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Physics. — *"Note on the insulating power of liquid air for high potentials and on the* KERR *electro-optic effect of liquid air."* By Prof. ZEEMAN.

1. In a series of experiments undertaken in order to look for an influence of an electric field on radiation frequency, an account of which I intend to publish rather soon, a small condenser consisting of metal plates immersed in liquid air was made use of. A selectively absorbing crystal the optical behaviour of which was to be studied, when under electric influence, was introduced between the plates of the condenser. A first question to be answered relates to the value of the electric forces which can be sustained by liquid air. The fact that the dielectric constants of various liquid gases could be measured by LINDE[1]), DEWAR and FLEMING[2]), and in the Leyden laboratory by HASENÖHRL[3]), proves that the gases investigated, among which figure also oxygen and liquid air, are good insulators. The methods of measurement used only involve, however, low voltages. HASENÖHRL gives for the sparklength at the terminals of his secondary wire 0.05 m.m. The small condenser in FLEMING and DEWAR's experiments is charged with 100 volts. The excellent insulating power of liquid air under still much higher potentials, is illustrated in a separate experiment due to the last named physicists, but which only came under my notice while writing the present paper[4]).

The high potentials in my experiments were obtained by means of a motor-driven influence machine. In order to keep the potentials as constant as possible, the arrangement given in the subjoined figure was used; it is the one often employed in analogous investigations. The condenser plates are connected to the inside and outside surfaces of a Leyden jar; between the machine and the jar a very high resis-

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[1]) LINDE. Wiedeman Ann. 56. p. 546. 1895.

[2]) FLEMING and DEWAR. Proc. R. S. London. p. 358. Vol. 60. 1896.

[3]) HASENÖHRL. Leiden, Communications n⁰. 52. These Proc. II, p. 211.

[4]) "As a further instance of the very high insulating power of liquid air, we may mention that we charged the small condenser when immersed in liquid air with a Wimshurst electrical machine, and, after insulating the condenser and waiting a few moments, closed the terminals of the condenser by a wire. A small spark was seen at the contacts. We have constructed a little Leyden jar, the dielectric of which was liquid air, and the coatings the aluminium plates. This liquid Leyden jar held its charge perfectly." l. c. p. 361.

It would have been possible in the light of this experiment to shorten somewhat our §§ 1—4.

tance is introduced. Two fine points or two bundles of fine needles shunt the machine. By varying the distance between the points or the needles the potential can be regulated to a given value.

2. The small condenser was placed inside an unsilvered Dewar vacuum vessel of 5,5 cm. internal diameter. The plates were of 4,5 cm. length, 1 cm. width, their distance being 3 mm. They were soldered to copper wires, covered by glass over their entire length. The wires passed through the ebonite cover of the vacuum vessel, their distance being 2,5 cm. It was immediately clear that liquid air was a very perfect insulator. Loud, brilliant sparks could be taken by means of a discharging rod from the wires in the neighbourhood of the ebonite cover. The potential could be estimated by means of a spark micrometer. Potentials of 30.000 Volts were obtained; this gives, the distance of the condenser plates being $^1/_3$ cm., an electric force of 90.000 Volt/cm. This value, however, does not indicate the maximum electric intensity in liquid air, nor the one always obtainable.

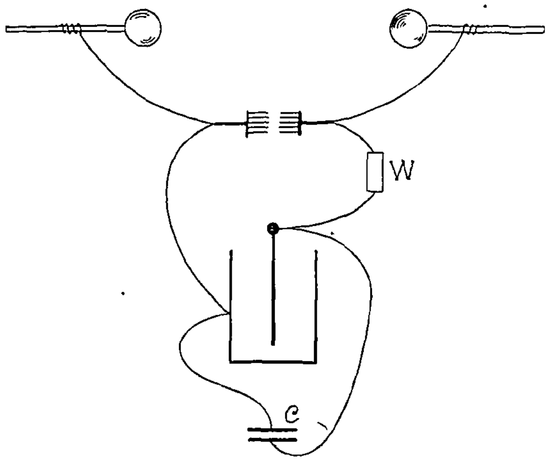

Fig. 1.

3. After continuing the observations for a short time the intensity of the sparks in the micrometer rapidly diminished. Even after removing the micrometer none or only poor little sparks could be got from the wires entering the vacuum vessel. It seemed probable that the moisture of the atmosphere after condensing on the ebonite cover produced a conducting layer which prevented any considerable difference of potential between the wires. A small box of glass and ebonite was placed on the ebonite cover and the air of the box dried by means of some chloride of calcium. The result was extremely satisfactory. There was now no difficulty of maintaining very high potentials for hours.

