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and in order $\theta_{\rm H_1} - \theta_{\rm He}$ at -252° by 0,0000013 to that $u_v = 0,0036614$

The first value which has been derived without extrapolation and which is therefore the most reliable, appears to agree perfectly with the one derived by me from the isothermals in § 1.

With regard to the method of derivation followed here we may remark that it allows of a fairly large accuracy. Though the certainty of the determinations of temperature on which it is based may be doubted to the absolute value, yet the only difference which comes into account here is known with sufficient certainty. The calculation mentioned above therefore not only gives an explanation of the too large differences found by TRAVERS, SENTER and JACQUEROD, but is also a welcome control for the coefficient of pressure variation of helium found in section 1.

Physics. — "The absorption spectra of the compounds of the rare earths at the temperatures obtainable with liquid hydrogen, and their change by the magnetic field", by JEAN BECQUEREL and H. KAMERLINGH ONNES. Communication N^o. 103 from the Physical Laboratory at Leiden.

§ 1. Introduction. The investigations of one of us (J. B.) ') proved that the absorption spectra of the compounds of the rare earths, cooled down to the temperature of liquid air, may serve to acquire new data for the nature, the number, and the motion of the electrons which play a part in the formation of these spectra. So it seemed to us of great importance to continue these investigations at the temperatures obtainable with liquid hydrogen, which are so many times lower and seem particularly adapted 2) to reveal the forces which the ponderable substance exerts on the electrons. For this purpose the apparatus used at Paris for the observation of the spectra were conveyed to the cryogenic laboratory at Leiden, so that we were enabled to obtain some three hundred of spectrograms which represent the observed phenomena. The study of these photographs will take a long time; we shall therefore confine ourselves on this occasion to the communication of some facts which immediately draw the attention.

¹) JEAN BECQUEREL, Radium IV. 9, p. 328 and IV, 11, p. 385 (1907).

²) H. KAMERLINGH ONNES, The importance of accurate measurements at very low temperatures. Comm. of the phys. lab. of Leiden Suppl. no. 9, p. 25 sqq. (1904).

§ 2. Apparatus. In the first place a few words about the arrangement of the experiments. It was the same for the experiments without and with the magnetic field. The crystals, fixed with wax on a small piece of platinum foil a, $(a_2, a_3 \text{ fig. } 3^a, \text{Pl. I})$, which was carried by a rod a_4 , were immersed in liquid hydrogen in a double-walled tube (b fig. 2, fig. 3^a), which is the continuation of a non-silvered vacuum glass b_2 , which contained liquid hydrogen and which is surrounded by another double-walled (c_{10}, c_{20}) tube c, also the continuation of a non-silvered vacuum glass with liquid air, on which it rests on pieces of cork b_2 . A clearance of 1/2 mm. between the two glasses (fig 3^a) proved sufficient to allow the liquid air to circulate along the hydrogen tube. This protects the hydrogen so effectively from access of heat that the evaporation is insignificant, even when the two tubes are placed between the hot coils of the magnet and the crystal is exposed to strongly concentrated electric light.

The walls of the narrow part of the tubes are very thin, and because the radiation of heat is independent of the distance of the walls they have been brought to an exceedingly small distance from each other (0.5 mm.), but without being anywhere in contact. Owing to the skill of Mr. KESSELRING, glassblower of the laboratory, who succeeded in doing this, we had at our disposal a tube of 4 mm. inner diameter filled with liquid hydrogen, protected by a tube of liquid air, the outer diameter of which is no more than 8 mm., which allows us to bring the poles of the magnet so near together that very strong fields are obtained even with hollow poles.¹,

The hydrogen tube must be closed hermetically. For this purpose it is fastened in a cap, d, which may be adjusted by means of a levelling board, f, with screws and sliding groove. The tube is brought from below into the cap, where it rests against a wooden cylinder, within d_o (fig. 2), and it is fastened with a thin rubber ring e_1 , which lies round d_o doubled over and is turned down when the tube is put in. To ensure tightness a rubber solution is put between ring and glass, and the rubber is pressed tight against the glass and the cap with copper wire. The cap is provided with: 1. the tube d_{30} , to which at d_{31} a head with packing cap d_{32} is screwed, in which the rod a_6 can turn (by means of a_7), and move up and down (by means of the nut d_{33}). 2. a tube d_1 to siphon over liquid hydrogen as

