the thermal molecular pressure will be needed, if values of B are to be derived from the comparison of thermometers with different initial pressure. The same is true with respect to possible corrections for deviations, as predicted by the theory of quanta.

7. *Approximate formula for the vapour-pressure of helium.* We did not succeed in representing our observations by NERNST's vapour-pressure formula, treated as interpolation-formula.

The BOSE-RANKINE form [1])

$$lg\, p_{cm.Hg} = A + B\frac{1}{T} + C\frac{1}{T^2} + D\frac{1}{T^3}$$

gave with

$A=+3.7290$, $B=-7.9780$, $C=-0{,}13628$, $D=+4.3634$

the results shown in Table V

TABLE V. Vapour-pressure of helium.

T	$p_{obs.}$	p_{calc}
1.475° K.	0.415 cm.	0.419 cm.
3.516	35.95	35 50
4.205	75.75	76.38
4.9	132.9	136.5
5.16	166.8	162.1

Even with this formula containing four constants the observations appear to agree only very imperfectly.

Physics. — *Methods and apparatus used in the cryogenic laboratory. XVI. The neon-cycle.* By H. KAMERLINGH ONNES. (Comm. 147*c* from the Physical Laboratory at Leiden).

(Communicated in the Meeting of June 26, 1915).

1. *Introduction.* In several accurate investigations on the law of dependence on the temperature of the properties of substances the difficulty is encountered, when going below 55° K., that not till 20° K. is reached liquid baths of the desired constancy are again available. The gap between 55° K. and 20° K. in a range which other-

[1]) C. A. CROMMELIN, Comm. N°. 138*c*.

wise extends far in both directions without any break and in which the temperature is under complete control from 90° K. to 55° K. by means of liquid oxygen and from 20° K. to 14° K. of liquid hydrogen, — this gap is all the more to be regretted as in the absence of a liquid bath comparisons of auxiliary thermometers with the helium- or hydrogen-thermometer in this region of temperatures are completely wanting. It would be specially valuable, if this gap could be filled for the lower portions of the temperature-range in question by the addition of a portion above the boiling point of hydrogen joining on to the range of reduced temperatures which is governed by hydrogen between 20° K. and 14° K As instances of investigations for which this extension would be greatly desired we can name (besides the equations of state of hydrogen and neon) that of paramagnetic susceptibility, that of specific heat, and that of galvanic resistance.

We have now succeeded in utilizing neon for this purpose. During the experiments which have led to this result some thermal quantities of neon were determined, which will be discussed in the next communication (147*d*, these Proceedings) by Dr. CROMMELIN and myself. Amongst other data the boiling point of neon was found at about 27° K. and the triple-point at about 24.5° K. By using neon exactly in the same way as hydrogen, the range of 14°—20° K. can, therefore, now practically be extended from 14° K. to 27° K. As we have also found, that there is no serious difficulty in constructing cryostats for pressures some atmospheres above the normal (e. g. with hydrogen it is possible to go from 20° to 25° K.), a pressure-cryostat with neon will probably allow us to ascend to a temperature of 34° K., by which it would become possible to study by the eye the critical phenomena of hydrogen in a bath of liquid neon. A future communication conjointly with Dr. CROMMELIN will, I hope, deal with an investigation of this question.

Further as regards the region from 34° to 55° K., we may mention even now, that one of the next communications will contain a description of an arrangement by which I have succeeded by a satisfactory method by means of hydrogen-vapour heated to the desired temperature in obtaining constant temperatures in this region. In a further communication to be given conjointly with Dr. CROMMELIN, which will follow soon afterwards we hope to give an experimental determination of the critical temperature of neon (compare our Comm. 147*d* below) made by means of this new arrangement. The same arrangement may also be utilized in the temperature-region from 20°—34° K. But for most experiments, particularly

when phenomena have to be followed by the eye, the cryostat with liquid neon is very much to preferred.

