁴

Onnes used the period 1895-1901, culminating in the founding of the Society to Promote the Training of Instrument-Makers, to place the training system that was so beneficial for his laboratory on a secure footing. There was plenty of time, since the cryogenic laboratory lay idle from 1895 to 1898. The Leiden training system received a firm boost in 1897, with the creation of the Janssen Fund for vocational training grants. The fund was used to supplement the modest weekly wages that the laboratory gave promising trainee instrument-makers from poor backgrounds. This grants system was Onnes' own idea, and it is a tribute to his inventiveness, powers of persuasion and organisational talent that he managed to persuade a wealthy benefactor from Amsterdam to give substantial financial support to trainees in a Leiden laboratory for a good many years.

Peter Wilhelm Janssen (1821-1903), born on the East Frisian island of Wangeroog and hence German by origin, had taken Dutch nationality in 1865. He was a successful grain and tobacco merchant, and in 1867 he founded the Deli Company, which worked tobacco plantations in East Sumatra. In Amsterdam Janssen sold the tobacco by order instead of putting it up for auction – a long line of carriages would stand waiting along the Keizersgracht on the way to his house. He made a fortune with this business. Janssen had a social conscience, and believed that he had an obligation to share the money he had made from Deli tobacco. In Amsterdam he supported the society 'Ons Huis' (Our Home) which opened the first Dutch educational community centre in the Jordaan district of Amsterdam in 1892, and in Leusden he supported a school where boys were taught basketry. In 1894 Janssen founded the Dutch Housing Foundation, which provided homes for the impoverished elderly, and

² *Het Natuurkundig Laboratorium der Rijksuniversiteit te Leiden in de jaren 1904-1922* (Leiden 1922) 79.

³ Huygens Laboratory, register of students at the Physics Laboratory's workshops.

⁴ *Het elektrotechnisch onderwijs aan de Avondschool van het Genootschap "Mathesis Scientiarum Genitrix" en de Praktische Vakopleiding in de werkplaatsen van het Natuurkundig Laboratorium te Leiden*, Notulen der Nederlandse Vereeniging voor Electrotechniek, 1897-1898, VI.

the peat district of Friesland also benefited from his generosity.⁵ His main concern was to provide training opportunities for the underprivileged. But although Janssen appears to have been bombarded with begging letters from an endless stream of organisations, few successfully prevailed upon his generosity.

It is unclear how Heike Kamerlingh Onnes and P.W. Janssen became acquainted. Janssen himself sometimes initiated charity projects after an acquaintance or a newspaper announcement had awakened his interest. Perhaps Heike's brother Onno, a member of Amsterdam's city council and the founder of the Commercial Information Office in 1903 (the eaves of the building, on Damrak, are still inscribed with the VOC motto *De cost gaet voor de baet uit*: 'investment comes before profit'), knew P.W. Janssen, and had told him about the system for training instrument-makers at Leiden's Physics Laboratory, whether or not at Heike's request. It is also possible that Dolf Onnes, Heike's youngest brother, who worked in East Sumatra and occasionally came to the Netherlands, played a role. Whatever the case may be, on 19 September 1897, Heike sent C.W. Janssen, who handled his father's correspondence, a letter with a detailed proposal for financial support.⁶

From this letter we can infer that C.W. Janssen had visited Onnes to tell him that his father would be 'glad to do something to promote technical and vocational training' and 'would like to know at the earliest opportunity how this could be arranged'. At which Onnes wrote to Amsterdam that he was now able 'to recommend something viable in this area related to my other efforts to help young workers to advance themselves, which may be what your father has in mind'.

Onnes' idea had been inspired by his experience managing a small fund for a boy who had to find a suitable course of training that did not exceed its resources. The boy's father had died, and money had been collected 'out of compassion' so that the step-father did not have an intolerable financial burden to bear. Onnes had suggested using the fund to pay for the boy's tuition fees and the expenses for the equipment required by the technical school and evening classes, and also to give the boy's stepfather a sum of money equivalent to the weekly wages that the man had to forgo because the boy was attending school instead of taking a job and contributing to the household's expenses. If the boy proved to have sufficient aptitude, Onnes explained, he could become a trainee instrument-maker at the laboratory after technical school, in which case the step-father would again be compensated from the fund for loss

⁵ Ria Efdée, *De P.W. Janssens's Friesche Stichting* (Oranjestad 1988).

⁶ Heike Kamerlingh Onnes to C.W. Janssen, 19 September 1897, archives Huygens Laboratory.

of income. 'In this way', wrote Onnes, 'the boy will certainly be able to make a good living and I hope he will end up in the position that his talents merit in society.'

Onnes worked out what all this would cost up to the boy's eighteenth birthday: it came to about 550 guilders. What he proposed to P.W. Janssen was to set up a fund for talented boys whose parents had few if any resources. 'These excellent workers will therefore not have to be as good as lost to society, but could be helped to advance in accordance with their abilities, whereas at present their parents are compelled to halt their remaining education completely and use them to bring some money home.' Onnes added that the plan had already been put to Dikshoorn, director of the MSG evening school, who had fully endorsed it. Should Onnes's idea appeal to P.W. Janssen, Dikshoorn was the ideal man to select the boys eligible for such assistance: 'not merely for ability to study but also for character and the guarantees that the family must furnish to make the experiment succeed.'

In his letter Onnes detailed the costs, on the basis of pupils aged 12-18 and three grant recipients a year. He calculated that 6,541 guilders was needed to give the system a flying start, after which 1,653 guilders a year would sustain it. Incidental grants had been given to able instrument-makers by Drenthe's Association of Technical Schools and certain 'gentlemen of Rotterdam'. But it would be much better, of course, to arrange this external assistance more systematically. My interest in this matter, wrote Onnes, is 'that I am surrounded by clever young assistants; I must be able to choose from the best workers to in order to benefit from them when setting up experiments. For instance, Blom's stay at my laboratory was of great value. A great deal can be achieved with a small group of workers like him. If I had sufficient money at my disposal, I would not have had to let an able young man like Blom go again so soon. But what the state allows us to pay in terms of salary or wages is very little, and any personal addition I can make is negligible.'

H.A. Blom had not in fact had to leave 'so soon' as all that. After graduating from teacher training school in June 1888, Blom came to work at the laboratory as an assistant, and in October 1896 (by which time his weekly wages had grown to 10 guilders and 15 cents) he left for the Electrical Engineering Institute in Frankfurt. In 1899 he returned with his diploma to continue his studies at the Polytechnic in Delft, while in the evenings he taught classes in electrical engineering at the MSG.

Onnes's proposal was well received by P.W. Janssen: to his 'profound satisfaction' a charter of foundation was drawn up in 1897 and the fund was created. 'If you knew how slowly we are accustomed to seeing our plans come to fruition', wrote an elated Onnes in a letter of thanks to C.W. Janssen, 'and how we must eke out small sums to progress one foot at a time, it will be even

clearer to you than my calculations can demonstrate that your father's princely support has touched me deeply.⁷ The Register of Trainee Assistants at the Physics Laboratory Workshops reveals that almost all the boys received grants, ranging from 50 cents to a few guilders a week. The Janssen fund was renewed after the six-year trial period, and the Janssens' descendants continued to administer it into the 1950s.⁸

The Leiden course in electrical engineering

Another initiative that Onnes seized enthusiastically to enhance the prestige of his training system – and hence make it more attractive – was the launch of the Dutch Electrical Engineering Society in 1895. In April that year the committee responsible for planning conferences and lectures to accompany the forthcoming World Exhibition in Amsterdam had raised the idea of including a conference for electrical engineers.⁹ It soon became clear that an international conference was too ambitious, but on 23 May a meeting was held at the Royal Zoological Society ('Natura Artis Magistra' or 'Artis'), from which emerged a plan for a national conference with a view to launching an electrical engineering society. A provisional executive committee was formed, presided over by J.A. Snijders, professor at Delft Polytechnic, where he pioneered classes in electrical engineering. Onnes, who became vice-president, knew Snijders from his days in Delft. He had succeeded him in teaching physics laboratory classes, and had taken over one of his lectures in the academic year 1880-1881 when Snijders was ill.

On the morning of Saturday 26 October 1895, over a hundred electrical engineers met at Artis, and by the afternoon the Electrical Engineering Society had been born. The founding members puzzled over by-laws, enjoyed a guided tour of the exhibition grounds, and dined on the ship 'Prins Hendrik'. Still, this successful inaugural meeting could not disguise the fact that the Netherlands lagged behind in this field.¹⁰ Snijders hoped that the new society could promote the building of an electrical engineering laboratory in Delft, a long-cherished wish. Meanwhile, Onnes too intended to use the society to further his own aims, which created tension between the two men.¹¹ Onnes was mainly interested in training electrical engineering technicians – this would directly

⁷ Heike Kamerlingh Onnes to C.W. Janssen, 9 October 1897, archives Huygens Laboratory.

⁸ Prof. J. van den Handel, 'Historisch overzicht van het Leidse Janssenfonds voor vakopleiding-beurzen', 23 June 1982, archives Huygens Laboratory.

⁹ Archives Huygens Laboratory.

¹⁰ *De Ingenieur* 1895, 487.

¹¹ See note 9.

benefit his blue-collar boys, and hence the laboratory. When he decided that the society was doing too little to further this aim, he threatened to bypass it and arrange the matter in a separate committee, provoking the wrath of Snijders. The outcome of this conflict was that in December 1895 the society set up a committee on the training of electrical engineering technicians, chaired by Kamerlingh Onnes.

Two years later a bulky report was published.¹² The committee concluded that only practical training could equip technicians for all the demands of their occupation. Its main concern, of course, was to produce good instrument-makers: 'Capable instrument-makers can be of such great value in electrical engineering, and employers in this field generally have so little information enabling them to judge their competence, that it struck us as essential to define the practical qualifications that an instrument-maker must possess.'¹³

At a meeting in Leiden that managers of instrument-makers' workshops (including Curvers and Kouw) were invited to attend, the training course was discussed in detail. The meeting concluded that besides aspiring instrument-makers, there was also a need for makers of mechanical instruments as well as electrical and physics laboratory equipment. The discussion then centred on requirements, in terms of practical skills. An aspiring instrument-maker, for instance, must be able to rapidly make a steel ruler, and to mill brass ball bearings or fashion a 'hexagonal domed nut together with the appropriate bolt'. A maker of instruments for the physics laboratory had to be able to produce a gauge for a mirror galvanometer and to have mastered the techniques of turning and carving wood, ivory, horn and ebonite; he was also expected to be able to harden, magnetise and colour steel. Besides all these practical skills, the committee concluded, assistants must possess 'an understanding of the principles of electricity and of mechanical draughtsmanship'.¹⁴ 'Technicians [dealing with electrical equipment] must above all be thinking workers.'¹⁵

The best way for this thinking worker to demonstrate his theoretical skill and general education would be by providing him with a diploma. The committee decided that the course could best be set up in consultation with the executive committee of the Electrical Engineering Society, which would also delegate second examiners. In addition, it was considered highly desirable for the students to take practical examinations in instrument-making. To be officially designated a 'technician' you would need two diplomas, to demonstrate a

¹² *Over de ervaring opgedaan bij de examens, ingericht volgens het Verslag van de Commissie voor de Opleiding van Electrotechnische Werklieden* (Leiden 1901) appendix 1.

¹³ *Ibid.*, 74-75.

¹⁴ *Ibid.*, 105.

¹⁵ *Ibid.*, 77.

command of theory and practice. The same applied, though with examinations at a lower level, to those seeking to be designated ‘assistant technicians’. Paid assistants would increase their practical skills while at work (and it was added that employers should not abuse the situation by putting their own interests first); theoretical knowledge would be acquired by attendance at evening classes. Leiden’s existing system of student instrument-makers working at the Physics Laboratory and studying at the MSG exemplified this ideal.

On 5 April 1898 the Electrical Engineering Society met at the Physics Laboratory in Leiden, giving Onnes a perfect opportunity to present his workshops and training system to an influential audience. The year before, Onnes had already held talks with the MSG’s directors Van Bemmelen, Van Dijk and Siertsema (the latter was also supervisor of the Physics Laboratory) on possible ways of expanding the MSG’s electrical engineering course.¹⁶ Onnes cited the Electrical Engineering Institute in Frankfurt as an example – from which his former trainee instrument-maker H.A. Blom had just graduated with distinction – and emphasised the importance of teaching both theory and practice. He felt that the MSG was the best establishment to achieve this, ‘both because it is the evening school with the most extensive curriculum in our country and because it gives students the opportunity to undergo practical training at the physics laboratory.’

The MSG management found these arguments persuasive, and contacted the electrical engineering society to decide how best to structure the evening classes in that subject. When Leiden city council agreed to raise the annual grant by 600 guilders, this inspired interior minister Goeman Borgesius to give the MSG an annual grant of 2,400 guilders. This support enabled the evening school to get the new course for ‘electrical technicians’ off the ground. In launching this unique form of vocational education, the MSG created a new national resource, and in 1899 the Society expressed the hope that soon, the Netherlands would no longer be dependent on foreigners in the area of electrical engineering.

In his speech on 5 April 1898, Onnes warmly welcomed the MSG’s new initiative and the city council’s support, which had ‘once again shown its concern and care for workers’ interests, this time coinciding with our Society’s objectives’.¹⁷ He dismissed the complaint that he sought to give electrical technicians a more thorough theoretical training than they needed, arguing that exactly the same objection had been raised a quarter of a century earlier when the first technical schools had been founded, and that these schools’ success had conclusively refuted that short-sighted view.

¹⁶ Gemeentearchief Leiden, *Mathesis Scientiarum Genitrix*, ‘kleine archieven’ no. 29.

¹⁷ *Op. cit.* note 4, 3-4.

Onnes seized the opportunity to explain the ideology underlying the training system. ‘The laboratory’s workshops provide trainee instrument-makers with what are in certain respects remarkably favourable conditions in which to develop into skilled workers’:

‘Everything will gladly be done for them that a compassionate patron can do for his pupils in their interests. Trainee instrument-makers do not need to do any shopping or suchlike, they are insured for invalidity and accidents, they are given grants to take out insurance for old age, their wages are paid during sickness, they are allowed leave for important matters, and as a rule enjoy three weeks’ annual holiday. In addition, their working hours are relatively short, namely 8 or 9 hours a day, laboratory conditions permitting.

But the trainee does not therefore have too easy a life, which would spoil him for later. For their short working day is offset by trainees’ obligation to attend evening classes and complete each year’s course satisfactorily. They must understand that for them, the years from 16 to 20 are the most important in their lives, and must learn to use the evening hours wisely. The guidance provided by their evening school, after which trainees are often given an opportunity to attend some classes at the local secondary school, combined with discussions with the researchers in the laboratory, can then lay the foundations on which the trainees can later build in independent study.

Places in the Physics Laboratory’s workshops are intended exclusively for young people who follow the precepts inculcated by the obligatory attendance at evening school. Only those who subscribe to these precepts carry within them the seeds of success in present-day society – that is, the necessary energy. Such pupils, who also possess aptitude and skill, can look forward to a bright future.¹⁸

Onnes conceded roundly that his laboratory could not function without ‘numerous adept assistants’: ‘every little piece of work [will be] used as part of the resources that are needed here, whether for education or research’. In practice, the manager Siertsema observed that this ‘curious, and as far as I know new, laboratory organisational structure, in which instrument-making plays such a large role’, was running smoothly.

After Van Bemmelen too had expressed his views, there was a guided tour of presentations by MSG and the workshops of the Physics Laboratory. MSG had brought along cables, arc lamps, batteries, galvanometers, dynamos, magnets, Leiden jars, pole finders and working plans (much of the equipment belonged to the laboratory and was available for use by the evening school at its request). The workshops turned up with filing work, a mercury commutator,

¹⁸ *Ibid.*, 11.

¹⁹ *Over de ervaring opgedaan bij de examens, ingericht volgens het verslag van de Commissie voor de Opleiding van electrotechnische Werklieden* (Leiden 1901).

power current switches, a gold leaf electroscope, resistance boxes, glass appliances, and so on. Those present, who were also shown around the cryogenic laboratory, must have been impressed – which was obviously the intention.

From 1898 onwards, students were required to take practical examinations in instrument-making under the auspices of the electrical engineering society, as recommended by the committee on the training of electrical engineering technicians. Theoretical examinations for technicians and aspiring technicians were also introduced. By this time, the Society had been subsumed, as the electrical engineering section, into the Royal Institute of Engineers (KIVI) – an operation that cost Onnes his seat on the executive committee. In an address given in Leiden on 3 November 1900, Onnes described the examinations as ‘outstandingly successful’.¹⁹ The MSG’s electrical engineering course, which had forty students by then, led the way in the Netherlands.²⁰

The Society to Promote the Training of Instrument-Makers

Meanwhile, the system for training instrument-makers in the physics laboratory, together with the Janssen grants and evening classes at the MSG, all of which Onnes had orchestrated with such care and expertise, threatened to collapse under the strain of its own success. The laboratory had to pay the students’ wages, 2 to 3 guilders a week, as well as buying the necessary materials. The more students were taken on (and in 1900 there were over 20), the more teachers were needed, and the laboratory simply did not have the resources to cope.

To resolve the situation, it was decided to found a Society to Promote the Training of Instrument-Makers. Onnes announced the forthcoming launch in his Leiden address to the electrical engineering section on 3 November 1900.²¹ On 5 March 1901, the new society’s first annual general meeting elected its executive committee. Kamerlingh Onnes became president (he would stay on until his death in 1926) while L.H. Siertsema, manager of the laboratory and a member of the board of the MSG, became secretary and treasurer. The other members were A.J. van Achtenberg, director of Leiden’s practical technical school, E.H. Groenman, who represented the Society of Secondary School Teachers, and J.H. Wilterdink, who lectured on astronomical instruments in Leiden. So through this committee, it was easy for Onnes to contact both the

²⁰ In 1900 four candidates took the examination to be admitted as trainee technicians, of whom two passed, and two took the technicians’ examination, both of whom passed. The figures for the years 1901-1905 (with numbers of passes in parentheses) were: 1901: 15 (12) and 3 (3); 1902: 12 (10) and 1 (1); 1903: 7 (7) and 10 (9); 1904: 10 (9) and 9 (6); 1905: 16 (14) and 9 (9). See *De Ingenieur*, 9 December 1905 and 17 March 1906.

²¹ *Op. cit.* note 19.



Ill. 33. Lab K in the Physics Laboratory with trainee instrument-makers ('blue-collar boys') and the instrument-maker Curvers, 1900. Kamerlingh Onnes founded his in-house training course for instrument-makers in 1901.

'suppliers' of students – technical schools – and a very important category of 'consumers' – secondary schools looking for laboratory assistants.

At its launch the society had 40 members, which number had increased to 73 by 1 January 1902. An annual membership fee was requested of 2 guilders and 50 cents. Five donors had provided initial lump sums of 100 guilders or more, including the Leiden University Fund (where Van Bemmelen had championed the cause).²² The most important donor was P.W. Janssen, who had pledged to contribute 750 guilders a year for the first three years – without which generosity the society could not have been launched at all.

A glance through the membership list makes it clear that Onnes had primarily canvassed in his own circle. Almost all his past and present assistants as well as his immediate associates joined the new Society, from Siertsema and Zeeman to Blom, Curvers, Kouw and Flim; from Lorentz to Dikshoorn and

²² Siertsema to LUF, 27 April 1901, Gemeentearchief Leiden, Leidsch Universiteitsfonds, inv. no. 204.

Van Bemmelen. He also roped in his family – not only Menso and Onno (Dolf, who was in Padang on Sumatra, joined a year later) but also his in-laws from The Hague (Bijleveld), who supplied three members. ‘Once the ball is rolling’, Siertsema wrote in a recruitment letter to Zeeman (then *lector* in Amsterdam) in August 1900, ‘we shall secure a government grant, besides which we have received pledges of substantial private donations. The success of this plan is therefore assured as soon as we have enough members to set ourselves up as a society.’²³

In May 1901 the secretary/treasurer wrote to inform Leiden city council that twelve boys who had attended Leiden technical school had been taken on as trainee instrument-makers. Siertsema further explained that one former trainee was now working as a machinist, two as draughtsmen at machine factories, two as instrument-makers, two as chief technicians, two as electrical engineering assistants, and ten as school laboratory assistants. Would Leiden city council award an annual grant of 500 guilders? A request to the Queen followed on 31 May, for an annual state grant of 2,500 guilders. Both the city council and the state responded positively,²⁴ and the provincial authorities of South Holland would also provide financial support.

The new society started out with 26 students.²⁵ They paid a maximum of 36 guilders a year, depending on parental income. Fewer than half of the trainees came from Leiden. The Society’s tasks included paying out the weekly wages, administering the Janssen Fund, holding examinations and appointing teaching staff. For the time being Onnes placed his own technicians Kouw, Flim, Bestelink (the machinist) and Baumbach (who taught glass-blowing for part of the year) at the Society’s disposal free of charge. The Society itself paid C.F. Bader, who taught a few classes each year in lacquering, and A. van Buuren, who taught a number of pupils how to forge steel as well as teaching surgical and orthopaedic instrument-making (this subject was dropped after his sudden death in 1906).

The Society took charge of the practical instrument-making examinations, which the KIVI had stopped providing for lack of funds in spite of the considerable demand for them. Of the 15 candidates in 1901, eleven passed, all of them trainees at the Physics Laboratory. The practical examinations lasted several days. One of the candidates handed in the towel on the very first day, ‘since he had evidently completely failed to understand the nature of the work he would be expected to do’. It was not always possible for trainees to obtain time off from work to take the examinations: the instrument-makers P.J. Kipp

²³ Siertsema to Zeeman, 24 August 1900, N-HA, Zeeman archives, inv. no. 137.

²⁴ Brievenboek Vereeniging tot bevordering van de opleiding tot instrumentmaker met kopieën van uitgaande post, archives Huygens Laboratory.

²⁵ Vereeniging tot bevordering van de opleiding tot instrumentmaker, Eerste Jaarverslag, 1901.



Ill. 34. Pupils of the instrument-makers' school helping to make plaster models of Ψ -surfaces in the back garden of the Physics Laboratory.

& Zn. in Delft would only allow their juniors time off for this purpose if their rivals did the same.

Just how closely attuned the instrument-makers' training course and the Physics Laboratory were from the outset, and how cleverly Kamerlingh Onnes used it to advance his laboratory, is illustrated by the advent of master glass-blower Oskar Kesselring. Glass played an increasingly important role in the cryogenic laboratory, where a start had been made on building a hydrogen liquefier, and blowing double-walled vessels and thin spiral tubes was a specialised art. Since Onnes could not find anyone in the Netherlands who was sufficiently expert in this technique, he placed an advertisement in German newspapers and journals in July 1901. 'The Society for the training of instrument-makers at the University of Leiden in the Netherlands wishes to employ a glass-blower trained in a wide variety of techniques. For information and salary, please contact the executive committee of the Society. [signed] Prof. H. Kamerlingh Onnes.'²⁶

²⁶ Orig. 'Vielseitig gebildeter Glasbläser wird als Lehrer und Werkstattführer gesucht vom Verein für die Ausbildung von Feinmechaniker an der Universität Leiden, Holland. Referenzen und Gehaltsansprüche an den Vorstand des Vereins.' See note 24.

The advertisement placed in *Die Henne*, a journal that was published in Ilmenau, Thüringen, elicited a response. On 3 February 1902, the 25-year-old F.O.W.H. Kesselring, trained at the technical school in Ilmenau (which was known for its high standard of glass-blowing), presented himself, and in April that year he started work in Leiden.²⁷ Onnes was unable to offer Kesselring, who, like Flim, was of crucial importance to the cryogenic laboratory, more than 900 guilders a year in salary. But because the Society to Promote the Training of Instrument-Makers added a monthly allowance of 45 guilders, Onnes was nonetheless able to hold on to his glass-blower. Flim received a similar allowance.

During their three years in the laboratory, the trainees acquired a varied course of training. In the two primary workshops run by Kouw and Flim (Curvers had left in 1900) they practised many aspects of instrument-making. They spend part of their time in Kesselring's glass-blowing workshop. From Van Buuren they learned how to forge steel, to make tongs and instruments, and to do nickel-plating. The machinist M.J. Bestelink, who had started as a trainee in 1896 and was appointed at the laboratory on 1 March 1902 (for an annual salary of 800 guilders, plus a 175-guilder allowance from the Society) also took on students. He taught them how to stoke the steam boiler, to operate the gas engines, and deal with switchboards, electric motors, generators and the storage cells / batteries of the electricity system. For the rest, the students were expected to help set up the experiments on the first floor, or to assist at demonstration experiments staged during lectures. Others were set to work making technical drawings or taught the principles of administration.

No ordinary workshop could compete with such varied activities. And the laboratory certainly had no shortage of applications. Candidate trainees would assist in the workshops for a few days on a trial basis in March or September, during which time they were given filing and other simple tasks to perform. Only those with a superior understanding of theory were expected to meet less stringent practical requirements. Candidates also had to pass an entrance examination for the fourth class of the MSG's evening school – a standard corresponding to the highest class of technical school. Trainees worked hard: from 7.30 to 12 noon and from 1.30 to 6 p.m. at the laboratory, and four evenings a week they attended compulsory classes. This was offset by the fact that employers were very eager to hire their services when they completed the course. From a list of 200-odd former students, published in 1919, it appears that a large proportion became laboratory assistants at secondary schools or laboratories, were appointed at the technical drawing departments

²⁷ Archives Huygens Laboratory.

of commercial companies, or secured jobs in electrical engineering. Former students also included the owner of a firm of electrical contractors, the director of a gasworks, a teacher at a technical school, a chief draughtsman, a chief electrician, a chief structural engineer, and a company manager. One of the boys later became the director of a match factory in Suriname.²⁸

The importance of the instrument-making training for the growth and success of the cryogenic laboratory was enormous – it was a classic case of symbiosis. In countless major and minor tasks, the permanent presence of a small army of ‘blue-collar boys’ proved to be a boon. The determination of isotherms at low temperatures needed many hands. ‘If the thermocouple and platinum thermometer are read simultaneously, as they frequently are,’ state Haga and Van Everdingen in the volume published to commemorate the 25th anniversary of Onnes’s doctorate in 1904, ‘these experiments require three or four staff to operate the cryogenic system; one observer to read the hydrogen thermometer with an assistant to illuminate the scales etc.; two observers for the thermocouple and platinum thermometer, and one to regulate the pressure. Fortunately, the Leiden laboratory has no shortage of assistants, partly thanks to its training system!’²⁹

For three-quarters of a century, the Physics Laboratory (renamed the Kamerlingh Onnes Laboratory in 1932) and instrument-makers’ training were closely interwoven. Crommelin, who was the laboratory’s supervisor from 1907 onwards, described this relationship as follows:

‘There is a very close relationship ... between the training and the laboratory, so close that the laboratory could not be imagined with the training or the training without the laboratory. The forging of these apparently so disparate variables into a harmonious whole may be termed a stroke of organisational genius. The training may be said to derive its specific, individual and anti-schoolish character precisely from the fact that it constitutes an organic part of the laboratory’s work; on the other hand, much of the laboratory’s scientific success (if such I may call it) has been, and still is, attributable to the fact that it has so many hands and minds at its disposal to overcome difficulties of a technical and constructional nature.’³⁰

Why was the combination of instrument-makers’ training and laboratory, which was so crucial to Onnes’s success in Leiden, not exploited anywhere else? The lack of any such system in Germany and Switzerland is attributable to the fact that these countries already had training courses for instrument-makers around the turn of the century. The Electrical Engineering Institute in

²⁸ *Lijst van oud-leerlingen uit de werkplaatsen van het Natuurkundig Laboratorium te Leiden* (Leiden, 1919).

²⁹ *Het Natuurkundig laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904) 50.

³⁰ *Het Natuurkundig Laboratorium der Rijksuniversiteit te Leiden in de jaren 1904-1922* (Leiden 1922) 86.

Frankfurt, the School for Instrument-Making in Biel, the instrument-making department at the Technical College and the Technical School for Metalworkers in Winterthur, the Industrial School in Mannheim, the Grand-Ducal Technical School of Instrument-Making in Ilmenau, the Industrial School in Basel, and the factories of Alioth in Münchenstein, Brown and Boveri in Baden, and those in Oerlikon – Onnes had visited them all.³¹ In the summer of 1902 another institute was opened: the Technical School for Instrument-Makers at Schwenningen.³² This abundance of training courses made it far more difficult for a laboratory to set up its own instrument-makers' training course than in the Netherlands, which had no such facilities.

The fact that the physics laboratories in Amsterdam, Groningen and Utrecht did not emulate Leiden may be explained – leaving aside the question of whether they could have done so without an Onnes or a Janssen Fund – by the less favourable conditions there. V.A. Julius in Utrecht never developed a research programme, and his successor, his nephew W.H. Julius, had very little money.³³ In Groningen, Haga had a new laboratory (specially designed for geomagnetic and galvanometric research), but he had far fewer resources than Onnes in Leiden. And in Amsterdam, where Zeeman and Sissingh conducted experimental research, there was no unity of purpose whatsoever.³⁴ The idea of 'big science', within which an instrument-makers' training course could occupy a natural position, existed only in Leiden.

Although the Leiden training system faced no competition from other universities, not even internationally, Onnes did briefly sense danger in 1903. In the government's efforts to invigorate vocational training in the Netherlands, he mused, it might decide to 'introduce a sharp distinction between technical and academic education and insist on them being provided in completely separate institutions.'³⁵ Onnes was apprehensive that this separation, which he thought an artificial distinction, would reduce government support for his instrument-makers' training. The comparison with the 'splendidly run and equipped school in Schwenningen, established with ample funds' certainly did not work out to Leiden's disadvantage – although there was plenty of room for improvement at the Steenschuur laboratory – and the likelihood of being overtaken by foreign institutions was slim, provided that 'the Government satisfies itself as to the existing state of affairs and supports the

³¹ *Op. cit.* note 12, 52-64.

³² H. Kamerlingh Onnes, *Een bezoek aan de vakschool voor instrumentmakers te Schwenningen* (Leiden 1903).

³³ Van Lunteren, 'Van meten tot weten', 128-134.

³⁴ Maas, *Atomisme en individualisme* 90-94.

³⁵ See note 32.



Ill. 35. Heike Kamerlingh Onnes with his assistants in front of the entrance to the Physics Laboratory, 1899.

Leiden school, the only one in the Netherlands, as liberally as Wurttemberg supports its own in Schweningen’.

This message, set down in a pamphlet and disseminated widely, was duly noted in The Hague: the request to raise the annual grant by 1,400 guilders was granted in 1903.

Under Onnes’s presidency, the membership of the Society to Promote the Training of Instrument-Makers grew to over 250. The number of students increased to almost fifty. In 1905 holiday courses were introduced; glass-blowing was particularly popular, and attracted numerous foreign students. The various examinations – elementary exams and those in physics, mechanics and electrical instrument-making, with the later addition of an examination for ‘beginning glass-blowers’ – were modernised in 1923 after complaints were received that they were old-fashioned. After this, everyone in Leiden was classified as a ‘trainee’, ‘worker’ or ‘master’ in the disciplines ‘instrument-making’ (electrical as well as metal instruments) or glass-blowing. The title ‘master instrument-maker’ was reserved for a handful of brilliantly skilled technicians, and only after years of practical experience.

The training course, which is known today as the Leiden Instrument-Makers’ School (LIS), has retained its independence up to the present day. Both university and LIS initially benefited from their close-knit connection. The blue-collar boys enabled the researchers to acquire good instruments cheaply, they helped with measuring procedures, and were deployed as guards, errand boys, caretakers and cleaners. Conversely, the LIS had teachers and materials at its disposal that would otherwise have been beyond its means as a small training school. Nonetheless, the two institutions started to go their separate ways in the 1970s. While the school had in the past always been run by professors (Kamerlingh Onnes, De Haas, Van den Handel), now, for the first time, someone from outside the university was appointed. In 1997 the LIS acquired its own accommodation, near the Huygens Laboratory, and its relationship with the university is now one of service-provider and client.³⁶ Even so, there still a special bond. The Kamerlingh Onnes Laboratory is still represented on the board of the LIS, and continues to be involved in the LIS’s examinations.

³⁶ ‘Een eeuw precies’. *Leidse Instrumentmakers School* (Leiden 2001).

21. Stolen rooms and other personnel matters

Hiring capable workers is one thing, but keeping them is another. This point was not lost on Kamerlingh Onnes, and the bold and inventive way he organised his Physics Laboratory ensured that his research staff could build on a solid and proficient team of technicians, with very little turnover at the top. Master glass-blower Oskar Kesselring, whom Onnes had lured to Leiden from Thüringen in 1901, stayed there for the rest of his life. Another permanent fixture was Gerrit Flim, who started as an apprentice instrument-maker in 1893 and rose to manager of the cryogenic laboratory. Flim was largely responsible for designing and making Leiden's hydrogen and helium liquefiers, albeit within theoretical parameters laid down by Onnes.

How did Onnes achieve this? Hendrik Casimir, who arrived in Leiden as a physics undergraduate in 1926 – after Onnes's time – described the old professor, on the basis of popular accounts, as 'a benevolent dictator'. 'He demanded a great deal from his people', wrote Casimir in 1991, 'but studied the details of their work and showed his appreciation for their achievements. One employee, who had arrived at the laboratory in 1915, related: "He summoned you to his office around the end of the year, you thought you were going to be given a pay rise – and thought you deserved one. He sent you away again without a penny extra, and somehow you still felt satisfied. I still don't really understand how he did it."¹

Casimir wrote that Onnes was good to his technicians within the limits of his odious 'class prejudice', but always put the laboratory's interests first. To illustrate Onnes's classbound views, Casimir said that the professor had reportedly advised Flim against sending his son to a HBS secondary school, and that Mrs Onnes had almost fainted when she heard that this same son, who eventually became a family doctor, was to marry the daughter of a professor. Flim apparently declined to take umbrage – 'As it seemed to me, it was my boy, my money, my decision.' It should be added, however, that Onnes paid for

¹ H.B.G. Casimir, *Mens en kosmos* (Amsterdam 1993) 173-174.

both Flim and Blom to attend science classes at the HBS in the 1890s to supplement their evening school studies. Contemporaries of Casimir pointed out firstly that the technicians loved to spin yarns about Onnes in idle hours when the liquefier was out of commission, embroidering them more and more after his death, and secondly that relations between the classes were different after the Second World War, when the Onnes anecdotes were recorded, than they had been at the time – before the First World War.²

Until 1900, Onnes had little to do with his technical staff. Kouw, whom he had inherited from his predecessor Rijke, had been encouraged to develop his considerable talents; he presided over one of the two workshops, and played a key role, as a mechanic, in setting up and expanding the internal training system for instrument-makers. In 1890 he had been joined by J.J. Curvers, who was put in charge of the new workshop behind the cryogenic laboratory and immediately distinguished himself by building an ethylene boiler. In the aftermath of the ‘explosive devices’ affair, Onnes had pressured the government into approving the appointment of a special laboratory technician to take care of the compressed and liquid gas cylinders. This position went to Curvers, while Flim was promoted from assistant custodian to take his place.

Thus in 1900, the staff of the Physics Laboratory consisted, besides Professor-Director Onnes himself (annual salary 6,000 guilders) a supervisor (Siertsema, 1,500 guilders), four assistants (Van Everdingen, Hartman, Meilink and Keesom; all 1,000 guilders), a laboratory technician (Curvers, 1,000 guilders), an instrument-maker (Flim, 900 guilders), a custodian / mechanic (Kouw, 900 guilders) and an assistant custodian (a job shared by two apprentice instrument-makers, each of whom was paid 300 guilders). The laboratory now had five times as many assistants (including the supervisor) and four times as many instrument-makers as in 1882 when Onnes was appointed. In contrast, Haga in Groningen was still making do with a single assistant, while Julius in Utrecht and Van der Waals in Amsterdam each had two. What is more, the Steenschuur laboratory had twenty ‘blue-collared boys’ who helped with measurements and numerous other tasks. Even by European standards, Leiden was very well staffed: only Oxford and Cambridge (which enjoyed generous private funding), Paris, Vienna and Berlin had larger physics laboratories.³ As early as 1893, acting assistant Wind referred to Onnes as the ‘factory boss’.⁴

² Personal communication by R. de Bruyn Ouboter.

³ Paul Forman, John L. Heilbron and Spencer Weart, ‘Physics circa 1900’, *Historical Studies in the Physical Sciences* 5 (1975) 18–23.

⁴ Wind to Zeeman, 18 March 1893, N-HA, Zeeman archives.

Onnes was well aware that he could not afford to pay high salaries and that there was always a danger of his permanent staff receiving more attractive offers elsewhere. Kouw, who had not had a rise since first being appointed in Leiden, was clearly underpaid, especially since his responsibilities had greatly expanded and he was forbidden to work for private clients. In 1898 Onnes sent off one of his characteristic letters requesting a salary rise for Kouw, who deserved to be in 'better circumstances'.⁵ He also tried (in vain) to procure a better pension for him. Kouw's career ended on a sad note. After being reprimanded by Onnes in 1898 for failure to pay his taxes on time, ten years later he brought himself within a hair's breadth of bankruptcy, and Onnes feared for the laboratory's good name.⁶ By the time Kouw retired in 1911, after fifty years in public service, he had forfeited every last gram of sympathy with his financial mismanagement, and there was little enthusiasm for 'some sort of anniversary celebration'. But Onnes, ever the loyal employer, arranged for his former supervisor to receive a gift of money as 'a ray of light' to grace his retirement.⁷

In mid-1900, Kamerlingh Onnes lost his chief instrument-maker, Curvers, to the state telegraph service repairs workshop. Curvers had been promised far more money – even a hurriedly arranged rise of 400 guilders could not keep him in Leiden – and Onnes was realistic enough not to try to place any obstacle in his path, however reluctant he was to see him go. On the contrary, when the chief engineer of the telegraph service repairs workshop had made eager enquiries about Curvers a few years earlier, Onnes had praised him to the skies and said he would be happy to see Curvers enjoying better financial circumstances.⁸ It was Onnes's way to be completely frank, verging on the naïve. On the other hand, his peerless organisational skills always enabled him to repair the damage.

In this case, the hero was the Amsterdam tobacco agent and philanthropist P.W. Janssen, the man who had provided a generous gift in 1897, initiating the grants system for trainee instrument-makers. At the beginning of 1900, Janssen had sent word that he wanted to do more to promote the development of the Leiden laboratory. Onnes avidly seized this opportunity, and by June he had drafted a well-conceived plan: 'Measures to promote the equipment, maintenance and use of measuring instruments in the Physics Laboratory

⁵ Heike Kamerlingh Onnes to *curatoren*, 17 May 1898, archives Huygens Laboratory.

⁶ Heike Kamerlingh Onnes to Crommelin, 8 September 1909, archives Huygens Laboratory.

⁷ Heike Kamerlingh Onnes to Zeeman, 19 September 1911, N-HA, Zeeman archives.

⁸ Hoofdingenieur herstellingswerkplaats Rijkstelegraaf to Heike Kamerlingh Onnes, 2 March 1900, archives Huygens Laboratory.

in Leiden'.⁹ At the heart of the plan lay a second Janssen Fund that would increase the cryogenic laboratory's resources.

Onnes reasoned as follows. The secret of the instrument-makers' training lay in 'intertwining' the apprentices' activities with the scientific work carried out by the research team. The only way to raise the standard of this training was to expand the research team, since this would boost the use of instruments – the driving force behind the training. The problem was that the government would only sponsor research directly linked to higher education. 'The government is highly reluctant to promote the interests of academic research, since Parliament, in its present composition, is well known to be biased against such proposals.' It was up to 'private initiative' to bridge the gap.

Plans to improve the training system, however, were received more favourably in The Hague. The idea of establishing a Society to Promote the Training of Instrument-Makers could undoubtedly count on government support, asserted Onnes. But since membership contributions would provide only a 'modest sum', Onnes suggested that Janssen might be willing to donate 750 guilders to the new society. This would at least enable him to hire competent staff, 'especially from Germany', to teach the apprentice instrument-makers special practical skills. Two years later Kesselring's appointment was a fact, and Onnes was able to raise the glass-blower's salary by hundreds of guilders a year for the practical instruction he gave the 'blue-collared boys'. In addition, the machinist Bestelink, appointed in 1902 (who also presided over the electrical installation), was given an annual increment. In short, the Society enabled Onnes to pay his technicians more, making his laboratory less vulnerable to 'avaricious' employers in search of capable technical staff.

Onnes also wanted to use the second Janssen fund to prevent his oldest assistant, E. van Everdingen, from leaving for financial reasons. Van Everdingen, for whom Onnes had previously arranged a student grant, earned only 1,000 guilders a year (the regular assistant's salary), and according to Onnes, his 'impecunious' father was still obliged to help out. A teaching job would solve Van Everdingen's problems overnight. To deter him from making this change, and to retain his talents for scientific research – and for the workshops – Onnes proposed giving him an immediate rise in salary, to be increased from 300 to 500 guilders a year in the space of three years. Would P.W. Janssen please provide the necessary 1,200 guilders?

Finally, Onnes wanted to use the second Janssen fund to pay for two extra assistants for his cryogenic laboratory. They would perform scientific measurements with 'high-precision instruments', instruments to be designed, made,

⁹ Heike Kamerlingh Onnes to C.W. Janssen, 5 June 1900, archives Huygens Laboratory.

tested and maintained in close collaboration with the trainee instrument-makers. Both the training course and science itself would benefit from such an arrangement. Onnes put the costs at 1,000 guilders per person for three years, thus totalling 6,000 guilders. Together, the proposed measures would cost 9,450 guilders. This was a hefty sum, but two weeks after receiving Onnes's proposals, P.W. Janssen's son gave the go-ahead on his father's behalf. Van Everdingen was happy with his salary rise, and rejected the offer of a better-paid scientific position at the meteorological institute (KNMI); the job went to his associate and fellow-assistant Hartman instead.

As for the two additional assistantships, Onnes wanted one to be shared by two of Zeeman's PhD students and the other to go to two foreign researchers: M. Boudin from France and Francis Hyndman from England.¹⁰ Good assistants were extremely hard to come by around the turn of the century. In January 1899 Onnes wrote to Röntgen asking if he knew of anyone, but the latter was experiencing the same problems in Würzburg. 'There are too few young people willing to take the necessary time to become physicists', replied (in Dutch) the man who had recently discovered X-rays.¹¹ But the Leiden laboratory had built up an excellent reputation by then. In April 1901, Onnes received a card from a man aged 22 in Milan who had just completed his Master's degree at Zürich's Federal Polytechnic Institute (Eidgenössische Technische Hochschule), offering his services as an assistant.¹² His name was Albert Einstein. But the self-addressed postcard, to Via Bigli 21, Milan, disappeared into a file at Onnes's home. That Einstein had enclosed his 1900 article in *Annalen der Physik* (his first publication) on intermolecular physics did not help. Onnes was looking for assistants with a marked practical bias, and Einstein did not suit that description. And if Onnes made enquiries of Weber, Einstein's former physics professor in Zürich, Weber may well have warned him that Einstein was a rather headstrong fellow.¹³

To Onnes's delight, the Janssen fund was renewed in 1903. He was particularly glad of being able to retain the extra assistants. 'Research as such receives very miserly support from the government', he complained again. 'And few wealthy individuals in the Netherlands are persuaded of the usefulness of scientific endeavour and willing to make funds available for it.'¹⁴ The series of assistants appointed with the aid of the second Janssen fund outlived P.W. Janssen, his son, and Kamerlingh Onnes, and did not come to an end until after the Second World War.

¹⁰ Heike Kamerlingh Onnes to C.W. Janssen, 9 July 1900, archives Huygens Laboratory.

¹¹ Röntgen to Heike Kamerlingh Onnes, 8 January 1899, MB, archives of Heike Kamerlingh Onnes.

¹² Einstein to Heike Kamerlingh Onnes, 17 April 1901, MB, archives of Heike Kamerlingh Onnes.

¹³ Abraham Pais, *Subtle is the Lord...* (Oxford 1982) 40-46.

¹⁴ Heike Kamerlingh Onnes to C.W. Janssen, 27 May 1903, archives Huygens Laboratory.

'And suppose Flim were to leave too!'

In his annual budgets, Onnes constantly emphasised the need for higher salaries for key employees to prevent them from leaving – deploying extra resources from the Janssen fund could always be tried as a last resort. In his 1904 budget, for instance, he accorded higher priority to expenditure on personnel than on purchases of high-precision instruments.¹⁵ This was because the year before, Siertsema, who in his capacity as supervisor kept the Leiden laboratory operating smoothly, had received an attractive offer from the meteorological institute KNMI (the supervisory board of which included Onnes himself).¹⁶ He was invited to take over as director of the department of 'observations on land' for an annual salary of 3,000 guilders. Onnes, who had only just managed to secure, with great difficulty, a raise from 1,500 to 1,700, intervened immediately. Drawing on the Janssen fund he paid Siertsema a substantial salary rise and lightened his workload – the supervisor was also secretary and treasurer of the instrument-makers' training course – by relieving him of the management of the workshops. It had the desired effect: Siertsema, who had initially been inclined to accept the KNMI's offer, decided to stay in Leiden. Van Everdingen left instead – a sad loss, but less serious. Onnes again urged the board of governors to give the supervisor a salary of 2,000 guilders, and this time his request was granted.

He did not always succeed. Less than twelve months later, Siertsema transferred to Delft, accepting a professorship at the Polytechnic, which was about to be upgraded to an Institute of Technology (Technische Hogeschool). And in 1907, Onnes's machinist Bestelink, who, like Flim, had risen through the ranks of the instrument-makers' course, was snatched up by the Coastal Lighting Service in IJmuiden. He was to earn 500 guilders more, with a house thrown in. Onnes tried to stave off this assault by proposing to raise Bestelink's salary to 1,000 guilders immediately, to rise to 1,600 in twelve years, promoting him to 'chief machinist' – to no avail. Once again the authorities had refused to listen, Onnes fumed in his budget proposals for 1909: 'What a waste of all the investment and effort'. It was impossible to find a good replacement for 800 guilders. What is more, the assistant supervisor too was thinking of leaving; he had been offered a job with the railway company for a salary completely beyond Leiden's means. At this point Onnes really exploded with rage: 'And suppose Flim were to leave too! He *must* be given a higher salary!'¹⁷ He had expressed this fear long before, in his 1905 budget proposals, writing: 'In

¹⁵ *Begroting* 1904, UB Leiden, Archief Curatoren, inv. no. 1659.

¹⁶ Notulen curatoren, 22 September 1902, Utrechts Archief, archives KNMI, inv. no. 2.

¹⁷ 1909 Budget, UB Leiden, Archief Curatoren, inv. no. 1661.

my view it would be devastating for the laboratory if no steps were taken to keep this laboratory technician.¹⁸ Flim, ‘the laboratory’s gem’, had been approached by the navy, which was offering him 500 guilders more in salary. His departure, like that of Curvers, would amount to downright destruction of capital, since the duties required by his new employer were of a lesser order.

And now four years had passed, and Flim’s position had still not improved. Onnes did not give up, however, and wrote to the board of governors that Henri Becquerel, the man who had discovered radioactivity in 1896, had arrived from Paris with a case of special equipment, and had spent eight weeks in the Physics Laboratory recording measurements of rare-earth compounds at liquid hydrogen temperatures – all thanks to Flim’s wizardry. A salary increase of four hundred guilders (to 1,400) and promotion to manager of the cryogenic laboratory were a bitter necessity, insisted Onnes.¹⁹ But the minister was intransigent, and Flim would remain a simple laboratory technician for another ten years. Once again Onnes was forced to draw on private resources.

Six years later, in his budget for 1915, Onnes sounded the alarm once more. Flim was still threatening to leave, and this was now part of a larger problem.

‘Factories are now introducing scientific methods; they are plundering my laboratory, finding easy spoils here, where workers are paid well below their abilities. Only recently a factory snapped up my two ablest assistants, one after another, and their eager eyes will inevitably fall before long on the laboratory technician of the cryogenic laboratory.’²⁰

Onnes was referring to Philips’ Incandescent Lamp Works in Eindhoven. In 1914, following the passage of the 1910 Patents Act (before which time knowledge was not restricted by law), Gerard Philips had set up his own research laboratory,²¹ luring away Onnes’s assistant Gilles Holst to become its director. In the same year, Ekko Oosterhuis, the Danish physicist Sophus Weber and the chemist Filippo (who had provided such sterling services in the isolation of inert gases) all left Leiden for jobs in Eindhoven. Others – P.G. Cath, A.T. van Urk and F.M. Penning – soon followed. Onnes had more or less precipitated this exodus himself. ‘A few years ago I advised Philips – one of my former students in Delft – to take on scientifically trained, talented young men at his factory’, he wrote to Van der Waals in 1914, from his holiday address in Switzerland. ‘And now he is stealing my best assistants. A fine future awaits these young people in this field, and I am pleased for all of them. Young birds

¹⁸ 1905 Budget, UB Leiden, Archief Curatoren, inv. no. 1660.

¹⁹ See note 17.

²⁰ *Begroting* 1915, UB Leiden, Archief Curatoren, inv. no. 2035.

²¹ Kees Boersma, *Het ontstaan en de geschiedenis van het Philips NatLab* (Amsterdam 2002).

must always leave their nest; I only wish their departures succeeded one another more slowly. At this rate it is becoming difficult to find assistants.²²

But relations between Leiden and Eindhoven – where Holst, in his quest for ‘the light bulb formula’,²³ sought to create an academic ambience – were excellent from the outset. The two laboratories shared an interest in the inert gases and helped each other whenever the occasion arose; in 1915 Holst borrowed a galvanometer with accessories and some small pieces of gold from Leiden. Casimir, who transferred from Leiden to Eindhoven in 1942, noted that Holst was a completely different type of director than Kamerlingh Onnes, and that his laboratory placed less emphasis on precision measurement.²⁴ Holst was certainly a less dominant presence. Still, in many respects the atmosphere at Philips’s physics laboratory resembled that in Leiden.²⁵ The ‘industrialised’ production of research results began in Leiden under Kamerlingh Onnes. In Eindhoven too, everyone worked as a team on orchestrated projects with well-defined objectives, and the emphasis was on acquiring in-depth expertise. In 1916 Holst started a programme of seminars at his laboratory, inviting Paul Ehrenfest, who had succeeded Lorentz as professor of theoretical physics in Leiden in 1912, to lecture in Eindhoven.

As early as 1902, even before Siertsema’s departure for Delft, Onnes had urged the authorities to approve the appointment of an additional supervisor. Six years later – by which time Kuenen had been appointed alongside Onnes as a second professor of experimental physics – this post had still failed to materialise. In May 1908, Onnes enumerated all the relevant tasks once again, for formality’s sake. Supervisor number one smelled of grease and oil: ‘Managing the day-to-day supervision of the junior staff, ensuring that equipment and accessories receive the proper care, arranging all the supplies – in a word, the overall technical management – calls for a highly competent supervisor who can devote all his efforts to this task.’ August Crommelin, a young man from an aristocratic family, was eventually appointed to the job in 1909 after having done most of the work concerned as an assistant for two years.

The new supervisor possessed a keen mind: ‘Just as indispensable to me’, wrote Onnes, ‘is a supervisor who can do the scientific work I need to ensure that the laboratory meets today’s requirements.’ More specifically, this meant checking the calculations and data processing entrusted to juniors, managing the laboratory’s scientific records, and following the latest developments with a view to possible PhD topics in Leiden. This theoretical position was

²² Heike Kamerlingh Onnes to Van der Waals, 20 July 1914, N-HA, Van der Waals archives.

²³ Holst to Fokker, 30 November 1913, Philips Company Archives.

²⁴ Casimir, *Haphazard reality*, pp. 235–237.

²⁵ I should like to thank Frans Saris for our discussions on this topic.

intended for ‘an academic assistant with proven talents and competence’.²⁶ A perfect job for Willem Keesom, who had been Onnes’s assistant since 1904. His mandate included non-scientific tasks such as personnel affairs, managing the library, supervising the drawing office, editing the *Communications* (including contacts with the printer) as well as regulating exchange subscriptions with foreign institutions and maintaining ties with the Dutch Society of Refrigeration Technology.

By 1910, when Onnes turned 57, P.W. Janssen was dead. Although his son extended the support of the second Janssen Fund, he reduced it to 500 guilders a year – not enough to retain the services of someone like Keesom. In 1908, Onnes had been compelled to contribute 1,000 guilders from his own pocket, without any income from salaried ‘sidelines’. Fortunately, the liquefaction of helium was now within sight, and new sponsors would soon present themselves. In September 1910, Kamerlingh Onnes and Kuenen had a staff consisting of Keesom (first supervisor) and Crommelin (second supervisor); five assistants: W.J. de Haas, S.W. Visser, G.J. Lorentz (daughter of H.A. Lorentz), C. Dorsman and J.A. Volgraff; laboratory technician Flim, instrument-maker Kesselring, and the mechanic / custodian Kouw. Whereas the rest of the country’s physics laboratories had scarcely advanced in the previous decade, Leiden had acquired a professor and a general supervisor since 1900. Germany, and above all the United States, witnessed similar advances in academic physics in this period.²⁷

A near-cosmopolitan laboratory

Liquid helium attracted swarms of foreign researchers to Leiden, but even before 1908, the laboratory maintained a wealth of international ties. The main magnet was its cryogenic laboratory, which started to bear fruit in 1896 and which *Nature* described in glowing terms that year. Among the first foreign guests were the Russian physicists Stoletov and Sokolov. They arrived in the summer of 1895, and saw the low-temperature cascade in operation, which fortunately performed perfectly during a demonstration. Onnes knew Stoletov – the father of the Moscow school whose members included Goldhammer and Lebedev (discoverer of light pressure) – from his Heidelberg period, and the Russian had also sided with Van der Waals and Onnes in the debate on the continuity of the gaseous and liquid states. He was therefore very welcome, and on returning to Moscow, Stoletov wrote (at Onnes’s request) a letter of

²⁶ 1909 Budget, UB Leiden, Archief Curatoren, inv. no. 1661.

²⁷ *Op. cit.* note 3.

recommendation for Kuenen, for whom an opening had arisen for a chair in Dundee – 20 or 30 lines of print in the third person would suffice, Onnes instructed the celebrity, his senior by twenty years.²⁸

In December 1897, Stoletov's student Kasterin had come to Leiden to do six months' optical research.²⁹ Although he had also hoped for some training in cryogenic techniques, this was impossible in the 'coldless era', and even postponing the visit for almost two years had not helped. Kasterin was unable to complete his research, and Onnes wrote to him repeatedly (sometimes in Russian, a language of which he had taught himself the rudiments during Kasterin's stay in Leiden), asking him to send a provisional article for submission to the Academy. The Russian finally published a paper, but not until 1900 (his contribution to the volume commemorating the 25th anniversary of Lorentz's doctorate), and there was no prospect of his returning to Leiden.

After this false start, Fritz Hasenöhr from Vienna, who presented himself to Onnes in November 1898, did a great deal better. Hasenöhr, a former student of Boltzmann's, worked in Leiden as a paid assistant, studying the dielectric constant of liquid oxygen and nitrogen oxide. Good assistants were hard to come by, and Onnes must have welcomed a gifted researcher such as Hasenöhr with open arms, in spite of Boltzmann's reservations about his diligence – 'Hopefully he will not disgrace me.'³⁰ Unlike Kasterin, the Austrian did complete his research with a paper, which Onnes presented to the Academy in September 1899 and which also found its way into the *Communications*.³¹

After this, Onnes enjoyed an uninterrupted influx of foreign researchers, all eager to work in Leiden. The *Naturforscherversammlung* of December 1898, an international conference in Düsseldorf attended by Onnes, Lorentz and Zeeman, may have boosted Leiden's image. From then on, Onnes's annual reports to the board of governors never failed to include a list of foreign guests who had visited his laboratory that year, from Ramsay and Rutherford to Boltzmann and Bohr, from Kelvin and Kármán to Joffe and Jeans, from Fermi and Franck to Meissner and Millikan. Everyone wanted to see Leiden's unique cryogenic laboratory for himself, and Onnes extended boundless hospitality to all, sometimes even putting visitors up at his own home.

²⁸ B.E. Yavelov and V.A. Volkov, 'A contribution to the history of scientific relations between the Netherlands and Russia', *Janus* LXXI (1984) 135-151.

²⁹ *Ibid.*, vol. 2, *Janus* LXXIII (1986-1990) 39-52.

³⁰ 'Hoffentlich macht er mir keine Schande': Boltzmann to Heike Kamerlingh Onnes, 14 November 1898, MB, archives of Heike Kamerlingh Onnes, inv. no. 292.

³¹ Fritz Hasenöhr, 'The dielectric coefficients of liquid nitrous oxide and oxygen', in KNAW, Proceedings, 2, 1899-1900, Amsterdam, 1900, pp. 211-228. *Comm.* 52.

This attitude paid dividends. The Association Internationale du Froid, founded in the autumn of 1908 (see chapter 22), awarded the Leiden laboratory grants amounting to many thousands of francs. But just when the society had approved a grant of 100,000 francs (almost 50,000 guilders), proposed by the French industrialist and engineer Georges Claude (who had founded L'Air Liquide in 1902) to enable a large number of international researchers to conduct a whole series of cryogenic projects in Leiden, the First World War broke out. Another industrialist, the Belgian sodium carbonate producer Ernest Solvay, had also slipped Onnes 5,000 in 1912,³² wanting to support the 'labour passionné' in Leiden. Onnes had evidently generated tremendous enthusiasm for his cryogenic laboratory among the world's leading physicists at the first Solvay conference, held in Brussels the previous year (see chapter 27).

Onnes's foreign assistants and guest researchers came from all over the world, from England and Spain to Sweden and Russia, and from America to Japan. Most were young physicists, whom Onnes initially set to work on his Leiden programme, guided by the theories of Van der Waals. But it soon became common, especially once the era of liquid helium had dawned, for the foreigners to come to use the cryogenic laboratory to expand their own research to include low temperatures. Thus, Marie Curie came to Leiden in July 1911 to determine the radiation of radium at temperatures of liquid hydrogen – the radiation intensity remained unchanged.³³ Some visitors, like Henri Becquerel and Pierre Weiss, brought their own apparatus and appliances with them. Onnes would sometimes keep the laboratory log in French, German or English for a while as an extra service.

The large contribution that foreigners made to the laboratory is clear from the steady stream of articles generated by their visits. From Fritz Hasenöhr's publication in 1899 until Onnes's departure as professor and laboratory director in 1924, a quarter of the *Communications* involved at least one foreign researcher. In comparison to Utrecht, Amsterdam and Groningen, experimental physics in Leiden could almost be called cosmopolitan. The arrival of Ehrenfest (in 1912), who had studied under Boltzmann in Vienna and worked under Joffe in St Petersburg, certainly enhanced this atmosphere.

³² France, Belgium, Luxembourg, Switzerland and Italy constituted the Latin monetary union in this period.

³³ P. Curie and H. Kamerlingh Onnes, 'The radiation of radium at the temperature of liquid hydrogen', in KNAW, Proceedings, 15 II, 1912-1913, Amsterdam, 1913, pp. 1430-1441. *Comm.* 135.

With assistants and colleagues alike, Kamerlingh Onnes's will was law at the Steenschuur laboratory. While Kuenen, his first student, recalled in 1904 that his research topic had been decided upon in 1887 in 'mutual consultations' in the director's office,³⁴ others remembered a more autocratic boss. In 1913, Gilles Holst wrote to his friend Adriaan Fokker, a fellow theoretical physicist: 'I believe that you underestimate the worth of the great KO; he undeniably plays a major role, albeit often in the manner of a bath superintendent'³⁵ – a reference to the cryogenic liquid baths in Leiden. Casimir thought Onnes 'a benevolent dictator', who was not unapproachable and certainly appreciative of certain social contacts, but who would never have dreamt of treating students and assistants as 'younger colleagues', let alone as independent researchers. 'In consequence he commanded far more respect and fear than admiration or love', wrote Casimir in 1983.

His style of leadership was authoritarian and would no longer be accepted today, but within that framework he behaved with all due decorum and never failed to mention his subordinates' achievements. He took it for granted that he determined the laboratory's programme and that all results were published under his name; only older staff members could be listed as co-authors.³⁶

This latter (untenable) remark about the publication culture in Leiden will be discussed in the chapter on superconductivity; here we will confine ourselves to the laboratory's research programme. The memoirs of Jan Burgers present the same image of Onnes as a dictator. Burgers – who would later work for years as professor of aerodynamics and hydrodynamics in Delft, emigrating to the United States in 1951 – arrived in Leiden in 1914.³⁷ Although mainly interested in theoretical physics, he attended one of Kesselring's glass-blowing courses. In January 1916 he became Onnes's assistant – which he himself said largely involved taking galvanometer readings as part of the general determination of temperatures. That Onnes was more than satisfied with him is clear from the salary rise he approved from 1 January 1917 (from 800 to 1,200 guilders a year), and from his disappointment when Burgers opted for a career in theoretical physics after all.³⁸

³⁴ J.P. Kuenen, 'Condensatie en kritische verschijnselen van mengsels'. *Het Natuurkundig Laboratorium der Rijks-Universiteit te Leiden in de Jaren 1882-1904* (Leiden 1904) 88-89.

³⁵ *Op. cit.* note 23.

³⁶ Casimir, *Haphazard Reality*, p. 163.

³⁷ Fons Alkemade, 'Biography', *Selected Papers of J.M. Burgers*, ed. F.T.M. Nieuwstadt and J.A. Steketeer (Dordrecht 1995) xi-cix.

³⁸ J.M. Burgers, 'Autobiographical notes' (1975) 25-35, Delft University of Technology, Burgers archives.

The problem was, Burgers explained to Thomas Kuhn in 1962, in an interview for the 'Sources for the History of Quantum Physics' project, that Onnes was so very domineering. Burgers described Onnes as a man who expected total dedication from his research team, technicians and assistants, and elevated devotion both to experimental physics and to the director to the norm. Even Kuenen, who had himself held a chair in experimental physics in Leiden since 1906, was not treated as an equal. According to Burgers, Onnes was so autocratic that he would never allow Kuenen to embark on an experimental project of his own choosing:

'Everything had to fit into the programme devised by Onnes. For assistants, the rule was that you had to work in the laboratory all day long and to spend the evenings recording your data meticulously in a notebook. Then you had the weekends to draft weekly reports. ... But in his heart he was a good person, and it was a bitter blow to him when I decided not to stay but to return to Ehrenfest.'³⁹

After the interview, Burgers told Kuhn over dinner that Keesom had been forbidden to do X-ray experiments with crystals in Leiden; he had to wait until he acquired an independent position at the National Institute of Veterinary Medicine in 1917.

Kamerlingh Onnes required his assistants to be available whenever they were needed, Burgers wrote in his memoirs. The Burgers archives in Delft contains a note dating from November 1917: responding to Burgers' request for leave for his Master's examinations, Onnes writes that he may 'of course' take time off 'where necessary.. but you will naturally want to arrange matters such that the work is disrupted as little as possible.'⁴⁰

'You were not expected to dally with theory; experimental physics consumed every working hour', Burgers noted in his memoirs. 'I did not want to subject myself to such a regime, since my interest in theoretical physics was too great for that, and Ehrenfest was putting too much pressure on me.' But his 'defection' did not arouse any resentment, and in 1918, when Burgers was offered a chair in Delft (even before obtaining his doctorate!), Onnes, approached for a reference, wrote that this candidate was someone 'to whom one could entrust any task whatsoever, which he will consider it his duty to accomplish'.⁴¹ And after Burgers' appointment, Onnes offered to help if Burgers wanted to measure the viscosity of liquid helium. Burgers showed no interest in this 'boring' enterprise – 'adding another figure to the table of physical constants' – but

³⁹ Burgers to Kuhn, 14 June 1962, Burgers archives.

⁴⁰ Heike Kamerlingh Onnes to Burgers, 14 November 1917, Burgers archives.

⁴¹ 'Bijlage bij de notulen van de 270^e vergadering der afdeling W, S & V, dd 1 oktober 1943', Burgers archives.

when superfluidity in liquid helium was discovered in the 1930s, he realised that he had passed up a wonderful opportunity.

Willem Keesom: loyal and thorough

Wilhelmus Hendricus Keesom (1876-1956), the son of a sheep farmer from the island of Texel, studied under Van der Waals in Amsterdam and joined Onnes's laboratory as an assistant in 1900. Aside from an intermezzo in Utrecht, he remained loyal to Leiden throughout his career. Casimir, who knew him well, called Keesom 'a typical product of the "knowledge through measurement" doctrine', but said that he was far more than a capable experimentalist: 'His knowledge of kinetic theory and thermodynamics was very thorough, and although his theoretical work did not attest to a great deal of imagination, it was extremely thorough.'⁴² After gaining his doctorate in 1904 (with Van der Waals as supervisor, but using Leiden measurements that had earned him a gold medal from Leiden), Keesom served as Onnes's theoretical supervisor and right-hand man from 1909 to 1917. Not until then did he finally secure a position at the national veterinary college in Utrecht, which was upgraded to an institute of higher education the following year. As a well-respected physicist, in spite of his humble origins, Keesom must have envisaged a rather more prestigious position.

Onnes was certainly not to blame for the long delay before Keesom finally acquired a professorship. In consultation with Lorentz, he had put Keesom's name forward as a possible successor to Van der Waals back in 1908, when the professor retired.⁴³ (In the event, the position went to J.D. van der Waals Jr). And when Lorentz left for Haarlem in 1912, and the Leiden faculty decided to sound out 'outstanding foreigners' for the professorship in theoretical physics, Keesom's name again appeared in the list of nominations, below Ehrenfest – who accepted the job. In Heidelberg, Lenard wanted the Dutchman to join him, as a theorist, and again Keesom was number two. But when the negotiations with number one fell through, the *Landesamt* passed over the unfortunate Keesom in favour of the third candidate, who came from Baden. After a chair in Riga too had eluded him, Keesom was approached in 1913 for Zürich, where Einstein, who recommended him highly, was leaving.⁴⁴ Weiss, who was in charge of experimental physics in Zürich and regularly visited Leiden to take magnetic measurements at low temperatures, made enquiries with Onnes. This time Keesom's chances were thwarted by the outbreak of the First World War:

⁴² Casimir, *Haphazard reality*, p. 168.

⁴³ Lorentz to Zeeman, 20 May 1908, N-HA, Zeeman archives.

⁴⁴ Einstein to Lorentz, 14 August 1913, N-HA, Lorentz archives.

the position in Zürich was left vacant for so long that he was already established in Utrecht before things started to move. In August 1917, Onnes wrote to Keesom at the veterinary institute that he was still in the running for the Zürich chair and advised him to give it another try – although he appreciated that moving to Switzerland might be a daunting prospect, given Keesom's large family – he had eight children!⁴⁵

In 1914 Keesom had also joined the battle in Utrecht for the succession of Peter Debye (who had taken over following Wind's death in 1911, after Einstein declined the post). The job went to Leonard Salomon Ornstein, who had gained his doctorate under Lorentz in 1908, before which he had worked as Onnes's assistant. This opened up prospects in Groningen, where Ornstein had been working as *lector* in mathematical physics since 1909 (as the successor to J.D. van der Waals Jr). Onnes praised Keesom's abilities to Zeeman, complaining that his supervisor was 'underrated'.

'It pained me that he was passed over for Ornstein in Utrecht. But that he could be passed over in Groningen would be truly outrageous. That is why I am so irritated by the disparagement reflected in Zernike's articles.'

Onnes thought Frits Zernike, who had trained in Amsterdam as a chemist, 'puffed up', and urged Zeeman to publicly support Keesom's candidature in Groningen.⁴⁶ To no avail. Groningen chose the rather unbiddable Zernike instead. Together with Ornstein, he had just published a trail-blazing article on statistical mechanics. In 1930, Zernike would invent the phase contrast microscope, for which he was awarded the Nobel Prize for Physics in 1953.

How should this lack of appreciation be explained? Keesom's strict Catholic background may have been held against him.⁴⁷ When Poelhekke published the controversial pamphlet *Het Tekort der Katholieken in de Wetenschap* ('The Paucity of Catholics in Academia') in 1900, prompting the launch of a society to advance Catholic emancipation, Keesom immediately signed up. It was not easy for a staunch, active Catholic to gain a foothold in Dutch academia in the early twentieth century. When the Wind vacancy came up in 1911, even a strong Catholic lobby on behalf of Keesom's candidature did not help;⁴⁸ Pieter Debye was appointed instead. A few months later, when the Lorentz succession was being discussed, Wander de Haas (who had just gained his doctorate under Onnes and had married Berta Lorentz) wrote

⁴⁵ Heike Kamerlingh Onnes to Keesom, 15 August 1917, N-HA, Keesom archives.

⁴⁶ Heike Kamerlingh Onnes to Zeeman, 17 February 1915, N-HA, Zeeman archives.

⁴⁷ H.A.M. Snelders, 'Keesom, Wilhelmus Hendrikus', *Biografisch Woordenboek van Nederland I* (The Hague 1979) 289-291.

⁴⁸ Julius to Einstein, 20 November 1911, Universiteitsmuseum Utrecht.

from the Bosscha laboratory in Berlin that Keesom should choose Leiden instead of going off to some Catholic university. ‘Catholics are always complaining about being disadvantaged; you should not miss this opportunity!’⁴⁹

Lorentz and his two little rooms

Finally, there was Lorentz.⁵⁰ Although he did not belong to Onnes’s research team, he had frequent dealings with him. Lorentz had taken over the large lecture from Onnes permanently in 1883, when Onnes was ill, and it became a millstone from which he was not released until 1906, when Kuenen returned to Leiden. The unanimous verdict on Lorentz was that he was kindness itself and possessed boundless understanding for everyone. And yet in 1912 he suddenly left, accepting a post at the Teylers Museum in Haarlem. This calls for a few words of explanation.

The account presented by Berta de Haas-Lorentz, Lorentz’s eldest daughter, and a physicist, forces us to conclude that Kamerlingh Onnes had upset his faithful colleague. In *H.A. Lorentz: Impressions of his Life and Work*, a collection of writings published in 1957, De Haas-Lorentz suggests that her father agreed to become director of research at Teylers Physics Laboratory and secretary of the Holland Society of Sciences (the headquarters of which were on the other side of the river Spaarne) partly because of an unpleasant incident that had taken place in Leiden around 1910:

‘The laboratory acquired a new annex with a lecture hall, one room for Lorentz, one for his assistant, and two small laboratories for Lorentz’s personal use. He had always felt the lack of such space; he had asked for it, and now it was his. He loved doing experiments, for pure enjoyment. Possibly as a result of a misunderstanding, the two small rooms were ‘temporarily’ added on to the large laboratory. I remember clearly my father’s disappointment about this ‘administrative measure’. But it was not discussed. My father preferred, rightly or wrongly, to keep the peace and not to make a fuss, unless it was quite unavoidable.’⁵¹

In his autobiography *Haphazard Reality* (1983), Hendrik Casimir, who studied under Lorentz’s successor Paul Ehrenfest (and who surprised friend and foe in 1942 by transferring to Philips), added: ‘I tend to think that Kamerlingh Onnes simply stole those little rooms; in any case, it would have been a simple matter for him to rectify the matter.’⁵²

⁴⁹ De Haas to Keesom, undated, N-HA, Keesom archives.

⁵⁰ Dirk van Delft, ‘The case of the stolen rooms’, *European Review* 12 (2004) 95–109.

⁵¹ G.A. de Haas-Lorentz (ed.), *H.A. Lorentz: impressions of his life and work* (Amsterdam 1957) 97–98.

⁵² Casimir 1993, 195.

This allegation is not corroborated by the sources. Onnes, who – partly because of his fragile state of health – was not eager to give a time-consuming series of lectures to medical students at the same time as setting up a first-class research laboratory, made numerous attempts, whether or not prompted by guilt, to relieve Lorentz's workload. He was initially unsuccessful. In June 1895 he tried to retain his gifted assistant Kuenen for the laboratory in Leiden by asking the faculty board to nominate him as a *lector*. But since all budgetary requests had to be submitted before 1 May,⁵³ the Minister had an easy way out: 'Come back next year' was The Hague's response. Kuenen was unwilling to wait that long, and accepted a professorship in Dundee.

The following academic year, Onnes did take prompt action to prevent Pieter Zeeman's departure. With an annual salary of 1,500 guilders, Zeeman was five hundred guilders cheaper than Kuenen, so why would the Minister waver? But The Hague once again balked at appointing the *lector* that would have made Lorentz's life easier. When Zeeman received an offer from Amsterdam in the autumn of 1896, shortly after his discovery of the widening/splitting of spectral lines by magnetism, and the faculty's letters to the board of governors had signally failed to elicit any positive response, Onnes went to The Hague to urge the Minister to retain Zeeman for Leiden as a *lector* working alongside Lorentz – and again drew a blank. Even Onnes's attempt to arrange a 500-guilder annual grant for Zeeman from Leiden university fund so that he might acquire the 'personal title' of *lector* without drawing on public funds, came to nothing.⁵⁴ This was a particularly bitter blow for Lorentz; earlier that year he had turned down an offer of a chair in mathematical physics in Utrecht. His relationship with Onnes, wrote the Leiden theorist in explaining his decision to the Utrecht professor W.H. Julius, was 'as pleasant as one could possibly wish'.⁵⁵

After events took another turn for the worse in 1897 – the position of *lector* was back at 2,000 guilders – Onnes let the matter rest for a few years. In the meantime, Lorentz was finding the lectures to medical students an increasingly heavy burden. In 1898 he accompanied Onnes to the *Naturforscherversammlung* in Düsseldorf. This first conference abroad brought him into contact with several German physicists, and whetted his appetite for more such events. Two years later, Lorentz attended the international physics conference in Paris, where he presented a comprehensive theoretical overview of all magneto-optical phenomena, including the Zeeman effect. He also made friends with the

⁵³ For the budgets, see UB Leiden, Archief Curatoren.

⁵⁴ Heike Kamerlingh Onnes to LUF, 3 December 1896, Gemeentearchief Leiden, Leidsch universiteitsfonds, inv. no. 203.

⁵⁵ N-HA, Lorentz archives, inv. no. 102.

mathematician and physicist Henri Poincaré. When your international star is rising so high, it is a little dreary to return to Leiden and show first-year medical students how to handle viewers and ammeters.

The faculty, undoubtedly egged on by Kamerlingh Onnes, therefore made a fresh attempt to sway the authorities in its budgetary proposals for 1901 (submitted around 1 May 1900). It wanted to promote supervisor Siertsema to *lector* (at the same salary) and to shift some of the supervisory tasks to a new assistant, who would be paid 1,000. To forestall any unwanted suggestions, the faculty explained once again (in Onnes's own words) why the physics professor did not teach the medical students himself, like his counterparts in Groningen, Utrecht and Amsterdam. It pointed out that the physics laboratories of these other universities were very different from Leiden, which was a 'major research centre' and a magnet to young physicists from other countries. Running a centre of this kind was so demanding that it was out of the question for Mr Kamerlingh Onnes to take on the lectures to medical students in addition to those he already gave to mathematics and physics students, with the possible exception of an hour a week for part of the year 'to get to know their faces'.

In submitting his own budget proposals for 1901, Onnes made a striking gesture. While requesting funds for an electrical installation and a machine building, he endorsed the faculty's plea for a *lector* to lighten Lorentz's workload, and agreed to allow the latter request to take precedence if necessary, in the interests of the physics department as a whole.

From Lac de Champex, where Onnes was spending his summer holiday for a health cure, he wrote to Lorentz in August that this new attempt too was unlikely to succeed. A new hospital being built in Utrecht would probably consume too much of the budget. 'It is really intolerable', wrote Onnes, 'that every attempt to obtain a rational solution to this problem [the need for another *lector*] comes to naught.' As a final resort to help Lorentz, Onnes professed his willingness to 'sacrifice' the extra assistant who was to have taken over some of Siertsema's responsibilities. 'If we submit this proposal', he wrote to Lorentz, 'the appointment of a *lector* will not cost the Minister a penny and it will merely be a question of his good will.' The Hague could not turn down such a generous gesture. On 1 January 1901, Siertsema himself was appointed as a *lector* and Lorentz was relieved of most of his teaching to the medical students. Unfortunately, however, Siertsema left for Delft in 1904 and was not replaced as a *lector* in Leiden; almost the entire teaching load for the medical students shifted back to Lorentz.

At this point, Lorentz, who was by then a Nobel prizewinner, had had enough. He had previously declined an offer of a chair in Vienna, where Ernst Mach had retired in 1901, when Siertsema had just been appointed to relieve

him. But at the end of January 1905 (after Siertsema's departure), when Röntgen himself turned up in Leiden to ask Lorentz to join him in the department of theoretical physics in Munich, Lorentz gave this attractive offer (he would only be teaching advanced physics students) serious consideration. That he was only dissembling to improve his position in Leiden, a common enough tactic even then, seems improbable. In any case, at the faculty meeting of 29 January, Lorentz said he would stay on two conditions – a personal assistant for theoretical physics, and no more medical students.⁵⁶

The faculty wrote to the Minister, via the board of governors, expressing its 'understandable dismay' at the prospect of losing Lorentz, describing it as 'a heavy blow, indeed a calamity'. Kamerlingh Onnes proposed a solution: to coax Kuenen back from Dundee to teach the medical students as a second professor of experimental physics. That would kill two birds with one stone, Onnes must have been thinking. Zeeman's name had also been mentioned, but he had far less teaching experience, and his optical research did not fit into the Leiden programme.⁵⁷ After some financial wrangling – Kuenen refused to come to Leiden for an annual salary of just 4,000 guilders, when he was being paid £550 a year in Dundee (about 6,600 guilders) – the appointment was arranged, and at the end of 1906 Lorentz was finally relieved of his medical students for good. He was also able to move into his own small institute of theoretical physics. Lorentz had not asked for this in the faculty. Onnes had submitted this proposal in May 1905 as part of his own budget for experimental physics. It was a comradely gesture prompted by the spectre of his friend's possible departure.

In 1905, when Lorentz's move to Munich was hanging in the balance, Onnes was given permission to convert the forge in the former gas engine building, diagonally behind the main building on the corner of Langebrug and Zonneveldsteeg (today Zonneveldstraat) into yet another annex. To mollify Lorentz, Onnes decided to convert it into a small lecture hall and two rooms for the professor of theoretical physics and his assistant. In November 1906 Lorentz was able to move into his new institute, and no longer had to teach in a noisy 'cold factory'. Even so, he was not entirely happy: he still wanted a space to perform independent experiments and a workshop where components could be made. Onnes had offered him an opportunity to do experimental work when he was appointed in 1882, but after an enthusiastic beginning, he had been too busy with the large lecture and the accompanying laboratory

⁵⁶ Faculty meeting of 29 January 1906, UB Leiden, Archief Senaat en Faculteiten, faculteit wis- en natuurkunde.

⁵⁷ Faculty to *curatoren*, 5 March 1906, UB Leiden, Archief Senaat en Faculteiten, faculteit wis- en natuurkunde, inv. no. 13.

sessions. A ‘private laboratory’ for Lorentz on the first floor of the main building in Onnes’s initial renovation plans for 1884 was eventually scrapped for lack of space.

After Lorentz and his assistant moved into their new institute of theoretical physics in November 1906, Onnes applied to the board of governors for permission to build a space for experiments and a workshop adjoining the lecture hall for theoretical physics. A glance at the plans before and after this renovation shows that the intention was not to create separate rooms, as one would infer from the remarks of De Haas-Lorentz and Casimir, but an annex that would align the old gas engine building with the rest of the physics wing’s façade on the Langebrug side. It seems obvious that this rapid expansion of the theoretical physics institute arose from Lorentz’s threat to leave. Whether Heike asked Lorentz if he might perhaps like to do some experiments, as he had in 1882, or whether Lorentz had suggested it himself, is unclear. In any case, Lorentz had derived great pleasure from performing experiments in 1883, and with the advent of Kuenen at the end of 1906, he finally had time to do so again.

The construction work started in the summer of 1907, when it would cause least disruption.⁵⁸ Although it was finished in October, Lorentz could not immediately enjoy the full benefit of his new laboratory and workshop. Lack of funds left both rooms poorly equipped, and Lorentz could not do much there. The next few years brought little improvement. Although the walls of the annex were tiled in 1908, and maintenance records state that the building was connected to the *bellentoestel* (possibly a telephone exchange) in 1913, six years after its construction, Onnes wrote to the board of governors that the professor of theoretical physics – by then Paul Ehrenfest, who had replaced Lorentz the year before – still lacked a fume cupboard, gas and water connections, direct electrical current, and high and low pressure facilities’ – an abysmal list.

Lorentz must have found all this extremely frustrating: he had been promised a laboratory and a workshop, and received little more than a superior bicycle shed. In 1921, when the theoretical institute acquired a second floor, which Onnes inaugurated in a ‘simple ceremony’ one Monday morning just before Lorentz’s weekly lecture (which he carried on teaching after his move to Haarlem), the laboratory and workshop had been renamed the ‘lobby’ and ‘entrance hall’. Lorentz, who had been installed as head of research at the Teylers Physics Laboratory in 1912, where he had ample opportunity to perform his own experiments, must have taken note of this ‘rectification’ (Casimir’s word) with some bitterness.

⁵⁸ Jaarverslagen Natuurkundig Laboratorium, 1906-1907, UB Leiden, Archief Curatoren.

Was Onnes to blame for this miserable tale? He complained in 1913 that his budget did not allow him to purchase a fume cupboard for the theoretical physics institute. In the same letter to the board of governors, he presented his annual list of requests for maintenance, improvements, repairs and new acquisitions. It included 75 items of furniture and the same number of items to improve the building. A modest selection from these requests was made each year in consultation with the Chief Inspector of Government Buildings, and Lorentz's laboratory and workshop were not, it seems, accorded high priority. Did Onnes make enough of an effort? It is unclear how much pressure Lorentz brought to bear on him. It was not his style to nag. According to his daughter Berta – who worked as Onnes's assistant from 1908 to 1910 and was therefore familiar with the situation in the laboratory – the matter was not discussed because her father did not want 'to make a fuss'.

And Onnes had other matters to consider. In spite of repeated requests, the left wing of the Steenshuur laboratory was still being used by inorganic chemistry, and since Kuenen's arrival in 1906 the Physics Laboratory had an 'appalling' lack of space. Onnes wrote annual accounts of his increasing misery, expressing his 'astonishment' in baroque prose. It was in this period that helium was finally conquered. For years, the Steenshuur laboratory contained the coldest place on earth, and Onnes was eager to capitalise on this success, both nationally and internationally. In 1911 followed the additional triumph of the discovery of superconductivity. These were golden years for Onnes: he reaped the rewards of a quarter of a century's hard work.

It is clear that Kamerlingh Onnes twice offered his friend Lorentz the opportunity to conduct independent experiments. On both occasions, however, the attempt misfired. In 1883, Onnes proved to be physically incapable of combining the development of his cryogenic laboratory with time-consuming lectures to medical students, after which Lorentz was kind enough to step in. And in 1907, Lorentz was given a small laboratory and a workshop lacking even the barest of essentials. Where the lectures were concerned, it took Onnes seventeen years to put matters right by securing approval for a new *lector* to relieve Lorentz, and another six years passed before the problem was resolved for good by the arrival of Kuenen; one could scarcely call Lorentz impatient. And in the case of the useless laboratory Onnes also did his best – there is no evidence for any kind of obstruction on his part – but when this problem too lingered on, Lorentz finally left for Haarlem in 1912. The friendship does not appear to have suffered from the move, however.

What about Berta's story? It will be clear that there was no question of her father's rooms being 'stolen'. Lorentz's daughter recorded her recollections after a time lapse of fifty years. Memory is a fantastic instrument, opening up brilliant vistas, but reliability is not its best asset.

22. Committee work: a necessary evil

In 1907, when Leiden acquired its own electricity grid, the local branch of the Society for Industry decided to mount an exhibition on ‘electricity in homes and businesses’, and asked Onnes to help organise it. Four weeks went by, and still the professor and director of the Physics Laboratory had not replied. When prompted a second time, he declined, explaining: ‘my present tasks consume too much of my energy’. He did agree, however, to lend out some of his apparatus for a public lecture on electrical engineering by his former trainee instrument-maker Blom, who had become an engineer.¹

Nine years earlier, Onnes had been invited to sit on a State Committee for Steam-Driven Machines, which had been mandated to investigate the adequacy of ‘State inspection of steam-driven machines other than steam boilers’.² The Committee held its final meeting in The Hague in July 1900, and in a letter to C.W. Janssen, who mediated in correspondence regarding the Janssen Fund, Onnes expressed his view of such memberships in no uncertain terms: ‘However great an honour it may be to be called away from my regular work to perform a task on the government’s behalf, I believe that my abilities are best employed in developing the laboratory.’³ In April that year, when he was called upon to make certain calculations for the Committee, Onnes had also complained to Van der Waals: ‘With this committee, I hope finally to have fulfilled my obligations of service to the Government.’⁴

That Kamerlingh Onnes much preferred to spend his time in his cryogenic laboratory was confirmed by the mathematician (and mathematical historian) Dirk Jan Struik (1894-2000). Struik studied in Leiden from 1912 to 1916, and his unpublished memoirs record: ‘Once a week we had to attend a lecture by

¹ Archives Huygens Laboratory.

² Ministerie van Waterstaat, Handel en Nijverheid to Heike Kamerlingh Onnes, 9 July 1898, *Staatsblad* 163, archives Huygens Laboratory.

³ Heike Kamerlingh Onnes to C.W. Janssen, 9 July 1900, archives Huygens Laboratory.

⁴ Heike Kamerlingh Onnes to Van der Waals, 14 April 1900, N-HA, Van der Waals archives.

Kamerlingh Onnes, who hated to leave his lab and showed it by reading out his notes in as dull a way as possible.⁵

Building up a world-class cryogenic laboratory was Onnes's mission: it filled his life and everything else had to give way. His precarious health gave him an added excuse to decline any additional activities. The Dutch Reformed Church, the Liberals, the local technical school, the society *Mathesis Scientiarum Genetrix* (which supervised the technical evening school), and the Society for the Promotion of the Public Good were only some of the organisations that tried and failed to cajole Onnes onto their boards. And while Lorentz regularly popularised science topics for public lectures, for instance at the local community centre or Teylers Museum, Onnes scrupulously avoided all contact with the lay public. Very occasionally he could be persuaded to write a piece for a periodical, but the press had to realise, he wrote to the editor-in-chief of the weekly *De Groene Amsterdammer* that the laboratory took up all his time, 'so that my situation is completely unsuited to the journalistic requirement of producing at the drop of a hat something wholly attuned to current affairs'.⁶

Still, Onnes did take on extra tasks now and then. There were some positions he could not refuse, as professor of experimental physics. The chairmanship of the Society to Promote the Training of Instrument-Makers, which presided over the 'blue-collar boys', was pure self-interest. Onnes's involvement with the Association Internationale du Froid and the Dutch Association of Refrigeration Technology, both of which were founded in 1908 (see chapter 27), also helped to advance the laboratory. Here we shall focus on Onnes's activities for the Academy of Sciences, the Holland Society of Sciences, the Van der Waals Fund and the Dutch Physics and Medical Science Conference. He was also a member of the board of governors of the Royal Dutch Meteorological Institute (KNMI) in De Bilt and – the odd man out – Leiden's city *gymnasium* school.

Leiden's gymnasium: no more prizes

Despite Kamerlingh Onnes's enthusiastic recollections of his 'wonderful' years at the HBS in Groningen, his son Albert, like Lorentz's son, was sent to the local gymnasium. The school had about a hundred pupils around 1900, and pupils could choose between an arts and a science stream, so that boys with an aptitude for science were catered for.⁷ But the gymnasium had nothing

⁵ Dirk Jan Struik, *Memoirs* (c. 1970), chapter V, 12.

⁶ Heike Kamerlingh Onnes to Wiessing, 20 March 1911, ISSG, archives of H.P.L. Wiessing, inv. no. 50.

⁷ A.M. Coebergh van den Braak, *Meer dan zes eeuwen Leids gymnasium* (Leiden 1988).

remotely approaching the standard of the HBS's superbly-equipped laboratories. There were no special rooms at all for the natural sciences in the school on Doezastraat (built in 1883) across the road from the Physics Laboratory, so these lessons had to be taught at the Boys' HBS on Pieterskerkgracht. Not until 1907 was one of the classrooms on the Doezastraat converted into a properly equipped physics laboratory.

Kamerlingh Onnes was on the gymnasium's board of governors at the time, having succeeded the anatomist Zaaier in June 1902, shortly before Albert was to start his third year. Onnes stayed on until October 1909 – three years after Albert left school. Some of the most drastic measures taken by the board of governors in the Onnes period included the abolition of the traditional system of prizes in 1904 and the abolition of decisive end-of-year exams two years later. Previously, each school year had ended with a special ceremony promoting all those who had passed these exams to the next year. In addition, the prizewinners (one in each class) would recite from memory the *oratiunculae*, words of thanks in Latin. Albert, who was in the fourth year when the prizes (always books) were jettisoned, must have been indignant: he had won the prize for the best student in his class each of the previous three years.⁸

In 1906 Albert took examinations in both arts and sciences, and did extremely well.⁹ He went off to study law. Why did he not follow in his father's footsteps? Perhaps an interview conducted with Onnes in 1922, his jubilee year, holds the explanation. The professor recalled, 'Not so long ago a young friend asked me, "Shall I become a physicist or a lawyer? – I am drawn to both." My friend, I said, not a physicist! If you can't choose, then stay away. A researcher has to be almost a madman, possessed by that one thing – unwilling and unable to do anything else. Then you will derive satisfaction from it, whether you discover something new or not. Otherwise you never will.'¹⁰ It is not unlikely that he was referring to his son Albert.