¹) Instead of the usual poles of the WEISS magnet we have used auxiliary pieces, p_{30} (see figs. 2 and 3), which prolong the cone to a section of 6 mm. diameter, with conic perforations, which have a diameter of 3 mm. on the side of the crystal.

indicated in Comm. N^o. 94 from the supply bottle into the apparatus, which tube is closed in other cases with a rubber tube with cock. 3. an outflow tube d_2 (fig. 2), which leads along cock k(fig. 1 and fig. 4) to the gasholder with pure hydrogen, to a safety tube l (fig, 1), along k_2 to an airpump, and past k_4 to the vacuum bottle r, from which the liquid hydrogen is siphoned over (the operation is elucidated by the diagrammatic fig. 4, which does not call for a further description).

We first have convinced ourselves that when the air has been exhausted from the hydrogen tube surrounded by c, this tube exactly occupies its place between the poles, without being strained by the supports q and i, when these have a suitable position, we then fill it along k_i with hydrogen from the gasholder, exhausting it repeatedly, then we pour liquid air through a funnel with filter into b_1 , which is covered with some cotton wool. The apparatus is then filled with liquid hydrogen through d_1 . In order to pass to the melting point of hydrogen, k_{1} is opened till crystals appear on the surface of the liquid hydrogen, through which the gas bubbles which rise from the heated crystal, are seen to make their way. If the apparatus has been filled in the way described before, observations with the crystals may be made uninterruptedly for several hours. The precautions taken to prevent mixing of hydrogen and air are indispensable. Air entering the apparatus, would sink down, and be sucked up in front of the crystal as soon as the magnetic field is applied, and intercept the light.

For every filling of the apparatus 1/4 liter of liquid hydrogen from the supply is generally used, and it was sufficient to do this twice a day to be able to observe all the day in case of ordinary as well as of low pressure; twice a week a quantity of 5 liters was prepared for these experiments, which was just sufficient to fill the apparatus also the second day after the preparation. As it was impossible to entirely prevent the hydrogen which evaporated at lowered pressure from being contaminated with air, it was not admitted again into the cycle. The hydrogen cycle proved its reliability by never failing us a single time in all these weeks.

I. PHENOMENA WHICH DEPEND SOLELY ON THE TEMPERATURE.

§ 3 Simplification of the spectra. On cooling to the temperature of liquid air $(T = 85^{\circ})$ one of us had found ') that almost all bands become narrower and divide, some new ones also appearing. In

1) JEAN BECQUEREL, l. c.

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general their intensity increases. The bands which decrease in intensity or which vanish altogether, are exceedingly few in number. The measurements on anomalous dispersion in the neighbourhood of some bands of tysonite had proved that this increase of intensity is not only the consequence of the bands becoming narrower, but also of a modification which, according to the theory of electrons on the supposition of quasi-elastic forces, indicates the increase of the dielectric constant in every band, and implies that the number of electrons which determine such a band, has increased.

Passing to the temperature of liquid hydrogen $(T = 20)^{\circ}$, we saw some bands continue to increase in intensity, but also others which showed an increasing absorption with fall of temperature down to that of liquid air, decrease both in intensity and in breadth. There are even bands having appeared in liquid air, which become almost invisible in liquid hydrogen. An example of such a change with the temperature is furnished by the bands 523.5 and 479.1 of tysonite.

The measurements of the anomalous dispersion in the neighbourhood of these bands had shown that the electrons belonging to these bands are about twice or three times as numerous at the temperature of liquid air as at the ordinary temperature. In liquid hydrogen the number has already become very small, and at the temperature of solid hydrogen (14°) hardly any electrons of this kind take part in the motion. Fig. 1, Pl. II, which represents the compensator fringes ¹) in the neighbourhood of band 523,5 of tysonite at different temperatures and with different thickness, allows us to measure the disturbance in the fringe with regard to height and breadth. Figs. 2 and 3, which we treat in § 8 and ¹, and which represent the magnetooptic phenomena, may elucidate this.