It was gratefully mentioned before, when the attempts to arrange a neon-cryostat were discussed for the first time (Comm. 112 June 1909), that the gas was very kindly put at our disposal by Mr. G. CLAUDE and the "Société d'Air Liquide" in Paris. This gas was rich in neon and from it the large quantity of pure neon which is now in circulation in the laboratory has been separated (Comp. Leiden Comm. Suppl. 21*b* p. 40—41). It is there described, how by a preliminary purification of the crude gas by means of freezing in liquid hydrogen, pumping off the helium and separation of the large quantity of nitrogen present, a gas was obtained almost totally free from hydrogen and helium and principally only containing some nitrogen. Continued fractionation further diminished the quantity of the admixtures and the ultimate purification was conducted by means of the neon cycle itself and the removal of the last traces of oxygen and nitrogen by the aid of carbon cooled in liquid air.

2. *The neon-liquefactor and neon-cryostat.* These are combined into one piece of apparatus (see fig. 1 below). The liquefactor somewhat resembles in its construction the apparatus for the purification of hydrogen (Comm. 109*b* March 1909). The cryostat is constructed exactly as the helium-cryostat in its most recent form (Comm. 123, June 1911). The connection between liquefactor and cryostat is essentially the same as that between the helium-liquefactor and the helium-cryostat of Leiden. Comm. Suppl. 21 fig. 5 (Oct. 1910). To facilitate a comparison with the helium-cryostat, the parts of the neon-liquefactor in fig. 1 are marked with the same letters as the corresponding parts of the helium-cryostat in the Plate of Comm. 123. For parts of modified construction, but of analogous purpose accented letters have been used.

The principle of the apparatus (comp. fig. 1) consists in this, that in the liquefactor the neon is made to condense on a spiral $a_1 a_2 a_3$ (comp. $a_1 a_2 a_3$ in Plate of Comm. 109*b*), which is cooled below the boiling point of neon by means of liquid hydrogen. From the coils of this spiral the liquefied neon flows down into the cryostat. If locally the temperature of the cooling-spiral descends below the melting-point of neon, the substance will there be deposited as a solid crust on the spiral. The external surface of the spiral, where this happens, and the remaining free passages between the spiral and the vessel, inside which the spiral is suspended are so large, that a considerable quantity of solid neon can be deposited in this

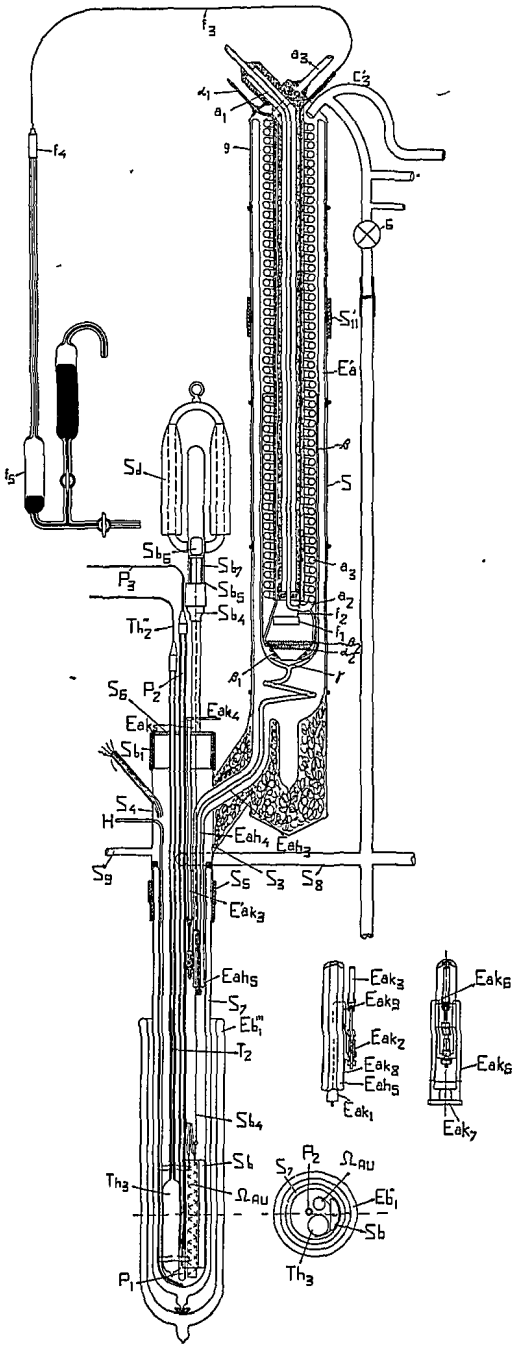

Fig. 1.

manner, without the apparatus becoming plugged. As soon as the lower part of the spiral returns to a temperature above the melting-point, the neon melts, drips down and flows into the cryostat.