When it was Kamerlingh Onnes's turn to resign, in October 1909, his fellow board members at the gymnasium urged him to stay. But in the age of liquid helium, which had dawned in Leiden the year before, Onnes was implacable. 'Greatly touched by the honour shown to me by the chairman's proposal and the members' endorsement', was his polite response, 'But I must not forget that my official duties are claiming more and more of my time, so that I can no longer fulfil an honorary position as well. Most regretably, I must bid this body farewell.'¹¹ In 1923 Onnes had dealings with the

⁸ Gemeentearchief Leiden, archives Stedelijk Gymnasium, inv. nos. 18, 19, 207-213.

⁹ Gemeentearchief Leiden, archives Stedelijk Gymnasium, inv. no. 475.

¹⁰ Van Itallie-Van Embden, 35.

¹¹ Heike Kamerlingh Onnes to *curatoren* Gymnasium, 16 October 1909, Gemeentearchief Leiden, archives Stedelijk Gymnasium, inv. no. 552.

gymnasium one more time, when he proposed an exchange of land with his Physics Laboratory.¹²

The competitions set by the Holland Society

The Holland Society of Sciences (based in Haarlem), founded in 1752 and the country's oldest learned society, elected Kamerlingh Onnes to its membership in 1886. The Society distinguished between directors (politicians, senior officials and entrepreneurs) and members (largely academics). While Bosscha was secretary (1885-1908) – a period spanning all Onnes's activities for the Society – an astonishing 180 competitions were set at the General Meeting every year (held at the magnificent Hodshon House in spring). This was indeed the Society's main activity, and twelve of the 180 would lead to a prize. At the rare moments at which an entry was received, a committee was formed to assess it.¹³

In 1887 Onnes devised his first competition, inviting students to test Van der Waals's law of corresponding states.¹⁴ It did not elicit any entries. In 1890, a competition set by Lorentz on the Kerr effect (the reflection of light in magnetised metal mirrors) did lead to a prize: the jury (Lorentz, Van der Waals and Kamerlingh Onnes) awarded a gold medal to Pieter Zeeman. Apart from this, apathy reigned. In 1897, when his Physics Laboratory was operating at full steam, Onnes – who had kept his head down for ten years – suddenly submitted four competition questions at once, all of them closely related to the current research in his laboratory. They did not elicit a single response, and Onnes did not try again. The Society's competitions were abolished in 1917.

In 1889 Bosscha proposed replacing the Huygens and Boerhaave medals (rather obscure prizes awarded once every four years to scholars from the 'exact' and 'natural history' disciplines) with grants for widely accessible surveys of academic disciplines, to be produced once every twenty years. As examples Bosscha cited the surveys presented by the chairmen of the different sections of the British Association for the Advancement of Science at its annual meetings.¹⁵ The plan was well received, and in 1890 the first 500 guilders were reserved for physics. At the General Meeting of May 1890, a committee chaired by Kamerlingh Onnes proposed 'the compilation and publication of

¹² Heike Kamerlingh Onnes to *curatoren*, 25 May 1923, UB Leiden, Archief Curatoren, inv. no. 1798.

¹³ J.A. Bierens de Haan, *De Hollandsche Maatschappij der Wetenschappen 1752-1952* (Haarlem 1952).

¹⁴ J.G. de Bruijn, *Inventaris van de prijsvragen uitgeschreven door de Hollandsche Maatschappij der Wetenschappen 1753-1917* (Haarlem 1977).

¹⁵ Notulen vergaderingen dagelijks bestuur en directeuren (Minutes of meetings of executive committee and directors) 1888-1890, N-HA, archive 444, inv. no. 18.

a systematic survey of experimental data, processed according to Van der Waals's theory, that could be used to test and expand this theory'.¹⁶ The theory of binary mixtures had only recently been formulated at this time, and Kuenen was just starting his work in Leiden.

Kamerlingh Onnes, Van der Waals and Lorentz were to have taken on this task, but no such publication ever appeared – nor did the Society have to fork out any money for most of the other disciplines. Precisely why the survey did not materialise is unclear. Perhaps the conflict that arose between Onnes and Van der Waals in 1894 about Kuenen's priority in the discovery of retrograde condensation played a role.

More successful was Onnes's lecture on the liquefaction of gases, complete with demonstrations and explanatory illustrations, which he gave to seventy directors and members at the Society's General Meeting of 1907. The demonstrations with liquid oxygen and hydrogen were a great success, and the Society's chairman thanked the speaker for his 'fascinating lecture and the rare and extraordinary spectacle'.¹⁷ Shortly before this, Onnes had given a similar lecture at the Eleventh Dutch Physics and Medical Science Conference at the Leiden laboratory.¹⁸ This was the sum total of his popularised lectures.

The Republic of Sciences

The Dutch Physics and Medical Science Conference was a remarkable society in more ways than one.¹⁹ Founded in 1887 in emulation of organisations such as the Jahresversammlung deutscher Naturforscher und Ärzte and the British Association for the Advancement of Science, it held conferences every two years, constantly moving the venue to reach a maximum number of researchers. It had four sections: physics and chemistry, natural history and biology, medicine, and physical geography and geology. Together they constituted a 'Republic of Sciences'²⁰ that sought to promote, encourage and fund scientific research.²¹ Unlike other learned societies, it scarcely imposed any membership

¹⁶ *Ibid.*, inv. no. 5.

¹⁷ *Ibid.*, inv. no. 6.

¹⁸ *Handelingen van het Elfde Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem 1907) 164-175.

¹⁹ R.P.W. Visser, 'Het Nederlandsch Natuur- en Geneeskundig Congres: over de relatie natuurwetenschap en samenleving, 1887-1900', in J.J. Kloek and W.W. Mijnhardt (ed.) *Balans en perspectief van de Nederlandse cultuurgeschiedenis* (Amsterdam 1991) 37-48.

²⁰ H. Zwaardemaker Cz., 'De voetstappen onzer wetenschap', *Herdenking van het 25-jarig bestaan* (Haarlem 1912) 22.

²¹ 'Reglement van de vereeniging "Het Nederlandsch Natuur- en Geneeskundig Congres"', *Handelingen van het Tweede Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem 1889) xiii.

conditions. The initiative met with an eager response: at the first conference, held in Amsterdam in the autumn of 1887, there were already 654 members, and six years later the figure had passed the 1,000 mark. Almost every researcher of note (and many others besides) in the Netherlands or Flanders registered, and luminaries and ‘private scholars’ attended in the hope of inspiration or controversy. Lengthy reports of these conferences were published in the annual proceedings (*Verhandelingen*).

The main theme of the speech with which the Amsterdam professor Stokvis opened the first conference was ‘the natural sciences in the Netherlands’.²² By analogy with the visual arts, this physician posited a link between natural sciences and nationality, ‘the sum of [the nation’s] physical and moral qualities’. In that sense the Netherlands was privileged, Stokvis maintained: the Dutch national character included precisely the qualities needed to foster scientific genius. Illustrating his argument with celebrities such as Stevin, Huygens, Swammerdam, Leeuwenhoek and Boerhaave, Stokvis enumerated these national virtues. The Dutch researcher was persistent, an excellent observer, adroit, honest, alert to matters of detail, unaffected, imaginative, and so forth – when Van ’t Hoff chaired the Fifth Conference in 1895 he added the quality ‘national equanimity’ to the list. It was high time, urged Stokvis, that society accepted its responsibility and gave science the scope it needed to flourish as it had in the Golden Age. It was not about popularising, but about concentrating resources, Stokvis insisted to his audience. By nurturing talent, giving priority to research in real laboratories rather than to teaching in lecture halls and classrooms, by the pursuit of pure natural science, exempting researchers from other duties (in other words, by paying them for doing research) – thus could Dutch science be helped to achieve its potential. No nation, concluded Stokvis, could achieve any loftier goal.

Kamerlingh Onnes was absent from the Amsterdam event but by the time of the Second Conference, held in Leiden in 1889, he was a member and non-attendance was not an option. Even so, it was not he but Lorentz, at the first session in the Physics Laboratory, who demonstrated that a negatively charged zinc plate lost its charge when irradiated with magnesium light (the photoelectric effect, for which Einstein provided a theoretical explanation in 1905), and gave a lecture on the mechanism of electrolytic conduction.

At the Fourth Conference (1893), Onnes was appointed to a committee, together with Bosscha and Haga (professor of physics in Groningen) mandated to prepare a report on ‘physics research requiring a minimum of equipment’. The idea had been proposed by Lorentz and his Utrecht colleague

²² B.J. Stokvis, *Nationaliteit en Natuurwetenschap* (Haarlem 1887).

V.A. Julius. Julius had noticed that ‘physicists do so few experiments, probably because secondary school teachers often lack good instruments and equipment’.²³ A week before the following conference, when time was getting short, Onnes wrote to Bosscha that he was disappointed by the limited number of subjects. The simplest piece of equipment, in his view, was ‘a clear head’. Inspired by his cryogenic work, Onnes suggested, as a ‘subject of immense simplicity’, an experimental project on the absorption of methyl chloride in indiarubber – although he readily admitted that methyl chloride (which could explode if handled carelessly) was ‘rather a strange substance’.

The letter to Bosscha is interesting because of the narrow view of research and education it reveals. According to Kamerlingh Onnes, nature is so rich in subject matter and lines of inquiry, ‘that it is almost impossible to set up a demonstration experiment without matters arising that lead one, in just a few steps, to the core of our ignorance.’

The difficulties confronting the experimentalist lie almost more in navigating a steady course between all the enticements rather than in any shortage of subjects. And those who also teach experimental science must master a vast array of subjects to do justice to the few they actually tackle. A subject such as that mentioned above [the absorption of methyl chloride in indiarubber] is unsuitable for academic instruction, because one cannot predict exactly what problems may arise, time-consuming intermezzos will intervene, and so forth. Academic experimental education focuses on projects with set time limits: one or two results per year. Once someone has completed his university education, however, time must not be a consideration; he must dedicate his life to science, or he will get nowhere.²⁴

In his letter to Bosscha, Onnes made a noteworthy proposal: he suggested setting up a national institute of calibration and measurement. What he had in mind was a decentralised form of the Institute of Metrology (Physikalisch-Technische Reichsanstalt) established in 1887 in Charlottenburg, near Berlin – maintained by a legion of HBS teachers. ‘Those wishing to play a useful role’, explained Onnes, ‘will find countless opportunities to do so – helping to verify the accuracy of apparatus, measuring instruments and so on – which will automatically raise issues of a more scientific nature. Indeed, ideally one might imagine a decentralised institute of metrology supported by grants approved by the Conference, providing successively to different groups the special equipment needed for a specific branch of scientific verification. It would be really Old Dutch – if only there were more Old Dutch people to be found.’

²³ *Handelingen van het Vierde Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem 1893) 97-98.

²⁴ Heike Kamerlingh Onnes to Bosscha, 12 April 1895, coll. Bosscha Erdbrink.

The report that Bosscha read out in Amsterdam incorporated these ideas – Haga seems to have made only a limited contribution. HBS teachers had only to perform a demonstration experiment to generate a rich fund of ideas for further research projects, and contrary to what Julius and Lorentz maintained, their own laboratories were perfectly adequate for such work. Even a limited array of equipment was not such a problem: ‘Our overseas neighbours may poke fun at “jampot and sealing-wax physics” if they want. Achievement depends on the individual. What counts for most are a scientific cast of mind, diligence and study.’²⁵ Only in relation to the latter were teachers, who relied on popular journals, at a disadvantage.

The proposal for a decentralised institute of metrology also found its way into the report: ‘University laboratories have a need for the verification of the accuracy of measuring instruments, the calibration of thermometer tubes, the calibration of manometers and resistance boxes, the preparation of pure substances, and so forth.’ Bosscha added that such work could reveal new properties in a measuring instrument of great importance to university researchers. After which he again drew on Onnes’s letters: Siertsema, who had been appointed supervisor in Leiden that year, had conducted a systematic study at the Physics Laboratory of the aneroid barometers that the geologist K. Martin had taken with him in 1893 on an expedition to Borneo (partly funded by a 1,000-guilder grant from the Dutch Physics and Medical Science Conference), which had revealed numerous facts regarding coefficients of temperature and elastic after-effect. The new volunteer corps, which provided ‘reliable support for the large laboratories, opportunities for experimentalists to practice, and a breeding ground for inventors’ should receive financial and other support from the Conference. For very little could be expected from the government, and the new institution was unlikely to receive the substantial bequests enjoyed by its German equivalent.²⁶

Julius was piqued about what he saw as the ‘misrepresentation’ of his position. Nonetheless he thought the report extremely important. Lorentz agreed. But the calibration and measurement institute was never heard of again. The hard work of launching it was probably not to Kamerlingh Onnes’s taste. But Onnes’s pupil L.M.J. Stoel, who had become a HBS teacher after attaining his doctorate, received a 250-guilder grant from the Conference in 1897 for some research on aneroid barometers. But the project evidently foundered: the money was repaid in 1908.²⁷

²⁵ J. Bosscha, ‘Rapport omtrent physische onderzoekingen, die met weinige hulpmiddelen zijn te volvoeren’, *Handelingen van het Vijfde Natuur- en Geneeskundig Congres* (Haarlem 1895) 111-125.

²⁶ Frans van Lunteren, ‘Van meten tot weten’, 102-103, 136-137.

²⁷ *Vereeniging ‘Het Nederlandsch Natuur- en Geneeskundig Congres’: Herdenking van het 25-jarig bestaan* (1912).

At the next Conference, held in Delft in April 1897, Onnes attracted attention once again. This time he proposed forming a physics subsection of the physics and chemistry section, to meet separately from the chemists on the second day of the Conference. It had already been decided six years earlier, at the Third Conference in Utrecht, to publish two-yearly surveys of Dutch physics research in the annual proceedings. This new proposal for increasing specialisation was debated at length and eventually adopted. Dutch physicists now had a society of their own for the first time, and Onnes was thus one of the forefathers of the Dutch Physics Society, founded in 1924.

Kamerlingh Onnes never gave regular addresses at these conferences, but in 1907 and 1919, when Leiden hosted the event again, he did provide demonstrations with explanations.²⁸ In his commemorative speech in 1912 to mark the Conference's twenty-fifth anniversary, the chairman, Zwaardemaker referred to this contribution in veiled terms. After discussing 'that whole current of thermodynamic thought, sprung from the minds of Gibbs and Van der Waals, that great force that flowed along its first firm bed between our dykes' he continued his account of the 'magnificent victory march' of the Netherlands' physicists and chemists by noting that the work of Kamerlingh Onnes and his team had been presented 'relatively late', although the demonstrations of 1907, when Onnes and co. had gone to town and attracted 150 interested spectators to Leiden's cold front, 'wholly made good this lost ground'. Five years later, Zwaardemaker sighed that the conference was 'rather lagging behind again' since Kamerlingh Onnes was working hard, but expressed his hope that it would catch up later on.²⁹ In April 1919, Onnes, who had been unable to work with liquid helium for the entire duration of the First World War, managed to assemble his apparatus and raw materials just in time. The demonstration of liquid helium, with Niels Bohr in the audience – he had come to Leiden to lecture to the Conference on his quantum theory as an explanation of the spectral lines of gases and had received from Onnes a pile of *Communications* in advance³⁰ – was a great success.

²⁸ *Handelingen van het Elfde Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem 1907) 164-175. See also *Communications, Supplement* 18a and 18b and the *Vlugblad* of the 11th Conference (Leiden).

H. Kamerlingh Onnes, 'Demonstratie van vloeibaar helium', *Handelingen van het XVIIde Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem 1920) 152-159. *Comm. supplement* 43c.

²⁹ H. Zwaardemaker, 'De Voetstappen onzer Wetenschap', 16-17.

³⁰ Heike Kamerlingh Onnes to Bohr, 28 February 1919, archives of Niels Bohr (Copenhagen); Bohr to Heike Kamerlingh Onnes, 9 March 1919, MB, archives of Heike Kamerlingh Onnes.

Board of Trustees of the KNMI

The Royal Dutch Meteorological Institute (KNMI) was the brainchild of the Utrecht professor C.H.D. Buys Ballot. Having started making meteorological observations in 1848 at the military stronghold of Sonnenborgh, later chosen as the location of the observatory, Buys Ballot managed to persuade Minister Van Rheenen in 1854 to establish a national institute as an umbrella organisation for the various observation stations around the country.³¹ It was the first Dutch government institution for physics research.³² In 1897 it moved into larger premises in the Koelenborg estate in De Bilt, which impelled C. Lely, Minister of Water Management, Trade and Industry, to urge the appointment of a board of trustees.³³ The idea was that such a board would be best placed, together with the director (after Buys Ballot's death in 1890 the position passed to M. Snellen) to protect the KNMI's interests and to ensure that it steadfastly fulfilled its scientific remit.³⁴ A provisional committee was formed in February 1899 and appointed that summer as the first board of trustees. J. Bosscha – the country's most powerful physicist – took the chair, with two Leiden professors among the other four members: Kamerlingh Onnes and the astronomer H.G. van Sande Bakhuyzen.

Onnes was elected, of course, because of the definition of his professorship in Leiden: his chair was in experimental physics and meteorology. The latter did not amount to much, if truth be told: while Rijke had at least included the subject in the curriculum each year – after which the lectures were unerringly cancelled for lack of students – his successor Kamerlingh Onnes found it more convenient to ignore meteorology altogether. Gerard Sizoo, one of Onnes's last students in the 1920s, remembered that Onnes never taught the subject. 'A cloud consists of drops; that is all you need to know', Kamerlingh Onnes is said to have assured him.³⁵

The KNMI's board of trustees met about ten times a year, generally in De Bilt, and occasionally at the institute's Amsterdam branch. The minutes record that Kamerlingh Onnes attended quite regularly and was an active participant, certainly when the new workshop for instrument-makers was on the agenda. Onnes soon made it clear that he wanted to apply the same strict criteria as in Leiden. In October 1899 he informed his fellow board members that he had

³¹ *Koninklijk Nederlands Meteorologisch Instituut 1854-1954* (The Hague 1954) 17-28.

³² Frans van Lunteren, 'De oprichting van het Koninklijk Nederlands Meteorologisch Instituut: Humboldtiaanse wetenschap, internationale samenwerking en praktisch nut', *Gevina* 21 (1998) 216-243.

³³ Letter from C. Lely, 24 May 1898, Utrechts Archief, archive 90, inv. no. 1196.

³⁴ *Staatsbegroting 1899, memorie van toelichting*.

³⁵ G. Sizoo, personal communication, 13 July 1990.

deduced that the workers who performed calculations at the KNMI earned 77 cents an hour, which he thought extremely generous. To offset this generosity, he proposed lengthening their working day –from six to nine hours a day.³⁶ He also opposed raising the salary of the KNMI's assistant instrument-maker before he had acquired his instrument-maker's apprenticeship certificate in Leiden,³⁷ and on 22 September 1902 he proposed stipulating that candidate observers must have completed at the very least a three-year HBS school.

At the meeting of 2 June 1902, Onnes had taken an equally inflexible stand vis-à-vis H. Ekama, director of the section 'Observations on land'. Ekama had asked the trustees to give up one or two evenings a week to teach the course for headmasters and headmistresses in Utrecht. 'Mr Onnes is opposed', the minutes record. 'As an official of the Institute, Mr E. is neglecting the duties entrusted to him and is therefore not entitled to lay claim to the board's support.' Ekama immediately tendered his resignation, and was replaced internally by C.M.A. Hartman, who had gained his doctorate under Onnes. Hartman himself was replaced on 1 January 1905 by E. van Everdingen, up to then Onnes's assistant, and from 1 February 1905 C.H. Wind's successor as managing director of the KNMI.

In October 1906 Onnes resigned from the board of trustees. He was not dissatisfied with what the board had achieved: 'reorganisations have raised academic standards over the past four years', he concluded at the meeting of 26 October 1903. Just apply Leiden norms, he must have thought, and everything will automatically work out for the better.

Leiden's torrent of texts and the Academy of Arts and Sciences

No one in the history of the Royal Netherlands Academy of Arts and Sciences submitted as many articles to it as Kamerlingh Onnes. In the period 1892-1926, the Academy published over three hundred 'communications' from Leiden's Physics Laboratory – all were also translated into English for the *Communications*. They were submitted by Onnes (or by a fellow Academy member on his behalf when he was ill) at the monthly meetings of the physics section. Half the time he himself was the author or co-author; the remaining texts were by staff and/or foreign guests. The Academy's secretary must have had mixed feelings about this torrent of texts from Leiden (1913 was the peak year, with an astonishing 24 articles). There was simply no end to it, and then there were the expensive fold-out sheets with illustrations that were often enclosed with the texts!

³⁶ Letter of 13 October 1899, Utrechts Archief, archive 90, inv. no. 90.

³⁷ Notulen vergadering curatoren 22 September 1902, Utrechts Archief, inv. no. 2.

The Royal Academy of Sciences (the epithet ‘Netherlands’ was added in 1938) was the successor organisation to the Royal Institute of Sciences, Literature and Fine Arts which King Louis Napoleon established by decree in 1808 – the political decentralisation existing under the Republic had made it impossible to found a national academy. In 1851 Minister Thorbecke had abolished the Royal Institute (of which he himself was a member) in response to a surge of criticism; it was replaced by the Royal Academy of Sciences, which was mandated to ‘promote the entire field of mathematics and physics’. Four years later a new ‘Literature’ section was added to this ‘Physics’ section.³⁸ The Academy advised the government both in response to requests and on its own initiative, and its remit included encouraging cooperation between academics in the Netherlands and its overseas possessions and forging international ties.³⁹

In 1883, the year of Onnes’s election to the Academy, the physics section had fifty members (today it has 110), including a handful of Dutch physicists, as well as foreign, corresponding (Dutch academics abroad) and retired members – the later being over seventy years of age. The meetings held at the Trippehuis, on the last Saturday of every month (except for July and August), were generally attended by 50% to 80% of the members. In January 1883, Onnes was nominated as a member of the Academy by the physicists Lorentz (Leiden) and Bosscha (Delft), the mathematicians Korteweg (Amsterdam) and Bierens de Haan (Leiden), and the astronomer Van de Sande Bakhuyzen (Leiden; then chairman of the physics section). Others competing for the three vacancies in the physics section were the Utrecht biologist Hubrecht, the Leiden cell biologist Hoek, and one Steuerwald. Haga’s name was also mentioned – he was teaching at the state HBS in Delft at the time – but Onnes’s candidacy was accorded more weight, and Mees’s future successor in Groningen was banished to the waiting room for a few years.⁴⁰

The procedure continued a month later with the reading out of the letters of recommendation. Onnes’s letter had been drafted by Lorentz, and its signatories included, besides those who had nominated him, the Utrecht academics Grinwis and Buys Ballot (who shared responsibility for teaching mathematics and physics), Mees, and the Delft mathematician Baehr (whose advice Onnes had requested when preparing his doctoral dissertation). Onnes certainly had no lack of support. The letters of recommendation submitted on behalf of Hubrecht and Hoek bore only three signatures each, and Steuerwald had to make do with one.

³⁸ This explains why the KNAW is known in English after this date as the Royal Society of *Arts and Sciences* – transl.

³⁹ K. van Berkel (ed.), *Het oude Instituut en de nieuwe Akademie* (Amsterdam 2000).

⁴⁰ N-HA, Akademiearchief, inv. no. 8.

In their letter of recommendation, Lorentz *cum suis* extolled Onnes's 'scientific research projects, which – though not numerous – excelled, in their opinion, in great thoroughness and originality'.⁴¹ The multi-facetedness of his talents too was praised, as being 'constantly manifest to all who know him'. Most of the letter focused on Onnes's doctoral dissertation: his article on the law of corresponding states had received 'favourable reports' and had subsequently been accepted for publication by a committee of the Academy in its 1881 *Verhandelingen*.

Four more weeks passed, and at the March meeting a vote was held on whether or not to admit the candidates to the actual vote in April. Two-thirds of those present had to be in favour; all four candidates passed this screening. Of only 21 members present, 19 approved the candidacies of Onnes and Hubrecht, 16 Hoek's and 14 Steuerwald's. To conclude this laborious procedure, of the 35 members present at the April meeting, in the first round of voting 13 voted for Onnes and Hubrecht, 5 for Hoek and 1 for Steuerwald. In the second and third rounds, Onnes received 16 and 20 votes, respectively, and was thus duly elected. The loser in this procedure was of course Steuerwald. Unfortunately, Onnes's health had collapsed at the beginning of March and he was staying with his mother in Hengelo waiting for approval to go abroad for a health cure, and he therefore missed the next few meetings. By September 1883 he had recovered sufficiently to travel to Amsterdam: the minutes record, 'Mr Kamerlingh Onnes is escorted into the meeting and is welcomed by the chairman.'⁴²

In the forty years of Onnes's regular membership of the Academy, he attended 47% of the meetings – a little below average attendance. Lorentz attended 74% in the same period. Onnes's attendance was highest (65%) at the April meetings, which voted on new members. Onnes was frequently absent because of ill health: his doctor advised him against going to Amsterdam if he had a cold, and in cold weather he did not accompany Van der Waals to his home at P.C. Hoofstraat – all in all his figures for non-attendance were therefore much higher in the winter. It should be added that the difference between Onnes and Lorentz stemmed mainly from two factors: from 1910 to 1921 the latter chaired the physics section (and missed only four of the 120 meetings) and in the last seven years of his membership, Onnes's health was so poor that he attended fewer than ten meetings.

Without unduly putting himself out – except for one occasion, to be discussed below – Onnes acquitted himself creditably of his obligations as an

⁴¹ *Ibid.*, inv. no. 560.

⁴² *Ibid.*, inv. no. 8.

Academy member. His far higher attendance in April reflects a certain commitment (Lorentz's attendance figures were no higher in that month). Onnes frequently sat on ad hoc committees formed to assess the articles that were submitted, on subjects ranging from the density of the interior of the earth to magnetic observations in the east of Brazil. He wrote a solid and affectionate obituary for Mees in 1886. And he sat on the committee that advised the government on lightning conductors for buildings such as the National Archives in Den Bosch, the Mauritshuis Picture Gallery in The Hague, and the Natural History building in Leiden.

Onnes was often quick to nominate new – foreign – members. In January 1884 he put Haga's name forward as well as that of his former teacher Kirchhoff, for whom he wrote an impassioned recommendation.⁴³ Of the two, only the latter, described as a man of 'brilliant discoveries' including the application of spectral analysis to the 'chemistry of the stars', which Onnes described as one of the two greatest discoveries of the century – secured the necessary votes. A few years later, Onnes and Lorentz managed to get Clausius too approved as a foreign member of the Academy. In 1892 the Leiden pair nominated Ludwig Boltzmann, another foreign scientist, but withdrew their proposal when Van der Waals suddenly – without prior consultation – proposed Gibbs (a brilliant if rather unapproachable scientist), who was a major influence on Van der Waals's work.⁴⁴

It was a great blow to Onnes that he was unable to secure the election of J.D. van der Waals Jr, who had succeeded his father in Amsterdam in 1908. He was nominated time and time again, from 1914 onwards, but to no avail. Haga (elected in 1896, ten years after he had succeeded Mees) considered that Van der Waals Jr. had 'not achieved anything'.⁴⁵

As noted above, Onnes used the Academy as a vehicle to publish his laboratory's research. So did Van der Waals and Lorentz (and later Zeeman, Wind, Haga, Van der Waals Jr., Ornstein, Julius and others) but Onnes was uniquely prolific. Coincidentally, the Academy issued new publication guidelines in 1891, just when the Physics Laboratory was operating at full capacity. The *Mededelingen* (Communications) would henceforth carry full-length articles instead of the non-technical summaries of research findings presented by members at meetings. Academy members could also contribute their own students' 'communications' or articles for this publication, while the *Verhandelingen* (Proceedings), which appeared at irregular intervals, was reserved for

⁴³ N-HA, Akademiearchief, inv. no. 560.

⁴⁴ F.H. van Lunteren, 'Wetenschap voor het vaderland. J.D. van der Waals en de Afdeling Natuurkunde', K. van Berkel (ed.), *De Akademie en de Tweede Gouden Eeuw* (Amsterdam 2004) 53.

⁴⁵ Heike Kamerlingh Onnes to Zeeman, 20 March 1923, N-HA, Zeeman archives.

longer papers, often by non-members. The annual volume of collected *Mededelingen* immediately grew to an immense volume. Two hundred pages long in 1892-1893, it passed the thousand mark eleven years later, and in the peak year of 1915-1916 it reached almost two thousand.

The English-language *Proceedings* were another innovation. Back in the early 1890s Onnes had urged the Academy to publish a French translation of the *Mededelingen*.⁴⁶ The proposal was dismissed as too costly, and three years later it was decided to publish an English version. This language would reach a readership at least as large as French, besides which the Netherlands already had its *Archives Néerlandaises*. For Onnes there was an advantage to choosing English, in that he could now suddenly recover half the translation costs for his *Leiden Communications* from the Academy.⁴⁷ In 1904, when the *Mededelingen / Proceedings* passed the thousand-page mark, some grumbled that it was growing beyond all reason and Van der Waals – the physics section’s rigorous secretary – urged that illustrations be kept to a minimum. Onnes, who included endless fold-out technical drawings and graphs with his countless articles, retorted that illustrations were absolutely essential for certain subjects. However, it was decided that communications from non-members would henceforth have to be submitted by two members instead of one, a measure that had little effect.⁴⁸

Of the Academy committees to which Onnes belonged, two are noteworthy: a study of noise levels in ‘cellular prisons’ and a report on the influence of an electric tramway on a nearby laboratory. The former started work in January 1896. The justice minister Van der Kaay wanted the Academy to recommend ways of reducing these noise levels and to estimate the costs involved, taking architectural criteria and proper hygiene into account. The object was to prevent prisoners from communicating with each other or shouting obscenities at visitors. Van der Waals chaired the committee, with Onnes as secretary, the other members being Lorentz, the Amsterdam biologist Forster and the Delft hydraulic engineer Van der Dieson – the architect of much-admired bridges over the rivers Lek and Waal. The committee was active for over two years and Onnes did a vast quantity of work for it. He had time on his hands, since the protracted dispute on the dangers of explosion, initiated by Leiden city council in 1895, had brought work at his cryogenic laboratory to a standstill (see chapter 17).

The subject of prison cells was a political hornets’ nest.⁴⁹ Solitary confinement, a lawful penalty since 1851, was a highly controversial and emotive issue.

⁴⁶ Meeting of January 1895, N-HA, Akademiearchief, inv. no. 19.

⁴⁷ Heike Kamerlingh Onnes to Van der Waals, 1 October 1898, N-HA, Van der Waals archives.

⁴⁸ Meeting of 27 February 1904, N-HA, Akademiearchief, inv. no. 11.

⁴⁹ H. Franke, *Misdaad en straf in Nederland* (Utrecht 1990).

Notwithstanding the risk of inflicting physical and mental anguish on detainees, solitary prison cells had been introduced nationwide in 1886. While the Society for the Moral Improvement of Prisoners was convinced of the salutary effects of solitary confinement, others branded it a cruel system that fostered insanity and increased the risk of suicide. Supporters and opponents of prison cells debated the issue fiercely, and it was against this political and social background that the Minister submitted his request.

The committee did not rush to judgment. A report stretching to over seventy pages finally saw the light of day eighteen months later, discussing every aspect of the problem and making detailed proposals for improvement.⁵⁰ Van der Waals and Onnes had started by visiting the Minister to obtain a clearer definition of the committee's brief, before undertaking action on various fronts. The committee then researched the approach taken in other countries and made a thorough study of the literature on sound insulation, heating and ventilation – Onnes sent his assistant Leuret to comb the library of the Polytechnic in Delft and make summaries. The committee members themselves visited eight prisons around the country, from the dome-roofed prison in Breda to the penitentiary on Weteringsschans in Amsterdam. The committee's final recommendations were tested experimentally in the Physics Laboratory in Leiden: Onnes's instrument-maker, Curvers, built the equipment and Leuret performed the experiments.⁵¹

Thus, on 2 May 1896, the *crème de la crème* of Dutch physics, accompanied by a renowned architect, descended on the prison at Scheveningen to study the acoustics. The architect/engineer of prisons and courthouses, one Metzelaar, had informed the committee that while standing out on the dunes one evening, he had been able to clearly follow a conversation between two prisoners. The distinguished visitors confirmed that the noise levels were unacceptably high. When Van der Diesen stood in a cell and shouted 'lion tiger blockhead cat dog owl!', Onnes standing in the adjoining cell with his ear against the heating pipe, could easily distinguish the words.⁵² What is more, the committee discovered that the prisoners in cells 79 and 83 – with three cells in between – could communicate excellently by tapping on the heating pipe. At Breda, which they had visited a few weeks earlier, the soundproofing had been much better: when Onnes shouted 'one two three cable beer!' in cell 4, Van der Diesen scarcely heard a sound in cell 5. On the other hand, prisoners in Breda could talk through the open windows. All these findings were clearly set out in the first part of the report, together with an overview of foreign approaches.

⁵⁰ KAW, *Verslagen*, June 1897.

⁵¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 277.

⁵² Notebook Van der Diesen, N-HA, Akademiearchief, inv. no. 200.

The recommendations in the second part of the committee's report included re-routing the heating pipes and switching to a system of artificial ventilation. Prisoners caught trying to communicate would have their windows shut and, in the interests of hygiene, mechanical ventilation (blowers) would be used instead. The report discussed the new system from every angle, clarified by nine drawings. The quantity of fresh air needed by a prisoner, background noises and friction: everything was calculated and where necessary studied experimentally. In conclusion, the committee calculated the energy required to power mechanical ventilation, demonstrating that a few horsepower would suffice for an entire prison. Seldom will any Minister have received such a comprehensive report – and without an executive summary. The committee members explained – as befits all good scientists – that their work was not done, and professed their willingness to supply further information; if necessary they would be happy to demonstrate the experiments they had performed in Onnes's Physics Laboratory. The Minister had hoped to receive the report rather earlier, to help him decide on the new prison to be built in Haarlem; he sought an interim recommendation and accordingly opted for a design based on the dome-roofed prison in Breda.

It briefly looked as though the committee could bask in glory after having devoted such a disproportionate amount of effort to its task. In July 1897, the Minister announced a trial of the proposed system in a wing of Leeuwarden's special prison. But then everything went wrong. That month the government fell, and the new justice minister, the progressive jurist Cort van der Linden, was far less convinced of the benefits of solitary confinement than his predecessor. During the parliamentary debate on the 1898 national budget, members asked the Minister for his personal view of the Academy's report. In his Memorandum of Reply, Cort van der Linden wrote that he thought it possible that the proposed remedy of sealing the cells off from the outside world with only artificial ventilation, producing a constant buzzing noise in the cells, would disturb the mental state of many if not all prisoners. It was also a very expensive solution.

The committee was furious. In the Academy's meeting of November 1897 its members vented their emotions in a letter to the Minister.⁵³ Not only were Van der Linden's comments inaccurate, but he had also misunderstood the whole tenor of the report. The idea was not to drown out noise in the cells with a buzzing noise; there would be only a 'low hum'. Nowhere did the report suggest 'sealing cells off from the outside world'; the mere threat of closing cell windows in the event of misbehaviour would suffice to enforce discipline.

⁵³ KAW, *Verslagen*, November 1897.

Besides, keeping cell windows closed as a punitive measure would not harm prisoners' health, provided it did not last too long. The supposed expense of the plans was also a fiction. Some parts of the report, the committee observed tartly, had evidently escaped the Minister's attention. It must have dawned on the scientists around this time that such an exhaustive Academy report was rather wasted on politicians.

The committee sent its reply to the Minister on the Academy's behalf. Now it was the turn of Cort van der Linden to erupt in rage. In March 1898 he sent the Academy two letters. The first began: 'I might have hoped that the Royal Academy, acting as an advisory body to the government, not least where it felt called upon to deliver an unsolicited recommendation, would be able to express its views without descending into insult.'⁵⁴ The rest of the letter, with its scattering of sophistries, left Onnes cold. 'Enclose Minister's reply', he wrote to Van der Waals. 'Very angry. He has found a few weak spots, but only by making a very great effort.' In any case, wrote Onnes, the allegation that the committee had 'wrongly protested against a caricature of its report' had not been disproven.⁵⁵ In his second letter, Cort van der Linden cancelled the experiment with artificial ventilation in Leeuwarden prison announced by his predecessor. A different solution would have to be found. At the Academy's April meeting, a rejoinder was composed, expressing regret that the Minister had rejected the invitation to observe the experiments for himself. But enough was enough, and the meeting decided – to general applause – to take no further action; the committee was disbanded.

The second Academy committee on which Onnes placed his stamp was in 1907, when the Minister wanted to know whether a new electric tramway passing close to the Physics Laboratory on Westersingel in Groningen would prejudice the research performed there.⁵⁶ Special measures had been taken in building the laboratory, which Haga had moved into in 1892, to equip it for experiments involving magnetism: the building contained no iron (its pipes, heating elements, nails etc. had all been made of non-magnetic metals such as copper and lead), and columns had been added to banish vibrations.

The advent of a power station in Groningen, said Onnes (chairman), Julius and Zeeman in their report, was not in itself a problem. True, the use of the earth as the neutral conductor could cause eddy currents, which might impede local geomagnetic measurements. For the rest, however, Groningen's protection from magnetic disturbances was exemplary, and Haga's laboratory had an excellent international reputation. But the building of a tramway in front of

⁵⁴ N-HA, Akademiearchief, inv. no. 200.

⁵⁵ Heike Kamerlingh Onnes to Van der Waals, 12 March 1898, N-HA, Akademiearchief, inv. no. 200.

⁵⁶ KAW, *Verslagen*, 30 November 1907.

the laboratory, with the rails as neutral conductor, would be nothing short of a disaster. 'It would be really dreadful', Onnes wrote to Zeeman.⁵⁷ 'In a word', concluded the Onnes Committee, 'It would render the laboratory completely useless for the purposes of magnetometric observations and greatly reduce its capacity for galvanometric measurements.' One possible remedy was to power the tram with batteries in the vicinity of the laboratory, between Friese Straatweg and A-kerkhof, or alternatively to use two overhead cables and hence avoid any disruptive current passing through the rails. Omitting to take such precautions would be 'irresponsible'. The advisory report went unheeded: the tramway was built in 1910 and passed Haga's laboratory without any precautionary measures.

The research Onnes had done in 1907 served him well five years later, when the prospect arose of a tramway in Leiden. The plans initially envisaged a route through Van der Werff Park, opposite the Physics Laboratory, and as soon as Onnes heard about it he started gathering defensive ammunition. On the faculty's behalf he asked Zeeman in Amsterdam, Julius in Utrecht and Haga in Groningen to describe their own experiences in this area. Zeeman reported that the disturbing vibrations caused by the passing of each tram were the worst problem.⁵⁸ Julius too had experienced problems,⁵⁹ and Haga wrote that he now had to use his magnetometers at night, in spite of his building's heavy columns, because of the vibrations caused by the trams. The overhead cables for the discharge current advocated by the Onnes committee had still not been installed, he added: negotiations were still in progress.⁶⁰ Poor Haga must have been driven to distraction – Willem Frederik Hermans used this dismal train of events for his short story 'Twee gebouwen, twee geleerden' (Two buildings, two scholars), published in 1992 in the collection *De laatste roker*.

Leiden was spared the tram for the time being. The physiologist Einthoven, who had a laboratory behind Onnes's and worked with sensitive wire galvanometers, and the director of the National Museum of Natural History, adjacent to Van der Werff Park, had also objected. De Gijsselaar, chair of the board of governors, now worried that the Leiden-Hague route would be shifted to the land designated for the new teaching hospital.⁶¹ But this did not happen. In 1916 Leiden city council renewed their plans for a tramway through Van der Werff Park, unleashing a fresh wave of indignation on the part of the three

⁵⁷ Heike Kamerlingh Onnes to Zeeman, 23 November 1907, N-HA, Zeeman archives.

⁵⁸ UB Leiden, Archief Curatoren, inv. no. 1798.

⁵⁹ *Ibid.*

⁶⁰ *Ibid.*

⁶¹ *Ibid.*

professors. This time, the Natural History museum wanted the route to be as close to the water as possible,⁶² which must have displeased Onnes. The latter wrote to the chief inspector of state university buildings, protesting in the strongest possible terms about the imminent tramway, which would instantly destroy his laboratory's ability to make electrical measurements.⁶³ 'If there has to be a tram, then at least build it at a good distance away, and use a double trolley system'. Onnes then proposed a different route, further away from the laboratory. He got his way.

A barometer in the Westerkerk

In 1898, to mark the twenty-fifth anniversary of the publication of Van der Waals's doctoral dissertation, the Van der Waals Fund was established.⁶⁴ Some institutes immediately donated lump sums, and academics, former students and admirers contributed five guilders a year. The Fund was set up to support experimental research related to Van der Waals's theories, initially performed under the watchful eye of the master himself – who asked Onnes to join the executive committee in 1906. Annual meetings were held in the Trippenhuys (chaired by Julius, from Utrecht) after Academy meetings. They were generally in December, and Onnes was frequently absent because of the cold.

The Van der Waals Fund did not create much work for Onnes, and it had the advantage of giving him a small say in the goings-on in Amsterdam. The Fund was dormant for the first few years, but it livened up after Van der Waals's retirement in 1908. Philip Kohnstamm, Van der Waals's assistant, was appointed professor. He had set up a new line of research in 1904 with money from the Van der Waals Fund: thermodynamic experiments at high pressure. Among the apparatus purchased was a press that could achieve pressures of up to 6500 atmospheres. The first publications appeared in 1910 in the Academy's *Verslagen*. One important decision was the appointment of a Leiden-trained instrument-maker in 1911. That same year, Onnes offered to provide a loan to the Fund (with interest) to help purchase instruments, but that proved unnecessary.⁶⁵ After the pioneering work of the French scientist Emile Amagat, the Netherlands too embarked on high-pressure research.

After 1915 the Fund slumped into inactivity again – seven years without a publication – caused by a variety of factors: mobilisation during the First

⁶² *Ibid.*

⁶³ *Ibid.*

⁶⁴ J.M.H. Levelt Sengers and J.V. Sengers, 'Van der Waals Fund, Van der Waals Laboratory and Dutch High-Pressure Science', *Physica A* 156 (1989) 1-14.

⁶⁵ N-HA, Van der Waals archives, inv. no. 89.

World War, Amsterdam's switch from thermodynamics to Zeeman's spectral research, and the shift in Kohnstamm's interest towards philosophy and educational theory. Furthermore, both Amsterdam's pressure balances proved to be less accurate than previously thought. In 1915 Dr E.J. Smid, an assistant working on the Fund's behalf, compared the balances (which Kohnstamm had ordered from the manometer factory Schäffer and Budenberg in Maagdenburg) with a closed hydrogen manometer in Leiden (which could attain 100 atmospheres and had been calibrated using the Leiden open standard mercury manometer dating from 1898). She discovered deviations of 1 in 400, even at relatively low pressures.

This was a blow, especially since a pressure balance of the same type, purchased by the Physikalisch-Technische Reichsanstalt (PTR) in Charlottenburg, achieved far better results. Crommelin discovered in 1921, when he was supervisor at the Leiden laboratory, that the Maagdenburg company had built some highly accurate pressure balances for the PTR, subsequently producing a cheaper, much simplified model for the market. He concluded that Kohnstamm must have purchased one of these simpler models.⁶⁶ The Amsterdam professor, who had not published anything in physics for years, reacted as though stung by a wasp. He denied categorically having purchased second-rate equipment. He had bought a different type, a 'differential piston gauge', and its accuracy was quite reasonable.⁶⁷ Kohnstamm demanded a rectification, and Crommelin immediately obliged.⁶⁸

At the board meeting of December 1915, after Smid had performed her calibration work in Leiden, Onnes said he was considering building a long open mercury manometer with steel tubes, similar to the one constructed in the Eiffel Tower by the French high-pressure physicist Amagat. The instrument's capabilities would eclipse the 120 atmospheres in Leiden. A year later an ambitious new assistant was appointed in Amsterdam – Teun Michels. He breathed new life into the Van der Waals Fund in the 1920s and eventually brought Onnes's plan to fruition.

Onnes himself promoted the project in an interview published in the *Algemeen Handelsblad* of 18 April 1925. 'It is the duty of a small nation to prove its *raison d'être* by supporting and promoting academic endeavour', he told the reporter. The pressure gauge was to be constructed in the tower of the Westerkerk, and since the state was tight-fisted, as usual, private funds would be needed to implement the wonderful plan, which would give the Netherlands

⁶⁶ C.C. Crommelin, 'Thermometrie en Monometrie', *Het Natuurkundig Laboratorium der Rijksuniversiteit te Leiden in de jaren 1904-1922* (Leiden 1922) 228-229.

⁶⁷ Kohnstamm to Crommelin, 7 December 1922, UB Leiden, Stationsweg archives.

⁶⁸ Crommelin to Kohnstamm, 11 and 16 December 1922, UB Leiden, Stationsweg archives.

a further scientific boost in the rivalry of nations. There was praise for Michels, who worked with Onnes one day a week. It was his task to exploit the instrument's scientific potential. 'Would it not be an honour for our small country to possess such a treasure', said Onnes, 'and should we not do our utmost to promote the construction of this mercury column?' 'But what is needed', continued the journalist, 'is money – a great deal of it!' And the article continued with an urgent appeal to the generosity of the Dutch people.

The Dutch people responded; over 30,000 guilders poured in. Companies such as Stork of Hengelo and Werkspoor in Amsterdam also played their part.⁶⁹ It briefly seemed as though the gauge would be built in the new Dam Hotel, but the tower of the Westerkerk was chosen after all. With a height of 27.5 metres, the mercury column was suitable for pressures of up to 3,000 atmospheres, and continued to function into the 1950s. Kamerlingh Onnes never saw it.

⁶⁹ A.J.P. Maas, *Atomisme en individualisme*, 186-187.

23. Cold war (11)

When Gerrit Flim resumed his ethylene stocktaking activities on 4 June 1898, after a coldless spell of three years,¹ the race to liquefy hydrogen had just produced a winner: James Dewar. The British scientist had read out his 'Preliminary Note on the Liquefaction of Hydrogen and Helium' at the regular meeting of the Royal Society in London.² Two days earlier, he said, he had collected 20 cc of liquid hydrogen in a double-walled insulated glass flask in the basement laboratory of the Royal Institution. The liquid was clear and colourless and had a relatively high refractive index. Dewar had hoped to collect more, but after five minutes his installation had become clogged with freezing air in the pipes. He had succeeded, however, in immersing two thin tubes into the liquid hydrogen. One was open at the top, and the air at the level of the liquid hydrogen froze immediately. The second tube was connected to a spherical vessel containing helium gas, and its immersion triggered a process of condensation. 'All known gases have now been condensed into liquids', Dewar proudly concluded.

Dewar's semi-triumph (it was not the helium that had been condensed but an impurity it contained) was short-lived. The next speaker was William Ramsay, professor of chemistry at University College, London, and the first scientist to have demonstrated the presence of helium gas on earth, in 1895. He observed that it was not Dewar but Karol Olszewski (with whom Ramsay had collaborated) who had first liquefied hydrogen. At the Royal Society's meeting of December 1895, when Dewar, reviewing his work at low temperatures, announced that he expected to liquefy hydrogen very soon, Ramsay had made the same claim. In vain had Dewar waited for two and a half years for some word of confirmation from Cracow, and now that damnable Ramsay had come to plague him again.

¹ Notebook 1, MB, archive 444.

² James Dewar, 'Preliminary Note on the Liquefaction of Hydrogen and Helium', *Proceedings of the Royal Society of London* 63 (12 May 1898) 256-258.



Ill. 36. James Dewar, inventor of the double-walled glass container with a vacuum between the walls (the thermos flask) in the Royal Institution, London, around 1900.

Irritated, Dewar challenged Ramsay to make good his claim. He could not. In fact at the following Royal Society meeting, Ramsay had to admit that he had just received a letter from Olszewski denying that he had ever managed to produce static (gently boiling) liquid hydrogen. But this assertion was not intended for the *Transactions*. Dewar responded, partly because the affair had attracted considerable publicity, with a detailed demonstration of liquid hydrogen at the Royal Institution's Friday evening lecture.³

What drove Ramsay to antagonise a fellow scientist in this way? His challenge to Dewar, a fellow Scot, for the Royal Institution professorship in 1877, had infuriated the ten years older Dewar, which reaction may in turn have vexed Ramsay.⁴ Then there had been some bother about the discovery of argon. In 1894, John William Strutt (Lord Rayleigh), who presided over the Royal Institution's top-floor laboratory, had drawn attention to a minor discrepancy in density between atmospheric and chemical nitrogen gas – something that Cavendish too had observed in 1785. Rayleigh contacted Ramsay, an expert in analysing gases, and on 13 August they presented their discovery of argon at a meeting of the British Association for the Advancement of Science. Dewar then sent letters to the *Times* disputing the discovery – saying it conflicted with his own observations – and suggested that the gas might be an allotrope of nitrogen. Ramsay shrugged off the attack, but he must have lost any residual affection for Dewar by this point. To determine the critical temperature and pressure of the new inert gas he turned to Olszewski; the two men had both studied chemical analysis under Bunsen in Heidelberg. After the liquid hydrogen incident, Ramsay could scarcely ask Dewar for a favour – a pity, since liquid hydrogen would have been very useful for separating helium and argon. Fortunately he had a capable assistant at his private laboratory at University College, Morris Travers, who built his own hydrogen liquefier within two years and published the construction details.⁵ In his article for *Philosophical Magazine*, Travers stressed that the main section of his device had cost less than a hundred pounds – he had probably recycled parts from other setups – and that the compressor, engine, gas holder and Hampson air liquefier had cost a total of £200.⁶ That was an oblique dig at Dewar, who was always complaining about towering costs. In building his hydrogen liquefier, which produced half a litre at a time, Travers had been helped by the lawyer and inventor William Hampson, who in 1895 – at the same time as, but independently of, Carl Linde in Berlin

³ James Dewar, 'Liquid Hydrogen', *Proceedings of the Royal Institution* 16 (1899) 1-14.

⁴ For information on Ramsay, see Morris W. Travers, *A life of Sir William Ramsay, K.C.B., F.R.S.* (London 1956).

⁵ Morris W. Travers, 'The liquefaction of hydrogen', *Philosophical Magazine* 1 (1901) 411-423.

⁶ *Nature* 63 (29 November 1900) 122-123.

– had applied for a patent on a refrigerator based on the Joule-Thomson effect (discussed below). Dewar was also on bad terms with Hampson, to say nothing of his furious row with Karol Olszewski; he was a man with few friends.

James Dewar grew up in Kincardine-on Forth, Scotland, where his father had a pub and a wine business.⁷ In the winter of 1852, at ten years of age, he fell through the ice on a pond and became seriously ill with rheumatic fever. During his long convalescence, the local furniture-maker taught him to build violins, to develop the muscles in his fingers and arms – an activity to which Dewar later ascribed his dexterity in the laboratory. He studied at Edinburgh University and in 1875 secured a chair in experimental physics at Cambridge. In that bastion of academic tradition, the stocky, irascible and highly opinionated Scot soon acquired a name for poor lectures and coarse language. His talents were not fully appreciated.

But Dewar was a real showman, and he was in his element giving the Friday evening lectures in the theatre of the Royal Institution, London. His first appearance, in March 1876, was so successful that a year later the Institution too gave him a professorship (in chemistry), and he and his wife moved into a flat in the building. In 1887 he succeeded John Tyndall as director. By then, Dewar had earned his spurs in the science of cold. As soon as he heard about Cailletet's liquid oxygen, he ordered the device the Frenchman had used from Paris, and in the summer of 1878, Dewar was able to present drops of liquid oxygen to his audience.⁸ His demonstration of liquid hydrogen in 1899, in the presence of colleagues and the cream of London society, to mark the Royal Institution's hundredth anniversary, was immortalised in a painting by Henry Jamyn Brooks.

Dewar's best-known technical contribution to cryogenic research is the 'Dewar flask' he invented in 1892,⁹ a double-walled glass container with a vacuum between the walls, silver-coated to minimise thermal conduction and radiation. He refused on principle to apply for a patent, and the containers were later mass-produced as thermos flasks. In December 1892, Dewar demonstrated his invention at a Friday lecture. With great theatricality, he smashed the tip of one of his glass vessels. The intervening space immediately filled with air, destroying the thermal insulation: the gently boiling liquid oxygen started bubbling furiously. In 1905, Dewar discovered that charcoal was very efficient at absorbing gases at low temperatures,¹⁰ which resulted in a better vacuum and simplified the process of obtaining pure hydrogen and helium.

⁷ Henry E. Armstrong, *James Dewar 1842-1923* (London 1924).

⁸ James Dewar, 'The liquefaction of gases', *Proceedings of the Royal Institution* 8 (1878) 657-663.

⁹ James Dewar, 'Liquid atmospheric air', *Proceedings of the Royal Institution* 14 (1893) 1-12.

¹⁰ James Dewar, 'Studies on charcoal and liquid air', *Proceedings of the Royal Institution* 18 (1906) 433-447.

In 1884, Dewar had built his own apparatus to obtain static liquid oxygen. That was a year after Wroblewski and Olszewski, who both independently (they had ended their collaboration) achieved the dynamic liquefaction of hydrogen in Cracow in 1884. Dewar praised the Poles' 'brilliant accomplishment' and said that Olszewski's successful experiments meant it would soon be possible to determine the critical temperature and pressure of hydrogen.¹¹ That was the last time Dewar said anything pleasant to or about Olszewski.

In 1886, Dewar was ready to produce solid oxygen. The apparatus he had developed represented an advance on Olszewski's. Unfortunately, Dewar published the principle (without the technical details, which he never revealed) in the *Proceedings of the Royal Institution* as an appendix to an article entitled 'Recent Research on Meteorites' (an edited version of one of his Friday evening lectures).¹² Thus, Olszewski, who failed to notice this article, later assumed, wrongly, that Dewar had simply copied his metal cryostat without citing the source – even though Olszewski had sent the relevant French publication of 1890 to London. At the beginning of 1895, through the mediating offices of Ramsay, Olszewski sent a memorandum ('Claim for Priority') to the journal *Nature*,¹³ and a long article to *Philosophical Magazine* entitled 'On the Liquefaction of Gases'.¹⁴ In the latter, the Pole gave an overview of his cryogenic work, after first accusing Dewar of having on several occasions merely repeated experiments performed in Cracow.

Dewar hit back ferociously in the next issue of *Philosophical Magazine*.¹⁵ Why had Olszewski waited four years to make his accusation? And had Dewar not already used metal before, back in 1886? The Scot called Olszewski's claims 'bizarre' and 'unfounded' and to taunt his opponent he said he was greatly looking forward to reading English translations of Wroblewski's articles. Without them, he said, the merits of Olszewski's claim to priority were shrouded in mystery. A year later Dewar turned his guns on Ramsay, though without mentioning him by name.¹⁶ How in heaven's name was it possible, Dewar wondered, that certain fellow-countrymen effusively praised meagre contributions to science and rushed to judgment about matters of priority, instead of studying thoroughly the articles by the worthy Wroblewski.

¹¹ James Dewar, 'On the liquefaction of oxygen and the critical volumes of fluids', *Philosophical Magazine* 18 (1884) 210-216.

¹² James Dewar, 'Recent research on meteorites', *Proceedings of the Royal Institution* 11 (1886) 541-550.

¹³ Charles Olszewski, 'On the liquefaction of gases – A Claim for Priority', *Nature* 51 (10 January 1895) 245.

¹⁴ Charles Olszewski, 'On the liquefaction of gases', *Philosophical Magazine* 39 (January 1895) 188-212.

¹⁵ James Dewar, 'On the liquefaction of gases', *Philosophical Magazine* 39 (February 1895) 298-305.

¹⁶ James Dewar, 'New researches on liquid air', *Proceedings of the Royal Institution* 15 (1896) 133-146.

In the article in question, 'New Researches on Liquid Air', Dewar published a schematic illustration of the installation he used to produce liquid oxygen (or air). The Scot worked with a cascade of ethylene and carbonic acid, induced oxygen to expand under high pressure through a Joule-Thomson valve and applied the principle of regeneration: returning cold oxygen pre-cooled the oxygen gas entering the system. Dewar noted that Kamerlingh Onnes had also applied this principle, independently of others, for machines made in his cryogenic laboratory. Dewar did not provide detailed drawings of his apparatus, supposedly because it was constantly being modified, and the underlying principle was not a secret. Olszewski was a little more forthcoming in his own articles, but only Onnes revealed the properties of his equipment down to the smallest technical details.

The cascade method was inadequate for purposes of obtaining static liquid hydrogen – 'static' meaning gently boiling in a Dewar flask. With pumped-out liquid oxygen, 54 K (-219°C) could be attained – any lower and the oxygen would freeze. Since the critical temperature of hydrogen was 33 K, a gap of over 30° had to be bridged before any liquid hydrogen could start to form. This gap was bridged by the Joule-Thomson effect. In 1852, James Joule and William Thomson (Lord Kelvin) had experimented with air passing through a tube and encountering a porous plug, behind which it expands. As it passes the plug, the air does not perform any external work, but as molecules attract each other and the distance between them increases with expansion, there is a small temperature effect, even in the absence of any exchange of heat with the surroundings (adiabatic process). A thermodynamic calculation shows that this effect, depending on the values of a and b in the Van der Waals equation of state (constants that determine the mutual forces between the molecules and their volume), can work both ways: below the so-called inversion temperature there is cooling instead of heating. In the case of hydrogen, this temperature is about -193°C.

In 1895, Linde and Hampson independently designed refrigerators for liquid air based on the Joule-Thomson effect. The one devised by Linde, a successful Berlin refrigerator manufacturer, was the first to be made operational. Dewar became embroiled in a dispute with Hampson in May 1898. Shortly after Dewar's communication about liquid hydrogen to the Royal Society, Hampson wrote a letter to *Nature*, claiming that he had visited the Royal Institution in November 1894 and had explained the workings of his (as yet unpatented) Joule-Thomson machine to Robert Lennox, Dewar's assistant. Dewar had allegedly incorporated the information into his own design for a hydrogen liquefier without giving Hampson any credit. The next issue of *Nature* carried a furious retort from Dewar claiming that Hampson was a nonentity, and the combatants exchanged abuse three more times that summer. So it is hardly

surprising that Hampson helped Travers to build a hydrogen liquefier for Ramsay later that year.

Respectful correspondence

In July 1895, when Dewar was at loggerheads with Ramsay and Olszewski, he received a letter from Kamerlingh Onnes. It was the beginning of a correspondence marked by mutual respect that would stretch to fifty letters and last until December 1922, just a few months before Dewar's death.¹⁷ Onnes had been making summaries of some of Dewar's main articles since 1884, and kept them in a file together with pieces published in the British journal *The Electrician*.¹⁸

Onnes initiated this correspondence at a critical time in his career: Leiden city council had just ordered him to halt all work on compressed gases while his licence application was under consideration, because of the alleged risk of explosion. At the time, Onnes had no idea that his cryogenic laboratory would lie idle for three years, and cheerfully told Dewar, for whom he professed great admiration, about his recent experiences with liquid oxygen.

I have many times shown the exquisite blue liquid, that we got after so much labour, to scientific friends, coming even from Russia. When I poured it into one of your vacuum vessels, where the ebullition stopped and the mercury mirror appeared, this sight never failed to charm whoever loved science. I brought liquid oxygen in one of your vacuum glasses to my aged predecessor Rijke, living at some distance from the laboratory, who was delighted to see some experiments with it performed in his reading room, and I then returned in my laboratory and there was enough oxygen left to pour it back into my permanent bath.

I am sure that your vacuum glass is the greatest advance in low temperature work since 1883.¹⁹

Dewar underlined this last sentence. He got his librarian to ask Onnes for six copies of *Communication* 14, which included a survey of the cryogenic work done in Leiden up to and including liquid oxygen. Happy to oblige, Onnes despatched a complete series of his journal to the Royal Institution. He described his working methods, complained about the lack of support for his

¹⁷ Kostas Gavroglu, 'The myths of low temperature physics', *European Journal of Physics* 21 (1993) 171-190.

I am very grateful to Kostas Gavroglu for allowing me to study his transcript of the Dewar-Kamerlingh Onnes correspondence.

¹⁸ MB, archives of Heike Kamerlingh Onnes, inv. no. 191.

¹⁹ Heike Kamerlingh Onnes to Dewar, 18 July 1895, archives of the Royal Institution.

work in Leiden, and expressed the hope that his position as a researcher would improve if foreign celebrities took an interest. And then he got to the point: whether he could meet Dewar and see him working on his cryogenic installations next time he came to London.

Dewar wrote back immediately. Still smarting from Olszewski's frontal attack in January, he accused Onnes too of having credulously swallowed the Polish claims. In a footnote to *Communication* 14 (presented to the Academy's meeting of December 1894 and subsequently translated), Onnes had had the effrontery to say that Dewar's 1886 installation produced liquid oxygen 'on a small scale' without transferring it to a separate vessel. 'Small indeed!' Dewar's installation produced 22 cc liquid oxygen each time, no less than Olszewski's. After a 'terrible explosion' in 1886, when ethylene and oxygen had come into contact and ignited as a result of human error, his work had been suspended for three years, after which a larger liquefier was made operational in 1891. 'The fact is', Dewar concluded bluntly, 'that I never learnt anything in the way of manipulation of liquid gases from Prof. Olszewski.'

In the hostile climate created by the Pole, there could be no visits to the Royal Institution laboratory for the time being, wrote Dewar. Even Raoul Pictet, who had founded a company laboratory for refrigeration technology in Berlin in 1886, was unwelcome: the details of his apparatus had not yet been published, and more accusations were the last thing Dewar needed. 'Of all earthly aberrations, base actions in science are the most contemptible, and the recent criticism of my work has done little to enhance the dignity of science.'²⁰ It would have been easy for Onnes too to quarrel with the Scot. But to what purpose? He did later reproach Dewar for failing to mention, in his 'brilliant address' to the British Association for the Advancement of Science in 1902, that Onnes had been the first – well before Linde – to make systematic use of the regeneration principle in the liquefaction of gases²¹ (he had reproached Karl Olszewski on the same point a few months earlier;²² priority was a sensitive issue). Dewar hastened to apologise, and wrote that he had in fact mentioned Onnes's priority in an article published in 1896.²³ Hostile climate or not, August Crommelin – a student of Onnes's at the time – *was* welcome at the Royal Institution in early 1904; Dewar himself showed him round.²⁴

²⁰ Dewar to Heike Kamerlingh Onnes, 20 July 1895, MB, archives of Heike Kamerlingh Onnes.

²¹ Heike Kamerlingh Onnes to Dewar, 29 December 1903, archives of the Royal Institution.

²² Olszewski to Heike Kamerlingh Onnes, 24 March 1902, MB, archives of Heike Kamerlingh Onnes.

²³ Dewar to Heike Kamerlingh Onnes, 5 January 1904, MB, archives of Heike Kamerlingh Onnes.

²⁴ Heike Kamerlingh Onnes to Dewar, 29 December 1903, archives of the Royal Institution; Dewar to Heike Kamerlingh Onnes, 5 January 1904, MB, archives of Heike Kamerlingh Onnes.

In March 1896, Onnes wrote again.²⁵ This time he enclosed *Communication* 23, the translation of the communication that Onnes had submitted to the Academy a week earlier: ‘Observations on the liquefaction of hydrogen, on thermodynamic similarity, and the use of vacuum glasses’. Enclosed with it was a photograph of the boiling flask and boiling chamber of the oxygen cycle, described in *Communication* 14. Onnes’s latest article discussed ways of liquefying hydrogen – only in theory, since testing his ideas experimentally was impossible during the authorities’ ban. So Onnes’s second letter was largely a plea to Dewar to support his struggle to keep the cryogenic laboratory – support that was forthcoming by return of post (see chapter 17). His praise for Dewar’s ‘splendid research’ as presented in the *Proceedings of the Chemical Society* in December 1895 (and his tactful omission of the information that he had also asked Olszewski for support) must have placated the Scot. The ‘splendid research’ included the dynamic liquefaction of hydrogen: under a pressure of 200 atmospheres, cooled by liquid air at atmospheric pressure, the hydrogen flowed through a regenerator coil terminating in an expansion valve. Using the flow of partly liquid hydrogen thus produced, Dewar was able to solidify oxygen. But collecting the turbulently evaporating hydrogen in a vacuum glass vessel was still a bridge too far.

The race for liquid hydrogen was still undecided in 1895. As early as 1884, the Poles Wroblewski and Olszewski had liquefied this gas very briefly, but neither they nor Dewar had yet got it to boil gently. Olszewski did determine the approximate critical pressure and critical temperature of hydrogen in 1891 and 1895, figures that were crucial to defining the conditions that would be required.

In *Communication* 23, Onnes wrote that he had spent years brooding over a method for liquefying hydrogen. A patent recently obtained by Solvay, evidently based on principles similar to those he had in mind, had prompted him to publicise his ideas. The key to Onnes’s approach was the law of corresponding states. If a device could liquefy oxygen from room temperature in a single stage, he concluded, it must be possible with hydrogen too, provided that the initial temperature was that of liquid oxygen. Onnes had initially considered using a small, self-cooling expansion engine,²⁶ an original idea that testified to thermodynamic insight, but insurmountable mechanical problems prevented the manufacture of such an engine. None of the manufacturers he consulted could

²⁵ Heike Kamerlingh Onnes to Dewar, 6 March 1896, archives of the Royal Institution.

²⁶ H. Kamerlingh Onnes, H., ‘Opmerkingen over het vloeibaar maken van waterstof, over thermodynamische gelijkvormigheid en over het gebruik van vacuumglazen’, *Verslagen* 4 (January 1896) 240–241. *Comm.* 23.

solve the problem – later on, Georges Claude finally succeeded in applying the principle in his air liquefiers (as did Kapitza and Collins in their helium liquefiers many years later). As soon as Onnes heard about Linde's (and Hampson's) Joule-Thomson method, in 1895, he too tried this approach, although it was theoretically a retrograde step compared to the engine idea. The design of the Leiden hydrogen liquefier – which was not completed until 1906 – relied heavily on the analysis made in 1896. Van der Waals, once again, provided the guiding principles.

The best liquid hydrogen installation in the world

Although his cryogenic laboratory lay idle from 1895 to 1898, Onnes was always confident of victory, and his staff were hard at work behind the scenes preparing for the assault on liquid hydrogen. In 1898 yet another annex was built on Langebrug: it was to house a more powerful gas engine (40 hp), a room for 'chemical operations', and another lab (Aa) for the hydrogen liquefier. Pending the arrival of the necessary pumps and cryostats, it was used as a drawing office and as a room in which to make plaster models of Ψ^2 -surfaces.

That the hydrogen liquefier was not fully operational until 1906 was largely because Onnes was adamant about the stringent standards it had to meet. There was no point, since Dewar's achievement in May 1898, in quickly putting together a piece of equipment that could produce a little liquid hydrogen, which would at best be useful for some small orienting experiments; Leiden had lost that race. What Onnes wanted was a liquefier that produced several litres of liquid hydrogen per hour in a continuous process, with maximum economy. This hydrogen, drained into Dewar flasks and siphoned off into a measuring cryostat in another part of the laboratory, was to constitute a liquid bath with temperatures that could be stabilised to a hundredth of a degree.

But the workshops of the Physics Laboratory had an enormous job on their hands making the necessary preparations: they had to modify the extra vacuum and compression pumps, build the hydrogen liquefier and measuring cryostat, fine-tune an installation to purify commercially available hydrogen, improve the cascade, incorporate a cycle for liquid air, and make various auxiliary devices. When finally completed, however, the result was something to be proud of. 'The hydrogen liquefier for continuous use produced in Leiden', announced Onnes in his 1906 description, 'possesses enough individual features to take its place as an independent construction alongside those used by Travers and Olszewski, which could not fulfil the demands of the Leiden measurements.' Onnes felt indebted to Dewar and Hampson, the

former for his idea of placing the regenerator coil in a vacuum glass, and the second for his successful design of such a spiral in his oxygen liquefier.²⁷

Let us look at the situation in 1904, the year in which the British guest researcher Hyndman discussed the Leiden installations in a lengthy article in *Engineering*.²⁸ The cascade had been fundamentally upgraded. For instance, the boiling flask in the methyl chloride circulation (designed by Pictet), which did not have an integrated heat exchanger, had been comprehensively renewed on the basis of experience gained with the ethylene boiling flask designed by Onnes himself.²⁹ In 1899 a large vacuum pump was purchased for 2,900 Swiss francs from the Burckhardt factory in Basel, which greatly expanded the capacity of the methyl chloride cycle, so that the production of liquid ethylene was not interrupted while the methyl chloride was being topped up. A comparable Burckhardt pump had been deployed in the ethylene cycle three years earlier; Onnes had made endless adjustments to it while waiting for the licence that would enable him to resume work. The pumps could move 360 cubic metres of gas an hour, and were used in Leiden in conjunction with smaller pumps whose suction operated on the compression side.³⁰

Around 1900 the cascade was expanded with a cycle for liquid nitrogen, the idea being to gain access to temperatures between -196 and -210°C, a range in which the vapour pressure of oxygen is so small that maintaining a precisely stable temperature was almost impossible. Making pure nitrogen was a tricky business, and the compressor and vacuum pump in the nitrogen cycle had to fulfil rigorous criteria. Since the boiling point of nitrogen is just below that of oxygen, the Brotherhood pump sufficed for the oxygen cycle, freeing up the Cailletet pump plus booster for the nitrogen cycle. The nitrogen liquefier consisted of a high glass cylinder into which the nitrogen was fed under high pressure by a heat exchanger, and condensed, transferring heat to liquid oxygen.³¹

²⁷ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory at Leiden. X. How to obtain baths of constant and uniform temperature by means of liquid hydrogen', KNAW, Proceedings, 9 I, 1906, Amsterdam, 1906, pp. 156-180. *Comm.* 94f.

²⁸ H.H.F. Hyndman, 'The Cryogenic Laboratory at Leiden', *Engineering*, 4 and 11 March 1904.

²⁹ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory VI. The methyl chloride circulation', KNAW, Proceedings, 6, 1903-1904, Amsterdam, 1904, pp. 668-678. *Comm.* 87.

³⁰ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory V. Arrangement of a Burckhardt-Weiss vacuum pump for use in the circulations for low temperatures', KNAW, Proceedings, 5, 1902-1903, Amsterdam, 1903, pp. 633-636. *Comm.* 83.

³¹ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory IV. A permanent bath of liquid nitrogen at ordinary and reduced pressure', KNAW, Proceedings, 5, 1902-1903, Amsterdam, 1903, pp. 631-633. *Comm.* 83.

Once a second Burckhardt pump had been purchased in 1905, the range from -196 to -210°C became accessible using an oxygen cryostat.³²

The air liquefier was constructed along much the same lines as the one for nitrogen, but was a little bigger. This time an open cycle was used: atmospheric air was compressed to 10 atmospheres with a Brotherhood pump after the carbonic acid had been removed, and fed through a spiral immersed in liquid oxygen at the bottom of the apparatus. The liquid air produced in this way, at 5½ litres an hour, was transferred to Dewar flasks and kept at the laboratory. In 1903, 66 litres were produced; annual production grew to 442 litres in 1904 and 1,462 litres in 1907.³³ The liquid was always in stock, and was sent to teachers and professors (from home and abroad) at their request for two guilders a litre. Liquid air was also used in Leiden as a pre-coolant in the hydrogen liquefier.

By 1905, everything was in place for the assault on hydrogen, after at least one serious mishap. The Crossley gas engine, installed in 1900, had seized up in November 1904 when a bolt in the crankshaft snapped – a construction error that the Manchester company initially refused to acknowledge. It was a year before the parties came to terms and the engine was repaired.³⁴ By then, two low-speed, oil-lubricated, two-stroke Burckhardt compressors (which pumped the gas from 25 to 250 atmospheres) and the large vacuum pump for pumping out liquid air at 1.5 to 2 mm of mercury pressure (another Burckhardt; Onnes was a regular customer in Basel) had been standing ready in lab Aa for months. An initial experiment with a small liquefier, inspired by Hampson's installations (liquid air, 1898) and Olszewski's (liquid hydrogen, 1902), failed because the liquefier broke down. But on 16 June 1905 all went well, and Leiden finally had its liquid hydrogen. The yield: a quarter of a litre, about 15 cc of which could be decanted.

That was not much, and it was soon decided to build a large hydrogen liquefier that would produce three to four litres an hour. The reliability of the new regenerator coil with expansion valve, terminating in a Dewar flask, was successfully tested with nitrogen, after which the installation produced its first litre of liquid hydrogen on 20 February 1906. Measurements were taken from 5 May onwards (comparing several thermometers at liquid hydrogen temperatures), and when Onnes went to the Academy's meeting of 28 May, he took a

³² H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory VIII. Cryostat with liquid oxygen for temperatures below -210°C', KNAW, Proceedings, 8 I, 1905, Amsterdam, 1905, pp. 79-82. *Comm.* 94d.

³³ W.H. Keesom, 'Prof. Dr. H. Kamerlingh Onnes †: Zijn levenwerk, de stichting van het Cryogeen Laboratorium', *Physica* 6 (1926) 81-98.

³⁴ Correspondence on the Crossley engine can be found in the archives of the Huygens Laboratory.

four-litre vessel of the fluid with him, that he had prepared the previous day, to use for demonstrations.³⁵

Keeping the liquefier continuously operational was not an easy task. The electrolytic hydrogen supplied by the Schiedam company Oxygenium contained oxygen and nitrogen impurities that could not be completely frozen out in a bath of liquid air. In practice, the hydrogen pressure was slowly increased until the stopcock of the expansion valve froze solid. After it thawed, a pump sucked out the contaminants, yielding hydrogen with less than 0.001 of impurities.³⁶ In February 1908, Onnes made a free-standing separator, a hydrogen purification device on the basis of the pure liquid hydrogen already present.³⁷ The new liquefier exceeded his wildest expectations, by producing four litres an hour, and was the best in the world. Dewar's device was plagued by freezing stopcocks, while those made by Travers and Olszewski (both built in 1902) were non-continuous and yielded only a few hundred cc of liquid hydrogen.³⁸ In 1906, 71 litres of hydrogen were collected in Leiden, and a year later the figure had risen to 167 litres.

Improving the hydrogen cryostat was more difficult. It was originally equipped with a Dewar beaker, which simplified the construction. When the vacuum glass vessel burst after a few rounds of measurements – Onnes was fortunate in that his measuring instruments, which had recorded entire series of observations, survived the blast – a safer cryostat was built. Dewar glasses were exposed to huge temperature differences, and added to the tension generated by the vacuum there was always a risk that they might burst, a risk that increased with size. Onnes's glassblower, Kesselring, later elevated the technique of making wide double-walled glass cryostats into an art, but for the time being all risks were kept to an absolute minimum. The new cryostat was more complex in design but functioned very well and was more economical in its use of liquid hydrogen.

³⁵ See note 33.

³⁶ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory IX. The purifying of gases by cooling combined with compression especially the preparing of pure hydrogen', KNAW, Proceedings, 8 I, 1905, Amsterdam, 1905, pp. 82-85. *Comm.* 94e.

³⁷ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory. XV. An apparatus for the purification of gaseous hydrogen by means of liquid hydrogen', KNAW, Proceedings, 11, 1908-1909, Amsterdam, 1909, pp. 883-886. *Comm.* 109.

³⁸ K. Olszewski, 'Apparate zur Verflüssigung von Luft und Wasserstoff', *Annalen der Physik* 10 (1903) 768-782.

The assault on helium

As soon as Kamerlingh Onnes had subdued hydrogen in 1906, he started planning the assault on helium. His only rivals were Dewar and Olszewski. Travers was on his way to Bangalore to take up his new position as director of the Indian Institute of Science. The departure of Ramsay's right-hand man, who had drawn on his cryogenic experience to set up liquid air installations around Europe and who had liquefied hydrogen in Bonn and Berlin in 1903 (the first to do so in Germany), meant one less contender. In fact Travers had already abandoned his hydrogen liquefier in London at the end of 1903 to accept a professorship in Bristol. Ramsay could not operate the apparatus himself, and after all the inert gases had been discovered his interest shifted to the new phenomenon of radioactivity. He was content with having produced liquid air.

Dewar had made a renewed bid to subdue helium in 1901. After his failed attempt of three years earlier, he reverted to the Cailletet method, which was based on one-step expansion and hence required far less helium than a cycle. Dewar obtained his helium from the hot springs in Bath, in the form of gas (mainly nitrogen) containing a small proportion (0.0005) of helium; he then extracted the helium by using chemical reactions that removed the nitrogen, oxygen and carbon dioxide, and/or used cooling to condense all substances present besides helium. By passing the helium through a U-shaped tube immersed in liquid hydrogen, he 'froze out' impurities as much as possible. While the underside of the Cailletet tube was immersed in liquid hydrogen that was pumped out (at 16 K), Dewar allowed the helium in the lowest part of the glass tube, which was compressed to 80 atmospheres, to expand. There was nothing to be seen – not even a trace of mist. From the fact that hydrogen (purified in the same way) did produce a mist in the Cailletet tube following expansion at twice the critical temperature (33 K), but not at 2.5 times that value, Dewar concluded that the critical temperature of helium must be below 9 K.³⁹

Olszewski's first attempt to liquefy helium dated from the end of 1895. Shortly after Ramsay had discovered the presence of this gas on earth, he had sent a little of it to the Pole, as he had previously done with argon. Unsurprisingly, rapid expansion of helium at the temperature of liquid oxygen did not produce any result. Olszewski's calculations led him to suspect that the boiling point of helium must be lower than 9 K.⁴⁰

³⁹ James Dewar, 'The Nadir of Temperature and Allied problems. Bakerian Lecture', *Proceedings of the Royal Society* 68 (1901) 360-366.

⁴⁰ K. Olszewski, 'Ein Versuch das Helium zu Verflüssigen', *Annalen der Physik* 59 (1896) 184.

In 1905 a new publication arrived from Cracow. Olszewski wrote that he had doubted Dewar's claim to have produced liquid helium back in 1898, but had kept quiet because he lacked the resources to repeat the experiment himself. He commented airily that the 'news' of liquid helium had thus been able to spread around the globe for three years and had found its way into numerous textbooks, and that correcting the error would be no mean task.⁴¹ He also reported a series of experiments performed in 1902 by Travers and Jaquerod, who had cooled their Cailletet tube with liquid or solid hydrogen and allowed the helium to expand at 60 atmospheres, without producing a result.

In his 1905 attempt, Olszewski too started with liquid hydrogen, used a larger Cailletet tube and increased the pressure on the helium (derived from the mineral thorianite that had just been discovered on Ceylon) to 180 atmospheres. Again, there was nothing to see. Based on calculations similar to those he had made in 1895, the Pole now concluded that helium's boiling point must be below 2 K, and suggested that its liquefaction might prove impossible. Dewar's calculations, on the other hand, made in 1904 on the basis of the measured absorption of helium in charcoal at very low temperatures (compared to that of hydrogen), had led him to estimate that helium's boiling point was above 5 K.⁴²

When it became clear that the helium could not be subdued in a Cailletet tube (in the 1930s, Francis Simon did manage to make liquid helium with such a 'single-shot' approach), the only solution was to switch, after all, to the approach that had worked in producing static liquid hydrogen: to build a liquefier with circulating helium, a regenerator coil and an expansion valve, and to pre-cool it all using liquid hydrogen. In his 1901 Bakerian Lecture, Dewar produced calculations showing that, starting with liquid or solid hydrogen, it must be possible to liquefy helium by this method, provided its critical temperature was no lower than 6 to 8 K, corresponding to a boiling point of 4 to 5 K.⁴³ Dewar held that liquefying helium was not the last step towards attaining absolute zero, and he alluded to the (impossible) discovery of a new inert gas, twice as light as helium, which would make it possible to attain even lower temperatures.

By May 1903, Dewar had made considerable progress. In a letter to Kamerlingh Onnes, the Scot (who, like Onnes, was always complaining of poor health) wrote that he had prepared a quantity of helium and planned to start the circulation very soon, but with liquid nitrogen instead of liquid hydrogen

⁴¹ K. Olszewski, 'Weitere Versuche, das Helium zu Verflüssigen', *Annalen der Physik* 17 (1905) 994-998.

⁴² James Dewar, 'New Low-Temperature Phenomena', *Proceedings of the Royal Institution* 18 (1905) 177-192.

⁴³ See note 39.

as pre-coolant. 'It is however a very complicated and risky business as you well know', he added. 'I have already lost 1 cylinder of helium by the breaking of vacuum vessels during the course of its circulation at liquid air temperatures and I dread any repetition of the disaster.' After which he paid his Dutch rival a genial compliment: 'I only wish that I had again the gift of growth so that I might begin my scientific career after a training in your Dutch school of science.'⁴⁴

Onnes replied (rather tactlessly) that Dewar would not have suffered the disaster with the lost helium if he had been using the Leiden mercury compressor for pure gases, the Cailletet pump that Onnes had modified with blood, sweat and tears at the beginning of his cryogenic career. It was quite true. Looking back in 1908, Dewar said that two problems had plagued him: obtaining a sufficient quantity of pure helium, and making enough liquid hydrogen to keep the helium cycle operational. All this, he admitted, called for an industrial approach, worlds apart from practice at the Royal Institution. 'In my work I have never been able to do anything unless substantially with my own hands', Dewar wrote to Leiden in 1904, and: 'In pioneering work assistants are a waste'.⁴⁵ At that time, Onnes had assembled a small army of 'blue-collar boys' around him, headed by outstanding technicians such as Flim and Kesselring.

But there was one thing that Onnes did not have – helium. Early in June 1905 he wrote to the directors of the hot springs in Bath, but they referred him to Dewar. Onnes immediately despatched a letter to London.⁴⁶ 'I thought you occasionally had helium-containing gas from them but now I learn from the letter that you have put up [in Bath] a plant of machinery there for extracting the gases regularly. Of course, if I had been aware of this, knowing your kindness, I would have addressed myself immediately to you in the hope that you will let me share in the costs as well as in the profit.' Onnes said that he was now ready to begin the precise determination of the helium isotherms, an important stage in determining the critical temperature and a job for which his laboratory had the ideal facilities – Dewar had previously said that accurate measurements and pioneering work did not go together.⁴⁷ Onnes was desperately impatient to obtain a few litres of pure helium gas, and in the absence of any other supplier he turned to Dewar. By way of reassurance, Onnes added that it would take him two years to purify the helium from Bath to the desired standard. And weren't the isotherms the ideal route towards finding a reliable critical point, which would in turn answer the pressing question of whether it was actually feasible to liquefy helium using the Joule-Thomson approach?

⁴⁴ Dewar to Heike Kamerlingh Onnes, 7 May 1903, MB, archives of Heike Kamerlingh Onnes.

⁴⁵ Dewar to Heike Kamerlingh Onnes, 5 January 1904, MB, archives of Heike Kamerlingh Onnes.

⁴⁶ Heike Kamerlingh Onnes to Dewar, 8 June 1905, archives of the Royal Institution.

⁴⁷ Dewar to Heike Kamerlingh Onnes, 18 January 1905, MB, archives of Heike Kamerlingh Onnes.

But this was asking rather too much of Dewar's generosity. 'We both want the same material in quantity from the same place at the same time and the supply is not sufficient to meet our great demands', came the blunt reply. 'It is a mistake to suppose the Bath supply is so great.'⁴⁸ To soften his refusal, he said that if poor health prevented him from carrying on his work, he might pass on his helium to Onnes. The message was clear, and Onnes set about finding a different supplier. Ramsay proved more amenable. In response to Onnes's request, he wrote that his helium did not contain any neon (a great advantage over Dewar's) and that the air it contained could easily be removed by passing the gas through liquid hydrogen; traces of hydrogen could be removed chemically. 'As soon as Travers has finished with it', wrote Ramsay, 'Leiden is welcome to it.'⁴⁹ However, the purification process was more difficult than Ramsay had suggested. Leiden and London both discovered, independently of each other – as Dewar at length grudgingly acknowledged – that compression at as low a temperature as possible was the best way of freezing impurities out of helium.⁵⁰

In London the helium cycle was not going well. The laboratory assistant Lennox had wanted to make a metal liquefier, but Dewar (like Onnes) wanted glass, to be able to see what was going on. Dewar's installation devoured liquid hydrogen: six litres of it evaporated within just four minutes of helium circulation. Worse still, the installation used to purify the helium from Bath was malfunctioning. As a result, the stopcocks used in the helium cycle became clogged or got stuck because of freezing neon. Collaboration with Ramsay, who was a past master in purifying inert gases, might have saved the day, but that was impossible after the row back in 1898. Besides, Dewar also needed a pump that could compress the helium without contaminating the cycle. And to crown it all, a young Royal Institution technician turned the wrong stopcock one day, and Dewar's entire stock of pure helium leaked away overnight.⁵¹

In Leiden, the assault on helium was assigned to lab E', a small room that had been made available in 1903, along with a space for electric motors used to drive the cascade pumps. Crucial to the chances of success were both the inversion temperature, below which the Joule-Kelvin process provided cooling, and the critical temperature, below which the scientists would come within sight of liquid helium. Reasoned estimates of the critical temperature differed widely: Olszewski put it at 1.7 K, and Dewar at 5 to 6 K. It was up to Onnes to ascertain the correct value by conducting precision measurements – his speciality.

⁴⁸ Dewar to Heike Kamerlingh Onnes, 12 July 1905, MB, archives of Heike Kamerlingh Onnes.

⁴⁹ Ramsay to Heike Kamerlingh Onnes, 19 July 1905, MB, archives of Heike Kamerlingh Onnes.

⁵⁰ Dewar to Heike Kamerlingh Onnes, 24 July 1905, MB, archives of Heike Kamerlingh Onnes.

⁵¹ Mendelssohn, *The quest for absolute zero*.

In 1905, a start was made on measuring helium isotherms at temperatures ranging from 100°C to -259°C (freezing hydrogen). But before the isotherms had been determined, an alternative method of determining critical temperature presented itself. At the Academy meeting of November 1906, Onnes submitted a short communication on a spectacular phenomenon: a gas that sinks in liquid.⁵² This ‘barotropic’ effect involved helium gas compressed above liquid hydrogen until it sank. Van der Waals’s theory of binary mixtures – which had generated an enormous quantity of research in Leiden, thanks mainly to Kuenen, Verschaffelt and Keesom – is applicable to such a situation.

Onnes poured a mixture of 1 part helium to 6 parts hydrogen into a glass tube, immersed the whole in liquid hydrogen and gradually increased the pressure. Up until 49 atmospheres, he saw liquid hydrogen gradually detaching itself from the mixture, separated from the gas, which consisted primarily of helium, by a hollow meniscus. At that point, the gas suddenly sank through the liquid and remained at the bottom as ‘a large drop’. Further compression to 60 atmospheres and releasing pressure to 32 atmospheres caused the bubble to shrink and expand in the manner of a gas. At 32 atmospheres the bubble rose again. By changing the pressure, Onnes could manipulate the bubble, causing it to rise or sink as he wished. Studying the ins and outs of this effect, including its relationship to the Ψ -surfaces of helium and hydrogen, would take some time, said Onnes. He therefore confined himself to a cursory description of the phenomenon.

Working out the theory of this bizarre effect was just the kind of thing that Willem Keesom, then supervisor of the Physics Laboratory, revelled in. Within a month he had worked it all out down to the smallest detail. One of his findings was that it was possible to infer from the nature of the barotropic phenomenon using helium and hydrogen an estimate of the critical temperature of helium. If only one ‘barotropic tangent chord’ could be drawn in the Ψ or Gibbs surface of the hydrogen-helium mixture at -253°C, and this seemed very likely, Keesom could infer that the critical temperature was less than 0.09 that of hydrogen. At length he concluded that the critical temperature of helium was below 2 K. The results of his study of the barotropic effect were written up in two communications, one with Kamerlingh Onnes and Keesom as authors, and one with only Keesom.⁵³ The latter was very unusual, and reflects Onnes’s respect for his supervisor’s theoretical ingenuity.

⁵² H. Kamerlingh Onnes, ‘Contributions to the knowledge of the psi-surface of Van der Waals. XI. A gas that sinks in a liquid’, KNAW, Proceedings, 9 I, 1906, Amsterdam, 1906, pp. 459-460. *Comm.* 96a.

⁵³ H. Kamerlingh Onnes and W.H. Keesom, ‘Contributions to the knowledge of the psi-surface of Van der Waals. XII. On the gas phase sinking in the liquid phase for binary mixtures’, KNAW, Proceedings, 9 II, 1906-1907, Amsterdam, 1907, pp. 501-507. *Comm.* 96b; W.H. Keesom, ‘Contributions

But the value thus determined for the critical temperature of helium cannot have made anyone happy. It looked as if Olszewski had been right with his estimate of 1.7 K, which meant that the Joule-Thomson method held out little prospect of success with helium, even starting with solid hydrogen. The helium isotherms, which provided the only way of accurately determining critical temperature, now became all the more important. It was a year before Onnes published his first results. They concerned isotherms ranging from 100°C to -217 °C (freezing oxygen), and extrapolating from his results, Onnes established that the Boyle point lay at about -250°C, so that Joule-Thomson expansion of helium through a valve would indeed provide cooling if the process started at the freezing point of hydrogen. Comparison with hydrogen led to a critical temperature of 6 K – which figure was corrected, after applying the law of corresponding states, to 5.3 K. Since Onnes suspected that helium would deviate from the law of corresponding states more than hydrogen, he expected the value to work out somewhat lower in practice.⁵⁴

This was a much more welcome estimate of critical temperature. More good news: at the beginning of 1908, the isotherms at -252°C and -259°C confirmed the previous result.⁵⁵ Heartened by this figure, Onnes too, undeterred by the failures of Olszewski, Dewar and Travers, decided to try condensing helium using one-step expansion in a glass test tube. There was no harm in trying. Onnes used more helium gas than his predecessors, collected the gas in a special receptacle after expansion and added a small beaker at the bottom of the test tube to increase heat insulation.

