Citation:

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

have been lighted, the thermostat adjusts itself to a temperature that is practically determined by the quantity of mercury present in the apparatus. The utility of the apparatus is therefore greatly increased. To give an idea of the capabilities of the apparatus temperatures taken on some of the measuring days are given below. The temperature was taken immediately before the water was allowed to flow into the manometer jacket.

	12 h. 15 m.	12 h. 45 m.	2 h. 15 m.	3 h. 5 m.	4 h. 55 m.
March 22nd '11	16.04	16.07	16.07	16.07	16.07

	3 h. 40 m.	3 h. 55 m	4 h. 20 m.	4 h. 45 m.	5 h. 25 m.	6 h.
March 30th '11	19.00	19.00	19.00	19.00	19.00	19.05

So that the temperature as can be seen remains for hours at a time constant to less than 0.01°.

How far this constancy of the temperature can be utilised to keep the temperature of the volumenometer constant depends upon the constancy of the room temperature; its heat insulation however can still be improved. If sufficient care is taken to keep the room temperature constant, one is usually successful in keeping the gradual change of the temperature of the volumenometer to within 0°.03 per hour [1]), and any single temperature measurement remains certain to 0°.02.

Physics. — "*Further Experiments with Liquid Helium.* D. *On the Change of the Electrical Resistance of Pure Metals at very low Temperatures, etc.* V. *The Disappearance of the resistance of mercury.*" By Prof. H. Kamerlingh Onnes. (Communication N°. 122^b from the Physical Laboratory at Leiden).

As was mentioned in a former Communication (April 1911) I have made a more accurate examination of the resistance of pure mercury at helium temperatures, in which I have once more had the assistance of Messrs. Dorsman and Holst. The resistance was now measured with the differential galvanometer by the method of the overlapping shunts (Kohlrausch) and also by the method of the measurement of current strength and of potential difference. By this it was confirmed that at 3° K. the value of the resistance sinks to below 0.0001 times the value of the resistance of solid mercury at 0° C. extrapolated from the melting point. But from the present measurements it has also been ascertained that the actual value of the resistance is very much smaller than this upper limit which I was able to ascribe to it from my former measurements.

1) For the comparison of mercury columns as in Table II constancy to within 10 times this value will be sufficient.

The value of the mercury resistance used was 172.7 Ω in the liquid condition at 0° C.; extrapolation from the melting point to 0° C. by means of the temperature coefficient of solid mercury gives a resistance corresponding to this of 39.7 Ω in the solid state. At 4°.3 K. this had sunk to 0.084 Ω that is, to 0.0021 times the resistance which the solid mercury would have at 0° C. At 3° K. the resistance was found to have fallen below 3×10^{-6} Ω, that is to one ten-millionth of the value which it would have at 0° C. As the temperature sank further to 1°.5 K. this value remained the upper limit of the resistance.

The next step was obviously to look for the point at which the resistance first becomes measurable as the temperature is raised. The temperature of this point was found to be slightly more than 4°.2 K. at which the resistance was found to be 230 micro-ohms or one hundred thousandth of the resistance (solid) at 0° C. As the temperature was raised to that of the boiling point (4°.3 K.), the resistance rose once more to 0.084 Ω. This change took place more quickly than the rate of change to which the formula given in the December (February) Communication leads — exactly how much more quickly is not yet known but it certainly seems to be increased very much more rapidly. A point of inflection which does not appear in the formula given — a formula which I regarded as incomplete also on account of the method by which it was deduced, seems to occur between the melting point of hydrogen and the boiling point of helium in the curve which represents the resistance as a function of T.

The more the upper limit which can be ascribed to the resistance remaining at helium temperatures decreases, the more important becomes the observed phenomenon that the resistance becomes practically zero. When the specific resistance of a circuit becomes a million times smaller than that of the best conductors at ordinary temperatures it will, in the majority of cases, be just as if electrical resistance no longer existed under those conditions. If conductors could be obtained which could be regarded as being devoid of resistance as long as their cross section was not excessively small, or conductors of the smallest possible sections, either cylindrical with diameters of the order of the wave length of light, or films of molecular dimensions, whose resistance would be but small, if there had no more to be reckoned with the JOULE development of heat in increasing the current in a bobbin to exceedingly high values, because the development of heat in a circuit of constant current strength could be made extremely small compared with the latent heat of vaporization of the liquid which can be used for cooling, — then further experiments in all possible directions would give the fullest promise, notwithstanding the great difficulties which are encountered when working with liquid helium. It is therefore all the more necessary to establish beyond all possibility of doubt the property of which advantage would be taken in such experiments. With this end in view modifed measurements are being made.

It is further worth noting that just as the resistance of constantin changed but little when the temperature fell from ordinary to liquid hydrogen temperatures so too the change is slight as the temperature sinks further to those of liquid helium. This property was utilised to obtain rough confirmation of the value of the latent heat of vaporization of helium, which can be calculated from CLAPEYRON's formula using the data which have already been published concerning its vapour pressure and vapour density. (Compare the above remarks as to the ratio between the JOULE heat development to the latent heat of the liquid which is used for cooling).

Physics. — *"Researches on Magnetism. III. On Para- and Dia-magnetism at very low temperatures."* By H. KAMERLINGH ONNES and ALBERT PERRIER. Communication N°. 122^a from the Physical Laboratory at Leiden.

§ 1. *Introduction.* In an earlier research (Comm. N°. 116, April 1910) we investigated the magnetisation of oxygen down to temperatures close to the freezing point of hydrogen, and we found deviations from CURIE's law which seemed to us to be connected with the problem as to how far the electrons which occasion magnetic phenomena are frozen fast to the atoms when the substance is cooled to very low temperatures[1]). This made it very desirable to extend the research, especially as far as hydrogen temperatures were concerned, to other paramagnetic substances which follow CURIE's law at ordinary temperatures. If, as we found to be the case, it were found that deviations of the same character as those for oxygen were encountered with these substances also: it might well be assumed that such deviations, and also, should they be connected with the freezing of the electrons, this freezing itself

[1]) This idea of which repeated use has been made in former Communications (cf WEISS and KAMERLINGH ONNES, Comm. N°. 114, Febr. 1910 p. 9 note 1) did not appear to be applicable to the case of ferromagnetic substances (loc. cit. p. 9) as the temperature sank to the freezing point of hydrogen. Our experiments give rise to the further question as to how these substances would behave when the temperature was lowered still further.