§ 4. Maximum of intensity of every band for a definite temperature. It follows from the foregoing that several bands pass through a maximum of intensity with decrease of the temperature. In general the place of this maximum is different for different bands. When in the experiment with tysonite described in § 3 we wait till the last traces of hydrogen evaporate from the crystal, immediately after when the temperature of the crystal rises, the band 523,5 is seen to greatly increase in intensity. Without doubt the maximum for this band lies at a temperature not far above the boiling point of hydrogen. All the crystals of xenotime, tysonite, parisite, apatite, monazite, didymium sulphate, preseodymium sulphate, neodymium sulphate, exhibit

¹⁾ JEAN BECQUEREL, Radium IV no. 9 p. 328.

similar phenomena. The green line 523,5 of neodymium which is exceedingly fine and sharp at $T = 20^{\circ}$, has almost vanished at $T = 14^{\circ}$.

We have further examined the influence of the fall from $T=91^{\circ}$ to $T=58^{\circ}$ by immersing the crystals in liquid oxygen boiling at the airpump. The change in this region is only slight. This confirms the conclusion drawn from what was observed in heating from $T=20^{\circ}$ upwards that the maximum must lie near this latter temperature and at all events far below $T=58^{\circ}$.

Naturally the question obtrudes itself whether those few bands, whose intensity diminishes between the ordinary temperature and that of liquid air, do not also pass through a maximum either between $T = 290^{\circ}$ and $T = 95^{\circ}$, or at a temperature above $T = 290^{\circ}$. It will be difficult to decide the question, because in consequence of the broadening and overlapping of the bands the change of each of these bands in itself escapes observation.

§ 5. Change in width. In the previous experiments ²) it had been found generally valid for all bands measured down to the temperature of liquid air, that the width of the bands was proportional to the square root of the absolute temperature. This is the law which for the case of a gas may be deduced from the formulae formerly developed by LORENTZ ²)

When we pass to the temperature of liquid hydrogen this law appears to be no longer valid for some bands, whereas for others the order of magnitude of the change seems to remain the same. In the figures 1, Pl. II obtained by the method of the compensator fringes, it is very clearly to be seen, that 523.5 of tysonite is not half as broad at $T = 20^{\circ}$ as at $T = 85^{\circ}$, as the law of the \sqrt{T} would require. And it was this very band which had served to show experimentally, that this law held down to $T = 85^{\circ}$ with a high degree of approximation.

The question whether there is a minimum of width, could not be solved yet. At first sight some bands do not seem to contract any further between $T = 20^{\circ}$ and $T = 14^{\circ}$, two of xenotime seem even to get wider.

With regard to the totality of the phenomena of change of width in liquid and solid hydrogen we may further observe that in these even more than in liquid air³) the spectra manifest a pronounced

3) That tysonite and xenotime have this tendency has been observed by JEAN BECQUEREL, Radium 1. c.

¹⁾ JEAN BECQUEREL, Radium IV no. 9 p. 328.

²) H. A. LORENTZ. Kon. Akad. v. W. VI p 506 and p. 555 (1898).

tendency to assume the character of gas spectra when the temperature decreases. Some absorption lines of praseodymium and neodymium sulphate, cleared of broad bands that covered them, are even finer than the D-lines.

§ 6. The approach to a limit of the double refraction of crystals in the non absorbed parts of the spectrum. If we watch the bands, by the aid of which the double refraction is investigated, with change of temperature, we observe the following. If the crystal is heated above the ordinary temperature, they are greatly displaced. When the temperature is lowered to that of liquid air they move in the opposite direction. For a crystal of tysonite we have also examined them with further cooling with liquid hydrogen. In spite of the great difference of temperature the displacement is then hardly perceptible. This may point to the fact that the difference of the expansion of the crystals in the different directions approaches a limit at very low temperatures.