On 28 February, Onnes allowed 7 litres of helium to expand from 100 atmospheres to 1 atmosphere at -259°C. To his not inconsiderable astonishment, the glass tube beneath the expansion stopcock filled with a flaky, snow-like mass, while the most he had hoped for was a faint mist. The experiment was repeated eight or nine times, with the same result each time – although it gradually became more difficult to see because condensation formed on the outside of the tube.⁵⁶ ‘At the expansion of the helium’, Onnes reported in his later communication to the Academy, ‘a dense grey cloud appeared, from

to the knowledge of the psi-surface of Van der Waals. XIII. On the conditions for the sinking and again rising of a gas phase in the liquid phase for binary mixtures’, KNAW, Proceedings, 9 II, 1906-1907, Amsterdam, 1907, pp. 501-507. *Comm.* 96c.

⁵⁴ H. Kamerlingh Onnes, ‘Isotherms of monatomic gases and their binary mixtures. I. Isotherms of helium between +100°C and -217°C’, KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 445-450. *Comm.* 102a.

⁵⁵ H. Kamerlingh Onnes, ‘Isotherms of monatomic substances and their binary mixtures. II. Isotherms of helium at -253°C and -259°C’, KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 741-744. *Comm.* 102b.

⁵⁶ Notebook of Gerrit Flim, MB, archive 444.

which separated out solid masses floating in the gaseous helium, resembling partly cotton wool and partly denser masses, as if floating in a syrupy liquid, adhering to the walls and sliding downwards while at the same time vanishing rapidly (in 20 seconds). There was no trace of melting.⁵⁷

The news spread through the laboratory like wildfire: 'solid helium!' Onnes announced the spectacular news at the Academy's meeting of 29 February – the very next day – and sent Dewar a telegram. The Scot responded in sportsman-like fashion by sending his congratulations, and felt called upon to notify the *Times*. Six weeks later, Dewar sent the newspaper another letter, this time to explain that the 'solid helium' produced in Leiden had turned to be a mistake. In the meantime, Onnes had withdrawn his Academy communication, 'On the condensation of helium', which title had already been listed in the *Verslagen* of February 1908, and a month later he produced an analysis: 'Experiments on the condensation of helium by expansion'. In his eagerness to be first, he had ignored his own principles. Whereas Zeeman had not published his observation of the influence of a magnetic field on light, in 1896, until he had first performed a series of thorough supplementary experiments, Onnes had completely failed to subject his helium flakes to critical scrutiny – and had made a fool of himself as a result.

'I had for some time the conviction', Onnes recalled in his improved Academy communication in March, 'that I had seen solid helium rapidly giving off vapours.' But further investigation revealed that the phenomena observed were in fact attributable to the presence of hydrogen in the helium: absorption experiments with charcoal exhibited impurities of almost 0.5 per cent. This hydrogen had frozen during the expansion and then rapidly evaporated. It remained curious that no more than 1.5 mm³ of solid hydrogen had been able to fill much of a 7 cm³-test tube with flaky masses. In addition, it appeared that a solid substance could rise or fall in a gas in response to the pressure – a variant of the barotropic effect. Interesting, but a minor matter. When Onnes repeated the experiment with purified helium, there was no trace of any flakes. 'The condensation of pure helium', Onnes concluded his analysis, 'remains an open question, which calls for further extensive research.'⁵⁸

In a postscript, Onnes said that he had since repeated the expansion experiment at a higher helium outflow velocity, producing a faint mist that vanished within a second. More traces of hydrogen? Or was the rather different appearance indicative of a helium liquid mist? Unfortunately the test tube had

⁵⁷ H. Kamerlingh Onnes, 'Experiments on the condensation of helium by expansion', KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 744-747. *Comm.* 105.

⁵⁸ *Ibid.*

broken and Onnes could not continue the experiment. This time he was careful not to draw any hasty conclusions: 'Reaching a decision on the critical temperature of the helium will first require a systematic continuation of the research, which will take some time in light of the difficulties attached.'

Onnes did not wait for the English translation of his communication to appear in print, but sent a version of his own to Dewar at the beginning of April.⁵⁹ The Scot replied that he had sent a rectification and – relieved that he had not yet been defeated after all – paid Onnes a compliment: 'I wish all scientific men were as magnanimous as yourself in making immediate correction of faulty inferences from experimental data they had reason to believe at that time was correct.' If Onnes tried to throw sand in his rival's eyes by asserting that it would be some time before the decisive experiment could be performed, Dewar acted no differently. 'If your value of 5°Abs of T_c [critical temperature] is correct, then we are a long way from [achieving] static helium liquid or solid.' He added that the Royal Institution, lacking endowments, could not afford to perform such very expensive experiments.

While Dewar carried on battling with frozen stopcocks and clogged pipes, Leiden was making rapid progress. Unwilling to wait for the results of the helium isotherms, Onnes had gone ahead and built a helium liquefier with a regenerator coil and Dewar flask, a 'translation' of the successful hydrogen liquefier to as small a size as possible, all guided by the law of corresponding states. After three months of working flat out – blowing the large vacuum glass vessels taxed Kesselring's skills to the limit – the apparatus could be assembled and there was enough pure helium to attempt liquefaction. Kamerlingh Onnes had obtained the extra helium (a few hundred litres) required for the circulation method from his brother Onno, who ran the Commercial Information Office in Amsterdam. Onno arranged for two sacks of helium-containing monazite sand from North Carolina that had been shipped to Hamburg by a Norwegian company (mistakenly believed by the mediating agent, the Amsterdam branch of the *Transvaalsche Bank- & Handelsvereniging*, to contain *Zinnasche*, tin oxide) to be transported to Leiden at the end of April.⁶⁰ Onnes paid 5 krone per kilo,⁶¹ about 300 guilders in total. To extract the helium, the monazite sand was processed in Leiden by a rather complicated and time-consuming procedure (see Prologue) under the supervision of the chemist H. Filippo.

⁵⁹ Heike Kamerlingh Onnes to Dewar, 7 April 1908, archives of the Royal Institution.

⁶⁰ MB, archives of Heike Kamerlingh Onnes, inv. no. 310.

⁶¹ Christiani Bergbureau to Physics Laboratory, 19 October 1908, archives of the Huygens Laboratory.

Onnes was not entirely happy with his helium isotherms: those at lower temperatures, it appeared, yielded a lower critical temperature than those at higher temperatures. And he was tormented by the spectre of a glass vacuum vessel bursting, destroying months of work. Then there was the question of whether the Cailletet pump plus booster, with its maximum capacity of 1,400 litres of gas per hour (measured at room temperature) would be powerful enough: the Burckhardt pump in the hydrogen cycle could handle 15 times as much. Not until it became clear that the hydrogen liquefier continued to function with liquid air at atmospheric pressure and the Burckhardt pump was running four times as slowly as normal did Onnes start to feel more confident that the Cailletet pump was equal to the task in the helium cycle. Then there was the problem of the liquid hydrogen, which had to be produced in the morning, before the assault on helium. The law of corresponding states told Onnes how much hydrogen he needed and how much time the helium experiment would take. 'They remained just below the limit at which one would have to advise against doing the experiment in the way designed', wrote Onnes, 'but just how close it was to that limit only became clear afterwards.' In short, the result balanced on a knife-edge.

But the experiment was successful: on 10 July 1908, after a long and arduous day's work, liquid helium was observed at half past seven in the evening (see Prologue). The Academy report of this achievement is one of the high points in the Dutch-language literature of physics, and §4, *The experiment*, deserves to be quoted in full:

After on July 9th the available quantity of liquid air had been increased to 75 litres, all apparatus examined as to their closures, exhausted, and filled with pure gas, we began the preparation of liquid hydrogen on the 10th of July, 5.45 a.m., 20 litres of which was ready for use in silvered vacuum glasses ... at 1.30 p.m. In the meantime the helium apparatus had been exhausted while the tube with charcoal belonging to it was heated, and this tube being shut off, the gas contained in the rest of the helium circulation was freed from the last vestiges of air by conduction over charcoal in liquid air through the side-conduit. The hydrogen circulation of the helium apparatus was connected with the hydrogen gasholder and the air-pump, which had served as methyl chloride pump in the preparation of air the day before, and this whole circulation was exhausted for so far as this had not yet been done, and filled with pure hydrogen. Moreover the space between the vacuum glasses ... which was to be filled with liquid hydrogen as a protection against access of heat, was exhausted and filled with pure hydrogen, and the thermometers and thermo-elements were adjusted.

At 1.30 p.m. the cooling and filling of the glasses which, filled with liquid air, were to protect the glasses which were to be filled with liquid hydrogen, began with such precautions that everything remained clear when they were put in their places. At 2.30 a commencement was made with the cooling of the graduated vacuum glass and of

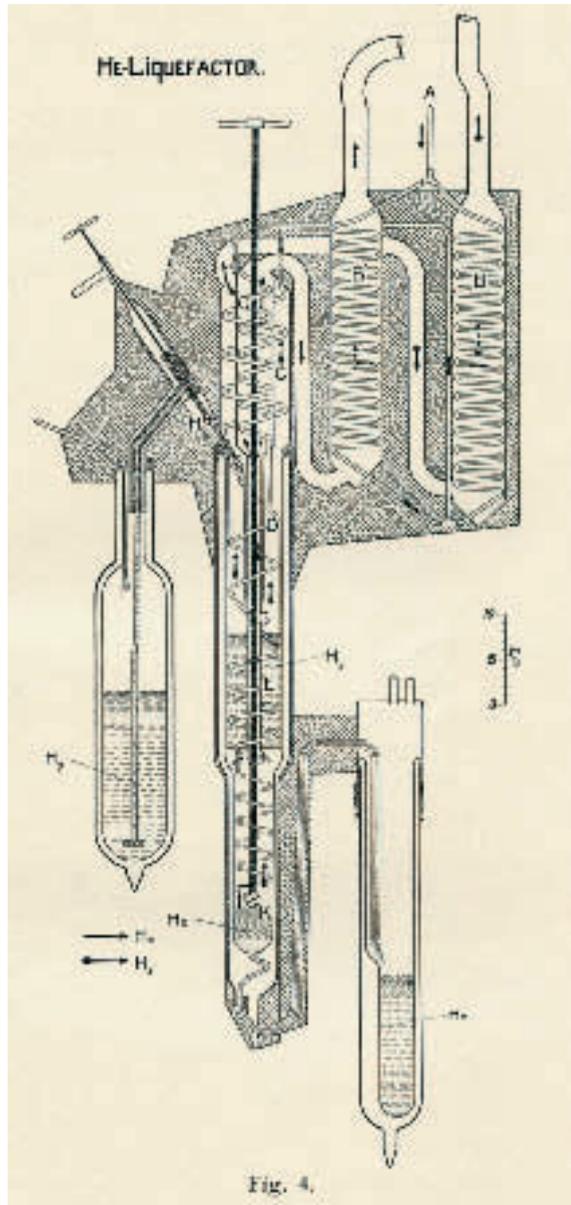
the hydrogen refrigerator of the helium liquefier by the aid of hydrogen led through a refrigerating tube, which was immersed in liquid air. At 3 o'clock the temperature of the refrigerator had fallen to 180° according to one of the thermo-elements. Then the protecting glass ... was filled with liquid hydrogen, and after some delay in consequence of insignificant disturbances, the filling of the graduated vacuum glass and the hydrogen refrigerator with hydrogen began at 4.20 p.m.

At the same time the helium was conducted in circulation through the liquefactor. The pressure under which the hydrogen evaporated was gradually decreased to 6 cm Hg, at which it remained from 5.20 p.m. The level in the refrigerator was continually regulated according to the indication of the thermometer-level indicator and the reading of the graduated glass, and care was taken to add liquid hydrogen ... and liquid air wherever necessary ... In the meantime the pressure of the helium in the coil was slowly increased, and gradually raised from 80 to 100 atms. between 5.35 and 6.35 p.m.

At first the fall of the helium thermometer which indicated the temperature under the expansion cock, was so insignificant, that we feared [some] defect, which would have been a double disappointment because just before also in the gold-silver thermo-element, which served to indicate the same temperature, some irregularity had occurred. After a long time, however, the at first insignificant fall began to be appreciable, and then to accelerate. Not before at 6.35 an accelerated expansion was applied, on which the pressure in the coil decreased from 95 to 40 atms., the temperature of the thermometer fell below that of the hydrogen. In successive accelerated expansions, especially when the pressure was not too high, a distinct fluctuation of the temperature towards lower values was clearly observed. Thus the thermometer indicated e.g. once roughly 6° K.

In the meantime the last bottle of the store of liquid hydrogen was connected with the apparatus: and still nothing had as yet been observed but some slight waving distortions of images near the cock. The thermometer indicated first even an increase of temperature with accelerated expansion from 100 atms., which was an indication for us to lower the circulation pressure to 75 atms. Nothing was observed in the helium space then either, but the thermometer began to be remarkably constant from this moment with an indication of less than 5° K. When once more accelerated expansion from 100 atms. was tried, the temperature first rose, and returned then to the same constant point.

It was, as Prof. Schreinemakers, who was present at this part of the experiment, observed, as if the thermometer was placed in a liquid. This proved really to be the case. In the construction of the apparatus ... it had been foreseen that it might fill with liquid, without our observing the increase of the liquid. And the first time the appearance of the liquid had really escaped our observation. Perhaps the observation of the liquid surface, which is difficult for the first time under any circumstance, had become more difficult as it was hidden by the thermometer reservoir. However this may be, later on we clearly saw the liquid level get hollow by the blowing of the gas from the valve and rise in consequence of influx of liquid on applying accelerated expansion, which even continued when the pressure descended to 8 atms. So there



Ill. 37. Schematic image of the helium liquefier connected to a helium cryostat. The hydrogen (H_2) served as a pre-coolant. The helium gas (He) enters the installation in a closed circuit at A, after which it passes through the regenerator spirals (in which returning gas pre-cools the gas entering the system), exiting at the expansion valve K (which can be operated externally using a long rod) and undergoing Joule-Thomson cooling. This construction leads to a drop in the temperature of the helium in each successive cycle until it eventually liquefies. It is then siphoned off into a separate cryostat, which has space for instruments and the substances to be researched.

was no doubt left that the critical pressure [is] also above one atmosphere. If it had been below it, the apparatus might all at once have been entirely filled with liquid compressed above the critical pressure, and only with decrease of pressure a meniscus would have appeared somewhere in the liquid layer; this has not taken place now.

The surface of the liquid was soon made clearly visible by reflection of light from below, and that unmistakably because it was clearly pierced by the two wires of the thermo-element.

This was at 7.30 p. m. When the surface had once been seen, it was [not] lost sight of [again]. It stood out sharply defined like the edge of a knife against the glass wall. Prof. Kuenen, who arrived at this moment, was at once struck with the fact that the liquid looked as if it was almost at its critical temperature. The peculiar appearance of the helium may really be best compared with that of a meniscus of carbonic acid e.g. in a Cagniard de la Tour tube. Here, however, the tube was 5 cm wide. The three liquid levels in the vacuum glasses being visible at the same time, they could easily be compared; the difference of the hydrogen and the helium was very striking.

When the surface of the liquid had fallen so far that 60 cm³ of liquid helium still remained – so considerably more had been drawn off – the gas in the gasholder was exhausted, and then the gas which was formed from this quantity of liquid was again separately collected. In the course of the experiment, the purity of this gas was determined by means of a determination of the density (2.01), which was afterwards confirmed by an explosion experiment with oxyhydrogen gas added, and further by a careful spectroscopical investigation.

At 8.30 the liquid was evaporated to about 10 cm³, after which we investigated whether the helium became solid when it evaporated under decreased pressure. This was not the case, not even when the pressure was decreased to 2.3 cm. A sufficient connection could not be quickly enough established with the large vacuum pump, which exhausts to 2 mm., so this will have to be investigated on another occasion. The deficient connection, however, certainly made the pressure decrease below 1 cm., and perhaps even lower. That 7 mm. was reached is not unlikely.

At 9.40 only a few cm³ of liquid helium were left. Then the work was stopped. Not only had the apparatus been taxed to the utmost during this experiment and its preparation, but the utmost had also been demanded from my assistants.

But for their perseverance and their ardent devotion every item of the programme would never have been attended to with such perfect accuracy as was necessary to render this attack on helium successful.

In particular I wish to express my great indebtedness to Mr. G.J. Flim, who not only assisted me as chief of the technical department of the cryogenic laboratory in leading the operations, but also superintended the construction of the apparatus according to my direction, and rendered me the most intelligent help in both respects.⁶²

⁶² H. Kamerlingh Onnes, 'The liquefaction of helium', KNAW, Proceedings, 11, 1908-1909, Amsterdam, 1909, pp. 168-185. *Comm.* 108.

The liquefaction of helium marks the culminating point of Onnes's career as a scientist – he was almost 55 years of age. Given the construction he was using, with high-pressure pipes and a regeneration coil, the fact that he succeeded with only 200 litres of helium, and 160 litres in reserve, was an outstanding achievement. To Onnes's regret, the large Burckhardt pump from the air cycle, which could pump down to 2 mm mercury pressure, could not be connected so quickly, so that the pressure did not go any lower than 2.3 cm that first time. That corresponded to 1.7 K, insufficient to freeze helium – it later transpired that this required high pressure. The purity of the helium used in Leiden was beyond dispute: stopcocks continued to function perfectly and even the final remains of the fluid were crystal-clear. The provisional boiling point, as determined using a helium gas thermometer, was corrected to 4.5 K (a few tenths too high). Critical pressure and density were both surprisingly low. Onnes was also struck by the volatility of liquid helium.

After telegraphing Dewar, Onnes quickly set about writing a communication for the Academy. Methods, the helium liquefier (including schematic drawings and a photograph) and the preparation of the helium were all described in detail. There was praise for Dewar's 'brilliant inventions' and for Van der Waals's theory, and a special word of thanks for the technical staff. After which a riveting account followed of the events of 10 July and the properties of helium – one of the great highlights of the Dutch literature of science. That same month – no doubt thanks to the Academy's secretary, Van der Waals himself – the communication was printed and circulated as a separate appendix to the report of the June meeting, which had already been published,⁶³ and Onnes was even able to send the English translation (with extra clarification in footnotes) to London before the end of the month. That it had indeed been a knife-edge success was clear from the fact that when the experiment was repeated, with the helium being illuminated by a lamp placed to one side at the critical spot, no liquefaction took place.⁶⁴

The news was a blow for Dewar. This time he had not the slightest inclination to notify the *Times*. He put the news about liquid helium in a footnote to an article he was about to send off for publication, 'The Nadir of Temperature and Allied Problems', in which he had described his woes with stopcocks freezing solid and had estimated that 100 to 200 litres of helium ought to be enough (Onnes used 200 litres plus 160 litres held in reserve). He and his assistant Lennox soon fell out. Lennox, who had lost an eye in the course of his

⁶³ H. Kamerlingh Onnes, 'Het vloeibaarmaken van het helium'. *Verslagen*, 17 (June 1908) 163-179. *Comm.* 108.

⁶⁴ See note 33.

cryogenic efforts, resigned and swore never again to set foot in the Royal Institution as long as Dewar lived. He remained true to his word.

Two months after his defeat, Dewar was sporting enough to give a presentation on Onnes's behalf at a meeting of the British Association in Dublin – Heike's health had collapsed after the triumph and he was unable to leave home. It was a lightly adapted version of *Communication* 108, the translation of the Academy article. 'The Dublin meeting of the British Association will be memorable for two things', Dewar wrote to Leiden afterwards. '(1) The liquefaction of Helium by Prof. Dr. Onnes. (2) The Bursting of the Ramsay Bubble of transmutation of the Elements and other Unreliabilities.'⁶⁵ Dewar would never again concern himself with liquid helium; he did apply himself, however, to soap membranes.

⁶⁵ Dewar to Heike Kamerlingh Onnes, 29 September 1908, MB, archives of Heike Kamerlingh Onnes.

24. Old peat and neighbourhood squabbling

The Physics Laboratory kept records of everything. Kamerlingh Onnes was not fond of surprises and ran a tight ship, with his supervisor (initially Siertsema, and from 1907 onwards Crommelin) playing a central role. Besides deciding how much old peat and how many hectolitres of Ruhr coal were needed for the winter, the supervisor also arranged external ties and acted as Onnes's official secretary. But even before this position was created, the Steenschuur was an extremely orderly workplace. On 8 December 1886 the scientists began using an order book to record what was needed and who had placed the order, along with the date and the name of the supplier or agent. Onnes's assistant De Vries made the first entry: he ordered 'a few oil pots' from the Delft instrument-makers P.J. Kipp & Sons – the laboratory's main supplier. Twelve months later, 400 orders had been processed, twenty years (and nine order books) later the lab was up to order no. 4395: assistant Teddy Jolles needed some 'gaskets and machine oil'.¹

Anything that had been borrowed or lent out was recorded just as scrupulously. Onnes's students often came to borrow instruments – Sissingh and Zeeman in Amsterdam, for instance, or Siertsema in Delft. A tangent galvanometer was loaned out in 1900 to the physiologist Dekhuijzen – who had been a member of the municipal executive and Onnes's adversary during the safety controversy. That same year, the solar eclipse expedition led by the Leiden astronomer Wilterdink borrowed from Onnes a Rühmkorff inductor (which supplied high voltage) and some Leiden jars (early condensers or capacitors) and took them off to Sumatra. Frequent borrowers included the local teaching hospital and Endegeest insane asylum. The laboratory sometimes provided these institutions with technical assistance – mending X-ray tubes and charging batteries, for instance.

Since Flim had built an open mercury manometer capable of measuring up to 64 atmospheres in 1898, the Physics Laboratory acted as a calibration

¹ Bestelboekjes I to XIII, archives Huygens Laboratory.

institute. Organisations such as the navy and the Ministry of Waterways and Public Works (steam inspection department) no longer needed to send their manometers to Berlin to be checked by the Institute of Metrology (Physikalisch-Technische Reichsanstalt), but could calibrate their instruments free of charge in Leiden, an initiative launched by Kamerlingh Onnes 'in the interests of education'. The opportunity was enthusiastically seized. Shortly after the standard manometer came into use, Onnes contacted Miss F.J. Eldering, a teacher at the local girls' HBS school and persuaded her to perform the calibrations as an unpaid assistant.²

One good turn deserves another, and the navy and war ministry came to the aid of Onnes's laboratory on numerous occasions. In fact they lent him their Brotherhood pumps – for use in the cascade – before Leiden had its standard manometer, and this probably encouraged Onnes to make his generous offer of calibration. In January 1899, Delft's artillery depot gave Onnes twenty Rühmkorff reels, which were immediately incorporated into students' lab work.³ Four years later, the gun foundry in The Hague presented him with a hydraulic pump that could attain pressures of up to 250 atmospheres.⁴ The Leiden team could also go to the artillery construction workshops in Delft to have their fraises sharpened,⁵ or to get help assembling a large electromagnet.⁶

Once the cryogenic laboratory was producing liquid air on a large scale, teachers and professors were constantly coming to buy a few litres of it, generally for demonstrations. Leiden supplied Dewar tanks with liquid air at 2 guilders a litre (plus postage and packaging), carefully wrapped up and sent by train – customers bore the risk of breakage (at 13 guilders 40 a tank). Some orders came from as far afield as Paris and Berlin. After 1906 the laboratory also supplied liquid hydrogen, at 16 guilders a litre. In 1907, H. du Bois, professor at the Bosscha Laboratory in Berlin, asked Onnes (who was going in that direction anyway to attend a conference) to bring some with him, since Pictet had 'let him down'. Du Bois wanted to expand his study of low temperatures, but even Onnes drew the line at taking some liquid hydrogen along in his luggage: 'Besides other objections, it seems to me that the other passengers might not be entirely amenable to having some H₂ stored in the luggage net of a

² Heike Kamerlingh Onnes to *curatoren*, 12 December 1898, archives Leiden Institute of Physics.

³ Stapelmagazijnen Delft (Delft Depot) to Heike Kamerlingh Onnes, 23 January 1899, archives Huygens Laboratory.

⁴ Jaarverslag 1903-1904, UB Leiden, Archief Curatoren, inv. no. 1560.

⁵ Constructie Werkplaatsen (construction workshops) Delft to Heike Kamerlingh Onnes, 7 February 1910, archives Leiden Institute of Physics.

⁶ Heike Kamerlingh Onnes to Elant, 15 April 1910, archives Leiden Institute of Physics.

sleeping car next to a burning gas flame throughout the night.⁷ Onnes must have thought it a grotesque suggestion. Once, when an American visitor was about to light his pipe in a laboratory where experiments were being performed with liquid hydrogen, the vigilant professor-director quickly knocked the box of matches out of the man's hand.

A very special request for liquid air arrived on Onnes's desk on 1 June 1908. It was a telegram from Prince Hendrik's aide-de-camp Van Suchtelen at Het Loo Palace: 'His Royal Highness would be most gratified to receive from you, if possible, a bottle of liquid air for the purposes of cooling certain apartments.'⁸ The temperature had soared that week, and perhaps all the publicity surrounding the solid helium fiasco had brought the cryogenic laboratory to the prince's attention. Onnes immediately telegraphed back that he had just exhausted his stock but that he would make the delivery in person the next day if so required. The price had by then risen to 2 guilders 50 per litre. Onnes then proceeded to squash any royal illusions of a pleasantly cool interior: 'Please inform His Royal Majesty that cooling a chamber with liquid air is only possible if the chamber is small and closed, and that even then the cooling lasts for only a short while: liquid air cannot hence be used as a serious cooling procedure, but should be regarded only as an interesting experiment that demonstrates the intense cold of liquid air by the cold it produces for a few moments.'⁹

Onnes followed up his telegram with an explanatory letter. His offer to make the first delivery in person had been because he wished to explain the use of the liquid air, to ensure that Prince Hendrik did not burn himself with it. Having had heard nothing more on the matter, Onnes assumed that light had dawned in the palace. 'Had I appeared with a bottle of liquid air, it would have become clear that while I could produce all sorts of interesting cooling effects, I could not provide the solution that His Royal Highness had envisaged. That would certainly have been a disappointment.'¹⁰ The Prince of the Netherlands, having absorbed this lesson in elementary physics, thanked Onnes for his trouble through his aide-de-camp.¹¹

The Physics Laboratory kept a special file for instructions and recipes, from procedures for cleaning batteries, making carbon copies on the Hammond typewriter, blackening brass and silvering mirrors to a recipe for 'Ramsay stop-cock grease'. Another folder contained all the special regulations that applied in the laboratory. Since the safety controversy that had paralysed the laboratory

⁷ Du Bois to Heike Kamerlingh Onnes, 1907, MB, archives of Heike Kamerlingh Onnes.

⁸ Van Suchtelen to Heike Kamerlingh Onnes, 1 June 1908, archives Leiden Institute of Physics.

⁹ Heike Kamerlingh Onnes to Van Suchtelen, 1 June 1908, archives Leiden Institute of Physics.

¹⁰ Heike Kamerlingh Onnes to Van Suchtelen, 3 June 1908, archives Leiden Institute of Physics.

¹¹ Van Suchtelen to Heike Kamerlingh Onnes, 11 June 1908, archives Leiden Institute of Physics.

from 1895 to 1898 (see chapter 17), careful records had been kept of all canisters of compressed or liquid gases on the premises. A register in the corridor had a separate card for each canister, with the date of receipt, name of the gas, make and serial number of the gas canister, storage place within the laboratory, pressure, weight, and empty weight. Whenever a canister was moved, the details were updated, including the reason for the move. It was forbidden to place gas canisters near heaters or to expose them to direct sunlight for any length of time. Where safety was concerned, Onnes was stricter than any authority had ever required.

One of the documents in this ‘special regulations’ folder was an absurd-looking agreement with the physiologist Einthoven, whose own building was adjacent to the Physics Laboratory. It specified in detail the times at which Onnes could use his pumps and machines, and began like this: ‘The steam engine shall not be operated: on Monday, Tuesday, Wednesday or Thursday evening after 7 p.m., or on Wednesday afternoon after 2 p.m. Operation shall also be forbidden at other exceptional times, in response to a request submitted by Professor Einthoven at least hours in advance. When it is necessary to operate the gas engine on evenings on which the steam engine is idle, this shall be communicated three days in advance. Should it later transpire that it will not in fact be necessary to operate the gas engine that evening, this will be communicated without delay. The number of steam-engine-free evenings on which the gas engine is operated shall not exceed 24 during any 3-month period.’¹² And so on and so forth. Given the strong terms and immense detail in which this agreement was couched, the reader will not be surprised to learn that Onnes and Einthoven were not friends, and that the agreement was the result of a fairly unpleasant series of negotiations.

How had this unpleasantness arisen? The site known since the gunpowder disaster as the ‘Small Ruin’ was occupied by a huddle of four laboratories: anatomy, inorganic chemistry, physics and physiology. The first three shared the Steenschuur building, with physics occupying the right wing, chemistry the left, and anatomy the rear section. Onnes dearly wanted to have the entire building to himself – in 1894 he submitted detailed plans for the chemistry wing – and the repeated delays in building the new inorganic chemistry laboratory (organic chemistry had moved to Vreewijk in 1901) was a thorn in his side. Plagued by a lack of space, Onnes was constantly complaining to the board of governors about his ‘increasingly dire situation’. But he was on extremely good terms with his chemistry neighbours (first Van Bemmelen, and

¹² Einthoven file, archives Huygens Laboratory (also contains copies of letters from Heike Kamerlingh Onnes to Einthoven).

later Schreinemakers), and the two departments frequently helped each other out. One chemistry assistant (Meerburg) helped to heat the ethylene, and another (Filippo) helped with the extraction of gases (for instance helium from monazite sand). Since the departure of Zaaijers, Onnes had also been on amicable terms with the anatomy department.

Physiology was a different matter. The dynamic Willem Einthoven had been appointed professor and director of the Zonneveldsteeg laboratory in 1886, at only 25 years of age, and he was soon presiding over ground-breaking research on respiration, bronchial asthma, the eye, and the electrophysiology of the heart. Einthoven tackled things on a smaller scale than Onnes, but otherwise there were many similarities: they shared the same inventiveness, perseverance, and gift for diplomacy.¹³ And Einthoven, like Onnes, hated wasting time, and preferred upgrading his existing lab to moving elsewhere.

Relations soured in the 1890s, when Einthoven started working on the electrical registration of cardiac activity. Initially he used a capillary electrometer, but this slow, mercury-filled instrument soon proved unsatisfactory and he went looking for something better. At length he designed his own solution, in the form of a 'string galvanometer', which he presented in 1901. A very thin silver-coated quartz wire placed in the homogeneous field of a magnet coil started oscillating in a lateral direction as a result of the Lorentz force that the small cardiac currents exerted on the wire. While he was developing this instrument, Einthoven borrowed various items from his neighbour Onnes, such as a Rühmkorff inductor (1895-96) and a Thomson galvanometer (1899-1901). In 1906 Einthoven even succeeded in measuring so-called telecardiograms of heart patients at the local teaching hospital, with electrodes connected to his wire galvanometer by a 1.5-km long cable. For this magnificent achievement he was awarded the Nobel Prize for Medicine in 1925.

A major disadvantage of the string galvanometer was its extreme sensitivity to earth vibrations in the vicinity. And Onnes's steam engine and gas engine produced an abundance of such vibrations. To solve the problem, Einthoven – like Onnes himself – had built a vibration-free room at his physiology laboratory, by installing a 100-ton stone pillar in the floor, unconnected to the foundations. It helped, but it was not always sufficient, and from 1895 onwards Einthoven repeatedly wrote that he was in urgent need of a solution. He had never opposed Onnes during the latter's long safety controversy with the authorities, but the director of the Physics Laboratory had never been willing to guarantee a lack of vibration in return, complained an embittered Einthoven in 1905, 'not even for one hour!'¹⁴

¹³ Otterspeer, *Wiekslag*, 180.

¹⁴ Einthoven to Heike Kamerlingh Onnes, 23 October 1905, archives Huygens Laboratory.

Three years earlier, the two had still been on comradely terms. Onnes had finally obtained permission to build a new boiler-house on Langebrug; he planned to put a steam boiler there to provide the laboratory with central heating. The steam engine, the mobile 15 hp Westinghouse he had bought in 1887, would be installed in the new control room adjoining the boiler-house. A new licence under the Nuisance Act would be needed for all this, and Onnes sent off the application in April 1902.¹⁵ As in the safety dispute of 1895, neighbours were given an opportunity to object, but no one did so. At the June Academy meeting, Einthoven too assured Onnes that he would not make any trouble. 'I said that it would be impossible to undertake an obligation not to use the steam engine for a certain number of days', noted Onnes after that exchange in Amsterdam's Trippenhuus. 'In an emergency we might be able to rely on a large storage battery.'¹⁶ For if the pumps in the cryogenic laboratory were powered by batteries, the steam engine and gas engine could be turned off, allowing Einthoven to use his string galvanometer without any disruptive vibrations.

But in 1905, when Onnes decided he needed a more powerful, 25 hp steam engine (and wanted to increase the pressure in the boiler from 6 to 8 atmospheres), Einthoven – who was in the process of developing his telecardiograms – could not take it any longer. This time he did submit a notice of objection, setting in motion another bureaucratic hullabaloo like the one in the 1890s, which was pursued right up to the Council of State. Although Onnes assured the committee set up by the Provincial Executive that he would install the new, 'quieter' steam engine with especial care, reducing rather than increasing the level of vibration, Einthoven insisted that more steam power meant more misery for his laboratory. Onnes also offered to use batteries – Leiden did not acquire mains power until 1907 – instead of the new steam engine four evenings a week, and even on special occasions in the daytime, if requested three hours in advance, but to no avail.

At this, the Minister instructed the combatants to draw up their own contract. This was no easy task, since Einthoven – to Onnes's great annoyance – insisted on bringing in not just the steam engine but also the steam compressors and electric motors for which Onnes had secured a licence many years before. Switching off the machines that produced power in the evening was often impossible, said Onnes. This was because the room where magnetic measurements were recorded was right underneath the lecture hall where Lorentz taught his medical students. And students moving about disturbed the

¹⁵ Heike Kamerlingh Onnes to *curatoren*, 25 April 1902, archives Huygens Laboratory.

¹⁶ *Notitie* Heike Kamerlingh Onnes, 27 June 1902, archives Huygens Laboratory.

galvanometers, which meant that measurements had to be taken in the evening. After a flurry of lengthy and increasingly bad-tempered letters back and forth, Onnes came up with the agreement containing the passage quoted above, to which Einthoven reluctantly added his signature. Ensuring compliance was a fresh administrative challenge: ‘12 times in each three-month period, before 10 a.m., notification will be given that on evenings on which the steam engine and gas engine will be idle, the electric motors and small steam compressors with a combined capacity exceeding 1 hp will also not be operated.’¹⁷

Things went wrong again in April 1908, when Onnes acquired a 4 hp Brotherhood steam compression pump on loan from the navy. It came with ten cylinders for compressed gas, which were useful for storing hydrogen – an essential ingredient in preparing liquid helium. Yet another licence was needed, and Einthoven – who kept a weather eye on any increase in vibrations – protested again. ‘What an awful business’, groaned Onnes to his right-hand man, Crommelin. ‘I would never have thought it remotely possible: objecting to a little 3 hp pump that is, I believe, 50 metres away [from Einthoven’s vibration-free lab], while the 25 hp steam engine and 40 hp gas engine are both so much closer.’¹⁸ In Onnes’s eyes, the licence application had been a ‘mere formality’, and he considered Einthoven’s whining about ‘serious harm’ and ‘increased vibration’ to be entirely misplaced. Einthoven, in his turn, considered that no one but he could judge the adverse effects.

The subsequent correspondence degenerated into a full-scale slanging match. Einthoven felt that Onnes refused to take his objections seriously, while Onnes thought that Einthoven was making a mountain out of a molehill and made no bones about it in his letter of 12 December. After politely thanking Einthoven for congratulating him on the liquid helium triumph, he abandoned his cordial tone altogether: ‘How gladly would I forget the delay that you caused in the work that led to the liquefaction of helium, by your actions against the Physics Laboratory. And look now! You are already doing the exact opposite of promoting the further achievements that you wish the cryogenic laboratory once again, without gaining any real benefit for your own work.’¹⁹

Onnes was particularly annoyed that he had closed down his steam and gas engines on Wednesday afternoons, ‘greatly to the detriment of the work’, to give Einthoven an opportunity to do some delicate experiments, only to hear the gas engine of the physiology laboratory roaring away on those same Wednesday afternoons. Onnes considered Einthoven’s request that the new

¹⁷ See note 12.

¹⁸ Heike Kamerlingh Onnes to Crommelin, 4 September 1908, archives Huygens Laboratory.

¹⁹ Heike Kamerlingh Onnes to Einthoven, 12 December 1908, MB, Einthoven archives.

pump not be used after 11 o'clock in the morning without the approval of the physiology laboratory or his deputy simply impracticable. 'Leaving aside the fact,' he added, 'that it is hardly proper that I should have to ask the subordinate of a younger colleague for permission to do something I deem to be desirable.'

Eindhoven was so furious that he declared the correspondence to be at an end,²⁰ which Onnes acknowledged 'with surprise but also regret'.²¹ To move the matter along, he wrote to the board of governors that he would use the new pump solely to replace the two (by then malfunctioning) Brotherhood pumps he already had, such as to cause no increase in vibrations at all. Replacing these pumps with new ones, as Eindhoven had suggested, would cost several thousand guilders, he added, whereas the new pump he had just acquired was free. Once he had been granted his licence, he would do an experiment to convince Eindhoven; only then would the pump be made operational.²²

This was an offer that the board of governors and the Minister could hardly refuse – the financial argument must have been compelling in any case – and the licence was quickly granted. Then came the squabbling about the experiment. Van der Waals, who had joined the board of governors after his retirement in 1908, stepped into the arena as referee. By July 1909 the ordeal was finally over, and a relieved Onnes thanked his friend for all the trouble he had taken. 'What would have happened had you not intervened?' he wrote to Amsterdam, adding: 'One can hardly imagine a greater hindrance to one's work than exposure to an attack such as this one by E.'²³

The quarrel with Eindhoven was never patched up. When he too presented plans for expansion in 1913, and started eyeing the chemistry department's garden, Onnes lost no time in pointing out his prior claim.²⁴ When Onnes finally took possession of the chemistry wing immediately after the First World War, he embarked on a major programme of expansion and renovation, and Eindhoven found himself hemmed in. Onnes was deaf to the protests of his sole remaining neighbour against the new upper storey planned for the theoretical physics building, even after Lorentz and Ehrenfest had suggested forgoing the expansion to keep the peace.²⁵ Onnes wanted theoretical physics close by and that was that. Even at the end of his career there was to be no

²⁰ Eindhoven to Heike Kamerlingh Onnes, 24 December 1908, archives Huygens Laboratory.

²¹ Heike Kamerlingh Onnes to Eindhoven, 29 December 1908, MB, Eindhoven archives.

²² Heike Kamerlingh Onnes to board of governors, 5 January 1909, archives Huygens Laboratory.

²³ Heike Kamerlingh Onnes to Van der Waals, 13 September 1909, N-HA, Van der Waals archives.

²⁴ Heike Kamerlingh Onnes to Eindhoven, 27 October 1913, MB, Eindhoven archives.

²⁵ Ehrenfest to Lorentz, 9 February 1921, N-HA, Lorentz archives; UB Leiden, Archief Curatoren, inv. no. 1799.

reconciliation. When Onnes received a visiting Japanese professor in 1924 who also wanted to see Einthoven's string galvanometer, he asked Keesom, who was himself a professor by then, to arrange it.²⁶

Generous but not a fool

The Physics Laboratory was always flooded with visitors – even more so after the success with liquid helium in 1908. Onnes and Crommelin sometimes suspected industrial espionage. For instance, the German chemistry professor Fritz Haber expressed interest in the purification apparatus for liquid hydrogen that Onnes had designed. He was referred to P.J. Kipp & Sons in Delft, but, deterred by the long delivery time, asked if he might send an assistant, an able mechanic, to Leiden. Onnes wrote to Kipp & Sons saying that he had resolutely rejected the idea.

I replied that all our accessories and advice are at the disposal of Dutch instrument-making companies, but that I could not make them available to foreigners, and therefore did not wish this assistant to come. ... There is little pleasure to be gained from such foreign information. ... It appears, however, that [Haber's] aim was to come and copy from us; at least, I am very disappointed that he did not place an order with you.²⁷

In the summer of 1909, a Professor Ernst Gehrke of the Physikalisch-Technische Reichsanstalt in Charlottenburg paid his respects. Onnes thought it rather odd that someone who could travel whenever he wanted should have chosen to come when the director was on holiday in Switzerland. Still, there was little harm in showing the man round. 'If it is a casual visit it does not much matter if Gehrke derives little profit from turning up at an unexpected time.' Crommelin was instructed to cover up the cryogenic showpieces: 'I assume you have wrapped up the helium devices well in insulating material and closed off the hydrogen room'. But if Gehrke had not come to sound Crommelin out but displayed real scientific interest, Onnes added, there could be no objection to showing him everything.²⁸

Crommelin wrote back that Gehrke had already been and gone, that he had reacted very enthusiastically and full of admiration when shown around the cryogenic laboratory, and that there was no question of the German sounding him out. 'As I said, I don't think he was able to study much for the purposes of copying it, if such had been his intention, which I don't think it was. He didn't

²⁶ Heike Kamerlingh Onnes to Keesom, 18 September 1924, N-HA, Keesom archives.

²⁷ Heike Kamerlingh Onnes to Giltay, 30 December 1908, archives Huygens Laboratory.

²⁸ Heike Kamerlingh Onnes to Crommelin, 22 August 1909, archives Huygens Laboratory.

see anything of the *construction* of the He and H₂ apparatus (it was all wrapped up) and the muddle of tubes and stopcocks in labs E and Aa [the rooms with the cascade and the hydrogen liquefier, respectively] must have made his head reel. If I nonetheless showed him too much, I apologise. He also displayed [enthusiastic] scientific interest ... in the cryostats, which I had to explain to him in detail, and in the piezometers. In addition I had to explain about the instrument-making workshop.²⁹

So even though Onnes published the details of all his apparatus, it seems that there were still things to be concealed from those who came to pry. ‘It is a terrible pity’, he wrote to Crommelin, ‘that occasionally someone will come who is not imbued with our Dutch spirit and ideas and hence tries to spoil the beauty of scientific endeavour. And that one ends up having to make “arrangements” where one would like nothing more than to be wholly forthcoming and show what one has.’³⁰ In short, Leiden’s openness was rather less than absolute; Onnes was generous but not a fool.

Foreign visitors, won over by the marvels of the cryogenic laboratory and the hospitality of its director, enhanced Leiden’s reputation in physics, and Onnes was never too tired to show celebrities around or to invite them to his home. This sometimes led to wonderful favours in return. In October 1909, Bertram Boltwood, a physics professor in Manchester, wrote to Onnes that after visiting Leiden he had written to a friend at the Welsbach Light Company in the United States, asking if helium could perhaps be extracted from the thorianite that was used to manufacture mantles for gas lamps. Boltwood had heard from Onnes himself that Leiden urgently needed fresh supplies and he was happy to help procure some extra helium if he could, so that the ‘interesting and valuable’ experiments with that gas might be continued.

The reply from Gloucester City (New York) was that about a thousand litres of helium could be supplied, free of charge, and that the Welsbach Light Company would be happy to take over the two casks of monazite sand that Onnes had finished with.³¹ In September 1910 the monazite sand was shipped to New York on the SS ‘Rotterdam’ of the Holland-America Line, and a month later the SS ‘Nieuw Amsterdam’ transported to Rotterdam eight steel cylinders that would yield 125 litres of pure helium gas. Onnes was absolutely delighted.

In the summer of 1911, Crommelin wrote to America that Leiden once again had urgent need of helium, and would prefer ordering from Welsbach

²⁹ Crommelin to Heike Kamerlingh Onnes, 24 August 1909, archives Huygens Laboratory.

³⁰ Heike Kamerlingh Onnes to Crommelin, 4 September 1909, archives Huygens Laboratory.

³¹ Boltwood to Heike Kamerlingh Onnes, 10 October 1909, archives Huygens Laboratory.

than to go through the expensive and time-consuming procedure of heating monazite sand in the laboratory.³² He would see to it, replied Welsbach, but it might take some time. In May 1912, Crommelin sent another urgent plea: eighty litres of helium had been lost in Leiden after a glass vessel had broken, and the helium work had virtually ground to a halt³³ – and that at a time when research on superconductivity was in full swing (see chapter 29). Crommelin shrewdly notified a Berlin firm, in response to a request, that as far as he was aware, no large quantities of helium were obtainable anywhere.³⁴ In March 1913 the SS ‘Noordam’ transported four metal drums to the Netherlands – less than the first shipment but just as welcome. It was to be the last: after the outbreak of the First World War, helium proved to be of military value.

³² Crommelin to Miner, 19 June 1911, archives Huygens Laboratory.

³³ Crommelin to Miner, 1 May 1912, archives Huygens Laboratory.

³⁴ Crommelin to Hecht, Pfeiffer & Co, 3 April 1912, archives Huygens Laboratory.

25. *Die Zustandsgleichung*

The menu for the Senate dinner on 8 February 1904, the Foundation Day of the University of Leiden, looked distinctly like a physics project. The dishes and wines, from *Huitres en Zélande* and *Irroy demie Sec* to *Croûte de foie gras Germanique* and *Bourg Pommard*, were printed on a Gibbs surface, such as those that the Physics Laboratory had recently started making from plaster. It was a light-hearted gesture on the part of the new rector, Heike Kamerlingh Onnes. The menu also displayed a drawing of Rapenburg canal with an unlikely collection of buildings: Onnes's parental home in Groningen, the University of Groningen, the ruins of Heidelberg Castle, the Polytechnic on the Oude Delft canal, the University of Leiden and the Physics Laboratory – a drawing by Menso. The drawing on the back of the menu showed Heike in his 'Cyclops' cave' experimenting with pendulums under the watchful eye of some dogs, together with a photograph of lab E with the cascade for liquid oxygen.¹

On 21 September 1903, at the opening of the academic year, Onnes, previously secretary to the Senate, had taken over as rector from the economics professor H.B. Greven. The events that took place during his term of office were not of the dramatic kind. A committee was set up to rescue the professors' portraits in the Senate chamber, some of which were in a sorry state. To prevent any further decay of this precious collection, as Onnes duly noted in his regular report, the Senate had used its own funds to save the portrait of Daniël Heynsius 'from certain demise' – laboratory or painting, it made little difference for Onnes's choice of words.² The death of Paul Kruger, President of Transvaal – who had lived in exile since the Boer War of 1899 – offered the Senate members an opportunity to declare their support, along with the rest of the country, for the cause of their 'South African kinsmen'; earlier that year Leiden had established a chair in South African law.

¹ The menu has been preserved in the collection of the Academisch Historisch Museum Leiden.

² 'Verslag Lotgevallen', *Jaarboek Rijksuniversiteit Leiden 1903-1904*, 33-63.

Among the more serious matters that arose during Onnes's term as rector was the political pressure to create denominational professorships and universities. Abraham Kuyper, founder of the Protestant 'Anti-Revolutionary' Party, who had won the elections in 1901, wanted to expand the scope for denominational schools, and in June 1902 he sought the view of the University of Leiden. The predominantly Liberal Senate was unenthusiastic about 'sectarian lecterns and universities', and feared that appointments might be skewed by party-political considerations that would undermine the quality of education.³ The philosopher Bolland, who never minced words, held that studies should be free from theological pressure, adding that he would know exactly what to do with 'a Papist and a Reformed philosopher' if they were to appear on his staff.

Kamerlingh Onnes, who had said in 1902 that the idea of denominational professorships and universities had not been properly thought through, now observed rather joylessly, as rector, that the plan had 'come to fruition' in The Hague and that Leiden wished it well. Setting out his view of the university, he wrote: 'For us, the main priority remains that our nation should enjoy the support of science in the present-day struggle for existence to no lesser extent, and if possible to a greater extent, than other nations. What matters is the international competition in university education. And it is of the utmost importance to give State universities the necessary staff and resources, so that they do not fall short in that competition.'⁴

The student fraternity attracted a fresh wave of negative publicity during Onnes's term as rector. The anthropologist De Groot denounced the games of dice being played for high stakes at the student society and wanted the rector to intervene. Roulette was another ineradicable evil. As usual, the Senate refrained from strong censure, reluctant to jeopardise its good relations with the fraternity.⁵ Onnes, who had himself once been president of the Groningen student fraternity, was not inclined to react with harsh measures. Even when the umpteenth complaint was received concerning a freshman who had been beaten up badly during initiation, he merely sent a polite letter to the fraternity's official representatives, saying that he trusted that the fraternity would not tolerate any rough treatment of freshmen, who were forbidden to retaliate. The fraternity heartily concurred, and replied that freshmen could always complain to the fraternity's president. The rector wrote back expressing himself perfectly satisfied on this score. That was on 3 October, the date on

³ Otterspeer, *Wiekslag*, 385-387.

⁴ *Op. cit.* note 2, 33-34.

⁵ UB Leiden, Archief Rector Magnificus en Senaat, inv. no. 2, 19 October 1903.

which the Relief of Leiden is celebrated, and that evening Onnes attended a concert at the fraternity's society as if nothing had happened.⁶

'My memories of the hours spent in the company of students were among the most enjoyable of my term as rector', said Onnes in September 1904, upon relinquishing the rectorship to the classical scholar Van Leeuwen. It was the fraternity, above all, that he had in mind: 'The fraternity's leaders showed themselves to be one with us in their love of the Alma Mater.' Student life, he said, 'brings young people of the most diverse origins together in an unconstrained fashion, by virtue of their common interests, inclinations, recreation, hobbies and pleasures, and encourages them to exchange views, so that they can learn to appreciate each other's different ideals, beliefs and persuasions. What a wealth of resources to enrich later life with memories that will be cherished to the end, to develop individuality and character, and to pave the way for us to become a nation of brothers!'

As for students who declined to join the fraternity, Kamerlingh Onnes detested them. He censured the aspiring East Indies officials who had been studying at the University of Leiden since 1902 (before then they had been trained in Delft), most of whom commuted. 'I consider it my duty to point out', wrote Onnes in one of his regular reports, 'that this seriously undermines the academic education of many students and presents serious disadvantages [to them]. ... Those students who choose not to benefit from the privilege of moving in the student world will find themselves without a significant source of support later in life.'⁷ But Onnes's idealised view of university life was rooted in the past, when students were still a fairly homogeneous group, recruited from the élite. In the early twentieth century, the differences became more marked, as did certain tensions. Rich and poor, liberals and socialists, fraternity members and individualists: within the new, more fragmented student population, the time for the unconstrained enjoyment of each other's company had passed.

The main highlight of the rectorship was the traditional Foundation Day address, given in the main auditorium on 8 February. Marking the university's 329th anniversary, Onnes took the opportunity, as was customary, to illuminate some of his own research. Adopting the not unpredictable title, 'The significance of accurate measurements at extremely low temperature', he gave an overview of international achievements in cryogenic experimental science, before turning to discuss the challenges facing the Leiden laboratory.⁸

⁶ *Ibid.*, inv. no. 107, 30 September and 3 October 1903.

⁷ *Op. cit.* note 2, 59-62.

⁸ H. Kamerlingh Onnes, *De betekenis van nauwkeurige metingen bij zeer lage temperaturen* (Leiden 1904).

Onnes had prepared his address very thoroughly.⁹ He had asked his brother Menso to comment on a draft of the speech, and read it out to his wife Betsy to check that it was no more than an hour long. He could not sleep on the night before he was to deliver his address, but as soon as he climbed the steps to the lectern in the packed university building, he felt ‘very calm and elated’, and took the time to look around the audience, greeting many of those he knew: Bosscha, Van der Waals, Sissingh, Zeeman, other former students, his son Albert, his young nephew Harm (whose father, Menso, was in Algeria with Kitty) and more distant relatives. His thoughts automatically gravitated to the day on which he had delivered his inaugural address from the same lectern, on 11 November 1882. His sister Jenny had been seated beneath the organ on that earlier occasion, and her eyes seemed to say, ‘How sad that Mother cannot be here!’ Now, too, Antje Coers was unable to witness Onnes’s moment of glory; she had died in 1899. ‘How much more inner joy the day would have given, if Mother had been able to experience it’, wrote Menso from Grand Hôtel Mustapha Supérieur in Algiers.¹⁰

But there was little time for such reflections, and Onnes launched into his address with an unwavering voice. Later that month he would recall, in a letter to Menso: ‘From the beginning the audience listened attentively and I noticed immediately that the subject gripped them. ... Even during the more difficult passages there was complete silence, and by reading a little more expressively I was able to hold their attention until I arrived at something that was easier to comprehend. It all went down very well ... it was an unqualified success.’

The dinner at the elegant Levedag hotel in Breestraat passed off in an equally pleasant way. Containers with liquid air had been brought along, with which the guests (including Heike’s old student friend Tellegen) could perform little experiments. The rector proposed toasts to the Queen and the University of Leiden, and the agreeable evening concluded with a serenade sung by the student fraternity. Betsy, Albert and other relatives watched the events from the other side of Breestraat, from the rooms occupied by Crommelin (who was then still a student). The rector waved to them all cheerfully. In his final word of thanks, he observed to the fraternity that the ‘regrettable incidents’ of the previous year were not yet forgotten, but that slander perpetrated by ‘the enemies of Leiden’s intellectual pursuits’ was out of order, and that he was convinced that the student fraternity would be shown to be as sound as a bell.¹¹

⁹ Heike Kamerlingh Onnes to Menso, 28 February 1904, coll. De Knecht.

¹⁰ Menso to Heike Kamerlingh Onnes, 4 February 1904, MB, archives of Heike Kamerlingh Onnes, inv. no. 221.

¹¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 221.

But we are running ahead of ourselves; let us return to the address itself. In this speech, which was considerably elaborated in the printed version, Kamerlingh Onnes sang the praises of what Casimir had called in 1983 the ‘spiral of science and technology’:¹² ‘In seeking to realise completely new possibilities, technology is competing with experimental physics. The former almost always follows the latter swiftly; in return for the new impulses it receives, it places invaluable aids, intended in the first place for society, at the service of further scientific research.’ The cryogenic work in Leiden, too, had inspired ‘giant leaps in technology’:

‘Van Marum’s milligrams of ammonia, Faraday’s grams of carbonic acid, have become hundreds of thousands and millions of kilograms. Refrigerators, using liquid gases, have boosted the effectiveness of breweries and abattoirs and have made life on board ocean steamers and in the tropics bearable. In hundreds of thousands of steel flasks, produced rapidly from molten steel using the Mannesmann procedure, just as the glass-blower shapes his flasks from liquid glass, carbonic acid travels around the world, to be used in preparing and serving carbonated drinks, in extinguishing fires and in untold other applications. Krupp uses it to cool cannons to produce the appropriate shrinkage. Sulphurous acid is transported in tankers from roasting furnaces to factories. 100-horsepower machines have already been built to produce liquid air; air distilleries that will supply cheap oxygen are currently being developed.’¹³

But Onnes’s heart was in pure science. In the second half of his address, he unfolded his programme: research into the equation of state and the law of corresponding states. These worked only by approximation, and to achieve a better fit with the results of measurements, Onnes proposed empirical formulas with an astonishing 25 constants.¹⁴ The question that arose was what these constants could teach one about the ‘nature of molecules and their mutual interaction’. In this connection, measurements of monatomic substances such as helium, argon and neon were the most interesting, preferably at the lowest possible temperatures. But in the 1890s, when Onnes had perfected his cascade, inert gases were not yet available and such efforts had initially focused on hydrogen. Precision work was all-important: ‘Since the law of corresponding states predicts approximately the behaviour of normal substances, only accurate measurements are of any scientific value.’

¹² Casimir, *Haphazard Reality*, 294.

¹³ H. Kamerlingh Onnes, *De beteekenis van nauwkeurige metingen bij zeer lage temperaturen* (Leiden 1904), 15.

¹⁴ H. Kamerlingh Onnes, ‘Expression of the equation of state of gases and liquids by means of series’ KNAW, Proceedings, 4, 1901-1902, Amsterdam, 1902, pp. 125-147; *Comm.* 71.

Onnes had a vision: to determine experimental equations of state to such a degree of accuracy – something he predicted would take physicists the rest of the twentieth century – as to render the accompanying (coordinating) empirical formulas for specific heat, coefficients of expansion, vapour pressure and so forth redundant. ‘For every substance there will be a single equation of state embracing all these variables ... and it will be the *empirical equation of state* that people will look up in tables, just as one now looks up the empirical formula for, say, a coefficient of expansion.’ A Gibbs surface, which Onnes described as a model incorporating still more observational findings, theoretically provided even more comprehensive information, which could also be presented in the form of a table. Using the graphic representation of a Gibbs surface was of mainly didactic importance: by rolling a plate over such a surface you could clarify a particular situation.

‘Whichever way we look, there is a constant demand for cryogenic laboratories to produce an immense amount of high-precision work’, observed Onnes in justification of his efforts since 1882 – including specialisation and relinquishing the ideal of a wider ‘Huygens laboratory’. This brought him to his eloquent closing words: ‘There can be no doubt that we stand at the threshold of great discoveries in physics that will revolutionise every aspect of our lives. A presentiment of these changes is thrilling through physicists’ minds and inspiring them in their work. The gleaming light that reveals the presence of radium emanation is condensed in a tube cooled by liquid air; this same gleam of light is dissipated under the influence of heat, and is borne away by a gas. Will one of the first rays of the dawn of our future be captured, perhaps, in a cryogenic laboratory?’¹⁵

Thermometers, manometers and other high-precision instruments

High-precision cryogenic measurements, that was the meat and drink of the Leiden laboratory. The requisite apparatus and measuring instruments were developed in the workshop and glass-blowing facilities of the Physics Laboratory, under the supervision of Flim and Kesselring. The temperature in the cryostats had to remain constant to a few hundredths of a degree for hours on end. A standard pressure gauge and a standard thermometer had to be made, along with secondary manometers (piezometers) and thermometers, calibrated using these standard instruments, to keep the measurements manageable. It was a huge job for Onnes’s instrument-makers. Numerous detailed descriptions of

¹⁵ H. Kamerlingh Onnes, *De beteekenis van nauwkeurige metingen bij zeer lage temperaturen* (Leiden 1904), 37.

pieces of equipment and instruments, including their performance, found their way into the Academy's *Verslagen* (and the *Communications*). A quarter of the articles produced by Onnes and his students dealt with methods and techniques. 'Many a young physicist', wrote Keesom, 'was tried in the crucible of the accurate calibration of thermometers or piezometers and their accessories to prove his suitability for high-precision quantitative experimental work.'¹⁶

Although developing such high-precision instruments may appeal to the imagination rather less than the liquefaction of helium or the discovery of superconductivity, it was the backbone of the Leiden programme.

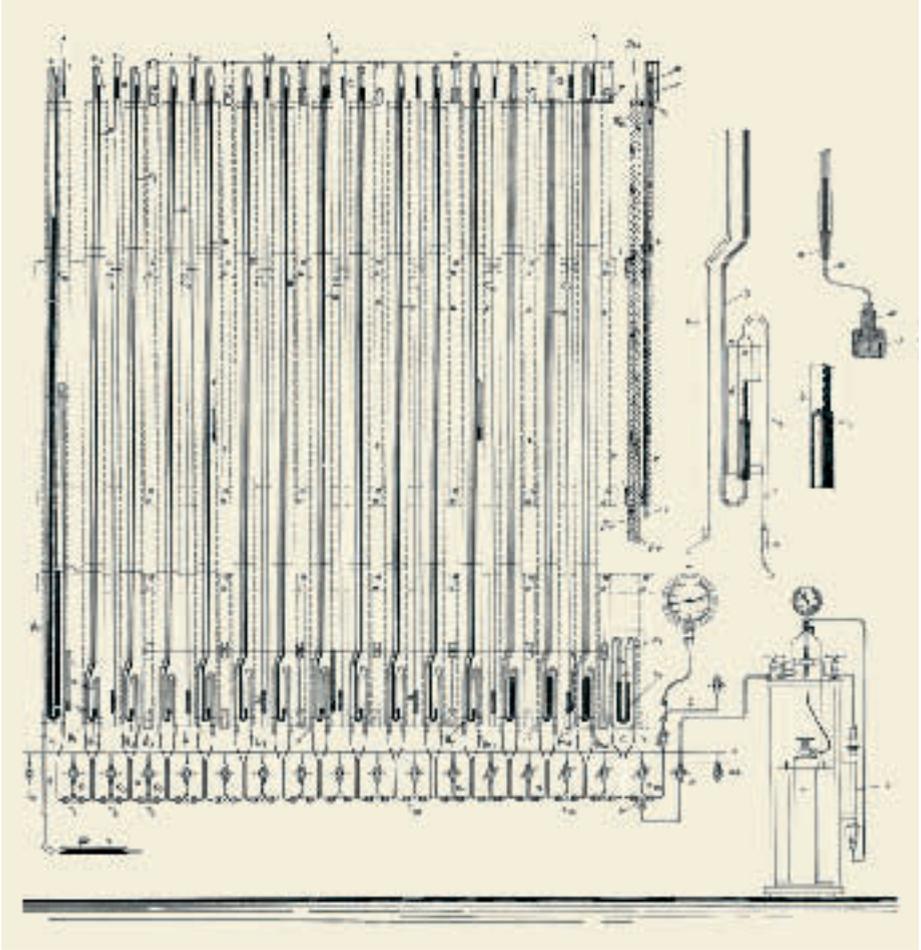
The standard open manometer used in lab G was built by Flim in 1898, at which time it had a range of 64 atmospheres.¹⁷ It was an indispensable instrument: only from a mercury manometer could pressure be read directly. Given that 1 atmosphere corresponds to a column of mercury about 76 cm high, 64 atmospheres would require one towering to over 40 metres! The French scientist Regnault had actually built such a giant in the tower of the Collège de France, Paris. But in the absence of any such tower in the immediate vicinity of Leiden's cryogenic laboratory, Onnes tried a different approach. The mercury manometer was split up into 15 partial manometers, each one 3.1 metres long, corresponding to 4 atmospheres. If the first tube did not suffice, as many full tubes as necessary were connected in order to cope with the pressure to be measured. By using the last seven J-tubes as a differential manometer, it was feasible, by combining them with a calibrated sealed mercury manometer, to reach 100 atmospheres in three stages.

The pressure on one J-tube was transmitted to the next by compressed gas. Elsewhere this was done with water, but liquid transmission had the disadvantage of introducing impurities into the manometer. The initial idea was to use 12-metre glass tubes, mounted on a wall beside a staircase, but this arrangement had the disadvantage of making it harder – and more time-consuming – to read the height of the mercury column with a viewer (cathetometer). To correct for temperature effects, the standard mercury manometer was equipped with eight thermometers. The connections between the steel capillaries and glass tubes were later improved to reduce the risk of leakage, using solder instead of an adhesive (copied from Cailletet).¹⁸ In addition, the stopcocks and

¹⁶ *Het Natuurkundig Laboratorium 1904-1922*, 91.

¹⁷ Kamerlingh Onnes, H., A standard open manometer of reduced height with transference of pressure by means of compressed gas, in: KNAW, Proceedings, 1, 1898-1899, Amsterdam, 1899, pp. 213-227. *Comm.* 44.

¹⁸ H. Kamerlingh Onnes, 'Improvement to the open mercury manometer of reduced height with transference of pressure by means of compressed gas', KNAW, Proceedings, 8 I, 1905, Amsterdam, 1905, pp. 75-76; *Comm.* 94b I.



Ill. 38. Standard open mercury manometer, built by Gerrit Jan Flim in 1898. It consisted of fifteen glass tubes, each one 3.1 metres in length and connected in series, and it was capable of measuring gas pressures of up to 64 atmospheres. Though accurate, it was an unwieldy instrument to use. In practice, the standard open manometer was used mainly to calibrate closed manometers.

couplings of the manometer were drenched in oil, so that any leakage would be betrayed by rising bubbles.

In practice, the standard open mercury manometer – a tiresome thing to use, like all cathetometers that had to be read from small balconies attached to the ceiling of lab G – was deployed primarily for calibrating sealed manometers, including pressure balances. Besides being easier to use, ‘secondary’ manometers

took less time to set up; adjusting the open manometer sometimes took as long as 45 minutes. Moreover, they were only marginally less precise than the standard manometer. This precision was achieved by determining the volume of the compressed gas in the volumenometer to an accuracy of 0.01 per cent. At this level of precision, the shape of the mercury meniscus in the manometer tube could no longer be regarded as hemispherical. Schalkwijk performed an exhaustive study of the volume occupied by the mercury meniscus, culminating in a 24-page Academy article.¹⁹ The first calibration of a sealed mercury manometer produced in Leiden took place in 1902.²⁰ In 1915 the calibration was improved to 100 atmospheres, thereby achieving the desired accuracy of 1 in 10,000²¹ – ten times as good as Kohnstamm's pressure balance in Amsterdam.

Thermometers using mercury (which freezes at -39°C) are of no use in a cryogenic laboratory. Leiden initially used hydrogen for its primary low-temperature thermometers, following a recommendation by the *Comité international des poids et mesures* in 1887. In the 1890s Onnes worked with two models: 30 and 90-cc glass bulbs on stems with an internal diameter of 0.25 mm.²² The larger the bulb, the more accurate the thermometer, but the harder it was to incorporate the instrument into a cryostat, where every millimetre of space counted. By adjusting the mercury meniscus in the volumenometer at a fixed point, the thermometer volume could be kept constant. Since pressure is proportional to absolute temperature in the case of an ideal gas, the scale with two data points, in practice that of crushed ice (0°C) and boiling water (100°C), was fixed. Necessary corrections included those for the 'false volume' (the volume between gasmeter bulb and manometer) and the shrinkage of the glass at lower temperatures. To deal with the latter, Onnes asked his assistants W. Heuse (1903) and Jacob Clay (1906) to determine the coefficient of expansion of Jena 16III and Thüringen glass.²³

¹⁹ J.C. Schalkwijk, 'Precise isothermals. I. Measurements and calculations on the corrections of the volume of the mercury meniscus with standard gas manometers', KNAW, Proceedings, 3, 1900-1901, Amsterdam, 1901, pp. 481-488. *Comm.* 67.

²⁰ H. Kamerlingh Onnes and H.H.F. Hyndman, 'Isotherms of diatomic gases and their binary mixtures. IV. The compressibility of hydrogen at 0°C and 20° ', KNAW, Proceedings, 4, 1901-1902, Amsterdam, 1902, pp. 761-767. *Comm.* 78.

²¹ H. Kamerlingh Onnes, C. Dorsman and G. Holst, 'Isothermals of diatomic substances and their binary mixtures. XVII. Preliminary measurements concerning the isothermal of hydrogen at 20°C from 60 to 90 atmospheres', KNAW, Proceedings, 18 I, 1915, Amsterdam, 1915, pp. 458-464. *Comm.* 146a.

²² H. Kamerlingh Onnes, 'Over het meten van zeer lage temperaturen. I en II', *Verslagen* 5 (May and June 1896) 37-47 and 79-93. *Comm.* 27.

²³ H. Kamerlingh Onnes and W. Heuse, 'On the measurement of very low temperatures. V. The expansion coefficient of Jena and Thüringer glass between $+16^{\circ}$ and -182° ', KNAW, Proceedings, 7, 1904-1905, Amsterdam, 1905, pp. 674-684. *Comm.* 85; H. Kamerlingh Onnes and J. Clay, 'On the

In practice, hydrogen gas was far from ideal. In order to measure temperatures to an accuracy of 0.01°C , an extra correction was needed, the size of which was dictated by the course of the hydrogen isotherms. In the years 1906-1908, Cornelis Braak determined these isotherms for temperatures down to the liquid oxygen range.²⁴ Wander de Haas added the range for liquid hydrogen in 1912.²⁵ By this time, the Laboratory had also started using a helium thermometer, for which Onnes determined the corrections himself. In 1914 a differential thermometer was added: a double gas thermometer, with both a hydrogen and a helium reservoir. The corrections, calculated from the values of the isotherms, could thus be checked against one another. The two thermometers were found to correspond to an accuracy of 0.02°C , thus establishing the reliability of the laboratory's gas thermometers. This differential thermometer was subsequently used to calibrate thermometers with oxygen, nitrogen, neon and argon, each time against hydrogen. The advantage of this experimental approach was that it made the calculation of the corrections – and hence also the accurate determination of the isotherms – unnecessary.

Gas thermometers are precise, but they are slow and awkward to use. In practice they were used mainly to calibrate secondary thermometers: thermocouples, metal wires and vapour pressures. These did respond quickly and were a great deal easier to use. Onnes began by taking as his secondary thermometer (following Wroblewski) a thermocouple of 'German silver' (an alloy of copper, nickel and tin) and copper.²⁶ A thermocouple consists of two lengths of wire of different metals, connected at their ends. When the two junctions differ in temperature (one being fixed at 0°C , the other at the temperature in the cryostat) a thermal voltage is generated that may rise to 5 to 10 millivolts, depending on the particular combination of metals.

The choice of the combination of German silver with copper was dictated by the fact that the resistance of German silver does not vary greatly with temperature. The result of a calibration was an empirical formula expressing temperature as a function of thermal voltage. In 1885, Wroblewski in Cracow had taken three calibration points: boiling water (100°C), boiling ethylene at

measurement of very low temperatures. X. Coefficient of expansion of Jena glass and of platinum between $+16^{\circ}$ and -182° , KNAW, Proceedings, 9 I, 1906, Amsterdam, 1906, pp. 199-207. *Comm.* 95b.

²⁴ H. Kamerlingh Onnes and C. Braak, 'Isotherms of diatomic gases and their binary mixtures'. VI, VII, KNAW, Proceedings, 10 I, 1907, Amsterdam, 1907, pp. 204-206; KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 419-421. *Comm.* 97a, 99a, 100a,b.

²⁵ W.J. de Haas and H. Kamerlingh Onnes, 'Isotherms of diatomic gases and their binary mixtures. XII. The compressibility of hydrogen at and below the boiling point', KNAW, Proceedings, 15 I, 1912, 1912, pp. 405-417. *Comm.* 127c.

²⁶ *Op. cit.* note 20.

normal pressure (-103°C) and pumped-off boiling ethylene (-131°C). Through these three data points (and zero) he drew a cubic graph: $t = aV + bV^2 + cV^3$ (with t = temperature in relation to the fixed point; V = thermal voltage; a , b and c are constants). The physicists in Leiden were unimpressed by the formula's accuracy.

Thermocouples proved to be far from the reliable high-precision thermometers that Onnes had envisaged. In 1903 he switched to the combination constantin-steel, which produced three times the voltage.²⁷ This voltage was determined in a bridge circuit using a galvanometer. When Einthoven presented his string galvanometer, Onnes hoped that he too might draw some benefit from it – the war with his neighbour had not yet broken out. A calibration extending to liquid oxygen (with thirty data points in total) was translated into a 5th-power formula. At -200°C this still produced a 0.15 degree margin of error. Adding two calibration points in the hydrogen range (-252 and -259°C) increased the margin of error to 0.75 degree.²⁸ This was worlds removed from the hundredth of a degree that Onnes had set out to achieve. Whether it would help to expand the formula with a sixth power was far from certain. One thing was clear, however: doing so would multiply the quantity of calculations needed to even more grotesque proportions. In 1914, Holst tried seven different metal-copper combinations and calibrated them at hydrogen and helium temperatures.²⁹ But these thermocouples too failed to deliver.

To make matters worse, thermocouples turned out to be unstable. At the same temperature, the thermal voltage turned out differently from one occasion to the next, in spite of the wires being carefully prepared – it was completely unpredictable. No formula could cure an ailment of that kind. Thus Leiden's thermocouples fell from grace. By the end of the First World War they had been jettisoned altogether.

Meanwhile, the Leiden team had gained ample experience with thermometers made of metal wires, in which resistance declined with increasing cold. The first results dated from 1902, when Meilink took a full range of

²⁷ H. Kamerlingh Onnes and C.A. Crommelin, 'On the measurement of very low temperatures. VI. Improvements of the protected thermoelements; a battery of standard thermoelements and its use for thermoelectric determinations of temperature', KNAW, Proceedings, 6, 1903-1904, Amsterdam, 1904, pp. 642-648. *Comm.* 89.

²⁸ *Ibid.*, IX. 'Comparison of a thermoelement constantin-steel with the hydrogen thermometer', KNAW, Proceedings, 9 I, 1906, Amsterdam, 1906, pp. 180-198. *Comm.* 95a,f.

²⁹ H. Kamerlingh Onnes and G. Holst, 'Further experiments with liquid helium. M. Preliminary determination of the specific heat and of the thermal conductivity of mercury at temperatures obtainable with liquid helium, besides some measurements of thermo-electric forces and resistances for the purpose of these investigations', KNAW, Proceedings, 17, 1914-1915, Amsterdam, 1915, pp. 760-767. *Comm.* 142c.

measurements using a platinum thermometer.³⁰ Platinum thermometers had previously been compared with a hydrogen thermometer by Olszewski, Dewar and others. To be certain that the temperatures of the hydrogen and platinum thermometers in the liquid bath of the cryostat did not diverge, the naked wire (0.1 mm thick) was wound around a glass cylinder into which a screw thread had been etched (a cutting tool was used later on), while the bulb of the hydrogen thermometer was inserted *into* the cylinder. The resistance was determined using a Wheatstone bridge. Two of the branches in this electrical circuit consisted of reels of manganin wire, while the third was a resistance box (calibrated in the German Institute of Metrology). Meilink established that up to -180°C , the data points could be plotted using a quadratic function of resistance against temperature. The platinum thermometer was accurate up to 0.2 of a degree in that range. More calibration points would undoubtedly have improved this performance.

After this, Jacob Clay compared a platinum and a gold thermometer.³¹ The gold wire had a purity of 99.995%, as supplied by the national mint. The relative resistances of both metal thermometers were determined using a differential galvanometer at half a dozen temperatures, from melting ice to pumped-off oxygen. Gold proved to have a flatter calibration graph than platinum, which meant that gold thermometers were more suitable for extrapolation.

From 1904 onwards, the cryogenic laboratory in Leiden had a calibrated platinum thermometer at its disposal, known as 'Pt_M'. In the period 1906-1908, Clay and Onnes expanded the measurements using gold and platinum to the liquid hydrogen range. For theoretical reasons, they also tried out other metals and alloys.³² The platinum thermometer Pt₁ that the two supplied acquired the status of 'secondary standard thermometer'. Even when the wire suddenly broke in 1906 and had to be soldered, this platinum thermometer (renamed Pt₁') remained useful, although it had to be recalibrated. The calibration that Holst and Onnes performed in 1913 showed that Pt₁' could certainly achieve an accuracy of 0.02 degrees, and that the changes relative to the calibration of 1906-1907 were minimal.³³

³⁰ B. Meilink, 'On the measurement of very low temperatures. IV and VII. Comparison of the platinum thermometer with the hydrogen thermometer', KNAW, Proceedings, 4, 1901-1902, Amsterdam, 1902, pp. 495-500 and KNAW, Proceedings, 7, 1904-1905, Amsterdam, 1905, pp. 290-299. *Comm.* 77 and 92.

³¹ H. Kamerlingh Onnes and J. Clay, 'On the measurement of very low temperatures. XII. Comparison of the platinum thermometer with the gold resistance thermometer', KNAW, Proceedings, 9 I, 1906, Amsterdam, 1906, pp. 213-216. *Comm.* 95d.

³² For an overview, see C. A. Crommelin, 'Electrisch geleidingsvermogen (behalve in den suprageleidenden toestand) en thermoelectriciteit', *Het Natuurkundig Laboratorium 1904-1922*, 383-400.

³³ H. Kamerlingh Onnes and G. Holst, 'On the measurement of very low temperatures. XXIV. The hydrogen and helium thermometers of constant volume, down to the freezing-point of hydrogen

Converting the calibration into a formula expressing temperature as a function of resistance produced a mountain of calculations: only by cramming a large number of terms into such a formula would the required accuracy come within reach. Determining all the coefficients and calculating the temperatures was an enormous job. Although fellow professor Ernst van de Sande Bakhuizen, an astronomer who was more than familiar with endless series of data points, showed Onnes a technique for avoiding the 'least squares regression' approach (the standard method for plotting the best graph through a series of data points) with only minimal loss of accuracy, the calculations were still monstrous. To lighten this burden, Holst and Onnes introduced a two-phase approach: an approximation formula with a limited number of terms produced a rough value of the temperature without too many calculations, after which greater precision could be achieved by reading the correction in a deviation curve.

Unlike thermocouples, the platinum and gold thermometers did perform consistently: the results did not change with the passage of time. The only problem arose from the possible presence of impurities. The wires were made by Heraeus, a German instrument-making company in Hanau, and it later appeared that the manufacturers had introduced impurities into the metal during processing.

There was a fourth type of thermometry, which did not involve struggles to devise consistent thermometers. Every liquid has its own characteristic vapour pressure curve, obtained by plotting the vapour pressure above the enclosed liquid against temperature. So measuring vapour pressure, in combination with this curve, comes down to determining temperature. This type of 'thermometer' does not change and is internationally 'exchangeable'. In 1907, Kamerlingh Onnes and Braak built a vapour pressure apparatus that could be used as a thermometer.³⁴ They concluded that this was the ideal piece of equipment for the purpose; its margin of error was only 0.001°C , considerably more accurate than the gas (0.02°C) and resistance (0.01°C) thermometers.

In the years 1910-1918 the vapour pressure curves of a whole series of liquids were measured in Leiden, partly in the course of thermometry experiments and partly in relation to the equation of state. The liquids concerned were argon, helium, carbon dioxide, methyl chloride, water, ammonia, hydrogen,

compared with each other, and with the platinum resistance thermometer', KNAW, Proceedings, 17, 1914-1915, Amsterdam, 1915, pp. 501-507. *Comm.* 141a.

³⁴ H. Kamerlingh Onnes and C. Braak, 'On the measurement of very low temperatures. XXI. On the standardising of temperatures by means of boiling points of pure substances. The determination of the vapour pressure of oxygen at three temperatures', KNAW, Proceedings, 11, 1908-1909, Amsterdam, 1909, pp. 333-341. *Comm.* 107a.

oxygen, nitrogen and neon.³⁵ Everything depended on the purity of the liquid. Where hydrogen, oxygen and nitrogen were concerned, this was achieved using a cryogenic process – any impurities were ‘frozen out’. Argon required a different approach. To begin with, air was passed over a heated mixture of 90% calcium carbide and 10% calcium chloride. The resulting raw argon went through additional purification by being passed over a heated ‘Hempel mixture’: twenty parts of unslaked lime to four of magnesium and one of sodium. And that was not all: ‘The remaining traces of nitrogen were eliminated by causing the nitrogen to combine in a light arc with added oxygen. The surplus oxygen was then removed by passing the gas over heated copper. Finally, the tiny quantity of neon originating from the air had to be removed. This was done by fractionated distillation at -217°C (in liquid oxygen under sharply reduced pressure).’³⁶ Crommelin, who was the argon man in Leiden, must sometimes have felt as if he had become a chemist.

The data points resulted in a vapour pressure curve for each individual substance. As a general form, Onnes chose: $\log p = a + b/T + c/T^2 + d/T^3 + A \log T + BT + CT^2 + DT^3$ (with p = pressure, T = absolute temperature and a to D constants). In each separate case, two to five terms from the above series would be singled out, with the rest of the constants being set at zero.

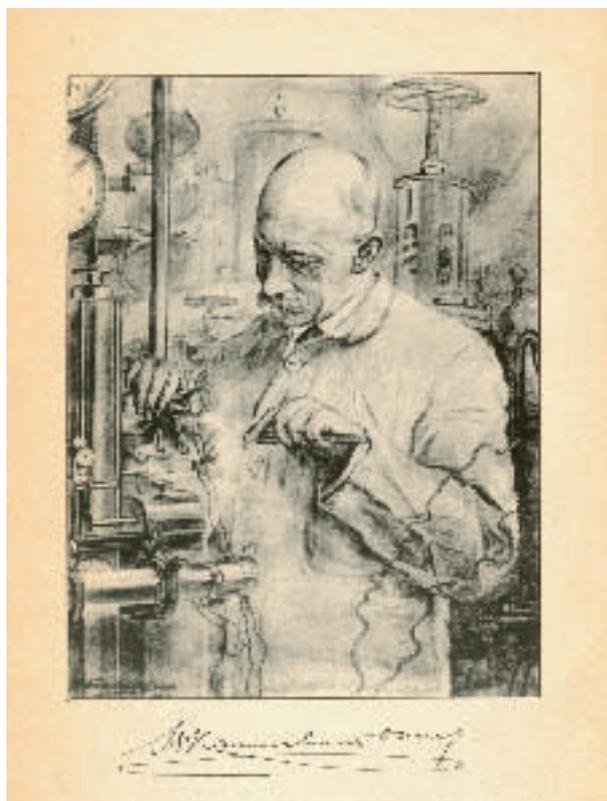
All these low temperatures were confined to cryostats, dewar flasks to which liquid from the liquefier was transferred. Special equipment (stirring rod, metal thermometers, vacuum pump, etc.) was used to keep the temperature in these cryostats constant – to an accuracy of 0.01°C – for as long as necessary. Since it was initially impossible to blow large dewar flasks – the glass broke under the resulting tension – the technically far more complex boiling chamber remained in use until the First World War, even though Leiden’s first cryostats had been introduced in 1902. It was not abandoned until Kesselring succeeded in making viable cryostats with a width of 12 cm and more.

The temperature in the cryostat could be adjusted precisely through the pressure above the liquid present. The lower the pressure, the colder the temperature – down to a certain minimum. Switching to a different liquid opened up a different temperature range. Methyl chloride achieved temperatures from -24 to -90°C , laughing gas (nitrous oxide) from -90 to

-102°C , ethylene from -104 to -160°C , methane from -161 to -183°C , oxygen from -183 to -217°C , hydrogen from -253 to -259°C and finally, helium could attain the range from -269 to -272°C . This left a gap between oxygen and

³⁵ For an overview, see W.H. Keesom, ‘Thermodynamische onderzoekingen’, *Het Natuurkundig Laboratorium 1904-1922*, 114-127.

³⁶ *Ibid.*, 115-116.



Ill. 39. Kamerlingh Onnes at work in his cryogenic laboratory; drawing by Menso Kamerlingh Onnes, 1904 (Wagenaar Hummelinck Collection).

hydrogen. For this range, liquid neon was used, but it covered only the temperatures from -246 to -249°C , besides which the use of neon presented certain disadvantages. In 1917 Onnes therefore introduced the hydrogen vapour cryostat³⁷ (improved in 1921). In this new apparatus, a current of hydrogen gas, finely adjusted by a heat resistor combined with a metal thermometer, kept the experimental chamber at the desired constant temperature, in between that of liquid hydrogen and of pumped-off liquid oxygen.

The first experiments with liquid helium were performed in the liquefier itself. Onnes wanted to build a separate helium cryostat, similar to the hydrogen

³⁷ H. Kamerlingh Onnes, 'Methods and apparatus used in the cryogenic laboratory. XVII. Cryostat for temperatures between 27°K and 44°K ', KNAW, Proceedings, 19 II, 1917, Amsterdam, 1917, pp. 1049-1058. *Comm.* 151a.

one, but this proved a hugely exacting task. In 1910 a successful transfer of liquid helium to a separate vessel was finally achieved,³⁸ but that turned out to have been a question of luck: subsequent attempts failed. A year later, after various adjustments had been made, the helium cryostat was ready for use.³⁹ A separate cryostat provided more space for instruments, and in 1911 Onnes determined helium vapour pressure at temperatures above the normal boiling point.⁴⁰ The helium cryostat was initially attached to the liquefier; not until December 1923 did the scientists manage to transport the helium to a different space within the laboratory.⁴¹ The building of a helium vapour cryostat for temperatures extending to 13 K also ran into technical difficulties, which Onnes and Flim eventually overcame in 1922. A second dewar glass was inserted upside down into the silver-coated dewar glass containing liquid helium.⁴²

An empirical equation of state

This entire frenzy of instrument-making, calibration and calculation was all intended to advance the Great Plan: research into the equation of state, the law of corresponding states, and related areas of thermodynamics. The first goal was to determine the isotherms of hydrogen – when the initial preparations were being made in 1893, Ramsay had yet to discover helium on earth. In 1901, when Onnes had calibrated the manometers, thermometers and piezometers at his disposal, Schalkwijk decided to tackle the first hydrogen isotherms – those in close proximity to 20°C. In the years that followed, attention shifted to lower temperatures, after which the circle was completed in 1915, when the isotherm of 20°C was measured once again. At 100 atmospheres, the correspondence with the experiments of the French high-pressure pioneer E.H. Amagat turned out to be better than 99.9%.

³⁸ H. Kamerlingh Onnes, 'Over het bereiken van temperaturen, belangrijk beneden het kookpunt van helium', *Gedenkboek aangeboden aan J.M. van Bemmelen* (Den Helder 1910) 441-446.

³⁹ H. Kamerlingh Onnes, 'Further experiments with liquid helium. E. A helium cryostat', KNAW, Proceedings, 14 I, 1911, Amsterdam, 1911, pp. 204-210. *Comm.* 123.

⁴⁰ H. Kamerlingh Onnes, 'Further experiments with liquid helium. F. Isotherms of monatomic gases etc. IX Thermal properties of helium', KNAW, Proceedings, 14 II, 1911-1912, Amsterdam, 1912, pp. 678-684. *Comm.* 124b.

⁴¹ W.H. Keesom, *Helium* (Amsterdam 1942) 171.

⁴² H. Kamerlingh Onnes and W. Tuyn, 'Further experiments with liquid helium. R. On the electric resistance of pure metals. XI. Measurements, concerning the electric resistance of ordinary lead and of uranium lead below 14° K', KNAW, Proceedings, 25, 1922, Amsterdam, 1922, pp. 451-457. *Comm.* 160b.

Van der Waals's equation of state was of little practical usefulness. It was so inaccurate with the measured isotherms that Onnes decided in 1901 to resort to an empirical equation of state.⁴³ In the absence of any empirical findings in Leiden, he used the measurement series published by the Frenchman Amagat for hydrogen, nitrogen, oxygen and carbonic acid. After trying out numerous variants, he decided to use the equation $pV = A + B/V + C/V^2 + D/V^4 + E/V^6 + F/V^8$. The 'virial coefficients' A to F were still functions of temperature. Values for the virial coefficients could be distilled – after a fiendish amount of calculation – from every accurately determined isotherm. Temperature, pressure and volume were expressed in terms of the critical values of these variables, to make it possible to compare different substances. This yielded a *reduced* empirical equation of state with *reduced* virial coefficients. The latter were cast in the form of equations, each of which contained four constants, later raised to five – which meant that the reduced empirical equation of state had a dizzying 25 constants.

One problem in the research on the equation of state was that the experiments on monatomic and diatomic substances took in only relatively small intervals of reduced temperature and pressure. 'Sticking together' small intervals to obtain a wide-ranging experimental reduced equation of state was problematic: it was permissible only where the law of corresponding states was strictly accurate. Still, even in the case of a mere approximation, an averaged-out, reduced equation of state had a certain value, in particular as a reference. In 1908 one was put together on the basis of observations with hydrogen, oxygen and nitrogen (Amagat), isopentane (Young) and ether (Amagat, Ramsay, Young).⁴⁴ That same year, Keesom studied a 'disturbance function' to improve this 'VII.1.', as the averaged-out reduced equation of state had been dubbed, in the neighbourhood of the critical point.⁴⁵ An even better idea was to narrow the expression down to an empirical, reduced equation of state for monatomic substances: that was more accurate still. In 1911, Crommelin took the first step in this direction by publishing the reduced empirical equation of state for argon.⁴⁶

⁴³ H. Kamerlingh Onnes, 'Expression of the equation of state of gases and liquids by means of series', KNAW, Proceedings, 4, 1901-1902, Amsterdam, 1902, pp. 125-147. *Comm.* 71.

⁴⁴ *Comm.*, supplement 19, May 1908.

⁴⁵ H. Kamerlingh Onnes and W.H. Keesom, 'On the equation of state of a substance in the neighbourhood of the critical point liquid-gas. I. The disturbance function in the neighbourhood of the critical state', KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 603-610. *Comm.* 104a.

⁴⁶ H. Kamerlingh Onnes and C.A. Crommelin, 'Isotherms of monatomic substances and their binary mixtures. XIII. The empirical reduced equation of state for argon', KNAW, Proceedings, 15 I, 1912, 1912, pp. 273-280. *Comm.* 128.