4. Next to the external perturbations resulting from a deposit on the ebonite cover, two other causes of irregularities, originating in the liquid air may be mentioned. One is due to small crystals of ice and solid carbon dioxide present in the liquid air. These small crystals are attracted by the electrically-charged plates, the liquid air becoming at the same time very transparent. A discharge between the plates is much favoured by the crystals. As soon as the plates are uncharged the crystals disperse into the liquid. If the air is freed from these crystals by filtration ¹), then there is still another cause of disturbance, viz. the generation of gas in the liquid air. The small bubbles take their origin from one or two points of the inner surface of the vessel, and the succeeding bubbles form a file moving irregularly through the liquid. As long as the small bubbles remain outside the space between the condenser plates they do not interfere with the voltage attainable between the plates. If, by some hydrodynamical accident, a gas bubble arrives between the plates their difference of potential immediately goes down, the discharge taking place under intense ebullition of the liquid.

The general conclusion to be drawn from these considerations is, that for attaining high potentials the liquid air must be carefully freed from impurities and that the visible generation of gas must be reduced as far as possible; the DEWAR vacuum vessel must be in excellent condition.

5. After being satisfied that it was possible to maintain high potentials for a considerable time, I tried to prove still more convincingly that large electric forces exist in the interior of the liquid air. For it were possible, though rather improbable, that a surface layer existed at the surface of the condenser plates so that there is a large potential gradient in the neighbourhood of the plates, but only a small one in the liquid air. If we succeed, however, to discover the KERR electro-optic effect in liquid air, we have proved at the same time the existence of large electric forces in the interior of the liquid.

6. It was to be expected that the electric double refraction of liquid air shall be small. Recently R. LEISER ²) succeeded in measuring the KERR electro-optic constant of several vapours and gases.

Notwithstanding his method was very sensitive he did not succeed in establishing an effect, even if the gases were under a pressure of 2 atmospheres, for nitrogen, oxygen, carbon monoxyde and nitric oxid.

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¹) The liquid air, which I had the pleasure to receive many times from the Leyden cryogenic laboratory, was remarkably transparent.

²) R. LEISER. Physikalische Zeitschr. p. 955. XII. 1911.

The same vaccuum vessel with immersed condenser referred to above (§§ 1—4) was also made use of for experiments concerning *electric double refraction of liquid air*. The optical arrangement is partially identical with the one recently described [1]) and figured below.

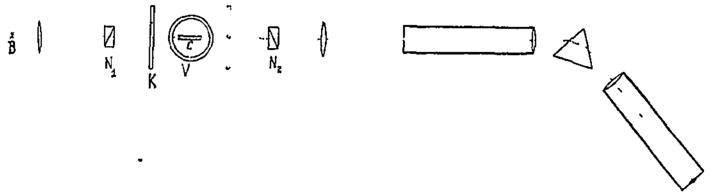

Fig. 2.

The light of an arc lamp B, traverses the nicol N_1, then the compensator, the vacuum vessel with condenser, the nicol N_2 and is finally analysed by means of a low dispersion spectroscope. An image of the black band exhibited by the compensator between crossed nicols is projected upon the slit of the spectroscope. In the former experiments referred to the spectroscope was absent.

The prismatic analysis had the following meaning. As is well-known the absorption spectrum of oxygen exhibits conspicuous bands. They are strongly developed by the 5.5 cm. of liquid air. As the vacuum vessel is not closed, and as the boiling-point of nitrogen is lower than that of oxygen, the former gas evaporates more quickly and the percentage of oxygen of the residual gas becomes gradually high. The wavelengths of the oxygen bands have been measured [2]) by OLSZEWSKI, LIVEING and DEWAR, and BACCEI. The most conspicuous bands, in the most luminous part of the spectrum, are at 581—573 and at 481—478. It seemed possible that the electric double refraction could have a considerable value in the neighbourhood of the absorption lines, being insensible in the other parts of the spectrum. In that case an effect would become apparent only by spectral analysis. In the cases of magnetic double refraction and of magnetic rotation of the plane of polarisation in sodium vapour the absorption lines indeed are lines of exception.

