Citation:

Beckman, A. & H. Kamerlingh Onnes, On piezo-electric and pyro-electric properties of quartz at low temperatures down to that of liquid hydrogen, in:
KNAW, Proceedings, 15 II, 1912-1913, Amsterdam, 1913, pp. 1380-1383

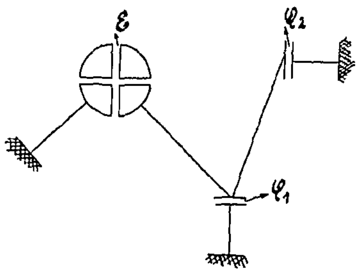
Physics. — "*On piezo-electric and pyro-electric properties of quartz at low temperatures down to that of liquid hydrogen.*" By H. KAMERLINGH ONNES and Mrs. ANNA BECKMAN. Communication N°. 132*f* from the Physical Laboratory at Leiden.

(Communicated in the meeting of February 22, 1913).

§ 1. *Introduction.* As many qualities of solid bodies are much simplified at very low temperatures by the considerable decrease of the caloric motion, it seemed desirable to examine also the piezo- and pyro-electric effects under these probably favourable circumstances. In order to make a preliminary inquiry into this branch of the subject we have measured the piezo-electric modulus of quartz, perpendicular to the axis, down to the temperatures of liquid hydrogen.

Then we have also, at the temperatures of liquid air and liquid hydrogen, observed the pyro-electric phenomenon of quartz, which FRIEDEL, CURIE and others have examined at higher temperatures.

§ 2. *Measurements of the piezo-electricity of quartz at low temperatures.* The measurements were effected by the generation of electricity on a quartz plate, which was kept at low temperatures and compared with a similar plate at ordinary temperature. The generated charge was measured with a quadrant electrometer. Both the plates were of the same sort as is used in the ordinary CURIE's instrument, that is to say, they were cut out of the crystal parallel to the optical axis and with the broadest side perpendicular to one of the electrical axis.



They were 7—8 cm. long, 2 cm. broad and 0.06 cm. thick. The two broad sides were coated with tin [1]). One of the tin coatings of each plate was earthed, the two others were metallically connected with one another and with one pair of quadrants of the electrometer, as is shown in the figure. The other pair of quadrants was earthed.

All the connections were enclosed in brass tubes, which were in

[1]) The tinfoils were apt to get loose from the plate in the liquid oxygen, which gave rise to blisters; it would of course be better to employ a platinized quartz plate, silvered: Then, too, the use of cementing material between the metal coating and the quartz would be obviated.

connection with the earth. The electrometer needle was kept at a constant potential of 120 volts.

The quartz plate Q_1 was suspended in an earthed metal case and carried a scale pan, on which weights could be placed, in order to stretch the plate. Q_2 was put in a DEWAR glass; its lower end was fastened in a brass support, which was carried by the cap of the vacuum vessel; the uppermost end was suspended by a brass rod to one arm of a balance, whose other arm carried a scale, which could be loaded with weights. In order to be able to close the vessel hermetically (which was quite necessary), and at the same time make the free movement of the rod through the cover possible, it was simplest, for these preliminary measurements, to use an elastic india rubber tube which closed round the rod and the tube in the cap. As we shall see this had only a slight effect on the relative measurements.

Within the glass the quartz plate and the support were surrounded by a brass net in connection with the earth.

The measurements were made in the following way: first the plate Q_1 was stretched by a weight (500 gr.) and the deviation of the electrometer needle was observed. Then this plate was earthed, and when the connection with the earth was broken, the weight was removed and the deviation of the electrometer to the other side was observed. The sum of these deviations is proportional to the quantity of electricity generated. Then the electricity which was generated on Q_2 was measured in the same way. Immediately before and after the measurements the electrometer was calibrated with a WESTON element. The sensibility changed very little.

The insulation was generally very good, so that there was seldom any need of making corrections for leakage.

Always five or seven turnings of the electrometer needle were observed. From these the eventual corrections for incomplete insulation could be calculated.

§ 3. *Results.* I. Both the quartz plates at room temperature ($T = 290°$ K.).

The deflections were

						mean values
Q_1	126.7	127.2	127.0	127.6	127.4	127.2
Q_2	163.7	164.0	163.6	163.2	163.3	163.6

The WESTON element (1.018 Volt) gave 34.4.

