Physics. — "*On the dielectric constants of liquid and solid hydrogen*". By M. WOLFKE and H. KAMERLINGH ONNES. Communication N°. 171*c* from the Physical Laboratory at Leiden.

(Communicated at the meeting of September 27, 1924.)

Preliminary experiments on the dielectric constant of liquid hydrogen were already earlier undertaken by G. BREIT and H. KAMERLINGH ONNES [1]). We have now carried out these measurements with greater accuracy, and also determined the dielectric constant of solid hydrogen.

These measurements were made by the same method and with the same apparatus as was employed in the determination of the dielectric constant of liquid helium [2]); we may, therefore, refer to this work for all particulars.

The dielectric constant was calculated as ratio of the capacity of the condenser filled with liquid, resp. solid hydrogen to its capacity at the same temperature in vacuo. The accuracy of the measurement is about 0.1 °/₀.

In order to estimate the possible error which might arise through the conduction current in the filled condenser, we have approximately determined the specific resistance of the liquid and the solid hydrogen galvanometrically. We obtained the following results: 1.3×10^9 Ohm for liquid hydrogen and more than 10^{11} Ohm for solid hydrogen calculated per cm^2 cross section and cm length. Hence both in liquid and in solid condition hydrogen is such a good insulator, that there is no call for a correction on account of the conduction in the condenser.

The measurements were made with three different wavelengths, between 400 and 600 m. wavelength. For every wavelength six measurements were made, and the arithmetical mean was taken from these values; the final value was calculated from these means by the method of least squares.

In the measurements at the temperature of the boiling point under

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[1]) These Proceedings 27, p. 617, Leiden Comm. No. 171*a*.

[2]) M. WOLFKE and H. KAMERLINGH ONNES, these Proceedings 27, p. 621; Leiden Comm. No. 171*b*.

atmospheric pressure the glass vessel [1]) containing the condenser was filled with liquid hydrogen, and tightly closed. This vessel was placed in a DEWAR vessel, also filled with liquid hydrogen, which could evaporate freely into the air. A DEWAR vessel with liquid air served as protection against the heat from outside. For the capacity of the condenser filled with hydrogen we obtained in this way the following values in cm of the measuring scale:

capacity:	210.2	210.4	210.6	210.3	210.5	210.1
weight:	5.56	8.85	1.37	45.5	24.4	8.92.

Taking the given weights into account, we get as mean value:

$$210.3. \qquad (1)$$

After these measurements had been completed, the hydrogen was removed from the condenser vessel by means of a vacuumpump, and then the vessel was evacuated. In the same way as before, the capacity of the evacuated condenser was determined; we obtained the following values:

capacity:	171.7	171.9	171.8	172.1	171.5	172.0
weight:	33.3	0.99	2.38	1.91	9.9	8.47,

with a corresponding mean value of:

$$171.7. \qquad (2)$$ [2])

The ratio of the two capacities (1) and (2) gives the required value of the dielectric constant of liquid hydrogen:

$$K = \frac{210.3}{171.7} = 1.225. \qquad (3)$$

A second series of values measured in the same way gave the following value for the dielectric constant of the liquid hydrogen

$$K = 1.224. \qquad (4)$$

These two values (3) and (4) differ less from each other than 0.08 %. We consider the first value (3) as more accurate, as in the second measurement the determination of the capacity of the evacuated condenser did not immediately follow the measurement of the capacity of the filled condenser, but was made later. The dielectric constant

[1]) M. WOLFKE and H. KAMERLINGH ONNES, loc. cit. cf. fig. 3.

[2]) The coincidence with the value found for the capacity of the evacuated condenser at atmosphere temperature, given in the preceding communication, is only accidental; cf. also the following footnote.

of liquid hydrogen at the boilingpoint under atmospheric pressure has thus the following value:

$$K = 1.225 \pm 0.001.$$

Besides those determinations we have carried out experiments on the dependence of the dielectric constant of liquid and solid hydrogen on temperature.