In applying this principle of liquefying the neon by cooling with

liquid hydrogen the difficulty lies in the circumstance, that the boiling-point and melting-point of neon are only a few degrees apart. The construction of our apparatus is specially designed to meet the difficulty arising from the almost unavoidable freezing of the neon. If we had applied LINDE's principle of liquefaction on neon, cooled only in liquid air, and had thus liquefied neon in the same manner as DEWAR first showed, how to liquefy hydrogen, this difficulty of the neon freezing would not be encountered. But in that case the other difficulty would make itself felt, that only a part of the available gas appears as liquid in the bath. As long as neon is still so difficult to obtain as at present, this objection weighs very much more than that inherent in the principle of our apparatus. Moreover as we have the excellent hydrogen-cycle ready at our disposal, it would be much more complicated constructing a separate neon-cycle with liquid-air cooling only, than following the method adopted. In future, when neon will be equally easily obtained as at present hydrogen and there will thus be no necessity for anxiously guarding against the smallest loss and such a loss will be considered in the same light as a loss of hydrogen is now, it will become more profitable to prepare the liquid hydrogen itself by means of a neon-cycle. For that case a purifying-apparatus of neon by means of liquid neon, similar to that of hydrogen described in Comm. 109, will be practically a necessity. If the neon is not completely deprived beforehand of the less volatile admixtures, such as nitrogen, the narrow tubes of the regenerator-spiral, through which the gas is made to flow during its expansion, would be apt to get plugged. In the method chosen by us it is of no account, whether the neon still contains a few percentages of the less volatile constituents, like nitrogen. Without obstructing the passages they are deposited on the less cooled upper parts of the spiral, while the neon is liquefied or solidified on the lower coils. If the temperature of the cooling spiral is so regulated that the vapour-pressure of neon at that temperature is above one atmosphere, while the solid nitrogen and oxygen have still only a negligible vapour-pressure, all the liquid and solid neon which might be present will evaporate and the less volatile admixtures of the neon can all be retained in the apparatus and so removed from it. This procedure may be utilized for the purification of the neon (see § 3). We will however at present adhere to the supposition, made in the beginning of our description, that the neon is already pure.

The liquid neon flowing down from the spiral is caught (fig. 1) in the silvered vacuum-vessel with silvered draw-off-tube E_{ak3} and

then flows through the small stop-cock E_{ak1} into the vacuum-vessel S_7 of the cryostat; for the description of the cryostat and its pump-stirrer we may refer to Comm. 123*b*, where the lettering is identical. The difference between the valve used at present (for details see separate drawing in fig. 1) and that of Comm. 123*b* is of minor importance and consists in the valve not having a turning movement, but moving vertically up and down, being guided by the two rods E_{ak6} and carried by the german-silver strip E_{ak7}. The small stop-cock is connected to the orifice E_{ak5} by means of two german-silver rings E_{ak8} and E_{ak9}.

Fig. 1 represents the condition, in which the cryostat contains a helium-thermometer Th_3''' with capillary Th_2''' (as in the Plate of Comm. 123*b*, this time however the thermometer used in Comm. 147), a resistance ΩAu, as in the same Plate, and moreover a piece of apparatus for the measurement of the vapour-pressure of hydrogen above its boiling point (vessel P_1, which contains the liquid hydrogen, besides tube and capillary P_2, P_3, P_4 for connection with the further apparatus): the measurements with this arrangement will be dealt with in a communication to be made conjointly with Mr. P. G. CATH.

Two tubes are attached to the cover of the cryostat, S'_8 (comp. figure of Plate in Comm. 24, where however the corresponding letter is wanting) and S'_9 leading to a manometer and the apparatus (comp. § 3) for regulating the temperature in the cryostat.