The next challenge was to relate the 25 constants, the product of a phenomenological approach, to the structure of the molecules and their mutual attraction. Keesom in particular would distinguish himself with his theoretical work. In 1912 he derived formulas for the second virial coefficient for diverse types of interactions between molecules, with Boltzmann's statistical approach.⁴⁷ Keesom also applied Planck's new quantum theory to the equation of state (see chapter 28). It should be added that the empirical equation of state formulated by Onnes in 1901 survived many alternatives, and is still used by physicists today.

Critical opalescence

Odd-man-out in Leiden's research on the equation of state was critical opalescence. A pure substance (or a mixture of two substances) scatters incident light to a degree dependent on the colour of the light, the angle of vision, and the temperature. This effect is seen in sunlight penetrating the earth's atmosphere – the blue sky is the result of a more marked scattering or opalescence of red light. The dispersal of light, observed the British scientist Rayleigh in 1899, occurs with density fluctuations: on a micro-scale, air molecules are not evenly distributed in space; their criss-cross movements lead them to form brief, random local accumulations.

In November 1907, Kamerlingh Onnes and Keesom worked on a study of light scattering in ethylene at temperatures falling to the critical value of just over 11°C.⁴⁸ Keesom, who did the lion's share of the work on this project, left open the possibility that, regardless of molecular density fluctuations, the ethylene gas would condense into a haze of extremely fine drops near the critical point. The experiment was set up to find the dimensions of these drops (if they existed) and the length scale of the fluctuations. To this end, an optical setup had been arranged with a Nernst lamp, a collection of lenses, prisms and nicol prisms, and a spectroscope. In their Academy article (February 1908), which refuted the notion of drops, Onnes and Keesom called their measurements 'provisional'. The race to liquefy helium took priority, and the work on critical opalescence was put on the back burner – no sequel ever materialised.

⁴⁷ W.H. Keesom, 'On the deduction of the equation of state from Boltzmann's entropy principle', KNAW, Proceedings, 15 I, 1912, 1912, pp. 240-256. *Comm.* 24a. See also *Comm.* 24b, 25 and 26.

⁴⁸ H. Kamerlingh Onnes and W.H. Keesom, 'On the equation of state of a substance in the neighbourhood of the critical point liquid-gas II. Spectrophotometrical investigation of the opalescence of a substance in the neighbourhood of the critical state', KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 611-623. *Comm.* 104b.

This also had to do with advances made elsewhere. Three weeks before this Academy article was published, the Polish theoretical physicist Marian von Smoluchowski gave a theoretical description of critical opalescence in *Annalen der Physik*,⁴⁹ just in time for Keesom to incorporate his most important results. Thus Keesom, building on Smoluchowski's theory, had derived an opalescence formula enabling him to test this theory against the measurements taken in Leiden – the Pole came through with flying colours. In the Academy's *Verslagen*, this formula was simply stated without explanation, but the English version in *Proceedings* (and *Communication* 104b) included a footnote explaining how it had been derived.

Two years later, Einstein too derived an opalescence formula, following a stricter route, and ended up with the same result as Keesom.⁵⁰ In February 1911, when Einstein gave a guest lecture at the invitation of Leiden students, he went to see Onnes and Keesom and the conversation naturally turned to opalescence. Einstein said he was looking forward to seeing an experimental verification of his opalescence formula, to which Onnes replied that Keesom had already performed this test. Einstein immediately acknowledged the priority that had been established in the brief footnote to *Communication* 104b, and urged Keesom to publish his formula separately in *Annalen der Physik* – which the Dutchman duly did.⁵¹ It should be said, however, that Einstein was unimpressed by Keesom's derivation. In 1911, when the young professor Wind died and a successor had to be chosen for the chair in Utrecht, Julius asked Einstein whom he rated more highly as a physicist – Keesom, Debye or Ornstein.⁵² The father of relativity theory replied from Zürich that Debye seemed to him the better theorist, and that Keesom, in order to derive his formula from Smoluchowski's theory, had taken a step that the Polish physician himself had rightly described as unfounded.⁵³ The Utrecht professorship was offered forthwith to Debye.⁵⁴

⁴⁹ Marian von Smoluchowski, 'Molekular-kinetische Theorie der Opaleszenz von Gasen im kritischen Zustande, sowie einiger verwandter Erscheinungen', *Annalen der Physik* 25 (1908) 205-226.

⁵⁰ Albert Einstein, 'Theorie der Opaleszenz von homogenen Flüssigkeiten in der Nähe des kritischen Zustandes', *Annalen der Physik*, 33 (December 1910) 1275-1298.

⁵¹ W.H. Keesom, 'Spektrophotometrische Untersuchung der Opaleszenz eines einkomponentigen Stoffes in der Nähe des kritischen Zustandes', *Annalen der Physik* 35 (1911) 591-598.

⁵² Julius to Einstein, 20 November 1911, Utrecht University museum, Julius archives, map vacature Wind.

⁵³ Einstein to Julius, 22 November and 18 December 1911, Utrecht University Museum, Julius archives, map vacature Wind.

⁵⁴ H.A.M. Snelders, 'De bemoeienissen van Lorentz en Einstein met de Utrechtse leerstoel voor theoretische fysica (1911-1914)', *Gevina* 10 (1987) 57-71.

In the meantime, the Amsterdam chemistry student Frits Zernike had submitted an article on critical opalescence to the Holland Society of Sciences as a competition entry. He won a gold medal (though he would rather have had some money) and elaborated his article, which was divided into a theoretical and an experimental section, into a doctoral dissertation.⁵⁵ In 1914, while he was working as an assistant to the astronomer Ko Kapteyn in Groningen, Zernike wrote a ground-breaking article on opalescence, together with Leonard Ornstein, repairing shortcomings in Einstein's 1910 article.⁵⁶ Onnes and Keesom were unpleasantly surprised by the dissertation of 1915. Onnes immediately dashed off an indignant letter to his friend Professor Haga, director of the Physics Laboratory in Groningen. He was incensed that Zernike had made not mentioned the fact that Onnes and Keesom had been the first to measure opalescence in simple substances. To add insult to injury, Zernike had expressed a theoretical objection to the Leiden approach, which Onnes exposed as false.⁵⁷ Zernike's earlier criticism of Keesom's statistical approach to gases had also irritated Onnes, who believed in Keesom's ability to 'fathom the theoretical depths of phenomena' – rather an overstatement in the case of critical opalescence. But even though Jean Perrin, the French physicist who used critical opalescence to calculate Avogadro's number (and thus to demonstrate the existence of molecules), referred in his book *Les Atomes* to 'le beau travail de Mr. Keesom', and Keesom's experimental approach to critical opalescence was emulated elsewhere, none of this helped to advance the man's career.

Keesom did derive honour, however, from the mammoth article 'Die Zustandsgleichung' (The equation of state) that he wrote with Onnes, which was published in the *Encyclopädie der mathematische Wissenschaften* in 1912.⁵⁸ It provided a comprehensive survey of the results achieved to date by theoretical research into the equation of state and the law of corresponding states. Keesom, who did the majority of the work for this article, won universal acclaim for his accomplishment.⁵⁹ Pieter Zeeman described the publication as 'a superb monument of – and to – Dutch science', the *Fortschritte der Physik* called it the most extensive and comprehensive work ever written on the equation of state, Jellinek referred to it in volume II of his textbook of physical

⁵⁵ Frits Zernike, *L'opalescence critique, théorie et expériences* (Amsterdam 1915).

⁵⁶ L.S. Ornstein and F. Zernike, 'Accidental deviations of density and opalescence at the critical point of a single substance', KNAW, Proceedings, 17, 1914-1915, Amsterdam, 1915, pp. 793-806.

⁵⁷ Keesom to Zernike, 28 February 1915 (draft), MB, Keesom archives, box 1.

⁵⁸ H. Kamerlingh Onnes and W.H. Keesom, 'Die Zustandsgleichung', *Encyclopädie der mathematische Wissenschaften* 5 (Leipzig 1903-1921) 615-945.

⁵⁹ Heike Kamerlingh Onnes to Dekhuijzen, 22 July 1916, National Archives in North Holland (N-HA), Keesom archives.

chemistry as an ‘inexhaustible quarry’, and Lorentz extolled the article’s extreme thoroughness and comprehensiveness.⁶⁰ The same letter in which Einstein deprecated Keesom’s theoretical contribution to critical opalescence was full of praise for the *Encyclopädie* article – which had only been available in the form of proofs until then. ‘It is more than a mere paper’, wrote Einstein. ‘It displays throughout a keen eye for important and interesting subjects, besides which it exhibits great clarity and a pleasingly graphic cast of mind.’⁶¹ Max Planck, who pioneered the ‘old’ quantum theory at the beginning of the century, praised the meticulousness of the article, and fellow German scientist Arnold Sommerfeld called the work ‘monumental’.

The *Encyclopädie der mathematische Wissenschaften* was an idea devised by Felix Klein, Heinrich Weber and Franz Meijer. In 1894 they conceived the idea of marking the turn of the century by bringing together, in a concise form, all the knowledge acquired thus far in the fields of pure and applied mathematics, including the mathematics of physics and technology.⁶² The project, published jointly by the Academies of Science in Göttingen, Leipzig, Munich and Vienna, kept expanding and would eventually run to over 30,000 pages in dozens of volumes. It was not finished until the 1920s. Famous *Encyclopädie* articles include Wolfgang Pauli’s entry on the theory of relativity, Lorentz’s brilliant articles on electron theory, and Maxwell’s theory of electromagnetism; the article by Paul and Tatiana Ehrenfest on the foundations of statistical mechanics also acquired the status of a classic. Not all the entries attained this standard, but as a whole, the encyclopaedia was a monument to the power of human thought.

Both the volumes on physics were coordinated by Arnold Sommerfeld, who was then professor of theoretical physics in Aachen. In 1898, in the preparatory stages of the project, Sommerfeld and Felix Klein travelled to Leiden, where they secured a promise of cooperation from Lorentz – Kamerlingh Onnes was still rather hesitant. The correspondence between Onnes and Sommerfeld on the *Encyclopädie* (it is mostly Onnes’s letters that have been preserved) began on 13 September 1899. Onnes wrote that he declined to participate in the project. It was unclear to him exactly what the editors had in mind, especially given that physicists dealt differently (far less rigorously) with mathematics than mathematicians. Onnes did express his approval, however, of the fact that authors were being sought in the Netherlands.⁶³

⁶⁰ Lorentz to Keesom, 7 October 1912, N-HA, Keesom archives, inv. no. 17.

⁶¹ ‘Es zeigt sich überall ein scharfer Blick für das Wichtige und Interessante, ferner eine grosse Klarheit und wohltuende Anschaulichkeit des Denkens’, Einstein to Julius, 18 December 1911, Utrecht University Museum, Julius archives, map vacature Wind.

⁶² *Encyclopedie der mathematische Wissenschaften*, vol. I (Leipzig, 1898-1904), V-XX.

⁶³ Heike Kamerlingh Onnes to Sommerfeld, 13 September 1899, Deutsches Museum, Sommerfeld archives.

Sommerfeld, undeterred, shrewdly suggested that Korteweg, who had published on Gibbs surfaces, could help Onnes with the mathematics. In his reply, Onnes sighed that he could scarcely refuse a second time. Korteweg would take care of the mathematics, while Onnes promised to contribute ‘a few pages’ on the experimental side of things. Now that the requirements in terms of length and deadlines had been relaxed, wrote Onnes, Leiden was willing to contribute an article. Either he or one of his students would provide it; Sommerfeld could expect an article in a few months’ time.⁶⁴

That was rather an optimistic prediction. In May 1900, Onnes wrote that he could not promise to submit the article by Easter 1901. To be on the safe side, he suggested October as deadline, so that he could use the summer holiday if pressed for time.⁶⁵ Sommerfeld immediately agreed.⁶⁶ But that was only one in a series of postponements. In March 1901, Onnes wrote that now that his assistant Max Reinganum had left for Münster, he would be glad of a replacement to help write the *Encyclopädie* article. Could Sommerfeld perhaps ask Klein if he knew of a student interested in Gibbs models who might be able to help him in Leiden?⁶⁷ Onnes sent off similar enquiries to others in Germany, and in 1902 W. Heuse, a student of Emil Warburg’s at the Institute of Metrology in Berlin, started work in Leiden as an assistant.

In May 1903, Onnes seized the opportunity of the looming rectorship to explain a further delay. In the same letter he asked Sommerfeld to suggest yet another assistant; Heuse had left.⁶⁸ The new arrival was H. Happel, who greatly disappointed Onnes and was sent packing within the year. Meanwhile, other contributors were starting to submit articles on related subjects (Bryan on thermodynamics, Boltzmann on the kinetic theory of gases, and Minkowski on capillarity). Onnes had to guard against overlaps, and his working area kept shrinking.⁶⁹ Still, there was no question of giving up: Onnes now regarded it as his duty ‘to do justice to the role played by Van der Waals and the Dutch physicists who have followed in his footsteps in the development of the equation of state.’ Holland was one of the key players, and deserved its place in the limelight.

⁶⁴ *Ibid.*, 20 February 1900.

⁶⁵ *Ibid.*, 25 May 1900.

⁶⁶ Sommerfeld to Heike Kamerlingh Onnes, 26 May 1900, MB, archives of Heike Kamerlingh Onnes, inv. no. 309.

⁶⁷ Heike Kamerlingh Onnes to Sommerfeld, 20 March 1901, Deutsches Museum, Sommerfeld archives.

⁶⁸ *Ibid.*, 8 May 1903.

⁶⁹ *Ibid.*, 20 April 1904.

In 1904 – the ‘few pages’ had mushroomed into a vast project; light dawned when Onnes decided to enlist the help of his assistant Willem Keesom, who had just gained his doctorate, for the encyclopaedia article. This proved to be a brilliant move. For eight years, alongside his activities as an assistant and supervisor, Keesom laboured on the project systematically and with immense dedication – with such thoroughness, in fact, that the end seemed further away than ever. By June 1905, Onnes was forced to admit that he had fallen even further behind his (most recently updated) schedule. A proposal to print at least part of the article remained unanswered. In 1909, Lorentz – who was also late – wrote to Sommerfeld that Keesom was working away diligently but that it was unclear if much remained to be done. In December 1911, after another three years of arduous effort, the article was finally finished.

But what an article! With its 327 pages, *Die Zustandsgleichung* is the second longest article in the *Encyclopädie* – Smekal’s piece on quantum theory from 1925 is twenty pages longer. Almost all the 1,125 footnotes were added by Keesom, and testified to his wide-ranging knowledge of the literature. The monograph derived its significance, wrote Onnes, ‘not so much from its length and comprehensiveness as from the deeply incisive criticism to which Dr Keesom subjected every part’. It was published as ‘supplement 23’ in the *Communications*, along with name and subject indexes. It was not a fully rounded whole. Shortly after it appeared in 1912, Keesom – still going strong – published a few theoretical articles on the second virial coefficient that would have fitted perfectly into *Die Zustandsgleichung*. Marbled boxes of archives with handwritten notes testify to Keesom’s colossal effort, with Onnes’s comments along the way.

26. Huize ter Wetering

Kamerlingh Onnes went bald quite early in life. Photographs do not lie. While the first-year student Heike, at just seventeen years of age, was still posing self-confidently for the photographer with a dark – if thinning – head of hair, five years later, as president of Groningen's student fraternity, he already had receding temples. During his first few years as a professor in Leiden his hairline continued to recede, and before the new century dawned, Onnes, not yet fifty years old, was quite bald. Moreover, the once slim young man had become heavy-set in middle age. What did not change was his proud gaze, his air of determination, his prepossessing manner and his class-consciousness.¹

The professor's class-consciousness was ingrained, but it did not impede good relations with his staff. On Sunday afternoons Onnes went to have tea with his technicians, travelling in a small carriage. But in the Physics Laboratory, his will was law. His unique demeanour was a combination of mildness and *fortiter in re* (firmness in action), as Academy president Went expressed it in 1926.² On the one hand he could enjoy a boat trip with his technical staff to the Brasemer Lake to celebrate the 25th anniversary of his doctorate – with a brass band playing the Dutch national anthem, the 'Wilhelmus', as they sailed away, and Heike and Bé 'contributing energetically to the cheerful mood'³ – and on the other hand, he thought nothing (according to an anecdote told by De Nobel) of summoning Flim from his house on the opposite bank of the Galgewater by sounding a ship's bell. At which the manager of the cryogenic laboratory would dutifully cross the water in a little rowing-boat.⁴

Heike was a family man. He attended the occasional concert, but as he grew older he scarcely ventured out of the house in the evening air, on his doctor's advice. He was highly susceptible to colds, which all too easily developed into

¹ There is a series of photographs of Kamerlingh Onnes in *In memoriam Heike Kamerlingh Onnes 1853-1926* (Leiden 1926).

² F.A.F.C. Went, 'Heike Kamerlingh Onnes', *Verslagen* 35 (February 1926) 210.

³ MB, archives of Heike Kamerlingh Onnes, inv. no. 196.

⁴ Jacobus de Nobel, 'The discovery of superconductivity', *Physics Today*, September 1996, 41.

bronchitis – forcing him to rest. ‘I have become so fearful of the evening air’, Onnes said to Van der Waals in 1912, explaining apologetically why he could no longer stay to dine with his friend after the Saturday Academy meetings.⁵ Heike and his family spent six weeks of the summer months in the mountains of southern Germany and Switzerland, so that he could – quite literally – recover his breath in health resorts such as Montreux, Bentheim, Lac de Champex and Lungern.

Heike discussed family matters with his brother Menso. Their main source of concern was Onno. In 1888, after a few small jobs in Amsterdam, he had become secretary to Van Marken, director of the Yeast and Methylated Spirits Factory in Delft. Since Onno was ‘more a man of action than of the pen’, Menso and Heike sometimes had to provide a little guidance.⁶ In 1895 he returned to Amsterdam, where he earned a living providing commercial information and had a seat on the city council from 1897 to 1907. As the director of the Netherlands Company for the Protection of related interests in South Africa, Onno was active during the Boer War, and as the inspired secretary of the South Africa Committee in Amsterdam, he provided a splendid counterbalance, remarked Heike, to the ‘*bourgeois satisfaits*’ who ruled the roost there.⁷

Onno’s marriage plans had caused a considerable stir. His sudden announcement that he was engaged to be married, in May 1901, had greatly shocked his elder brother, who was indignant that he had not been consulted about this ‘most important decision’ in Onno’s life. Then, Heike briefly considered that matrimony might bring great joy, until he heard that the fiancée was Lottie, an assistant. This ‘second shock’ was the bigger blow, Heike confided to Menso, ‘since I knew he was forfeiting his chance of a career... And I still don’t see how he managed to avoid that disaster.’

Onno was 39 years of age, and scarcely knew Lottie when he proposed; she had made him wait for three weeks before giving him her answer. Heike, who could see that Onno had no intention of ‘suppressing his passion’ and wanted to marry at all costs, considered that the most suitable surroundings for the couple to become better acquainted would be in family get-togethers.

‘These surroundings are more congenial to [Onno’s] ideals than the bourgeois and less refined circles that he tends to frequent. I ascribe a substantial role in this choice to a reaction against what he perceives in us as a lack of idealism, unstinting effort, open-mindedness, sincerity, courage and self-confidence, independence from convention and suchlike. Let him become better acquainted with those circles; he will find that

⁵ Heike Kamerlingh Onnes to Van der Waals, 17 December 1912, N-HA, Van der Waals archives.

⁶ Menso to Heike Kamerlingh Onnes, 19 September 1888, coll. De Knecht.

⁷ Heike Kamerlingh Onnes to Menso, 28 August 1899, coll. De Knecht.

they are more materialistic than we are, although we are not blameless, unless he has truly discovered a remarkable character. In this serious matter of his happiness, there must be no question now of prejudice or shattering illusions. If he and Lottie do not achieve the harmony that he will ultimately want to achieve, it must be because he and Lottie cannot do so – not because their brothers or sisters have done or omitted to do such-and-such, or thought or preferred such-and-such.⁸

Heike asked Onno if Lottie might not like to help him with the ‘export paper’ – Onno was editor-in-chief of the *Algemeen Nederlandsch Exportblad en supplementen*⁹ – but this was too difficult for ‘a girl like that’. At which Heike assessed the quiet Lottie against his ultimate yardstick. ‘Without money, without a name, Onno could perhaps have at his side a woman as a mother, with such boundless strength and energy, such health and good humour, such inner common sense, such inexhaustible kindness and self-denial – a heroine, as Rosenstein rightly called Mother¹⁰ – if so, one would not have a moment’s worry about the future, then the good in Onno could be nurtured, and his disappointment and bitterness assuaged.’

Heike thought it unlikely that Onno would leave his fiancée in the lurch. His brother had urged the necessity for her to come and stay in Leiden, and ‘the passionate way in which he was constantly patting and pulling at her and handling the more or less conspicuous parts of her anatomy’ also spoke volumes. ‘In any case, to marry has become Onno’s heart’s desire’, sighed Heike, ‘and he may have thought that this is the only way to do so – would perhaps rather sacrifice an honourable career, and seek to achieve power by financial means, something he has always condemned in the past.’ But while the head of the family briefly entertained the notion of frightening Lottie off by telling her that Onno had been seriously ill and ‘would be unable to obtain life insurance’, he decided this would be going too far.

Heike need not have worried; the marriage was called off. Instead of sinking into depression, Onno expanded his ‘export paper’ into a Commercial Information Office, which he set up on Oudebrugsteeg in Amsterdam – he had the VOC motto ‘De cost gaet voor de baet uit’ (‘investment comes before profit’) inscribed on the eaves of the building. Six years later, Onno launched an offensive to move the Colonial Museum from Haarlem to Amsterdam and to expand it into an Overseas Institute. A three-day public campaign yielded pledges worth over 800,000 guilders,¹¹ but the plan collapsed when the city

⁸ Heike Kamerlingh Onnes to Menso, 27 May 1901, coll. De Knegt.

⁹ KB, manuscripts collection, file of Onno Kamerlingh Onnes.

¹⁰ This was when Onno had been taken seriously ill in the autumn of 1882; the medical professor Rosenstein advised a health cure, and his mother immediately took him to the Riviera. See chapter 11.

¹¹ O. Kamerlingh Onnes, *Een Overzee-Instituut te Amsterdam* (Gorinchem 1910).

council allocated the hoped-for site, on Damrak beside the Exchange, to the 'fashion-house' De Bijenkorf. By then Onno had managed to get his Office represented on the board of Heike's Dutch Society of Refrigeration Technology (see chapter 27). He finally married after all; Gesina Elfring became his wife in 1915. Onno also produced paintings, which he occasionally exhibited, and in old age he published a book of verse.

The three houses

In the 'Special festive programme' handed out to the guests at Heike and Be's silver anniversary party on 14 September 1912, the second act was a reading for three voices entitled 'The three houses'.¹² 'House in Vreewijk', read by cousin Willy, praised the peace and quiet in Leiden's green suburbs, the meadow with tall trees, the bank of the pond with its abundant yellow and purple irises – and then noted that Heike was always late for dinner. Stationsweg, 'played' by Marijke (Menso's eldest daughter), came into the picture in 1892, after little Albert had almost died from the 'cold, damp vapours rising from Vreewijk's ground'. The apartment on the drier Stationsweg (initially in Oegstgeest, but reassigned to Leiden after the border changes of 1896) was far less spacious, so that the gentlemen were obliged to smoke their after-dinner cigars 'standing around the peat-shed'.

In 1898, after staying briefly with Menso, who had a villa on the river Rhine (on what is known today as Haagweg), Heike rented the country house 'Villa Nova', very near his brother's home, likewise overlooking the water. The house (on ground assigned until 1920 to the municipality of Zoeterwoude, then to Leiden) belonged to the director of the Museum of Ethnography, who had decided to spend his final years in Batavia. Mother Antje stayed alternately with Heike and Menso, contributing 2,750 guilders a year to their households from the Feerwerd brickworks. When she was staying with Menso, Heike could invite foreign scholars to stay. In March 1899, he had to write to William Ramsay and Arthur Schuster (Heike had met the latter during his *Wanderjahr* in Heidelberg) to regretfully cancel an invitation to stay: his mother had fallen dangerously ill. He wrote to Zeeman that he would be missing the Academy meeting 'on account of my mother's indisposition, which has caused us grave concern over the past few weeks and continues to do so'. On 10 April 1899 Antje died, after initially being cared for in her eldest son's home, at the nursing home Veld- en Rijnzicht, at the age of 69. After her death, Heike would always carry her last letters with him in his wallet.¹³ Menso later recalled 'how some

¹² Coll. De Knegt.

¹³ Heike Kamerlingh Onnes to Van der Waals, 18 July 1900, N-HA, Van der Waals archives.



Ill. 40. Huize ter Wetering on Galgewater (Haagweg) after its renovation in accordance with a design by Menso Kamerlingh Onnes in 1906 (collection of G.A. Kamerlingh Onnes-Baroness Van Dedem).

small thing could make Mother so truly merry and festive, and how it is thanks to our numerous affectionate family days that even in the darkest and most careworn years the sunshine remained, the reflection of Her greatness and unsung virtues and talents.¹⁴

In December 1904, Heike purchased 'Villa Nova', complete with trees, boathouse, stable, summer-house (recalling the old eighteenth-century summer-house and playground), coach-house, shed and garden for 14,000 euros, roughly twice the annual salary of a professor. The house underwent thorough renovation according to plans designed by Menso. On both sides it acquired extensions with bay windows, creating balconies for two of the bedrooms. Heike sat on the south balcony to breathe the fresh air that so benefited his health – a curtain was hung up to protect him from the wind and from the gaze of curious passers-by. Menso endowed 'Huize ter Wetering', as the house became known, with an elegant but austere façade, a 'rich fantasy in lines of a magical beauty'¹⁵. Blinds were installed, all the upper-storey windows were

¹⁴ Menso to Heike Kamerlingh Onnes, 8 August 1907, coll. De Knegt.

¹⁵ *Op. cit.* note 12.

given small panes of glass, and Menso explained that the new roof-tiles, which were ‘wonderfully evenly laid’, created a distinctive roof.¹⁶ Inside, in the new living room, hung work by Menso and by Floris Verster, including a water-colour entitled ‘Grief’ and a view of Vreewijk. The painting with old mother Antje – ‘How wonderful it would be if this were to work out well’, Heike had encouraged his brother¹⁷ – was given a place of honour.

On the opposite bank of the Galgewater was the boathouse of the student rowing club Njord. The students had little regard for modesty, according to an anecdote told by Casimir. ‘One year, when the teams had started on their spring training, they adopted the habit of diving into the water after their practice sessions, and saw no need to pull on bathing suits. Mrs Onnes was scandalised and told her husband to do something. So he sent off a letter expressing interest in the oarsmen’s training, mentioned their swimming with approval, but begged their indulgence: he had a weak stomach and two young maidservants, and since their swimming had started his dinner was constantly being dished up burnt.’¹⁸ Truth or fiction, the story illustrates Heike’s affection for typically boisterous student behaviour.

As in the case of so many professors, Heike’s family was the safe base, the fortress, from which he operated.¹⁹ The family belonged to the Dutch Reformed Church, but were scarcely active members of the congregation. Bé and the live-in maidservants kept a neat, well-ordered household. ‘Without my wife I would never have been able to achieve all that’, Heike recalled in 1922. ‘She toiled on my behalf; always put me first, always received my guests, took an interest in the fortunes of my young people.’²⁰ Dutch domesticity set the tone at Huize ter Wetering. ‘I am in poor health’, Heike remarked in the same interview, ‘I have to take that into account; we have learned to conserve my strength. That is why our circle has become so small; we do not go to concerts, plays or dinners.’ Even so, the house on the Haagweg was a hub of science and culture. Foreign house-guests such as Philipp Lenard, Madame Curie, Albert Einstein and Niels Bohr were welcomed hospitably, and Menso and Floris Verster attracted other artists such as Jan Toorop, Albert Verwey and Carel Lion Cachet to the house; the latter designed batik motifs and Jugendstil interiors for passenger ships.

Heike and Bé’s son Albert seems never to have given his parents any cause for concern. He was a model pupil at the *gymnasium* and a diligent law student.

¹⁶ Menso to Heike Kamerlingh Onnes, 25 August 1906, coll. De Knegt.

¹⁷ Heike Kamerlingh Onnes to Menso, 28 August 1899, coll. De Knegt.

¹⁸ Casimir, *Haphazard Reality*, 164.

¹⁹ Otterspeer, *Wiekslag*, 395

²⁰ Itallie-van Embden, *Sprekende portretten*, 47.

In 1915 he obtained a doctorate on the strength of a dissertation *Openbare wegen over particulieren grond*, after which he led an unremarkable life as a lawyer and a civil servant (at the Ministry of Defence). In his youth he played with Menso's children; contact with the Catholic neighbours was confined to affable nods by way of greeting. Strong family affection abounded in the Onnes household. Here is a passage from a moving letter in which Heike thanked a niece (the daughter of one of Bé's brothers) for her letter congratulating him on his 65th birthday.

Dear child, You gladdened my heart so amicably with your affectionate congratulations. I am so touched that you remember your uncle so faithfully and thus share in his joy and happiness. This 65th birthday was indeed a remarkably happy day for me. Just remember last year, dear child, when your uncle was bedridden around this time; I was compelled to celebrate my birthday in the bedroom – or sick room it was, then. I was certainly taken care of very sweetly. Aunt and Albert sat with me, and Albert read to me from *Paul Kelver*, a very fine book by Jerome K. Jerome that you should read too some time, but the joy and happiness with which we were able to celebrate my birthday this last Sunday, that was such a very different affair! Yesterday I met father and mother at the birthday of Grandfather Bijleveld, and was able to tell him that you had given me so much pleasure with your warm epistle, and I was also so happy to add that such splendid new nephews have arrived and that you are all having such an enjoyable time together there in the dunes [of Bloemendaal]. That is such a fortunate thing for the rest of your lives, to forge ties of friendship when you are young. Now that you do so with such ease, it will scarcely occur to you that in later life you will do well to bind [such friends] close to you with steel hooks! Will you always feel the same tenderness for your uncle as you show him now, which gives him such pleasure?

Now I must close, dear child. With great affection from myself and your aunt, your loving uncle, Heike.²¹

A quarter of a century's friendship with Van Bemmelen (1890), a quarter of a century's 'Illustrious port club' (1899, friends from his student days in Groningen): such milestones were celebrated with festive dinners. Letters to current and former employees marking cheerful or sad events expressed a similar affection. In 1909, Heike congratulated his students Jacob Clay and Teddy Jolles on the birth of their first daughter. 'What a wonderful gift you have been given. If she grows up like her mother, and why should one expect otherwise, she will be assured of everyone's sympathy and affection and will be a ray of sunshine in your home.' After which he recalled the infancy of his own son Albert: 'You will soon be touched by the mere sound of that little voice

²¹ Heike Kamerlingh Onnes to his niece, 23 September 1918, coll. Prakke-Bijleveld.

coming from the crib – and then the little fingers that I am sure you will not dare to touch, any more than I did with my boy – they seem so delicate.²²

In 1915, Clay's treatise on the concept of 'natural law' (*Schets eener kritische geschiedenis van het begrip natuurwet in de nieuwere wijsbegeerte*) won a competition set by those responsible for administering the Stolp Bequest at the University of Leiden.²³ Heike quickly dispatched a letter to the prizewinner, who was then a teacher in Delft, congratulating him on his 'important work on natural law'.²⁴ As a PhD student, Clay combined the 'knowledge through measurement' physics of Kamerlingh Onnes with the Hegelian ideas of the grandiloquent, gruff but inspiring self-made philosopher Bolland.²⁵ Although in 1912, in his inaugural address in Delft, Clay called the master rhetorician a 'profound master of logic'²⁶, not everything that Bolland hurled into the world could count on his endorsement. In 1908, Bolland called Lorentz's electron theory 'a piece of fiction ... that was already known to the ancient Greeks'²⁷ and just before the publication of his *Natural Law*, Clay tried – in vain – to stop the Society for Pure Reason (Bolland's fan club) from publishing his address 'Natuurkunde en natuurbegrip' ('Physics and understanding nature'), in which he accused physicists of navigating by 'the capricious light of the imagination' instead of trusting to his superior conceptual theory. 'Thus, even from the mouth of a man such as Lorentz, physics stutters in woefully un-magisterial tones when it speaks of Space and Time.' Bolland also scoffed at Einstein's relativity theory, as a 'mathematical prank seeking to present itself in the guise of physics'.²⁸ Fine rhetoric, and complete rubbish.

Heike considered that Clay had found his niche with his *Schets*. 'Examining the philosophical reflections of Helmholtz, Poincaré, Mach and others in the light of – and expanding them with – insights gained more recently in the field of physics, and considering them in relation to the theory of knowledge, which you have also studied from the philosophical side, while your own experimental work on the boundaries of current knowledge has familiarised you with the essence of research into natural phenomena, seems to me an undertaking full of promise.'

²² Heike Kamerlingh Onnes to Clay, 11 December 1912, coll. Frieling-Van Osselen.

²³ For Clay's philosophical activities, see K. van Berkel, 'Wetenschap en wijsbegeerte in het werk van Jacob Clay', *Citaten uit het boek der natuur* (Amsterdam 1998) 241-263.

²⁴ Heike Kamerlingh Onnes to Clay, 25 November 1915, coll. Frieling-Van Osselen.

²⁵ Willem Otterspeer, *Bolland*.

²⁶ J. Clay, *De drieledigheid der natuurkennis. Rede, uitgesproken bij de opening zijner lessen in de natuurphilosophie aan de Technische Hoogeschool te Delft op Woensdag 14 February 1912* (Haarlem 1912) 29-30.

²⁷ Bolland, *De natuur: proeve van toegepaste zedeleer* (Leiden 1908). See Otterspeer, *Bolland*, 457.

²⁸ Otterspeer, *Bolland*, 488-489, 493-494.

How did Heike behave with close colleagues? Kuenen and Keesom were his students, and they had very little say in determining the direction of the laboratory's research. Within the limits of this power structure, relations were cordial. Lorentz, who had left Leiden for Haarlem in 1912 to become curator of Teylers Museum and secretary to the Holland Society of Sciences, had known Heike since their student days, and the two had sustained a 'loyal, untroubled friendship', Lorentz would aver at Onnes's grave.²⁹ In a long article outlining Lorentz's scientific work for the *Chemisch Weekblad*, marking Lorentz's departure as a full professor in Leiden, Heike recalled his kindness in taking over the big weekly lectures from him back in 1883, 'a gesture of the warm friendship which binds Lorentz and myself, which has made the privilege of having worked with him – for thirty years now – something I have valued immensely'.³⁰

Casimir remembered Lorentz as 'an extremely amicable man ... happy to help people when they asked for it, but someone who scrupulously avoided concerning himself, if unasked, with other people's affairs; in that respect he was diffident and almost shy'.³¹ His successor Paul Ehrenfest – Lorentz's own choice – was a very different kind of man.³² Ehrenfest, who was born in 1880 and gained his doctorate in Vienna under Ludwig Boltzmann, came from St Petersburg to Leiden in October 1912. Not everyone in the Netherlands was pleased with the appointment of a foreigner. Jacob Clay (writing in the daily newspaper *NRC Handelsblad*) called it 'a disgrace',³³ earning him a mild reprimand from Lorentz: 'Is that not putting it rather too strongly?'³⁴

Immediately after Ehrenfest's appointment, Heike sent a letter of congratulations to St Petersburg, with an offer of friendship and of help settling into Leiden.³⁵ His new colleague wrote back by return of post that he was 'unfortunately unskilled as an experimentalist' but that he took a lively interest in laboratories that were wholly immersed in the spirit of experiment (with 'volldurcherlebten Experiment'). 'I consider myself extremely fortunate to be entering the atmosphere of your school now.' Ehrenfest admitted that he had

²⁹ H.A. Lorentz, *Collected Papers*, Volume IX (The Hague 1939) 407.

³⁰ H. Kamerlingh Onnes, 'H.A. Lorentz', *Chemisch Weekblad* 9 (30 November 1912) 942-961.

³¹ Casimir, *Haphazard Reality*, 65.

³² Martin J. Klein, *Paul Ehrenfest, Volume I: the making of a physicist* (Amsterdam 1970). Vol. 2, on the period from about 1920, was never published. See also Pim Huijnen, '*Die Grenze des Pathologischen: het stille leven van fysicus Paul Ehrenfest 1904-1912*', master's thesis at the University of Groningen, August 2003.

³³ *Nieuwe Rotterdamsche Courant*, 2 October 1912.

³⁴ Lorentz to Clay, 3 October 1912, coll. Frieling-van Osselen.

³⁵ Heike Kamerlingh Onnes to Ehrenfest, 29 September 1912, MB, Ehrenfest Scientific Correspondence.

much to learn in the field of low temperatures, and promised that he would not shrink from asking ‘foolish questions’. He also confessed candidly that his ‘erratic temperament’ was bound to lead him into blunders. To guard against any irreversible damage, he urged Onnes and Lorentz to give him the benefit of their advice, including friendly criticism or correction when necessary.³⁶

Ehrenfest arrived in mid-October, and took lodgings, together with his wife, the mathematician and educationalist Tatiana Afanaseva, their two young daughters, a Russian nanny, and Tatiana’s aunt, in Hotel Pension Futura on Stationsweg. Heike and Bé soon invited them for Sunday tea. After a friendly start, relations became somewhat more businesslike, since their personalities were too different for a real friendship. In his diary, Ehrenfest described Kamerlingh Onnes as ‘a friendly gentleman’ who was perhaps not dissimilar to the physicist Daniel Chwolson in St Petersburg – which was not a compliment.³⁷ The Ehrenfest family soon found a house on Groenhovenstraat and in 1914 they moved to a villa designed by Tatiana in Witte Rozenstraat. The space, the beige plaster, the unusual arrangement of the interior and the house’s setting amid a garden all made a stark contrast to the Dutch red-brick terraced houses that dominated the rest of the street.

This splendid house – more precisely, its ground-floor study, complete with blackboard – was the venue for the Wednesday colloquiums that were to achieve a certain fame. Unlike Lorentz, who preferred to remain silent until he had a fully-rounded theory to present, Ehrenfest saw debate and lively interaction with his peers as essential elements of life as a physicist. ‘Ehrenfest’, recalled his student Casimir, ‘was not only a merciless critic of anything that was stupid or lacking in clarity, but he was also, and perhaps more notably, a passionate admirer of beauty and profundity’³⁸ With Ehrenfest there was never a dull moment. His lectures and speeches were animated events, and he peppered his German with marvellous expressions such as ‘Das ist wo der Frosch ins Wasser springt’ (‘That is where the frog jumps into the water!’; that is the whole point). He associated freely and informally with students, sometimes even helping in the choice of a fiancée. At his initiative, the lecture room in the theoretical institute, in the former gas engine room of the Physics Laboratory, was turned into a student library – the first of its kind in Leiden.³⁹ This ‘Bosscha reading room’ – Johannes Bosscha purchased this name with a

³⁶ Ehrenfest to Heike Kamerlingh Onnes, 3 October 1912, MB, Ehrenfest Scientific Correspondence.

³⁷ Klein, *Ehrenfest*, 196.

³⁸ Casimir, *Haphazard Reality*, 66.

³⁹ Otterspeer, *Wiekslag*, 379.

2,500-guilder grant⁴⁰ – was very popular with the students. It subscribed to *Annalen der Physik*, *Philosophical Magazine* and *Zeitschrift für Physik*, which students could consult on the premises. Ehrenfest was also a driving force within ‘De Leidsche Flees’, a student society that organised lectures – it had even managed to rope in Einstein in 1911. The debating club ‘Christiaan Huygens’, which recruited its members among talented students of mathematics, physics, chemistry and astronomy – people like Jan Burgers, Dirk Struik, Dirk Coster, Marcel Minnaert, Hans Kramers, Anton Pannekoek, Nettie Roosen-schoon, Nel and Johanna van Leeuwen – always invited Ehrenfest to attend its meetings.

It will be clear that the vivacious Ehrenfest and the more formal Kamerlingh Onnes had little in common. Onnes rarely showed up for the colloquiums at Witte Rozenstraat, since he preferred not to expose his fragile health to the evening air. He and Ehrenfest were good colleagues whose mutual respect flourished at a certain distance. Onnes never mentioned Tatiana, and did not close his letters to Ehrenfest with affectionate regards ‘from our house to yours’ as in his correspondence with Zeeman or Lorentz. Even so, when Ehrenfest sent Onnes some ‘lovely flowers’ when he was ill in 1917, Onnes wrote back a cordial letter into which he sprinkled a few words in Russian.

The two men had little scientific contact, but Ehrenfest rushed over to see Onnes perform his experiment with a persistent superconducting current (see chapter 29). They even published an article together. In 1914 they submitted to the Academy a sparkling, insightful derivation of Planck’s formula for the number of ways in which fixed packets of energy can be distributed among a set of oscillators.⁴¹ Ehrenfest informed Lorentz that he and Onnes had greatly enjoyed writing the article, which soon became well known among physicists.⁴² Max Planck in turn wrote to Onnes from Berlin that he thought it an ‘interesting piece’.⁴³ What Heike’s contribution consisted of is not entirely clear.

Zeeman’s windows

The commemorative volume produced to mark the 25th anniversary of Heike’s doctorate has a frontispiece with a chalk drawing by Menso. It shows the professor clad in a laboratory coat standing in his cryogenic laboratory, pouring

⁴⁰ K.A.R. Bosscha to Lorentz, 1 June 1913, N-HA, Lorentz archives, inv. no. 9.

⁴¹ P. Ehrenfest and H. Kamerlingh Onnes, ‘Simplified deduction of the formula from the theory of combinations which Planck uses as the basis of his radiation theory’, *Proceedings*, 17, 870-873, 1914. *Comm. supplement* 37.

⁴² Klein, *Ehrenfest*, 255-256.

⁴³ Planck to Heike Kamerlingh Onnes, 10 March 1915, MB, archives of Heike Kamerlingh Onnes.

out a glass of liquid air. A perfect union of cold and art such as only the Kamerlingh Onnes family could produce.⁴⁴

Heike followed every turn of his brother's artistic career. Menso experimented with photography, including prints – 'those also go with the trade'⁴⁵ – and painted live models, still lifes and landscapes. After his marriage to Kitty Tutein Nolthenius, his output shrank. That was related to his ill health (he had only one kidney), and his interest gradually shifted towards the decorative arts and architecture. Menso scarcely moved in artists' circles, preferring to converse with the academics who came to Heike's house. He made portraits of a number of them, including Lorentz, Van Bemmelen and Zaaijer as well as his brother, and some of these paintings are now among the *Icones Leidensis* in the Senate room of the university building. A self-portrait dating from 1907 shows Menso 'in luminous yellow and white', as the critic Conrad Kikkert noted in *Elsevier's Geïllustreerd Maandblad*,⁴⁶ brushes in one hand, cigarette in the other, straw hat and a neatly trimmed beard. He exuded an air of distinguished aristocracy, 'placed in a room throbbing with the life conveyed by his brush-strokes'.

Menso painted Lorentz in 1915, to celebrate the fortieth anniversary of the aging physicist's doctorate. The painting was Heike's idea, and he consulted Pieter Zeeman on the choice of artist. He noted that Menso would not focus on his fee, adding that his brother painted only 'great minds', never models (which he had abandoned after his early years) or 'ordinary people'.⁴⁷ Menso's portrait of Zaaijer had cost 600 guilders. Veth and Toorop could also be considered, said Heike, although he feared that Toorop was rather too eccentrically modern, so that a portrait by him might not find favour, at least in scientific circles.⁴⁸ And Toorop's penchant for mysticism was surely the direct opposite of Lorentz's own mindset.⁴⁹ Heike also suggested his brother-in-law Floris Verster, who had recently made a portrait of Mrs Kröller ('Bremmer goes into raptures about his work'), and noted that Isaac Israëls was also a perfectly good choice ('I hear that he is the best'⁵⁰). Menso might be less modern, but the psychological element in his work produced a greater understanding. Furthermore, having a painter who lived locally would make the portrait

⁴⁴ Dirk van Delft, 'Koude en kunst: opkomst en ondergang van de familie Kamerlingh Onnes', *De Gids*, 165 (December 2002) 945-952.

⁴⁵ Menso to Heike Kamerlingh Onnes, undated (prob. 1887), coll. De Knecht.

⁴⁶ Conrad Kikkert, 'M. Kamerlingh Onnes', *Elsevier's Geïllustreerd Maandblad* 38 (1909) 361-370.

⁴⁷ Heike Kamerlingh Onnes to Zeeman, 26 October 1915, N-HA, Zeeman archives.

⁴⁸ *Ibid.*, 15 December 1915.

⁴⁹ *Ibid.*, 17 January 1916.

⁵⁰ *Ibid.*, 29 December 1915.



Ill. 41. Heike Kamerlingh Onnes at home in Huize ter Wetering, around 1920.

sessions easier to arrange. If Menso was chosen, he would have to be positively urged to accept: 'My brother only dares to take on work when the client expresses a firm preference for him.' The portrait of Lorentz was well received, and cost the contributors to the anniversary gift (154 in total⁵¹) 1,400 guilders.⁵² Later on, the Academy commissioned Menso to make another version; this later one hangs in the Trippenhuis.

Menso's son Harm also made a chalk drawing of Heike in the laboratory, depicted in profile in simple lines, near a gas flask, for the 1922 commemorative volume (forty years as a professor). As a boy Harm had developed an interest in technology. He drew trains, and loved tinkering with all sorts of machines under the supervision of his clever uncle Heike, whose house was

⁵¹ *Ibid.*, 11 April 1916.

⁵² *Ibid.*, 16 April 1916.

his second home.⁵³ At one point he even thought he had invented a perpetual motion machine from rotating magnets and running water. He had an aversion to book learning. In 1911, when he was eighteen, his father put him out of his misery and allowed him to leave the *gymnasium* to spend his time drawing and painting – not at an academy, however, which his father felt would only harm his originality.

Harm was frequently to be found at his uncle Heike's Physics Laboratory, sketchbook in hand. His 'Laboratory of Heike Kamerlingh Onnes' (1920) with its robust machines, undoubtedly intended for the pursuit of absolute zero, is drawn on paper. A rather later sketch, with Heike leaning on a table, bears the caption: 'Uncle Heike waiting for the liquefaction of helium in an experiment to make it solid'. Harm also made paintings in the laboratory: he depicted flasks, cryostats, and the large magnet. There is a highly stylised work entitled 'The laboratory of Professor H. Kamerlingh Onnes' (1921): it is an oil painting without depth, a cubic representation of experimental physics. Like his father Menso, Harm was a gifted portraitist. He painted Albert Einstein with a distracted gaze, and produced an angular profile of Paul Ehrenfest (twice; one is owned by the Stedelijk Museum, Amsterdam, the other hangs in the Lorentz Institute), Tatiana Ehrenfest, Menso and Kitty, his uncle Heike and his sister Marijke. Members of the Supreme Court sat for him in later years.

In 1921 Heike commissioned his nephew to design the stained-glass windows that were to illustrate the Zeeman effect. Four years earlier, as part of the project 'De Vonk' in Noordwijkerhout that he had executed with his friend J.J.P. Oud and Theo van Doesburg, he had produced stained-glass windows for the hall, only to hear from Van Doesburg that the cheerful multi-coloured images ruined his tile mosaic. Now, with Zeeman's windows, Harm's took his artistic 'revenge' in magnificent style. Half-way down the corridor of the Physics Laboratory, near lab I, three stained-glass windows were inserted into the wall behind which Zeeman had achieved his triumph, each one measuring 1.75×0.72 metres. Together they depicted the discovery – and explanation – of the Zeeman effect. Subdued and austere in shape and colour, in a style recalling the work of Bram van der Leek, they adorned the corridor: Zeeman peers at the sodium light between green electromagnets while Lorentz ponders his formulas. Art and science merge in the geometric patterns of the stained glass. In 1997 the windows were moved to the ground-floor hall of the Oortgebouw.

⁵³ Willem L. Baars, Jetteke Bolten-Rempt, Doris Wintgens Hötte, *Harm Kamerlingh Onnes* (Leiden 2000).

27. Monsieur Zéro Absolu

Applications of cold are almost as old as the world. Zimrilim, king of Mari (the Babylonian name for present-day Tell-Hariri in Syria), built an ice-house on the bank of the Euphrates, around 1700 BC. The ice was wrapped in rags and straw to make it last longer. The Chinese also used ice long before the beginning of the Christian era to conserve fruit and vegetables.¹ The Romans cooled their wine with ice, and Pliny the Elder attributed the invention of the ice-bucket to the emperor Nero. In the Middle Ages, the courts of Baghdad and Damascus had Lebanese snow delivered by camel.

The mid-nineteenth century witnessed a sharp increase in the demand for natural ice during the summer months in Europe, North America (where ice was soon being used by the middle classes) and the colonies. The demand was perhaps greatest among breweries producing lager, which ferments at 5-8°C, unlike the 20° to 30°C of many English beers. The advent of railways and steamships boosted trade in natural ice from Scandinavia and Canada, but suppliers could not keep pace with the growing demand. Furthermore, rising concern about the sawing of blocks of ice from polluted rivers and lakes gave an extra impetus to the development of machines that could manufacture clean artificial ice. The producers of natural ice lowered their prices in a fruitless effort to reverse the tide.

The first machine to produce a continuous output of ice was invented by the French businessman Ferdinand Carré. His idea was to release ammonia from a water solution by heating it, to condense the vapour under pressure until it was liquefied, and then to allow this liquid to evaporate and expand in a sealed space. This would extract heat from an adjoining space with water, which would immediately freeze. The vapour would be absorbed by the 'aqua ammonia', after which the cycle would be repeated. A prototype was placed in a brewery in Marseille in 1859. Carré's ice machine achieved a certain fame

¹ Rudolf Plank, 'Geschichte der Kälteerzeugung und Kälteanwendung', *Handbuch der Kältetechnik* 1 (Berlin 1954) 1-5.

when it was displayed at the Paris world exhibition of 1867. He was already doing a brisk trade before then: the Confederates had bought several machines from him during the American Civil War (1861-1865). After some adjustments made by Mignon and Rouart in Paris, the vapour absorption device was one of the best-selling refrigerators in the years 1870-1885, especially in France. After that it was superseded by the vapour compression refrigerator, which is based on a far simpler construction.²

This system, which is still applied in household refrigerators, artificial ice rinks and industrial plants today, was invented by the French engineer Charles Tellier, earning him the title 'le père du froid'. It uses a closed cycle. A compressor is used to compress methyl ether (which was later replaced by methyl chloride, sulphur dioxide, carbonic acid gas, and most notably ammonia); a water-cooled condenser turns this into liquid, which evaporates in the space to be refrigerated (in a system of pipes – the main difference with regard to Carré's system) and thus extracts heat from it. Tellier built his first refrigerator in Paris in 1863. Four years later he installed an improved version, using methyl chloride as coolant, in an ice factory in Marseille. Commercially speaking, the most successful machines were compression refrigerators using ammonia, launched in 1875 after theoretical studies carried out by the scientifically trained Carl von Linde. The *Gesellschaft für Linde's Eismaschinen A.G.* in Wiesbaden supplied its first machine to a brewery in Munich and was soon the market leader. By 1890 the German company had sold about a thousand machines, and around the turn of the century the Wiesbaden factory was sending off one or two of its refrigerators every day.

A major innovation made possible by the new refrigerators was the export of frozen meat from Australia, New Zealand and South America to Europe. Cooling the meat with ice proved not to be an option; steamships were still slow in the 1870s, and clippers too took over 100 days to cross the ocean. The problem had to be solved with machines. In 1876, Tellier built a compression refrigerator on board the French ship *Le Frigorifique*. This steam-powered three-master sailed from Marseille to Buenos Aires with a cargo of frozen meat, to return to Le Havre a year later. Though not a commercial success, the voyage had demonstrated that shipping frozen meat across the oceans was technically feasible.

Bulk transportation imposed more stringent demands, and the problem with Tellier's machine was that if built on a larger scale, it sometimes broke down. Besides this, the toxicity of the coolants and the risk of explosion de-

² J.F.H. Koopman, 'Iets over de Warmte en het voortbrengen van Koude', *Mededeelingen van de Nederlandsche Vereeniging van Koeltechniek* 8 (March 1910) 1-25.



Ill. 42. Back garden of the Physics Laboratory with gas container.

tered shipowners from taking the plunge. It was another type of refrigerator that made them change their minds: the air expansion machine patented by the Scottish butchers Bell and Coleman in 1877. This cooled the produce by the rapid expansion of compressed air, and in spite of poor efficiency – large steam engines were needed to compress the necessary quantities of air – and problems with frozen water vapour, the sailing vessel *Strathleven* transported 34 tons of frozen meat from Australia to England safely in 1879 using one of these machines.

While it was electrical engineering that had taken the world by storm in the last quarter of the nineteenth century, the baton passed to the cold industry in the early years of the new century. Buyers included breweries and ice-cream factories, cold storage and refrigerated transport companies, hospitals (for the conservation of dead bodies), dairy, chocolate, rubber and perfume factories, dyeworks and factories for liquid carbonic acid, ammonia or air. Those involved in building mineshafts and subway tunnels soon saw the potential of cold in their line of business: refrigerant pipes could be used to create a wall of frozen ground, after which it became far easier to dig out the space inside. In September 1908, the Netherlands and its colonies had over 400 refrigerating machines, divided among 300 different companies and organisations. Dairy

farms had 95, ice-cream factories 90, breweries 67, slaughterhouses 16, and there were another 50 on steamships and navy vessels. In short, cold was a growth market.³

In this atmosphere of up-and-coming cold, of new, hitherto unsuspected applications, of changing economies such as that of Argentina, of a proliferation of technical problems in need of a solution, the idea arose in France – which had soon been overtaken in this field by Germany – of a major international ‘congress of refrigeration’. The Parisian engineer J. de Loverdo was the prime mover, and in May 1907 a circular was distributed calling for participants. The initiative soon attracted a wide-ranging and distinguished band of supporters including l’Institut de France, the French Parliament, the Collège de France, l’Académie de Médecine, major transport companies, the Ministry of War, the Institute of Agriculture, the French land credit association, the Institut Pasteur, Paris city council, and the society of engineers and hygienists. No one interested in cold could afford to be absent from the *Premier Congrès International des Industries Frigorifiques*, which was finally held in the Sorbonne university from 5 to 10 October 1908 under the more appealing and inclusive name of *Premier Congrès International du Froid*.⁴ The broad aim was to exchange ideas and discoveries in the field of cold technology.

To keep the conference manageable, it was divided into six sections: low temperatures, refrigeration installations, applications of cold to foodstuffs, applications of cold in other industries, applications of cold in trade and transport, and a final section that would examine the relevant legislation. The name of the conference made it clear that it was not to be a one-off initiative. Ideas for an international institute for cold and science, or for training courses in refrigeration technology, to be founded in Paris, soon proved over-ambitious. Instead, the preparatory committee offered to set up an Association Internationale du Froid. Its remit would be to perform research on scientific, technological and industrial applications, to set up a library covering all aspects of the field, to publish articles and inform its members, to provide courses, set up excursions, and organise a biennial conference on the subject of refrigeration, to be held in a different country each time.

National committees were formed to ensure that all went smoothly. These coordinated the submission of reports for Paris; and once the Association du Froid actually got off the ground, they would have seats on its executive committee. The committee formed to watch over Dutch interests was chaired

³ J.F.H. Koopman, ‘Les machines frigorifiques aux Pays-Bas’, *Mededeelingen van de Nederlandsche Vereeniging van Koeltechniek* 5 (1909) 6–51.

⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 190.

by Kamerlingh Onnes, who had also been asked to represent the Dutch government in Paris. The 35 committee members included a large number of professors from the Institute of Technology in Delft, but there were also representatives of breweries (Heineken, d'Oranjeboom), Leiden's municipal slaughterhouse, the agriculture inspectorate, the army, the Koninklijke Hollandsche Lloyd shipping company, Vriesseveem cold storage, and oil companies. Even Onno's Commercial Information Office was represented on the committee. J.P. Kuenen, who had been appointed as Leiden's second professor of experimental physics the previous year, took on the position of secretary. In practice, the work was done by J.F.H. Koopman, mechanical engineer at a glass factory in Delft and Schiedam and the representative of the Royal Institute of Engineers. The dominant influence of technological science in the committee was reflected by the appointment of Van der Waals as honorary chairman.⁵

The committee met on 13 July 1908, three days after the conquest of helium, at the Physics Laboratory in Leiden. Just as in 1895, when Onnes had shrewdly exploited his membership of the executive committee of the new Dutch Electrical Engineering Society to enlist support for his instrument-makers' training system, he immediately saw how the Paris conference – and subsequently the Association Internationale du Froid – could be used to the benefit of the cryogenic work in Leiden. So at that first meeting at the Steenschuur laboratory, Onnes immediately proposed setting up a Dutch Society of Cold Technology – only England, the United States and France were faster. Koopman publicised the plan through articles in the trade journal *De Ingenieur* and the daily newspaper *Algemeen Handelsblad*, and on 23 September 1908 the national society had its first meeting, at Onnes's home. The eighteen men present, including Onno, elected their host as chairman and F.B. Löhnis, state inspector of agriculture, as his deputy. Löhnis represented the other end of the spectrum from Onnes, in that he wanted the society to focus on promoting economic interests. 'Our society is more concerned with applications ... than with the pure scientific work, however closely the two may be related.'⁶

It is true that the Society of Cold Technology – which grew slowly but surely, with 146 members five years down the line – was mainly concerned with applications. High on the agenda were imports of frozen meat ('cheap food for the people'; England had fed its soldiers with such meat in the Boer War; but how was it to be vetted as fit for human consumption?) and the conservation

⁵ *Mededeelingen van de Nederlandsche Vereeniging voor Koeltechniek*, 1 (1908) 12-14.

⁶ *Mededeelingen van de Nederlandsche Vereeniging voor Koeltechniek*, 4 (1909) 2-3.

of fresh fish. The society met twice a year and built up a tradition of visiting a refrigeration installation after each meeting, such as Vriesseveem cold storage in Amsterdam, d'Oranjeboom brewery in Rotterdam and IJmuiden fish market. Onnes rarely missed a meeting, and served as a skilful chairman until his death in 1926, though he undoubtedly saw the society primarily as a means to ensuring his continued involvement in the activities in Paris.

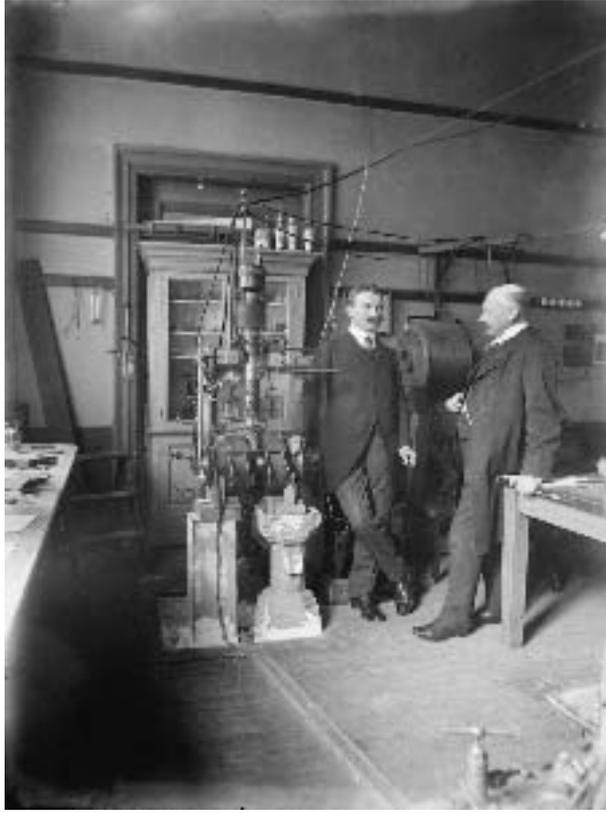
The Premier Congrès International du Froid was a resounding success.⁷ The formal opening session on the morning of Monday, 5 October 1908, in the amphitheatre of the Sorbonne, attracted 3,000 people from 40 countries, and in the course of the week the number of people attending passed the 5,000 mark. The organisers had not counted on anything like this rush of interest, and the first few days were at times chaotic. Even so, numerous reports were presented at the section meetings (13 of them Dutch), international networking flourished, and the excursions were very popular. The conference was chaired by the Frenchman André Lebon, a former minister of trade and colonies. The chairmen of the national committees were all invited to say a few words. Onnes took the opportunity to define the mission of the Association Internationale du Froid: 'to bring together all knowledge bearing on low temperatures'.

His liquid helium made Onnes the star of the conference. The tense events of 10 July had taken their toll on his health, and Onnes was forced to leave the presentation of his paper 'Sur la liquéfaction de l'hélium' to Professor E. Mathias of Toulouse (who had described Leiden's cascade in 1896 in *Revue générale des sciences pures et appliquées*). That Onnes's paper was scheduled for a section meeting instead of the main programme provoked widespread disappointment. Jacques-Arsène d'Arsonval, chairman of the first section, put the Dutchman emphatically in the limelight at the closing session: 'I am happy to be able to pay him the public tribute of conveying your affectionate admiration.' The audience responded with enthusiastic applause.

Earlier that day, d'Arsonval and Onnes, together with their fellow physicists Cailletet, Claude, Pictet, Ramsay – who was representing the British government; Dewar declined to attend the conference⁸ – and Von Linde had defended the interests of scientific cryogenic research. In the avalanche of recommendations that the conference adopted on its final day, applied cold technology predominated, but there were also two follow-up proposals to the goal that Onnes had formulated at the opening session. First: 'An international association shall

⁷ J.F.H. Koopman, 'Het 1ste Internationaal Congres voor Koelindustrieën te Parijs', *De Ingenieur*, 21 and 31 October, 14 November 1908. *Med. Ned. Ver. Koeltech.* 2.

⁸ Heike Kamerlingh Onnes to Dewar, 25 September 1908, archives of the Royal Institution; Dewar to Heike Kamerlingh Onnes, 29 September 1908, MB, archives of Heike Kamerlingh Onnes.



Ill. 43. Heike Kamerlingh Onnes with Albert Perrier, who conducted several series of magnetic measurements in Leiden as a guest researcher.

be set up, with headquarters in Paris, the primary objective of which will be to promote scientific research on cold technology in different countries, in particular relating to extremely low temperatures'. And second: 'This association shall be given the opportunity to make it possible and practicable for physicists of all countries to perform research at the cryogenic laboratory in Leiden, and to give this institution the resources it needs to perform a wide range of research on very low temperatures.'⁹ Both proposals were adopted, and Onnes must have been very put out that his poor health prevented him from attending the 'magnificent party' at the Hôtel de Ville hosted by Paris city council.

⁹ J.F.H. Koopman, 'Het 1^{ste} Internationaal Congres voor Koelindustrieën te Parijs', *De Ingenieur*, 21 and 31 October, 14 November 1908. *Med. Ned. Ver. Koeltech.* 2.

The Association Internationale du Froid duly materialised. It was founded on 25 January 1909, in the presence of delegates from 35 countries. Onnes, felled by bronchitis, was unable to go to Paris (Kuenen stood in for him¹⁰) but was elected to the executive committee nonetheless. Lebon was appointed president of the new association, and De Loverdo became its director. The Paris conference led to the establishment of six international committees. Vice-president Onnes was chosen to chair the ‘first committee’, which was to concern itself with scientific matters, and which also included Cailletet, Guillaume (of the Bureau des Poids et Mesures) and Dewar. Among the first problems that this committee addressed was the absence of standard units in the cold industry, but it soon became clear that achieving agreement between Europe and the Anglo-American world was unattainable in the short term. Also on the Association’s agenda was cryo-biological research. At the Paris conference, the Delft microbiologist Martinus Willem Beijerinck had submitted a treatise on the influence of low temperatures on microbes, some of the research for which he had performed in the cryogenic laboratory in Leiden.

While the Association started life with a few dozen members, by the time of the Vienna conference in October 1910 it had 1,700. Argentina contributed most, with 1,000 members – all because of its frozen meat – and the United States, at 370, also had a strong contingent. For all America’s numerical preponderance, however, 92% of the financial contributions came from Europe.¹¹ In this regard, the Netherlands cut a sorry figure. Paris had counted on the Dutch Society of Cold Technology joining as member-benefactor, with a minimum annual contribution of 500 francs, about 235 guilders. This would have meant half of the money paid in contributions to Koopman going to Paris. More than 50 guilders was simply not on the cards.¹²

In the run-up to the Vienna conference, the Netherlands provided 15 members – good for 300 francs in contributions. That was 200 francs below the limit conferring entitlement to a seat on the executive committee, De Lovardo warned darkly¹³ – Onnes had tried arguing that small countries merited a seat with 250 francs, but to no avail.¹⁴ For purposes of comparison: Italy had

¹⁰ MB, archives of Heike Kamerlingh Onnes, inv. nos. 169 and 301. A German-Austrian proposal to postpone the founding of the Association until the second congress of refrigeration in Vienna was strongly opposed by Kuenen, on the instructions of Kamerlingh Onnes. To be doubly sure of getting his message across, Onnes also sent a telegram to this effect to the president, Lebon, who agreed.

¹¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 190.

¹² *Med. Ned. Ver. v. Koeltechniek*, 4 (1909) 20.

¹³ De Lovardo to Heike Kamerlingh Onnes, 24 August 1910, MB, archives of Heike Kamerlingh Onnes, inv. no. 190.

¹⁴ *Bulletin de l'Association Internationale du Froid*, 1 (August 1910).

35 members, contributing a total (including the government contribution) of 5,000 francs, Russia, with its 13 members, contributed the same amount, France provided 50 members and 2,300 francs, Portugal 20 members and 1,000 francs, Great Britain 45 members and 750 francs, and Belgium's 20 members paid a total of 500 francs. The problem was that the Dutch government initially paid a meagre 100 francs. Not until December 1912, when the third conference, in Chicago, came within sight, did the Ministry of Agriculture, Industry and Trade finally join as member-benefactor with an annual contribution of 500 francs. E. Gouault (who had taken over after the death of De Loverdo) sent a jubilant letter from Paris saying that the Netherlands was now suddenly entitled to *two* seats on the executive committee¹⁵ – the second seat was for Löhnis.

The second 'congress of refrigeration', from 6 to 11 October 1910 in Vienna, attracted over 3,000 participants. Onnes, whose health was greatly improved since Paris, was able to take part in the social events arranged in the margins of the conference: festive performances at the Hofopera and Hofburgtheater, a banquet for 1,800 people in the town hall – enhanced with *Kaiserwein* and a leather cigar-case with the city's coat of arms as a memento for every guest – and on Sunday a trip to the Semmering. Other excursions too were on offer, to Budapest and Prague, but Onnes decided to give them a miss.

The Vienna conference, too, was brimful of cold. In the first section, Onnes presented a paper entitled 'Research performed in the cryogenic laboratory in Leiden'.¹⁶ It gave a survey of results achieved at the Steenschuur in the previous two years, with the emphasis on contributions by foreign guest researchers. Thus, Mathias, working with the support of the Paris Academy, had determined the densities of liquid oxygen and saturated oxygen vapour.¹⁷ Leiden had also been studying the inert gas neon,¹⁸ which Onnes had obtained in an impure state as a gift from Claude, director of l'Air Liquide. Existing research projects were being expanded in the cryogenic laboratory to include lower temperatures. In the area of liquid hydrogen, Lenard and Pauli from Heidelberg had come to Leiden to study phosphorescence in rare

¹⁵ Gouault to Heike Kamerlingh Onnes, 15 January 1913, MB, archives of Heike Kamerlingh Onnes, inv. no. 266.

¹⁶ H. Kamerlingh Onnes, 'Onderzoekingen verricht in het kryogeen laboratorium te Leiden', *Mededeelingen van de Nederlandsche Vereeniging voor Koeltechniek*, 12 (February 1911) 26-39. *Comm. supplement* 21b.

¹⁷ E. Mathias and H. Kamerlingh Onnes, 'The Rectilinear Diameter for Oxygen', in KNAW, Proceedings, 13 II, 1910-1911, Amsterdam, 1911, pp. 939-956. *Comm.* 117.

¹⁸ H. Kamerlingh Onnes. 'Isotherms of monatomic gases and their binary mixtures. III. Data concerning neon and helium', in KNAW, Proceedings, 12, 1909-1910, Amsterdam, 1910, pp. 175-178. *Comm.* 112.

earths,¹⁹ and father and son Becquerel had studied the phosphorescence of the uranyl compounds.²⁰ Magnetism at low temperature was the subject of a project by Pierre Weiss²¹ and Albert Perrier²² from Zürich. Onnes had helped his foreign guests with their experiments where necessary (Becquerel and Weiss had turned up with their own apparatus, including a powerful electro-magnet) – and carried on with his own research on liquid helium when he had time.

The invasion of foreign researchers that had been unleashed by the Paris conference enhanced Onnes's status in Vienna. As soon as he had finished his presentation, the Brussels professor Jules-Émile Verschaffelt, who had studied under Onnes, got to his feet. Speaking for a group including his colleagues Claude, Richard Mollier (a specialist in technical thermodynamics from Dresden), Suida and Hasenöhrl (a student of Boltzmann's who had been one of Onnes's first foreign guest researchers in 1898), he expressed the following proposal: 'Section I, fully persuaded of the great importance of the research conducted by Professor Kamerlingh Onnes, calls on the Association Internationale du Froid to extend a special grant for the benefit of this research.' Von Linde too heartily endorsed this proposal, and it was adopted unanimously. Full of gratitude (and not without cunning), Onnes said that such a grant should be supervised by Cailletet, Von Linde, Dewar, Olszewski and Van der Waals – an illustrious company.²³

¹⁹ P. Lenard, H. Kamerlingh Onnes and W.H. Pauli, 'The behaviour of the phosphorescent sulfides of the alkaline earths at various temperatures, and particularly at very low temperatures', in KNAW, Proceedings, 12, 1909-1910, Amsterdam, 1910, pp. 157-174. *Comm.* 111.

²⁰ J. Becquerel and H. Kamerlingh Onnes, 'The absorption spectra of the compounds of the rare earths at the temperatures obtainable with liquid hydrogen, and their change by the magnetic field', in KNAW, Proceedings, 10 II, 1907-1908, Amsterdam, 1908, pp. 592-603. *Comm.* 103; Henri and Jean Becquerel and H. Kamerlingh Onnes, 'On phosphorescence at very low temperatures', in KNAW, Proceedings, 12, 1909-1910, Amsterdam, 1910, pp. 76-88. *Comm.* 110.

²¹ Pierre Weiss and H. Kamerlingh Onnes, 'Researches on magnetization at very low temperatures', in KNAW, Proceedings, 12, 1909-1910, Amsterdam, 1910, pp. 649-677. *Comm.* 114.

²² H. Kamerlingh Onnes and Albert Perrier, 'Researches on the magnetization of liquid and solid oxygen', in KNAW, Proceedings, 12, 1909-1910, Amsterdam, 1910, pp. 799-835. *Comm.* 116; H. Kamerlingh Onnes and Albert Perrier, 'Researches of magnetism. III. On para- and diamagnetism at very low temperatures', in KNAW, Proceedings, 14 I, 1911, Amsterdam, 1911, pp. 115-122. *Comm.* 122a; H. Kamerlingh Onnes and Albert Perrier, 'Researches on Magnetism. IV. On Paramagnetism at very low temperatures', in KNAW, Proceedings, 14 II, 1911-1912, Amsterdam, 1912, pp. 674-678. *Comm.* 124a.

Albert Perrier and H. Kamerlingh Onnes, 'Magnetic researches. V. The initial susceptibility of nickel at very low temperatures', in KNAW, Proceedings, 14 II, 1911-1912, Amsterdam, 1912, pp. 1004-1007. *Comm.* 126.

²³ *Med. Ned. Ver. v. Koelt.*, 13 (March 1911) 1-22.

The Association's meeting in Vienna on 10 October also produced results that were music to Onnes's ear. A proposal was adopted to set up a grants system enabling young physicists to perform research 'relevant to cold technology' in Leiden's cryogenic laboratory. Verschaffel's plan too was approved. This did not gird the executive committee into action, however, until the meeting of 29 December 1912, over two years after the Vienna conference. That was – not coincidentally, we may be sure – a week after the first 500-franc contribution had been made over to Paris by the Dutch government. On the initiative of Charles Édouard Guillaume (with whom Onnes was then engaged in a lively correspondence on accurate temperature scales), a scientific grants committee was set up, which proposed in April 1912 that Leiden's cryogenic laboratory, 'which performs research of incontestable importance'²⁴ and d'Arsonval Paris laboratory each be given 5,000 francs, the idea being that the grant would be repeated the following year. This was only partially successful: Onnes received 2,500 francs in 1913 – governments defaulting on their pledges had weakened the Association's financial position.²⁵

Onnes was delighted with the grant – he politely demanded a free hand in its allocation²⁶ – and immediately wrote to the members of the proposed supervisory committee. In his letter of 19 May 1912 to Dewar, he said that he greatly appreciated the gift promised by the Association, since it accentuated 'the international character that my laboratory has acquired'.²⁷ The venerable company of pioneers of cold, supplemented with 'the master of us all' Van der Waals (an epithet conferred by James Dewar),²⁸ imposed no restrictions on Onnes whatsoever. Dewar held that the Dutchman should be accountable to no one, and stated that the scientific community had complete confidence that the money would be well spent.²⁹ Which did not stop the Scot accepting a seat on the supervisory committee. In his report on the allocation of the grant, Onnes mentioned several new guest researchers in the cryogenic laboratory: Bengt and Anna Beckman from Uppsala and Sophus Weber from Copenhagen. Mathias and Perrier had continued their experiments in Leiden, while Rutherford (Manchester) and Knudsen (Copenhagen) had been sent some pure helium gas.³⁰

²⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 190.

²⁵ Heike Kamerlingh Onnes to Van der Waals, 17 February 1913, N-HA, Van der Waals archives.

²⁶ *Bulletin de l'Association Internationale du Froid*, 18 (July 1912).

²⁷ Heike Kamerlingh Onnes to Dewar, 19 May 1912, archives of the Royal Institution.

²⁸ Heike Kamerlingh Onnes to Dewar, 18 November 1908, archives of the Royal Institution.

²⁹ Dewar to Heike Kamerlingh Onnes, 22 May 1912, MB, archives of Heike Kamerlingh Onnes.

³⁰ *Bulletin de l'Association Internationale du Froid* 30 (1913) 122-131.

The third international congress of refrigeration, in September 1913 with the dual venues Washington and Chicago, attracted far less interest: only 800 people attended, 670 of them from the host country, and South America was not represented at all. Kamerlingh Onnes was not fit enough for the strenuous journey, and Kuenen went in his place. On Onnes's behalf, Kuenen submitted six proposals to the first section (which had since been split up at Onnes's initiative into three subsections: physics, chemistry and thermometry, with headquarters in Leiden; biology, based in Paris; and units, based in Sèvres). Three of these proposals related to the activities of the Leiden subsection,³¹ progress made by the thermometry committee (headed by Guillaume and Onnes),³² and research into the thermodynamic properties of the coolants ammonia and methyl chloride – as requested by the refrigeration conference in Vienna. This last report had been submitted to a preparatory committee that Onnes had not set up until August. Its members included Arthur Gray (a former assistant of Onnes's), his boss Samuel Stratton of the Bureau of Standards (Washington), Mathias Verschaffelt, Sidney Young (Dublin; supported Onnes in his crusade against the opponents of Van der Waals's continuity theory) and Kuenen. Membership of this committee was an honorary position; none of its members were going to make Onnes's life difficult.³³

The report on thermometry, for which Onnes had set up a similar international committee (always good for networking), contained far-reaching proposals. For the entire range below 100°C, it recommended the helium thermometer as the best high-precision instrument. There was also a great deal of interest in the way in which readings of gas thermometers could be converted into temperatures on the Kelvin scale. This scale begins at absolute zero (which Onnes defined as -273.09°C), with the same distance between degrees as the Celsius scale. The necessary corrections could be calculated strictly thermodynamically, on the basis of observations of the Joule-Kelvin effect, but these experiments ran into unexpected difficulties at very low temperatures. Fortunately there was an acceptable alternative: they could be calculated using the equation of state, based on measurements of isotherms. This was an area in which Leiden had ample experience.³⁴

The other three reports submitted by Leiden in Chicago concerned the cryogenic laboratory's research. Gilles Holst presented old and new measurements

³¹ 'L'organisation des travaux de la section pour la physique, la chimie et la thermométrie', *Bulletin de l'Association Internationale du Froid* 48 (July 1914) 193-199.

³² H. Kamerlingh Onnes, 'Avant-Projet du premier Rapport de la commission préparatoire pour la thermométrie des basses températures', *Comm. supplement* 34a (1913).

³³ MB, archives of Heike Kamerlingh Onnes, inv. no. 270.

³⁴ C.A. Crommelin, 'Thermometrie en manometrie', *Het Natuurkundig Laboratorium 1904-1922*, 211-221.

of ammonia and methyl chloride,³⁵ and Kuenen presented an overview of research performed in the cryogenic laboratory since Vienna. Madame Curie had spent a week in Leiden, seeking to establish whether radioactivity underwent any change at extremely cold temperatures (it did not).³⁶ Perrier had continued his magnetic research, a field in which Onnes also put his assistant Oosterhuis to work. There had been more research on helium, Keesom's theoretical work was mentioned, and as the icing on the cake, the conference heard the story of the discovery of superconductivity (see chapter 29). Once again, the cold in Leiden, unique in the world, had produced exciting science.

The French engineer Georges Claude was impressed. Echoing Jules-Émile Verschaffelt's initiative in Vienna, he launched a plan in Chicago, with the support of Carl von Linde, to set up a special fund for Onnes. He himself promised to contribute 10,000 francs to it (about 5,000 guilders), and d'Arsonval added another 1,000 francs. The proposal was adopted at the closing session of the conference, after which the executive committee of the Association, at its meeting of 7 February 1914 – fired by enthusiasm about the Nobel Prize that Onnes had just won (see chapter 30) – called for international contributions to a fund of 100,000 francs. The Association itself contributed 2,500 francs. At a *dejeuner à midi* at Hotel Mirabeau, just before the meeting, Onnes had been fêted for his prize. It was then that d'Arsonval gave him the title 'monsieur zéro absolu', raised his glass and expressed the fervent hope that Onnes would do countless more 'pointless' experiments (an ironic exhortation to keep to pure science rather than economically attractive applications).³⁷ Onnes must have felt jubilant in Paris: tributes from fellow scientists, a fortune in the offing – what could possibly be better? But then the First World War erupted into Europe, dashing his plans.

³⁵ G. Holst, 'Discussion des mesures faites précédemment sur les propriétés thermique de l'ammoniaque et du chlorure de méthyl', *Comm.* 144b (1913); G. Holst, 'Nouvelles recherches sur les propriétés thermiques de l'ammoniaque et du chlorure de méthyl', *Comm.* 144c (1913).

³⁶ P. Curie and H. Kamerlingh Onnes, 'The radiation of radium at the temperature of liquid hydrogen', in KNAW, Proceedings, 15 II, 1912-1913, Amsterdam, 1913, pp. 1430-1441. *Comm.* 135.

³⁷ *Bulletin de l'Association Internationale du Froid* 44 (March 1914) 113-119.

28. The quantum and zero-point energy

‘Nineteenth-century clouds over the dynamical theory of heat and light’: it was under this title, resonant with *fin-de-siècle* overtones, that Lord Kelvin presented his Friday evening lecture to the Royal Institution on 27 April 1900. The seventy-year-old doyen of nineteenth-century physics, speaking at the lectern from which Dewar had so often enthralled his audiences, broached two thorny issues that defied the classical physics of Newton and Maxwell. The first concerned the relative motion of ponderable matter (with mass) in relation to the ether – Albert Einstein would dispel this cloud in his *annum mirabilis* 1905 with his special theory of relativity, by simply dispensing with the concept of ether.

The second problem related to specific heat. Measurements had shown that the specific heat of many substances had a value far lower than that prescribed by the classical theory. The lower the temperature, the greater the deviation, so that Leiden’s cryogenic laboratory was automatically interested. Here too, a radically new physics had to clear the air. In December 1900, Max Planck explained the spectral-energy distribution of radiation emitted by a black body (a hypothetical object that absorbs all electromagnetic radiation that falls on it) with his radiation law. This law implies the idea of *energy quantisation*: the premise that light energy is radiated only in discrete amounts or *quanta*, the size of which is determined by frequency. Planck based his radiation law (retrospectively) on Boltzmann’s statistical interpretation of entropy, and the science historian and philosopher Thomas Kuhn has shown that Planck did not propose or even unconsciously suggest quantisation in his original derivation of the law.¹ One of the first to point out that a consistent derivation of Planck’s law of black body radiation led inescapably to the positing of energy quantisation was Albert Einstein. Planck’s role as the father of quantum theory has remained controversial to this day.

¹ Thomas S. Kuhn, *Black-body theory and the quantum discontinuity 1894-1912* (Oxford 1978) 125-130.

Planck's radiation law initially attracted little interest from within the field. For years he remained hopeful that his results could be reconciled with classical theory. It was a vain hope. The 1900 radiation law was to pave the way for quantum theory, and there was no way back. Six years later Einstein applied the new approach to the specific heat of condensed matter, and the results tallied precisely.

Kamerlingh Onnes had been raised on, indeed immersed in, classical physics. Although the kinetic theory of gases and electron theory had advanced in great strides in the latter half of the nineteenth century, the entire edifice of physics still rested on three pillars: Newtonian mechanics, Maxwellian electromagnetism, and the thermodynamics of Thomson, Clausius and Gibbs. But by 1911 there was a growing realisation, in Leiden as elsewhere, that there was more between heaven and earth than classical physics. Measurements in the areas of specific heat, magnetism and electrical resistance in extreme cold made theoretical renewal unavoidable, and Planck's quantum theory, though far from complete, at least provided some initial premises to go by.

Ever the pragmatist, Onnes was quick to concede that classical theory fell short in certain areas, and he saw that it made sense to rise to the new theoretical challenges. 'At low temperatures, one is simply in the dark without quanta', Onnes concluded frankly in a letter of October 1914 to Julius in Utrecht – one of his many letters seeking to advance Keesom's career. Although it made 'no sense at all' within the reasoning of classical theory, the quantum idea did produce a whole series of 'daring hypothetical applications' that Leiden could use. Planck's theory revealed close relationships between a variety of phenomena, and Onnes predicted that a great discovery would suddenly shed light on this 'quantum connection'.²

Jan Burgers has noted that Onnes took a keen interest in quantum theory because of its potential significance to his experimental work.³ In Onnes's own words: 'Quantum theory may also prove significant ... to high-precision thermometry at low temperatures, and thus raises issues that are of fundamental importance to the cryogenic laboratory.'⁴ Keesom was of immense support to Onnes in this new project. Where 'compelled to enter the quantum territory', Keesom had perhaps a tendency to adopt 'unduly strong hypotheses and unduly bold derivations'. But Onnes went on to say that the most important

² Heike Kamerlingh Onnes to Julius, 19 October 1914, Universiteitsmuseum Utrecht, Julius archives, map vacature Debye.

³ J.M. Burgers' interview of T.S. Kuhn and Martin Klein, 9 June 1962, as part of the project 'Sources for the history of quantum physics', Burgers archives, Delft University of Technology.

⁴ Heike Kamerlingh Onnes to Dekhuijzen, 22 July 1916, N-HA, Keesom archives, inv. no. 17.

thing was to identify as many phenomena as possible that were linked to the quantum peculiarity. While Keesom's quantum work was sometimes more than bold, 'at times even wild', what mattered was whether it was productive. And he was convinced that it was.

Although Keesom's quantum experiments constantly missed the mark in relation to specific heat, as will emerge below, his theoretical work made a real impact. As the in-house theorist of the cryogenic laboratory, this was where his main duties lay. 'His position requires him to stay abreast of all theoretical issues impinging on the laboratory's work', wrote Onnes in yet another letter of recommendation;⁵ such was Keesom's performance in this, the most difficult part of his job, that Onnes felt confident about basing the laboratory's theoretical principles entirely on his recommendations. The growing significance of low temperatures to theoretical physics had greatly expanded Keesom's working area. With his acute insight and infallible memory, Keesom possessed such encyclopaedic scholarship that he was constantly being consulted not just by his colleagues at the cryogenic laboratory but by 'all the physicists in Leiden'.

That Leiden had embraced the new quantum theory in 1911 was closely related to the first Solvay Conference, which had been held in Brussels from 30 October to 3 November that year. The driving force behind the conference was Walther Nernst (discussed at length below), the man who had been first – in 1909, in Berlin – to test Einstein's quantum theory of specific heat experimentally. Kamerlingh Onnes's laboratory had a new rival.

Nernst, who came from a distinguished Prussian family and boasted an impressive moustache, was a physical chemist with an outstanding command of thermodynamics.⁶ In 1906, shortly after his move to Berlin's Institute of Physical Chemistry, the dynamic and restless director published an article to which he attached such importance – modesty was not his *forte* – that he immediately ordered three hundred offprints.⁷ This article, 'The calculation of chemical equilibria from thermal measurements',⁸ contained the provisional formulation of what was initially called 'Nernst's theorem', and later 'the third law of thermodynamics': when the temperature approaches absolute zero, the

⁵ Heike Kamerlingh Onnes to Julius, 19 October 1914, Universiteitsmuseum Utrecht, Julius archives, map vacature Debye.

⁶ Diana Kormos Barkan, *Walther Nernst and the transition to modern physical science* (Cambridge 1999); K. Mendelsohn, *The world of Walther Nernst: the rise and fall of German science* (London 1973).

⁷ Cyril Domb, 'Thermodynamics and statistical mechanics (in Equilibrium)', Laurie M. Brown, Abraham Pais and Sir Brian Pippard (ed.), *Twentieth Century Physics I* (Bristol 1995) 535.

⁸ Walther Nernst, 'Über die Berechnung chemischer Gleichgewichte aus thermischen Messungen', *Königliches Gesellschaft für Wissenschaften Göttingen*, 1 (1906).

difference between total and free energy tends to zero. In 1912 Nernst reformulated his law to posit the theoretical unattainability of absolute zero: at that point, entropy tends to zero, making it impossible to remove any more heat from the system. The third law of thermodynamics did not meet with a hearty reception in the Netherlands, where followers of Van der Waals such as Van Laar and Kohnstamm felt they needed no instruction in thermodynamics.⁹

Nernst did not initially posit a link between his theorem and quantum theory. He used it to determine chemical equilibria (such as that between grey and white tin, with a transitional temperature of 19°C) and set up his laboratory on Bunsenstrasse so as to enable him to determine specific heat at low temperatures, for the purposes of verifying his theorem. Liquid air was not cold enough, and Nernst therefore came to look round the cryogenic laboratory in Leiden in 1909 – a visit that led him to conclude that he never wanted anything to do with such a complicated technique.¹⁰ Nernst was a restless man who liked quick results, and the prospect of investing years of his life in building up cryogenic installations as Onnes had done made him shudder. Once back in Berlin, he designed a small hydrogen liquefier that his chief instrument-maker whipped up for him – such that no one else could use it. The permanent liquid baths used in Leiden, which were stable to 0.01°C, were out of the question in Berlin. When Keesom came to check the lie of the land, in the summer of 1914, he was able to reassure Onnes that for the time being at least, Leiden had nothing to fear from Berlin. Nernst was very far from achieving liquid helium, and the same applied to the Institute of Metrology and the Kaiser Wilhelm Institute, besides which there was ‘nothing there remotely approaching Leiden’s hydrogen baths etc.’¹¹

But Nernst had no wish to achieve anything of the sort. He wanted to test his heat theorem, a project that did not require high-precision measurements. With a view to measurements of specific heat, Arnold Eucken – he and the Lindemann brothers were Nernst’s main assistants – designed a vacuum calorimeter that performed so well that Leiden copied his method. A small block of the substance to be examined was suspended in a vacuum (which provided excellent heat insulation) and thin platinum wire was wrapped around it. The wire made it possible to add a measured quantity of heat to the block (acting as a miniature electric heater), while the accompanying temperature rise followed from the increased resistance in the heating wire. Baths of liquid air or hydrogen, whether or not pumped off, raised the ‘sample’ to

⁹ Kipnis et al., *Van der Waals and molecular science*, 170–171.

¹⁰ Kurt Mendelssohn, *The quest for absolute zero*.

¹¹ Keesom to Heike Kamerlingh Onnes, 30 July 1914, N-HA, Keesom archives, inv. no. 18.

the required initial temperature (12 K at the lowest), after which the specific heat would be measured in stages as the temperature rose.

Nernst's vacuum calorimeter was ready for use at the end of 1909, with the hydrogen liquefier following a little over a year later. It was time to harvest some results. Quantum theory too had elicited conclusions about specific heat by then. This was of vital importance. In classical physics, specific heat was a constant – different for each substance, but independent of temperature. As long ago as 1819, Dulong and Petit had determined this value as 25 joules per mole for monatomic substances. Thirteen years later, Franz Neumann had generalised this result to embrace chemical compounds. But it was simply not right. Regnault had already reported discrepancies, and in 1872 Heinrich Weber discovered that the specific heat of diamond did in fact vary with temperature. He found that 25 joules per mole was a limiting value not attained until 1300°C; at room temperature, the value was only 7.5. This sharp decrease at lower temperatures was confirmed by other experimentalists, most notably by Dewar in 1905.