Connection of the change of the absorption bands occurring §7. at very low temperatures with the electronic theory. Already in \S 3 we pointed out the connection of the change of the bands with that of the number of the electrons which are concerned with a certain band according to the electronic theory coupled with the assumption of quasi-elastic forces. The experimental problems raised by $\S3$ and $\S4$ may be defined as follows in the language of this theory ¹): to determine as functions of T on one side the number and on the other side the damping coefficient (proportional to the width of the band) of the electrons which belong to a certain band. We might make use of the position of the maxima to find mutually related bands, in the first place in the different spectra of one crystal. An investigation into the connection between what we already know about these functions and what the change of the electrical resistance of the metals leads us to expect about the action of forces exercised by the ponderable substance on the electrons naturally suggests itself.²) At very low temperatures we shall no longer be justified in considering the electrons as a perfect gas, but we shall rather have to compare them to a vapour which precipitates on parts of the atoms (dynamides (LENARD)), and solidifies at still lower temperature ³). When we approach these centres the paths of the electrons are subjected to changes which modify the free

¹⁾ Cf JEAN BECQUEREL. Radium l. c

²) H. KAMERLINGH ONNES. Loc. cit.

³) A metal would become transparent at very low temperature.

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ength of path in the same way as VAN DER WAALS' quantity b is subjected to a change by the forces exerted by the molecules on each other.¹)

The three states of aggregation which we used just now as an illustration of the behaviour of the electrons, might perhaps be considered as referring to the stability of different paths of the electrons, and the quasi-elastic force might be connected with the conditions for the electrons moving in these paths.

If we further note that it is the ratio of the absolute temperatures on which the degree of change of the spectra depends (compare the transition from T = 20 to T = 14 with that from T = 290 to T = 95), we may accept for the present as a heuristic image the idea that we may speak of corresponding states according to different units of temperature caused by mechanic similarity of the motion of the electrons round the centres.

II. PHENOMENA DEPENDING ON THE TEMPERATURE AND ON THE STRENGTH OF THE MAGNETIC FIELD.

§ 8. Constancy of the change of the frequency of vibrations under the influence of the magnetic field at all temperatures.

According to the experiments made by one of us previously (J. B.), when a uniaxial crystal is placed with its axis in the direction of the lines of force and of the ray of light, some absorption . bands are resolved into two components, which belong to the absorption of two circularly polarized rays of opposite sense. The difference of frequency of vibration of the two components had then proved to be independent of the temperature. It follows now in a still more convincing way from the comparison of the divergence of the two bands at the temperature of liquid hydrogen with the divergence at the temperature of liquid air, that within the limits of errors of observation, the difference of frequency of vibration is entirely independent of the temperature. According to the theory of LORENTZ this constancy of the divergence of the bands, which is observed both for those which behave in the sense of the ZEEMAN-effect as for those which behave in opposite sense, must be considered as proceeding from the invariability of the relation e/m. Accordingly the observations in liquid hydrogen seem to furnish a strong support to the argument in favour of the existence of positive electrons derived from the constancy of this quotient.²)

¹⁾ Calculated by REINGANUM according to the theory of BOLTZMANN.

²) Le Radium tom V. p. 17 1908.

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§ 9. Partial polarisation of the components of some bands. In a foregoing communication (CR. 19 Aout 1907) one of us (J. B.) has demonstrated, that the band 624,97 of tysonite becomes double in each of the two spectra of left-handed and right-handed circularly polarized light, which are obtained by means of a plate of a quarter wavelength and a rhombohedron. Therefore in both components of the magnetic doublet of the band the polarisation is not perfectly circular. The band behaves as if it were owing both to positive and to negative electrons with the same period of vibration, and the same ratio e/m, in which the number of positive electrons is to be put as the largest, because the strongest component belongs to it.

At the temperature of liquid hydrogen the same phenomenon is observed with some bands which become at the same time fine – and bright (fig. 2 Pl. I band 522. 1). In general the same thing is found on reexamining the spectra at the temperature of liquid air and at the ordinary temperature, though it is more difficult to see. Some time ago DUFOUR again found the same phenomenon in emission bands of fluorcalcium put into the flame.