The temperature in the cooling-spiral $a_1\ a_2$ in the liquefactor, a, being protected from supply of heat by a covering of wool, may be regulated by the aid of the thermometer $f_1 f_2 f_3 f_4 f_5$, exactly as in the apparatus for the purification of hydrogen, for the description of which we may again refer to Comm. 109.

Care has to be taken, that only liquid neon can enter the draw-off tube. For this purpose a small vessel β is contrived, which fits in the vacuum-vessel with a thin layer of flannel; it is open at the bottom and just above the opening β_2 carries a filter β_1, which can be warmed by means of hydrogen of ordinary temperature which can be blown through the tube α_1 and the small spiral α_2; by which means the temperature of the draw-off tube can be permanently kept above that of the melting-point of neon. Solid and less volatile substance, say nitrogen, which might fall down, is retained on the filter and if the nitrogen which has collected there happened to melt by the temperature rising it flows on the small tray γ, where it remains while only liquid neon can flow down[1]).

[1]) In order to make the arrangement completely adequate — solid nitrogen is lighter than liquid neon — this tray should be provided with a standing-up rim of gauze, which was not yet the case.

3 *The neon-cycle.* This cycle is very similar to that of helium (Comm. 108 July 1908). The neon is stocked under compression in one or more receivers R_1 (fig. 2). From R_1 the gas is made to flow into the gasometers G_1, G_2, floating in oil and arranged exactly as in the hydrogen-cycle (Comm. 94*f*, June 1906), the oil being here also freed from air and moisture.

If necessary, the neon, before it is brought into circulation, can

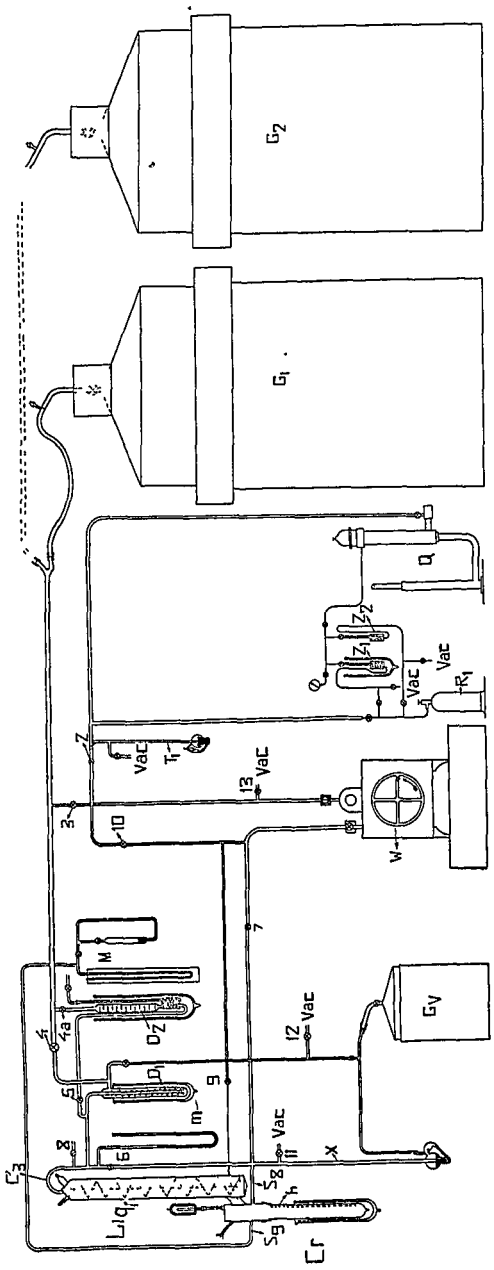

Fig 2.

be drawn under pressure through carbon, cooled with liquid air, by means of the compressor with mercury-piston Q (compare Comm. 54 Jan. 1900) and returned to R_1 or to the gasometer in purified condition. The carbon is contained in Z_1 (which is cooled) and Z_2 (a reserve tube), copper hardsoldered receivers which may be exhausted by the mercury-airpump (*vac* in the figure) at red heat. The remaining gas is transferred by the air-pump to a gasholder for impure neon. The way of using the cocks and the object of the safety-tube T, which in case of need takes back the gas to the gasholder for impure neon, as also of stop-cock 2 will be clear without special elucidation.