This ran entirely counter to Ludwig Boltzmann's results in the 1870s; he had used kinetic theory to place the 25 joules per mole determined by Dulong and Petit on a sound (statistical) footing. He had shown that the specific heat of monatomic crystals was $\frac{1}{2}R$ ($R = 8.31$, the ideal gas constant) per 'degree of freedom' (ways in which an atom develops energy). An atom in a crystal lattice can oscillate in three independent directions around its position of equilibrium (kinetic energy) and possesses a kind of elasticity (potential energy) in the same three directions. Together this makes six degrees of freedom, and $6 \times \frac{1}{2}R = 3R$; thus, $R=8.31$ produces the result 3×8.31 , or 25. Measurements yielding a far lower result therefore undermined the foundations of classical theory. Boltzmann, when confronted with the anomalous value found for diamond, suggested that the solution might be that atoms formed 'clumps' at low temperatures in crystal lattices. But how did this work with gases, which also displayed lower than expected values for specific heat? It was at this point, in 1900, that Kelvin told his audience about the 'cloud' troubling the air of classical physics.

It was the daredevil Einstein who pointed the way in 1906, by applying a quantum hypothesis to the specific heat of solid substances. The domain of quantum theory, hitherto confined to radiation, was now expanded to include the physics of crystal lattices – which greatly fostered the dissemination and acceptance of the new ideas. Einstein hypothesised that the oscillating atoms in a crystal lattice possessed the same average quantity of energy as Planck had assigned to electrically charged oscillators in the derivation of his radiation law. For the rest, he simplified matters by positing that the atoms all oscillated at the same frequency, independently of one another. The result was a formula

for specific heat that tended to the classical value of $3R$ at high temperatures, but at low temperatures decreased exponentially to zero. Einstein's formula accorded very satisfactorily with Weber's measurements for diamond, a clinching result for quantum theory.¹²

In February 1910, when Berlin was still having to work with liquid air, Nernst and his team published the first two articles in the series 'Untersuchungen über die spezifische Wärme bei tiefen Temperaturen' ('Studies of specific heat at very low temperatures') in the proceedings of the Prussian Academy of Sciences. The results of a whole year of measurements with metals and salts confirmed the prediction that specific heat fell sharply at low temperatures. 'The results suggest', wrote Nernst, concluding his lengthy report, 'that the value tends to zero, in line with Einstein's theory.' Measurements taken in the liquid hydrogen range would provide more conclusive evidence. The Berlin hydrogen liquefier was ready in January 1911, and within a month a whole battery of measurements had been accumulated, yielding the specific heat of copper, aluminium, tin, zinc, diamond and lead. At the same time, theory was being developed at a feverish pace. Nernst and F.A. Lindemann developed a modified Einstein theory which allowed for two possible frequencies instead of one, which accorded even more closely to the observations. The two also pointed to a similarity in the graphs, plotted against temperature, of specific heat on the one hand, and the electrical resistance of metals on the other, all in relation to electron theory and quantum theory.¹³

As already noted, Onnes's laboratory faced stiff competition from Walther Nernst's Institute of Physical Chemistry from 1910 onwards. The two laboratories had very similar financial resources. In the years 1910-12 Nernst had an annual budget of 15,000 marks (about 9,000 guilders).¹⁴ He managed to gather another 10,000 marks of private contributions on top of this government grant – including 5,000 marks in 1912 from the Belgian soda producer, amateur scholar and philanthropist Ernest Solvay. Onnes was allocated a materials grant of 12,000 guilders in this period (compared to 6,000 in Utrecht and 4,500 in Groningen). He exploited the success of liquid helium by persuading the government to give him an additional grant of 5,000 guilders for 'magnetic equipment' for three years running, from 1912 to 1915. In the two years previous to this, Onnes had wheedled an extra 2,500 guilders out of the government for 'improvements to the helium apparatus'.

¹² Albert Einstein, 'Die Plancksche Theorie der Strahlung und die Theorie der spezifischen Wärme', *Annalen der Physik* 22 (1907) 180-190. The article was submitted in November 1906.

¹³ Diana Kormos Barkan, *Walther Nernst*, 172-173.

¹⁴ Barkan, *Walther Nernst*, 205.

Unlike Nernst, Onnes could not rely on help from home-grown industrialists. The kind of close ties that German university laboratories maintained with companies such as Siemens and Bayer were unknown in the Netherlands. So when Solvay came to look round the Leiden laboratory, shortly after the first Solvay Conference in Leiden, he was given red-carpet treatment. ‘On Friday Mr Solvay will be visiting the laboratory’, Onnes had written to Crommelin from the Brussels hotel Métropole in November 1911. ‘We must arrange for a big hydrogen display.’¹⁵ The demonstration produced the desired result: the Belgian industrialist donated 5,000 francs (2,350 guilders) to the laboratory.

Leiden and Berlin also differed minimally in terms of personnel and output of publications. While Nernst had two fellow professors and four or five assistants, Onnes had Kuenen at his side (though his time was largely taken up with teaching) and in addition to his supervisors Keesom and Crommelin he had two or three assistants performing research.

While Nernst and his team produced a total of 120 articles in the period 1906–1914, the number of Communications from Leiden was slightly greater. The main difference between the two laboratories was that after 1910 Nernst was focusing primarily on specific heat at low temperatures and related thermodynamics, while Onnes had several lines of research going at the same time, besides which Leiden also aspired to a role as an international service laboratory (see chapter 27). All this activity limited the research on specific heat. After the German successes in the spring of 1911, Onnes naturally downgraded this research line and focused instead on superconductivity and magnetic susceptibility, fields in which Leiden was clearly leading the way.

Feast for diabolical Jesuits

After the publication of Einstein’s article on specific heat in 1906, Nernst’s team had been more or less alone in studying quantum effects in condensed matter. But in 1911 the interest in quantum theory – which until then was more heuristics than theory – was given a tremendous boost by the first Solvay Conference.¹⁶ Nernst conceived the idea for these meetings of a select group of leading scholars in the summer of 1910, shortly after he returned from visiting Einstein in Zürich. Planck thought it too early for a conference on quantum theory, but Nernst went ahead and presented his plan to Ernest Solvay in July.

¹⁵ Heike Kamerlingh Onnes to Crommelin, 4 November 1911, Huygens Laboratory, archives of Heike Kamerlingh Onnes.

¹⁶ Pierre Marage and Grégoire Wallenborn (ed.), *The Solvay Councils and the Birth of Modern Physics* (Basel 1999).

The Belgian agreed to sponsor the event and on 30 October 1911 an international group of twenty physicists, theorists as well as experimentalists, gathered at the Métropole Hotel in Brussels. For three days they shut themselves off from the outside world to discuss radiation theory and quanta, the theme chosen by Nernst. Those present included the luminaries Planck, Einstein, Lorentz, Sommerfeld, Poincaré, Rutherford, Wien, Marie Curie, Langevin and of course Nernst himself. Kamerlingh Onnes also attended, although his name was not on the provisional list that Nernst sent in July to Lorentz, who was to chair the conference.¹⁷ The photograph of participants also included Solvay, but the ‘gravito-matérialitique’ that he broached in his opening address was listened to politely and then ignored until the closing ceremony.

The first Solvay Conference has been endowed with near-mythical status. In an age in which international conferences were rare, the idea of a roomful



Ill. 44. Participants in the first Solvay Conference, in October 1911 in Hotel Métropole in Brussels. Seated, from left to right: Walther Nernst, Marcel Brillouin, Ernest Solvay, Hendrik Antoon Lorentz, Emil Warburg, Jean Perrin, Wilhelm Wien, Marie Curie and Henri Poincaré. Standing: Robert Goldschmidt, Max Planck, Heinrich Rubens, Arnold Sommerfeld, Frederick Lindemann, Louis de Broglie, Martin Knudsen, Friedrich Hasenöhr, H. Hostelet, T. Herzen, James Jeans, Ernest Rutherford, Heike Kamerlingh Onnes, Albert Einstein and Paul Langevin.

¹⁷ Nernst to Lorentz, 15 May 1911, N-HA, Lorentz archives.

of brilliant minds studying in depth a theme at the forefront of physics was completely new. For the study of quantum theory, the year 1911 was a turning-point: after the Brussels event had highlighted specific heat, a far larger proportion of physicists suddenly started taking an interest. In the Métropole and Solvay's Institute of Physiology, a dozen articles were discussed (all of which had been distributed to those attending in advance); the papers by Lorentz, Planck, Nernst, Sommerfeld and Einstein, in particular, provoked a lively debate. Onnes, who contributed relatively little to the discussions, presented his most recent results regarding electrical resistance, including the superconductivity he had discovered in April 1911 (see chapter 29).¹⁸ The story, larded with a sprinkling of quantum theory, was received in silence: only Langevin asked a question.

Lorentz's chairmanship was praised to the skies. 'It was so enjoyable', wrote Onnes to Crommelin from the Métropole, 'to see that no one could find enough words to praise that extraordinary clarity, ease and friendliness with which he led the discussions, contriving to create and preserve a pleasant, amicable, agreeable and yet serious tone, amid all the differences of opinion.'¹⁹ All this did not change the fact that the conference had raised more questions than it answered. Quantum theory was more of an aid than a mature theory, as Einstein put it, and most of those present assumed that it would eventually be reconciled with classical theory. In one letter, Einstein described the Brussels gathering (alluding to the almost magical world of quanta) as 'a feast for diabolical Jesuits'.²⁰ The success of Solvay 1, it should be added, can be ascribed largely to the French-language publication of the lectures and discussions.²¹

Even before the conference, Solvay had toyed with the idea of setting up an Institute of Physics. Encouraged by the letters of thanks he later received from the conference-goers, he decided to follow through with his plan, and asked Lorentz for his opinion. The latter, with characteristic diplomacy, persuaded Solvay that the new institute should allocate grants for research in physics and physical chemistry as well as organising regular conferences. Lorentz himself chaired the institute's nine-man scientific committee (which

¹⁸ H. Kamerlingh Onnes, 'Rapport sur les Résistances Électriques'. P. Langevin and M. de Broglie (ed.), *La théorie du rayonnement et les quantas* (Paris 1912) 304-312. *Comm. supplément* 29.

¹⁹ Heike Kamerlingh Onnes to Crommelin, 4 November 1911, Huygens Laboratory, archives of Heike Kamerlingh Onnes.

²⁰ 'ein Delicium für diabolische Jesuitenpatres'; Martin J. Klein, A.J. Kox and Robert Schulmann (ed.), *The Collected Papers of Albert Einstein* 5 (Princeton 1993) 349.

²¹ P. Langevin and M. de Broglie (ed.), *La théorie du rayonnement et les quantas* (Paris 1912). Two years later, a German edition (incorporating more recent results) was published by Eucken.

included Onnes), and a separate committee was formed for administration and management. For the position of salaried secretary Onnes suggested his student Jules-Émile Verschaffelt, the man who had kindly proposed a special grant for the Leiden cryogenic laboratory at the Vienna congress of refrigeration in 1910; the appointment was duly approved.²²

The institute opened its doors on 1 May 1912, with one million francs in funds from Solvay: this would keep it going for thirty years, by which time physics would have emerged triumphant. Grant applications were assessed by members of the scientific committee. Of the 36 proposals submitted for 1913, half were approved, to the tune of about 40,000 francs. An application from Otto Sackur from Breslau was completely demolished by Onnes in characteristically mordant style, with an infusion of Dutch chauvinism. Sackur wanted to test the gas law experimentally at low temperatures, on the basis of his own published theory. But the foundations of his argument were unsound. 'It has escaped Mr Sackur's attention', Onnes wrote in his assessment, 'that the matter of equations of state at extremely low temperatures has been studied for helium and hydrogen by the laboratory in Leiden, which has conducted numerous large research projects in this area.' Why had Sackur omitted all mention of the Leiden publications in his grant application? Furthermore, Onnes continued, the German scientist had not published anything in the experimental field that was remotely related to the present project proposal. 'It seems to me that Mr Sackur's application lacks the maturity that would qualify it for consideration.'²³

The second Solvay Conference, held in 1913, which attracted a larger British contingent and the first non-European – R.W. Wood from Baltimore – focused on 'the structure of matter'. This time Kamerlingh Onnes did not deliver a paper, and he contributed very little to the discussions. The theme bore little relation to the current cryogenic research programme in Leiden. The X-ray diffraction of crystals (a subject broached in Brussels by Max von Laue and William Bragg²⁴) did not arouse Onnes's interest until 1917, when Keesom applied it successfully in his new position at the National Institute of Veterinary Medicine in Utrecht. Keesom had wanted to embark on this type of research while he was still attached to the laboratory in Leiden, but Onnes had vetoed the plan.²⁵

²² Heike Kamerlingh Onnes to Lorentz, 29 December 1911, N-HA, Lorentz archives, inv. no. 39.

²³ N-HA, Lorentz archives, inv. no. 155/156.

²⁴ *La Structure de la Matière* (Paris 1921) 75-112 and 113-124.

²⁵ J.M. Burgers' interview of T.S. Kuhn and Martin Klein, 9 June 1962, as part of the project 'Sources for the History of Quantum Physics', Burgers archives, Delft University of Technology.

The first Academy Communication to mention quantum theory (albeit obliquely) was no. 119, submitted to the meeting of February 1911. That same month, Berlin published measurements of specific heat at temperatures in the liquid hydrogen range, in verification of Einstein's theory. The news must have come as a bombshell to the Leiden team.

Onnes began the series 'Further experiments with liquid helium' by reporting on measurements of the vapour pressure and density of liquid helium and helium vapour between 1.5 and 4.3 K, and of resistance in a platinum wire in the same temperature range.²⁶ The observed maximum in liquid density at 2.2 k 'in a substance as simple as helium' raised questions that were significant from the viewpoint of molecular theory in Onnes's mind – not until the 1930s would physicists realise that at 2.17 K, helium becomes a superfluid, completely losing its internal friction (viscosity) and flowing effortlessly through the thinnest of capillary tubes.

After some reflections on 'molecular attraction' and Einsteinian 'vibrators' (he also broached the latter subject in his discussion of the resistance of platinum), Onnes formulated the key question: what happens to molecular attraction at absolute zero? Further research on the bizarre values found for the density of liquid helium, together with measurements of related properties such as its capillarity, internal friction, specific heat, refraction of light, and dielectric constant, would provide clarification. For this ambitious programme to have any chance of success, there had to be more space for the necessary instruments and specimens. So it was extremely fortunate that Flim had just solved the by no means trivial technical problems involved in building a separate helium cryostat, attached to the liquefier.

But things were to work out differently. Shortly after the Academy meeting of February 1911, Leiden discovered superconductivity. This meant that the helium cryostat was otherwise occupied until the First World War – when it went out of commission until 1919 because of a lack of helium. In June 1912 the heat conduction and specific heat (using a Nernst-type vacuum calorimeter) were measured of the superconductor mercury, but this was to see whether these values would display any remarkable change at the critical point of 4.19 K (which they did not). All these measurements were rough and provisional. The experiment would be improved to yield accurate values, but the time-consuming and difficult research on superconductivity took precedence. When the war crippled the helium work, Onnes and Holst decided to publish

²⁶ H. Kamerlingh Onnes, 'Further experiments with liquid helium, A. Isotherms of monatomic gases etc.' KNAW, Proceedings, 1911, 1093-1113. *Comm.* 119.

their meagre results after all – three years late.²⁷ The article also referred to research on a series of thermo-elements. This too was plagued by inaccuracies; nonetheless, Onnes and Holst concluded that the thermal voltage of all the combinations of metals they had used tended to zero at the temperature of liquid helium, which was in line with what Nernst and Keesom had deduced in 1913 on the basis of quantum theory.

Where was Keesom? Was he not the obvious person, as Leiden's expert on thermodynamics, to take up the gauntlet that Berlin had thrown down, in February 1911? Keesom did in fact give a paper at the thirteenth Dutch Conference of Physics and Medical Science in Groningen, in April that year, entitled 'The heat of vaporisation of hydrogen'.²⁸ Curiously, it was not translated into a *Communication* for over two years. Here too one suspects that Keesom planned to do more, but that the experiments could not be performed for the time being, and that not wanting to let the Berlin team have things all its own way, Onnes decided in September 1913 to go ahead with publication in his *Communications*.

In the paper he presented in Groningen, Keesom unfolded a research programme. 'A start was made on this research in the cryogenic laboratory in Leiden, with calorimetry at very low temperatures', his story began. 'Only Dewar was publishing calorimetric determinations at the temperatures that can be obtained with liquid hydrogen.' He was referring to measurements taken at the Royal Institution of the heat of vaporisation of hydrogen at atmospheric pressure and that of the (average) specific heat of diamond, graphite, ice and brass, published in 1905. Leiden had started on the calorimetry line in 1911, with measurements of the heat of vaporisation of hydrogen at atmospheric and reduced pressure. Determinations of specific heat, in particular that of metals, would follow in due course, Keesom explained in Groningen.

Keesom's result for the heat of vaporisation of hydrogen was much lower than Dewar's. He attributed the discrepancy to an error made by the British scientist in determining the heat fed into the system: Dewar had extrapolated the specific heat of lead (which he dropped into the liquid hydrogen in measured portions) to low temperatures, and that was inadmissible. 'Further determinations regarding the specific heat of lead and other metals are greatly to be

²⁷ H. Kamerlingh Onnes and G. Holst, 'Further experiments with liquid helium, M. Preliminary determination of the specific heat and of the thermal conductivity of mercury at temperatures obtainable with liquid helium, besides some measurements of thermoelectric forces and resistances for the purpose of these investigations', *KNAW, Proceedings*, 17, 1914-1915, Amsterdam, 1915, pp. 760-767. *Comm.* 142c.

²⁸ W.H. Keesom, 'De verdampingswarmte van waterstof', *Handelingen van het 13^{de} Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem, 1911) 45-52. *Comm.* 137e.

desired with a view to Einstein's theory', said Keesom. 'This is all the more important now that Kamerlingh Onnes has shown that the galvanic resistance of metals at low temperatures is also probably determined by the energy of Planck's vibrators. Reports will be submitted at a later stage on measurements taken with an apparatus in which the temperature rise is determined by a block of lead that is brought to the temperature of liquid hydrogen when a measured quantity of energy is supplied to it.'

In short, in the spring of 1911, Leiden's cryogenic laboratory was embarking on an ambitious programme of measurements of specific heat. But at that precise moment, Nernst got his hydrogen liquefier up and running and Berlin trumped Leiden in the area of specific heat, with determinations of lead, copper and a number of other metals. In Groningen Keesom was still unaware of this setback, but in the *Handelingen* he included a footnote referring to the communications of Nernst (16 March) and Lindemann (4 May) in the Prussian Academy. Leiden's reply, the first instalment of its series 'Specific heat at lower temperatures', including the promised measurements of lead, was not published until 31 October 1914.

It was not for lack of trying. At the first Solvay Conference, Onnes reported that he and Keesom (in practice it was Keesom who had done the work) had been making calculations with Nernst's 'splendid theory' concerning the specific heat of gases and his application of the quantum hypothesis to rotation [of diatomic molecules].²⁹ Correcting *en passant* a mistake made by Nernst,²⁹ the two had concluded that at temperatures below 14 K, hydrogen manifested itself as a monatomic gas. A determination of specific heat with a view to confirming this result was 'in the pipeline'. The adiabatic decompression of the gas, Onnes observed in Brussels, could not have exposed this monatomic property. Meanwhile, Leiden had switched to Kundt's method (based on sound tests at low density), which appeared to be a promising approach.³⁰

Unfortunately, Leiden's plans were dogged by 'unexpected difficulties', and on 1 February 1912, Eucken, who was working with compressed gases in Berlin, beat Keesom to the prize.³¹ Nine months later, Keesom was at least able to show, in the fourth of a series of theoretical articles – a kind of offshoot of the mammoth article *Die Zustandsgleichung* – that the monatomic property of hydrogen gas at low temperatures was implicit in its isotherms,³²

²⁹ Heike Kamerlingh Onnes to Julius, 21 October 1914, Utrechts Universiteitsmuseum, Julius archives, map vacature Debye.

³⁰ *Theorie du Rayonnement et les Quanta*, 301.

³¹ A. Eucken, 'Die Molekularwärme des Wasserstoffs bei tiefen Temperaturen', *Sitzungsberichte der Königlich Preussische Akademie der Wissenschaften*, 1 February 1912, 141-151.

³² W.H. Keesom, 'On the second virial coefficient for monatomic gases, and for hydrogen below the Boyle-point', *KNAW, Proceedings*, 15 I, 1912, pp. 643-649. *Comm.* supplement 26.

but that was mere salve to the wound. In September 1913 Onnes expressed the hope (through Kuenen) at the third international congress of refrigeration that he would be completing the experiment on the monatomic property of hydrogen 'in the foreseeable future',³³ but it was never heard of again.

How could Leiden have allowed Berlin to get the better of it in this way? It happened as a direct result of Onnes's efforts to make Leiden into an international centre of cryogenic research. With the steady stream of guest researchers, many of them wanting to use the hydrogen installation (which was needed, on top of everything else, for the production of liquid helium), it was impossible for Keesom to make headway. He was forced to stand by, powerless to act while Eucken raced ahead. Onnes acknowledged the problem, but felt that the foreign visitors must take precedence. 'Had this great rivalry in low temperatures not developed', he wrote in October 1914, 'Keesom would have had a good chance of becoming the first to deduce the monatomic property of hydrogen both from its specific heat and from its isotherms.'³⁴

These were hectic years for Onnes and his laboratory. Since the 1908 congress of refrigeration, one foreign physicist after the other was coming to take advantage of Leiden's cryogenic installations. The Becquerelles, Lenard and Pauli, Weiss, Perrier, Mathias, Marie Curie, Anna and Bengt Beckman, Sophus Weber: they all worked in the temperature range of liquid hydrogen. One of the most extensive projects was the magnetic research of Albert Perrier, who came to take measurements in Leiden several times between 1910 and 1914. In the latter half of 1912, Bengt Beckman created a stir with eight articles on the Hall effect. To Onnes's considerable distress, his laboratory was still having to operate in unbearably cramped conditions: the chemistry wing had not yet been vacated. Not until 1914 was permission finally granted for a prefabricated annex in the laboratory's garden, modelled on the one in Heidelberg.

Berlin's second victory over Leiden came with the experimental verification of the specific heat theory that Peter Debye had postulated in March 1912, at a meeting in Bern of the *Schweizerische Naturforschende Gesellschaft* (Swiss Academy of Natural Science). Debye, born in Maastricht in 1884 and trained at the Institute of Technology in Aachen, was working in Zürich in 1912, when he presented his idea of the crystal lattice as a large 'composite molecule'. Whereas Einstein had asserted in 1906 that all atoms oscillate at the same frequency, Debye posited the existence of several values, up to a maximum frequency determined by the number of atoms in the lattice. This

³³ H. Kamerlingh Onnes, 'Report on researches made in the Leiden cryogenic laboratory between the Second and Third International Congress of Refrigeration', *Comm.* 34a (September 1913) 10.

³⁴ Heike Kamerlingh Onnes to Julius, 21 October 1914, Utrechts Universiteitsmuseum, Julius archives, map vacature Debye.

premise yielded a specific heat that in the vicinity of absolute zero would be proportional to the third power of the temperature.³⁵ In his article in *Annalen der Physik*, Debye showed that his theory accorded excellently with the measurements of the specific heat of lead, diamond, copper and zinc recorded by Nernst and Lindemann in 1911. For Leiden and Berlin alike, stringent experimental verification of Debye's T^3 law posed a fresh challenge. Both laboratories threw themselves into the task.

Sadly for Kamerlingh Onnes and Keesom, they chose to experiment with lead – and that was the wrong metal: in lead, the third-power law does not take effect until temperatures so low that even liquid hydrogen is too ‘warm’. When Eucken and Schwers were able to gratify Debye with their measurements in April 1913,³⁶ Leiden, which was nowhere near finished, threw in the towel. Only high-precision measurements – which were beyond Berlin's reach – were of any relevance now, was the characteristic conclusion. Evidently there was yet another foreign visitor at work in the Steenschuur laboratory: there was a twelve-month delay before measurements were resumed.

All this was bitterly disappointing for Keesom. In the introduction to his Academy Communication of 31 October 1914 (submitted together with Onnes), he put as brave a front on the situation as possible. Nernst *cum suis* had not set up the successful round of specific heat measurements until Leiden had predicted them.³⁷ The long time lag at the Leiden laboratory was justified by invoking the improved temperature scale that Onnes and Holst had published in May 1914. In a footnote, the Dutchmen criticised their German rivals for basing their temperature readings on a platinum thermometer with obsolete calibration. Which did not alter the fact, Onnes and Keesom conceded, that the results that Eucken and Schwers had found for lead were correct. The correspondence of the Leiden values with Debye's theoretical graph was not perfect. Calculating with the aid of the theory postulated by Max Born and Theodor von Kármán, published shortly after Debye's and in principle superior to it, did not improve matters. In June 1915, measurements were taken of the specific heat of copper.³⁸ Once again Leiden achieved a higher degree of

³⁵ Peter Debye, ‘Zur Theorie der spezifischen Wärmen’, *Annalen der Physik* 39 (1912) 789–839.

³⁶ A. Eucken and F. Schwers, ‘Eine experimentelle Prüfung des T^3 -Gesetzes für den Verlauf der spezifischen Wärme fester Körper bei tiefen Temperaturen’, *Verhandlungen der Deutsche Physikalische Gesellschaft* 15 (1913) 578–592.

³⁷ W.H. Keesom and H. Kamerlingh Onnes, ‘The specific heat at low temperatures. I. Measurements on the specific heat of lead between 14° and 80°K. and of copper between 15° and 22°K’, in KNAW, Proceedings, 17 II, 1914–1915, Amsterdam, 1915, pp. 894–914. *Comm.* 143.

³⁸ W.H. Keesom and H. Kamerlingh Onnes, ‘The specific heat at low temperatures. II. Measurements on the specific heat of copper between 14 and 90°K’, in KNAW, Proceedings, 18 I, 1915, Amsterdam, 1915, pp. 484–493. *Comm.* 147a.

accuracy than Berlin, and again minor discrepancies were noted relative to Debye, and again Keesom could do very little with all these results.

A third article, giving the specific heat of solid and liquid nitrogen, appeared in January 1916.³⁹ This time, Berlin beat Leiden by two weeks. ‘Our results correspond in general to those of Eucken’, wrote Onnes and Keesom in a footnote, after reading the *Verhandlungen der Deutsche Physikalische Gesellschaft*. They must have been climbing the walls in frustration.

Nernst was ‘not amused’ with Leiden’s criticism of his determinations of temperature. In *Der neue Wärmetheorem*, a book he wrote at the end of 1916, he vehemently denied having relied on an outdated Leiden platinum calibration. ‘Fortunately’, he remarked, ‘we possess a direct method of checking for any discrepancies between the temperature scales used by Kamerlingh Onnes and those used by myself and my team.’ After which he went on to say that Onnes and Keesom had studied lead and copper using his method and for the ‘characteristic temperature’ (which is determined by the maximum frequency in Debye’s theory) of those metals they had found 88 and 315 degrees, precisely the same values that Berlin had determined somewhat earlier. In the case of liquid and solid nitrogen, too, there was at most 2% difference between the two laboratories’ results. ‘It is naturally highly satisfying’, Nernst concluded, not without malice, ‘to observe that Kamerlingh Onnes and Keesom too have found our methods to be wholly reliable.’⁴⁰

In short, in its research on specific heat Berlin completely eclipsed Leiden, both experimentally and theoretically. Not until November 1917, when Nernst had made his laboratory available to the German war effort and Keesom had been in Utrecht for almost a year, did Leiden achieve one small success. In their fourth and final article on specific heat, Onnes and Keesom achieved a first with their determination of the specific heat of solid hydrogen.⁴¹ Since the gold thermometer was only calibrated down to 14 K, the values recorded were provisional. The same Academy Communication presented measurements of liquid hydrogen, but once again – the story is acquiring an air of dreary inevitability – Eucken had got there first. No more caloric measurements were made at the Steenschuur laboratory for the time being. Not until

³⁹ W.H. Keesom and H. Kamerlingh Onnes, ‘The specific heat at low temperatures. III. Measurements of the specific heat of solid nitrogen between 14°K. and the triple point and of liquid nitrogen between the triple point and the boiling point’, in KNAW, Proceedings, 18 II, 1916, Amsterdam, 1916, pp. 1247-1255. *Comm.* 149a.

⁴⁰ W. Nernst, *The New Heat Theorem*, Dover edition (New York 1969) 52.

⁴¹ W.H. Keesom, ‘The specific heat at low temperatures. IV. Measurements of the specific heat of liquid hydrogen. Preliminary results on the specific heat of solid hydrogen and on the heat of fusion of hydrogen’, in KNAW, Proceedings, 20 II, 1918, Amsterdam, 1918, pp. 1000-1004. *Comm.* 153a.

1922 (see chapter 32) did Leiden resume this line of research, with some highly intriguing determinations of the heat of vaporisation and the specific heat of liquid helium.

A hypothesis squared

As a cryogenic theorist, Keesom was expected to keep a weather eye on all new developments. ‘Over the past ten years, he has tackled the theoretical issues almost single-handedly’, Onnes stated in 1914.⁴² This included zero-point energy. At the first Solvay Conference in 1911, there was a fierce debate on Planck’s ‘second quantum hypothesis’,⁴³ which was then just six months old and had been formulated to help resolve inconsistencies between the radiation law and Maxwell’s classical electromagnetism. The difference with Planck’s approach in 1900 was that this time, in the equilibrium between matter and radiation only energy emissions were expressed in quanta; the absorption of energy was described as a continuous process instead of taking place in measured amounts.⁴⁴ This premise was far-reaching in its consequences: the expression for the average energy of Planck’s vibrators (oscillators) contained an extra term, in comparison to 1900, which did *not* depend on temperature. This meant that at absolute zero, a *zero-point energy* still remained. It was this enigmatic concept, which Onnes described as a ‘hypothesis squared’ and which theoretical physicists did not fully comprehend until the birth of quantum mechanics in 1925-26, which Keesom eagerly set about exploring.

But Einstein had got there first. In March 1913 he joined forces with the PhD student Otto Stern – taking time off from his titanic struggle with gravity that would culminate two years later in his Theory of General Relativity – to publish an article in *Annalen der Physik* that attracted considerable attention and that he would soon have cause to regret.⁴⁵ Later translated as ‘An argument for the acceptance of molecular agitation at absolute zero’, it gave an approximation formula for the specific heat of hydrogen gas that corresponded quite closely to the low-temperature measurements that Nernst’s assistant Arnold

⁴² Heike Kamerlingh Onnes to Julius, 14 September 1914, Utrechts Universiteitsmuseum, Julius archives, map vacature Debye.

⁴³ M. Planck, ‘Eine neue Strahlungshypothese’, *Verhandlungen der Deutsche Physikalische Gesellschaft* 13 (1911) 138-148.

⁴⁴ Jagdish Mehra and Helmut Rechenberg, *The Historical Development of Quantum Theory I* (New York 1982) 113-136.

⁴⁵ A. Einstein and O. Stern, ‘Einige Argumente für die Annahme einer molekularen Agitation beim absoluten Nullpunkt’, *Annalen der Physik* 40 (1913) 551-560.

Eucken had published in 1912.⁴⁶ The key to this success was zero-point energy. Omitting this term resulted in a theoretical specific heat curve that was completely inaccurate. Nernst had already derived a simple quantum formula for the specific heat of diatomic molecules back in 1911, taking their rotations into account, but this formula too was inconsistent with Eucken's results.

The question thus arose of how the rotational energy of molecules *should* be quantised. Einstein assumed for the sake of convenience that all molecules rotated at the same frequency, and endowed them with average energy in line with Planck's second quantum hypothesis, that is, including a zero-point term. This seemed to work perfectly for the specific heat of hydrogen gas. Even so, it was worrying that Planck referred to oscillators rather than rotators. Paul Ehrenfest delivered some harsh criticism and proposed an alternative that accorded just as well with the Berlin measurements, and Einstein ended up having to retract the disputed article during a debate at the second Solvay Conference in the autumn of 1913. He had decided to jettison the whole idea of zero-point energy – for one thing, it was difficult to reconcile with superconductivity – and in a letter to Ehrenfest in November 1913, Einstein declared the concept to be 'as dead as a doornail'.⁴⁷ 'Mr Keesom severely weakened it', Einstein wrote to his Leiden colleague, 'even though he was sincerely doing his best to strengthen it.'⁴⁸

It was certainly true that Keesom himself was very far from writing off zero-point energy. In April 1913 he argued vigorously for its existence at the Wolfskohl Conference in Göttingen, a series of readings on the 'kinetic theory of matter' organised by the mathematician David Hilbert. The speakers during this 'Gaswoche' were Planck, Debye, Nernst, Smoluchowski (the opalescence man), Sommerfeld and Lorentz.⁴⁹ Keesom, who attended every one of the lectures, gave his fellow scientists a foretaste, during the discussions, of the theoretical research he planned to present to the Academy the following month.

After Planck's lecture, Keesom raised the subject of the quantisation of the translational movement of monatomic molecules, in particular in helium.⁵⁰

⁴⁶ Arnold Eucken, 'Die Molekularwärme des Wasserstoffs bei tiefen Temperaturen', *Sitzungsberichte der Königlich Preussische Akademie der Wissenschaften* (1912) 141-151.

⁴⁷ Martin J. Klein, A.J. Kox, Jürgen Renn and Robert Schulmann (ed.), 'Einstein and Stern on Zero-Point Energy', *The Collected Papers of Albert Einstein*, vol. 4 (Princeton 1995) 270-273.

⁴⁸ Einstein to Ehrenfest, November 1913, in Martin J. Klein, A.J. Kox and Robert Schulmann (ed.), *The Collected Papers of Albert Einstein*, vol. 5 (Princeton 1993) 563-564.

⁴⁹ *Vorträge über die kinetische Theorie der Materie und der Elektrizität* (Leipzig 1914).

⁵⁰ *Ibid.*, H. Kamerlingh Onnes and W.H. Keesom, 'Über die Translationsenergie in einatomigen Gasen beim absoluten Nullpunkt', 193-194.

W.H. Keesom, 'On the equation of state of an ideal monatomic gas according to the quantum theory', in KNAW, Proceedings, 16 I, 1913, Amsterdam, 1913, pp. 227-236. *Comm.* supplement 30a.

This feat had been accomplished in the spring of 1912 by Hugo Tetrode, an Amsterdam prodigy who was studying in Leipzig.⁵¹ At barely seventeen years of age, the introverted Tetrode – when Einstein and Ehrenfest went to visit him in Amsterdam, he is said to have instructed his servant to send them away, explaining ‘the master does not receive’ – published an astonishing article in *Annalen der Physik* in which he had an ideal monatomic gas exchange energy quanta with the radiation with which it was in equilibrium.⁵² Thus, molecular motion was construed in a sense as a system of stationary waves.

Otto Keesom did something similar in the same period. In the case of helium at 0°C and at 1 atmosphere, Keesom stated in Göttingen, this approach led to a 1.8% discrepancy relative to the value prescribed by Boyle’s Law. In 1907, Onnes had measured a deviation of 0.05% – in the opposite direction. Applying Tetrode’s approach, but incorporating zero-point energy, led Keesom to a calculated discrepancy of only 0.012%, which was in the right order of magnitude, and moreover in the right direction. The same approach worked for the compressibility of helium between 0 and 100°C. All this led Keesom to conclude in Göttingen that ideal monatomic gases ‘probably’ possessed zero-point energy. Too rash a conclusion, thought the German theoretical physicist Arnold Sommerfeld. While Keesom’s approach seemed tempting at first sight, Sommerfeld observed in his own lecture four days later, he said that he had ‘grave misgivings’ about it.

The subject of zero-point energy came up most frequently in connection with Leiden’s magnetic research. At the Paris congress of refrigeration in 1908, the Swiss scientist Pierre Weiss, a pioneer in this field of physics, persuaded Onnes to allow him to expand his research to liquid hydrogen temperatures in Leiden. He brought with him his 132-kilo electromagnet from Zürich. His assistant Albert Perrier later came to Leiden several times to continue Weiss’s magnetic research. Onnes found it all so fascinating and innovative that he set his assistant Oosterhuis to work on the same subject in 1912. That same year he ordered a magnet of the same type as Weiss’s from Maschinenfabrik Oerlikon, near Zürich, for 8,280 Swiss francs. It had special pole shoes and was wound around with a thousand hollow copper coils through which cooling water circulated.⁵³ It was delivered in the summer of 1913. The colossus weighed a ton, stood on a rotating base with wheels and had a capacity of 50,000 gauss,

⁵¹ H.B.G. Casimir, ‘Hugo Tetrode (1895-1931): Een geniale outsider’. In *Mens en kosmos* (Amsterdam 1993) 180-189.

⁵² H. Tetrode, ‘Die chemische Konstante der Gase und das elementare Wirkungsquantum’, *Annalen der Physik* 38 (1912) 434-442; H. Tetrode, ‘Bemerkungen über den Energieinhalt einatomiger Gase und über die Quantentheorie für Flüssigkeiten’, *Physikalische Zeitschrift* 14 (1913) 212-215.

⁵³ MB, archives of Heike Kamerlingh Onnes, inv. no. 72.

making it twice as strong as the one Onnes had acquired on loan in 1910. Simultaneously with the experiments, which yielded fourteen 'magnetic studies' in the period 1910-1914, Keesom undertook three 'wild' theoretical exercises. Onnes gave the enterprise his blessing; it was 'necessary' and 'productive' to boot.⁵⁴

The magnetic research performed in Leiden focused on Curie's Law.⁵⁵ In 1895, Pierre Curie (Marie's husband; he died in 1906) determined experimentally that magnetic susceptibility, the variable indicating the degree to which magnetic atoms (molecules) are aligned by an applied magnetic field, varies in inverse proportion to temperature. The underlying theory dates from 1905 and was first formulated by Paul Langevin. It hinges on the balance between two conflicting tendencies. First of all, temperature change induces random orientations in the magnetic molecules, and the higher the temperature the more powerfully it does so. Opposing this tendency to disorder is the order that the external magnetic field tries to create: it pulls the magnetic axes of the molecules in one direction, in the same way that the earth's magnetic field aligns compass needles. The average equilibrium can be calculated using a statistical approach, which led Langevin to formulate what became known as Curie's Law.

But this law was far from accurate in all cases. Discrepancies arose, especially at low temperatures, which explains the interest in the Leiden laboratory. In 1907, Weiss posited his hypothesis of the molecular field, according to which below a certain temperature (different for each substance), magnetic molecules can keep each other aligned spontaneously through their mutual interaction. Above this 'Curie temperature', the substance is paramagnetic and thus adheres to the susceptibility prescribed by the law of Curie-Weiss; at lower temperatures it is ferromagnetic. Examples include magnetite, iron, cobalt and nickel. The magnetic research in Leiden also extended to liquid and solid oxygen, as well as paramagnetic substances such as iron sulphate, gadolinium sulphate, manganese chloride and platinum.⁵⁶

In June 1913, Oosterhuis applied himself to the task of explaining the deviations from Curie's Law at low temperatures.⁵⁷ He reasoned as follows.

⁵⁴ Heike Kamerlingh Onnes to Julius, 19 October 1914, Universiteitsmuseum Utrecht, Julius archives, map vacature Debye.

⁵⁵ Gavroglu and Goudaroulis, *Through measurement to knowledge*, lxxx-lxxxvii.

⁵⁶ For an overview, see Pierre Weiss, 'Les recherches magnétiques au Laboratoire cryogène de Leyde'. *Het Natuurkundig Laboratorium 1904-1922*, 233-274.

⁵⁷ E. Oosterhuis, 'Magnetic researches IX. The deviations from Curie's law in connection with the zero point energy', in KNAW, Proceedings, 16 I, 1913, Amsterdam, 1913, pp. 432-440. *Comm.* supplement 31.

According to Langevin's theory, magnetic susceptibility is inversely proportional to the rotational energy of the molecules. Given the sizeable deviations, this assumption must be incorrect and should be abandoned. Instead, what could be more logical than to try Einstein and Stern's formula for average rotational energy, including zero-point energy? Oosterhuis elaborated the new approach to paramagnetism – assuming, for the sake of convenience, that in a solid substance too, magnetic molecules can rotate freely – and discovered that for manganese sulphate, it accounted very well for the deviations from Curie's Law, right down to temperatures in the liquid hydrogen range. Yet another argument in favour of the existence of zero-point energy, Keesom concluded in satisfaction.⁵⁸

Meanwhile, Keesom was applying zero-point energy to the theory of ferromagnetism. He took the idea of stationary waves from quantum theory for monatomic ideal gases and applied it to rotating molecules. Keesom rejected Ehrenfest's calculations with individual rotators: in the absence of a force, any comparison with Planck's oscillators was invalid. Analogous to Debye's theory, stationary waves yielded a whole spectrum of frequencies rather than a single one as Einstein and Stern had assumed. To test his model, Keesom asked Oosterhuis to try it out in his theory of paramagnetism. This produced theoretical results that were roughly as good as those achieved using Einstein and Stern's approach. This strengthened Keesom's conviction that zero-point energy – which was, after all, the factor that the two models had in common – must be a correct assumption. He also applied the stationary wave method to the spontaneous magnetisation that occurred in ferromagnetism.⁵⁹ For magnetite, Keesom's theoretical findings corresponded convincingly to the measurements recorded by Weiss and Kamerlingh Onnes in 1910. For nickel the correspondence was somewhat less marked, but it was still good enough to corroborate, 'in outline' the assumptions adopted in the approach with stationary waves and zero-point energy.

Finally, in April 1914, Keesom applied his theory to paramagnetism in a situation with a variable distance between the magnetic molecules.⁶⁰ In February that year, Kamerlingh Onnes and Perrier had tested mixtures of

⁵⁸ W.H. Keesom, 'Over het arbeidsvermogen van de draaiende beweging der moleculen', *Handelingen van het XVIIe Vlaamsch Natuur- en Geneeskundig Congres* (Ghent 1913) 68-73.

⁵⁹ W.H. Keesom, 'On the magnetization of ferromagnetic substances considered in connection with the assumption of a zero-point energy. II. On the susceptibility in the excited ferromagnetic state', in *KNAW, Proceedings*, 16 I, 1913, Amsterdam, 1913, pp. 468-476. *Comm.* supplement 32b.

⁶⁰ W.H. Keesom, 'On the manner in which the susceptibility of paramagnetic substances depends on the density', in *KNAW, Proceedings*, 17 I, 1914, Amsterdam, 1914, pp. 110-122. *Comm.* supplement 36c.



Ill. 45. Staff of the Physics Laboratory in 1914. Standing, from left to right: Willem Keesom (supervisor), Sophie Weber (assistant), H.A. Kuijpers (assistant), August Crommelin (supervisor). Seated: Ekko Oosterhuis (assistant) and Heike Kamerlingh Onnes (Director).

(non-magnetic) liquid nitrogen and (magnetic) oxygen, and their analysis had led them to conclude that the deviations from Curie's Law were incompatible with the existence of zero-point energy. A negative molecular field must be the answer, they said.⁶¹ Keesom refuted their arguments by showing that his approach with quanta and zero-point energy worked at least as well. In a letter to Lorentz, he predicted that by the time of the next Academy report, zero-point energy would long since have recovered from the heavy blow it had sustained, 'by leading me to a different, in my view better, mode of calculation, with the result that the observational results referred to are entirely compatible with the assumption of zero-point energy.'⁶²

⁶¹ Albert Perrier and H. Kamerlingh Onnes, 'Magnetic researches XIII. The susceptibility of liquid mixtures of oxygen and nitrogen and the influence of the mutual distance of the molecules upon paramagnetism', in KNAW, Proceedings, 16 II, 1913-1914, Amsterdam, 1914, pp. 901-916. *Comm.* 139d.

⁶² Keesom to Lorentz, 12 March 1914, N-HA, Lorentz archives.

To resolve this issue, a series of magnetic measurements and measurements of specific heat were planned in Leiden, with alloys of nickel (magnetic) and copper (non-magnetic), but the project fell through when Keesom left for Utrecht. Onnes, who had set Keesom to work on magnetism because it was so ‘hopelessly difficult to find one’s way in it’, had watched full of admiration as his protégé arrived at ‘impeccable deductions . . . even in areas that are wholly inscrutable’, endeavouring to progress through intuition, but ever mindful of the experimental results.⁶³

Thus, the balance of evidence seemed to be tipping in favour of zero-point energy. The specific heat of hydrogen gas (Einstein and Stern), the deviations from Curie’s Law (Oosterhuis), ferromagnetism (Keesom), the influence of the distance between molecules (Keesom): it seemed that none of these results could be explained without the assumption of zero-point energy. What is more, other, retrospective, clues could be found. When Jean Becquerel determined the absorption spectra of a number of minerals at the temperature of liquid hydrogen in Leiden in 1908, his working hypothesis was that the width of the absorption spectra would vary in inverse proportion to the velocity of the molecules. Proceeding on the basis of zero-point energy, that ought to yield spectral bands of a constant width – precisely what Becquerel and Onnes saw. ‘One would be inclined to conclude’, said Keesom, ‘that in such experiments with a spectroscope, one observes the zero-point velocity of the molecules directly.’⁶⁴

Not everyone approved of Keesom’s approach. On 1 May 1913, Lorentz, whom Keesom consulted regularly, mentioned some objections he had to Keesom’s most recent work. He was referring to the presentation at the Wolfskehl conference the week before, and to Keesom’s idea of applying the quantum approach to monatomic ideal gases to a system of free electrons.⁶⁵ It should be noted that the supervisor of Leiden’s Physics Laboratory was doing all this work in his spare time: ‘Professor Onnes objects to my concerning myself at the laboratory with matters other than the programme, which I consider completely fair.’ Lorentz felt that while Keesom’s basic idea was ingenious, working it out in practice would prove extremely difficult.⁶⁶ A week later, Wilhelm Wien, editor-in-chief of *Annalen der Physik*, who had also attended the Göttingen conference, wrote that Keesom’s idea of tracking down the zero-point energy of molecules would run into ‘insuperable difficulties’,

⁶³ Heike Kamerlingh Onnes to Julius, 19 October 1914, Universiteitsmuseum Utrecht, Julius archives, map vacature Debye.

⁶⁴ MB, archives of Heike Kamerlingh Onnes, inv. no. 72.

⁶⁵ Keesom to Lorentz, 29 April 1913, N-HA, Lorentz archives.

⁶⁶ Lorentz to Keesom, 1 May 1913, MB, Keesom archives, box 1.

certainly in the case of solid substances.⁶⁷ In October, Keesom discussed molecular rotational energy at the Wednesday evening colloquium at Ehrenfest's home, where he will undoubtedly have had to fend off a barrage of criticism.

Lorentz took the zero-point energy 'escapades' into consideration when recommending a successor for Debye in Utrecht. He acknowledged that Keesom had frequently found elegant and surprising explanations for experimentally determined facts. Nonetheless, he felt obliged to express his grave doubts about the foundations of Keesom's theory. Lorentz thought the stationary waves 'difficult' (he initially wrote 'impossible') to defend, and it was worse still when Keesom let these waves loose on rotating molecules, 'magnecules' and electrons. 'Here, it seems to me, an unmistakable air of frivolity creeps in, the justification of which by the results appears to me to be open to question.'⁶⁸ On the other hand, Ornstein's 'circumspection' was also not ideal: 'Theoretical physics has undeniably entered a stage in which one can scarcely make any headway, it seems, without embracing somewhat bold and adventurous hypotheses.'

Lorentz was not an enthusiastic devotee of quantum theory. One of the other candidates mentioned for the Debye vacancy was Niels Bohr, the man who published three articles in 1913 (when he was still working with Rutherford in Manchester) explaining the hydrogen atom and its line spectrum – a major breakthrough. In an age in which quantum theory was still a quagmire, Lorentz called the Dane 'one of the best exponents of the "adventurous" school'. Lorentz actually thought the Bohr atom overly speculative, but he was forced to concede that it dovetailed perfectly with the Balmer series (a series of spectral lines of hydrogen). 'This makes one think there must be something in Bohr's theory.' Even so, Bohr was unsuitable for Utrecht. 'He may turn out to be brilliant later on, but you will not be surprised, after what I have said, that I would not venture to recommend him over Dutch candidates at this stage.'⁶⁹

In short, quantum theory, including zero-point energy, brought more confusion than consensus to the world of physics in the years 1911-1915. While Einstein had declared the concept of zero-point energy to be dead, Planck still supported his brainchild wholeheartedly in 1915. 'I have almost completed an improved formulation of the quantum hypothesis applied to thermal radiation', he wrote to Kamerlingh Onnes (who had congratulated him on his *Pour le Mérite* medal for art and science). 'I am more convinced than ever that zero-point energy is an indispensable element. Indeed, I believe I have the strongest

⁶⁷ Wien to Keesom, 9 May 1913, MB, Keesom archives, box 1.

⁶⁸ Lorentz to Julius, 14 October 1914, Utrechts Universiteitsmuseum, Julius archives, map vacature Debye.

⁶⁹ *Ibid.*

evidence for it.⁷⁰ While Bohr's approach with his quantum jumps of energy steadily gained ground, it was not until the 1920s that Planck's theory of zero-point energy was finally discarded.

In spite of Planck's enthusiastic letter to Onnes, Leiden deserted the theory of zero-point energy after 1914. The First World War ended the cooperation with Perrier, Oosterhuis left to work for Philips, Keesom went to Utrecht, and the plans for a series of measurements of magnetism and specific heat in alloys of copper and nickel were shelved. Zero-point energy was no longer an issue. But things were not entirely that straightforward. In October 1920, Onnes organised a mini-conference on the theory of magnetism to mark Einstein's arrival as professor by private appointment in Leiden. It was attended by Lorentz, Ehrenfest, Einstein, Kuenen, Langevin, Weiss, Keesom and Onnes. This gathering served as the basis for a report submitted to the third Solvay Conference of April 1921, and contained the programme for a new series of magnetic measurements in Leiden: *Paramagnétisme aux basses températures*.⁷¹ Strikingly, Onnes ignored the issue of zero-point energy, and focused completely on molecular fields – negative or otherwise. In 1914 he had still contended that Keesom's approach with its zero-point energy was just as good if not better. Weiss, who wrote an article on magnetism in the volume commemorating the fortieth anniversary of Onnes's doctorate, likewise said nothing in his piece about zero-point energy.

Onnes's reversion to a shaky idea from classical physics (the negative molecular field) instead of embracing a quantum approach is curious. Perhaps Lorentz and Ehrenfest had convinced Onnes that Keesom's theoretical manoeuvres were unsound. After the Leiden conference on magnetism, Onnes asked his former right-hand man to calculate a particular aspect of the molecular field for liquid oxygen. Keesom faithfully complied, his results culminating in a small piece for the Academy.⁷² The introductory section discussed the causes underlying discrepancies relative to Curie's Law. Four different possibilities were discussed, among which the molecular field and zero-point energy were the only serious contenders. Keesom avoided entering into a discussion of the arguments for and against these two alternatives, but could not resist adding a footnote pointing out the international status of the zero-point energy hypothesis. He quoted articles from *Annalen der Physik* (dating from 1916 and

⁷⁰ Planck to Heike Kamerlingh Onnes, 10 March 1915, MB, archives of Heike Kamerlingh Onnes, inv. no. 306.

⁷¹ H. Kamerlingh Onnes, 'Paramagnétisme aux basses températures', *Atomes et électrons* (Paris 1923) 131-164. *Comm.* supplement 44a.

⁷² W.H. Keesom, 'On the deviations of liquid oxygen of the law of Curie', KNAW, Proceedings, 23, 1920-1921, Amsterdam, 1921, pp. 1127-1136. *Comm.* supplement 44c.

1917) in which zero-point energy had been elaborated on the basis of the new quantum theory, and stated that Paul Langevin supported the concept.

In short, zero-point energy was far from dead. On the contrary, it survived Planck's second quantum theory, and reached firm ground in the mid-1920s – also in magnetism – as an element of quantum mechanics.

29. ‘Supra-conductivity’

The discovery of superconductivity was not celebrated with a triumphant fanfare. Unlike the liquefaction of helium, which was the culmination of a long battle with nature, the superconductivity of mercury was stumbled upon in a moment of serendipity. No one had been looking for it, and no one understood what it meant when they found it. We have no eye-witness reports, and the lab books have been lost. This story does not star a heroic Bé feeding her husband sandwiches as he toiled among the vacuum pumps and cryostats, there are no telegrams of congratulations from fellow scientists or enthralling Academy articles akin to those of July 1908 marking the first liquid helium. Instead, we find dry provisional reports – at times not even presented personally by Onnes, who occasionally left his assistant to report observations of resistance in metals. We do not even have any letters to Van der Waals or Zeeman reporting in colourful detail on something idiotic happening with frozen mercury at 4.19 K.

In spite of this documentary hiatus, however, we do have some second-hand sources for the discovery of superconductivity in 1911. Jacobus de Nobel, who first worked at the cryogenic laboratory in 1931 as a physics student, later rising to the position of lector and remaining loyal to Leiden throughout his career, received a vivid account of the events of April 1911 in a letter from Gerrit Jan Flim.¹ It confirms the main details: little heroism, more luck than good management, and a starring role for a trainee instrument-maker who dozed off. Of course, the story may well have been embroidered.

Measurements of the electrical resistance of frozen mercury at temperatures of liquid helium were part of the Physics Laboratory’s regular programme. Gilles Holst, Onnes’s assistant, pressed the buttons while Onnes and Flim turned the stopcocks. Assistant Cornelis Dorsman was also involved in the research on electrical resistance. Onnes started off using a U-shaped tube of mercury with platinum lead wires at each end. The resistance of the

¹ Jacobus de Nobel, ‘The discovery of superconductivity’. *Physics Today*, September 1996, 40-42.

mercury wire was measured using a Wheatstone bridge. The helium cryostat was in lab E'; the mirror galvanometer (with a light beam functioning as 'pointer', to be read in the dark) in the magnetic lab I, dozens of metres away. Flim took care of the helium bath, while Holst sat in lab I following the point of light on the dial on the wall, adjusting the bridge circuit and noting the resistance values at equilibrium. The men bellowed instructions at each other through a speaking tube.

The temperature in the helium cryostat was adjusted by pumping out the liquid bath with varying degrees of vigour. To prevent the precious helium gas from leaking away, the helium pressure was always kept at a level slightly lower than air pressure. In the event of a leak, an inflow of air would immediately seal the leak by freezing. The underpressure was kept at the desired level by fine-adjusting a stopcock in the pipe of the pump. This boring job, wrote De Nobel, came down to peering at an oil manometer and operating a lever as soon as the oil level changed. It was a perfect job for a trainee instrument-maker, who was spirited away from a workshop to provide an extra pair of hands.

Holst, Onnes and all others concerned were disgruntled to observe that the resistance of mercury at the temperature of liquid helium was zero. They immediately concluded that the wires in the cryostat had short-circuited, said De Nobel, and set about repeating the measurements. They had to wait at least a week for a new run of the helium liquefier, but the short-circuit kept recurring. It was therefore decided to replace the U-tube with a W-shaped tube, with platinum wires at all five points. This made it possible to determine the resistance of four sections of mercury wire independently. Four short circuits! What in heaven's name was going on? The answer did not dawn until the 'blue-collar boy' operating the oil manometer dozed off, with the result that the pressure in the helium cryostat slowly rose and the temperature rose from just below 4 K to the boiling point of helium, 4.25 K. When the transition or critical temperature was passed at which a superconductor regains electrical resistivity, Holst, in lab I, suddenly saw his galvanometer needle swing to the side. Finally the truth dawned; Leiden had discovered superconductivity. It is a great story, but the account of the change from a U to a W-shaped tube is nowhere to be found in the published reports, and may well have been an imaginative embellishment.

More than thermometry alone

Leiden had ample experience measuring the resistance of metals: since 1902 the laboratory had been using platinum and gold wires as thermometers, calibrating them with gas thermometers. After the liquefaction of helium in July 1908, it

made sense to extend this area of research to temperatures of 4.2 K and below. Pending the arrival of a separate helium cryostat, this meant expanding the space with liquid helium to accommodate the gas and resistance thermometer as well as the dilatometer (the latter to determine density). In December 1910, the series 'Further experiments with liquid helium' was launched using this adapted liquefier. It was far from ideal. There was no room for a stirring rod, which made it harder to achieve an even temperature in the bath. Nonetheless, the observations yielded an intriguing graph when the density of liquid helium was plotted against temperature, and the resistance of platinum too produced startling values at liquid helium temperatures.

There was a sudden leap forwards in the theory of the conductivity of metals in 1900, when the German scientist Paul Drude applied the kinetic theory of gases to electrons in metals.² He posited that conductivity in metals was produced by an 'electron gas' – free electrons that moved around the metal, colliding with atoms, which travelled in one direction only if there was a difference in potential. Drude deduced that conductivity was inversely proportional to absolute temperature. This implied that electrical resistance (the inverse of conductivity) would fall linearly with declining temperature, tending to zero at absolute zero. The problem with this result was that experiments conducted by others, such as Dewar, had yielded a curved rather than linear graph. Measurements of resistance recorded in Leiden by Meilink and Clay in the period 1902-1908 confirmed this picture.

Clearly, the electron theory required some adjustment. In 1901 Lord Kelvin presented a modified theory, in which resistance passed through a minimum as temperature declined, but then suddenly soared to infinity as temperature approached absolute zero. Kelvin published his article in the jubilee book published to mark Bosscha's retirement (and subsequently in *Philosophical Magazine*) at the invitation of Onnes, who coordinated the contributions.³ Kelvin argued that at sufficiently low temperatures, electric forces would prevent 'electrions' (his term for electrical charges) being plucked away from atoms. When the temperature rose, resistance would initially fall because of electrions shooting away. If it was too hot, the atoms would vibrate so vigorously as a result of their thermal motion that the electrions could not get through and resistance would rise again. This meant that resistance reached a minimum at a certain temperature.

² For an overview of experimental and theoretical advances in relation to conductivity, see Per Fridtjof Dahl, *Superconductivity, its historical roots and development from mercury to the ceramic oxides* (New York 1992) 13-49.

³ Kelvin to Heike Kamerlingh Onnes, 30 August 1901, coll. Bosscha Erdbrink.

Onnes embraced this idea in his inaugural address as rector of the university in 1904, although he preferred the term ‘dynamids’ coined by Philipp Lenard of Heidelberg to Kelvin’s ‘electrions’. Dynamids, the building blocks of atoms, were ‘exceedingly small in relation to their distance from one another’ and consisted of ‘two particles with opposite electric charges, which go together in the manner of a planet and its satellite’. According to Lenard’s theory (published in 1903), free electrons, ‘the comets of atoms’, moved from one atom to another ‘like the molecules of a gas or vapour’. In the case of a fall in temperature, the velocity of the free electrons would decline, so that they would collide with the dynamids less frequently and resistance would decrease. But this decline would be halted when ‘the vapour of electrons that fill[ed] the space of the metal [was] precipitated to an increasing degree on the atoms’. This explained why resistance passed through a minimum value, ‘as Kelvin first proposed’, whereas at absolute zero, ‘a metal, like glass, would no longer conduct at all’. ‘The electricity would be congealed, as it were, in the metal.’ An alternative way of eliminating the ‘comet-like’ nature of electrons would be to place the metal in a magnetic field.⁴

The problem with the Kelvin/Lenard theory was that no one had ever observed the postulated minimum resistance. Although the values of Onnes’s platinum and gold resistances levelled out at low temperatures, that was not the same thing as a minimum, and in 1910, the question of whether resistance tended to infinity or zero at absolute zero was still undecided. Since Leiden had been able to measure resistance in liquid hydrogen, Onnes (like Dewar) inclined to the latter view. Only experimental results could resolve the issue. So it was more than thermometry alone that made Onnes curious about the values of resistance in liquid helium.

The measurements recorded in December 1910 using platinum wire Pt_B, which Jacob Clay had calibrated previously (in June 1907) in the liquid hydrogen range, provided a surprise: no minimum, no reduction tending to zero, but a lower value that remained constant.⁵ How could this be explained? Onnes concluded that impurities in the platinum had caused a residual resistance independent of temperature, and that resistance in pure platinum would tend to zero at the temperature of liquid helium. In April, Onnes similarly registered a stable residual value in a gold wire between 4.2 and 1.5 K. Clay had previously

⁴ H. Kamerlingh Onnes, *De beteekenis van nauwkeurige metingen bij zeer lage temperaturen* (Leiden 1904) 32–35.

⁵ H. Kamerlingh Onnes, ‘Further experiments with liquid helium. B. On the change in the resistance of pure metals, at very low temperatures. III. The resistance of platinum at helium temperatures’, *KNAW, Proceedings*, 13, 1910–1911, Amsterdam, 1911, pp. 1107–1113. *Comm.* 119.

established for gold that resistance declined if the wire contained fewer impurities. Metals that were 100% pure, it appeared, became perfect conductors at 4.2 K.

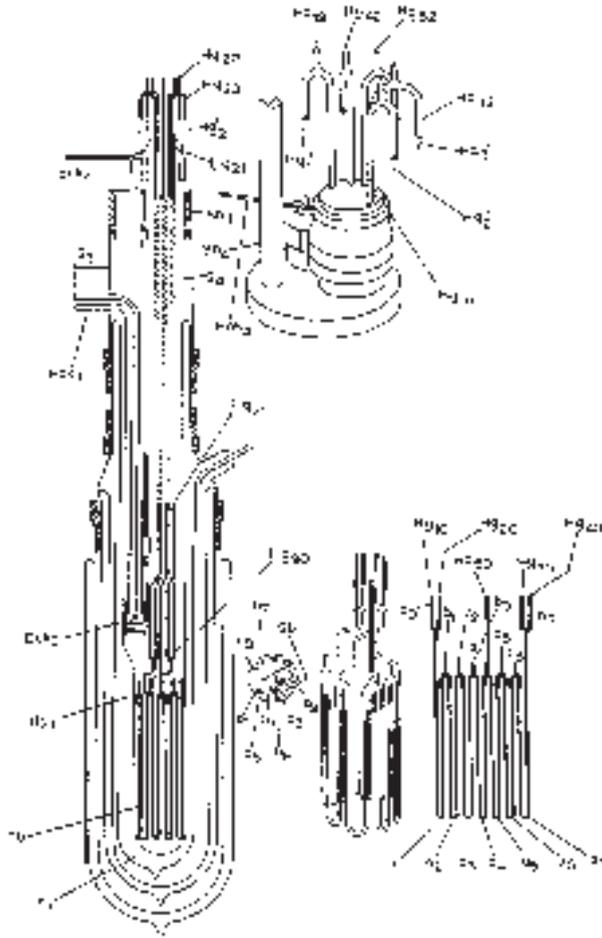
Kelvin's minimum, including the deposits of electron vapour at even colder temperatures, could be consigned to the rubbish heap – that much was clear. To explain the 'remarkable decline in resistance, virtually to zero' at 4.2 K, and the fact that resistance remained zero at even colder temperatures, Onnes invoked Planck's quantum theory. Drawing on the 'vibrators' from Einstein's theory of specific heat and a potpourri of Planck, electron theory and Einstein, he produced a formula for conductivity (relative to that at 0°C) as a function of temperature. At low temperatures, it was not the electrons but the vibrators that froze solid, in relation to their frequency. The value of this frequency followed from determinations of specific heat, as Nernst had shown.

The hypothesis of the virtual disappearance of the resistivity of a pure metal at extremely low temperatures was tested in April 1911 in an experiment using mercury.⁶ Mercury could be produced in an extremely pure form by multiple distillation in a vacuum. Mercury treated in this way would be transferred to a glass capillary tube twisted into a zigzag shape, with an internal diameter of only 0.05 mm and a height of 20 cm.⁷ Since mercury contracts when it freezes, little reservoirs of mercury ('heads') were attached to the upper bends of the capillary, which, by providing an additional supply, prevented the mercury from becoming detached from the glass when it coagulated (cooling was effected with extreme caution from the bottom to the top using liquid air). The thread would often break in spite of these precautions, but sometimes the experimentalists succeeded in making a mercury thread of a sufficiently great resistance – in practice this was in the order of 100 ohms at 0°C (an extrapolated value; mercury melts at -39°C).

It was completely impossible to fit this mercury thread construction into the helium liquefier, even if the row of seven U-shaped capillary tubes was bent into the shape of a cylindrical mantle, so the only solution was to wait until the separate helium cryostat was ready for use. It was finally ready – complete with stirring rod – in April 1911, and the research on resistance resumed

⁶ For a detailed account of the history of superconductivity, see Dahl, *Superconductivity*. See also Kostas Gavroglu and Yorgos Goudaroulis (ed.), *Through Measurement to Knowledge* (Dordrecht 1991) lxvi-lxxviii; P.H.E. Meijer, 'De ontdekking van de supergeleiding', *Nederlands Tijdschrift voor Natuurkunde* 61/8 (2 May 1995) 146-148; C.A. Crommelin, 'De suprageleidende toestand van metalen', *Het Natuurkundig Laboratorium 1904-1922* (Leiden 1922) 401-428.

⁷ H. Kamerlingh Onnes. 'Further experiments with liquid helium. G. On the electrical resistance of pure metals etc. VI. On the sudden change in the rate at which the resistance of mercury disappears', in KNAW, Proceedings, 14 II, 1911-1912, Amsterdam, 1912, pp. 818-821. *Comm.* 124c.



Ill. 46. Experimental set-up to determine the electrical resistance of mercury, resulting in the discovery in April 1911 of superconductivity at temperatures below 4.2 K. The frozen mercury is in a series of narrow glass capillaries which are suspended in the helium cryostat, furnished with in and out coming wires to measure electrical potential and amperage.

using mercury and gold. Onnes determined the oscillatory frequency of the mercury vibrators by applying a sort of law of corresponding states for metals, taking the melting point as the corresponding temperature. This led to the prediction that at 4.2 K, the resistance of the mercury wire would decline sharply compared to the value at liquid hydrogen temperatures, but that it would nonetheless remain measurable. At lower temperatures, he predicted that the resistance would decline further, becoming immeasurably small at

1.5 K. Not long afterwards, Onnes learned that Lindemann in Berlin had derived a far higher value for the frequency in 1910 on the basis of ‘more specialised’ graphs, while the Leiden value made the experiment with mercury ‘extremely enticing’. If he had read this a little earlier, Onnes – who always studied the recent literature himself or ensured that Keesom did so – might well have decided against mercury. He remarked that in this case it was ‘perhaps fortunate’ that he had been unaware of Lindemann’s article.⁸

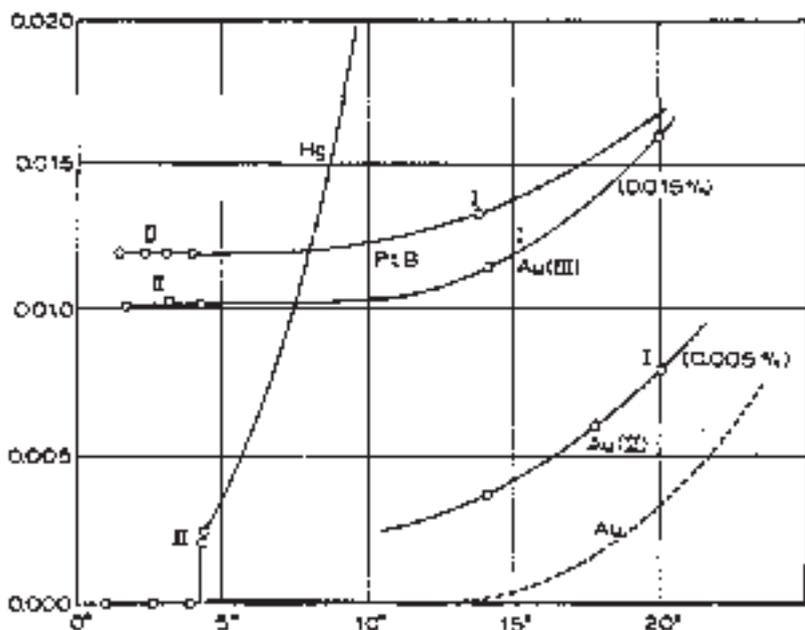
The provisional but ‘necessary’ communication to the Academy, in April,⁹ gave the following results for the resistance of mercury (in each case in relation to the value at 273 K): 0.034 at 13.9 K, 0.0013 at 4.3 K and less than 0.0001 at 3 K. ‘The experimental fact that a state can be induced in a pure metal in which galvanic resistivity is zero, or in any case immeasurably small, is certainly in itself a matter of great importance,’ said Onnes. He added that his idea of Planck’s vibrators as the determining factor for the resistivity of metals had received ‘significant corroboration’. That was not all. The frequency of the mercury atoms corresponded to a wavelength of 0.5 mm, ‘while Rubens [at the Institute of Metrology, Berlin] has recently found that a mercury lamp emits vibrations of extremely long wavelengths, approximating 0.3 mm’. These findings forged an ‘unexpected bridge’ between the temperature-dependence of resistivity and long-wave emissions. Intriguing and exciting physics.

A month later, Onnes had measured the resistivity of the mercury wire once again using a differential galvanometer and the ‘overlapping shunts’ method, which yielded more accurate results.¹⁰ At 3 K resistivity was found to have fallen below 0.000003 ohm, less than 10^{-7} of the value at 0°C (39.7 ohms). Resistance was actually measurable at temperatures slightly higher than 4.2 K. In November 1911, Onnes returned to the subject of the sudden jump in resistivity, which occurred more rapidly than his vibrator formula could account for. Earlier that month, at the First Solvay Conference, Paul Langevin had asked whether the mercury did not perhaps undergo some modification at the point of this ‘jump’ – an alteration into a different crystal structure (allotrope), for instance. Measurements of the specific heat and thermal conductivity of mercury were in the pipeline – they did not display any such jump in values –

⁸ H. Kamerlingh Onnes, ‘Further experiments with liquid helium. E. A helium cryostat’, in KNAW, Proceedings, 14 I, 1911, Amsterdam, 1911, pp. 204-210. *Comm.* 123a.

⁹ H. Kamerlingh Onnes, ‘Further experiments with liquid helium. C. On the change of electric resistance of pure metals at very low temperatures etc. IV. The resistance of pure mercury at helium temperatures’, in KNAW, Proceedings, 13 II, 1910-1911, Amsterdam, 1911, pp. 1274-1276. *Comm.* 120b.

¹⁰ H. Kamerlingh Onnes, ‘Further experiments with liquid helium. D. On the change of electrical resistance of pure metals at very low temperatures, etc. V. The disappearance of the resistance of mercury’, in KNAW, Proceedings, 14 I, 1911, Amsterdam, 1911, pp. 113-115. *Comm.* 122b.



Ill. 47. Graph in which electrical resistance (R) is plotted against temperature for various metal wires (gold, platinum, mercury). In mercury, resistance suddenly vanishes at 4.2 K: superconductivity.

and for the time being, Onnes suggested that the likeliest explanation was that the sudden fall in resistivity was primarily attributable to the higher frequency of the mercury vibrators below 4.2 K.

It is interesting to look at the three titles of Onnes's first reports on superconductivity: 'The resistance of pure mercury at helium temperatures' (April), 'The disappearance of the resistance of mercury' (May) and 'On the sudden change in the rate at which the resistance of mercury disappears' (November). One step at a time – typically Onnes.

In the meantime, Onnes had shifted his attention to something else: seeking to establish an upper limit for mercury resistance at 3.5 K, he passed a sizeable current through the seven U-shaped tubes and observed some 'peculiarities', as he noted meaningfully.¹¹ In his regular Christmas letter to Waldemar

¹¹ H. Kamerlingh Onnes. 'Further experiments with liquid helium. G. On the electrical resistance of pure metals etc. VI. On the sudden change in the rate at which the resistance of mercury disappears', in KNAW, Proceedings, 14 II, 1911-1912, Amsterdam, 1912, pp. 818-821. *Comm.* 124c.

Voigt in Göttingen, Onnes wrote that the decrease in the resistance of mercury was ‘a great mystery’ to him.¹²

It was over a year before the next article on superconductivity appeared. Although Onnes had presented part VII in the series ‘On the galvanic resistance in pure metals’ in December 1911, entitled ‘The movement of electricity through mercury below $4^{\circ}19\text{ K}$ ’, he withdrew it again after it had been deferred to the Academy’s January report. Clearly, he had not yet fully mastered all the details. Part VII was now published in instalments in February, March and May 1913, and the sheer length of the article – almost forty pages – shows just how hard Onnes must have been toiling away over his frozen mercury.¹³ Theoretical reflections on vibrators had to be set aside in favour of an exacting experimental struggle. What made this struggle more difficult still was that the liquid helium itself was a source of constant problems. At one point in 1912 all the helium leaked away as a result of human error, and Onnes had to beseech the Welsbach Light Company to send fresh supplies.

The introductory section of *Communication* 133 contains a characteristic account of the situation in lab E’.

‘A day of experiments with liquid helium requires a great deal of preparation, and when the experiments treated of here were made, before the latest improvements in the helium circulation were introduced, there were only a few hours available for the actual experiments. To be able to make accurate measurements with the liquid helium then, it is necessary to draw up a programme beforehand and to follow it quickly and methodically on the day of experiment. Modification of the experiments in connection with what one observes must usually be postponed to another day on which experiments with liquid helium could be made. Very likely in consequence of some delay caused by the careful and difficult preparation of the resistances, the helium apparatus would have been taken into use for something else. And when we could go on with the experiment again, the resistance sometimes became useless ... because in the freezing the fine mercury thread separated, and all our preparations were labour thrown away. Under these circumstances the detection and elimination of the causes of unexpected and misleading disturbances [the development of heat in lead wires and the difference in thermal potential arising between mercury “legs”] took up a great deal of time.’¹⁴

¹² Heike Kamerlingh Onnes to Voigt, 22 December 1911, Deutsches Museum, Munich, Sonder-sammlungen.

¹³ H. Kamerlingh Onnes. ‘Further experiments with liquid helium. H. On the electrical resistance of pure metals etc. VII. The potential difference necessary for the electric current through mercury below $4^{\circ}19\text{K}$ ’, in KNAW, Proceedings, 15 II, 1912-1913, Amsterdam, 1913, pp. 1406-1430. *Comm.* 133 a,b,c.

¹⁴ *Ibid.*

As 1912 drew on, the residual resistance in the ‘superconducting state’, as Onnes called the new effect, became smaller still. At 2.45 K the resistance of a mercury wire was at most 2.10^{-10} of that at 0°C . To establish this limiting value, the current was increased as much as possible. The question of whether the resistance of a superconductor was truly zero or whether there was still some ‘micro-residual resistance’ remained unanswered. If the current was increased beyond a certain value, the superconductivity disappeared, expressed in the development of heat in the mercury. This maximum current depended on the configuration of the wire and increased at lower temperatures. Some wires attained 1,200 amperes per mm^2 in pumped helium. To his amazement, Onnes discovered that mercury containing impurities – gold, cadmium or amalgam – also superconducted; all the trouble taken to purify the mercury turned out to have been wasted effort. Finally, it was established that Ohm’s Law applied at temperatures above the transition point.

In December 1912, tin and lead were also found to act as superconductors, with transition temperatures of 3.78 K and approximately 6 K respectively (Onnes did not yet have a cryostat for the temperature range between liquid helium and liquid hydrogen). Amalgamated tin superconducted at 4.29 K, strangely enough a higher transition temperature than that of its constituents tin and mercury. Onnes researched tin and lead far less thoroughly than mercury.¹⁵ He did succeed in making coils from these metals, however. This was done as follows. A brass core was covered with pure tin or lead and fashioned into a cylindrical shape using a lathe. From this cylindrical mantel, a kind of thin chisel or razor-blade was used to cut (in the path of a spiral or screw thread) a wire with a cross-section of 0.01 mm^2 that was superior to a drawn example. From 1.75 metres of wire (made from shorter pieces melted together) superconducting tin or lead coils were wound around glass cylinders, using silk to insulate the turns of the coil from each other.

The making of the first tin coil – 300 turns of $1/70 \text{ mm}^2$ and 1 cm high – immediately provided a surprise. While a straight wire of that thickness could take 8 ampères in liquid helium, the little tin coil lost its superconductivity at 1 ampere. Onnes assumed that eliminating ‘bad places’ in the coil (and hence better thermal conductance) would substantially increase the maximum current. The superconducting coil thus became a prototype of a coil magnet without iron. Whereas a normal magnet took so much current at high field strengths that there was a risk of it burning through (the heat developed could not

¹⁵ H. Kamerlingh Onnes, ‘Further experiments with liquid helium. II. On the electrical resistance etc. VIII. The sudden disappearance of the ordinary resistance of tin, and the super conductive state of lead’, in KNAW, Proceedings, 16 II, 1913-1914, Amsterdam, 1914, pp. 673-688. *Comm.* 133d.

escape rapidly enough), a superconducting coil did not have this problem. Jean Perrin's dream – a magnet of 100,000 gauss, cooled with liquid air – appeared, through superconductivity, to be turning into reality. In normal conditions, a monster magnet of this kind would need to be cooled by an hourly supply of 1,500 litres of liquid air (or 700 litres of hydrogen), which (aside from the technical impossibility of such a construction) would make the Perrin magnet as expensive as a warship! Now, with a coil of superconducting tin or lead, the project was no longer an idle fantasy.

In his report to the third international congress of refrigeration in Chicago in September 1913, Onnes calculated that 10,000 gauss with a lead coil of 1,000 turns need not be a problem, while a coil diameter of 30 cm held out the prospect of 100,000 gauss.¹⁶ This scale of operations would call for a much larger helium cryostat and a more powerful helium liquefier, however, 'which could be realised in Leiden with a relatively modest amount of financial support' – Claude promptly launched an initiative in Chicago to raise 100,000 francs in subscriptions for the Leiden laboratory. Onnes pointed out, however, that a magnetic field has the effect of increasing the resistance in an electric wire – in the latter half of 1912, Bengt Beckman researched this phenomenon extensively in Leiden.¹⁷ Since Onnes assumed that in the case of superconductors, only a strong field would produce a visible effect, a 50-kilogauss magnet was ordered from Oerlikon in Switzerland.

A report was submitted on these experiments in February 1914.¹⁸ A small 1,000-turn lead coil ($1/70 \text{ mm}^2$) was wound around a hollow brass core with a diameter of 1 cm; it was wound non-inductively (with wire folded double) so that it did not generate a magnetic field. In an external magnetic field of 10 kilogauss, superconductivity disappeared and the coil suddenly acquired a substantial resistivity. At 2 K a similar effect was seen. Contrary to expectations, the superconductivity disappeared even in far weaker fields: at 4.25 K, 600 gauss sufficed; slightly more was needed at 2 K. Tin had an even lower threshold value. It had been wholly unnecessary to wait for the new electromagnet! Whatever the case may be, the fantasy of a superconducting magnet with a force of 100,000 gauss lay in tatters.

¹⁶ H. Kamerlingh Onnes, 'Report on the researches made in the Leiden cryogenic laboratory between the second and third International Congress of Refrigeration'. *Comm.* Supplement 34b, 25-27.

¹⁷ Bengt Beckman, 'Hall-effekt und Widerstandsänderung im transversalen Magnetfeld im Bereiche der niedrigsten Temperaturen', *Het Natuurkundig Laboratorium 1904-1922*, 436-453.

¹⁸ H. Kamerlingh Onnes, 'Further experiments with liquid helium. I. The Hall-effect and the magnetic change in resistance at low temperatures. IX. The appearance of galvanic resistance in superconductors, which are brought into a magnetic field at a threshold value of the field', in KNAW, *Proceedings*, 16 II, 1913-1914, Amsterdam, 1914, pp. 987-992. *Comm.* 139f.

For Onnes it was beyond dispute that ‘threshold field’ and ‘critical’ or ‘transition’ temperature were related: in both cases, the wire suddenly acquired resistivity. The maximum current in a superconductor might be part of the same equation. This latter idea was not worked out in detail, as a result of which Onnes missed a golden opportunity. It was Francis Briggs Silsbee of the Bureau of Standards in Washington who was the first to reach the ‘obvious conclusion’ in 1916, having studied Onnes’s data scrupulously, that the threshold value [of the current] was the precise value at which the magnetic field generating the current was equal to the threshold field.¹⁹ To put it differently, the ‘threshold current’ was not an independent value at all; it was a direct derivative of the ‘threshold field’.

Onnes provided the crowning touch to his work in this area by generating a persistent current in a superconducting circuit.²⁰ The idea had occurred to him as soon as he had stumbled on the superconducting mercury. In a closed electric circuit, if the ‘pump’ (a battery, say) ceases to work, the current will soon subside. Conversely, Onnes saw measuring the time taken for it to subside (‘relaxation time’) as a method of ascertaining the micro-residual resistance – which he still favoured over zero resistance – of the superconductor. With all the puzzling and plodding amid breakdowns, tracking down the source of errors, and transitional temperatures, currents and fields, it was not until April 1914 that Onnes finally got down to conducting this ‘extremely simple experiment’. The little lead coil proved its worth again. It possessed a resistance of 736 ohms at room temperature. At 1.8 K this figure was lower by a factor of at least 20 billion, and combined with a self-inductance of 10 millihenry this yielded a ‘time to half-value’ (the time taken for the strength of the current to be halved) of at least one day. This was a promising result.

The experiment was performed as follows. The coil was placed in the ‘dry’ helium cryostat, with the magnetic axis horizontal, after which the external electromagnet was switched on. This imposed magnetic lines of force on the coil, which was countered by an induction current. Since the coil possessed normal resistivity, the induction current soon died down. Then the cryostat was filled with helium and the external electromagnet was switched off. Again the lead coil reacted with an induction current, and this time the current persisted because the lead was superconducting. This persistent current in the short-circuited lead coil revealed itself through its magnetic effect on a compass needle immediately outside the cryostat. Compensating for this effect

¹⁹ Dahl, *Superconductivity*, 98-99.

²⁰ H. Kamerlingh Onnes, ‘Further experiments with liquid helium. J. The imitation of an ampère molecular current or a permanent magnet by means of a supra-conductor’, in KNAW, Proceedings, 17 I, 1914, Amsterdam, 1914, pp. 12-20. *Comm.* 140b.

by using a subsidiary coil yielded an estimated persistent current of 0.5 to 0.6 ampères. The compass needle was watched carefully for one hour. The observations led to the conclusion that within a 10% margin, the current in the superconducting lead coil remained at the same level. Onnes would dearly have loved to demonstrate this spectacle at the Academy, but for the time being he could not transport the helium cryostat, which was still attached to the helium liquefier.

The sheer simplicity of the persistent current had great imaginative appeal. 'Although the experiment mainly confirmed my deductions as to what had to be expected', wrote Onnes, 'a deep impression is made by the very striking realisation which it gives of the mechanism imagined by Maxwell, completed by the conception of electrons.'²¹

The experiment was repeated a month later, using the same superconducting lead coil but this time with the copper compensatory coil being immersed in liquid air and set up in a fixed position relative to the needle.²² The temperature was 2 K, aside from brief periods (every few hours) in which the helium in the cryostat was topped up. A current of 2 ampères was chosen – low enough to ensure that even at 4.25 K (the temperature while the helium level was being topped up) the threshold value was not exceeded. The outcome of this improved experiment was that the current lost strength at the rate of less than 1% per hour – a 'time to half-value' of at least four days.

But was there really a current passing through the lead coil? Was it not possible that unknown magnetic properties – of the coil's brass cylindrical mantle, for instance – were causing the effect on the magnetic needle outside the cryostat? That Onnes did not allow himself to jump to conclusions is clear from an ingenious experiment he performed. He suspended a little hook from a long, thin rod protruding from the cryostat, and with this hook he broke the closing wire of the coil, while a ballistic galvanometer registered the rapidly falling current at 0.3 ampères.²³ When a superconducting signalling key was incorporated, at Kuenen's suggestion, this experiment could be repeated at will. Finally, Ehrenfest suggested using a thick lead ring instead of a coil: numerous turns in parallel instead of in series. In a ring with an internal diameter of 2.4 cm, 0.3 cm thick and 0.35 cm high, Onnes achieved a persistent current of 320 ampères.

²¹ *Ibid.*, 19–20.

²² H. Kamerlingh Onnes, 'Further experiments with liquid helium. J. The imitation of an ampère molecular current or a permanent magnet by means of a supra-conductor. [cont'd.]', in KNAW, Proceedings, 17 I, 1914, Amsterdam, 1914, pp. 278–283. *Comm.* 140c.

²³ H. Kamerlingh Onnes. 'Verdere proeven met vloeibaar helium. L. Over het voortduren van stroomen zonder electromotorische kracht in suprageleidende banen.' (sequel to J). *Verslagen* 17 (June 1914) 487–493. *Comm.* 141b.

Onnes had spent three years, assisted by Holst and with the technical support of Flim and Kesselring, experimentally unravelling an entirely new, complex phenomenon, one step at a time. Down-to-earth pragmatic questions predominated; as far as theory was concerned, he was completely at sea. Planck's quanta had been brought in straight away in 1911, but Onnes was soon compelled to admit that this theory was unable to account for the sudden jump in resistance. In the Academy article of May 1913 he did include some theoretical reflections – he would elaborate on them at the 1921 and 1923 Solvay conferences. He raised the question, for instance, of whether, in the superconducting state, electrons still had a free path, or if they did not in each case cover a distance of only molecular dimensions. This idea linked up with [Johannes] Stark's hypothesis concerning the movement of the framework of the valency electrons along the shearing surfaces of the metal crystals. But Niels Bohr had already shown the unproductiveness of Stark's approach.²⁴

A more promising approach was that of Willy Wien, who had set out in 1913 to reconcile the free electron with quantum theory. For high temperatures, this yielded a resistance proportional to temperature, whereas at low temperatures there was a quadratic relationship – which remained without experimental corroboration. Keesom too hazarded an application of quantum theory. He applied his ideas on the ideal monatomic gas, including zero-point energy, to free electrons in metals, which can also be regarded as a sort of 'gas'.²⁵ This approach did away with the freezing of electrons at absolute zero, one of the problems with electron theory. Onnes, who had forbidden his theoretical supervisor to work on this subject in laboratory time, described it in 1916 as 'a highly felicitous move'. Keesom had presented a plausible argument in support of Wilhelm Wien's hypothesis that when metals cooled, electron velocity did not fall below a certain minimum. But Keesom was lost when it came to explaining superconductivity, and he was not the only one. 'The theoretical explanation of the phenomena of superconductors is in a poor state', observed Crommelin in the 1922 commemorative volume. Not until the 1950s was superconductivity furnished with a quantum mechanical explanation, with the so-called BCS theory, after the initials of its three authors, Bardeen, Cooper and Schrieffer.

²⁴ Dahl, *Superconductivity*, 87–92.

²⁵ W.H. Keesom, 'On the theory of free electrons in metals', in KNAW, Proceedings, 16 I, 1913, Amsterdam, 1913, pp. 236–245. *Comm.* Supplement 30b.

Co-authorship versus acknowledgments

Onnes published eight articles on superconductivity between April 1911 and April 1914. He was the sole author in each case. Was this unfair to Holst? After all, it was Holst who, when the resistance in the mercury vanished one spring day in 1911, had seen the galvanometer needle swing in the dark. ‘Having come to the end of my communications on this series H of experiments with liquid helium’, Onnes concluded his major article on superconductivity in May 1913, ‘I should like to thank Mr G. Holst, assistant at the Physics Laboratory, for the dedication with which he has supported me in these matters, and Messrs G.J. Flim, manager of the cryogenic laboratory, and O. Kesselring, glassblower at the Physics Laboratory, for their important help in setting up experiments and making the necessary appliances.’²⁶ And Onnes concluded the article of February 1911, with determinations of the resistance of platinum and gold in liquid helium, with the following acknowledgment: ‘I should like to express my sincere gratitude to Mr C. Dorsman, who assisted me throughout this project with his keen judgment, and to Mr G. Holst, who performed the measurements with the Wheatstone bridge with meticulous care.’ All perfectly decent, but there was clearly no question of co-authorship.

According to Hendrik Casimir, who was a close associate of Holst’s at Philips’s NatLab, the young Holst must have been disappointed by this state of affairs, although he never said so or complained about it.²⁷ In his autobiography *Haphazard Reality*, Casimir discussed this matter at greater length: ‘Had anyone suggested to Kamerlingh Onnes’, he wrote,

‘that Holst should have been co-author from the beginning and should regarded at least as co-discoverer, he would probably have been highly surprised. After all, he himself had created the possibility of carrying out measurements at helium temperatures – to that Holst had not contributed. He himself had given instructions to measure the electric resistance of mercury, partly because on the basis of a theoretical speculation, he counted on the possibility that it might decrease rapidly at very low temperatures. Under these circumstances, no competent experimental physicist given that task could possibly have failed to discover superconductivity. That Holst was very competent he did not deny; for that he had given him ample and well deserved credit.’²⁸

²⁶ H. Kamerlingh Onnes. ‘Further experiments with liquid helium. H. On the electrical resistance of pure metals etc. VII. The potential difference necessary for the electric current through mercury below 4°19K’, in KNAW, Proceedings, 15 II, 1912-1913, Amsterdam, 1913, pp. 1406-1430. *Comm.* 133 a,b,c.

²⁷ Casimir, *Waarneming en visie*, 126.

²⁸ Casimir, *Haphazard Reality*, 165-166

That would have been Onnes's reasoning, muses Casimir, and '[t]he argument sounds rather convincing'. Casimir adds that according to later customary practice, Holst *would* have been considered a co-author, and that Holst himself applied a completely different policy as director of the NatLab. From May 1914 onwards, Holst, who started work at Philips on 2 January that year (a far more lucrative job²⁹), was in fact listed as author or co-author of a handful of *Communications* (of experiments performed in 1913). Had this change been inspired by Onnes's desire to remain on friendly terms with Eindhoven?