§ 10. Asymmetry of the right- and left-handed components. The experiments at the temperature of liquid air had proved ¹) that when the rays of light run parallel to the lines of force the rightand left-handed components very often differ in strength. No regu- / larity had been found in these differences, the asymmetry was now in one, then in the other sense.

If we pass to the temperature of liquid, or better still, to that of solid hydrogen, the asymmetries, which sometimes change their sign, become exceedingly great; one component increases in intensity at the expense of the other, even to such a degree, that some components vanish almost entirely on the side of the greater wave lengths. An example is furnished by fig. 3, Pl. III referring to 654,2 and 643,4 of xenotime, one component of which is very intense, the other very faint. Apatite shows the same thing.

In solid hydrogen almost all the components which diverge towards the small wave lengths, become very sensibly intenser than those of opposite sign.

§ 11. Variation of the magnetic rotation of the plane of polarisation in the neighbourhood of the absorption bands.

a. Simple bands. The experiments of MACALUSO²), H. BECQUEREL³),

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¹⁾ JEAN BECQUEREL Le Radium V. No. 1. p. 9. 1908.

²) CR. CXXVII p. 548, 1898.

³) CR. CXXV p. 679. 1897 CXXVII p. 899. 1891.

ZEEMAN¹) have proved that in the neighbourhood of the bands which exhibit the ZEEMAN-phenomenon, the rotation of the plane of polarisation on both sides of the band is positive, and in the inside of the magnetic doublet negative. The experiments made with uniaxial crystals²) with the axis placed parallel to the lines of force and to the beam of light either at the ordinary temperature, or at the temperature of liquid air, have proved that the regular change of the magnetic rotatory power with the wavelength of the light is subjected to a disturbance of the same kind on both sides of the band, and to an opposite disturbance at the middle of the band. This disturbance is positive outside the band for the bands belonging to negative electrons, and negative for the bands of positive electrons.

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At the temperatures of liquid and solid hydrogen the same phenomena are observed, at least when the asymmetry of the left- and right-handed components is not too large. In the neighbourhood of some bands whose components are very unequal, opposite disturbances are observed on both sides of the band — as is easily explained by means of the usual figures of the anomalous dispersion. These phenomena are clearly visible on the figures. 4 Pl. III and 5 Pl. IV.

These figures have been obtained by a method which was already used in former experiments "). Against the slit of the spectroscope a BABINET compensator was fixed between two crossed Nicols in such a way that the fringes were perpendicular to the slit. Before the compensator a plate of a quarter of a wave-length is placed in such a way that the two opposite circularly polarized vibrations are changed into two rays rectilinearly polarized parallel and normal to the principal direction of the compensator. The deviations of the fringe in the spectrum in the neighbourhood of the bands are proportional to the difference of phase of the circularly polarized rays in the crystal plate.

In the figures we find for band 522.15 fig. 4 the symmetrical case, for band 523.7 fig. 4, and 642.3 fig. 5 the dissymmetrical case with disturbance in the same direction, for band 537 fig. 4, and 654.2 fig. 5 the opposite disturbance on both sides of the band.

b. Compound bands. The phenomena of absorption at lower temperatures have shown that several bands may be resolved into two or more. These components behave differently with respect to the magnetic field, because some belong to positive, others to negative

- ¹) Arch Neerl. VII p. 465. 1902.
- ²) JEAN BECQUEREL, Radium IV No. 2 p. 49. 1907, V No. 1 p. 5. 1908.
- 3) JEAN BECQUEREL, C.R. May 21 1906.

electrons. Therefore we meet with disturbances in the magnetic rotation which are different for the different bands, and whose effects are superposed. Thus two bands placed side by side, one of positive and the other of negative electrons, may give rise to disturbances in opposite direction in the dispersion of magnetic rotation. It is perhaps to this that we must look for the explanation of what

is observed in band 577 of tysonite, which is clearly double in

liquid hydrogen. In general we may say that with regard to the theory of the magnetic rotation for absorption bands, the conclusions drawn from experiments at the ordinary temperature do not lead to a definite result. For at the ordinary temperature it is uncertain whether we have really to deal with a simple band. On the other hand at the low temperatures, at which the bands become narrow, and their change in the magnetic field may be closely followed, it is easy to find the true explanation of the different types of disturbances in the magnetic dispersion of rotation for the bands in the different cases.