For this purpose the DEWAR vessel containing the hydrogen bath, in which the glass vessel with the condenser was placed, was brought in connexion with a vacuumpump. Through sucking off of the evaporating hydrogen the vapour pressure could be reduced, and thus the temperature of the hydrogen bath could be lowered. An arrangement regulating the velocity of the sucking off of the hydrogen vapour enabled us to keep the pressure and the temperature constant throughout a measurement.

On account of the slight expansion of metals at low temperatures the capacity of the evacuated condenser was assumed to be constant, and put at the value 170.7 like the value found before.[1])

The temperatures corresponding to the measured pressures of the hydrogen vapour in equilibrium with the liquid phase have been taken from the work of P. G. CATH and H. KAMERLINGH ONNES[2]).

The temperatures corresponding to the vapour pressures of the solid phase, were calculated from J. E. VERSCHAFFELT's equation[3]).

The measurements of the dielectric constant in these experiments do not claim the same degree of accuracy as the earlier ones, especially those of solid hydrogen at low temperatures are not very accurate. The measurements had to be made very quickly, and therefore only two readings were made for each value, and there is no guarantee that temperature equilibrium between the hydrogen bath and the interior of the condenser had been sufficiently reached.

Table I gives a survey of the results obtained.

It follows from the above values that *the dielectric constant of liquid hydrogen increases with falling temperature to within the neigh-*

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[1]) Viz. at the boiling point of helium, cf. the preceding communication. The determinations at the latter temperature have been preceded by those at the boiling point of liquid hydrogen and have been followed by those at the lower hydrogen temperatures. Between the first and the second series of measurements the relative value of the capacity has changed a small amount (from 171.7 to 170.7), the apparatus having been modified somewhat in the mean time.

[2]) P. G. CATH and H. KAMERLINGH ONNES, these Proceedings 20, p. 1155; Leiden Comm. No. 152a.

[3]) Fourth Intern. Congres of Refrig. Londen 1924, Reports and Comm. First Intern. Comm. Intern. Inst. of Refr. No. 2, p. 23; Arch. Néerl. d. Sc. ex. et nat. (III A) 8 (1924).

TABLE I.

Bath	Pressure of the bath	T.	K
liquid hydrogen	755 mm. Hg	20.33 °K	1.225
„ „	357	18.05	1.234
„ „	80	14.64	1.241
solid „	58	14.0	1.248
„ „	42	13.5	1.224
„ „	35	13.3	1.212
„ „	32	13.2	1.211

bourhood of the meltingpoint, where it reaches its highest value, after which it decreases in solid hydrogen on further decrease of temperature.

This behaviour is often shown by the dielectric constant on transition of a substance from the liquid phase to the solid phase [1]).

We will also use the values of the dielectric constant of hydrogen to test the CLAUSIUS-MOSOTTI formula. Only the first three values of the table, which refer to the liquid state of hydrogen, can be used for this purpose. We derive the corresponding densities of the liquid hydrogen bij interpolation from the results of E. MATHIAS, C. A. CROMMELIN and H. KAMERLINGH ONNES [2]), and we then calculate the constants of the CLAUSIUS-MOSOTTI formula:

$$\frac{K-1}{K+2} \cdot \frac{1}{D} = const.$$

The calculated values are recorded in the following table.

TABLE II.

T	D	K	$\frac{K-1}{K+2} \cdot \frac{1}{D}$
20.33 °K	0.0709	1.225	0.984
18.05	0.0733	1.234	0.987
14.64	0.0765	1.241	0.973

We see from this that the CLAUSIUS-MOSOTTI formula is satisfied to about 1 °/₀ in liquid hydrogen.

[1]) Cf. H. ISNARDI, Zs. f. Phys. 9 (1922) p. 153.

[2]) These Proceedings 29, p. 935; Leiden Comm. No. 154*b*.