How did Onnes view authorship? It is not true, as has been claimed, that at the Physics Laboratory, co-authorships were confined to the more experienced members of staff.³⁰ Until 1906, Onnes's assistants simply published their research results in the *Communications* under their own names, without mentioning Onnes at all. This changed with the advent of Jolles, Braak, Fabius and Clay. From then on, Onnes was always cited first and the assistant as second author. When a foreigner took part, such as Becquerel, Mathias or Weiss, Onnes was the second author. There were a few exceptions, however. In 1906, when Keesom studied the theory underlying the barotropic effect (the sinking of a gas in a liquid), he was permitted to publish the findings under his own name. Four years later, Crommelin published two articles on argon vapour pressure under his own name, and W.J. de Haas enjoyed this privilege in 1911 and 1912 for his experiments with volumenometers. After that we see a rather mixed picture: sometimes assistants published under their own names, and sometimes Onnes was the author or co-author; increasingly often, he was the second author and his assistant the first.

A letter of recommendation for Keesom, dating from 1916, shows how Onnes viewed this issue. 'Where an experimental project has been published under both our names', wrote Onnes, 'the addition of my own name generally signifies little more than that the research was performed in a field for which I had provided the facilities in Leiden; it in no way detracts from Dr Keesom's merit in accomplishing his special work in this area, in which numerous difficulties remain for the experimentalist. Where the articles published by Dr Keesom and myself concern a more theoretical matter, we will necessarily have set it up jointly, but in all cases the execution was his work and the method too was frequently his choice.'³¹ An earlier letter of recommendation written in 1911 states: 'He published under his own name only when I expressly requested it.'³²

²⁹ Casimir, *Waarneming en visie*, 128.

³⁰ Dahl, *Superconductivity*, 93.

³¹ Heike Kamerlingh Onnes to Dekhuijzen, 22 July 1916, N-HA, Keesom archives, inv. no. 17.

³² Heike Kamerlingh Onnes to Julius, 28 November 1911, Utrechts Universiteitsmuseum, Julius archives, map vacature Wind.

Back to Holst. In the light of the above, it is striking and peculiar that he was not allowed to be co-author of the articles on superconductivity. Did it have something to do with the fact that Holst did not yet have a doctorate, and that he had been trained in Zürich rather than Leiden? Ekko Oosterhuis, who had gained his doctorate under the solid scientist Haga in Groningen, did publish under his own name in 1912. Did Onnes consider that arranging decade resistance boxes and mirror galvanometers in a darkened room at some distance from the cryostat with the superconductor was too meagre to qualify as co-authorship? Later on, Onnes would say of Holst that he was ‘not a Kuenen, by a long chalk’. His recommendation of Holst for Academy membership sounds rather mechanical: ‘Where his work in Leiden is concerned, it may be noted that he was involved in the discovery of the superconductivity of metals and in the further research on superconductivity.’³³

Goes round and round and round

How did the world react to superconductivity? Japanese scientists were quick to take note. On 12 September 1911, Hantaro Nagaoka, a physics professor from Tokyo who had visited the cryogenic the previous year as part of a tour of European institutes, congratulated Onnes on his ‘brilliant discovery of the great conductivity of mercury in the neighbourhood of absolute zero’.³⁴ Closer to home, at the first Solvay conference in November, the reactions were lukewarm. That Onnes’s presentation of superconductivity in Brussels should have elicited only one question scarcely reflects much audience excitement.

Far more enthusiastic was E. Lemaire in *La revue générale du froid*, the French journal of refrigeration technology.³⁵ Upon receiving the provisional *Communications* of April and May 1911 on superconductivity in Paris, he had immediately packed his bags and gone to Leiden, to find out more of this subject, which he considered to be of the greatest importance from both the scientific and the technological viewpoint, from Kamerlingh Onnes himself. In his article, which appeared in September 1911, he immediately raised the subject of Perrin’s giant magnet. A superconducting coil without any development of heat, said the author, would be able, with the immense strength of its magnetic field, to ‘destroy the atom by force’ and hence increase our knowledge of matter.

³³ N-HA, Akademiearchief, inv. no. 560.

³⁴ H. Nagaoka to Heike Kamerlingh Onnes, December 1910 and 12 September 1911, MB, archives of Heike Kamerlingh Onnes.

³⁵ E. Lemaire, ‘L’organisation du laboratoire cryogène de Leyde (Pays-Bas). Dernières recherches du professeur Kamerlingh Onnes sur la résistivité électrique des métaux purs au voisinage du zéro absolu’. *Revue générale du froid* 3 (1911) 475-483.

What did make a profound impression on the scientific community was Onnes's persistent current, which theorists found totally baffling: it was at odds with the physics of the day. Max Planck informed Onnes that his 'amazing discoveries of currents without friction have been noted in Berlin with the greatest possible interest.'³⁶ Paul Ehrenfest, who had witnessed the experiment, told Lorentz that he was flabbergasted. 'I attended a fascinating experiment at the laboratory', he wrote to Haarlem in April 1914. ... 'Unsettling, to see the effect of this "permanent" current on a magnetic needle. It is almost tangible, the way the ring of electrons goes round and round and round in the wire – slowly and virtually without friction.'³⁷

The appreciation that counted most took the form of letters of recommendation to the Nobel Committee. The discovery of superconductivity, like the liquefaction of helium in 1908, led to Kamerlingh Onnes being nominated in Stockholm for the most coveted award of all. While the 1912 winner – to the amazement of friends and foes alike – was the Swedish inventor Nils Dalén, the following year brought Onnes the great prize.

³⁶ Planck to Onnes, 10 March 1915, MB, archives of Heike Kamerlingh Onnes.

³⁷ Ehrenfest to Lorentz, 11 April 1914, N-HA, Lorentz archives, inv. no. 20. 'Ich habe im Laboratorium einem faszinierenden Experiment beigewohnt Es ist unheimlich die Wirkung dieser "permanenten" Ströme auf eine Magnetnadel zu sehen. Man fühlt fast handgreiflich wie im Draht der Elektronenring runderdreht, runderdreht, runderdreht – Träge und fast ohne Reibung.'

30. A chocolate from Stockholm

On the morning of Wednesday 12 November 1913, a telegram was delivered to Huize ter Wetering. It read: NOBEL PRIZE FOR PHYSICS AWARDED TO YOU / PARTICULARS FOLLOW BY LETTER / SECRETARY AURIVILLIUS.¹ Was Kamerlingh Onnes at home? Did an excited Bé or Albert rush to telephone the laboratory? Whatever the case may be, it was a festive day in Leiden. The late newspaper *NRC* carried the news that same evening, with a full column ('Reuter report from Stockholm'), informing its readers that the prize included a sum of money to the tune of 197,000 francs,² almost 100,000 guilders. Three years after the Nobel Prize for Van der Waals came this new triumph. The Netherlands – 'a superpower in physics' according to Waldemar Voigt³ – really counted in the world of science.

A day later, along with a flood of congratulatory telegrams and letters, came the promised letter from Stockholm. The entomology professor Christopher Aurivillius, secretary of the Swedish Academy of Science, invited Onnes to attend the formal prize-giving ceremony in Stockholm on 10 December, the anniversary of Alfred Nobel's death. He also pointed out that any Nobel Lecture would have to be given within six months. After that followed a request for Onnes to give his age (60), and Gustaf Granqvist, who chaired the Nobel Committee for Physics, sent a telegram from Uppsala warning Onnes that his lecture must not be more than one hour long.⁴ Onnes had already confided to Zeeman his intense pride at being added to the distinguished company: 'How striking are the mutual ties that exist among the four corners of the square, that after Lorentz, Zeeman, and Van der Waals, is now completed with me!'⁵

¹ 'NOBELPREIS FUER PHYSIK IHNEN ZUERKANT / NAEHERES BRIEFLICH / AURIVILLIUS SEKRETAER'; MB, archives of Heike Kamerlingh Onnes, inv. no. 134.

² *Nieuwe Rotterdamsche Courant*, 12 November 1913.

³ Waldemar Voigt, *Chemiker Zeitung*, 11 December 1913, 1518-1520.

⁴ See telegram (note 1).

⁵ Heike Kamerlingh Onnes to Zeeman, 15 November 1913, N-HA, Zeeman archives.

Nobel prizes had soon become a concept after their introduction in 1901. The last will and testament of Alfred Nobel, who had died in his villa in San Remo on 10 December 1896, had a thunderous surprise in store: of his fortune of over 30 million krone (20 million guilders), the fruits of dynamite production, he left his family – to their considerable astonishment – only 1 million. The rest was to be placed in a new fund from which five Nobel prizes would be awarded annually: for physics, chemistry, physiology or medicine, literature, and peace. The will stated that the prizes were to be awarded to those who had performed the greatest service to humanity in the year of the award.⁶

After some difficult negotiations among the various parties, the Nobel Foundation presented its statutes in June 1900. These stipulated that the prizes should be awarded for ‘discoveries, inventions and improvements’. Recent work was to take precedence – older results or inventions would be considered only if their significance had not been demonstrated before. The third factor was that they must be of benefit to humanity. The prizes for physics and chemistry were awarded by the Swedish Academy of Science, following nominations by the Nobel Committees in these fields. The Karolinska Institute would decide on the prize for physiology or medicine, the Swedish Academy for the Nobel Prize in Literature would award the prize in literature, and the Norwegian Parliament would decide on the Peace Prize. A sixth Prize in Economics was added in 1969.

No prize could be awarded without a nomination.⁷ Those eligible to submit nominations in physics were members of the Swedish Academy, members of the relevant Nobel Committee, previous laureates, physics professors in the Scandinavian countries, a group of six or more foreign professors, and individual scientists (the last two categories at the invitation of the Swedish Academy). There was no question of selection according to the highest number of votes cast. The Nobel Prize for physics has on occasion been awarded on the basis of a single nomination.

The first Nobel Prize for physics, in 1901, went to Wilhelm Conrad Röntgen, in recognition of his extraordinary achievement as the discoverer of X-rays, six years earlier. Of the 34 valid nominations, sixteen were for Röntgen as against six for his compatriot Lenard, for discovering cathode rays. The Swedish Academy blocked a proposal submitted by the Nobel Committee and the physics section of the Academy to award the prize to the two men jointly, arguing that Lenard’s achievement, unlike Röntgen’s, had not benefited humanity.

⁶ Elisabeth Crawford, *The beginnings of the Nobel institution: the science prizes, 1901-1915* (London 1984) 217.

⁷ Elisabeth Crawford, J.L. Heilbron, Rebecca Ullrich, *The Nobel population 1901-1937: a census of the nominators and nominees for the prizes in physics and chemistry* (Berkeley 1987) 1-2.

Zeeman received two nominations. Kamerlingh Onnes, the only Dutchman to submit a recommendation, nominated Van der Waals.⁸ Favouring one's fellow-countrymen was considered perfectly understandable. The French and British excelled in this area: in the first fifteen years of the Nobel Prize for Physics, three-quarters of their nominations were for compatriots. The Netherlands, Germany and the United States named fellow-countrymen in half of their nominations. Onnes, after a long period of silence, nominated Max Planck in 1914, Albert Einstein in 1920, and Jean Perrin in 1924 and 1926, following an agreed Dutch line.

Lobbying was part of the game from the outset. This is well illustrated by the award of the prize to Lorentz and Zeeman jointly in 1902. The Swedish mathematician Gösta Mittag-Leffler fervently wanted the prize to go to a mathematical or theoretical physicist, and favoured the Frenchman Henri Poincaré. But it was a hard mountain to climb, since the Uppsala school that dominated the Nobel Committee had an experimental bias. Poincaré was nominated an astonishing 51 times between 1904 and 1912, the year of his death, but never secured the prize.

Mittag-Leffler, who belonged neither to the Nobel Committee nor the Academy's physics section, tried to manipulate nominations through his network. He saw the Nobel Prize for Lorentz as a means to the end of crowning Poincaré. He also hoped that lobbying for the Dutchman might torpedo the chances of the physical chemist Svante Arrhenius, who, as an internationally respected member of the Nobel committee, was himself a spider in the web. Mittag-Leffler instructed Poincaré to focus his report on one or two key aspects of Lorentz's work: the Nobel Prize was not intended to crown an entire oeuvre. He also advised the Frenchman to involve the well-respected Zeeman by emphasising Lorentz's role in explaining the Zeeman effect. Finally, Poincaré was urged to seek out fellow countrymen – the more the merrier – to sign his report, after which Mittag-Leffler would continue lobbying in Germany and Britain. All this yielded ten nominations for Lorentz, four of which were declared invalid because Mittag-Leffler had secured them by telephone. Zeeman himself did not receive a nomination until the last minute – from Arrhenius himself. This proved decisive. The combination with Zeeman, an experimentalist with a spectacular discovery to his name, made the shared prize for Lorentz acceptable to the Nobel Committee.⁹ The press had wrongly predicted that Marconi would be honoured for his discovery of wireless telegraphy – he did not secure the award for another seven years.

⁸ *Ibid.*, 20–21.

⁹ Elisabeth Crawford, *The beginnings of the Nobel institution: the science prizes, 1901–1915* (London 1984); 136–140.

The 1910 Nobel prize for Van der Waals was the result of a fierce battle behind the scenes. Mittag-Leffler had launched a worldwide campaign in his determined lobby for Poincaré, passionately arguing that the time was ripe for the physics prize to be awarded to a pure theoretician. He wrote to over fifty of those eligible to submit nominations, including all previous winners, resulting in 34 nominations – a prewar record. Lorentz and Zeeman put their heads together and agreed to support Mittag-Leffler's action. They initially considered nominating both Kamerlingh Onnes and Poincaré: 'Should P. carry off the prize this year, we can forcefully promote the O. proposal next year', Lorentz wrote to Zeeman. 'Perhaps we could ask Lenard to join in, in that case.'¹⁰ Onnes's name had been put forward after the liquefaction of helium, in July 1908. The Dutch scientists had evidently given up on Van der Waals after a five-man offensive of Julius, Lorentz, Sissingh, Wind and Zeeman had failed in 1907. It counted against Van der Waals not only that he was a theorist, but also that his equation of state and his law of corresponding states were over a quarter of a century old.

Within the Nobel Committee, the strong pro-Poincaré lobby largely aroused irritation. Another influential factor was the death of the member Knut Ångström, shortly after the deadline for nominations had passed. Röntgen, aware of Ångström's poor health, had nominated him at the last minute (the only one to do so) for his work on solar radiation. Under the statutes, it was possible to award Ångström a posthumous prize, but only in 1910. The Nobel Committee decided to seize this last opportunity, and voted by a majority of three to two to award the prize to Ångström for his high-precision experimental work (and his services to the Committee), instead of honouring Poincaré's mathematical physics. Since it was uncertain how the Academy would react to the idea of a new laureate who was already dead, the Committee nominated Van der Waals too – Arrhenius rapidly prepared a report on the law of corresponding states. That Van der Waals (who had thus far been nominated only by the chemist T.W. Richards of Harvard University) was now considered eligible for a prize was directly related to the liquefaction of helium. Had Kamerlingh Onnes not emphasised in 1908 that navigating by the 'beacon' of the law of corresponding states had provided the basis for his victory? While the physics section of the Swedish Academy did not express a preference for either Ångström or Van der Waals, the Academy as a whole balked at crowning a corpse, leaving Van der Waals as the sole laureate in 1910.¹¹

¹⁰ Lorentz to Zeeman, 24 January 1910, N-HA, Zeeman archives, inv. no. 105.

¹¹ Elisabeth Crawford, *The beginnings of the Nobel institution: the science prizes, 1901-1915* (London 1984), 140-148.

Kamerlingh Onnes was delighted to hear that the Nobel Prize had been awarded to his old friend. When he and Van der Waals were presented with gold medals by the Society for the Promotion of Physics, Medical Science and Surgery, in the autumn of 1908, and each in turn hung the ribbon around the other's neck in the main auditorium of the University of Amsterdam, Onnes gave a speech of thanks in which he referred to Van der Waals with Dewar's epithets 'the master of us all' and 'the creator of all our ideas'. Dewar considered that Van der Waals had not received the international recognition that he deserved.¹² Onnes heartily agreed, and wrote to Dewar that the only possible explanation was that it would take time for scientists to realise the greatness of his work. It had been years before anyone had paid attention at all. 'Only your Maxwell displayed any appreciation, Clausius had not the faintest idea of its enormous significance. ... Boltzmann did see Van der Waals's work in the correct perspective, but he too failed to appreciate his revolutionary views.'¹³ Within two years, recognition came after all.

The Nobel Prizes were an instant success with the general public: they derived added prestige from the rivalry between countries, rather like the Olympic Games, and from the large sum of money attached to the prize. It was an age of rampant nationalism. *Deutschland in der Welt voran!* blazed German headlines in 1905, when three of the five prizes were awarded to Germans – echoing Count Von Bülow's war cry at the Battle of Waterloo. In 1910, with the tenth anniversary of the Nobel Prizes, one German newspaper noted with satisfaction that Germans had accounted for more of the 62 prizes awarded thus far than any other national group. There was some malicious pleasure at the expense of the United States, which had produced only two laureates – and Michelson had been born in Germany. But the Americans did not demean the prizes: 'The history of modern science', wrote *Cosmopolitan Magazine* in 1906, 'might be written without going outside the names of the Nobel prizes for beneficent discoveries in physics, chemistry and medicine.' An exaggeration, but it reflects the status of the prize.¹⁴

¹² Dewar to Heike Kamerlingh Onnes, 17 November 1908, MB, archives of Heike Kamerlingh Onnes.

¹³ Heike Kamerlingh Onnes to Dewar, 22 November 1908, archives of the Royal Institution. 'The sole explanation is that his work wants time to be seen in its full greatness by the general scientists'. Onnes continued that it had been many years before this work had attracted any general interest. 'There was only your Maxwell who appreciated well, Clausius did not grasp the scope of the work at all. ... Boltzmann had an adequate idea of Van der Waals's work. But he himself has not found the appreciation he deserved [for] his revolutionising views.'

¹⁴ Elisabeth Crawford, *The beginnings of the Nobel institution: the science prizes, 1901-1915* (London 1984), 188-193.

Scientists were initially less impressed. Authoritative journals such as Britain's *Nature*, France's *Revue Scientifique* and the United States' *Science* devoted scant information to the Nobel Prize in the first few years, and many scientists asked to make nominations failed to respond (including Kamerlingh Onnes in 1902). In 1911 a questionnaire conducted by the *Svenska Dagbladet* among the laureates crowned thus far revealed that it was the financial award that had meant most to them; they did not mention prestige. But as soon as it became clear that many Nobel prizewinners had previously won major prizes such as the Rumford Medal (Royal Society) or the Prix Lacaze (Académie des Sciences), the Swedish prize gained in reflected glory.¹⁵

Onnes too won the Rumford medal first, in 1912 – two years after the University of Berlin had awarded him an honorary doctorate. 'I am very happy about it', he wrote to Jacob Clay. 'The Royal Society stands in high esteem, and has been very astute in its awards. Frequently, I believe, they have helped to provide redress for someone who was not appreciated in his home country. Mendeleev, for one. Well, that was not necessary in my case! Our own country has paid tribute to me, so much so that one might be embarrassed, were not sincere gratitude for appreciation such a splendid feeling.'¹⁶

The liquefaction of helium earned Kamerlingh Onnes six nominations in 1909. Some of those who nominated him – Julius, Lorentz and Zeeman, and Mathias (a regular visitor at Leiden's cryogenic laboratory) – were close acquaintances. The experimental physicist F. Pockels from Heidelberg was a colleague of Onnes's friend Waldemar Voigt, while the Parisian chemist Henri Louis le Châtelier (who repeated his nomination in 1910, 1912 and 1913) may have known Onnes from the first international congress of refrigeration. Eight of the 1909 nominations were for the brothers Wilbur and Orville Wright, the aviation pioneers who had invented the first powered aircraft to sustain flight – which had taken off from the beach of Kitty Hawk, North Carolina, five years before. Nonetheless, that year's prize honoured a different practical invention: the wireless telegraphy of Marconi and Braun.

In 1912, after the discovery of superconductivity, Onnes was again considered in Stockholm. Once more he received six nominations, from Julius and Lorentz, Le Châtelier, Emile Warburg (an old acquaintance from the Institute of Metrology in Berlin), Charles Fabry (Marseille, of the Fabry-Perot interferometer) and Edmond van Aubel (Ghent; in 1897 he had disputed Zeeman's priority regarding the discovery in Leiden of the widening of spectral lines in a magnetic field). It looked as if things would go better this time. The Nobel

¹⁵ *Ibid.*, 200-216.

¹⁶ Heike Kamerlingh Onnes to Clay, 4 December 1912, coll. Frieling-Van Osselen.

Committee and the physics section, with liquid helium still fresh in their minds, unanimously nominated Onnes. But the Academy decided otherwise: as in 1909, the prize went to an inventor. The Swede Nils Gustaf Dalén, nominated by his fellow countryman Erik Johan Ljungberg (his name had not come up in previous years), was awarded the prize for his automatic regulation of the gas-light used in lighthouses and light buoys.

The result was a victory for the large contingent of engineers within the Academy. Frustrated by the paucity of applied scientists among Nobel laureates, they had sought redress.¹⁷ It had already been noted in December 1911, at a meeting of the Swedish Association of Inventors (Svenska Uppfinnareföreningen) that Thomas Edison had declared his intention to refuse a Nobel Prize if he was offered one, out of protest against the perceived slight to engineers. The Swedish inventors, outraged that neither of their celebrities Fredrik Kjellin and Gustaf de Laval had yet been honoured with the Nobel Prize for chemistry, sent a letter of protest to the Academy. Their allies within the Academy's technology section expressed this displeasure in 1912 by bypassing the candidate proposed by the Nobel Committee, Onnes, in favour of the engineer Dalén. Shortly before the decisive meeting, the unfortunate Dalén had lost his sight in an accident, and the engineers' resentment was bolstered by sympathy. When the time came to decide, Dalén won 37 votes, as against 28 for Onnes. He was the only laureate in the history of the Nobel Prize to win on the basis of a single nomination (considering the total over time); the nominator Ljungberg proposed only this one name.¹⁸

In 1913, Onnes's luck changed. Support came from the quartet of Lenard, Le Châtelier, Weiss and Warburg, and from the Polish trio of Natanson, Witkowski and Zakrzewski (the latter had worked as Onnes's assistant). The Poles wanted their compatriot and cryogenic pioneer Karol Olszewski to share the prize, but their hopes remained unfulfilled. Lenard and Warburg also presented alternative pioneers in the realm of cold: James Dewar and Carl von Linde. But the Swedish Academy awarded the Nobel Prize for Physics to Onnes alone, 'for his investigations on the properties of matter at low temperatures which led, *inter alia*, to the production of liquid helium'. Not a word about superconductivity, although it was this discovery in particular that held out the prospect of practical applications. The theorists were baffled by superconductivity, but that its explanation was related to quantum theory seemed fairly clear. It is possible that Arrhenius, who took little interest in quantum theory because it was related to the Heat Theorem of his arch-enemy, Walther Nernst, found

¹⁷ Robert Marc Friedman, *The politics of excellence: behind the Nobel prize in science* (New York 2001) 57.

¹⁸ Elisabeth Crawford, *The beginnings of the Nobel institution: the science prizes, 1901-1915* (London 1984) 160, 166.

it inconvenient to award a prize for superconductivity. The Academy's explanatory report also referred to Einstein's special theory of relativity. This was well on the way to becoming worthy of a Nobel Prize, in spite of the meagre amount of experimental corroboration. But some of the Academy's members said that comparing Einstein to Copernicus or Darwin, as some letters of nomination had done, was going too far.¹⁹

Borne around the ball in triumph

At the beginning of December, Heike travelled by train to Stockholm, together with Bé, their son Albert and his brother Onno – who spoke Swedish.²⁰ They took rooms at the Grand Hôtel, near the harbour and opposite the Royal Palace and commanding a view of the Nord-Strom and Lake Mälaren. They were in high spirits. 'We greatly enjoyed the trip to Stockholm', Heike wrote to Van der Waals (unlike Bé, who had complained about the 'bad train carriages' in a letter to her sister Virginie).²¹ Heike was also impressed by the 'stately hotel with all its splendour, cheerfulness and comfort' and their cordial reception, and praised the Swedes for their combination of dignity and 'simple good-naturedness'.²²

In preparation for the ceremony on 10 December, the great day, Heike sent his brother to gather some facts about the Swedish monarchy. He also asked Onno (and Albert) to make summaries of speeches of thanks by past Nobel laureates.²³ 'In difficult times', Lorentz had pronounced at the banquet in 1902, rising to his new public role, 'if one cannot see any light in matters of complexity, one will derive strength from the idea of the Nobel Prize.'

It was an established tradition for the presentation to take place in the large auditorium of the Music Academy. The ceremony began at 5 p.m. with the performance of a choir. Onnes was the first to receive his award, followed by fellow laureates Alfred Werner (chemistry) and Charles Richet (medical science) – the Indian Rabindranath Tagore (literature) was conspicuous by his absence. The presentation speech was made by Academy president Gunnar Nordström. He commented on the relationship between Onnes's work and that of Van der Waals, gave a brief account of the race for liquid helium and discussed electron theory as a perfect example of a research area that promised to yield surprising results in temperatures approaching absolute zero. In this

¹⁹ Abraham Pais, *Einstein lived here* (Oxford 1994) 71.

²⁰ *Nieuwe Rotterdamsche Courant*, 15 December 1913.

²¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 127c.

²² Heike Kamerlingh Onnes to Van der Waals, 5 January 1914, N-HA, Van der Waals archives.

²³ MB, archives of Heike Kamerlingh Onnes, inv. no. 127b.

connection Nordström referred to the work on quantum theory performed by Planck and Einstein, two names that were acquiring momentum within the Nobel Committee (and who would both eventually be honoured, in 1918 and 1921 respectively). Then it was time for a beaming Onnes to step up to King Gustav V, who hung the Nobel medal around his neck.

The special banquet at the Grand Hôtel in honour of the new laureates began at 7 p.m., with almost two hundred guests. Heike sat between Crown Princess Margaret and Countess Louise Wachtmeister, diagonally opposite Bé; Albert and Onno were seated at transverse tables. Getting through the menu – *Tortue claire, Suprême de turbotin Walewska, Poularde Massenet, Chauffroix de cailles Lucullus, Salade, Fonds d'artichauts Maintenon, Parfait praliné, Friandises* and *Fruits* – took several hours. As for wine, the guests were regaled with ‘Madère Old’, Château Smith Haut Lafite (1905), Rudesheimer (1908), Charles Heidsieck (Demi-sec, Brut, 1904) and ‘Porto Very Superior Old’. Heike tucked a ‘very fine chocolate’ into the pocket of his evening dress for his sister Jenny, just as he had done as a student, so many years ago.²⁴

The toast that Heike proposed struck exactly the right note. ‘Deeply moved’, he began, ‘I should like to express my heartfelt gratitude on this festive occasion, which derives a magical glow from the Royal presence, for the honour that has been paid to me, to which I attach all the more significance having received it from the hands of His Majesty the king.’ No difficulty was so great, he continued (echoing Lorentz) but the lustre of the Nobel Prize imparted fresh courage. He then exalted Van der Waals and Dutch science in general. ‘Science is an international field of endeavour, but countries must struggle in their pursuit of it,’ said Heike. He also made a gesture to Swedish physics. ‘In token of my sincere feelings of gratitude’, Heike concluded, referring to the friendly reception he had been given by the Swedes and to the gracious opening comments by Nordström, president of the Academy, ‘I propose a toast to the physicists of Sweden.’²⁵

It was a merry gathering at the Grand Hôtel, judging by the report in the Dutch daily newspaper *NRC*: ‘The party, which lasted until midnight, was highly animated; at the end, the prizewinners were hoisted into the air by the young singers and older decorated gentlemen and carried around the hall in triumph. The festive mood was relaxed and extremely cheerful – very different

²⁴ *Ibid.*, 127c.

²⁵ *Ibid.*, 127b. ‘Mit tiefer Rührung spreche ich bei dieser Feier, welcher die Beteiligung des Königlichen Hauses ihren Zauber verleiht, meines innigst gefühltes Dankens für die mir heute erwiesene Ehre, deren Bedeutung noch dadurch erhöht wird, dass ich sie aus den Händen seiner Majestät des Königs empfangen dürfte. ... Die Wissenschaft ist ein internationales Gut, aber in den Pflege derselben haben die nationen zu wetteifern.’

from the stereotype of such festivities.²⁶ It is quite possible that Onno, who returned to the Netherlands earlier (and was given the chocolate to pass on to Jenny) was the source of this report. The Swedish newspapers noted that the student song *Sjungom studentens lyckliga dag!* was sung during the banquet.²⁷

Onnes's Nobel Lecture, given in the sumptuous auditorium of the Academy the following afternoon, gave a comprehensive overview of thirty years of cryogenic activities.²⁸ Heike invited his listeners to 'follow me into the Leiden laboratory'. The cascade, the hydrogen installation, the measuring apparatus, the assault on helium, the thermodynamic, magnetic and electrical research, superconductivity: he dwelt on each in turn, scrupulously mentioning every assistant and technician who had contributed to the work, as well as every non-Dutch scientist who had used the cold in Leiden to extend his or her own research. Slides of the installations were shown using a magic lantern, enlivening the story and helping to clarify it – the complexity of the helium cryostat, with its Dewar flasks like Russian nesting dolls, must have dazzled his audience.

Heike explained that the original objective of the cryogenic work in Leiden, namely to test Van der Waals's equation of state, had gradually been extended as time went on, culminating in an intense specialisation in experiments at low temperatures. Opening up the liquid helium range, 'which brought temperatures within reach that for certain phenomena can be equated in practical terms to absolute zero', had yielded surprising new discoveries. 'Since Nernst's heat theorem, and more notably Planck's quantum theory and his theory of zero-point energy, measurements at low temperatures have been of the greatest possible significance for physicists.'

²⁶ *Nieuwe Rotterdamsche Courant*, 15 December 1913.

²⁷ MB, archives of Heike Kamerlingh Onnes, inv. no. 127c.

²⁸ H. Kamerlingh Onnes, *Untersuchungen über die Eigenschaften der Körper bei niedrigen Temperaturen, welche Untersuchungen unter anderem auch zur Herstellung von flüssigem Helium geführt haben* (Stockholm 1915). 'Das Nernst'sche Wärmetheorem und besonders die Planck'sche Lehre von den Quanten und der Nullpunktsenergie hat Messungen bei tiefster Temperatur geradezu in der Vordergrund des physikalischen Interesses gerückt. Wohl ist das Faraday'sche Problem, ob alle Gase verflüssigt werden können, Schritt für Schritt im Sinne der van der Waal'schen Worte "Stof wird wohl immer Anziehung zeigen" gelöst worden, und damit eine fundamentale Frage weggefallen. Zugleich ist aber durch die von Planck gestellte Frage ein, wahrscheinlich nicht weniger fundamentales Problem gegeben, zu dessen Lösung Untersuchungen über die Eigenschaften der Körper bei tiefen Temperaturen beitragen können. ... In der Zukunft sehe ich überall im Leydener Laboratorium Messungen ausführen in Kryostaten, nach welchen das flüssige Helium transportiert wird wie jetzt die andere flüssige Gase, und in welchen auch über dieses letzte Gas frei, so zu sagen wie über Wasser, verfügt wird. Inzwischen liegt Arbeit genug vor der Hand, die geeignet ist, schon, wenn auch noch mühsam (wie einst als wir mit der Benutzung des flüssigen Sauerstoffs anfangen), in der Nähe des Verflüssigungsapparats gemacht zu werden, und die beitragen kann um den Schleier zu lüften, den bei gewöhnlicher Temperatur die Wärmebewegungen über die innere Welt der Atomen und Elektronen spannen.'

‘It is true that Faraday’s problem as to whether all gases can be liquefied has been solved step by step in the sense of Van der Waals’ words “matter will always show attraction”, and thus a fundamental problem has been removed. At the same time, however, the question asked by Planck introduces a problem which is probably no less fundamental, to the solution of which investigations into the properties of substances at low temperatures can contribute.’

Heike concluded with a vision of the future.

‘In the future I see all over the Leyden laboratory measurements being made in cryostats, to which liquid helium is transported just as the other liquid gases now are, and in which this gas also, one might say, will be as freely available as water. In the meantime there is plenty of work which can already be done, albeit with difficulty (as when we began to use liquid oxygen), in the neighbourhood of the liquefying apparatus, and which can contribute towards lifting the veil which thermal motion at normal temperature spreads over the inner world of atoms and electrons.’

Heike was not feeling very well when he gave his Nobel lecture. The ‘extremely merry but rather enervating party’ of the previous evening had taken its toll, and he had immediately succumbed to a bad cold. Had he followed the doctor’s orders on this occasion, he would not have given the lecture. But he decided to risk it and carried out all his responsibilities on the day’s busy schedule: At 2 p.m. the lecture in the Academy’s auditorium, followed by an audience with the queen, and in the evening he dined with the king, to the sounds of Wagner, Verdi and Bonelli. All this was too much for Heike’s frail constitution, and the following morning Bé urged him to take to his bed – as soon as he had gone to the bank to cash the Nobel cheque. For ten days he was confined to the Grand Hôtel.

‘I benefited from the stories of B. and Albert, who saw many beautiful things and met with great friendliness, while I remained behind and let the illness run its course’, Heike wrote to Van der Waals. Bé and Albert took a trip to Uppsala, where they went to see Bengt and Anna Beckman, who had worked with Onnes the year before. Being under house arrest gave Heike ample opportunity to answer letters from the home front. While his father-in-law wrote that it was fortunately ‘fine weather’ in Stockholm for the invalid, other relatives wrote more informal, lively accounts. His niece Virginie, who called her uncles by the diminutives *Ontje* and *Heikje*, wrote, ‘How wonderful that a Nobel prizewinner should be nicknamed ‘little goat’ [*heikje*]; it is wholly characteristic and speaks volumes, to my mind.’ She also reported that a letter had been delivered to Huize ter Wetering with at least a hundred exclamation marks, containing a description of a perpetual motion machine. Jenny too sent greetings: ‘I remember the room on the Zoutstraat, how you carried me on your arm, and now things are being made easy for me once again, and I bear a

name that you have made famous'. And to Bé: 'How very fortunate that a man should have brought his nurse and female bodyguard with him on his journey; how grateful the little goat will be, I [little owl] can already see his little eyes gazing at you'.²⁹

On the day of the winter solstice, Heike, Bé and Albert set off on their homeward journey. 'Seen off with flowers, we were then received just as cordially in Copenhagen, and this time I could enjoy the sightseeing,' Heike wrote to Van der Waals. 'In short, it was a journey full of the most marvellous memories together with B. and Albert, which makes it so much more precious.' Back in the Netherlands, Heike went to see the Swedish envoy even before Christmas: he donated 1,000 krone of his prize to a Swedish charity for children's holiday camps.³⁰ Nor did he forget his wife, for whom he bought a diamond brooch.³¹

This sixth Nobel prize awarded to a Dutchman (Jacobus van 't Hoff had secured the first chemistry award in 1901, for his pioneering work on chemical equilibrium and osmotic pressure, and former minister of state Tobias Asser had won the peace prize in 1911) received extensive coverage in the press. Crommelin wrote a beautifully illustrated article for *Panorama*,³² Kuenen went to town in *Chemisch Weekblad*,³³ and Van der Waals published a piece in *De Gids*, ending with the 'satisfying reflection' that the Netherlands had now carried off its fourth prize for physics.³⁴ Nationalist sentiments of a different flavour were expressed in the Belgian periodical *De Vlaamsche Hoogeschool*, in an article accompanied by Menso's 1909 portrait of Heike. Musing darkly on the three Nobel laureates from Leiden, the author wrote: 'This attests to a level of scientific excellence in the face of which all the Belgian bluster in defence of the French Institute in Ghent must fall silent: Belgian science is still waiting for its *first* Nobel Prize.'³⁵

²⁹ MB, archives of Heike Kamerlingh Onnes, inv. no. 127c.

³⁰ *Ibid.*: *Central styrelsen för Stockholms Skolloukolonier*.

³¹ Communicated personally by Jeanne Kamerlingh Onnes.

³² *Panorama*, 10 December 1913.

³³ J.P. Kuenen, 'De toekening van den Nobel-prijs aan H. Kamerlingh Onnes', *Chemisch Weekblad* 10 (29 November 1913) 1012-1023.

³⁴ J.D. van der Waals, 'De Nobelprijs in Natuurkunde voor 1913, toegekend aan prof. dr. Heike Kamerlingh Onnes te Leiden', *De Gids*, 78 (1914) 180-183.

³⁵ *De Vlaamsche Hoogeschool*, 3 (Nov./Dec. 1913) 1-8, esp. 1.

31. World War: turning-point

The revolver shots that rang out in Sarajevo on 28 June 1914, ending the lives of Franz Ferdinand, heir to the Austro-Hungarian throne, and his wife, did not deter Kamerlingh Onnes from travelling to the Swiss Alps that summer. No one in the Netherlands seriously entertained the possibility of war, let alone a world war. Once Onnes had settled into the Grand Hotel in Baden with his wife, he wrote to Van der Waals that their son would be joining them in the last week of July.¹ Though Albert had been expecting to start military service at the end of August, he had failed the medical examination on account of a 'minor ailment' (flat feet), so that his parents would not, after all, have to cut their holiday short to take him back. The schedule included a follow-up health cure in Klosters, not far from Zürich – a perfect opportunity to visit Pierre Weiss, who had been given a year's sabbatical and would undoubtedly be doing some low-temperature experiments in Leiden as part of his magnetic research.

Three days later, Austria-Hungary imposed on Serbia – which was blamed for the assassination – an ultimatum that was virtually impossible to meet, and on 28 July Austria declared war on its neighbour. When Russia responded with wholesale mobilisation, Germany, feeling threatened, declared war on both Russia and its ally France. The German forces invaded by a roundabout route (to avoid the Verdun-Belfort fortress system in France) and on 4 August they violated Belgian neutrality, most notoriously burning to the ground the city's celebrated university library on 24 August. After the attack on Belgium, Great Britain in turn declared war on Germany. For over four years the Great War would set the earth aflame, with Italy, Bulgaria, Romania, Greece, the Ottoman Empire, Japan and the United States all being drawn into the conflict, in the course of which over nine million lives were lost.

As soon as the graveness of the situation in Germany became clear, Heike and Bé immediately fled to the Netherlands. Once they arrived home safely,

¹ Heike Kamerlingh Onnes to Van der Waals, 20 July 1914, N-HA, Van der Waals archives.

distraught after their experience, Onnes gave Zeeman a vivid account of their difficult return journey.

‘The journey from Switzerland, including our efforts to catch the last train due to pass the border at Schaffhausen, travelling during the mobilisation days of 1 and 2 August, with the constant fear that the train would be halted by unexpected military demands, frequently changing trains, but fortunately getting closer and closer to home, fighting and jostling for a place, the miserable situation at our borders, and then the panic that erupted in the train here, my wife was very badly affected by it all and she is now only gradually starting to recover.’²

Like everyone else in the Netherlands, including the government, Onnes was taken completely unawares by the conflict. ‘Right up to the last moment’, he wrote to Lorentz, ‘I thought that the crime against humanity that is now being perpetrated could have been avoided.’³ Onnes had been informed about the outbreak of hostilities straight away by Voigt, Wien and Lenard in Germany. Lenard, in defence of the Germans’ actions, included a virulent anti-British pamphlet with his letter, a text that he had himself dashed off in a euphoric mood of national solidarity.⁴ After J.J. Thomson had allegedly neglected to cite Lenard’s work on cathode rays correctly, the Heidelberg experimentalist had developed a disproportionate aversion both to the British and to theoretical physics. In his pamphlet, Lenard denounced Britain’s ‘unannounced’ intervention. He called for continental Europe to respond to Britain’s power-hungry conduct, in whipping up anti-German feeling among the French and Russians for its own selfish aims, by instituting an intellectual blockade.

‘How should one reply to that?’ Onnes wrote to Zeeman. ‘And after Leuven? And after the kidnapping of Solvay? And after [the partial destruction of] Reims Cathedral?’ Despite these qualms, Onnes sent his usual Christmas card to Lenard in 1914, with ‘best wishes for the new year’.⁵ Onnes favoured a policy of strict neutrality, and to avoid offering any of the combatants a pretext to regard the Dutch as antagonistic – which he argued could place the nation in jeopardy – he turned down a request by the weekly *De Groene Amsterdammer* to write an article in response to the destruction of Leuven’s library; Lorentz wrote the requested piece instead. ‘I am very much afraid’, Onnes wrote to editor-in-chief Wiessing, ‘that plenty of issues will arise in which it will be desirable for the combatants to

² Heike Kamerlingh Onnes to Zeeman, 23 September 1914, N-HA, Zeeman archives.

³ Heike Kamerlingh Onnes to Lorentz, 15 August 1914, N-HA, Lorentz archives.

⁴ Alan D. Beyerchen, *Scientists under Hitler*, Yale 1977.

⁵ Lenard to Heike Kamerlingh Onnes, 29 December 1914, MB, archives of Heike Kamerlingh Onnes, inv. no. 222.

be convinced that we bear no grudges, but that we will brook no interference with our neutrality and will defend ourselves to the last against any intruders.⁶

In mid-October Onnes met with Lorentz to discuss the most recent developments. The Germans had seized the French Nobel laureate Richet as a prisoner-of-war, and Lorentz and Onnes had been asked to seek the support of the physicist Warburg in Berlin to press for his release. Onnes had also sought out pacifists among Germany's physicists. He decided against Ostwald and Förster, whom he barely knew, and fixed on Ferdinand Braun from Strasbourg as the best person to contact.

By then, several physicists had already been killed in action. 'So many good men will be lost in Germany', wrote Gilles Holst on 30 September. 'Baedeker was the first, I think, and there is a long list of names in the latest edition of the *Physikalische Zeitschrift*. I hope we may be spared such glories.'⁷ Among the fallen were Fritz Hasenöhr of Vienna and Max Reinganum of Freiburg, former assistants of Onnes who had rapidly ascended the career ladder to professorships – Onnes wrote an obituary for Hasenöhr in the *NRC* of 19 October 1915. Walther Nernst, who abandoned his Berlin laboratory immediately when war broke out and enlisted with the drivers' corps, concluded that the Germans could not win after the *Blitzkrieg* faltered outside Paris. He lost both his sons at the front.⁸

A piece of propaganda that provoked outrage among the Allies was the *Aufruf an der Kulturwelt* ('Appeal to the Civilised World') written in October 1914, translated into ten languages and distributed on a vast scale. 'To the civilised world!', began the pamphlet. 'We, representatives of German art and science, protest to the entire civilised world against the lies and slander with which our enemies seek to sully Germany's fine cause in the arduous struggle for our existence that has been imposed on us.' After several more lines in this vein came a litany of repudiations: '*It is not true* that Germany must bear the blame for this war.... *It is not true* that we maliciously violated Belgian neutrality.... *It is not true* that our troops behaved with brutish violence against Leuven. With a heavy heart they were obliged to retaliate by a partial shelling of the city after the raging population had guilefully ambushed them in their quarters.... *It is not true* that the struggle against our so-called militarism is not a struggle against our culture'. And in conclusion: 'Rest assured that we will fight this fight to the end as a civilised nation, for whom the heritage handed down by Goethe, by Kant, is as sacred as hearth and home. To this we solemnly swear, by our names

⁶ Heike Kamerlingh Onnes to Wiessing, 10 September 1914, ISSG, archives of H.P.L. Wiessing, inv. no. 50.

⁷ Holst to Heike Kamerlingh Onnes, 30 September 1914, archives of the Huygens Laboratory.

and our honour.' The text was signed by 93 leading figures in the German arts and sciences, including Fritz Haber, Felix Klein, Philipp Lenard, Walther Nernst, Wilhelm Ostwald, Max Planck, Wilhelm Röntgen and Wilhelm Wien. Conspicuous by their absence were Albert Einstein, who had been invited to Berlin in April 1914 by Nernst and Planck, and the mathematician David Hilbert. Einstein's refusal was considered acceptable because of his Swiss citizenship; Hilbert, who was of Prussian origin, had a rougher ride, and had to endure cries of 'Traitor!' from his students.⁹

British and French reactions to the *Aufruf* were no less nationalistic in tone and made all fear the worst. *The Times* hit back within a week with a petition containing a litany of "It is true!" rejoinders, signed by 150 intellectuals. In France, a compilation of articles by intellectuals and cultural figures was published in 1916 entitled *Les Allemands et la Science*. Emile Picard, secretary of the Académie Française, summarised its message by stating: 'Seldom have the Germans brought forth original and fertile ideas'. Picard's own article outlined his views of what should happen after the war. 'As far as intellectual life is concerned', he said, 'we believe that it is desirable to sever all intellectual ties with Germany as soon as possible, since it remains tomorrow's enemy, whose sole concern will be to await the moment at which it can seize the opportunities it has missed today.... The structure of international conferences must be reformed. In their present form, they have been a springboard for Germanic aspirations. With our friends and allies, we shall hopefully succeed in organising conferences from which Germany is excluded, since its barbarity has placed it beyond the pale of civilised nations.'¹⁰ Prophetic words.

The war spelled doom for all Onnes's plans. While in February, at the festive dinner in Paris that the Association Internationale du Froid had hosted in honour of his Nobel prize, the prospect had been held out of a fresh subscription of 100,000 francs to Leiden's cryogenic laboratory, this treasure-fleet had now sadly been torpedoed. 'The war has dealt our laboratory a terrible blow', Onnes lamented to Lorentz in mid-August.

'The international subscription [for the laboratory] had only just been set in motion. Everything connected to it will now naturally come to a halt, and with it, all manner of things I was on the point of achieving for Leiden. Even keeping the laboratory going as normal will be fraught with endless difficulties. It relied entirely on an increasing

⁸ K. Mendelssohn, *The world of Walther Nernst*, 79-81.

⁹ Constance Reid, *Hilbert* (New York 1996) 137-138.

¹⁰ W. Otterspeer, J. Schuller tot Peursum-Meijer, *Wetenschap en wereldvrede: de Koninklijke Akademie van Wetenschappen en het herstel van de internationale wetenschap tijdens het Interbellum* (Amsterdam 1997) 21-26.

number of large advances that I can no longer provide. You will understand the depth of my concern.¹¹

That same day, Onnes wrote to Texel that Keesom was welcome to stay with his family, since the laboratory would not be opening until 1 September, 'and even then with a simplified schedule'. Again he expressed his concern about the war. 'For the laboratory too, difficult days lie ahead. We have already over-spent this year's budget. We can obviously forget the money that the laboratory was to receive from foreign subscriptions, which was to pay off our debts.' Onnes's personal fortunes were also at a low ebb: 'My own capital and income have been badly affected by the conditions, even compelling us to make drastic cuts in our domestic expenses.'¹² The situation was much the same five weeks later, and Onnes continued his lament to Zeeman: 'It is only with the greatest of difficulty that I can pursue a semblance of effective management. These are truly dark days. Extra assistants such as we had in the past are out of the question, for instance, certainly for the time being.'¹³

Onnes's personnel was greatly depleted by the war conditions. Mobilisation deprived him of one full-time and one part-time assistant, two laboratory technicians and two teachers in the instrument-making training course.¹⁴ Practical examinations for trainee instrument-makers and holiday courses were cancelled in 1914, the distribution of *Communications* abroad was severely curtailed, and printing was actually halted temporarily at the end of 1915.¹⁵ After the German invasion of Belgium, Jules-Émile Verschaffelt, professor at the Free University in Brussels, had fled to Leiden, where Onnes took his former assistant under his wing and gave him a position at the laboratory starting on 1 January 1915. He was less pleased with the arrival of Marcel Minnaert, a Flemish radical who wanted to exploit the German occupation of Belgium to achieve the ideal of a Flemish University in Ghent. Preparing to take up a professorship in physics at the new institution, he had come to Leiden to bolster his knowledge, largely by working with Ehrenfest.¹⁶

Onnes expressed his opposition to a Flemish university in a cautiously worded but nonetheless forthright and politically charged letter to Arnold Sommerfeld. He had been asked whether Keesom might be interested in accepting a position in Ghent – Sommerfeld had raised the matter with Onnes

¹¹ Heike Kamerlingh Onnes to Lorentz, 15 August 1914, N-HA, Lorentz archives.

¹² Heike Kamerlingh Onnes to Keesom, 15 August 1914, N-HA, Keesom archives, inv. no. 18.

¹³ Heike Kamerlingh Onnes to Zeeman, 23 September 1914, N-HA, Zeeman archives..

¹⁴ Begroting voor 1916, UB Leiden, Archief Curatoren, inv. no. 2026.

¹⁵ Jaarverslagen 1913-14, 1914-15 and 1915-16, UB Leiden, Archief Curatoren, inv. no. 1565.

¹⁶ Leo Molenaar, *De rok van het universum: Marcel Minnaert, astrofysicus 1893-1970* (Amsterdam 2003) 103-105.

on 18 May 1916, at the request of the committee appointed to set up the new university (the *Gener Studienkommission*). Keesom was in principle available, since his appointment as Einstein's successor in Zürich, which Onnes had described as 'confirmed',¹⁷ had been thwarted by the war – the latest in a long line of disappointments for the supervisor. In his reply to Sommerfeld, having first announced the imminent resumption of the distribution of Leiden's *Communications*, Onnes wrote that Keesom would certainly feel honoured by an invitation to go to Germany, but Ghent was out of the question because of the opposition of the Flemish. He added that Lorentz was of the same mind. The point was that a university 'holds a morsel of a nation's soul within it'. Onnes was all in favour of equal rights for the Flemish, but a Flemish university must be proposed within the framework of Belgian legislation and not by external interference. He then launched into an explanation of Dutch neutrality, urging Sommerfeld to appreciate that academics such as himself had friends among both the warring sides.

'When we stand up for freedom and justice vis-à-vis our friends, without fear or favour, we are merely acting in accordance with the honour and duty that are incumbent on men of science. In reaching a bold judgment in a matter such as this, it is a contributory factor that the love of liberty is one of the foremost characteristics of our nation. We display this trait now once again, when we prepare ourselves for the extreme case in which we may be compelled to defend our independence to the last drop of blood if – God forbid! – it should prove necessary.'

Were Sommerfeld to consider the matter from the human side, Onnes suggested, he might well revise his opinion and agree that Dutch academics should not be lecturing at a Flemish institution in Ghent if the Flemish themselves were against it. In conclusion, he wrote: 'My wife and I feel deeply for all the suffering that surrounds you, and sincerely hope that you and yours may be spared any personal suffering at home.'¹⁸ Sommerfeld respected the position

¹⁷ Heike Kamerlingh Onnes to Lorentz, 14 September 1914, N-HA, Lorentz archives.

¹⁸ Heike Kamerlingh Onnes to Sommerfeld, 6 June 1916, Deutsches Museum, Sommerfeld archives. 'Wenn wir uns den Freunden auf der einen Seite gegenüber aussprechen, so kann das nicht anders als so, dass die auf der anderen Seite es anhören können ohne an unsere Freundschaft zu zweifeln. Und wenn wir ohne Ansehen der Person für Freiheit und Gerechtigkeit bei unseren Freunden eintreten, so tun wir nun, was die Männer der Wissenschaft sich immer zur Ehre und Pflicht gestellt haben. Zur Sicherheit des Urteils in die jetzige Frage trägt gewiss bei, dass die Freiheitsliebe ein erster Charakterzug unseres Volkes ist. Das zeigen wir auch jetzt wieder, nun wir uns ja aufs äusserste rüsten, um unsere Unabhängigkeit, wenn es, was Gott verhüte, nötig würde, bis auf den letzten Tropfen Blutes zu verteidigen. ... Meine Frau und ich denken mit inniger Teilnahme an all dem Leid von dem Sie umringt sein werden, wir hoffen innig, das Ihnen und den Ihrigen persönliches Leid im engeren Kreis gespart wird.'

adopted in Leiden, and forwarded the letter to Wien: ‘The enclosed letter from Kam. Onnes will interest and please you.’¹⁹

Renovation and extension

Supervisor Crommelin found it totally impossible to run the laboratory as normal after the outbreak of war. Both his assistants had joined the army, Berlin suppliers such as Kahlbaum and Coehius were suddenly unable to supply sulphuric acid or ‘German silver’,²⁰ and all extra activities had to be cancelled. By September 1914, Crommelin was already having to refuse requests for liquid air from teachers and other scientists: ‘Renovations combined with the present conditions (the need to economise), have brought work at the cryogenic laboratory to a complete halt, and I suspect that this situation may well persist for some time.’²¹



Ill. 48. Bidding farewell to the old lecture hall of the Physics Laboratory in 1922. Standing behind the demonstration table is J.P. Kuenen, second professor of experimental physics, whose main task was teaching.

¹⁹ Sommerfeld to Wien, 15 June 1916, Deutsches Museum, Sommerfeld archives.

²⁰ Bestelboekjes XI and XII, archives of the Huygens Laboratory.

²¹ Crommelin to Reudler, 22 September 1914, archives of the Huygens Laboratory.

The ‘renovations’ involved a new lab for experiments with liquid helium and an annex in the garden, with rooms for drawing and administrative work as well as for Professor Kuenen, supervisor Crommelin, and the library.²² All this produced a considerable upheaval, besides which the reversal of the hard-fought salary increase for technical personnel (including 300 guilders for Flim and 500 for the two supervisors) after the outbreak of war, as a government economy measure, must have been depressing.²³ Furthermore, fuel rationing was introduced in 1917, and the personnel found themselves working in the cold. Only the small theoretical physics annex was heated, and at length the bitter cold caused work to be abandoned on Saturdays as well as in the Christmas holidays. Onnes decided to replace his steam engine with 30-hp and 10-hp electric motors. This time, obtaining the necessary licences under the Nuisance Act was not a problem: the changes were all to Einthoven’s benefit.

The cold in the laboratory and the impossibility of reaching the health resorts in Switzerland and southern Germany had an adverse effect on Onnes’s health. He had to exercise caution at all times, and was frequently absent. In April 1917 a stubborn case of bronchitis confined him to his home for the rest of the year; he had to instruct Crommelin by telephone.²⁴ ‘The bronchitis has affected me more than usual’, Onnes wrote to Zeeman, excusing himself yet again from attending an Academy meeting, ‘and since we unfortunately no longer have Switzerland in reserve – which I have sorely missed for several years now – I must take care to banish all trace of it.’²⁵ True, Heike could always take refuge in Menso’s villa in the dunes by Katwijk’s northern boulevard, but that was ‘a very different kind of life than past years in the mountains’.²⁶ By January 1918, Onnes was fit enough to go in to the laboratory, weather permitting, provided he went by carriage and avoided any kind of exertion. He cautiously resumed his classes for advanced students, temporarily teaching them in his own study at home.

The war drastically stemmed the flow of foreign visitors. Only an occasional researcher now came to work in Leiden, too few to sustain the cryogenic laboratory’s international status. Verschaffelt, an old friend, remained until 1919 to perform a series of experiments on the viscosity of liquid hydrogen, using a torsion pendulum with a ball. A.L. Clark from Toronto stayed for a few months and published some work on critical phenomena with Kuenen.

²² Jaarverslag 1913-14, 1914-15, UB Leiden, Archief Curatoren, inv. no. 1565.

²³ Begroting 1916, UB Leiden, Archief Curatoren, inv. no. 2036.

²⁴ Archives of the Huygens Laboratory.

²⁵ Heike Kamerlingh Onnes to Zeeman, 29 June 1917, N-HA, Zeeman archives.

²⁶ Heike Kamerlingh Onnes to Zeeman, 21 August 1915, N-HA, Zeeman archives.

Finally, Julio Palacios Martinez of Madrid stayed for two years, determining isotherms of neon, hydrogen and helium.

With these few exceptions, there was a sad dearth of foreign input. The laboratory did welcome two distinguished visitors in the 1914-1915 academic year, however: Frederick Lindemann and Ernest Solvay. The former was on his way from Berlin, where he was one of Nernst's bright assistants, to London. In 1919, Lindemann became an Oxford don. It was Oxford's Clarendon laboratory that produced Britain's first liquid helium, in 1933,²⁷ and Churchill would appoint Lindemann as his scientific advisor. The industrialist and philanthropist Solvay, who had been released by the Germans, was a good friend of Onnes's, and had bolstered the funds of the laboratory and instrument-makers' school on several occasions. Albert Einstein too came to Leiden for two weeks in October 1916, having been invited by Paul Ehrenfest – a journey that was far from easy to arrange. Onnes briefly considered giving Einstein some 'Thorium E' to take back to Berlin for the Prague professor O. Hönigschmid, who had kindly offered the Leiden laboratory a specimen of radium G (an isotope of lead), possibly a superconductor. In the event, the exchange was effected through an envoy.²⁸

The Dutch policy of neutrality was also applied in the laboratory. When the Amsterdam physicist E.I. Smid had calibrated both of Amsterdam's pressure balances against the standard open mercury manometer, together with Crommelin (see chapter 22), and was considering publishing the results in a foreign journal besides submitting a piece to the Academy,²⁹ Onnes insisted that 'for the sake of neutrality' she offer her article to an English-language as well as a German-language journal, suggesting *Annalen der Physik* and the *Philosophical Magazine*.³⁰ And when Palacios Martinez wanted to take some glassware back to Madrid, and heard from the instrument manufacturer that this would cause problems since the raw materials came from Germany, he was advised to take the glass along as hand luggage instead of sending it by ship.³¹

²⁷ R. Berman, 'Low temperature physics and cryogenics at Oxford'. Ralph G. Scurlock (ed.) *History and Origins of Cryogenics* (Oxford 1992) 322-324.

²⁸ Heike Kamerlingh Onnes to *curatoren*, 10 July and 2 December 1916, UB Leiden, Archief Curatoren, inv. no. 1799.

²⁹ C.A. Crommelin and Mej. E.J. Smid. 'Comparison of a pressure-balance of Schäffer and Budenberg with the open standard-gauge of the Leiden Physical Laboratory between 20 and 100 atmospheres, as a contribution to the theory of the pressure-balance', in KNAW, Proceedings, 18 I, 1915, Amsterdam, 1915, pp. 472-483, *Comm* 146c.

³⁰ Crommelin to Kohnstamm, 22 August 1916, archives of the Huygens Laboratory.

³¹ Marius to Cath, 31 January 1917, archives of the Huygens Laboratory.



Ill. 49. Laying the foundation stone of the renovated and expanded Physics Laboratory, 10 October 1919. Standing beside Kamerlingh Onnes is Lorentz, and behind him is Crommelin.

A year later, Solvay came to visit again, and Onnes hosted a festive meal in his honour at the Hôtel des Indes.³² The guests included Verschaffelt, Lorentz and Crommelin, and besides the protracted war and the Institut de Physique (which prepared the Solvay conferences and allocated grants), the topics of discussion included a new financial donation from Brussels. Now that one could no longer use the services of the Institute of Metrology in Berlin, for which there was no Dutch equivalent, the Leiden laboratory was sometimes asked to repair X-ray tubes for medical and scientific use or to blow new ones. To put this work – which was useful to society but placed a strain on the glass-blowing team – on a viable footing, Onnes suggested privatising the glass-blowing facility. Solvay concurred and provided 2,500 guilders to help make it possible.³³

The research output of the Physics Laboratory was slashed by the war. Some assistants' places remained unfilled, and Keesom's departure for Utrecht

³² MB, archives of Heike Kamerlingh Onnes, inv. no. 219.

³³ MB, archives of Heike Kamerlingh Onnes, inv. no. 257.

on 1 January 1916 was an enormous loss. Much of the remaining work was produced by Verschaffelt³⁴ and Pieter Geert Cath. The latter gained his doctorate under Onnes's supervision at the end of 1917, with a dissertation entitled 'Measurements relating to the temperature scale below 0°C'.³⁵ Leiden was scarcely able to attain temperatures below that of liquid hydrogen in the period 1914-1919; the lack of helium gas meant that the helium liquefier lay largely idle. The main cryogenic advance was the building of a hydrogen vapour cryostat for the difficult temperature range between 27° and 55° K.³⁶ Nernst's laboratory too had had to abandon its low-temperature research at the outbreak of war. When Nernst returned from the front, at Christmas 1914, the German high command ordered him to switch to the development of chemical weapons. But the poison gas he had in mind was not deadly enough for the generals, and Fritz Haber was appointed in his place. Haber proposed the use of chlorine, and was there when it was tested in action at Ypres on 11 April 1915: 5,000 dead.

The war years did bring one piece of good fortune: a new building for the inorganic chemistry department. In February 1916 the die was finally cast: a second laboratory was approved in Vreewijk, where organic chemistry had already acquired premises in 1901. Better late than never, Onnes must have thought, although he could not help complaining to the board of governors – and hence indirectly to the responsible minister – about the injustice of the repeated postponement of the promised expansion of his physics building. 'What is to be realised now is something I broached in the days of my inaugural address.... But I have had to watch an entire generation grow up before the plans I believed were to be executed came to fruition.'³⁷ Onnes recalled the minister's promise, back in 1889, that an entirely new chemistry laboratory would be built 'within the foreseeable future'. After condemning the severe lack of space in the main auditorium, which created impossible conditions for

³⁴ J.E. Verschaffelt, 'The viscosity of liquefied gases', I to X, Published in the *Proceedings* in the period 1915 to 1918, IV and IX jointly with C. Nicaise. KNAW, Proceedings, 18 I, 1915, Amsterdam, 1915, pp. 840-859; *ibid.* 860-867; 18 II, 1916, Amsterdam, 1916, pp. 1038-1045; *ibid.* 1659-1675; 19 II, 1917, Amsterdam, 1917, pp. 1062-1073; *ibid.* 1073-1079; *ibid.* 1079-1084; *ibid.* 1084-1088; 20 II, 1918, Amsterdam, 1918, pp. 986-990. *Comm.* 148b,c,d; 149b; 151d,e,f,g; 153b. In the same period Verschaffelt also published on surface tension in small drops of liquid.

³⁵ Summarised in P.G. Cath and H. Kamerlingh Onnes. 'Sur la mesure des températures très basses. XXX. Etc.' *Archives Néerlandaises des Sciences exactes et naturelles*, 1922, 1-30. *Comm.* 156a.

³⁶ H. Kamerlingh Onnes. 'Methods and apparatus used in the cryogenic laboratory. XVII. Cryostat for temperatures between 27°K and 44°K', in KNAW, Proceedings, 19 II, 1917, Amsterdam, 1917, pp. 1049-1058; *Comm.* 151a.

³⁷ Heike Kamerlingh Onnes to *curatoren*, 7 February 1916, UB Leiden, Archief Curatoren, inv. no. 1798.

Kuening, Onnes asked the government to consider removing anatomy too from the Steenschuur building; instead, it could be given new premises, as a matter of priority, on the grounds of the new teaching hospital.

Moving the anatomy department could also, perhaps, create some space for the physiology laboratory, the fourth occupant of the complex opposite Van der Werff Park. Professor-director Einthoven wanted to expand it, and found Onnes constantly obstructing his plans. Einthoven had planned his new vibration-free laboratory close to the physics labs, and in view of ‘the strife we have had in the past’, Onnes noted to the board of governors in June 1914, this was asking for trouble – especially since the ‘mechanical energy’ in the Physics Laboratory needed to be significantly increased.³⁸ ‘Never give an inch’ was one of Onnes’s mottoes.

Onnes kept up the pressure from his holiday address in Baden, two weeks before Europe descended into hell. The board of governors must appreciate, he wrote, that liquid helium had to be transportable within a few years; only then could the cryogenic laboratory sustain its position as an international centre. Here he mentioned the subscriptions initiated by the Association Internationale du Froid: ‘money from abroad to fund research’.³⁹ That was on 12 July. The very next day he sent another letter to the board of governors, again expressing his fears concerning potential sources of trouble and impediments to the expansion of the Physics Laboratory: ‘I have a sense of impending doom’. And in any case, why had physiology’s vibration-free pillar not been placed on far firmer piles long ago?⁴⁰

When it became clear, in the spring of 1916, that the anatomy department too would eventually be moving out, it was time to draw up plans for renovation and expansion. The possibility of a new physics building in another part of the city was briefly floated – Einthoven’s dearest wish – but Onnes persuaded the Government Architect to drop this idea.⁴¹ The important thing now was to be cagey and not to antagonise the government or parliament. When the *NRC* daily newspaper asked Onnes for an interview that would touch on his department’s poor accommodation and that was scheduled for the beginning of November 1916, Onnes deferred it until after the parliamentary debate on the budget, ‘so as not to arouse the impression of advertisement’ and putting approval of the initial 100,000-guilder renovation grant in jeopardy.⁴²

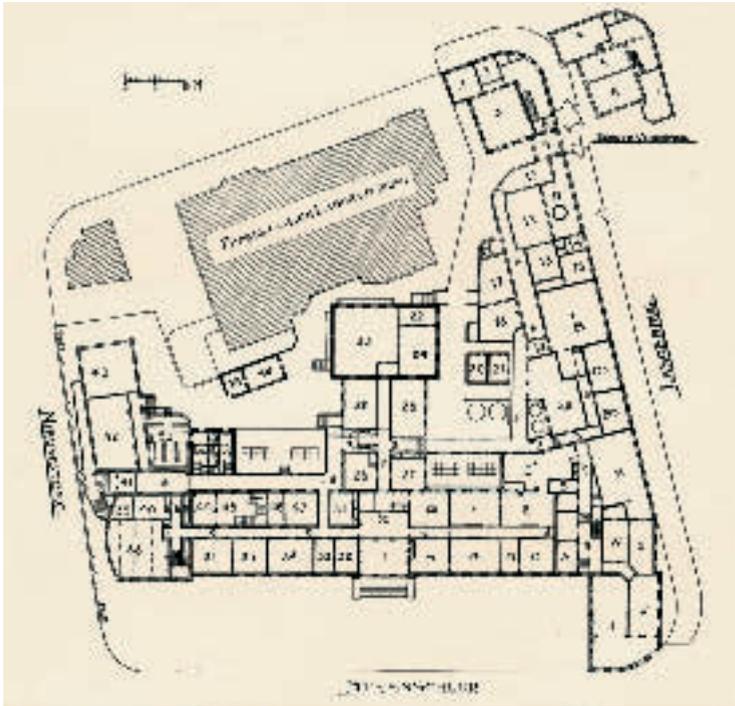
³⁸ *Ibid.*, 15 June 1914.

³⁹ *Ibid.*, 12 July 1914.

⁴⁰ *Ibid.*, 13 July 1914.

⁴¹ C.A. Crommelin, ‘Verbouwing en uitbreiding’, *Het Natuurkundig Laboratorium 1904-1922*, 69-77.

⁴² Meyer-Cluwer to Crommelin, 31 October 1916; Crommelin to Meyer-Cluwer, 2 November 1916, archives of the Huygens Laboratory.



Ill. 50. Plan of the Physics Laboratory in 1922, after the chemistry and anatomy departments had been moved elsewhere. 1. room of H.A. Lorentz; 2. room of the theoretical physics assistant; 3. large lecture hall for theoretical physics; 4. Bosscha reading room; 5. library; 6. small lecture-room for theoretical physics; 7. room of Paul Ehrenfest; 8. hall; 9. hall and central heating boiler-room; 13. forge; 14. high-voltage station; 15. space for bench work; 16. control and engine room; 17 / 18. rooms for electrotechnical measurement; 19. new high-voltage station; 20 / 21. canister storage sheds; 22. glass-blowing annex; 23. glass-blowing area; 24 / 25 / 27. experimental rooms; 26. experimental room with vibration-free pillar; 28. laboratory assistant's workshop; 29. space for gas thermometers; 30. storehouse; 31. weighing room; 32. Supervisor Crommelin's room; 33. room of Professor-Director Kamerlingh Onnes; 34 / 35 / 36 experimental rooms; 37. toilets; 38. demonstration room with vibration-free pillar; 39. waiting-room; 40. packing room; (above 38 / 39 / 40 was the main lecture-hall); 41. porch main entrance; 42. physics instrument-makers' workshop; 43. electrical instrument-makers' workshop; 44. students' cloakroom; 45. stairwell; 46 / 47. experimental rooms; 48. storage space for acids; 49. storage space for flammable fluids; 50. washing area for technical staff; A. room for height experiments; C. Room for magnetic measurements; D. Cryostat assembly room; E. Room for liquid methyl chloride, ethylene, oxygen etc. (cascade); E'. Room for liquid helium; F. Room for piezometers; G. Room for manometers; H. room for electrical measurements; I. Room for galvanometers; K. instrument-makers' cryogenic laboratory; P. room for vacuum pumps; U. room for magnetic measurements; V. Experimental room; W. Storage room; X. room for the volumenometer; Aa. room for liquid hydrogen; Bb. room for liquid air; Cc. room for electrical ovens; a t/m h. corridors.

Throughout the 1917-18 academic year, Onnes, Kuenen, Crommelin and P.J.M. van Oerle (district architect for state university buildings) met every Saturday afternoon to advance their plans. The interior of the Steenschuur complex was to undergo renovation. In addition, the small theoretical physics building at the corner of Zonneveldsteeg and Langebrug would acquire a new upper storey (Onnes was deaf to Einthoven's objections and to the concerns raised by Ehrenfest and Lorentz about prejudicing their good relations with physiology), besides which new premises would be built on Nieuwsteeg, with workshops for instrument-makers on the ground floor above the large new auditorium, and a bicycle shed, the boiler-house for the central heating, and a 'room for constant temperatures' in the basement. On 18 November 1918, after the architectural plans had been approved and the initial funds transferred, ground was broken on 18 November 1918, shortly after the chemistry wing had been vacated. The pile-driving operation took place in the spring, and on 10 October 1919, a modest ceremony took place in which Onnes, with Lorentz at his side, laid the building's foundation stone. The work would take seven years to complete.

But what a splendid building it was! (See the ground plan, Ill. 50) The main entrance was moved to Nieuwsteeg. Behind the old anatomy wing was a spacious glassblowing section as well as numerous other workshops. The cryogenic laboratory too was greatly expanded. It acquired a new Claude system for liquid air, with a capacity of 30 litres an hour, a second hydrogen liquefier, and a neon cycle in the cascade enabling electrical experiments to be performed in the liquid hydrogen range without any risk of explosion. The top floor of the theoretical physics wing included the Bosscha reading room, a library, a small lecture-room and Professor Ehrenfest's study. The laboratory was linked up to the mains, which rendered the gas engine, steam engine and steam boiler redundant. The site of the former glassblowing workshop was reserved for a giant electromagnet, for which Siemens & Halske were contracted in January 1924; Onnes had made an initial sketch for it back in 1917.⁴³ The magnet had to withstand a 444-ampere current for 60 minutes at a stretch (at 136 volts) and would cost an estimated 33,000 guilders. It was delivered in 1925 and parked under a lean-to, pending the arrival of the necessary trolley, travelling crane and switch installation. Onnes did not live to see the 14-ton leviathan in action.⁴⁴

On 11 November 1918, the Armistice between the Allied forces and the Germans was signed in a railway carriage in the forêt de Compiègne. The proclamation of an all-out submarine war on 1 February 1917 had driven the Americans, already prepared by President Woodrow Wilson (whose slogan

⁴³ MB, archives of Heike Kamerlingh Onnes, inv. no. 72.

⁴⁴ W.J. de Haas, 'Rede bij de ingebruikneming van den nieuwen electro-magneet in het Kamerlingh Onnes-laboratorium', *Physica* 12 (1932) 113-124.



Ill. 51. The Physics Laboratory after the renovation and expansion of 1920-26. On the left at the corner on the first floor is the large new lecture-hall. In the foreground is the statue of Van der Werff, burgomaster at the time of the Spanish siege; in the background is the Pieterskerk (St Peter's Church).

'He kept us out of war' had helped to secure him a narrow re-election victory in 1916), to join the war effort after all; the overwhelming quantity of war materiel and troops they shipped to France tipped the weight in the Allies' favour. Severe penalties were exacted from the Germans: besides being forced to evacuate the territory west of the Rhine, they lost their entire fleet and forfeited 5,000 artillery pieces, 5,000 locomotives and 150,000 railway carriages to the victors. In the world of science, too reconciliation was a long way off. 'An incredible wave of hatred and vengefulness, envy and greed seems to have swept across the world', Onnes wrote to Van der Waals. He described the scenes he had witnessed in the scientific world as shameful, although he understood how they had come about, and focused his hopes on Wilson and his League of Nations, which must 'seal off the well of hatred'.⁴⁵

⁴⁵ Heike Kamerlingh Onnes to Van der Waals, 31 December 1918, N-HA, Van der Waals archives.

Onnes himself set up a relief campaign to help destitute academics and their families in Austria. Appeals for contributions were published in a number of newspapers and in the *Chemisch Weekblad* in July/August 1920, raising a total of 2,500 guilders.⁴⁶ 'Many of these intellectuals can no longer take any joy in life and are compelled to sacrifice their last few possessions to procure the bare necessities. Sadly, some of the finest have already perished.'⁴⁷ The signatories included the Groningen professors Heijmans (psychology) and Kapteyn (astronomy), the Leiden Arabist and Islamic authority Snouck Hurgronje (who also chaired the Academy's literature section) and Lorentz. A consignment of rice, barley, tins of sugar, coffee, tea and cocoa had already been sent through the Red Cross's channels to an aid organisation caring for Viennese children. This was undoubtedly an initiative launched by Bé, who had been working in the Netherlands on behalf of deprived children for years. 'I asked my grocer to take care of the packaging,' Onnes told Zeeman, 'and he explained that oats are best packed in pounds'. And Lorentz was told that the food parcel sent to the widow of Ludwig Boltzmann had filled a 'very great need'.

As for his own health, in the summer of 1920, Onnes was finally able to go to Switzerland again for a health cure. He had been ill, and not until August had the doctor given him permission to travel. 'I continue to hope ... that my stay there, which I have sorely missed for so many years, will prove a source of great sustenance as it was in the past.'⁴⁸

The new scientific order

Even before the victory against the Germans, scientists from the Allied powers were already contemplating punitive measures. The French, in particular, were consumed with hatred.⁴⁹ This was no new development. A Dutch 'petition of intellectuals', drafted in February 1915 by a committee calling itself the 'European Confederacy', had provoked vehement reactions. Addressed to heads of state, governments and members of parliament, the petition revolved around one central appeal, 'Forget what kept you divided and apart', and was distributed to foreign academics, with a text calling on them to sign it. Marcel Brillouin, professor of mathematical physics at the Collège de France and secretary to the first Solvay Conference in 1911, wrote a furious letter to Lorentz,

⁴⁶ Heike Kamerlingh Onnes to Zeeman, 10 June and 9 August 1920, N-HA, Zeeman archives.

⁴⁷ *Chemisch Weekblad* 17 (17 July 1920) 387.

⁴⁸ Heike Kamerlingh Onnes to Lorentz, 6 August 1920, N-HA, Lorentz archives.

⁴⁹ W. Otterspeer, J. Schuller tot Peursum-Meijer, *Wetenschap en wereldvrede: de Koninklijke Akademie van Wetenschappen en het berstel van de internationale wetenschap tijdens het Interbellum* (Amsterdam 1997), 61-74.

one of the signatories, telling him that he had lost six of those closest to him and that he found the petition highly offensive; forgiveness was anathema to him.

The Allies met in London in October 1918 to discuss the new scientific order. That the Americans opposed slamming the door in the Germans' faces permanently and wanted to provide for their eventual return, after some form of open penance, incensed the Belgians and the French.⁵⁰ The most important outcome of the conference was article 1 of the 'London Resolution': all the warring countries would withdraw from existing international organisations that included representatives of the Central Powers (most notably Germany and Austria), and the new structures created in their place might possibly admit countries that had preserved neutrality in the conflict (the Netherlands, the countries of Scandinavia, and Switzerland).

At a meeting held in Paris six weeks later, a proposal tabled by Picard was carried, to the effect that in the new Conseil International de Recherches – which was to replace the old Association of Academies – the admission of neutral countries would require three-quarters of the votes cast, whereas a two-thirds majority would suffice in the case of countries such as China and Peru. This was a flagrant insult, blazed the Groningen chemist F.M. Jaeger in an irate letter to Lorentz, who was chairing the Academy's physics section: 'From now on, the question of whether you, say, or Onnes, Zeeman, H. de Vries, Arrhenius, and so forth are deemed "worthy" to collaborate in the realm of science will be decided by a number of seventh-rate fellows from Serbia, Portugal, Montenegro, Japan, Siam and Brazil. Were it not that the matter could have more than one serious consequence, it would be absurd enough for a musical comedy'.⁵¹

The Groningen Academy members Kapteyn and Heijmans distributed an open letter calling for reconciliation and for the non-exclusion of the former Central Powers – 49 Academy members signed it, but Lorentz and Kamerlingh Onnes were not among them. The appeal won little support among the other neutral countries, and the French and Belgians flew into a rage again.⁵² The new Conseil was established on 28 July 1919. The Academy joined that same autumn – for tactical reasons. Letters were immediately despatched to Berlin and Vienna, stating that the Netherlands wanted to maintain its ties with the German and Austrian Academies. Onnes too warmly endorsed this

⁵⁰ *Ibid.*, 75-93.

⁵¹ Jaeger to Lorentz, 8 January 1919, N-HA, Lorentz archives, inv. no. 146.

⁵² W. Otterspeer, J. Schuller tot Peursum-Meijer, *Wetenschap en wereldvrede: de Koninklijke Akademie van Wetenschappen en het herstel van de internationale wetenschap tijdens het Interbellum* (Amsterdam 1997), 95-118.

position. When the new 'Union internationale de physique pure et appliquée' adopted statutes in 1923 confining membership to Conseil countries, Onnes was one of the six members of the Academy's physics section who drafted a dissenting report. They wanted to welcome contributions by all countries, and proposed setting up an organisation for international cooperation in physics to put this principle into practice, a national committee that would bypass the Union's channels.⁵³ Not until 1934 did the Germans seek to join the Conseil again – where they were now welcome. In 1922 the Conseil rejected a German request for admission; four years later it was the other way round, with the Germans snubbing an invitation to join, since they felt they had been treated with a lack of respect.

The frequently emotional discussions within the Academy about the decision to join the Conseil International de Recherches – Heymans resigned in frustration in 1919, and Kapteyn said he was 'suspending' his membership – largely passed Onnes by: his health had taken a turn for the worse, and after the outbreak of war he had rarely attended meetings. He was more involved, however, in the restructuring of the Association Internationale du Froid (founded in 1908; see chapter 27). This was triggered by the resignation of the president, André Lebon, on 12 December 1918. Lebon stated that he felt no desire whatsoever to 'hold consultations with representatives of countries that unleashed the recent catastrophe and made war in a criminal fashion, such being wholly incompatible with the spirit of human and scientific solidarity as pursued by the Association'.⁵⁴

At this, the director of the Association convened a meeting of the executive committee on 6 February 1919. The aim was to define its policy, based on the resolutions that Allied academics had adopted in London in October 1918, condemning the Central Powers for their brutal war crimes. Point two on the agenda provided for the application of 'article 5 of the statutes' to the governments of Germany and Austria-Hungary, Bulgaria and Turkey, as well as to individual members originating from these countries. Article 5 dealt with the expulsion of countries that failed to meet their financial obligations or that had committed a 'dishonourable deed'. Any members of the Association so expelled were entitled, under the statutes, to defend themselves against the charges and to lodge an appeal.

The meeting of 6 February in the 'Crédit Foncier [mortgage bank] d'Algérie et de Tunisie' in Paris was attended by only six of the 28 members of the executive committee. Onnes too had excused himself in advance, but he sent a telegram expressing his views regarding the Association's future. At this

⁵³ *Verslagen*, 32 (November 1923) 874–876. See also *Wetenschap en wereldvrede*, 119–134.

⁵⁴ *Bulletin Association Internationale de Froid*, 69 (October–December 1918) 47.

meeting, it soon became clear that excluding the 'Central Powers' countries was the only way to save the Association from certain demise. Even Onnes seemed to favour this view in his telegram, albeit merely on pragmatic grounds: it was high time to set about rebuilding the Association, and it made sense to proceed on the basis of the status quo. However, Onnes added, 'out of respect for the idea of a League of Nations as set forth in President Wilson's Fourteen Points, it would be a good idea to defer the definite approval of the decision to continue solely with participants from the Allied and neutral countries for one year, after the executive committee has discussed it again'.⁵⁵

The outcome of the meeting was that André Lebon was asked to stay on as president of the Association, and it was decided (emulating the policy adopted by the universities in Allies countries) to suspend the membership of 'enemy countries and all their citizens' for the time being. Discussions on restructuring to place the Association on a solid financial basis were postponed until the end of the peace talks in Versailles.

In a letter to Lorentz, who as chair of the Academy's physics section needed all his diplomatic abilities to prevent the fierce debates on the Netherlands' membership of the Conseil International de Recherches and the Dutch attitude to the Germans and Austrians from going off the rails, Onnes expressed his satisfaction about the result reached in Paris. Instead of the 'rash' and offensive proposal to *expel* the enemies for dishonourable conduct, their participation was to be *suspended*, while neutral countries such as the Netherlands would automatically retain their membership. Onnes commented *en passant* that while the conditions on which neutral countries could join the proposed Conseil International de Recherche were 'insulting' for a country of the Netherlands' scientific importance, the League of Nations would straighten this out. 'There is no going back, *l'humanité marche!*'⁵⁶

On 21 June 1920, the Association was replaced by the Institut International du Froid. This had a far more tightly-knit organisational structure, based on that of the International Agriculture Institute in Rome: instead of individual members it had participating countries in six categories, paying fixed contributions.⁵⁷ The Netherlands belonged to Group 4 and was expected to pay 4,000 francs; the Dutch East Indies, a step lower down the ladder, had to pay 2,000 francs.

The formal Conférence Internationale du Froid, held in the premises of the Ministry of Trade in Paris, was preceded by a meeting of the provisional executive committee, to which Onnes belonged. President Lebon, now back at his post, reviewed the organisational structure: the *Bulletin*, the grants, and the

⁵⁵ *Ibid.*, 70 (January-March 1919) 10-11.

⁵⁶ Heike Kamerlingh Onnes to Lorentz, 21 February 1919, N-HA, Lorentz archives, inv. no. 146.

⁵⁷ *L'Institut International du Froid*, 2 (21 June 1920) 37-64.

international committees, including the physics, chemistry and thermometry committee chaired by Kamerlingh Onnes. Lebon opened the meeting by congratulating the Dutchman on his recently acquired status of *membre correspondant* of the Académie – which proved that Onnes’s attitude to the Central Powers had not sown ill feeling among the French. ‘I have already received an honorary doctorate from Berlin (1910)’, Onnes wrote to Zeeman, ‘so that the circle of friends [in 1915 Onnes had acquired the honorary position of Foreign Member of the Royal Society] stands around me like a closed cycle.’⁵⁸

In the Great Hall at Rue de Varenne, it fell to Kamerlingh Onnes, ‘un grand savant à l’avant-garde de la science’, to respond – on behalf of the 42 countries attending – to the welcome speech given by Ricard, the French agriculture minister. Ricard emphasised that the war had truly brought home the benefits of refrigerating food. The next step was to make a concerted effort to improve the accessibility of the cold industry. A more far-reaching and useful goal than improving refrigeration could scarcely be imagined, the minister concluded. In his response, Onnes remarked, not without self-interest, that as long as the Institute followed in the Association’s footsteps, success was assured. The science of refrigeration had a golden future; developments had time and again exceeded their wildest expectations. What had begun with a little cloud of liquid air in a Cailletet test tube had grown into a refrigeration industry producing thousands of hectolitres annually, and – here Onnes turned to the man who had held out the prospect of a fortune for his laboratory at the 1913 conference in Chicago – ‘in the development of which Mr Claude has played such an important part’.⁵⁹

Liquid helium too, Onnes continued, would be incorporated into technology at some point in the future. Superconductivity would come to the aid of electrical engineers who were now still grappling with the loss of heat from their cables. But it must not be forgotten that *pure science* was where the greatest challenges lay. With a new artificial element, it might be possible to attain even lower temperatures. Concocting such an unknown element called for a profound understanding of the laws governing atomic structure. This automatically led to quantum theory, and in studying the properties of matter at very low temperatures, as determined by this theory, the science of cold came ‘extremely close to the most fundamental problems within present-day science’. After which Onnes sounded his final chord. ‘On behalf of all the delegates, I should like to convey

⁵⁸ Heike Kamerlingh Onnes to Zeeman, 13 June 1920, N-HA, Zeeman archives.

⁵⁹ *L’Institut International du Froid. II. Sa Constitution définitive* (Paris 1920) 52–54. ‘c’est au nom de tous les délégués ... si je vous remercie ... et de vous offrir nos meilleurs voeux pour le bonheur de cette France que nous aimons tous et dont le nom brille d’une gloire éternelle par les bienfaits que l’humanité doit à son grand génie.’

our very best wishes to this country of France, which we all love, and which basks in eternal glory by virtue of the blessings that humanity owes to its great genius.’

Finally, a few words should be said about the war’s influence on the Solvay Institute. The humiliation of the German and Austrian physicists was complete with the banishment of their leading celebrities from the Solvay conferences. ‘What attitude should we adopt vis-à-vis the Germans?’ asked Lorentz in a letter to Ernest Solvay in January 1919, in his capacity as chairman of the Institute’s scientific committee. While he could well imagine that the Belgians and French wanted nothing to do with them for the time being, there were great differences between individuals. Einstein was not ‘German’ at all, for instance, and others regretted having attached their names to the ‘Appeal to the Civilised World’ in 1914. ‘I would venture to suggest that we should not formally exclude the Germans; in a word, we must not slam the door in their faces for good.’⁶⁰

But Brillouin, who also sat on the committee, was intransigent, and even proposed banning pro-German physicists such as Debye, who had remained at his post in Göttingen during the war. Fellow committee members Lorentz and Onnes thought this was going much too far. The heated arguments culminated in the Comité Scientifique’s resignation, after which a new committee was formed, with Warburg, Nernst and Goldschmidt being replaced by W.H. Bragg (British), Righi (Italian) and Van Aubel (Belgian).⁶¹ An exception was made for Einstein, who was asked to give a talk on the Einstein-De Haas effect at the third Solvay Conference (see chapter 33).⁶² He accepted, but he was in the United States at the beginning of April 1921, and in 1924, too, he stayed away at Sommerfeld’s behest. ‘To have attended’, he wrote to Lorentz, ‘would have been to endorse a decision that I consider highly unjust.’ Einstein let it be known that he would prefer not to receive any more invitations; they would only hamper his efforts to resume friendly relations with foreign scientists. Not until 1927, after Germany joined the League of Nations, did the Brussels conference once again welcome a German contingent.

⁶⁰ *The Solvay Councils and the Birth of Modern Physics*, 112–115.

⁶¹ Lorentz to Einstein, 26 July 1919, MB, Archive 55.

⁶² *Ibid.*, 9 June 1920.

32. Declining years

Onnes continued to battle against ill health after the war. To keep the bronchitis at bay he had to adhere to a strict regime, avoiding fatigue and exercising caution in the Dutch climate. ‘Gone are the good old days when I could work at the lab from morning to evening and carry on at home’, he sighed to Van der Waals.¹ But Onnes kept going thanks to Bé’s solicitous attention and continued to be highly productive in his declining years.

Onnes treated his personnel well but expected them to work hard. When the public service union urged that workers be given Saturday afternoons off (‘an English Saturday!’) following demobilisation in 1918, the professor-director dismissed the idea out of hand. ‘It would be highly detrimental to the laboratory,’ he wrote to the board of governors.² Staff already had four or five weeks’ summer holiday, mandatory individual time off after overwork or ‘strenuous exertion’, besides which the working day did not start until 8.30 a.m. in the summer (8.00 a.m. in the winter). Moreover, leave was granted with ‘the utmost generosity’, even for recreational activities such as ice skating or enjoying ‘particularly fine summer days’. And anyway, the personnel showed no sign of wanting Saturday afternoons off. Even junior technicians enjoyed working long and hard, and their involvement in research gave them intellectual satisfaction. A much better idea, concluded Onnes, would be to pay them higher wages and thus to show appreciation for their dedicated work on Saturdays in the nation’s interest. On the file in which he kept the correspondence on this issue he scribbled the characteristic title, ‘Idleness initiative’.³ His arguments in favour of preserving the status quo were heeded: no Saturday afternoons off in the Physics Laboratory for the time being.

Liquid helium was very scarce during the war. The stocks of helium gas – about 300 litres – were just enough to keep the liquefier going for the first few

¹ Heike Kamerlingh Onnes to Van der Waals, 8 March 1919, N-HA, Van der Waals archives.

² Heike Kamerlingh Onnes to *curatoren*, 21 June 1918, UB Leiden, Archief Curatoren, inv. no. 1613.