§ 12. Magnetic rotatory power of the paramagnetic crystals. One of us $(J. B.)^1$ had previously shown that the negative magnetic rotatory power of the crystals of tysonite and parisite increases considerably with decrease of temperature. The rotatory power is about inversely proportional to the absolute temperature. If this is brought into connection with the law of CURIE that the paramagnetic susceptibility is inversely proportional to T, it appears that the negative rotation of these crystals is probably a consequence of the increase of the paramagnetic polarisation of the crystal.

If these crystals are placed in liquid hydrogen we find that the increase continues in the same way with decrease of temperature, and the rotatory power rises to exceedingly high values. The exact numbers will be given later, but in round numbers the rotation of the plane of polarisation of the blue light amounts to 150° for a plate of tysonite of 1 mm. in a field of 10000 Gauss at the boiling point of hydrogen. Xenotime, which gives a very slight rotation at the ordinary temperature, shows a considerable rotatory power in liquid hydrogen.

§ 13. Connection between the phenomena of the asymmetry of the left- and right-handed polarized components by the magnetic field at very low temperatures, and the electronic theory.

In connection with $\S 4$ the phenomena taken together give rise

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¹) JEAN BECQUEREL, Radium. Tom. V, Nº. 1, p. 5, 1908.

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to the supposition that for the paths of the electrons there exist conditions (fields) of stability, which are determined by the temperature. The action of the magnetic force and the change in the rate of vibration would then bring about that some electrons enter these fields of stability or leave them, both changes occurring either in the direction of greater union with or further separation from the centres which determine the paths, and the increase of this action at low temperature would be in connection with the small velocity. The influence on the stability of the paths, which is here considered, would be the same as manifests itself in the change by temperature of the number of electrons (see § 7) which satisfy the conditions of the motions which may be ascribed to quasi-elastic forces.

In this connection the question suggests itself if the greater stability of vibrations in a certain direction will not give rise to paramagnetic properties.

§ 14. Variability of the mass of the electrons with the direction of the movement. The theory of the magneto optic phenomena in crystals (VOIGT¹), JEAN BECQUEREL²)) leads to the following results.

The magnetic field gives rise to certain connections between the motions of the electrons in the different principal directions of the crystal. Let us consider the simple case which is repeatedly met with, viz. that the corresponding bands in the different spectra occupy the same place. In that case according to the theory the magnetic doublets will have to be symmetrical, and when the bands are sufficiently narrow to allow us to neglect the breadth, the deviations will be proportional to the square root of the product of the two magnetic constants which belong to the corresponding bands of the two spectra. If the beam of light and one of the principal directions 1, 2, 3 of the crystal are made to coincide with the direction of the magnetic field, those two of the three spectra of the crystal are observed which correspond with the vibrations normal to the lines of force.

Observation shows that both for the uniaxial crystals of xenotime and tysonite and for the biaxial crystals of didymium sulphate, neodymium sulphate, and praseodymium sulphate (which last exhibits some lines in liquid hydrogen as sharp as vapour lines) the doublets of the common band have the same divergence. A phenomenon of great importance is observed, when the spectra of vibrations normal to the lines of force are combined in different ways. If the directions 1, 2, 3 successively are placed in the direction of the

¹⁾ Nachr Kön. Ges. d. Wiss. Gottingen Juli 1906.

²) C.R. 19 Nov. 3. 10. 24 Dec. 1906. Radium IV n^o. 3 Mars 1907.

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Fig. 1. Anomalous birefrigency, tysonite, group in the green 2^d spectrum (RowLAND grating), thickness op plates 1.71 mM. in 1, 2, 3, 4 and 0.41mM. in 2 (in 2 the ordinary and extraordinary ray are interchanged).