The capacity of the electrometer, of the connections to Q_1 and of Q_1 itself was about 150 cm., that of the connection to Q_2 and of Q_2 was about 100 cm. By the cooling of Q_2 its capacity changes.

II. Q_2 in oxygen boiling under a pressure of 21 cm. $T = 78°.5$ K.

			mean values
Q_1	130.6	130.1	130.3
Q_2	165.2	165.7	165.4

One WESTON element 34.4.

III. Q_2 in boiling hydrogen, $T = 20°.3$ K.

				mean values
Q_1	129.6	130.5	130.0	130.0
Q_2	165.4	165.5	165.4	165.4

One WESTON 34.4.

IV. Q_2 at ordinary temperature, $T = 290°$ K.

						mean values
Q_1	127.1	127.4	127.1	126.8	127.0	127.0
Q_2	162.5	163.0	162 8	163.1	162.7	162.8

One WESTON 34.3.

In order to examine the influence of the elastic connection between Q_2 and the cap of the vacuum vessel, two measurements were made without the elastic tube, one at ordinary temperature and the other in liquid air. These gave

V. Q_2 at ordinary temperature, $T = 290°$ K.

						mean values
Q_1	126.2	126 8	127.7	127.5	127.1	127.0
Q_2	167.4	168.1	168.1	167.8	168.3	167.9

One WESTON 34.3.

VI. Q_2 at the temperature of liquid air, $T = 80°$ K.

						mean values
Q_1	129.3	129.6	129.8	129.7	129.9	129.7
Q_2	168.8	169.3	170.1	169.2	169.4	169.4

One WESTON 34.3.

By immersing Q_2 into the bath of low temperature the deviations are thereby changed for both the plates. The change was at the measurement

II	($T = 78°.5$ K.)	Q_1 + 2.4%	Q_2 + 1.1%
III	20.3	2.2	1.0
VI	80.0	2.1	0.9

The electricity generated on Q_2 was thus at all events less than at ordinary temperature. The decrease was 1 3 $^0/_{00}$, 1.2 $^0/_{00}$, 1.2 $^0/_{00}$. The influence of the elastic connection falls within the limits of errors of observation. In the absolute measurements the connection causes a decrease of about 3 $^0/_0$.

Thus we may conclude that the cooling from 290° K. to 80° K. causes a decrease of 1.2 $^0/_0$ in the piezo-electric modulus. A further cooling from 80° to 20° causes a much smaller change, it appears even less than 2 $^0/_{00}$ The importance of this result is perhaps that the change in the piezo-electricity by cooling to low temperatures seems to take place chiefly above the temperature of liquid air.

§ 4. *Pyro-electricity of quartz.* As has already been said, we also made some observations on the pyro-electricity of quartz at the temperatures of liquid air and hydrogen. The pressure under which the liquid round Q_2 boiled was changed. By the change of temperature, which is the consequence thereof, a pyro-electric charge is generated on Q_2. The deflections of the electrometer were

for 90° K to 86.5° K	+ 27.5 mm.	or per degree	+ 8 5 mm.	mean value per degree 7.8 mm.
86.5 ,, 82.5	+ 27.0 ,,	,, ,, ,,	+ 6.5 ,,	
82.5 ,, 78.5	+ 27.5 ,,	,, ,, ,,	+ 8.5 ,,	
78.5 ,, 90	— 89.0 ,,	,, ,, ,,	— 7.5 ,,	
20.3° K ,, 15.2° K	+ 6.5 ,,	,, ,, ,,	+ 1.4 mm.	1.6
15 2 ,, ,, 20.3 ,,	— 7.8 ,,	,, ,, ,,	— 1.6 ,,	
between 20.3,, and 15.8,,	± 14.3	(double deflect.)	± 1.7 ,,	

The deviation 7.8 per degree at the temperatures of liquid oxygen
1.6 per degree at the temperatures of liquid hydrogen

has by an increase of temperature the same direction as by a stretching of the plate.

We note that the generated pyro-electric charge is about proportional to the absolute temperature.

We wish to record our heartiest thanks to Mr. G. HOLST, assistant at the physical laboratory, for his assistance at our experiments.

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