³ Archives of the Huygens Laboratory.

years, but ‘substantial’ experiments were out of the question,⁴ and the helium liquefier had lain idle since the autumn of 1916. It was impossible to obtain supplies of monazite sand from the United States, and even the helium-containing distillates from Georges Claude’s liquid air machines were out of reach. The laboratory also had a lack of methyl chloride. When the Physics and Medical Science Conference was held in Leiden in April 1919, and Onnes badly wanted to demonstrate liquid helium to Niels Bohr, there was only half a kilo to be had in the whole country, just barely enough to keep the cascade operational – a little more was obtained by garnering remains of methyl alcohol from various quarters and treating them chemically.⁵

Somehow, although the crisis conditions and renovations had precipitated the laboratory into a ‘state of collapse’, a new helium liquefier was built. Its circulation was twice as fast as the old one (12 m³ per hour), the time needed to produce the first few drops was only 20 minutes, only half the quantity of liquid hydrogen was needed, and the production of liquid helium increased to 1.7 litres per hour.⁶ It was finally ready for use in April 1919; not earlier, since the indispensable reserve vacuum flasks could not be blown with the municipal ‘crisis gas’. While testing the new liquefier, Willem Tuyn and Onnes discovered that the metal thallium was a superconductor. The demonstration for the Physics and Medical Science Conference on Friday afternoon, 25 April, was a resounding success: ‘It was truly chilling [“koude drukte”], as many liked to jest’, Onnes wrote happily to Keesom.⁷

How the laboratory managed to expand its stock of helium gas after the war to the required 500 litres is unclear; perhaps Claude supplied a modest amount. In any case, stocks were running low again only a few months later. Encouraged by F.G. Cottrell, who had said, while visiting the cryogenic laboratory in the summer of 1919, that he had a factory in Texas for the accumulation of helium gas,⁸ Onnes took an unusual step; he wrote to the US Navy. On 2 September 1919 he despatched a telegram to Admiral Griffin of the Bureau of Mines in Washington, Cottrell’s employer. ‘According advice American colleagues I pray to send helium for continuing experiments lowest temperatures.

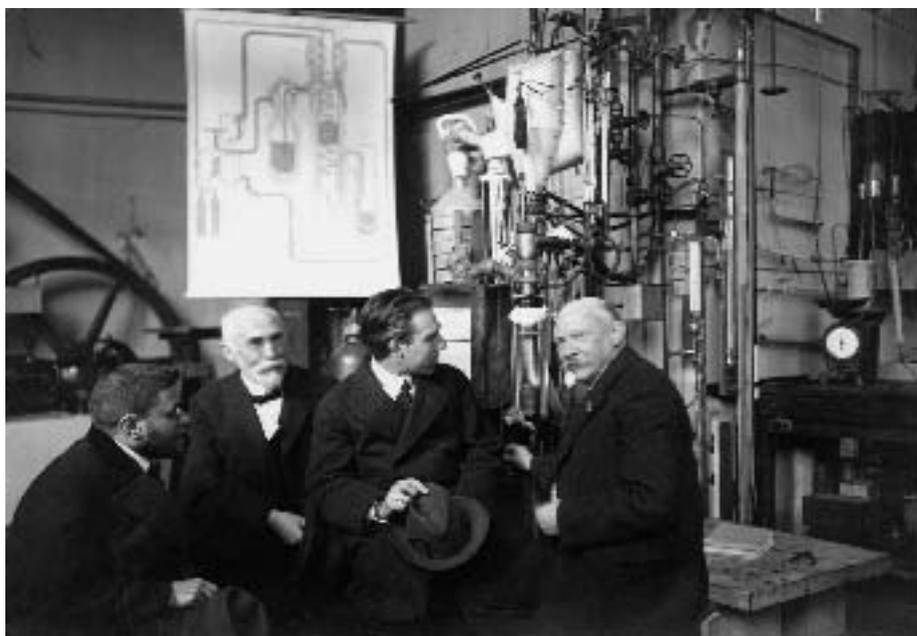
⁴ C.A. Crommelin, ‘Methoden en hulpmiddelen in het cryogeen laboratorium’, *Het Natuurkundig Laboratorium 1904-1922*, 53-55.

⁵ *Handelingen van het XVIIde Nederlandsch Natuur- en Geneeskundig Congres* (Haarlem 1920) 152-159. *Comm.* supplement 43c.

⁶ H. Kamerlingh Onnes, ‘Methods and apparatus used in the cryogenic laboratory. XIX The methyl-chloride and ethylene circulation The hydrogen liquefier and circulation. The helium liquefier and circulation, in KNAW, Proceedings, 29 II, 1926, Amsterdam, 1926, pp. 1176-1183. *Comm.* 158.

⁷ Heike Kamerlingh Onnes to Keesom, 12 May 1919, N-HA, Keesom archives.

⁸ Lab book kept by Crommelin, 6 October 1921, MB, archive 132.



Ill. 52. H.A. Lorentz, Heike Kamerlingh Onnes, Niels Bohr (Copenhagen) and Paul Ehrenfest with the second helium liquefier, 1919. Bohr visited Leiden to attend the ceremony at which his assistant Hans Kramers was awarded a doctorate (Academisch Historisch Museum).

For balancing suffered losses and advancing needed immediately one cylinder in next future twenty cubic meters.⁹ It may be noted that a standard 42-litre cylinder contained 5 cubic metres (under 120 atmospheres). And the first liquefaction of helium had succeeded in 1908 with 200 litres plus 180 litres in reserve. So Onnes's request for a consignment of what amounted to many thousands of litres of helium gas was not exactly modest.

But he did not need to be modest; the Americans were up to their ears in helium. As soon as war broke out, the Bureau of Mines had been instructed to search for sources of helium, to fill observation balloons and dirigibles – helium scarcely weighs any more than hydrogen, and has the advantage of being non-flammable. A factory was built at Fort Worth in Texas, where helium was extracted from natural gas by freezing the other constituents. Some 4,000 cubic metres of it, compressed in crates of steel gas flasks, were in storage, ready to be shipped to France when the armistice was signed there.¹⁰ Given that the US

⁹ Heike Kamerlingh Onnes to Griffin, 2 September 1919, archives of the Huygens Laboratory.

¹⁰ W.H. Keesom, *Helium* (Amsterdam 1942) 14-19.

Navy had 1,000-odd cylinders in store, the Dutch request for five was almost trivial. They arrived in Leiden in the autumn of 1919 – a gift worth thousands of guilders, Onnes told the board of governors.¹¹ The purity of the helium was far better than expected – averaging 96 per cent. One good thing, in any case, had come out of the world war.

Since it had such a large stock of helium gas, the Bureau of Mines decided to set up its own cryogenic laboratory, including a helium liquefier. R.B. Moore was entrusted with the task. In March 1921, Onnes mentioned in his budgetary proposals the Americans' plans to break Leiden's monopoly on liquid helium, although he expected this to take years – 'endless pumping and no staff', as one of Moore's colleagues put it.¹² Naturally enough, Onnes responded to this threat by asking the government to help consolidate his own position. Without a bigger materials grant and new permanent staff for the renovated and expanded laboratory, he wrote in his 1923 budget proposals, 'we shall be unable to maintain the position we have won in the international competition by virtue of our cryogenic laboratory'.¹³ Two years later, in his final budget before retirement, at the age of seventy, Onnes repeated his old lament one more time. 'Providing mountains of gold in the future will never be able to repair the damage done by failing to commit the requested support now.'¹⁴

Although the United States did not have a helium liquefier until the 1930s, the Canadian John McLennan was faster. His initiative too was sparked by the war. In 1915, the British also started looking for helium for dirigibles. The physics professor McLennan, of the University of Toronto, was asked to find it. In 1918, a factory for the production of helium gas was built in Hamilton (it was later moved to Calgary). A stock of 1,700 m³ was built up there from December 1919 until April 1920. McLennan also wanted a helium liquefier, and to curry favour with Kamerlingh Onnes he brought a full cylinder of helium with him as a gift when he came to visit the laboratory in September 1921. In token of his gratitude, Onnes not only allowed the Canadian to take a look in Flim's kitchen, he also gave him the complete technical drawings for both the hydrogen and helium liquefiers. McLennan had actually rather hoped that Onnes might build a miniature helium liquefier for him, capable of producing a tiny quantity of liquid helium, but that was out of the question.¹⁵ McLennan returned to Toronto, and sent his glassblower to learn from Kesselring how to make Dewar

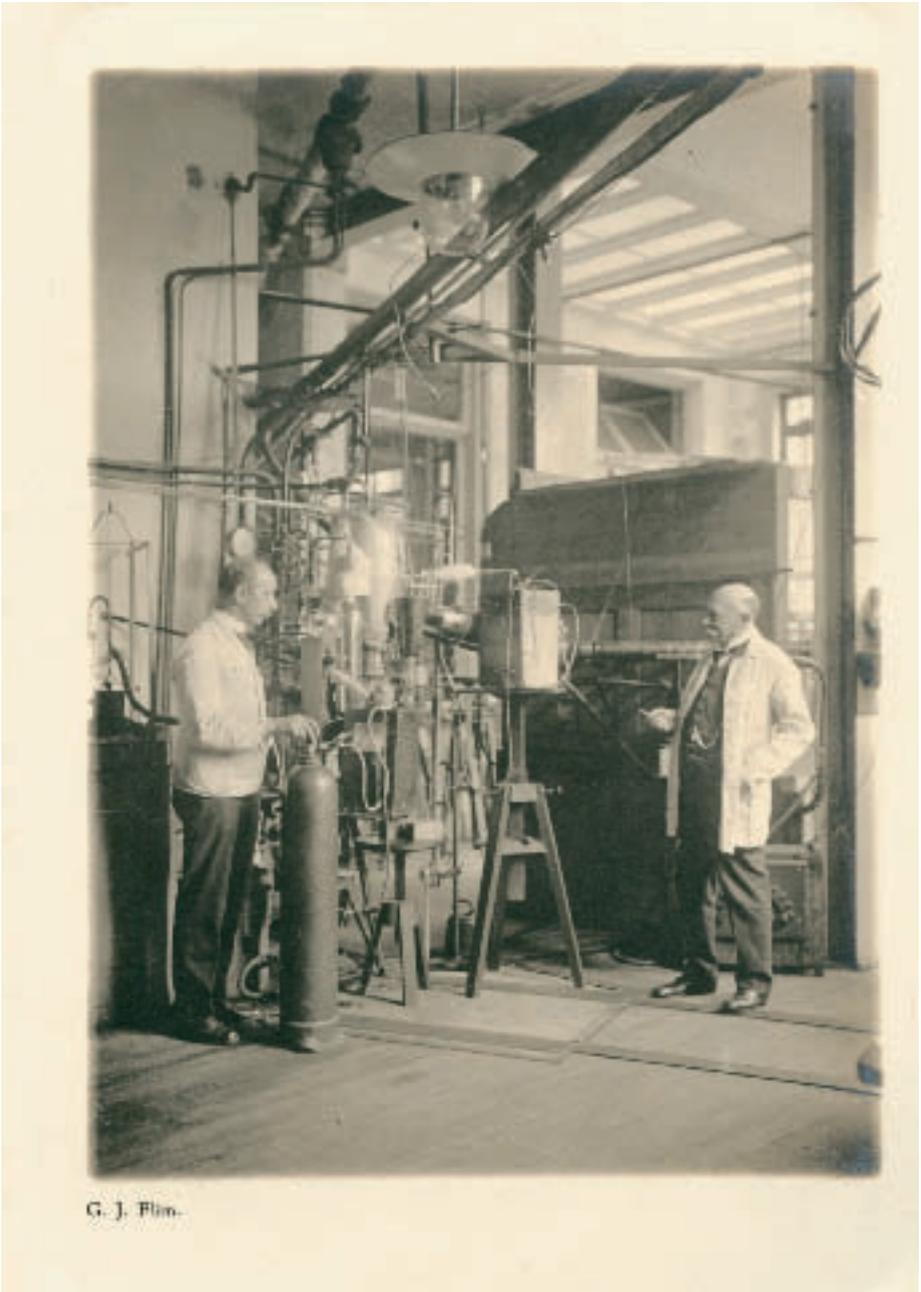
¹¹ *Begroting* 1921, UB Leiden, Archief Curatoren, inv. no. 2040.

¹² Lab book kept by Crommelin, 15 August 1921, MB, archive 132.

¹³ *Begroting* 1923, UB Leiden, Archief Curatoren, inv. no. 2042.

¹⁴ *Begroting* 1925, UB Leiden, Archief Curatoren, inv. no. 2044.

¹⁵ Lab book kept by Crommelin, 16 September 1921, MB, archive 132.



G. J. Flim.

Ill. 53. Heike Kamerlingh Onnes and the technical manager of the cryogenic laboratory, Gerrit Jan Flim, with the second helium liquefier, 1919.

flasks.¹⁶ Two years later, he collected his first drops of liquid helium,¹⁷ and Leiden had lost its fifteen-year monopoly. Onnes immediately invited McLennan to join the scientific committee of the Institut International du Froid.

This policy of openness surrounding cryogenic apparatus was far from incidental. Leiden had not only published the full details of its appliances, as Onnes noted at the fourth international conference of refrigeration in London in 1924, but it was also a matter of public record that comprehensive unpublished data and precise technical drawings, as well as details on materials and procedures, were supplied entirely free of charge.¹⁸ This was intended to promote a spirit of solidarity among existing and future cryogenic laboratories, and to multiply the benefits of the work done in Leiden. Cryogenic proliferation was not a danger to be averted but a goal to be pursued. True, this would change the boundaries of the experimental landscape, and colleagues would no longer have to go to Leiden to perform certain types of research, but there would still be a need for a laboratory that specialised in pioneering work and precision measurements at the very lowest temperatures.

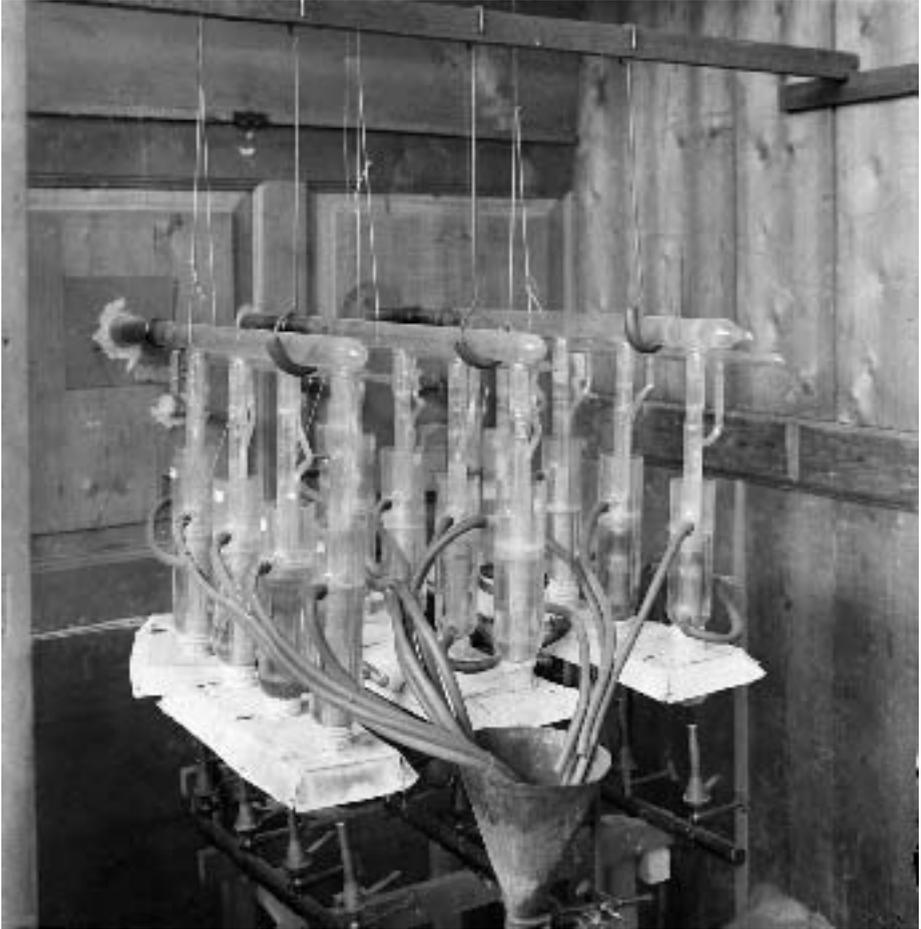
This lowest temperature was determined, for the time being, by the pressure above the helium bath. During the first liquefaction, on 10 July 1908, Onnes was able to pump up to a pressure of 10 mm Hg (the Burckhardt pump could not be connected up), corresponding to 1.7 K. A temperature of 1.38 K was attained in 1909 and 1.04 K in 1910, and since 1919 the record had stood at 1.00 K (at a pressure of 0.15 mm).¹⁹ It should be noted that these are values corresponding to the 1932 temperature scale. In the early years of liquid helium there was no accurate scale, as a result of which Onnes arrived at slightly different figures. Determining temperature with the aid of a helium gas thermometer seemed the obvious solution, but the problem was that the pressure in the glass bulb had to remain lower than the vapour pressure of helium; otherwise condensation would develop. Furthermore, this pressure had to be exceptionally low to minimise deviations from Boyle's Law – the basis for the gas thermometer. But gas pressures lower than 1 mm Hg were virtually impossible to determine with a mercury manometer. What is more, at low pressure, systematic errors were more pronounced as a result of thermomolecular differences in pressure.

¹⁶ McLennan to Crommelin, 10 August 1922; Crommelin to McLennan, 18 August 1922, UB Leiden, Stationsweg archives.

¹⁷ J.C. McLennan, 'The Cryogenic Laboratory of the University of Toronto', *Nature*, 112 (28 June 1923) 135-139.

¹⁸ H. Kamerlingh Onnes, 'Organisation and work of the 1st International Commission of the International Institute of Refrigeration'. *Comm.* supplement 48.

¹⁹ Keesom, *Helium*, 175.



Ill. 54. Battery of 16 glass diffusion pumps used in 1921 to achieve a temperature of 0.83 K, a record low temperature at the time, by pumping off liquid helium.

In practice, pressures between 1 and 0.001 mm Hg were measured with a Knudsen resistance manometer.²⁰ This consisted of a thin platinum wire mounted in a glass tube connected to the space in which the pressure was to be determined. If a current was passed through the wire, with the development of heat, a whole string of variables were related: the strength of the current depended on the resistance of the platinum, the resistance of the platinum depended on its temperature, the temperature depended on the

²⁰ C.A. Crommelin, 'Thermometrie en manometrie', *Het Natuurkundig Laboratorium 1904-1922*, 221-223.

thermal conductivity through the thin gas, and thermal conductivity depended on pressure. This chain of interrelationships meant that the strength of current was related to pressure, which was established by calibration. Pressure could therefore be determined by measuring the current. This method had a 0.5% margin of error. Since, in the case of an extremely rarefied gas in a tube, if the temperature at the two ends of the tube is different, there is also unequal pressure at these two ends (a consequence of the extended mean free path of the gas molecules in that situation), Onnes was compelled to mount his Knudsen resistance manometer in the cryostat in the helium bath.

The mystery of the migrating helium

Why aim for ever colder temperatures? One reason was that Onnes wanted frozen helium. That helium remained liquid even at a pressure of 0.15 mm Hg was a great disappointment. On the other hand, it had the advantage that the measurement range in which to determine material properties was extended further towards absolute zero than had been expected. Onnes described his efforts to attain the lowest possible temperature in a lecture to the Faraday Society and British Cold Storage and Ice Association, entitled 'On the lowest temperature yet obtained'.²¹ On 16 October 1922 he was to go to London to deliver it in person, as part of a General Discussion on 'The Generation and Utilisation of Cold', and had looked forward to finally having an opportunity to meet James Dewar in the flesh. Unfortunately, the doctor advised against the trip: too cold, too tiring.²² Onnes would eventually go to London in the summer of 1924 to attend the fourth international congress of refrigeration, but by then, Dewar was dead.

On 23 November 1920, Van der Waals's 83rd birthday, Onnes made a fresh attempt (by way of celebration) to break the 'cold record'. With an extra battery of pumps set up in series with the Burckhardt pumps, Onnes hoped to lower the pressure to 0.005 mm, as he wrote to Amsterdam the evening before.²³ This battery consisted of glass and iron 'Langmuir pumps', some of which had been provided by Philips. These mercury diffusion pumps, introduced in 1916 by the American Irvin Langmuir, worked on the basis of electrically heated vapour. Since naked flames were strictly forbidden in the helium lab (because of the presence of hydrogen), the Langmuir battery was set up in a small adjoining room

²¹ H. Kamerlingh Onnes, 'On the lowest temperature yet obtained', *Transactions of the Faraday Society*, December 1922; also published as *Communication* 159, 'Further experiments with liquid helium. P. On the lowest temperature yet obtained'.

²² Heike Kamerlingh Onnes to Dewar, 12 October 1922, Royal Institution, Dewar archives.

²³ Heike Kamerlingh Onnes to Van der Waals, 22 November 1920, N-HA, Van der Waals archives.

with a ventilator. Sadly for Van der Waals's party, this first attempt was unsuccessful. One of the glass diffusion pumps burst, wreaking havoc. 'It was a great disappointment', Onnes wrote to Lorentz, 'especially for all the work that was lost.'²⁴

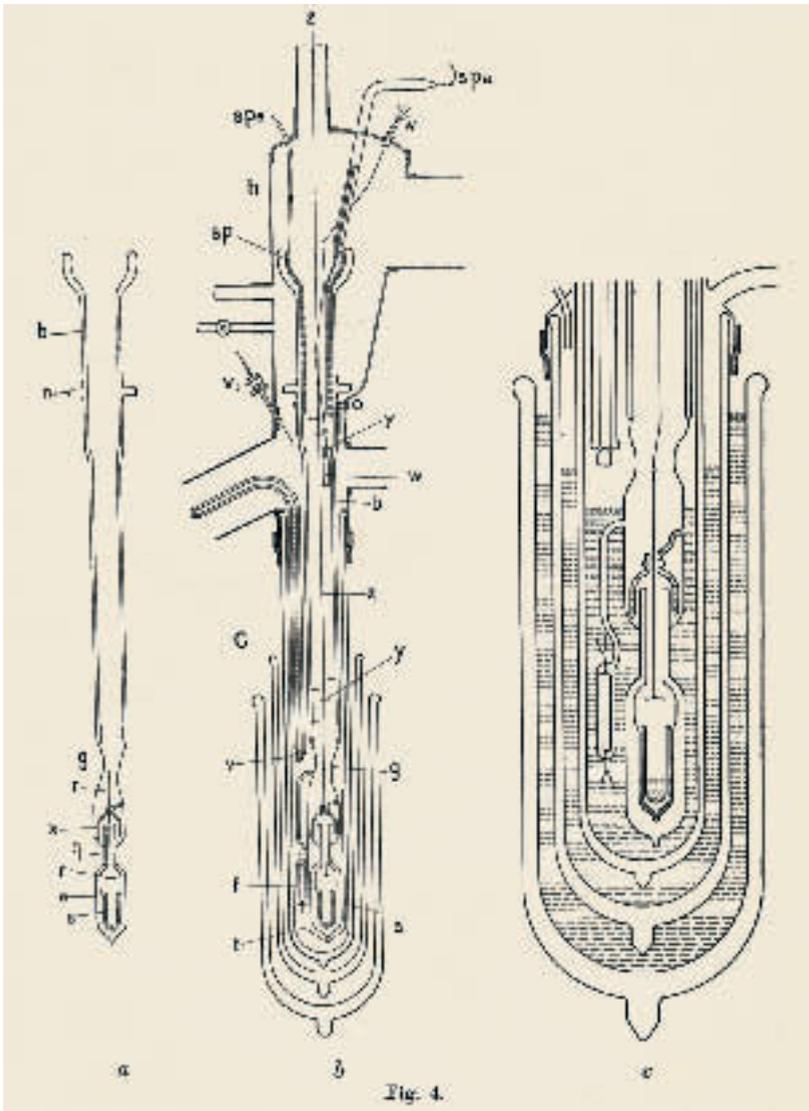
A year later the experiment was successful: on 13 October 1921, sixteen mercury diffusion pumps, deployed in concerted action with the Burckhardt pumps, reduced the pressure over the helium to 0.005 mm – as determined using a special low-pressure McLeod manometer. Particular attention had been paid to the heat insulation of the helium bath. Radiation from elements in the cryostat that were at room temperature (this could quickly soar, since radiative energy is proportional to the fourth power of temperature) was screened off from the bath using metal reflector screens that were in thermal contact with liquid helium. Radiation from above was intercepted by a small double-walled glass cover made by Kesselring, black on top and silver below, with liquid helium in the space in between – a 'masterpiece of glassblowing', said Onnes (see fig. 55).

On the day before the record-breaking attempt, the appliances were all pumped out to create a vacuum, and over 50 litres of liquid air was produced. Besides this, 24 litres of liquid hydrogen were made early the next morning. At about noon, liquid helium from the liquefier was transferred to the cryostat, after which the pumping could commence. Onnes hoped that the helium would freeze, but there was nothing to see, either with the naked eye or with the viewer, and the stirrer in the helium bath could still move freely. One striking detail, however, was that the level in the inner and outer vessels remained the same. If liquid was transferred from one of these spaces to the other using the stirrer, equilibrium was restored immediately (see fig. 55). Moreover, if light was shone on the outer casing, which greatly increased evaporation there, the levels also responded amazingly quickly.

Onnes, as always wary of jumping to conclusions, wondered if distillation was the answer. (Not until 1938 would scientists working in Oxford and in Charkov, Ukraine, discover that the effect was caused by a thin film of liquid creeping up the walls.) He hoped to be able to explain the phenomenon as soon as the laboratory had completed a scheduled series of measurements to determine the thermal conductivity of glass, helium vapour and liquid helium, and considered that it was also desirable to determine the specific heat and measure the viscosity of these substances. Onnes suspected a relationship with the previously observed maximum in the density of liquid helium at 2.2 K.²⁵ Einstein,

²⁴ Heike Kamerlingh Onnes to Lorentz, 7 December 1920, N-HA, Lorentz archives.

²⁵ H. Kamerlingh Onnes, 'On the lowest temperature yet obtained', *Transactions of the Faraday Society*, December 1922; also published as *Communication* 159, 'Further experiments with liquid helium. P. On the lowest temperature yet obtained'; see section 12.



Ill. 55. Schematic view of the bottom part of the cryostat with which Kamerlingh Onnes achieved the record low temperature of 0.83 K in 1921. In the outermost Dewar flask is liquid air, while the middle one contains liquid hydrogen and the innermost flask contains liquid helium; inside this is the glass construction within which the record low temperature was achieved, by continuing pumping to a very low pressure. A reversed, double-walled glass cap, filled with helium, was used to minimise the leakage of heat – a triumph of workmanship by the glass-blower Kesselring. The helium in the innermost double-walled flask and the helium immediately outside it ‘communicated’ at lightning speed through (as later emerged) a film creeping upwards along the sides, as a result of which the liquid levels were always the same.

who had visited Leiden three weeks before the successful experiment, was also at a loss. During a dinner at Onnes's home, at which the guests also included Jeans, Zeeman, De Sitter and Crommelin and at which 'the mystery of the migrating helium' was the main topic of conversation, Einstein claimed that the experiment provided 'absolute proof' that the evaporation heat of helium was zero at absolute zero. Half an hour later, he claimed 'the exact opposite' ... 'and so on and so forth'.²⁶

Onnes estimated that the new record-breaking cold was 0.82 K, a result he achieved by extrapolating from the graph of the inverse of the reduced temperature against the logarithm of the reduced vapour pressure. To remain on the side of caution, he rounded it up to 0.9 K – Keesom would later adjust the result to 0.83 K, using the 1932 temperature scale. Onnes thought it unlikely that he would be able to get much lower, partly because there was no element even more volatile than helium. Nonetheless, he was confident that absolute zero could be attained eventually. 'We may be sure', Onnes concluded his Faraday lecture (delivered by Crommelin in London), 'that the present difficulties will be overcome. First, some protracted and patient research is needed on the properties of matter at the lowest attainable temperature.' It was his familiar 'knowledge through measurement' approach: remaining focused on the initial objective, eschewing speculation, working empirically. It was an approach that had brought Leiden one success after another. But it failed to discover superfluidity. Hendrik Casimir, who, as supervisor of the Leiden laboratory, experimented with superconductors in the 1930s, together with Josina Jonker (whom he would later marry), observed as follows:

'The history of liquid helium demonstrates both the advantages and the disadvantages of the "knowledge through measurement" tradition. Systematic quantitative measurements produced important results, but a number of extremely surprising properties that could be observed qualitatively with simple pieces of apparatus were either completely overlooked or not examined further because they did not fit into any measurement programme. And precisely in that respect, the new low-temperature groups in Cambridge, Oxford and Moscow were able to outshine Leiden.'²⁷

One of these extremely surprising properties was the enormous increase in the thermal conductivity of liquid helium below 2.2 K. Onnes must have noticed that if heat was supplied to liquid helium, using a heating wire, it produced bubbles above 2.2 K but not below that temperature; the Leiden technicians,

²⁶ Lab book kept by Crommelin, 7 November 1921, MB, archive 132.

²⁷ Casimir, *Haphazard reality*.

in any case, were familiar with the phenomenon, remarked Casimir.²⁸ Yet Onnes did not report it. Why not? Because he was at a loss to explain it. A millionfold increase in thermal conductivity simply did not fit into his conceptual framework – what mechanism could possibly account for it? – and so the idea did not occur to him.²⁹ Nor did he subject the incredibly fast ‘distillation’ between inner and outer vessels to further investigation: he was nowhere near ready to digest the rapid-motion films of liquid helium, just a few hundred atoms thick, which were reported in 1938. Onnes noted that the surface of the liquid no longer stood out in a ‘razor-sharp’ line against the wall of the vessel below 2.2 K, and that liquid helium displayed ‘the customary signs of capillarity’ at these temperatures³⁰ – and that was all. Casimir would later observe that the Leiden technicians knew from experience that it was impossible to pump against a leak in an appliance immersed in liquid helium once the temperature fell below 2.2 K.³¹ But no one did anything with this knowledge: it was impossible to grasp the disappearance of viscosity in liquid helium in these circumstances; not until 1938 would the phenomenon be identified. Casimir, it should be said, was one of the up-and-coming researchers who was closely involved in this research in the 1930s and tried out various ideas, but somehow failed to take that one decisive step.

This indifference to odd phenomena that seemed to defy explanation was unfortunate for the American Leo Dana. He had gained a doctorate from Harvard in June 1922 on the strength of a dissertation on determinations of the evaporation heat of mixtures of liquid oxygen and nitrogen, and came to Leiden in September on a Sheldon travel scholarship, planning to conduct similar work at the temperature of liquid helium. Sixty years later, Dana recorded his experiences – a wonderful glimpse of the Leiden research world, enhanced by photographs of the cryogenic laboratory he had collected at the time.³² Dana arrived shortly before the day of Kuenen’s sudden death – discussed below. In the first few weeks of his stay in Leiden, the laboratory was in ‘a state of

²⁸ H.B.G. Casimir, ‘Superconductivity and superfluidity’, J. Mehra (ed.), *The Physicist’s Conception of Nature* (Dordrecht 1973) 481–498, esp. 493.

²⁹ Kostas Gavroglu and Yorgos Goudaroulis, ‘From *Physica* to *Nature*: The Tale of a Most Peculiar Phenomenon’, *Janus* LXXIII (1986–1990) 53–84, esp. 60.

³⁰ H. Kamerlingh Onnes, ‘On the lowest temperature yet obtained’, *Transactions Faraday Society*, December 1922; also published as *Communication* 159, ‘Further experiments with liquid helium. P. On the lowest temperature yet obtained’, 5.

³¹ H.B.G. Casimir, ‘Superconductivity and superfluidity’, J. Mehra (ed.), *The Physicist’s Conception of Nature* (Dordrecht 1973) 481–498, esp. 493.

³² Leo Dana, ‘My Experience at the University of Leiden, Holland, Low Temperature Research Laboratory, September, 1922 through July, 1923’, Russell J. Donnelly and Arthur W. Francis, *Cryogenic Science and Technology: Contributions by Leo I. Dana* (New York, 1985) 14–32.

confusion' and it was out of the question for him to meet Kamerlingh Onnes, who was suffering from yet another bout of ill health, besides which he had been deeply affected by the death of his colleague and close friend – the man who had been expected to succeed him.

In the hope of better times to come, Dana helped Onnes's PhD student Jan Boks perform some 'measurements on the compressibility of gas, using apparatus not very unlike that used by Boyle'. At the end of August, Onnes had sent word from Wengen that Dana should do some 'work on isotherms ... so as to familiarise himself with our working methods' and he had also instructed the American to learn Dutch 'to make things easier in the laboratory'.³³ After a few weeks Dana was heartily sick of isotherms and wrote Onnes a letter, suggesting that his Harvard professors might be disappointed if their researcher was not given any original research to do in Leiden. That was a good move; Onnes called a few days later and invited Dana to Huize ter Wetering. Onnes received the young man wearing a stylish purple dressing-gown; this, combined with the oriental carpets, antique furniture and paintings in the study, led Dana to conclude that the 'absolute zero' man was very well off. He was quite right: in 1921, Onnes's taxable income was 31,500 guilders, over four times as much as a professor's maximum salary;³⁴ probably indirectly due to his Nobel prize. After some small talk, the two men got down to business. Dana explained that he wanted to measure the specific heat and evaporation heat of liquid helium, and Onnes encouraged him to get on with it straight away. As the young scientist was leaving, Onnes advised him to bear in mind that 'Plums must be picked when they are ripe.'

Dana's visit to Onnes's home had certainly helped: all the doors in the cryogenic laboratory were suddenly open to him. The American praised the laboratory's well-oiled organisation, including its small army of blue-collar boys. Whatever he needed, it was put together in no time, ready to use for measurements. Dana eagerly used the trainees' services, and if it got late and the boys complained that it was dinnertime, he treated them to tea and cake. He started off with evaporation heat and then moved on to specific heat. 'As far as I recall', wrote Dana, 'neither Kamerlingh Onnes nor anyone else on the research staff took the slightest interest in my results, with the possible exception of Dr Crommelin.' That was not entirely true: in July 1923, in a festschrift for Schreinemakers (his former neighbour from inorganic chemistry), Onnes mentioned Dana's research, which was still ongoing, including his

³³ Heike Kamerlingh Onnes to Crommelin, 31 August 1922, UB Leiden, Stationsweg archives, inv. no. 52.

³⁴ Gemeentearchief Leiden, kohier der inkomstenbelasting 1920/21.

result that the maximum in the evaporation heat of helium truly existed.³⁵ Dana would have liked to study the remarkable phenomena he was uncovering in further detail, but he had exhausted his funds, and in July 1923 he returned to America, after a candlelit farewell dinner at Huize ter Wetering, complete with champagne.

Within two months, Dana had sent two draft articles to Leiden, where they vanished into a drawer. This seems an odd thing to have done with them. At the beginning of 1922, Boks had confirmed the maximum in the density of liquid helium at 2.29 K (according to the temperature scale used at the time) with a new series of more precise measurements³⁶ – the data even allowed for a jump in density. Not a word was mentioned about Dana's results at the fourth international congress of refrigeration, held in April 1924. But the question of what in the world happened to liquid helium at 2.2 K became ever more compelling, and in June 1925, Onnes did finally submit Dana's two articles to the Academy.³⁷

He had a special reason for doing so. On 9 March, Walther Meissner of the Institute of Metrology in Charlottenburg, Berlin, wrote that his helium liquefier had just produced its first few drops of liquid helium.³⁸ Onnes must have recalled the prewar days of Nernst and Eucken, when Berlin had completely thrashed Leiden in the realm of specific heat. 'Since Berlin will now soon be starting on specific heat', he wrote to Keesom, 'it seemed to me prudent, given the prevailing mentality in Germany, to demonstrate that Leiden tackled the subject first – several years ago, in fact.'³⁹ Onnes had asked Verschaffelt, whose help he frequently enlisted for editorial work on the *Communications*, to go through Dana's papers with a view to publication. Contrary to his usual practice, he started off by presenting abstracts for the Academy's *Verslagen* to record the date, explaining that it would take more time to prepare detailed

³⁵ H. Kamerlingh Onnes, 'Sur des observations concernant l'équilibre des phases liquides et gazeuses de l'hélium à basses pression', *Recueil des Travaux Chimiques des Pays-Bas* XLII, nos. 7/8 (15 July–August 1923) 535–538.

³⁶ H. Kamerlingh Onnes and J.D.A. Boks, 'Further experiments with liquid helium. V. The variation of density of liquid helium below the boiling point', *Reports and Communications of the Fourth International Congress of Refrigeration*, June 1924. *Comm.* 170b.

³⁷ L.I. Dana and H. Kamerlingh Onnes, 'Further experiments with liquid helium. B.A. Preliminary determinations of the latent heat of vaporization of liquid helium, in KNAW, Proceedings, 29 II, 1926, Amsterdam, 1926, pp. 1051–1060. *Comm.* 179c (contains additional information); L.I. Dana and H. Kamerlingh Onnes, 'Further experiments with liquid helium. B.B. Preliminary determinations of the specific heat of liquid helium, in KNAW, Proceedings, 29 II, 1926, Amsterdam, 1926, pp. 1061–1068. *Comm.* 179d (contains additional information).

³⁸ Meissner to Heike Kamerlingh Onnes, 9 March 1925, MB, archives of Heike Kamerlingh Onnes.

³⁹ Heike Kamerlingh Onnes to Keesom, 23 August 1925, MB.



Ill. 56. Triptych with a festive exhibition to mark the 40th anniversary of Kamerlingh Onnes's professorship on 11 November 1922. On the left the motto 'Knowledge through Measurement' from the 1882 inaugural address, in the middle a maxim of Van der Waals's: 'matter will always display attraction' (meaning that there is mutual attraction in the molecules of every gas, so that condensation into a liquid is always possible).

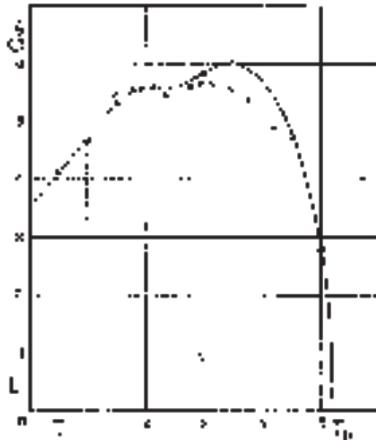
versions, which would include improved numerical values obtained with 'fresh discussions', if necessary.

This suggests that Onnes did not entirely trust the accuracy of Dana's measurements and would have preferred to repeat the experiments himself: the titles of both articles refer to 'provisional determinations'. One weak point in the experimental set-up to determine evaporation heat was the measurement of the vapour pressure (and hence temperature) at the calorimeter; there may have been a systematic error here. Worse still was the situation in the specific heat experiment. When heat was supplied to the double-walled calorimeter, it disturbed the equilibrium between vapour and liquid, and the evaporation that occurred to 'fill up' the manometer tube extracted heat (see fig. 55). The use of narrow tubes could minimise this correction and make both this and the correction for heat loss in the calorimeter easy to estimate. But the unwelcome condensation in the single-walled tube connecting the calorimeter and manometer was another matter. To prevent this condensation, the temperature in the outer helium bath was kept slightly higher than

that in the calorimeter. If the level of the liquid in the outer bath was (briefly) wrong, for instance because after heat had been supplied to the calorimeter using a heating wire, the equilibrium between vapour and liquid was momentarily disrupted, the values obtained for specific heat would be too high because of the condensation in the connecting tube. It was impossible to provide a quantitative correction of this error. Dana took no account of questionable data points.

The measurements of evaporation heat showed a maximum in the region of 3 K. There was a striking dip in the graph at 2.2 K (see fig. 57), prompting Dana and Onnes to add the following footnote:

‘There is also a curious irregularity near the temperature of maximum density. It is possible that the mere change in convection state when this temperature is exceeded introduces a change in a systematic error. It remains worthy of consideration, however, that the results, provided that their accuracy, in terms of the change with respect to neighbouring temperatures, is sufficient, might indicate that something occurs with the helium in the vicinity of the maximum density, within a small temperature range, possibly even discontinuously. The change in the density of the liquid also indicates something of the kind.’⁴⁰



Ill. 57. Graph of the evaporation heat of helium plotted against temperature, measured in 1922 by Onnes’s American assistant Leo Dana. The small dip in the graph at 2.2 K, the temperature at which the density of liquid helium reaches its maximum, later turned out to signify a change in the liquid: below 2.17 K, helium I changes into helium II, whereby there is sudden ‘jump’ in all its properties. Below this temperature, helium becomes a superfluid.

⁴⁰ *Op cit.* note 37, 1337.

According to Keesom, this was the first time in the literature that the possibility had been suggested of a discontinuity in a property of liquid helium.⁴¹ Keesom himself would later show, in 1932, that the dip in evaporation heat was directly related to the peak in specific heat. Dana's specific heat measurements of June and July 1923 indicated the existence of such a peak, but Onnes was loath to adopt this notion since most of the high values were attributable to uncontrolled condensation in the calorimeter and therefore did not count. Eventually, 16 data points were able to withstand critical examination. Dana and Onnes entered them all neatly into a table, but did not go as far as plotting a graph of specific heat against temperature. Furthermore, this time, measurements were only presented at temperatures above 2.6 K. Specific heat turned out to bear a more or less linear relationship to temperature, although the lowest temperatures exhibited upward deviations. Viewed retrospectively, these were a build-up to the peak.

But why should Dana have failed to take measurements below 2.2 K this time? Given the dip in the evaporation heat, he must have been particularly interested in determining specific heat around that temperature. In 1927 it emerged that Dana *had* in fact measured at around 2.2 K.⁴² That year, Keesom and guest researcher M. Wolfke, having observed a jump in the dielectric constant of liquid helium at 2.2 K,⁴³ posited the idea of a phase transition: when helium was undergoing cooling, it changed at 2.2 K from helium I to helium II, with various properties exhibiting a jump in values or passing through a maximum or minimum value. This had already been demonstrated for density, evaporation heat and dielectric constant, and the next question was whether specific heat too exhibited a 'crazy' pattern of this kind.

Examining Dana's original notebook, Keesom discovered that the American (or more probably Onnes) had wrongly left three measurements out of consideration. They indicated a higher specific heat than the measurements taken between 2.5 and 4.1 K: the peak he had been hoping to find really existed – although it was not until 1932 that Keesom and K. Clusius rigorously researched the specific heat of liquid helium and provided incontrovertible experimental proof of this peak.⁴⁴ Dana must have sensed that he was onto

⁴¹ W.H. Keesom, *Helium*, 232.

⁴² W.H. Keesom and M. Wolfke, 'Two different liquid states of helium', KNAW, Proceedings, 31, 1928, Amsterdam, 1928, pp. 90-94. *Comm.* 190b.

⁴³ M. Wolfke and W.H. Keesom, 'On the change of the dielectric constant of liquid helium with the temperature. Provisional measurements', KNAW, Proceedings, 31, 1928, Amsterdam, 1928, pp. 81-89. *Comm.* 190a.

⁴⁴ W.H. Keesom and K. Clusius. 'Ueber die spezifische Wärme des flüssigen Heliums'. *Proceedings Royal Acad.* 35 (April 1932) 307-319. *Comm.* 219e.

something important in July 1923: indications of a peak in specific heat and a dip in evaporation heat suggested that something odd was happening to the liquid helium. After the summer, when he had sent Onnes his two articles, Dana started work at the Linde Air Products Company in Buffalo, a subsidiary of Union Carbide.⁴⁵ He must have had mixed feelings in 1927 when the news broke of a phase transition in liquid helium.

300 sheets of graph paper

While Dana was in Leiden, the laboratory celebrated the 40th anniversary of Onnes's professorship. The staff had gone to town preparing for it, and an ensemble formed especially for the occasion performed Händel's 'Largo'.⁴⁶ On display at historically significant locations around the laboratory were appliances used between 1882 and 1922 – supervisor Crommelin was in charge of the laboratory's collection of recent instruments as well as the historical collection in the attic. Posters were hung on the walls with texts like 'Knowledge through Measurement', '0.82 K' (the lowest temperature attained), 'Matter will always display attraction' (a maxim coined by Van der Waals) and ' $pV = A + B/V + C/V^2 + D/V^4 + E/V^6$ ' (the empirical equation of state). At the place where helium was first liquefied on 10 July 1908, a bronze memorial plaque was installed. Cartoons were hung beside the staircases depicting 'certain obstacles' that had had to be overcome in the race to attain absolute zero, such as a passing car (vibrations) and exploding glassware – even the dogs from the 'Cyclops' cave' in Groningen were on display. An official group photograph of the scientific and technical personnel, including assistants and blue-collared boys, was made for the occasion; Flim's status is reflected by his prominent position in the front row.⁴⁷

Onnes was presented with two particularly noteworthy gifts at his party: a commemorative volume for 1904-1922, an even more voluminous sequel to the volume presented at the 25th anniversary of his doctorate. And from Paris, the Institut International du Froid sent word that it planned to pay tribute to Onnes by establishing a fund enabling researchers to perform low-temperature research in Leiden – Georges Claude sportingly set the ball rolling by immediately depositing the 10,000 francs he had pledged in Chicago back in 1913. So from 1922 onwards, the laboratory was welcoming researchers – post-graduate students as well as numerous professors – from all parts of the world.

⁴⁵ Donnelly and Francis, 59.

⁴⁶ MB, archives of Heike Kamerlingh Onnes, inv. no. 196.

⁴⁷ *Op. cit.* note 32. Dana's article with his recollections contains a great many photographs.

In his report to the fourth international congress of refrigeration, held in London in April 1924, Onnes enumerated twenty of the laboratory's guest researchers, from Sir Robert Hadfield from London, who had come to study ferromagnetism, to I. Samashima from Japan, who worked on Knudsen manometers, and J. de Wierusz-Kowalski, the Polish envoy to The Hague and an expert on phosphorescence.⁴⁸

So after a hesitant start caused by government cuts, after 1922 the renovated and expanded Physics Laboratory was running like a train. A few domestic statistics: every year the laboratory went through 300 sheets of graph paper, 1,000 sheets of carbon paper, 150 boxes of matches, three large bottles of ink, 60 notebooks, 24 erasers, 48 litres of paraffin oil, 48 bars of 'Sunlight' soap, and 120 rolls of toilet paper.⁴⁹ As for cryogenic statistics: in the 1922-1923 academic year, the laboratory produced 5,962 litres of liquid air and 1,328 litres of liquid hydrogen; there were 19 'helium days'.⁵⁰ Besides professors, supervisors and a few foreign researchers, the laboratory had some ten assistants (doctors and PhD students) in addition to a handful of students working on their master's degree. By comparison, in 1920, W.H. Julius's photometric laboratory in Utrecht had eight assistants, an observer, a laboratory technician and a few instrument-makers,⁵¹ operating with an annual budget of 8,500 guilders as opposed to Leiden's 30,165 guilders.

In the postwar period, Onnes's students chiefly studied isotherms, temperature scales and magnetism. Some of this research involved repeat experiments, using more accurate apparatus, and some involved the expansion of earlier research. The results were compared to the empirical, reduced equation of state and the law of corresponding states. Determinations of the second virial coefficient B provided information about intermolecular forces, a subject on which Keesom had performed some theoretical calculations. In the case of helium, a simple, monatomic gas, it was hoped that accurate measurements of deviations in the law of corresponding states might illuminate quantum effects. Onnes

⁴⁸ *Op. cit.* note 18. Besides those already named, they were J. Beattie (MIT, thermometer calibration), J. Timmermans (Brussels, melting points), J.C. Swallow (London, hydrogen isotherms), J.R. Roebuck (Madison, Joule-Kelvin effect), L.I. Dana (Harvard, helium), E. Mathias (Clermont-Ferrand, rectilinear diameters), T. Verschoyle (Nortwich, mixtures), K. Hof (Otten, paramagnetism), L.J. Jackson and G. Breit (US, crystals), J.C. McLennan (Toronto, spectroscopy), L. Vegard (Christiania, cosmic radiation), J. de Smedt (Leuven, X-ray diffusion), J. Becquerel (Paris, phosphorescence) and M. Wolfke (Warsaw, dielectric constant).

⁴⁹ Heike Kamerlingh Onnes to *curatoren*, 10 November 1921, UB Leiden, Stationsweg archives.

⁵⁰ W.H. Keesom, 'Prof. Dr. H. Kamerlingh Onnes; Zijn Levenswerk, de stichting van het Cryogeen Laboratorium', *In Memoriam Heike Kamerlingh Onnes* (Leiden 1926) 27.

⁵¹ H.G. Heijmans, *Wetenschap tussen universiteit en industrie. De experimentele natuurkunde in Utrecht onder W.H. Julius en L.S. Ornstein 1896-1940* (Utrecht 1994) 164.

therefore reacted enthusiastically when Einstein speculated (in a letter dealing mainly with the approaching golden jubilee of Lorentz's doctorate) on quantum corrections to the equation of state and the law of corresponding states; see also chapter 33).⁵² Einstein's basic premise, he replied, was completely in line with his own leitmotif.⁵³ Was not the abiding strength of Leiden's experimental research that its work was always embedded in a theoretical framework?

A theoretical framework of this kind was completely absent when it came to Leiden's research on superconductivity. At the third Solvay Conference, in April 1921, Onnes provided a survey of the results achieved since 1911 (when he presented the superconducting mercury at the first Solvay Conference).⁵⁴ Since then, mercury had been joined by lead, tin, thallium,⁵⁵ and the lead isotope radium G.⁵⁶ Thallium wires with a thickness of 0.2 and 0.5 mm, wound bifilar around a porcelain cylinder into which a notch cut in the path of a spiral or screw thread had been baked, had already been continuity-tested at 0°C at the beginning of 1917. In June 1919 the 'jump temperature' was established as 2.32 K. A year later, it was the turn of lead and uranium lead (radium G). Both isotopes, with atomic weights of 207.20 and 206.06 respectively, were continuity-tested in a special helium vapour cryostat that could deal with the difficult temperature range between 4 and 14 K. The jump temperature of both lead and uranium lead was established as 7.2 K; any deviation was at most 0.025 of a degree.

That was striking: one would have expected the difference in mass between the two types of atoms, as Onnes pointed out at the third Solvay Conference, to yield different frequencies of the Planck vibrators, expressed in different 'jump temperatures'. Not until the 1950s did it become clear that an isotope effect of this kind does in fact exist, and that the jump temperature is inversely proportional to the root of atomic weight. For lead and uranium lead, this

⁵² Einstein to Heike Kamerlingh Onnes, 4 November 1924, MB, archives of Heike Kamerlingh Onnes.

⁵³ Heike Kamerlingh Onnes to Einstein, 13 November 1924, MB.

⁵⁴ H. Kamerlingh Onnes, 'Les superconducteurs et le modèle de l'atome Rutherford-Bohr'. *Atomes et électrons. Rapport IIIième Conseil Solvay* (Paris, 1923) 165-197. *Comm.* supplement 44a (without discussion).

⁵⁵ H. Kamerlingh Onnes, 'Further experiments with liquid helium Q. On the electric resistance of pure metals etc. X. Measurements concerning the electric resistance of thallium in the temperature field of liquid helium', in KNAW, Proceedings, 25, 1922, Amsterdam, 1922, pp. 443-450. *Comm.* 160a.

⁵⁶ *Ibid.*, R., etc. XI. 'Further experiments with liquid helium. R. On the electric resistance of pure metals etc. XI. Measurements concerning the electric resistance of ordinary lead and of uranium lead below 14°C', in KNAW, Proceedings, 25, 1922, Amsterdam, 1922, pp. 451-457. *Comm.* 160b.

yielded a difference in jump temperature of 0.02 K, just within Onnes's margin of error.⁵⁷

In Brussels, Onnes posed the question of whether superconductivity was confined to a limited number of metals. The question of micro-residual resistance was also raised: Onnes believed that this really existed. He posited that the phenomenon of persistent current was in accordance with the Lippmann rule: the magnetic flux trapped within a superconducting circuit (in a lead ring, for instance) is unchangeable (otherwise an induction voltage could arise in the ring, which could lead to a current of infinite strength at zero resistance). Lippmann, whom Onnes had met in his Heidelberg days, had formulated his rule in 1919. This supposition (which later turned out to be erroneous) led to the doctrine of the 'frozen field': if a massive superconductor – that is, not a ring or hollow sphere – is cooled to below the transition temperature in the presence of a constant magnetic field, the magnetisation will remain unchanged, even if the field is then switched off. This preconceived notion blocked all real progress in the understanding of superconductors, and continued to be upheld until Meissner discovered in 1933 that in massive superconductors, the current flows only on the surface.⁵⁸

Onnes ended his 1921 Solvay address with a list of questions that were in urgent need of answers and that were inspired by Rutherford and Bohr's model of the atom (only certain electron orbits can exist in an atom, each one with a fixed energy level). Together, these questions made up a programme that accorded a key role to an external magnetic field, but that did not get off the ground in any coherent way in Leiden.⁵⁹ Instead, a fifth superconductor was announced in June 1923, namely indium, with a jump temperature of 3.40 K.⁶⁰

The fourth Solvay Conference, held in April 1924, was devoted to electrical conductivity in metals. Since Onnes was absent through illness, Keesom, who had returned to Leiden, presented the latest discoveries in the field of superconductivity.⁶¹ He started by reporting a downward readjustment of micro-residual resistance. Whereas back in 1911, Onnes had reported in Brussels, for

⁵⁷ Dahl, *Superconductivity*, 101.

⁵⁸ Casimir, *op cit.* note 27, p. 339; Dahl, *op cit.* note 57, 102-103.

⁵⁹ Gavroglu and Goudaroulis, *Through Measurement to Knowledge*, lxxiii-lxxviii.

⁶⁰ W. Tuyn and H. Kamerlingh Onnes, 'Further experiments with liquid helium, S. On the electric resistance of pure metals etc. XII. Measurements concerning the electrical resistance of Indium in the temperature field of liquid helium' in KNAW, Proceedings, 26, 1923, Amsterdam, 1923, pp. 504 – 509.
Comm. 167a.

⁶¹ H. Kamerlingh Onnes, 'Nouvelles expériences avec les supraconducteurs'. *Solvay 1924*, 251-281.
Comm. supplement 50a (without discussion).

superconducting lead at 4.2 K, a residual value of 0.5×10^{-10} of the resistance at 0°C , new experiments with persistent current had reduced this figure by another factor of ten. These experiments had been possible since the helium cryostat had been detached from the liquefier, finally banishing the rumbling noise that had been the bane of the cryogenic laboratory. The researchers started by looking at persistent currents in two concentric superconducting lead rings, one of which was then rotated through a specified angle. The equilibrium that developed between the electrodynamic torque on the moveable ring and the torsion torque of the suspension was watched closely for six hours. From its stability, Onnes concluded that the variation in the relative current strength was less than $1/2100$ per hour, corresponding to a micro-residual resistance smaller than previously assumed by a factor of ten. The inner ring was then replaced with a hollow glass ball, on which a thin layer of lead had been vaporised. By this procedure, Onnes hoped to show that the current in a superconductor flowed through fixed chains of adjacent atoms, an idea that Lorentz provided with a theoretical basis,⁶² and that Einstein too more or less endorsed, in the absence of a better idea.⁶³ From the durability of the equilibrium attained between the ball and the ring followed a micro-residual resistivity that was lower still – by another factor of ten. But Onnes refused to go that last step from an infinitesimally small resistivity to zero: that would be pure speculation, and speculation was an indulgence he never permitted himself.

Interestingly, Einstein had expressed his suspicion, on the basis of the idea that electricity is conducted along a linked chain, that resistivity would arise at the contact point between two attached superconductors – a block of tin with blocks of lead on either side, for instance – because the velocity of electricity transport would differ from one substance to another in a chain of this kind. But when Onnes tried it out, he found that the combination too acted as a superconductor.⁶⁴

In his reflections in 1924, Onnes returned to a question that Paul Langevin had raised in Brussels back in 1911: whether superconductivity was related to allotropy – that is, changes in the structure of matter. Dana had planned to investigate in Leiden whether any heat effect arose at the point at which tin

⁶² H.A. Lorentz, 'On the motion of electricity in a spherical shell placed in a magnetic field', *Reports on the Fourth International Congress of Refrigeration* (Leiden 1924). *Comm.* supplement 50b.

⁶³ A. Einstein, 'Theoretische Bemerkungen zur Supraleitung der Metalle'. *Het Natuurkundig Laboratorium 1904-1922*, 429-435. For an English translation see arXiv, physics/0510251. See also Tilman Sauer, 'Einstein and the Early Theory of Superconductivity, 1919-1922', *Archive for History of Exact Sciences* 61 (2007) 159-211.

⁶⁴ Ehrenfest to Lorentz, 13 March 1921, N-HA, Lorentz archives.

became a superconductor, but lack of time compelled him to confine his study to an exploratory experiment that did not yield any conclusive results.⁶⁵ On the eve of the 1924 Solvay Conference, Keesom had made an X-ray photograph of superconducting lead using a Debye-Scherrer camera, and observed that its crystal structure was the same as at room temperature.⁶⁶ And during the discussion of Onnes's report, it turned out that the intensities of the peaks in the X-ray photographs of lead were also the same below and above the jump temperature, which meant, according to Paul Langevin and William Bragg, that the electron structure was also unchanged. At which Marie Curie pointed out that excellent conductors such as gold and copper were not superconductors, so that the underlying mechanism must be completely different.

Gerard Sizoo had just started on his PhD research in Leiden, which involved studying the influence of atomic distance on superconductivity. Wading through the dense theoretical fog hanging over the entire subject of superconductivity, Onnes had suggested that an elastic deformation of the atomic lattice might produce some perceptible effect. The graph of resistivity against temperature around the jump value shifted by 0.015°C , according to Onnes's report for the fourth Solvay Conference, in the case of a stretched tin wire. Onnes thought it likely that stretching, and hence increasing atomic distance, would foster superconductivity. It was Sizoo – who had started work at the Philips NatLab in 1918, then worked as Onnes's assistant in Leiden, and returned to work under Holst in Eindhoven in 1926, after gaining his PhD⁶⁷ – who studied the effects of stretching and compression in tin and indium. In June 1925 he and Onnes reported the results of their measurements to the Academy.⁶⁸ Compression (to 1,500 atmospheres) lowered the jump temperature as expected, in the case of tin by about 0.05 mK per atmosphere. That experiments conducted at high pressures of 193 and 300 kg/cm^2 exhibited virtually the same shift was most probably attributable to the freezing of the helium in the compression tube in these circumstances⁶⁹ – an effect that Onnes and Sizoo failed to see, in consequence of which it was another nine months before the discovery of solid helium was announced – by Keesom.

⁶⁵ *Op. cit.* note 54.

⁶⁶ *Op. cit.* note 50, discussion. See also W.H. Keesom and H. Kamerlingh Onnes, 'On the question of the possibility of a polymorphic change at the point of transition into the supraconductive state'. *Comm.* 174b.

⁶⁷ Kees Boersma, *Inventing structures for industrial research* (Amsterdam 2002) 35.

⁶⁸ G.J. Sizoo and H. Kamerlingh Onnes, 'Further experiments with liquid helium. CB. On the electrical resistance of pure metals. XIV. Influence of elastic deformation on the supraconductivity of thin and indium', KNAW, Proceedings 28, 1925, Amsterdam, 1925, pp. 656-666. *Comm.* 180b.

⁶⁹ W.H. Keesom, 'Solid helium', KNAW, Proceedings, 29, 1926, Amsterdam, 1926, pp. 1136-1145. *Comm.* 184b.

The influence of compression on the jump temperature had also attracted the interest of Franz Simon, who was working as a *Privatdozent* in Nernst's Institute of Metrology in Berlin in 1924. He wrote about it to Onnes, who immediately wrote back inviting him to come and work in Leiden; but fear of jeopardising his *Habilitation* (and economic prospects) deterred the German from accepting.⁷⁰ Simon was a Jewish war veteran with an Iron Cross who had been allowed to keep his academic position in the 1930s but nonetheless fled to Oxford, where he helped to build the Clarendon Laboratory into a first-class cryogenic laboratory.⁷¹ In February 1924 he suggested to Onnes, taking the existence of zero-point energy as a premise, that alkali metals might well be potential superconductors. This was when Herman Woltjer had just concluded that neither sodium nor potassium exhibited any sign of superconductivity, even at a temperature as low as 1.5 K.⁷²

Aside from his work on tracking down superconducting metals, Willem Tuyn also distinguished himself with some research seeking to verify the Silsbee hypothesis (see chapters 29 and 33). According to this 'wild theory',⁷³ the threshold current needed to disrupt superconductivity generates a magnetic field equal to the threshold field that produced this same disruption. Thus, threshold current and threshold field were intimately connected. While Silsbee based himself on limited prewar measurements of mercury, tin and lead, Tuyn collected data, on a large scale, on the magnetic threshold field at different temperatures in the case of lead, tin and indium. He also determined certain threshold currents for thallium, lead and tin. His results led him to conclude that Silsbee's hypothesis was correct.⁷⁴ A particularly original part of his work was an experiment with a tin cylinder containing a copper wire immersed in liquid helium with a temperature below the jump value. First, the strength of the current through the tin was increased until a point at which the superconductivity was disrupted. Then an opposing current was passed through the copper. The effect was to weaken the magnetic field generated by the current through the tin. According to the Silsbee hypothesis, superconductivity will be restored in

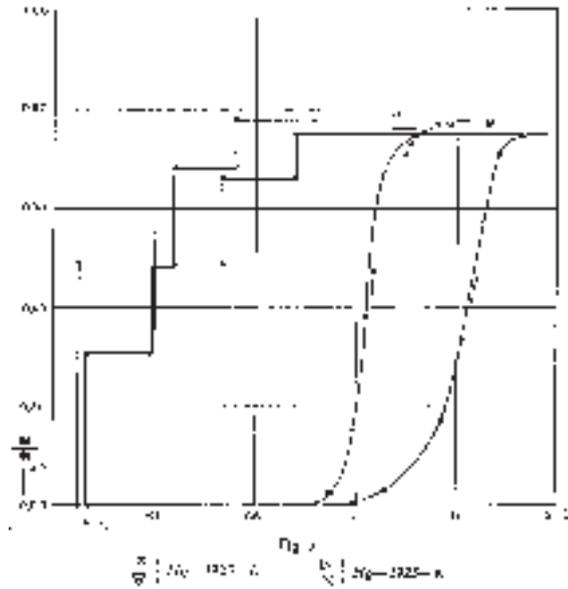
⁷⁰ Simon to Heike Kamerlingh Onnes, 3 June 1924, MB, archives of Heike Kamerlingh Onnes.

⁷¹ Dahl, *Superconductivity*, 139-141.

⁷² H.R. Woltjer and H. Kamerlingh Onnes, 'Further experiments with liquid helium. Y. On the electrical resistance of pure metals etc. XIII. On the electrical resistance of *Na* and *K* in the temperature region of liquid helium', *Reports, etc. IVth International Congress of Refrigeration* (Leiden 1924). *Comm.* 173a.

⁷³ W. Tuyn, *Weerstandsmetingen in vloeibaar helium* (Leiden 1924) 67-68.

⁷⁴ W. Tuyn and H. Kamerlingh Onnes, 'Further experiments with liquid helium. AA. The disturbance of supraconductivity by magnetic fields and currents. The Hypothesis of Silsbee.' Franklin Institute, *Journal* 201 (1926) 379-410. *Comm.* 174a. *Op. cit* chapter 29, note 53, 67-111.



Ill. 58. Diagram illustrating the phenomenon of hysteresis, discovered by Sizoo in 1925. In the graph of the electrical resistance of a superconductor plotted against the strength of the external magnetic field, if the field strength is *increased* the graph displays a smooth curve around the threshold field (with resistance returning), whereas if the field strength is *decreased*, there is a more abrupt, ‘jump-like’ decrease in resistance.

this situation, even if the current passing through the tin remains above the threshold value – which is in fact what happened.

Onnes’s last achievement in the area of superconductivity was his assistant Sizoo’s discovery of hysteresis: the phenomenon that the graph of a superconductor’s resistivity at values close to the threshold field is different when the magnetic field is being increased than when it is being reduced. This discovery was a prime example of serendipity. Sizoo’s research on the influence of the stretching or compression of superconductors on the jump temperature (launched in March 1924, shortly before Onnes’s retirement) acquired a logical sequel at the beginning of 1925, with a study of the influence of deformation of the atomic lattice on the magnetic threshold field. This influence proved to exist, but the discovery of hysteresis gave the experiment a surprising twist. After hysteresis had been established for tin,⁷⁵ it appeared far more

⁷⁵ G.J. Sizoo, W.J. de Haas and H. Kamerlingh Onnes. ‘Influence of elastic deformation on the magnetic disturbance of the supraconductivity with tin. Hysteresisphenomena’, in KNAW, Proceedings, 29 I, 1926, Amsterdam, 1926, pp. 221-232. *Comm.* 180c.

dramatically in the case of mercury, with sharp jumps in the downward branch of the resistance graph⁷⁶ (see Ill. 58). The mercury threads were contained in glass capillaries – even when they were cooled with great care, half of them broke. No clear conclusions could be drawn from the observations, but it was obvious that the way in which the crystallisation took place was a factor. This shifted the researchers' attention to hysteresis in mono-crystals – the growing of which, it should be added, was a complicated task in itself. In the 1930s, this yielded important new insights – not in Leiden, but in Berlin.⁷⁷

⁷⁶ W.J. de Haas, G.J. Sizoo and H. Kamerlingh Onnes, 'On the magnetic disturbance of the supraconductivity with mercury I', in KNAW, Proceedings, 29 I, 1926, Amsterdam, 1926, pp. 233-249. 'On the magnetic disturbance of the supraconductivity with mercury II', in KNAW, Proceedings, 29 I, 1926, Amsterdam, 1926, pp. 250-263. *Comm.*180d.

⁷⁷ The main reference here is to the discovery of the Meissner effect. See Dahl, *Superconductivity*, 132 and 197-201.

33. Successors

On 25 September 1922, two years before he was due to retire, Kamerlingh Onnes lost his close colleague Johan Kuenen, his chosen successor. ‘We have suffered a terrible blow’, he telegraphed to Keesom, ‘our good Kuenen, with whom I passed a happy hour only yesterday, died in the night of an internal haemorrhage.’¹ The laboratory, already chaotic amid the ongoing expansion and renovation work, was in turmoil for weeks, and a sick Onnes sat at home grieving over the loss of a ‘fine human being’.² That Kuenen had been weighed down since 1906 by such a heavy teaching load that he had scarcely been able to do any research, condemned to poor laboratory facilities and with little say in how things were run – these matters had never caused discord between master and pupil. If Kuenen had suffered, he had done so in silence.

Keesom must have been distraught at the news from Leiden, but at the same time, he must have realised that after almost six years at the National Institute of Veterinary Medicine in Utrecht, he would shortly be returning to Leiden. For who would Onnes rather have at his side than his faithful vassal and former supervisor, his mainstay in theoretical physics? And he was not wrong: the appointments committee that reported back to the mathematics and physics faculty on 8 December nominated Keesom. But the committee (the astronomer Willem de Sitter, Onnes, Lorentz and Ehrenfest) had understandably looked beyond the Kuenen vacancy. Lorentz would be seventy in April 1923, followed in September by Onnes, and the academic statutes provided for mandatory retirement in the academic year following that milestone – hence a year later for Onnes than for Lorentz. The Committee had resigned itself to the impossibility of replacing Lorentz (who had a part-time or ‘extraordinary’ professorship); that had been agreed in 1912. The men nominated to replace Kuenen and Onnes were Keesom and Wander de Haas, and if some insuperable problem

¹ Heike Kamerlingh Onnes to Keesom, 25 September 1922, N-HA, Keesom archives.

² Van Itallie-Van Embden, *Sprekende portretten*, 49.

arose, Crommelin, Holst and Verschaffelt might be considered. But the latter three were clearly seen as men of a lower calibre.³

The day before the faculty meeting, Onnes discussed his misgivings about the succession in a letter to Lorentz.

‘I shall have to hope and trust that the fruits of my intellectual work, now poised to attain heights that have been undergoing preparation for so long, will not be killed off by a new blow on top of the recent pressure of financial cuts.’⁴

Onnes was indignant that the expansion of the laboratory had not been accompanied by more personnel and a higher materials grant; even the extra money needed for lighting and cleaning was not provided automatically, he fulminated. Still, all would be well as long as ‘the superb spirit that reigns in the laboratory is preserved’. And this very spirit would be in jeopardy if the De Haas-Keesom nomination fell through. He considered his second choices, Crommelin and Holst, to be of an equal standard, although he wondered whether Holst, who was perfectly at home in Eindhoven, would be just as happy in Leiden. And he could well imagine that Crommelin, who as supervisor had been ‘the soul of technical management’, might have difficulty working under Holst, who was very far from being a Kuenen.

It was not a disaster that Lorentz was not being replaced. Since he had left for Haarlem, he had been teaching advanced students (and people who already had their PhD) on Monday mornings, and when it turned out that even part-time professors had to stop at seventy, Onnes arranged for Lorentz to carry on lecturing as a professor by private appointment, on behalf of Leiden University Fund. This would not cost the Fund a penny: ‘a group of friends’ would raise the 2,500-guilder fee and transfer it to the Fund’s account – Lorentz preferred not to be paid through Onnes.⁵

Some time earlier, the same Fund – again at Onnes’s instigation – had enticed the world-renowned Albert Einstein to Leiden. Einstein owed his fame to the British solar eclipse expeditions that took photographs on 29 May 1919 in Sobral (northern Brazil) and on the island of Principe (off the coast of West Africa).⁶ The general theory of relativity predicted that starlight would be slightly deflected by the curve of space-time in the vicinity of the sun. On 10 November, shortly before Arthur Eddington had presented the conclusive

³ Faculteitsvergadering, 8 December 1922, UB Leiden, Archief Senaat en Faculteiten, wis- en natuurkunde, inv. no. 12.

⁴ Heike Kamerlingh Onnes to Lorentz, 7 December 1922, N-HA, Lorentz archives.

⁵ Heike Kamerlingh Onnes to *leden universiteitsraad*, 1 June 1923, Gemeentearchief Leiden, LUF, inv. no. 63.

⁶ Abraham Pais, ‘*Subtle is the Lord...*’: *the science and the life of Albert Einstein*, 303–312.

eclipse results to the Royal Society, triggering Einstein's victory march in the media ('Revolution in science', blazed the headlines in the London *Times*: 'New theory of the universe / Newtonian ideas overthrown'), Onnes sent a telegram to Berlin, congratulating Einstein on the splendid new confirmation of his theory.⁷

The day before, he had proposed to the president of Leiden university council that the 'great Swiss scientist Einstein' (so soon after the war, the predicate 'Swiss' was far from trivial), a 'star of the greatest magnitude ... of the stature of Newton', be bound more firmly to Leiden by procuring an endowed chair for him. This construction had been possible since 1905, and Onnes was one of the first to propose such an appointment to Leiden University Fund.⁸ His timing was flawless – profiting from the wave of media interest in Einstein – and Onnes recalled the existing Leiden connection. 'Binding such a luminary to our Alma Mater would be a great boon', wrote Onnes, 'all the more so because Einstein was led to his discoveries by building on Lorentz's work in Leiden.'⁹

They had been tugging at Einstein for months. On 2 September 1919, shortly before the provisional results of the eclipse expeditions had been made public, Ehrenfest, who had become impatient with the endless bureaucracy surrounding Einstein's infrequent visits, invited the scientist to settle in Leiden, writing '*everyone* here agrees that we must act to bring you to Leiden. The matter is extremely simple: if you would just say "yes", it would be possible ... to arrange everything very quickly, taking your wishes into account.'¹⁰

After which Ehrenfest – who emphasised in his letter that Onnes was particularly enthusiastic about the idea – held out to Einstein the prospect of a Valhalla in Leiden: a salary he could set himself ('*our maximum* salary of 7,500 guilders would be *your minimum*'), no teaching obligations, free travel abroad, and a stimulating environment consisting solely of affectionate friends. 'Dear, dear Einstein!... Whatever you decide, do answer by return of post: "Mmmm, what you are suggesting is not such a bad proposition".'

It is unclear whether the board of governors would have been willing to entertain the idea – creating an extra chair in theoretical physics in a period of across-the-board financial cuts made little sense. The initiative was not discussed

⁷ '[H]erzliche Glueckwunsch zur glaenzenden neuen Bestaetigung Ihrer Theorie'; MB, archives of Heike Kamerlingh Onnes, inv. no. 71.

⁸ Willem Otterspeer, *Een welbestierd budget. Honderd jaar Leids Universiteits-Fonds 1890-1990* (Leiden 1990) 58.

⁹ Heike Kamerlingh Onnes to Vissering, 9 November 1919, Gemeentearchief Leiden, LUF, inv. no. 72.

¹⁰ Ehrenfest to Einstein, 2 September 1919, quoted in Martin Klein, *Paul Ehrenfest*, 310.

within the faculty. In any case, Einstein did not take long to reply.¹¹ It was certainly a splendid offer. Leiden would be a fine place to work and he liked the people there, but he would not be coming. He had promised Planck to remain in Berlin unless circumstances made it impossible. Nonetheless, he hoped to visit Leiden in the near future to strengthen their ties of friendship. Now as in 1916, arranging a visa was a difficult business, and at the last minute, Onnes had to write an urgent letter to the national passport office in The Hague to cut through the red tape.¹²

In the second half of October, Einstein stayed with Ehrenfest and his family.¹³ Upon returning to Berlin, he wrote his host a very affectionate letter: 'From now on, we shall remain in close personal contact. That is good for both of us, and we shall both feel less out of place in this world if we can rely on each other.'¹⁴ Moved, Ehrenfest immediately set about trying to get his friend appointed as a guest professor – at the same time as Onnes's efforts with Leiden University Fund. The idea of a 'comet-like existence', frequently returning to Leiden for three or four weeks at a time, appealed to Einstein. In December, Lorentz made him an official request on behalf of Leiden University Fund: to come to Leiden once or twice a year as he saw fit, with few or no obligations and a salary of 2,000 guilders for the endowed chair.¹⁵ In January, Einstein sent a telegram to Haarlem saying that he would be delighted to accept.¹⁶ In his November letter to the LUF, Onnes had mentioned a term of three years, after which the appointment would be reconsidered. Raising the necessary 6,000 guilders by private contributions would not be a problem. 'A glorious name such as Einstein's, which will live on in the next century, will surely be able to conjure up such a sum at the drop of a hat.'¹⁷ And Lorentz said that he was confident that fellow theoretical physicists would be willing to contribute.

Once again, red tape slowed everything down – the authorities confused Einstein with one Carl Einstein (no relation), an anarchist who lived with a 'red countess' in Brussels. In July 1920, however, the new construction was finally approved – aside from the extra royal decree needed because Einstein had a non-Dutch PhD. Meanwhile, Ehrenfest had been filling his prospective colleague in concerning Leiden protocol. For his inaugural address, Einstein was

¹¹ Klein, *Paul Ehrenfest*, 310–323.

¹² Ehrenfest to Lorentz, 5 October 1919, N-HA, Lorentz archives.

¹³ Dirk van Delft, 'Albert Einstein in Leiden'. *Physics Today*, April 2006, 57–62.

¹⁴ Einstein to Ehrenfest, 9 November 1919, MB, Ehrenfest scientific correspondence.

¹⁵ Lorentz to Einstein, 21 December 1919, MB, archive 55.

¹⁶ Einstein to Lorentz, 19 January 1920, Gemeentearchief Leiden, LUF, inv. no. 72.

¹⁷ See note 9.



Ill. 59. Albert Einstein and Heike Kamerlingh Onnes in 1921, the year in which Einstein took up his position as an extraordinary professor at the University of in Leiden. Sketch by Harm Kamerlingh Onnes.

not permitted to use a blackboard or slides; he could not even ‘talk with his hands’ since these had to be concealed beneath his gown. Ehrenfest explained all the words of thanks that had to be pronounced at the end of his speech, and advised him to pause for a glass of water before launching into them, so that the elderly gentlemen in the audience who had nodded off during the lecture could be startled into waking up. He even instructed Einstein in the correct way to pronounce the words ‘Ik heb gezegd’ [I have said], the standard closing formula.

Onnes too was greatly looking forward to Einstein’s arrival. He had set out his own interests in the matter in a letter to the LUF in December 1919. While conceding that Einstein’s main appeal lay in his theory of relativity, he stressed that the Swiss scientist had also produced other work of great significance.

‘The doctrine of the still highly mysterious quanta identified by Planck acquired universal significance as a result of Einstein’s research. Many of the phenomena related to this doctrine were first illuminated by low-temperature research, and the further exploration of its riddles will continue to require a great deal of low-temperature work.

Professor Einstein is therefore extremely interested in the activities of the cryogenic laboratory, and especially if this laboratory assumes the role of an international institute for such work, the information he provides can make a major contribution.¹⁸

Once Einstein had committed himself, Onnes too wrote to him, emphasising his high expectations of their cooperation.¹⁹ Since Einstein's work on quantum theory tied in with the Leiden low-temperature research, he repeated, the guest professorship would be a boon to the cryogenic laboratory and his help would be invaluable. Einstein's arrival would also benefit theoretical physics in general, and he looked forward to elaborating plans and clarifying problems with his new colleague.

On 27 October 1920, Einstein gave his inaugural address, on 'Ether and the Theory of Relativity'. In the meantime, he had come under fire in Berlin, where some saw him as a cosmopolitan Jewish pacifist with obscure theories. One of his university lectures had been disrupted in February, and in August 1920, when Einstein attended a meeting of the newly formed association of physicists (*Arbeitsgemeinschaft deutscher Naturforscher*) at the Philharmonie, terms of abuse – 'publicity-crazed dog', 'plagiarist', 'con-man', 'scientific Dadaist' – were hurled in his face. The man who had invented the theory of relativity, now a public figure, hit back hard but emotionally in the newspaper *Berliner Tagesblatt*, with Lenard the main butt of his attack. As soon as Ehrenfest read of the commotion in the newspapers, he again offered Einstein a position in Leiden, on his own authority. But the celebrity preferred to keep to the agreed guest professorship, initially at twelve-monthly intervals. Onnes seized the opportunity of Einstein's 1920 address to organise a three-day conference on magnetism, in his capacity as chair of the first committee of the International Institution of Refrigeration, with Einstein, Ehrenfest, Keesom, Weiss, Langevin and himself all taking part (see chapter 28).

Onnes was eager to hear Einstein's opinion on possible quantum corrections to the equation of state and the law of corresponding states, especially in the case of monatomic gases such as helium, neon and argon. There was plenty of empirical material to help shape new theories. In the summer of 1921, Onnes wrote from Hotel Tibilis Engelberg that he was looking forward to discussing quantum influences in November, when Einstein came for his second period as guest professor at Leiden, including the possibility of zero-point energy – in which Onnes did not believe.²⁰ In November 1924, Einstein again raised the matter of quantum corrections, and provided Onnes with some

¹⁸ Heike Kamerlingh Onnes to Vissering, 1 December 1919, Gemeentearchief Leiden, LUF, inv. no. 204.

¹⁹ Heike Kamerlingh Onnes to Einstein, 8 February 1920, MB.

²⁰ Heike Kamerlingh Onnes to Einstein, 13 August 1921, MB.

speculative formulas, the importance of which remained unclear, and which Onnes would have to examine in the light of the measured deviations from the law of corresponding states.²¹ Onnes replied that in spite of certain reservations he was ‘overjoyed’ with Einstein’s suggestions, and that the idea that quantum rules help to determine the time that molecules remain in proximity to one another had been an ‘epiphany’.²² But these remained vague ideas, and despite his conviction that they would lead to ‘great things’, he was too old to do anything with them himself. In 1953, when the director of the National Museum for the History of the Natural Sciences (now Museum Boerhaave) asked Einstein for character sketches to mark the hundredth anniversary of the birthdays of Lorentz and Kamerlingh Onnes, he said that scientific discussions with Onnes tended to be rather difficult. Onnes possessed a sound intuition, said Einstein, but he could not express himself clearly and he was not very open to the views of others.²³

The laboratory divides in two

Of the duo Keesom and De Haas, Willem Keesom was a sort of new Onnes. But who was Wander de Haas? Trained by Onnes, he had acquired his PhD in 1912 with a dissertation on measurements of the compressibility of hydrogen gas, a typical ‘knowledge through measurement’ product. De Haas, who had spent five years studying to be a notary before switching to physics, married Berta Lorentz, who had also worked as Onnes’s assistant. In 1913 the couple went to Berlin, where De Haas did magnetism research in Henri du Bois’s Bosscha laboratory and worked as a researcher at the Institute of Metrology from 1913 to 1915. It was in Charlottenburg that he and guest experimentalist Einstein had discovered the Einstein-De Haas effect: the phenomenon that an iron bar displays a tendency to rotate when magnetised.²⁴ It is a case of every action having an equal and opposite reaction: small atomic currents that under influence of the magnetic field suddenly turn the same way, arousing in reaction a rotation in the opposite direction in the iron bar as a whole. The subject was more complicated than Einstein and De Haas thought, and the value they obtained was too high (by a factor of two), but their basic assumptions were correct.

²¹ Einstein to Heike Kamerlingh Onnes, 4 November 1924, MB, archives of Heike Kamerlingh Onnes.

²² Heike Kamerlingh Onnes to Einstein, 13 November 1924, MB.

²³ Einstein to Maria Rooseboom, 27 February 1953, *Albert Einstein & Museum Boerhaave* (Leiden 1993) 40–41.

²⁴ A. Einstein and W.J. de Haas, ‘Experimenteller Nachweis der Ampèreschen Molekularströme’, *Verhandlungen der Deutschen physikalischen Gesellschaft* 17 (1915) 152–170.



Ill. 60. Wander Johannes de Haas, who, together with Keesom, succeeded Kamerlingh Onnes in 1924 as director of the Physics Laboratory.

In 1916, when De Haas was working under his father-in-law at the Teylers physics laboratory, he repeated the Berlin experiments in a modified form. In 1917 he acquired a chair in Delft, and five years later he took over Haga's position in Groningen. Earlier, after the sudden death of Du Bois, Professor Julius in Utrecht had asked Lorentz whether De Haas would be a suitable successor. Du Bois had fled from his private laboratory in Berlin after the outbreak of war, and had been given his own laboratory in Utrecht in exchange for his instruments. Mindful of the 'peculiar difficulty' of assessing his own son-in-law, Lorentz valiantly acquitted himself of the task.²⁵ He described De Haas as a

²⁵ Lorentz to Julius, 6 February 1919, Utrechts Universiteitsmuseum, Julius archives, map vacature Du Bois.

‘real experimentalist’ with qualities such as enthusiasm, inventiveness, great skill and inexhaustible patience, someone who was happiest in the laboratory. But Lorentz conceded that De Haas had little mathematical training, which did not prevent him gravitating towards subjects impinging on the foundations of physics. ‘For me, being more mathematically inclined, it is sometimes difficult to follow his train of thought’; even so, he added, De Haas might well be right. In the event, the Du Bois vacancy vanished overnight in 1920, when Ornstein took over as Julius’s successor in Utrecht.²⁶

Since De Haas had only recently started work in Groningen, it was decided to choose Keesom as Kuenen’s successor, after which Onnes could hand over to De Haas in September 1924. From the outset it was clear that the relationship between Keesom and De Haas, unlike that between Onnes and Kuenen, would be one of equals. This was rather odd. It is scarcely possible to imagine that Onnes, Lorentz and Ehrenfest placed the two on an equal footing. Keesom was the man of the *Encyclopädie* article, the ‘wild ideas’ about quantum theory, the barotropic effect (the sinking of a gas in a liquid). The Einstein-De Haas effect looked a little paltry in comparison. Evidently other factors played a role.

One possible factor is identified by Leo Dana, who was doing postdoctoral research in Leiden in this period. Since Keesom was a devout Catholic, and Leiden was a Protestant university, Dana says that Keesom, though clearly the best man for the job, would have been unacceptable to the board of governors and the ministry as the man in sole charge of the laboratory.²⁷ But it was sixty years later when Dana wrote down these recollections. No other documentation has surfaced suggesting such a semi-*Berufsverbot*. Onnes, Ehrenfest and Lorentz never mention it in their letters. It also seems rather improbable: in the 1920s, a period of denominational governments, it was not unusual for Catholics to be appointed to high office. Ruijs de Beerenbrouck served as the Netherlands’ first Catholic prime minister from 1918 to 1925, with the Reformed minister Visser as his minister of education, arts and sciences. True, this government blocked the appointment of the astronomer and Marxist theorist Anton Pannekoek as deputy director of Leiden’s Observatory in 1919, but that decision was motivated by fear of the ‘Red Peril’.²⁸ So Dana’s explanation seems implausible, and may have been mere hearsay.

²⁶ H.G. Heijmans, *Wetenschap tussen universiteit en industrie*, 57.

²⁷ Donnelly, *Cryogenic Science and Technology*, 25-26.

²⁸ David Baneke, “‘Hij kan toch moeilijk de sterren in de war schoppen’”. ‘De afwijzing van Pannekoek als adjunct-directeur van de Leidse Sterrewacht in 1919’, [“‘He can hardly subvert the stars’”: the rejection of Pannekoek as deputy director of the Observatory in 1919] *Gewina* 27 (2004) 1-13.

Probably neither Keesom nor De Haas wanted to play second fiddle. Once the royal decree confirming Keesom's appointment was passed (in February 1923), Onnes wrote to him about a plan for dividing the laboratory up.²⁹ Keesom wanted to manage the cryogenic laboratory, and would not accept a cut in salary. In April the appointments committee met with the two prospective directors and forged a satisfactory solution, whereby each would have his own empire. But for the time being, Onnes was still the boss. From Switzerland he wrote a ten-page letter enumerating all the assistantships: regular and extraordinary, full-time and half-time, private, trainee and unpaid assistants.³⁰ 'Having talented people in the laboratory is worth gold', he counselled Keesom, 'always providing their interests coincide with the laboratory's.' Just before the summer recess, the two new directors reached full agreement on the way in which examinations, practical laboratory work and lectures (including those for the medical students) were to be divided up. On 26 September, Keesom gave his inaugural address, on the importance of the quest for absolute zero. De Haas followed on 8 December 1924 with an address on 'Electricity and other currents'.

So the Physics Laboratory was now divided in two. Department 1, led by Keesom, included the cryogenic laboratory, and would perform thermodynamic research at low temperatures. Department 2, headed by De Haas, would focus on electrical and magnetic research. Supervisor Crommelin was rewarded for his loyal service by a promotion to deputy director and to a position as (unpaid) *lector* in instrumental science.³¹ Onnes summed up the details of the new arrangements in a letter to the board of governors.³² Department 1 would be housed in the old physics wing, and department 2 would move into the old chemistry wing. The old anatomy labs would be divided among them. The permanent and temporary personnel would also be divided up, and the same applied to the materials grant. The joint technical and administrative service was assigned to department 1. Essentially, there were now two laboratories with two directors. Ministerial approval followed in October 1924, with the additional provision that Crommelin's promotion was *à titre personnel*.

Onnes had already retired by then. 'I was still going strong at the official finish', he wrote to Zeeman at the beginning of August, just before leaving for Switzerland.³³ He certainly was: at the last moment, two of his students

²⁹ Heike Kamerlingh Onnes to Keesom, 25 February 1923, N-HA, Keesom archives.

³⁰ Heike Kamerlingh Onnes to Keesom, 20 July 1923, N-HA, Keesom archives.

³¹ Faculteitsvergadering 9 July 1924, UB Leiden, Archief Senaat en faculteiten, faculteit wis- en natuurkunde, inv. no. 12.

³² Heike Kamerlingh Onnes to *curatoren*, 16 July 1924, archives of the Huygens Laboratory.

³³ Heike Kamerlingh Onnes to Zeeman, 4 August 1924, N-HA, Zeeman archives.

(including the theorist Jan Tinbergen) were awarded Master's degrees and three gained PhDs: Johan Boks on 10 July, and Arend van Urk and Willem Tuyn the following day. Lorentz too attended the latter ceremony, and spoke some 'affable words'. 'We enjoyed a better life than we foresaw forty years ago', wrote Onnes in his letter of thanks.³⁴ A week later, Onnes invited the laboratory trainees to his illuminated garden. But there would be no real parting of the ways. Keesom and De Haas had invited Onnes to continue his 'research with liquid helium'. And the retiring director had declared himself willing to act in an advisory capacity if necessary, to help implement his plans for the laboratory's expansion.³⁵ Indeed, he looked forward to doing so: 'As long as I can perform to my own satisfaction, it will continue to benefit my health as it always has done.'³⁶

Poor Keesom. Even now that he was director, Onnes was still trying to control everything. In 1925 Keesom became overworked from all the strain. Paul Ehrenfest was so worried that he wrote to Lorentz, with characteristic frankness:

'I am very distressed that Keesom is suffering from exhaustion. Unfortunately, I cannot give Keesom and De Haas any substantial relief – although I offered to take over the medical students' examinations, for instance, in this difficult period of reorganisation, but for some unknown reason De Haas did not take me up on my offer of help. Could you perhaps indicate any way in which I might be of assistance in these difficult times? ... There is something else I feel compelled to say. It is a great pity that Onnes is still trying to run the show. I am completely ignorant of most of what goes on, and am happy to remain so. But in my close *personal* ties with students and assistants, I can't help noticing that Onnes's attempts to rule the roost produce some tragicomic effects – like the presence of a mother-in-law in a young couple's household. That Keesom and De Haas will have a good working relationship is perfectly clear. But Onnes's interference really worries me. The students, and more notably the assistants, are exactly like the cook who does not know whether to take orders from the lady of the house or her mother. ... Of course, everyone knows full well that the laboratory is Onnes's creation, but if his creation is to endure, he must *really* leave the young people to run it. I am afraid that Keesom is suffering badly from the interference, if only because of having to discuss everything for hours on end! ... You and only you may be able to help, Mr Lorentz.