522.1

Fig. 2. Left- and righthanded vibrations in a field of 18000 Gauss nearly. Xenotime, group in the green, 2d spectrum (RowLAND grating).

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Fig. 3. Left and righthanded vibration in 3 a field of 18000 Gauss nearly, Xenotime, group in the red, 2d spectrum (RowLAND grating); panchromatic plates of WRATTEN and WAINWRIGHT. 520.6 522.15 537



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Fig. 4. Xenotime, group in the green, 2^d spectrum (RowLAND grating) 1. magnetic circulair birefringency, plate thick 0.80 mM., field 15000 Gauss. 2. images by rhombohedron before slit, the incident light polarized to give equal intensities to the regions in the transparent part in the middle of the group. Field 15000 Gauss. 3. images given by rhombohedron before slit, incident light polarized under 45° with the horizon; field 18000 Gauss.

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Fig. 5. Magnetic rotation of the plane of polarization. Xenotime 24 spectrum (RowLAND grating); thickness 0.80 mM., field 18000 Gauss; (quarter of wavelength plate turned 90° in the one in respect to the other).



Fig. 6. Sulphate of Neodyme group in the orange, 24 spectrum ((RowLAND grating) spectra of the vibrations :

1	iff	the	principal	direction	а,	114	eid –	= 0	N,							
2			10		b_i	fle	d.	- 0	0.							
3	10		1.00		α,	a	and	b	normal	to	the	field	(18000	Gauss).		
4		**			b_{s}	a	and	b		.,						
5	**				a,	a	and	C	-		-		1	T		
6					с,	a	and	c			**					
7					b,	b	and	ť	++				1.0			
8			10	1.10	c,	b	and	ċ			**	10				

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Fig. 7. Sulphate of neodyme; spectra of vibrations in the directions α , β , γ group in the blue, 2^d spectrum (RowLAND grating) 1, 3, 7, 11, 19 2, 4, 8, 12, 15 β " "

16, 20 5 and 6, 9 and 10, 13 and 14	4 α ⁷	and"	β	normal	to	field	(18000	Gauss)
17 and 18,	β	and .	7	72	57	72		n
21 and 22	CX.	and	7	22		**		77

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field, we get the combinations 2.3, 1.3, 1.2 for the vibrations normal to the field. Experiment shows that the divergences of the pairs of doublets in these three cases are very different. Thus for a band of spectrum 1, the vibration being normal to the field, the magnetic doublet is different according as the direction normal to the field has the principal direction 2 or 3. The phenomenon is clearly seen in the figure which represents the group of bands in the orange for neodymium sulphate at -259° . Fig. 7 Pl. V gives a survey of the phenomena of the changes with the temperature and the magnetic field in the blue of neodymium sulphate. According to theory it follows from this that each of the three different directions has a different magnetic constant, and that therefore the vibrating system presents three different masses for the three kinds of vibrations.

As the corresponding bands in the two spectra occupy [the] same or only slightly different places, it follows that \inf_{s} first approximation the constant of the quasi-elastic force in each of the three directions must be proportional to the mass in that direction.

Physics. — "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." By Prof. KAMERLINGH ONNES and Dr. W. H. KEESOM. Communication N^o. 104ⁿ from the Physical Laboratory at Leiden.

§ 1. The great compressibility of a substance in the neighbourhood of the critical point liquid-gas and the properties connected with this, (such as the small variation of the thermodynamical potential at isothermal compression etc.) — which are derived from VAN DER WAALS' original equation of state and better still from³ his latest considerations about the compressibility of a molecule¹) — render it necessary that in deriving conclusions from observations in the neighbourbood of that condition we must take into account various circumstances, otherwise unnecessary for the experimental investigation of the equation of state of a homogeneous substance consisting of one component, which investigation includes that of the quantities of, saturation etc.

It is well-known that owing to the great compressibility the thermodynamic equilibrium is difficult to attain, in fact it has often

¹⁾ Comp. VAN DER WAALS, Proceedings June '03,