The cryostat is filled with the pure neon from the gasometer by stop-cock 4 through a drying-tube D_1 immersed in liquid air; from here it flows with stop-cock 6 open by c'_2 (comp. fig 1) into the liquefactor, from which as explained in § 2 the liquefied neon flows down into the cryostat. The vaporized neon escapes through S'_8 to the gasometers G_1 and G_2. When the cryostat is filled the small cock E_{ak_1} and stop-cock 6 are closed. The neon which might then evaporate in the liquefactor may escape through stop-cock 8 into the gasholder for impure neon.

As usual the cryostat has attached to it a safety-tube X; the gas which might escape through it is caught in the small safety-gasometer Gv. When the small cock E_{ak_1} is closed, the temperature of the bath may be regulated in the usual manner according to the indication of manometer M and with the aid of the differential-manometer shown beside it (comp. Comm. 83, Dec. 1902) by opening 7 more or less.

The apparatus itself and the connections may be evacuated by manipulating stop-cocks 10 and 11. The exhaustion is performed before the experiment to make sure of a proper operation of the cryostat and again after the completion of the experiment to transfer the gas contained in the apparatus back to the gasholder for impure neon. Before proceeding to the latter operation the liquid neon is transferred to the gasometers G_1 and G_2, either by allowing the liquid to evaporate with the cryostat connected to the gasometers, or by flowing the liquid to the gasometers by pressure through the syphontube h, allowing the liquid neon to evaporate in the passages on its way to the gasometers, or finally by pumping the liquid out and forcing it into the gasometers with the Siemens-pump W. The gas which is left in the Siemens-pump is transferred by the mercury-pump to the gasholder for impure neon with all the other gas remaining in the whole apparatus and connections at the end of the experiment as already mentioned.

To prevent too rapid an evaporation of the bath the cryostat-vessel S_7 (fig. 1) is protected by a tube with liquid air.

If the available neon is not quite pure and if it is still desired to start the work with it without the previous purification by means of the circulation under pressure over carbon cooled in liquid air, it will be possible instead of the drying tube D_1 to insert between 4 and 5 a carbon-tube D_2 arranged for purification under ordinary air-pressure, immersed in liquid-air with a drying-apparatus preceding it.

In the experiments the liquid gas in the bath was always obtained in a perfectly transparent condition. Only the first quantity of liquid neon which flows into the cryostat-vessel and evaporates there very rapidly, left behind a little of a white substance (solid nitrogen or solid air?) which dissolved again in the liquid gas which flows in afterwards. A slight ring-shaped deposit was also noticed above the liquid surface in the evaporation of the bath. The gas had thus not been quite pure; as a matter of fact this can hardly be expected, as long as it is allowed to come into contact with the oil of the gasometers. The use of the latter, however, simplifies the operations considerably, and the very slight impurity does not give the least trouble.

It was found that the quantity of liquid in the bath could be made as much as 400 cc.

I am glad to thank Mr. G. J. FLIM, chief instrumentmaker in the cryogenic laboratory, once again for his help in the construction of the apparatus described in this paper.

Physics. — "*Isothermals of monatomic gases and of their binary mixtures XVII. Isothermals of neon and preliminary determinations concerning the liquid condition of neon.*" By Prof. H. KAMERLINGH ONNES and C. A. CROMMELIN. (Communication 147*d* from the Physical Laboratory at Leiden).

(Communicated in the meeting of June 26, 1915).

1. *Isothermals of neon.* This section contains a first instalment of the isothermal-determinations, by which we hope to obtain the equation of state of neon at low temperatures. The isothermals of 0° C. and 20° C. have been investigated from 20—93 and from 20—84 atmospheres respectively; they give sufficient data for the connections which are required for the reduction of the observations concerning the isothermals of lower temperatures. Parts of isothermals for —182°.6 C., —200°.1 C., —208.°1 C., —213°.1 C. and —217°.5 C. are also given, which may serve as a first survey and even now