7. Before communicating the results of the investigation for double refraction, a difficulty in the observation must be mentioned. It is due to the strained condition of the imperfectly annealed walls of the vessel, causing *irregular* double refraction. As the four glass walls to be traversed by the light are all strained, it is not a matter

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[1]) P. ZEEMAN and C. M. HOOGENBOOM. These Proceedings November 1911.

[2]) KAYSER. Handbuch. Band III. S. 357

of surprise that it is only after some trials that a part of the glass wall is found remaining dark between crossed nicols. But even then the dark band, which is so extremely sensitive to small traces of double refraction, may be invisible. It is rather easy to project on the slit the black band of an ordinary BABINET-compensator. These compensators however proved to be not sensitive enough. At last we found a small part of the walls of the vacuum vessel which was in a state of ease, and admitted an observation to be made with a bar only slightly loaded. Probably some compensating device might be used with advantage (see § 9).

In the field of view of the spectroscope now appears the continuous spectrum with the vertical absorption lines due to oxygen and with an approximately horizontal band, which must change its position by eventual double refraction.

8. With this optical arrangement it was observed that by the gradual charging of the Leyden jar the horizontal band was displaced downwards; at a discharge of the liquid air condenser the band jumped back in its original position.

The double refraction is clearly visible along the whole spectrum. In the neighbourhood of the absorption bands no singular behaviour of the refraction was observed. The changes in the neighbourhood of the absorption bands certainly were not very large in comparison with the whole amount of double refraction. It is interesting to compare this result with observations of ELIAS[1]) concerning *magnetic* double refraction in a concentrated solution of erbium nitrate. Also in that case only very small anomalies were observed in the neighbourhood of the absorption lines.

Probably the absence of any large anomaly is in both cases due to the want of steepness of the curve representing the index of absorption as a function of the frequency.

9. In order to fix the sense of the electric double refraction in liquid air and to attempt at a rough approximation of its order of magnitude the following experiment was made. After the removal of the vacuum vessel (see fig. 2.) a thin strip of glass was introduced in the beam of light.

By compressing the strip in a vertical direction the dark band in the spectroscope moves downwards. Comparison of this result with § 8 shows that the electro-optic effect of liquid air is positive, like carbon disulfide.

The magnitude of the displacement in the case of the experiment

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[1]) ELIAS. Verhandl. deutsch physik. Gesellschaft. S. 958. 1910.

with an electric field of 50.000 Volt/cm. is comparable with that caused by the application of 1000 gms. on a strip of 15 mm. width.

According to WERTHEIM (Mascart. Traité d'Optique T. 2, p. 232) a load of 7 to 15 kilograms, say 10 kilograms per millimetre of width produces a relative difference of phase of $^1/_2\,\lambda$, so that with the strip under consideration a load of 140 kilogrammes would be required.[1] The estimated phase difference is therefore of the order of $^1/_2\,\lambda\,/\,140$, the electric force being 50.000 Volt/cm. From these data would follow a value for the KERR electro-optic constant of liquid air (oxygen) about 20 times smaller than that of carbon bisulfide.

Hence it need not astonish us that nobody has as yet succeeded in measuring the mentioned constant for oxygen under atmospheric pressure. Our numerical determination for liquid air has to be repeated with a better vacuum vessel. It must not be overlooked that the preceding observations (§ § 6—9), though satisfactory so far as they go, intend nothing more than establishing the existence of an effect and its order of magnitude; we see in its existence a very direct proof that liquid air is a substance, which represents extremely closely an ideal liquid insulator.

Physics. — "*Contribution to the theory of binary mixtures.*" XVII. By Prof. J. D. VAN DER WAALS.

The concentration of the gas phase between that of two coexisting liquid phases.

In the preceding contributions I discussed some forms of the curve for the course of T,x-figures of the plaitpoints. Leaving the cases in which closed figures occur, or those in which these curves do not extend to $x=0$ and $x=1$, on one side, I have only to deal with the cases beginning in the point $x=0$ and $T=T_{k_1}$, and terminating at $x=1$ and $T=T_{k_2}$. As such a curve must have a gradual and continuous course, and as no double points and cusps can occur in it, the course is always comparatively simple. Thus in the case treated in Contribution XIII, and drawn already in 1905 (These Proc. VIII p. 184) only a highest and a lowest value occur in fig. 3. Some particularities are, however, not perfectly accurate in this figure. So both in the highest and in the lowest point $\frac{dT}{dx}$ must be

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[1] c.f. RAYLEIGH. Phil. Mag (6) 4. p. 678 1902.