As you see, this letter ends on exactly the same note as almost all my earlier ones!³⁷

³⁴ Heike Kamerlingh Onnes to Lorentz, 17 July 1924, N-HA, Lorentz archives.

³⁵ Archives of the Huygens Laboratory.

³⁶ See note 33.

³⁷ Ehrenfest to Lorentz, 4 April 1925, N-HA, Lorentz archives. 'Es thut mir so sehr Leid, dass Keesom so übermüdet ist. Leider kann ich ja Keesom und De Haas nicht *wesentlich* entlasten. – Ich

Ehrenfest was right: after his retirement, Onnes simply remained at the helm. Whatever issue arose, whether it was about the interior design of the old anatomy wing (on which work started in 1924), the supervision of PhD students such as Gerard Sizoo (magnetism; De Haas's responsibility) and A.C.S. van Heel (optical research at low temperatures; under Keesom), plans for new experiments, the purchase of the new large electromagnet, editing the *Communications*, the claims submitted by the Physiology Laboratory (which was to have new premises on the site of the Academic Hospital; not realised until the 1960s!), the building of a small 'pavilion' for special experiments in Van der Werff Park,³⁸ consultations with foreign guests, or securing a financial donation from the Rockefeller Foundation, Onnes meddled with everything, and Keesom in particular must have found his interference maddening.

That is not to deny the value of some of Onnes's ideas. For instance, in 1925 he suggested setting the PhD student Van Gulik to work on the viscosity of highly cooled liquid helium. 'It could begin with a very simple qualitative study: flows through a capillary tube with a high-pressure manometer on either side', he explained to Keesom. 'Even if the only thing to emerge is that at 800 atmospheres and at 1°K, for instance, there is still a free flow through a capillary, which means that the helium is not yet solid – not in the ordinary sense, anyway – this could be worthwhile.'³⁹ That Onnes suggested performing a qualitative experiment *before* studying the phenomena more accurately

habe ihnen angeboten, während dieser schwierigen Organisationsperiode z.B. die Mediziner-Tentamina auf mich zu nehmen aber aus mir unbekanntem Gründen hat de Haas vor diesem Angebot etwas mit zu helfen bisher keine gebrauch gemacht. Ich möchte *Sie* bitten mir zu sagen wie ich wenigstens während dieser schwierige Zeit einigermaßen helfen könnte. Nun muss mir noch etwas von Herzen: Es ist doch wirklich sehr sehr schade, dass Onnes noch so stark hineinregiert. Von den meisten Dingen weiss ich ja nichts und *will* auch nichts davon wissen. Aber auch ohne dass ich es will, bekomme ich wegen meiner vielfachen *persönlichen* Beziehungen zu den Studenten und Assistenten doch recht deutlich zu sehen, dass das Hineinregieren von Onnes wahrhaft Tragikomische Schwierigkeiten schafft – precies wie die Anwesenheit einer Schwiegermutter in der Wirtschaft eines jungen Ehepaares. – Die Zusammenwirkung von Keesom u. de Haas wird – dass ist ganz evident – vortrefflich gehen. Aber das Hineinregieren von Onnes erfüllt mich mit grossen Sorge. – Die Studenten und besonders Assistenten befinden sich sehr oft exact in der Situation der Köchin, die nicht mehr weiss ob sie auf die oude mevrouw oder die jonge mevrouw hören muss. Jeder weiss natürlich sehr wohl, dass das Leidener Laboratorium die Schöpfung von Onnes ist, aber wenn seine Schöpfung wirklich bleiben soll, das muss er doch die Leitung *wirklich* in die Hände der Jüngeren legen. – Ich fürchte, dass Keesom nicht zum geringsten der Qual dieses Hineinregierens unterlegen ist. Allein schon die Stundenlange Conferenzen!! Wenn überhaupt jemand, so können einzig und allein *Sie* helfen Herr Lorentz. Sie sehen, auch dieser Brief schliesst wieder mit demselben Refrain wie – fast alle meine Briefe an Sie!

³⁸ Heike Kamerlingh Onnes to *curatoren*, 29 November 1924, UB Leiden, Archief Curatoren, inv. no. 1798.

³⁹ Heike Kamerlingh Onnes to Keesom, 23 August 1925, MB.

with a differential manometer is noteworthy, and belies Casimir's view that this playful approach was taboo in Leiden. What led Onnes to lapse from his faith at the end was the loss of the helium monopoly. Since McLennan in Toronto and more notably Meissner in Berlin had possessed liquid helium, he observed, qualitative processes had moved to the foreground. Perhaps, one wonders, it might have been a blessing for Leiden if it had lost its helium monopoly far sooner.

Gulik started on something different and the experiment was shelved. It was a missed opportunity: in January 1938, Kapitza in Moscow (with the help of the brilliant theorist Lev Landau) as well as Allen and Misener in Cambridge measured the capillary flow of helium II (i.e., cooled below 2.2 K), and discovered superfluidity. Solid helium, too, might have been discovered in the conditions suggested by Onnes. In fact, the experimental setup that Keesom used to freeze helium in the summer of 1926 relied heavily on a proposal made by Onnes the year before. It should be added that the Polish physics professor Mieczyslaw Wolfke, who measured the dielectric constant of liquid helium in Leiden in 1924 and 1925, and who published on the subject together with Kamerlingh Onnes and Keesom, had suggested to Onnes back in the summer of 1924 that helium could be forced to congeal under pressure, an idea that he also mentioned to Keesom a year later. On neither occasion, the Pole noted in his diary, did the others act on his suggestion of putting the helium under pressure.⁴⁰

While Onnes was worrying that the government might not provide sufficient funds for his expanded laboratory (the 40,600 materials grant provided in 1922 was reduced to 25,600 for the two subsequent years), numerous fundraising campaigns were launched abroad. The fund set up in November 1922 by the International Institute of Refrigeration in honour of the fortieth anniversary of Onnes's doctorate has already been mentioned; its main use was to pay post-doctoral physicists to conduct low-temperature experiments in Leiden. A few months after the creation of this IIF fund, Ernest Solvay's heirs sent a cheque for 100,000 francs (18,575 guilders). Onnes, a close friend of the Belgian industrialist, had spoken at his funeral and had written an obituary for *De ingenieur*.⁴¹

But all this was child's play, compared to the gift of \$100,000 forked out by the Rockefeller Foundation in 1924. On 1 April, the Physics Laboratory was visited by Wickliffe Rose, professor of philosophy and history, who was acting

⁴⁰ J. Rafolowicz, 'History of cryogenics in Poland'. Ralph G. Scurlock (ed.), *History and Origins of Cryogenics* (Oxford 1992) 112-113.

⁴¹ MB, archives of Heike Kamerlingh Onnes, inv. no. 219.

on behalf of the New York oil baron and philanthropist John D. Rockefeller Jr. In 1923 Rose was appointed president of the General Education Board within the Rockefeller Foundation, and one of his first acts was to set up the International Education Board (IEB).⁴² He set forth his ideas in a paper called ‘Scheme for the Promotion of Science on an International Scale’. The aim was to promote international science – which was described as being in America’s interest – by granting fellowships, and to a lesser extent by awarding grants to institutions. The underlying philosophy was ‘making the peaks higher’⁴³ – any notion of distributive justice was alien to Rose. Thus, the IEB funded a new wing for Niels Bohr’s Institute for Theoretical Physics in Copenhagen, which had been the main centre of quantum theory since 1920, as well as providing a series of fellowships to further invigorate the Institute’s work. The Rockefeller Foundation would commit a total of 20 million dollars to the IEB. To familiarise himself with the state of European science, to identify good places for fellowships and to promote his IEB, Rose toured fifty universities in nineteen countries from December 1923 to April 1924. The Netherlands (Utrecht and Leiden) was his final stop.

Onnes was ill, and Rose and his secretary Beckenhore were received by Keesom and Crommelin.⁴⁴ They were showed around the cryogenic laboratory, and fired an endless battery of questions at the director and his deputy. Rose said that one possibility was awarding a grant to help purchase instruments, in which case the Dutch government would be expected to match it with additional funds to make the instruments ‘productive’.

After the two Americans had left, Keesom rushed over to Huize ter Wetering for a council of war with Onnes. Since the donation had been tied to an additional government grant, it was imperative to secure a response from the relevant ministry before Rose left the country. Keesom and Crommelin went to The Hague on 4 April for preliminary consultations with Secretary-General Van Beeck Calkoen, after which they reported back to Rose at Hotel des Indes.⁴⁵ The Dutch and the Americans soon reached agreement at the education ministry: Rose, who was impressed by Leiden’s ‘unique laboratory’, would commit \$100,000 to purchase new instruments – one of the biggest donations the International Educational Board would ever hand out to an institution. The Dutch government would match this grant by adding an annual subsidy of \$4,000 (roughly 10,000 guilders), three-quarters of

⁴² R.B. Fosdick, *The story of the Rockefeller Foundation* (New York, 1952).

⁴³ Rein Siegmund-Schultze, *Rockefeller and the internationalization of mathematics between the two world wars* (Basel 2001) 18.

⁴⁴ Crommelin’s lab book, 1 April 1924, MB, archive 132.

⁴⁵ *Ibid.*, 4 April 1924.

which would pay additional personnel to conduct research with the new equipment.⁴⁶ It was further agreed that Keesom and Crommelin would contact the government very soon and notify Rose informally of the outcome.

The case was accorded such importance that the two men from Leiden were received by the minister himself, De Visser, who took great interest in the plan and asked the two scientists to submit an official proposal. He said he was willing to give it his wholehearted support in the cabinet.⁴⁷ Onnes, whose illness did not cloud his shrewd judgment in such matters, quickly informed the board of governors that the IEB grant would obviously not affect the materials grant that had already been approved for 1924. The sum requested in the budget 'for the procurement of instruments' was only meant to cover immediate necessities 'to prevent the laboratory's demise'.⁴⁸ That money – let it be clearly understood – was intended solely to 'make good some lost ground'. To propel the laboratory vigorously in the direction of its chosen specialisation would require more money, and in that light, Rose could not have come at a better time. After which Onnes asked for the special grant of 10,000 guilders that had been agreed. It would be better still if the government were to continue this extra support for a few years, and so Keesom wrote to New York asking whether the \$100,000 might not be spread over a period of ten years.⁴⁹

After the cabinet had expressed its great satisfaction with the \$100,000 grant,⁵⁰ and had agreed to keep its own side of the bargain, Onnes sent Rose a wish list for the first \$25,000. All the apparatus he requested was closely related to Leiden's ongoing research, including projects being conducted by guests; he did not seize the opportunity to strike out along some completely different path.⁵¹ The IEB warmly approved his list,⁵² and the first \$25,000 instalment was transferred in the course of 1925. The government added 5,000 guilders, which it topped up to the required 10,000 in 1928. Keesom and De Haas used their annual extra injection of funds (which continued until the Second World War) to help pay for five to ten research assistants, making Rockefeller a sort of 'Janssen writ large'. It may be added that Utrecht did not receive any money

⁴⁶ HKO and Keesom to *curatoren*, 15 April 1924, UB Leiden, Archief Curatoren, inv. no. 1799.

⁴⁷ Keesom to Rose, April 1924, archives of the Huygens Laboratory.

⁴⁸ See note 46.

⁴⁹ See note 47.

⁵⁰ HKO to *curatoren*, 5 June 1924, UB Leiden, Archief Curatoren, inv. no. 1799.

⁵¹ Heike Kamerlingh Onnes to Rose, 22 July 1924, archives of the Huygens Laboratory.

⁵² UB Leiden, Archief Curatoren, inv. no. 1799, Heike Kamerlingh Onnes and Keesom to *curatoren*, 6 October 1924; Rose to Heike Kamerlingh Onnes, 20 September 1924, archives of the Huygens Laboratory; Heike Kamerlingh Onnes and Keesom to Rose, 17 October 1924, archives of the Huygens Laboratory.

to pay research staff after Rose's visit, but Ornstein did secure an IEB grant of \$3,000 to buy and install a new Rowland grating.⁵³

Onnes's last major project was organising the golden jubilee of Lorentz's doctorate, on 11 December 1925. As chair of the organising committee, he mobilised 2,000 'friends and admirers' at home and abroad to contribute over 150,000 guilders to the 'Lorentz fund for the advancement of theoretical physics'.⁵⁴ He also spoke to the Academy about introducing a Lorentz medal, to be awarded every four years (the first one went to Max Planck in 1927), and made strenuous efforts to secure for his friend a Grand Cross of the Order of Orange Nassau.⁵⁵ In thanks for the many years Lorentz had spent teaching medical students, the medical faculty awarded him an honorary doctorate – Onnes was presumably not sorry that Einthoven, the professor designated to oversee the procedure, was in Sweden accepting his Nobel Prize. For the ailing Heike, it was a great relief that the doctor allowed him to make a speech at the university for 'Hentje', whose friendship he had cherished since the two had met in Arnhem, 54 years before. But as for joining the special dinner with guests including Marie Curie, Einstein, Bohr, and Eddington – that was too much of a strain.

⁵³ Heijmans, *Wetenschap tussen universiteit en industrie*, 60. Heijmans mentions a donation of 3,000 guilders, but the IEB's Annual Report for 1924-1925 refers to a gift of 3,000 *dollars* 'toward special equipment for physical research'.

⁵⁴ *Physica*, 6, January 1926, 5-14.

⁵⁵ Heike Kamerlingh Onnes to Zeeman, 12 September 1925, N-HA, Zeeman archives.

34. Duty, joy and harmony

‘My husband is in bed with a mild case of bronchitis. He is wheezing and coughing up a lot of phlegm, and he has a temperature,’ Bé wrote to Zeeman in mid-November 1925.¹ Onnes’s friends were used to his colds and other maladies; he had struggled with illness throughout his life and had always pulled through. With Lorentz’s golden jubilee just around the corner, he seemed to recover as usual: there he was with everyone else in the university building. But the next health cure in the Swiss Alps was a long way off, and death had sighted him.

Onnes was fortunately spared a senile decline such as that suffered by Van der Waals. When Heike sent a final letter to his ‘highly esteemed and deeply revered friend’² in 1920, for his 83rd birthday, announcing his new assault on the cold record, he closed with the words: ‘How wonderful it is if the past was good.’³ When Van der Waals died, in March 1923, he wrote in the daily newspaper *De Telegraaf* that he had ‘wistful memories’ of the time they had spent together, which had unfortunately shrunk to brief, sporadic visits. ‘It is as if the loss of the great man already belongs, in a sense, to the past.’

Six weeks later, Heike ventured some reflections on his own life. After a meeting of the scientific committee of the Solvay conferences, he and Bé were to have gone for a walk in the forêt de Soignes near Brussels; instead he was felled by a cold and found himself confined to bed at the hotel. It was an ideal moment for a contemplative letter to his former student, the physicist and philosopher Jacob Clay. In 1919, Clay had been appointed to a chair at the Institute of Technology in Bandung, in the Dutch East Indies, where he researched cosmic radiation and set up a training course for instrument-makers much like the one in Leiden. Heike recalled their days in the laboratory in 1905, when Clay and his wife Teddy Jolles had both been working as his assistants. His assessment reflects a light touch of melancholy: ‘For however many years

¹ Betsy Kamerlingh Onnes to Zeeman, 18 November 1925, N-HA, Zeeman archives, inv. no. 84.

² Heike Kamerlingh Onnes, ‘Ter herinnering aan Prof.Dr. I.D. van der Waals’, *De Telegraaf*, 11 March 1923.

³ Heike Kamerlingh Onnes to Van der Waals, 22 November 1920, N-HA, Van der Waals archives.

may have passed since then, and however much may have changed, one thing has remained the same: that I have always given what I could, not so much living as having my life lived for me, feeling myself pulled along as if by a maelstrom, which I myself had unleashed to swell to its inexorable force.⁴

Heike's brother Menso Kamerlingh Onnes died on 29 June 1925, 'after a few grim days'. 'An aristocratic demeanour, a mildly melancholy face', is how the newspaper the *Algemeen Handelsblad* described his self-portrait with easel and straw hat, that same afternoon.⁵ His son Harm, whom Menso himself had instructed in the art of painting, told Einstein and wrote that his father had greatly appreciated Einstein's visits to the Rijnsburgerweg house, especially when they made music together.⁶

Heike's final visit to his cryogenic laboratory was on 13 February 1926.⁷ Hans Kramers, who had spent ten years in Copenhagen as Niels Bohr's assistant flaunting his mathematical genius, linguistic prowess (his twin brother Jan was professor of Persian, Turkish and Arabic at Leiden) and skill on the cello, had been appointed professor of theoretical physics in Utrecht, and came to look around the Steenschuur one Saturday. The quantum world that he had helped to open up (but which did not really take shape until 1926, with the work of Heisenberg and Schrödinger) had little appeal to Onnes's generation. Heike had not progressed beyond the theories formulated by Planck before the war, and had complimented Lorentz only in January on his original description of Planck's energy elements as minute but finite.⁸ Onnes will have noted the discovery by George Uhlenbeck and Sem Goudsmit (students of Ehrenfest's), six months earlier, of the spin of electrons – a pure quantum property – but scarcely more than that.

The Tuesday after Kramers' visit, Heike was confined to bed with a mild case of bronchitis. At first the illness seemed fairly benign, but on Friday night he developed acute pneumonia with a high fever. By morning, the doctor had concluded that his patient was unlikely to recover.⁹ That Saturday, Lorentz came to visit, deeply concerned. 'I saw him for a few minutes on Saturday, and he spoke a few words', Lorentz wrote to Einstein: 'They had already given up hope.' Heike was barely conscious of the seriousness of the situation, Lorentz added. The following night, at 72 years of age, Heike slipped out of consciousness, and on Sunday 21 February 1926, at 10.30 a.m., came the 'peaceful end'.¹⁰

⁴ Heike Kamerlingh Onnes to Clay, 29 April 1923, MB.

⁵ *Algemeen Handelsblad*, 29 June 1925.

⁶ Harm Kamerlingh Onnes to Einstein, 30 June 1925, MB.

⁷ Crommelin's lab book, 13 February 1926, MB, archive 132.

⁸ Heike Kamerlingh Onnes to Lorentz, 6 January 1926, N-HA, Lorentz archives.

⁹ See note 7.

¹⁰ Lorentz to Einstein, 22 February 1926, MB, archive 55.

A whole sack full of letters of condolence from around the world found their way to Huize ter Wetering. One came from Louis Pierson in Wiesbaden, a close friend whom Heike had met in his year in Heidelberg.¹¹ Zeeman recalled his walks with Heike around the Raaphorst estate in Wassenaar, and how he had talked of Lorentz, whose dissertation he had stuffed into his pocket.¹² And Johannes Diederik Korteweg, who had made friends with Heike in Delft, while working under Bosscha, described him as having a ‘totally unselfish character; honest, fair, perspicacious in all matters’.¹³ Einstein wrote in similar terms: ‘I have known few people in whom duty and joy coincided so precisely as in him. From that sprang the glad harmony that he radiated.’¹⁴ ‘We are the poorer for his loss’, wrote the leading article of the *NRC* of 22 February, summarising the general sentiments.¹⁵

The funeral was held in Voorschoten on Thursday. Heike’s body was interred in the family tomb behind the Dutch Reformed church where his mother lay, next to his brother Menso. One account records that after the funeral procession passed the city limits, the horses gathered pace. The laboratory technicians, wearing tails and top hats, who were following the hearse and other carriages on foot, had trouble keeping up. When they finally arrived at the graveyard, one of them laughed, wiping the sweat from his brow, and said, ‘Just like the old boss to keep us running even after his death!’¹⁶

It was Lorentz who gave the funeral oration.¹⁷ ‘That I should have the privilege of conveying your feelings’, he said, addressing the crowd, ‘I owe to the loyal friendship, without a note of discord, that we shared for over half a century, and which was one of the best that life has given me. I experienced, perhaps more than any of his other friends, what a good and warm person Onnes was.’ He then gave a brief account of the life of ‘the student with a love of poetry’, who had made his cryogenic laboratory into a universally acknowledged centre of international cooperation and promoted the interests of theoretical as well as experimental physics. The jewel in the crown, perhaps, had been the discovery of superconductivity, and Lorentz emphasised that Onnes’s

¹¹ Louis Pierson to Betsy Kamerlingh Onnes, 23 February 1926, MB, archives of Heike Kamerlingh Onnes, inv. no. 93.

¹² Zeeman to Betsy Kamerlingh Onnes, 23 February 1926, MB, archives of Heike Kamerlingh Onnes, inv. no. 93.

¹³ Korteweg to Betsy Kamerlingh Onnes, 23 February 1926, MB, archives of Heike Kamerlingh Onnes, inv. no. 301.

¹⁴ Einstein to Betsy Kamerlingh Onnes, 25 February 1926, MB, inv. no. 295.

¹⁵ *Nieuwe Rotterdamse Courant*, 22 February 1926.

¹⁶ Casimir, *Haphazard Reality*, 167.

¹⁷ H.A. Lorentz, *Collected Papers*, vol. IX (The Hague 1939) 407.

mind had always been focused on ideas, in spite of the rigmarole of administration and materials that often claimed his attention. He retained this focus right up to the end. ‘And so he slipped away from us – and it could not have been otherwise – thinking of what had not yet been achieved and pondering unresolved problems.’

Dozens of other obituaries would follow. The most important Dutch ones, from Lorentz’s funeral oration and Keesom’s history of the cryogenic laboratory to a short piece by J.P. Wibaut in *De Socialistische Gids*, were published in a collective volume.¹⁸ In *Nature*, F.A. Freeth, a British physicist who worked at a metalworks and maintained close ties with Onnes’s cryogenic laboratory: ‘Turning to his personal side, it is impossible to speak of him without emotion. Onnes was one of the most genial, kind-hearted, and accessible men who ever lived. He made unremitting efforts towards the feeding of children in the destitute areas of Europe in the years immediately following the War. To young men, he was an inspiration. The writer will always remember, with gratitude, his extraordinary kindness and hospitality. He practically kept “open house”.’¹⁹ The ‘feeding of children’ probably refers to Onnes’s efforts to provide relief for Austrian families that had been reduced to poverty.

Two years after Onnes’s death, the student G.P. Nijhoff likened him to a general, in the Preface to his classical ‘knowledge through measurement’ dissertation. ‘You would never fail, during our Monday afternoon discussions – when we studied the real details of experimental science – to provide a concise summary showing how each person’s work fitted together in the larger whole. And when we suddenly saw how good it was, that we needed the self-discipline of soldiers – oh! as you used to express it so eloquently – to close ranks around the fortress of the unknown, I don’t know if we admired you more as a great physicist or as a great organiser.’²⁰

Now we can take stock with the benefit of eighty years’ hindsight. To do so, let us return to the key question formulated in the introduction to this book: how is Kamerlingh Onnes’s success in building up a low-temperature laboratory that was unique in the world to be explained?

Heike Kamerlingh Onnes inherited a great deal from his father besides weak lungs. Both loved hard work, and both were manufacturers: while Harm produced roof tiles, his famous son produced cold.

Heike’s entrepreneurial abilities proved invaluable. Building up a cryogenic laboratory of international status, of a size and personnel unequalled anywhere

¹⁸ *In memoriam Heike Kamerlingh Onnes: 21 september 1853 – 21 februari 1926* (Leiden 1926).

¹⁹ *Nature*, 117 (6 March 1926) 350–351.

²⁰ G.P. Nijhoff, *Metingen van den tweeden viriaalcoëfficiënt van zuurstof, waterstof en helium bij lage temperaturen* (Leiden 1928) Preface.

in the world, called for more than a great talent for physics. Anyone who entered the Steenschuur premises, especially lab E and the surrounding area, and beheld the profusion of tubes, taps, gas flasks, gas holders, liquefiers, Dewar flasks, cryostats, clattering pumps and droning engines, glass-blowing and other workshops, instruments and appliances for scientific research, would have felt as if he had come to a factory. It was indeed a ‘cold factory’, with Professor Kamerlingh Onnes as its director, determining policy and exercising tight overall control. As the director of an enterprise, he also set up a well-oiled organisation presided over by an administrative supervisor, a research team including assistants and postgraduate students, a manager, instrument-makers, glass-blowers, laboratory assistants, technicians, an engineer, an assistant supervisor, not to mention a small army of trainee instrument-makers to perform any number of odd jobs. Heike’s project was Big Science²¹. Unlike other laboratory directors, who struggled with the combined demands of organisational and teaching obligations and their own research, Kamerlingh Onnes thrived in this climate. Whatever complaints he may have had, they were never about being overworked.

This ‘Big Science’ approach, unique in its combination of focus and the large scale on which everything was tackled, could only succeed with someone at the helm who had persistence, courage, willpower, vision, and indestructible patience. Someone who ruled with a firm hand, but who at the same time had a gift for winning people over, persuading them, securing their loyalty. And someone with a peerless ability to manipulate the powers-that-be – Heike was always warning that what had taken years to achieve at the Steenschuur was in danger of being destroyed – and he kept up his dire warnings until the authorities gave their ‘expensive professor’ the space and the resources he needed to accomplish his goals. He was also a brilliant networker, with a keen eye for useful contacts both within and far beyond the field of physics, someone who pampered his guests and was far too shrewd to quarrel – with the notable exception of his neighbour Professor Einthoven – or to make enemies who might harm his interests. In short, Kamerlingh Onnes was brimming with organisational and social instinct – qualities that he had displayed as a young man, presiding over Groningen’s student fraternity *Vindicat atque Polit*, and without which his mission in Leiden would have had no chance of success. Onnes was a sound scientist, but his cryogenic laboratory owed its success to his talent for organisation, his social skills, and his unswerving focus on extremely low temperatures.

²¹ Helge Kragh, *Quantum Generations* (Princeton 1999) 74–80.

Onnes was also clever at creating win-win situations. One good example is the way in which he persuaded the Amsterdam tobacco agent and philanthropist P.W. Janssen to sponsor his work from 1897 onwards. A training system for instrument-makers, built into the Physics Laboratory, was a blessing for physics, not only in Leiden: it produced highly skilled workers who were in great demand at laboratories throughout the country and abroad. The second Janssen fund, which Onnes used to pay extra research assistants and to top up the salaries of key figures within his laboratory (Flim, Siertsema, Keesom) to discourage them from leaving, had been created with the brilliant argument that these extra researchers (whom the government declined to appoint) would need extra instruments and appliances, which would boost the instrument-makers' training system. Fundamental research in physics with a social conscience: it happened in Leiden.

The point was that the Dutch government was willing to fund education but would scarcely pay a penny for pure scientific research. When Kamerlingh Onnes started in Leiden in 1882, and immediately banished the historical collection of physics apparatus – much to the distress of his predecessor, the educationalist Rijke – to the attic to make room for a research laboratory, he cannily explained to the board of governors (and hence to the minister) that he was engaged in a process of educational innovation. Purchases of new instruments, necessary to set up research projects, were justified by invoking courses on 'molecular forces' and 'electrical measurements'. The second Janssen fund too was used to give research an added impetus outside government channels. In 1924, when the Rockefeller Foundation forked out \$100,000 to buy instruments and demanded that the Dutch government match the donation with an annual grant of 10,000 to take on extra researchers to use the new instruments, these conditions had to be detailed scrupulously in a contract – such was the narrow focus on education in The Hague.

When he started out, Onnes wanted a cryogenic laboratory for himself, to test the theories of Van der Waals. Back in 1873, when he had studied under R.A. Mees in Groningen, Heike had read Van der Waals's groundbreaking dissertation on the continuity between the gaseous and liquid states immediately after its publication, and had made notes on it in a special exercise book. That was in a time when even the existence of molecules was a rather new-fangled idea – let alone the concept that these molecules remained the same during a phase transition. Nonetheless, the work of physicists like Clausius, Maxwell and Boltzmann had made molecular physics (the kinetic theory of gases) into a hot item that appealed to Heike, whose talents overlapped theory and experimentalism. When he had finally completed his dissertation on the short Foucault pendulum in 1879 – part of the heritage from his year in Heidelberg, which provided conclusive proof of his experimental competence – he was

working in Delft as Bosscha's assistant, and he heard about Van der Waals's law of corresponding states as soon as it had been communicated to the Academy. Within a month, Heike had derived it himself on more general grounds, taking as his basic premise the principle of the mechanical equivalence of molecular motion. In his 'Knowledge through measurement' address in Leiden, in 1882, he set out a programme to test the validity of the equation of state and the law of corresponding states, the ultimate aim being to discover more about the structure of molecules and their mutual attraction. Private tuition by Van der Waals himself greatly influenced Onnes's ideas on this programme, both in the area of thermodynamics (including Gibbs) and the design of liquefiers.

Onnes's edifice rested on two foundation stones: precision and cold. Precision, because both the equation of state and the law of corresponding states were valid only by approximation, so that determinations of the *deviations* from those laws were needed to make further progress in physics. These called for high-precision measurements, a kind of work that was dear to Heike's heart. Long ago, when studying with Bunsen in Heidelberg, he had loved quantitative chemical analyses that were correct down to the smallest detail. Later on, his pendulum experiments – first under Kirchhoff in Heidelberg and then, as part of his PhD research, in the 'Cyclops' cave' beneath the university building in Groningen – were devised so ingeniously, and provided such accurate results, that no one was able to advance this subject one iota for many years. When Heike put some of his students to work on magneto-optical research (the Lorentz series) while he was still building up his cryogenic laboratory, their work (Sissingh, Zeeman, Wind) soon produced results of an accuracy that no foreign rival could approach.

Producing cold was essential, because to verify Van der Waals's theories it was obviously best to start by using simple substances (and mixtures), which had low critical temperatures. Monatomic inert gases would have been ideal, but these did not become available (largely thanks to Ramsay's work) until the 1890s. So Onnes started by using diatomic substances such as oxygen, hydrogen and nitrogen, as well as carbon dioxide (CO₂) and methyl chloride (CH₃Cl). The first few had critical temperatures far lower than 0°C, so there was no alternative but to create a cryogenic laboratory. This undertaking consumed almost all Onnes's energy in the first few years of his professorship.

In building his 'cold factory', Onnes drew freely on other people's inventions. He took the cascade idea from Pictet, his decision to use methyl chloride and ethylene for the first and second stages was inspired by Cailletet, the receptacle he devised for liquid oxygen derived from Wroblewski, the double-walled glass containers were an invention of Dewar's, and Joule-Kelvin cooling had first been applied by Linde and Hampson. But in each case, Heike added some subtle feature of his own, integrating all these innovations into

installations that bore the unmistakable stamp: 'made in Leiden'. For instance, he was the first to use systematic precooling in his cycles by inserting regeneration coils. In designing the cascade, which, after ten years of tinkering with pumps (the Cailletet pump was a particular problem, but once upgraded it proved indispensable) and boiling flasks, produced the first few drops of liquid oxygen in 1892, the golden rule was 'never to spill cold'. Moreover, both cascade and cryostats were tailor-made for Heike's research programme: the cryostats could be maintained at a constant temperature, to within 0.01°C, an essential criterion for experiments in which equilibrium developed only slowly.

These achievements, based on installations the specifications of which Onnes published in minute detail – unlike his rivals – made Leiden's cryogenic laboratory a unique centre for low-temperature research, which worked to a degree of accuracy unknown elsewhere. Until 1907, Leiden constantly repeated foreign experiments that allegedly cast doubt on the continuity of the gaseous and liquid phases (such as those of the Belgian scientist Pierre de Heen, who claimed to have made a device that could distinguish *molécules gasogéniques* from *molécules liquidogéniques*) and judged both experimental setup and apparatus inadequate. At the same time, Onnes remained affable to all the assailants of 'his' Van der Waals, and he once stopped off in Liège on his way to a health cure in Switzerland to have tea with De Heen. It is also striking that Heike was more or less the only cryogenic pioneer who managed to remain on friendly terms with James Dewar.

Priority in new discoveries was always a sensitive issue. The only time Onnes adopted a less than amiable tone to Dewar was when he considered that the Scot had given him too little credit for Leiden's priority in its systematic use of the principle of regeneration. When Johan Kuenen predicted and discovered retrograde condensation, after which Van der Waals objected, claiming he deserved the credit himself because the effect was implicit in his theory of mixtures, Heike unhesitatingly sided with his student, not flinching from a head-on clash with his mentor and friend. Priority also caused frayed tempers in the case of the Zeeman effect and in research on opalescence (Zernike did comparable work in Groningen without mentioning that Keesom had been the first to do so). In all such cases Heike remained forthright but courteous. While Zernike and Keesom never settled their differences, Onnes had no qualms about inviting the later inventor of the phase contrast microscope to come and take measurements using liquid oxygen in the early 1920s.

When Onnes first arrived in Leiden he envisaged building a Huygens-type laboratory with a wide range of physics experiments, but after 1900 he phased out the Lorentz series and specialised in low-temperature thermodynamics. Thermometry was an essential aspect of this work, and this in turn spawned research into graphs of temperature against resistance in metal

wires – culminating in 1911 in the discovery of superconductivity in mercury. In the meantime, a hydrogen liquefier had been built in 1906, and two years later Onnes had won the race for liquid helium. Again, the discovery was a means to an end – namely, a way of creating liquid baths of a constant temperature. In preparing his first liquid hydrogen, there was no need for Onnes to rush: that race was doomed to failure because the cryogenic laboratory was forced to lie idle in the period 1895-1898 while a battle was fought over the licence it needed to continue its work with ‘explosive devices’. In the case of helium, Onnes did succumb to the temptation of a rapid expansion experiment in February 1908, and unfortunately went astray by mistaking white flakes of frozen impurities for solid helium. It was Onnes’s industrial approach that earned him his victory over Dewar. The Scot had called it wasteful to enlist the help of assistants in fundamental research, but when Heike finally conquered helium on 10 July 1908, it was partly thanks to his army of technicians and blue-collar boys.

Whereas Onnes’s thermodynamic research initially focused on critical phenomena (with the discovery of retrograde condensation the greatest prize), in the 1890s it divided into two separate research lines. One involved fundamental research into the second virial coefficient and its relationship to the attractive force between molecules (Keesom), and into the densities of saturated vapour and liquid near the critical point (Crommelin, Matthias). For a large number of substances, properties such as boiling point, melting point, critical temperature, specific heat, evaporation heat, vapour pressure and the isotherms were measured meticulously, as part of the research on Van der Waals’s equation of state and the law of corresponding states. But these data also helped pave the way for the liquefaction of gases such as hydrogen, helium, neon and argon. Pure and applied research overlapped. In the case of ammonia, the refrigeration industry also took an interest, and Philips put argon in its half-watt lamps.

Little by little, Onnes expanded his empire. He had started out in 1882 with one assistant, one technician and half an assistant supervisor. The countless letters he wrote to the board of governors, earnestly and indefatigably predicting the laboratory’s demise if funds were not immediately made available for extra personnel, instruments, renovation and expansion, were highly effective. Onnes acquired a second assistant, a second instrument-maker, an engineer, a supervisor, apprentices, a laboratory assistant, a second supervisor, more assistants, more technicians. Then came a training scheme for instrument-makers, a Janssen fund, another Janssen fund, and a second professor of experimental physics to lighten Lorentz’s heavy teaching load. Meanwhile, the laboratory expanded down Langebrug, one building at a time – with aesthetic considerations swamped by functionality.

The end product was that the sleepy physics department that Onnes inherited from Rijke was transformed, within a quarter of a century, into a world-class cryogenic institute. Its materials grant exceeded the combined total accorded to Utrecht and Groningen. This gap widened still further after the liquefaction of helium in 1908, and in the early 1920s, Leiden's Physics Laboratory had more revenue than those of Utrecht, Groningen and the municipal university of Amsterdam put together.

Meanwhile, Heike set about reforming education within his department: advanced students no longer did isolated set experiments; instead, Onnes trained them personally as researchers – he hated lecturing. Among the first PhD students to be moulded individually by Kamerlingh Onnes were Johan Kuenen and Pieter Zeeman. Onnes demanded total dedication: evenings were reserved for writing up observations and weekends were for making weekly reports. Jan Burgers, who, as one of Onnes's assistants, helped in 1914 with observations of platinum and gold thermometers, was warned not to concern himself with theory (at least, theory unrelated to the experiments), and he promptly switched to Ehrenfest's team. Onnes gave his people an excellent training, but it was a training confined to 'knowledge through measurement' physics. When Zeeman interrupted his regular research in August 1896 – when Onnes was far away in Switzerland – to find out, using an improved set-up, whether magnetism influenced the colour of light, he was clearly breaking the rules. In Leiden, one worked on measurement programmes until they were finished. To Onnes, the problem with experimental physics was how to stay on course amid all the enticements. Not until the very end of his career, when the helium monopoly had been broken and he found himself contending with foreign competition, did he relax his stringent ban on exploratory trials and side-roads.

This emphasis on planned physics sprang partly from the prevailing conditions in cryogenics. In the early years of the cascade, liquid oxygen was not always available, and a researcher permitted to pour some of the blue fluid into his cryostat had to have a clear plan of what he was going to do that day. With helium, this situation persisted until the end: there were only 18 'helium days' in the year 1922-1923. Just as Heike's weak constitution forced him to be economical with his strength, he would never spill a drop of liquid helium simply to 'try something out'. As a result, the laboratory had a schedule with wall-to-wall measurement days, leaving no space for sudden inspiration or other disasters of that kind.

That said, it should not be thought that the Leiden team went about mindlessly measuring all day. Heike had always emphasised – even in his PhD thesis – the importance of cooperation between theoretical and experimental physics. In his cryogenic programme, he took Van der Waals's theory as his unfailing

beacon. He did have to abandon the equation of state in 1873, however, in favour of an empirical variant with 25 constants, with the task of formulating a theoretical interpretation of these constants. Keesom, more than anyone, was constantly there to help and advise – it was he who wrote most of the monumental *Die Zustandsgleichung*. Onnes's supervisor and 'in-house theorist' resolved a good many issues, such as explaining why a helium gas bubble sank in liquid hydrogen (the barotropic effect). And where quantum matters were concerned, it was Keesom who produced the 'wild ideas' Onnes had requested, to explain the results of measurements taken of paramagnetism and specific heat.

Problems arose only when there was a lack of a theoretical framework to guide the experiments, as in the case of superconductivity. Onnes did suspect, of course that quantum theory lay behind it, but that theory was still in its infancy and in practice one could do little with it. Onnes soon gave up grappling with the theory, and opted instead for a purely phenomenological approach. That produced some interesting properties – threshold field, threshold current, persistent current, the influence of deformation of the atomic lattice, hysteresis – but Onnes overlooked the hypothesis that threshold field and threshold current are linked (Silsbee), in the absence of a theoretical framework. In this area, the experiments were *ad hoc* explorations – wading through the fog. This could sometimes lead to the completely wrong conclusions being drawn – such as the 'frozen field' doctrine, which blocked real progress for years.

Onnes hoped to be able to exploit Einstein's arrival in Leiden in 1920, as a professor by special appointment, to come to grips with the influence of quantum theory on the equation of state, but their talks on this matter were rather unproductive. As Casimir pointed out several times, the 'knowledge through measurement' ideology produced an astonishing quantity of useful experimental data, and liquid helium was an immediate product of it, but as a *modus operandi* it was diametrically opposed to the playful, qualitative approach that is sometimes necessary in physics, to make the leap to a new insight. Onnes ignored signs – such as those pointing to helium's superfluidity below 2.19 K – or failed to see them altogether.

Leiden's cryogenic strength is clear from its long monopoly on liquid helium, which was not broken until 1923, by McLennan in Toronto. Two years later, Meissner in Berlin possessed the liquid too. All those years, Onnes could set up experiments involving preparations immersed in a helium bath, without any competition whatsoever. That also meant he could afford to ignore suggestions: there was no one to punish him for pride or a lack of interest, or for making the wrong choice. And so when the Polish guest researcher Wolfke suggested freezing helium by putting it under pressure, he was ignored by Onnes, and his idea was still not taken seriously a year later, when Keesom was in

charge. Monopolies do not sharpen one's alertness and mental faculties, and the laboratory's long unchallenged reign was not all to its advantage. As soon as the Germans had started to produce liquid helium, Onnes changed direction – the thrashing his team had received at the hands of Nernst and associates before the war still fresh in his memory – but by then he was old and sick.

A complex, large-scale establishment such as the cryogenic laboratory obviously benefited from having a tightly-knit organisation. Onnes's will was law at the Steenschuur, there was a place for everything, and everyone was expected to work hard. Onnes took good care of his personnel and visited the families of his staff and technicians if the occasion arose, but his own interests took precedence. That is why Kuenen scarcely had any room to conduct experiments of his own, and why if Keesom wanted to do theoretical work that was not directly related to current experimental research, he had to do it at home – after which his results turned out to be extremely useful to Onnes. For Lorentz, who was kind enough to take over the big lectures for medical students in 1883 for his physically weak friend, Heike spent years writing urgent letters before the authorities finally agreed – in 1901 – to appoint a *lector* (Siertsema) to relieve him. And in 1905, when Lorentz threatened to leave for Munich, after his teaching load had once again grown to unacceptable proportions, Onnes arranged for the creation of a small institute of theoretical physics and secured Kuenen's return to Leiden as a second professor of experimental physics, his primary task being the classes that Lorentz was desperate to shed.

When there was a battle to be fought, Onnes fought with total honesty – sometimes naively so. In 1896, when the licence dispute arose, and the existence of the cryogenic laboratory hung in the balance, he not only answered all the questions frankly but also happily volunteered to the city council an additional list of all the dangerous substances that he stored *inside* his laboratory. And in his scrupulously prepared memorandum of oral pleading, he did not shrink from describing the ravages wrought by the (few) accidents that had happened elsewhere as a result of the careless use of flasks of gas kept under high pressure. Onnes was an incurable optimist with a firm belief in the power of reason; cynicism and underhand dealings were completely alien to him.

Willem Keesom emerges from this history as a tragic figure. Onnes was full of praise for his supervisor's abilities, but at the same time he exerted constant pressure on him. Keesom was expected to toil away on his boss's theoretical issues, not his own. While Keesom was initially praised for his application of zero-point energy, Onnes later dismissed the concept, and his underling could count himself lucky if he could refer to it in a footnote. Keesom had wanted to embark on crystal research in Leiden, using X-ray diffraction, but Onnes vetoed it. Later, when he applied it successfully after his move to the National

Institute of Veterinary Medicine in Utrecht in 1917, Onnes rued his decision. When Leiden was being trounced repeatedly by Berlin, Keesom must have felt infuriated that his specific heat measurements had constantly been shelved, so that Eucken had pipped him to the post yet again. To add to Keesom's misfortunes, all Onnes's efforts could not get his right-hand man a professorship. When Keesom returned to Leiden in 1923 as Kuenen's successor, he had the foresight to demand control of the cryogenic laboratory straight away. Yet even after he had taken over in 1924, Onnes's continued interference made his life a misery.

After the advent of liquid hydrogen, Leiden increasingly developed into an international facility for physicists who wanted to continue their research on phenomena such as phosphorescence, paramagnetism, the Hall effect, dielectric constants, and absorption spectra, at lower temperatures than they had at their disposal at home. The First International Congress of Refrigeration, in 1908, where Heike stole the show with his liquid helium, set a steady stream of guest researchers (and visitors) heading for Leiden. This boosted the diversity of the laboratory's low-temperature work. But it also created a glaring lack of research space, because the government, contrary to pledges it had made long ago, kept postponing the reallocation of the left wing of the laboratory to physics (chemistry finally left in 1917). Onnes bent over backwards for his foreign guests and offered them his hospitality at Huize ter Wetering, but at the same time, the invasion created fragmentation, and authentic Leiden research, such as Keesom's work on specific heat, suffered as a result.

Onnes was on good relations with people everywhere, both inside and outside the university. During the wrangling about his Leiden appointment, he enjoyed the support of 'influential friends': Bosscha, Lorentz and Van Bemmelen. He persuaded the navy to loan him some compressor pumps (used to launch torpedoes from submarines), Delft's artillery depot gave him some Rühmkorff reels, the gun foundry in The Hague presented him with a hydraulic pump that could attain pressures of up to 250 atmospheres, and the artillery workshops in Delft helped with sharpening fraises and assembling a large electromagnet. He was also on good terms with Philips, which launched its own research laboratory in 1914, with Gilles Holst in charge. Equipment was loaned, and information exchanged, in both directions – both laboratories took a particular interest in inert gases (on the one hand because of their simple structure, on the other because of their suitability for light bulbs). Onnes made his standard mercury manometer available for the calibration of manometers.

After the licence dispute, the board of governors would have loved to see the back of Kamerlingh Onnes, but the atmosphere changed in 1899, when first Bosscha and then Van der Waals joined the board. Onnes's friendship

with Solvay paid dividends, and his activities on behalf of the International Association of Refrigeration proved equally lucrative. Although this organisation had been set up (in 1909) primarily to promote refrigeration applications, he managed to ensure that *pure* science would benefit from it, partly by pointing out that thousands of hectolitres of liquid air had been produced since Cailletet's little cloud of mist in 1877. Onnes was no stranger to opportunism. Addressing an audience in London he showered praise on Faraday, in Paris he referred to Cailletet and Claude as true pioneers of refrigeration, and in his own country he extolled Van Marum. Onnes had one enemy: Einthoven, his physiology neighbour, who hated Onnes's vibrations because of his sensitive string galvanometer, and who laid claim to land that Heike had already earmarked for his physics laboratory. In their feud, Heike never gave an inch. He was capable of being extremely unpleasant if he thought it necessary, and of keeping it up for years on end.

Heike was a product of the HBS, the new type of secondary school which emphasised science subjects and which had laboratories so well equipped that they were the envy of many a university. His favourite subjects were chemistry and history. It was not until his year in Heidelberg, where he found the chemist and experimentalist *pur sang* Bunsen to be a disappointment when it came to independent research, and where he started work on Foucault's pendulum as Gustav Kirchhoff's assistant, that Heike was converted to physics. From Kirchhoff, he learned to appreciate the interdependence of theoretical and experimental physics. Not everyone agreed. Rijke was against appointing Onnes as his successor because he was not a full-blooded experimentalist, and Leiden already had a theoretical physicist in the person of Lorentz. Rijke's fears proved groundless. After Heike secured the position, although he followed the theoretical discoveries of Lorentz and Van der Waals closely, his PhD students were set to work to test the new insights experimentally, while the professor-director himself tinkered dauntlessly on his cryogenic installations. Not until 1894, when the cascade was working, did he publish anything himself. Instrumental science was the heart of his enterprise, certainly in the first few years.

Heike was not untouched by the prevailing mood of rampant nationalism. Both the Lorentz and the Van der Waals research lines that he started were intended in part to boost Dutch physics amid the rivalries of the age. Thus nationalism went hand in hand with an international orientation. Like Lorentz, Onnes opposed the tendency to isolate German and Austrian scientists after the First World War. That he exercised tact in his efforts to repair ties with the former 'Central Powers' is clear from his election in 1920 – when feeling was running high on this subject – as corresponding member of the Académie Française.

To disseminate the results achieved in Leiden rapidly, Onnes launched the laboratory's own journal: the *Communications*. After Onnes's death, the British physicist Freeth wrote that this mode of publication had actually prevented the work done in Leiden from becoming as well known as it merited, but this seems questionable. Not only did the Leiden laboratory attract countless foreign visitors, but the *Communications* reached libraries and individual researchers in numerous countries. Anyone who wrote to supervisor Keesom (later Woltjer) asking for specific issues received them promptly by mail. For the English translation of the Academy articles (which made up the vast majority of each issue), Onnes relied on the help of foreign guests.

Customary practice regarding the authorship of articles emanating from Leiden changed over the years. As a rule, Onnes was named as author or co-author if he had initiated the project, for instance by formulating the research question. After 1910, assistants who were put to work making measurements were generally named as co-authors. That Holst (later the director of Philips' research laboratory) had to content himself with a few words of thanks for services rendered in the discovery of superconductivity was rather meagre even then, but to have credited him with the discovery because he saw the needle of an ampèremeter move in a room down the corridor would have been going too far. It was Onnes, after all, who had taken the initiative to measure the resistance, and who had included mercury in the programme because of its purity.

In the world of Dutch physics, Heike Kamerlingh Onnes was the first to have a chair in purely experimental physics. His contacts with fellow physicists were friendly but limited, and were largely confined to the monthly meetings of the Academy of Sciences. His closest relationships were with Van der Waals in Amsterdam, and with his friend Lorentz in Leiden. With Ehrenfest, a temperamental man with a wicked sense of humour, Onnes had little in common. Through Haga, another friend, Heike regularly took on assistants from Groningen. Amsterdam too supplied him with talented researchers, including Keesom. Leiden had more places than elsewhere, and if there were too few candidates, Onnes regularly asked foreign departments for recommendations.

Although Onnes's inaugural address had outlined plans for a wide-ranging physics laboratory, he soon became aware of the need to specialise. The limited number of assistants, if nothing else, made choices unavoidable, and added to the expensive apparatus needed to perform research that would meet the highest international standards, self-limitation was the obvious solution. Other laboratories too chose to specialise. While Leiden focused on low-temperature thermodynamics, Amsterdam specialised in magneto-optics (Zeeman) and high-pressure thermodynamics (Kohnstamm and Michels). Groningen (Haga) opted for research with X-rays, and Utrecht (Julius) worked on the intensities of spectral

lines. This development towards greater specialisation called for closer ties between departments. At the Dutch Physics and Medical Science Conference of 1897, it was Onnes who urged that separate meetings be organised for physicists. At the 1921 conference, the nation's leading physicists (including Onnes) took the initiative to found the Dutch Physics Society.

The majority of Onnes's students found employment within the field of science. A total of 22 assistants gained PhDs under his supervision. Schalkwijk, Keesom, Meilink and Dorsman all wrote PhD theses on measurements taken in Leiden, but under Van der Waals's supervision because they had gained their Master's degrees in Amsterdam; Holst was awarded his PhD in Zürich for the same reason. For purposes of comparison: in Amsterdam, Van der Waals had a total of 28 PhD students in the period 1878-1926, but four of them were really Onnes's students, and about half were engaged in theoretical research. Zeeman had 16 PhD students until 1926 (and another 14 from 1926 to 1943), while Sissingh and Kohnstamm in Amsterdam, Haga in Groningen and W.H. Julius in Utrecht had only a handful of people working on doctorates in experimental physics. The absolute record was held by Julius's successor Ornstein, who had 94 PhD students, but that was a generation later.

If we count everyone who co-authored a publication with Onnes, we come to forty students.²² Fifteen of these went on to become professors (two in Bandung

²² Overview of those who worked under Kamerlingh Onnes, in chronological order of the commencement of their duties at the Physics Laboratory. The list includes the year of their PhD and the supervising professor (where appropriate), their main research topic and their later position.

R. Sissingh, 1885 (Heike Kamerlingh Onnes), reflection of light in metal mirrors and the Kerr effect; professor in Amsterdam.

L.M.J. Stoel, 1891 (Heike Kamerlingh Onnes), internal friction; director of the HBS in Veendam.

J.P. Kuenen, 1892 (Heike Kamerlingh Onnes), mixtures; professor in Leiden.

P. Zeeman, 1893 (Heike Kamerlingh Onnes), Kerr effect; professor in Amsterdam.

E.C. de Vries, 1893 (Heike Kamerlingh Onnes), capillarity; teacher.

L.H. Siertsema, 1890 (Haga, Groningen), magnetic rotation of the plane of polarisation; professor in Delft.

C.H. Wind, 1894 (Haga, Groningen), Kerr effect; director of the KNMI, professor in Utrecht.

M. de Haas, 1894 (Heike Kamerlingh Onnes), internal friction; professor in Delft.

A. Lebret, 1895 (Heike Kamerlingh Onnes), Hall effect; industry.

E. van Everdingen, 1897 (Heike Kamerlingh Onnes), Hall effect; head of KNMI and professor in Utrecht.

A. van Eldik, 1898 (Heike Kamerlingh Onnes), capillarity; life insurance.

C.M.A. Hartman, 1899 (Heike Kamerlingh Onnes), mixtures; KNMI.

J.C. Schalkwijk, 1902 (Van der Waals, Amsterdam), isotherms of hydrogen; director of the HBS in Leiden.

J.E. Verschaffelt, 1899 (Heike Kamerlingh Onnes), capillarity, mixtures; professor in Brussels and Ghent.

W.H. Keesom, 1904 (Van der Waals, Amsterdam), mixtures; professor in Utrecht and Leiden.

in the Dutch East Indies), five ended up in meteorology, eight became teachers (four of whom became HBS directors), eight gravitated to industry (five of whom worked at the NatLab, Philips). One assistant died young, and Onnes's three female assistants (Jolles, Smid and Van der Horst) all married before completing their PhD training and gave up their careers. In 1922, when Onnes was celebrating his jubilee year, his colleague, Professor Kuenen, had just died, Sissingh and Zeeman were in Amsterdam, W.J. de Haas in Groningen, M. de Haas and Siertsema in Delft, Keesom in Utrecht, Verschaffelt in Ghent, and Clay had a position in Bandung. Of the professors of experimental physics working in the Netherlands at that time, only Utrecht lay outside Leiden's sphere of influence.

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- B. Meilink, 1904 (Van der Waals, Amsterdam); director of the HBS in Arnhem.
- C.A. Crommelin, 1910 (Heike Kamerlingh Onnes), inert gases, deputy director of the Physics Laboratory, Leiden.
- J. Clay, 1908 (Heike Kamerlingh Onnes), resistance thermometers; professor in Bandung and Amsterdam.
- C. Braak, 1908 (Heike Kamerlingh Onnes), isotherms of hydrogen; director of the magnetic and meteorological observatory in Batavia.
- T.C. Jolles, Gibbs surfaces.
- G.H. Fabius, 1908 (Heike Kamerlingh Onnes / Kuenen), critical phenomena of carbonic acid; director of the HBS in Bussum.
- W.J. de Haas, 1912 (Heike Kamerlingh Onnes), isotherms of hydrogen; professor in Delft, Groningen and Leiden.
- E. Oosterhuis, 1911 (Haga, Groningen), magnetism; NatLab Philips.
- C. Dorsman, 1908 (Van der Waals, Amsterdam), internal friction; director of life insurance company.
- S.W. Visser, 1913 (Kuenen), butane; assistant director of the magnetic and meteorological observatory in Batavia.
- G. Holst, 1914 (Weiss, Zürich), thermometry, ammonia and methyl chloride; director of NatLab Philips.
- H.A. Kuypers, 1924 (Heike Kamerlingh Onnes), isotherms of oxygen; teacher.
- E.I. Smid, 1914 (Kapteyn, Groningen), isotherms of hydrogen.
- P.G. Cath, 1917 (Heike Kamerlingh Onnes), thermometry, neon; NatLab Philips.
- H.R. Woltjer, 1914 (Zeeman, Amsterdam), magnetism; professor in Bandung.
- H. van der Horst, thermometry.
- W. Tuyn, 1924 (Heike Kamerlingh Onnes), superconductors; Physics Laboratory.
- T. van Urk, 1924 (Heike Kamerlingh Onnes), mixtures; NatLab Philips.
- F.M. Penning, 1923 (Heike Kamerlingh Onnes), isotherms of hydrogen and helium; NatLab Philips.
- L.C. Jackson, 1923 (Heike Kamerlingh Onnes), paramagnetism; professor in Bristol.
- G.P. Nijhoff, 1928 (Keesom), isotherms of oxygen, magnetic and meteorological observatory, Batavia.
- J.D.A. Boks, 1924 (Heike Kamerlingh Onnes), equation of states, helium; director HBS Leiden.
- F.P.G.A.J. van Agt, 1925 (Keesom), thermometry; teacher.
- G.J. Sizoo, 1926 (De Haas), superconductivity; professor at the Free University, Amsterdam.
- A.C.S. van Heel, 1925 (De Haas), low-temperature optics; professor in Delft.
- W. van Gulik, melting curve of hydrogen.

With his Big Science approach, his carefully orchestrated research programme, in which, instead of working individually, everyone contributed to a team effort in pursuit of a well-defined goal, Onnes set an example that other laboratories later emulated. But Onnes's influence should not be overstated. For instance, all his vigorous lobbying could not get Van der Waals Jr (his father's successor in Amsterdam) elected as a member of the Academy. His direct influence reached further in international circles. He belonged to the scientific committee of the Solvay Institute, and was deputy director of the International Association of Refrigeration. These positions gave him an international reputation as *monsieur zéro absolu*, and they generated revenue for the cryogenic laboratory. Leiden's unique position attracted numerous researchers who wanted to perform measurements in the temperature range of liquid hydrogen or lower. Over thirty foreign researchers (a third of whom were professors) came to Leiden to conduct cryogenic research,²³ and many times more visited the Steenschuur laboratory to see the cryogenic installations with their own eyes.

Heike invested all his energy in his laboratory. The only other thing that mattered to him was his family. After his father's death in 1880, he resolutely took over his role (as the eldest son) as the head of the family. Heike, who had often scored top marks for drawing at the HBS, took a fatherly interest in the artistic development of his brother Menso, made sure that Onno ended up with a good position, and kept the family's social status in good stead. In the year 1881-1882 – a disaster year aside from Onnes's appointment in Leiden – with the brickworks in Feerwerd near bankruptcy, and both Menso and Onno falling ill and having to leave immediately to spend months recovering abroad, it was Heike whose organisational talents helped the family get through this difficult period. His mother, brother Menso and sister Jenny all moved in with him in Leiden to save money. At length, the situation was saved by a series of advantageous marriages: alliances were formed with the daughter of the Advocate-General in The Hague (Betsy Bijleveld), a scion of a patrician family from Amsterdam (Kitty Tutein Nolthenius), and the son of the equally wealthy steward of Rhineland Water Board (the painter Floris Verster). Thus the Kamerlingh Onnes family – as the other members of the family starting

²³ The following foreign researchers worked in Leiden for varying periods of time: A.W. Gray, L.I. Dana, G. Breit (US); J.E. Verschaffelt (gained PhD under Onnes), C. Nicaise, J. Timmermans (Belgium); A.L. Clark (Canada); S. Weber (Denmark); E. Cohn, M. Reinganum, W. Heuse, H. Happel, W.E. Pauli, P. Lenard (Germany); H.H.F. Hyndman, J.P. Dalton, T. Verschoyle, L.C. Jackson (PhD under Onnes), J.C. Swallow (UK); M. Boudin, J. Becquerel, H. Becquerel, E. Mathias, Marie Curie (France); L. Vegard (Norway); F. Hasenöhr (Austria); C. Zakrzewski, M. Wolfke (Poland); J. Palacios Martinez (Spain); B. Beckman, A. Beckman (Sweden); P. Weiss, A. Perrier, K. Hof (Switzerland).

calling themselves, emulating Heike – recovered its former position in society. Huize ter Wetering, expanded on the basis of a taut design by Menso, became the meeting place of an artistic family, a place that breathed a cosmopolitan atmosphere, thanks to the numerous foreign guests who came to stay there, such as Bohr, Einstein, Madame Curie, and Ramsay.

Heike Kamerlingh Onnes drove his people like the wind drove the clouds, said Pieter Zeeman. The amazing thing is that a frail boy who missed a whole school year through illness when he was eleven (and sat at home reading Plutarch) and who was compelled to go to the Alps every summer for a health cure throughout his life, nonetheless possessed the energy and endurance to set up a large-scale enterprise such as his cryogenic laboratory and to make it such a great success. Helped by his wife, Betsy, Heike was able to focus his limited energy on that one goal. It is true that his programme made no provision for trying things out on impulse, but frivolities of that kind would never have produced liquid helium.

Epilogue: the Kamerlingh Onnes Laboratory

It was up to Willem Keesom and Wander de Haas to preserve the heritage of Heike Kamerlingh Onnes. They had a superb point of departure from which to start doing so. Not only did they have an extensive, newly renovated laboratory at their disposal, but thanks to the extremely generous gift of the Rockefeller Foundation (\$100,000 over ten years) for the purchase of instruments and the extra government grant (rising to 10,000 guilders a year from 1928 onwards) for the appointment of researchers to use the new equipment, they were off to a flying start.

Their efforts did not go unrewarded: Keesom scored an immediate success in the spring of 1926 by producing solid helium. This was a piece of good fortune, but the crucial idea (cooling liquid helium under high pressure) had been suggested to him the year before, by the Polish guest researcher Wolfke. And after the news reached the Malabar observatory in the Dutch East Indies, Karel Bosscha (the man who had once helped Heike to adjust his first pumps, and without whose generous donation the Bosscha reading room could not have been founded) wrote to Lorentz that he had suggested using high pressure to Onnes in 1921, when the latter had pushed the ‘cold record’ to new depths at 0.8° above absolute zero.¹

The identification of the so-called lambda transition in liquid helium at 2.19 K, and of the two related types of helium (I and II) with different properties, was one of the highlights of Keesom’s early years as director.² Together with his daughter Anna Petronella, Keesom determined many of these properties in the 1930s. In 1936 they discovered that helium II was a ‘super-heat-conductor’.³ Shortly afterwards, a whole series of strange effects were discovered in helium II at foreign laboratories.

¹ K.A.R. Bosscha to Lorentz, 1 October 1926, N-HA, Lorentz archives, inv. no. 9.

² W.H. Keesom and M. Wolfke, ‘Two different liquid states of helium’, KNAW, Proceedings, 31, 1928, Amsterdam, 1928, pp. 90-94. *Comm.* 190b.

³ W.H. Keesom and A.P. Keesom, ‘On the heat conductivity of liquid helium’, *Physica* 3 (1936) 359-360. *Comm.* 242g.

It took De Haas more time to achieve a notable breakthrough. In May 1933, a year after his team had officially started working with the large electromagnet, he managed to reach a temperature of 0.27 K, using adiabatic demagnetisation.⁴ That demolished Leiden's 'cold record' which Keesom had established in February 1932 (by pumping out liquid helium even more vigorously than Onnes had done in 1921) at 0.71 K.⁵ But unfortunately for De Haas – whose achievement was to a large extent the work of his assistant Eliza Cornelis Wiersma, with the theorist Hans Kramers also playing a notable role – the University of California had got there first. Further, in fact. A month earlier, on 12 April 1933, William F. Giauque (an electrical engineer from Canada) had announced that he had reached 0.25 K in Berkeley three days earlier.⁶ It must have been a great disappointment for Leiden, although De Haas reclaimed the record for cold on 7 July, with 0.08 K.⁷

Adiabatic demagnetisation as a cooling technique was proposed in 1926 by two scientists (independently of one another): William Giauque and Peter Debye (who was then a professor in Göttingen). It works like this. When a paramagnetic salt crystal (De Haas initially used the expensive cerium fluoride) is placed in a magnetic field (30 kilogauss with the large magnet) at a very low temperature (1 K), the magnetic axes of the atoms in the crystal lattice become aligned. The heat that is released is removed by bringing the crystal into thermal contact with liquid helium. If the magnetic field is then switched off, and if the crystal has by then been isolated from the surroundings (by pumping the helium out), the minute atomic magnets come 'unstuck' to some extent (demagnetised). That costs energy, which cannot be supplied from outside (adiabatic system), so that the crystal is forced to extract the heat from itself, thus cooling the salt.

So for a short time in 1933, Leiden was no longer the coldest place on earth. The Kamerlingh Onnes Laboratory, as the complex at Steenschuur had been named the year before, had to fend off more and more cryogenic competition. The monopoly on liquid helium was broken in 1923 by McLennan in Toronto, but after that the Canadian did not pose any further threat. This did not apply, however, to Meissner's laboratory in Berlin, which had liquid helium in 1925. Kharkov, in the Ukraine, succeeded in 1930. A year later, the National Bureau of Standards in Washington D.C., in the United States, won the race from Berkeley, which produced its first liquid helium in 1933 under the leadership of

⁴ W.J. de Haas and E.C. Wiersma, *Nature* 131 (20 May 1933) 719.

⁵ *Leidsch Universiteitsblad*, vol. 1, no. 9, 20 April 1932.

⁶ W.F. Giauque and D.P. MacDougall, *Physical Review* 43 (1 May 1933) 768.

⁷ W.J. de Haas, E.C. Wiersma and H.A. Kramers, 'Experiments on adiabatic cooling of paramagnetic salts in magnetic fields', *Physica* 1 (1933-34) 1-13. *Comm.* 229a.

Giauque – and immediately achieved another success in its application of adiabatic demagnetisation. That same year, the Clarendon Laboratory in Oxford too started producing liquid helium (Kurt Mendelssohn, who had fled from Nazi Germany, had taken a small liquefier with him from Breslau), followed in 1934 by the Mond Laboratory in Cambridge (designed by Peter Kapitza). When Kapitza was detained by Stalin while visiting his homeland later that year, he made a virtue of necessity and Moscow too acquired liquid helium. Research into superconductivity, superfluid helium and adiabatic demagnetisation was an international field of endeavour.

There is nothing intrinsically dramatic about losing the ‘cold record’ to another laboratory; it is the phenomena exhibited by a newly unlocked cryogenic area, and the interpretations placed upon them, that are truly interesting. Still, with the proliferation of cryogenic successes in the 1930s, the Kamerlingh Onnes Laboratory gradually lost its dominant position. It remained an international centre of low-temperature research, however, and the teams working under Keesom and De Haas achieved major advances. Guest researchers contributed substantially to these efforts. One was the Leningrad-trained Lev Shubnikov, a master in the making of mono-crystals. He and his wife and fellow physicist Olga Trapeznikova came to Leiden in the early 1930s and stayed for four years; he produced bismuth crystals of a very high standard of purity and determined their resistance in a magnetic field.⁸ (On his return to the Soviet Union, he fell victim to Stalin’s Terror in Kharkov). Periodic fluctuations in this magneto-resistance as a function of temperature are known as the Shubnikov-De Haas effect. Pieter van Alphen, one of De Haas’s PhD students, subsequently studied the diamagnetism of bismuth, which turned out to fluctuate as a function of the magnetic field at very low temperatures: the De Haas-Van Alphen effect.⁹

Fine physics, but a number of really important discoveries (the Meissner effect, superfluidity) were missed. How was this possible, given the laboratory’s enormous experience? One explanation might be that dividing the laboratory into two autonomous departments – cryogenic work and thermodynamics under Keesom, and magnetic, electrical and optical research under De Haas, had an adverse effect. Fragmentation seems unlikely to boost effectiveness. Even in

⁸ L.W. Schubnikow and W.J. de Haas, ‘A new phenomenon in the change of resistance in a magnetic field of single crystals of bismuth’, *Nature* 126 (4 October 1930) 500; L.W. Schubnikow and W.J. de Haas, ‘Neue Erscheinungen bei der Widerstandsänderung von Wismuthkristallen im Magnetfeld bei der Temperatur von flüssigem Wasserstoff’, *Proceedings* 3 (1930) 363–378. *Comm.* 207d and 210a.

⁹ W.J. de Haas and P.M. van Alphen, ‘Notitie over de afhankelijkheid van de diamagnetische susceptibiliteit van metalen van het magnetisch veld’, *Proceedings* 33 (1930) 680–682 and 1106–1119. *Comm.* 208d and 212a.

Onnes's days, the large part played by foreign guest researchers (with highly diverse projects) had undermined Keesom's progress in his thermodynamic work. The influx of guests continued after Onnes's death. To prevail, one has to have a team that is large enough to make rapid progress and that projects a unified image. Casimir, who returned to Leiden in 1933 from Zürich, where he had been Wolfgang Pauli's assistant, and served as supervisor of the magnetic and electrical department until 1942, when he left to work for Philips, regarded the contributions made by Keesom and his school and those of De Haas and his school as 'a single cohesive whole'.¹⁰ Nonetheless, the question remains of whether a construction with two directors of equal standing, each holding sway over a handful of assistants, was the right way to stay ahead of the international competition. In 1933, the year in which Giauque scored his success with adiabatic demagnetisation, Leiden suffered a second disappointment: De Haas and his assistant Josina Jonker (Casimir's wife) had just completed the measuring set-up to investigate the frozen-field hypothesis when Meissner produced his discovery that superconductors exclude magnetic fields.¹¹

Another unhelpful circumstance was that there was no love lost between the two directors. It was a case of incompatible temperaments. Keesom was a second Onnes (albeit duller and less creative), thoroughly sound and reliable, a lover of huge measuring programmes. De Haas, whose fine intuition in physics made up for a somewhat less solid mathematical background, was far more capricious. He was a man of madcap impulses and clever tricks, someone who worked on his experiments at night-time with his laboratory assistant (Van de Starre) so as not to be disturbed.¹² These divergent personalities clashed, besides which the atheist De Haas had an aversion to Keesom's Catholic piety. What made matters worse was De Haas's habit of swallowing his fury during discussions, and instead ventilating it to members of his team or students afterwards. His views would eventually find their way to Keesom indirectly, creating ill-will. Keesom was now in charge of the cryogenic installations, and the distribution of the scarce helium supplies was one of the sources of friction.¹³

As far as adiabatic demagnetisation was concerned, De Haas and Wiersma improved their 'cold record' to 0.0044 K in 1935.¹⁴ After the Second World

¹⁰ Casimir, *Haphazard Reality*, 174-175.

¹¹ W.J. de Haas and J.M. Casimir-Jonker, 'Untersuchungen über den Verlauf des Eindringens transversalen Magnetfeldes in einem Supraleiter', *Physica* 1 (1934) 291-296. *Comm.* 229d.

¹² Interview H.A.L. de Haas, 21 June 1990.

¹³ Interview H.B.G. Casimir, 11 July 1990.

¹⁴ W.J. de Haas and E.C. Wiersma, 'Adiabatic demagnetisation of some paramagnetic salts', *Physica* 2 (1935) 335-340. *Comm.* 236b.

War, C.J. Gorter, who became sole director of the Kamerlingh Onnes Laboratory in 1948, conceived the idea of applying adiabatic demagnetisation to atomic nuclei. But he was unfortunate in his choice of sample and Leiden lost to Oxford, where Franz (Francis) Simon attained a temperature of 0.000016 K in 1956. From then on, the coldest place on earth was never again in Leiden.

After the death of Lorentz in 1927, Leiden's theoretical physics was entirely in the hands of Paul Ehrenfest, a man who suffered from constant self-criticism and a lack of self-confidence, a fear that he could no longer keep up with developments in physics at the level he deemed to be necessary. In September 1933, his depression became so intolerable that he committed suicide, shooting first his mentally handicapped son and then himself. A year later, Ehrenfest was succeeded by Hans Kramers. When this celebrity died in 1952, Casimir, who was then one of the directors of Philips's NatLab, was asked whether he would be interested in returning to Leiden. 'Kramers died in 1952 and I might have become his successor', wrote Casimir in his autobiography. 'But when I went to have a look at the Institute of Theoretical Physics at Leiden I felt depressed. The old rooms, the old library, were almost exactly as they used to be, without new life, without any indication of growth. There was hardly any administrative assistance, there were only very limited funds for travelling and for inviting lecturers from abroad. It was returning to a past I had liked but that should be changed, and I had been too much part of that past to be able to effect the change.'¹⁵ The great days of Lorentz and Ehrenfest were over, and gifted researchers such as Uhlenbeck and Goudsmit opted for a career in the United States; Casimir elected to stay at Philips.

When the Rockefeller Foundation's injection of funds finally came to an end after the Second World War, a new benefactor immediately presented itself. The NV Bataafsche Petroleum Maatschappij donated a million guilders to the Kamerlingh Onnes Laboratory to increase the capacity of its cryogenic installations. In addition, an installation for strong magnetic fields was set up in the basement and the glass-blowing facilities were expanded and moved. These expanded facilities became operational in 1952.¹⁶ In the meantime, physiology, which had been scheduled to move to the new site of the academic hospital since the 1930s, was still occupying premises on Zonneveldstraat. The problem (lack of money) was finally solved in 1960, and demolition work started on the old physiology laboratory. In its place rose a cement structure (floated in the groundwater to minimise interference from vibrations) with the Lorentz Institute of Theoretical Physics on the top floor. Relics of

¹⁵ *Op. cit.* note 10, 279-280.

¹⁶ *De modernisering van het Kamerlingh Onnes Laboratorium te Leiden* (Leiden 1952).

the old institute, such as the wooden 'Lorentz gate' with its iron fixtures, crowned by a likeness of Lorentz in stone with an owl, and the wall of signatures of those who had lectured at the colloquia Ehrenfestii (including those of Einstein, Heisenberg, Oppenheimer and Planck), were transferred to the new building on Zonneveldstraat.

The beginning of the end of the Kamerlingh Onnes Laboratory was signalled in the early 1970s by the building of the Huygens Laboratory on grassland outside the city, in an area known as the Leeuwenhoek polder. It accommodated the departments of astronomy, astrophysics, cosmic radiation, molecular physics and biophysics as well as the physics laboratories. The official opening was in May 1976, with Casimir making the official speech. Not long afterwards, while environmental science and law were appropriating surplus space at the Kamerlingh Onnes Laboratory, more and more voices were raised in favour of relocating the entire physics department to the Leeuwenhoek site. In 1997, the Leiden instrument-makers' school moved into a new building behind the Huygens Laboratory, cementing the gradual parting of the ways between the training course and the laboratory.

Immediately in front of the Huygens Laboratory rose the J.H. Oortgebouw, with the Lorentz Institute, while the adjoining vibration-free measuring hall was proclaimed the new Kamerlingh Onnes Laboratory. On the ground floor of the Oortgebouw, the festive opening of which was attended by members of the Kamerlingh Onnes family, historical objects from the old location were assembled, including a helium liquefier (the one used in 1908 is in Museum Boerhaave), a Burckhardt vacuum pump dating from 1899, a water-cooled electromagnet, the Zeeman windows, and the wall of signatures.

It was not easy to find a new use for the old complex, which the passage of time and a lack of maintenance had given an air of decrepitude. Various options were considered and rejected: the herbarium could be moved there; the building could be transformed into a Grand Hotel, the site would be used for luxury apartments. In the end, the Steenschuur location was chosen as the new premises of the law faculty (which was languishing in the old organic and inorganic chemistry laboratories in Vreewijk). After drastic restoration and renovation – the little annexes along Langebrug and the original anatomy wing were pulled down, the courtyard was roofed over and the old main entrance reinstated – Prince Constantijn performed the official opening of the Kamerlingh Onnes Building, as the complex was renamed, in 2004.

Six years earlier, the physicists had held a special ceremony to mark their departure from the famous old laboratory. Again it was Casimir who spoke: 'Farewell my great lecture-hall, welcome a new master.'

The Kamerlingh Onnes Laboratory is no more: Long live the Kamerlingh Onnes Laboratory! A name like that, with all the glory and rich history that it

evokes, should be cherished. This view was shared by an international assessment committee that screened Leiden's physics department in 2002 (and awarded high marks to experimentalists and theorists alike). 'In contrast to physical infrastructure', wrote the committee, 'well-known names of institutes remain an asset even if they no longer reflect the organisational structure of the departments. These names should remain visible to the outside world.'¹⁷

Physicists still do ground-breaking experiments at temperatures close to absolute zero at the Kamerlingh Onnes Laboratory. One example is the quest for the gravitational waves predicted by Einstein using a massive copper ball fitted with resonators that these waves set vibrating. And the experimental physicist Dirk Bouwmeester, who was recently appointed in Leiden and is an expert on quantum computers and teleportation, is working on an experimental set-up intended to demonstrate that at intensely cold temperatures, a minuscule mirror can be in two places at once. Exciting research with enormous imaginative appeal, which – if successful – will do credit to the name of Kamerlingh Onnes.

¹⁷ *Research Assessment Applied Physics Delft University of Technology – Physics Leiden University* (2003) 30.

Glossary

- Absolute zero* – lowest possible temperature; 0 kelvin (0 K) = -273°C (to the nearest degree).
- Adiabatic demagnetisation* – cooling technique whereby a paramagnetic substance and a magnetic field are used to produce extremely low temperatures.
- Allotropy* – the same substance occurring in diverse crystal structures in (e.g. graphite and diamond).
- Barotropic effect* – the sinking of a gas in a liquid, e.g. compressed helium gas in liquid hydrogen.
- Boiling flask* – receptacle in which a gas expands and hence condenses into a boiling liquid.
- Cailletet compressor/pump* – pump with a mercury piston, which preserves the purity of the gas to be pumped out.
- Cailletet tube* – narrow tube containing gas under high pressure; when pressure is released through a small opening, cooling occurs.
- Calorimetry* – experiments (specific heat, evaporation heat) with calorimeters: canisters containing the substance to be studied, equipped with a heating wire and an electrical thermometer.
- Capillary* – narrow tube with an absorbent effect.
- Cascade* – multistage method of attaining low temperatures; the final temperature attained in one stage serves as the starting point for the next.
- Continuity* – the absence of a fundamental difference between a vapour and a liquid.
- Critical temperature* – temperature, different for every substance, above which only the gaseous state is possible.
- Cryogenic* – cold.
- Curie's Law* – formulates a relationship between the magnetic susceptibility of a substance and its absolute temperature.
- Dewar flask* – double-walled glass vacuum flask with excellent heat insulation.
- Dielectric constant* – property of a substance indicating its receptivity to an electric field.
- Diffusion* – the spontaneous mixing of different gases or liquids.
- Empirical equation of state* – a relationship established experimentally between pressure, volume and absolute temperature.
- Entropy* – measure of the lack of order (number of possible states) in a system.
- Equation of state* – relationship (e.g. the equation of state formulated by Van der Waals) between pressure, volume and temperature.
- Evaporation heat* – the quantity of energy that is required to evaporate 1 kilo of a liquid.
- Expansion valve* – valve that can be opened to allow compressed gas to escape, resulting in cooling.
- Ferromagnetism* – state in which the atoms in a crystal become miniature magnets that align themselves in the same direction.

First Law of Thermodynamics – a closed system is governed by the principle of the conservation of energy.

Galvanometer – sensitive ampèremeter (used to determine the strength of an electrical current).

Gas holder – receptacle for gases.

Gas thermometer – thermometer based on the change in pressure in a gas in a glass bulb.

Gauss – unit of strength of a magnetic field.

Gibbs surface – three-dimensional graph, with entropy and volume plotted in the horizontal plane and free energy vertically.

Hall effect – when an electrical current is passed through a block of metal, an electrical potential arises between the sides under the influence of a magnetic field.

Hysteresis – the phenomenon whereby the graph of e.g. electrical resistance is different when the magnetic field is being increased than when it is being reduced.

Inversion temperature – temperature below which the expansion of a compressed gas through a porous plug leads to a fall in temperature.

Isotherm – graphic relationship between pressure and volume at constant temperature.

Joule-Thomson effect – temperature change in a compressed gas flowing through a porous plug.

Kerr effect – optical phenomenon whereby the direction of polarisation of a ray of light (the plane in which the light wave oscillates) changes when it is reflected in a magnetised metal mirror.

Kinetic theory of gases – theory conceiving of a gas as a collection of molecules that are constantly hurtling past each other and colliding.

Law of Corresponding States – when pressure, volume and temperature are expressed in a critical measure, all substances behave in the same way.

Liquefactor – appliance used to condense a gas into a liquid.

Magnetic susceptibility – measure of the influence exerted by an external magnetic field on a substance.

Magneto-optical – optical effect caused by magnetism.

Micro-residual resistance – the minute electrical resistance that was believed (at an early stage) to persist in the superconducting state.

Molecular field hypothesis – hypothesis concerning the electrical field between the atoms in a crystal, formulated to explain magnetic phenomena.

Monazite sand – mineral containing thorium, from which helium arises as a result of radioactive decay.

Nernst's Theorem – see Third Law of Thermodynamics.

Ohm's Law – Electrical resistance equals voltage divided by current.

Opalescence – colour-dependent scattering of light by a liquid.

Paramagnetism – the minute atomic magnets in a crystal lattice become disordered by changes in temperature (oscillations around their state of equilibrium); they can be (partially) realigned by applying an external magnetic field.

Persistent current – a current that persists in a superconducting circuit, even if there is no source of electrical energy.

Polarisation – light that oscillates in a specific plane.

Psi-surface – three-dimensional graph for a mixture of two substances, where volume and the proportion between the two substances are plotted horizontally and free energy vertically.

Quantum theory – theory developed in the early 20th century, the basic principle of which is that radiation energy is not exchanged with matter in random quantities but in discrete parcels of energy.

Regeneration – principle whereby the expanded gas in a cyclical system cools the incoming gas on its way back.

Resistance thermometer – thermometer based on the variation in the electrical resistance of a material at different temperatures.

Retrograde condensation – effect whereby liquid is produced in a mixture through expansion.

Second Law of Thermodynamics – a closed system will strive to achieve maximum entropy.

Specific heat – the quantity of energy required to cause 1 kilo of a substance to rise in temperature by 1°C.

Spectral line – every substance emits characteristic colours when it is heated; this creates a spectral line that can be observed, e.g. through a prism.

Superconductivity – below a certain temperature ('jump point'), the electrical resistance of certain substances vanishes altogether.

Superfluidity – below a certain temperature, certain liquids (i.e. Helium) lose all internal friction (viscosity) and flow freely through even the narrowest of apertures.

Susceptibility – see magnetic susceptibility.

Thermodynamics – science of heat.

Thermo-element – measures the electrical potential that arises between the points of contact between two metals, when there is a difference in temperature between these points.

Thermometry – practical and theoretical matters relating to the measurement of temperatures.

Third Law of Thermodynamics – As a system approaches absolute zero, the entropy of the system tends to zero.

Threshold current / field – the strength of an electrical current / magnetic field above which a superconducting wire acquires resistance again.

Virial coefficient – constant in the equation of state.

Volumenometer – appliance used for the accurate measurement of volumes.

Wheatstone bridge – electrical circuit including e.g. a temperature-dependent resistance.

Zeeman effect – splitting of a spectral line under the influence of a magnetic field.

Zero-point energy hypothesis – hypothesis assuming that particles possess a quantity of residual energy at absolute zero.

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Chronology

1819		birth of father, Harm Kamerlingh Onnes
1829		birth of mother, Anna Gerдина Coers
1837		birth of Johannes Diderik van der Waals, Leiden
1853,	21 September:	birth of Heike Kamerlingh Onnes, Groningen
	18 July:	birth of Hendrik Antoon Lorentz, Arnhem
1851		Harm opens brickworks in Feerwerd
1860		birth of brother Menso
1863		Thorbecke's Secondary Education Act, introduction of 'Hogere Burger School' (HBS)
1863-1864		Pre-gymnasium
1865-1870		State HBS Groningen
1870-1876		Student at Groningen University
1871		gold medal for competition set by Utrecht University
1871(Nov.)-1873 (Apr):		student in Heidelberg under Bunsen and Kirchhoff
1872		silver medal for competition set by Groningen University
1873,	July:	Van der Waals's equation of state
1875-1876		president of Groningen student fraternity, Vindicat Atque Polit
1876,	March:	Higher Education Act
	June:	awarded Master's degree in physics
1877		Van der Waals appointed professor of physics in Amsterdam
		Lorentz appointed professor of theoretical physics in Leiden
	December:	Cailletet and Pictet make dynamic liquid oxygen in Paris and Geneva
1878-1882		assistant in Delft under Bosscha
1879,	10 July:	PhD thesis <i>Nieuwe bewijzen voor de aswenteling der aarde</i>
	August:	Van der Waals's Law of Corresponding States
	October:	death of father Harm
1881		General Theory of Liquids
1882		September: appointed professor in Leiden
	11 November:	inaugural address, 'knowledge through measurement'
1883	February:	sick leave, Lorentz takes over large lecture until 1907
	April:	joins Academy of Sciences
	April:	Wroblewski and Olszewski make static liquid oxygen in Cracow
	September:	Onnes family settles in Leiden
1885		first edition of the <i>Communications</i> published
1887		inauguration of the Dutch Physics and Medical Science Conference
	8 September:	marries Betsy (Bé) Bijleveld

1888		birth of Albert Harm
1891		Van der Waals's theory of mixtures
1892,	17 June:	liquid oxygen
	June:	Kuener's discovery of retrograde condensation
	December:	invention of Dewar flask
1895		William Ramsay discovers helium on earth
1895-1898		cryogenic laboratory idle during licence dispute
1896		discovery of Zeeman effect
1898		James Dewar produces static liquid hydrogen
1899,	April:	death of mother Antje
1899-1906		board member of KNMI, De Bilt
1901		empirical equation of state with 25 constants
1902-1909		founding of Leiden's instrument-makers' training course
1902		member of board of governors, Leiden gymnasium
1903-1904		Zeeman and Lorentz awarded Nobel Prize
1904		rector of Leiden University
1904		commemorative volume, 25th anniversary of doctorate
1905,	June:	liquid hydrogen
1906		Einstein's quantum theory of specific heat
		Nernst's heat theorem
1907		Kuener appointed second professor of experimental physics
1908,	10 July:	liquid helium
	September:	founding of the Dutch Society of Refrigeration Technology
	October:	first international congress of refrigeration, Paris
1909		founding of the International Association of Refrigeration
1910,	October:	second international congress of refrigeration, Vienna
1911,	February:	first publication on specific heat by Nernst, Berlin
	April:	discovery of superconductivity
		death of Bosscha
	October:	first Solvay Conference, Berlin
		Van der Waals awarded Nobel Prize
1911-1914		Keesom working on zero-point energy
1912		departure of Lorentz for Haarlem; Paul Ehrenfest appointed as his successor
		<i>Die Zustandsgleichung</i> (together with Willem Keesom)
1913,	September:	second Solvay Conference
	September:	third international congress of refrigeration, Chicago
	November:	Nobel Prize
1914		launch of Philips NatLab, director Gilles Holst
1914,	April:	persistent current
1914-1918		First World War
1917		Departure of Keesom for Utrecht
1916		Chemistry laboratory leaves Steenschuur
1917-1923		renovation and expansion of laboratory
1920		Einstein professor by special appointment in Leiden
1921,	April:	third Solvay Conference
		Harm Kamerlingh Onnes makes Zeeman windows

- 1922, September: death of Kuenen
 November: commemorative volume for 40th anniversary professorship
- 1923
 June: McLennan, Toronto produces liquid helium
 Death of Van der Waals
- 1924
 fourth Solvay Conference
 fourth international congress of refrigeration, London
- September: retirement; Wander Johannes de Haas appointed as his successor
 Rockefeller Foundation donates \$100,000 to the laboratory
- 1925
 death of Menso
- 1926, 21 February: death of Heike Kamerlingh Onnes
- 1928
 death of Lorentz

Sources and abbreviations/ terms used in references to sources

Afd(eling) wis- en natuurkunde	Maths and physics division
Akademiearchief	Archives of the Academy
Almanak van het Leidsche Studentencorps	Leiden Student Almanac
Archief Akademie van Wetenschappen	Archives of the Academy of Sciences
Archief curatoren	Archives of the board of governors
Archief Rector Magnificus en Senaat	Archives of the rector and senate
Archief Senaat en Faculteiten	Archives of the senate and faculties
Begroting	Physics
Begroting natuurkunde	Physics budget
B&W	Municipal Executive (Burgemeester en Wethouders)
Bestelboekjes	Order books
BZ	Minister of the Interior (Binnenlandse Zaken)
Coll.	Collection of
<i>Comm.</i>	<i>Communications from the Physical Laboratory of the University of Leiden</i>
Curatoren	Board of governors
Faculteitsvergadering	Faculty meeting
Gemeentearchief	Municipal archives
Hoofdingenieur herstellingswerkplaats Rijkstelegraaf	Chief engineer of the state telegraph repairs workshop
Ingekomen stukken	Incoming correspondence
ISSG	International Institute of Social History (Internationaal Instituut voor Sociale Geschiedenis)
Jaarverslag natuurkunde	Physics dept. annual report
Jaarverslagen Natuurkundig Laboratorium	Annual reports, Physics Laboratory
K	Kelvin
KAW	Royal Academy of Arts and Sciences
KB	National Library of the Netherlands (Koninklijke Bibliotheek)
KNMI	Royal Dutch Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut)
Koningin-Weduwe Regentes	The Queen Regent
Leden universiteitsraad	Members of University Council

Leidsche Studenten-Almanak	Leiden Student Almanac
Leidsch Universiteitsfonds	Leiden University Fund
LUF	id.
Map vacature ...	File on ... vacancy
MB	Museum Boerhaave
Memorie van Toelichting	Explanatory Memorandum
Ministerie van Waterstaat, Verkeer en Nijverheid	Ministry of Water Management, Industry and Trade
NA	National Archives (Nationaal Archief)
Nederlandse Vereeniging voor Electrotechniek	Dutch Electrical Engineering Society
N-HA	Noord-Hollands Archief
Notitie	Memorandum
Notulen curatoren(vergadering)	Minutes of board of governors' meeting
Raad van State	Council of State
Rapport hoorzitting	Report of the hearing
Rijksbegroting	National Budget
Rijksbouwkundige	Government Architect
UB Leiden	Leiden University Library (Universiteitsbibliotheek Leiden)
Utrechts Archief	Utrecht Archives
Vereeniging tot bevordering van de opleiding tot instrumentmaker	Society to Promote the Training of Instrument-Makers
Verslagen zittingen KAW	Reports of the meetings of the Royal Academy of Sciences
Waterstaat, Verkeer en Nijverheid	Ministry of Water Management, Industry and Trade
Wis- en natuurkunde	Maths and physics

Bibliography

Abbreviations:

Comm.: Communications from the Physical Laboratory at the University of Leiden

Verslagen: Koninklijke Akademie van Wetenschappen, Verslagen van de gewone Vergaderingen der Wis- en Natuurkundige afdeling.

Proceedings: Idem, Proceedings of the Section of Sciences.

1^e Gedenkeboek RHBS Groningen 1864-1889 (Groningen 1889).

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