Physics. — *"Electric double refraction in some artificial clouds and vapours."* (First Part). By Prof. P. ZEEMAN and C. M. HOOGENBOOM.

(Communicated in the meeting of November 25, 1911).

1. Some time ago one of us [1]) suggested a method of attacking the problem to discover an influence of electric fields on radiation frequency, as predicted by VOIGT [2]) from theoretical considerations. The experiments installed according to the mentioned method have not yet come to a definite close.

We intend to give here a short account of a parallel series of observations relating to a closely connected subject, which were begun already a considerable time ago.

They relate to the KERR electro-optic effect, the double refraction induced by powerful electrostatic fields. Till now the effect has been specially studied in solids and liquids; we intend to investigate the behaviour of some clouds and vapours.

If it is once proved that under the influence of electric forces double refraction is induced in clouds of suspended particles, then the phenomena may be pursued further, when the size of the particles is taken smaller and smaller. By increasing the sensitiveness of the optical method clouds of smaller and smaller values of double refraction and ultimately gases can be investigated.

COTTON and MOUTON [3]) in the course of their remarkable investigation of magnetic double refraction induced in liquids have formulated the hypothesis, already proposed by Sir JOSEPH LARMOR for the KERR electro-optic effect, that in both cases the double refraction is due to a directive action of the external field on the molecules of the liquid. The only cause interfering with a parallel arrangement of the molecules is their thermal motion. LANGEVIN [4]) has shown in how simple a manner this hypothesis of the molecular orientation explains quantitatively the phenomena mentioned and also others.

It seems still somewhat questionable in how far the hypothesis of molecular orientation may be applied without modification to gases, at least if exhibiting narrow absorption bands.

The study of artificial clouds seems interesting for the reason that the suspended particles play the rôle of the molecules in the

[1]) ZEEMAN. These Proceedings. January 1911.

[2]) VOIGT. Magneto- und Electro-optik. 1908. Kapitel 9. u. 10.

[3]) COTTON et MOUTON. Ann. de Chim. et de Phys. T. 19. 1910, cf. also the interesting paper of CORBINO. Physik. Zeitschr. 11. S. 756. 1910.

[4]) LANGEVIN. Le Radium T. 7. Sept. 1910.

hypothesis of molecular orientation. It is now possible to examine separately also the constituent particles; they can be shown to possess (or not to possess), before their exposition to the field, magnetically, electrically, and optically the symmetry of a solid of revolution.

Especially interesting are those vapours which exhibit narrow absorption lines. In this case the opinion expressed by VOIGT [1]) that in the neighbourhood of absorption lines the amount of the double refraction will assume considerable values, can be tested. Independently of a special form of theory there is much to be said in favour of this opinion.

2. There is only one investigation known to us, which seems to give evidence that electric forces induce double refraction in some clouds. E. BLOCH [2]) while investigating the influence of dust particles on the electric conductivity of gases, made the following two observations.

In the first place he found that a cloud of sal-ammonia, if present between the plates of a condenser and if seen against a dark background in diffuse light, becomes white and more manifest as soon as the plates are charged.

The other observation made by BLOCH is this. A parallelepipedical box is closed at two opposite sides by glass windows; two other sides consist of metal plates at a distance of a few centimetres and can be connected to an electric machine. If a cloud of sal-ammonia is introduced and the box is placed between crossed Nicols, then the light of a source behind the polariser is seen at once with the making of the field. The rest is perhaps given best in the original: "La modification de la lumière diffusée (ou diffractée) par les particules est donc accompagnée d'une anisotropie du milieu constitué par l'air et les particules. Il reste donc à savoir s'il y a biréfringence ou dichroisme et à faire l'étude quantitative du phénomène".

It is indeed easily seen that by induced dichroism alone, the light would reappear. Let the electric force be horizontal, and suppose the light issuing from the polariser being polarised under azimuth of 45°. Let the vibrations be resolved into vertical and horizontal components. If we suppose that the horizontal vibrations are absorbed powerfully by the vapour, but the vertical ones not, and that there occur no differences of phase, then on emerging the resulting vibrations will have an azimuth larger than 45° and there will be therefore revival of light.

[1]) VOIGT. l.c. p. 381.

[2]) E. BLOCH. C. R. T. 146. 1908.

3. Our experiments prove that in a cloud of sal-ammonia there is only double refraction but no dichroism. (see § 4).

The light from a NERNST filament is made parallel by means of a lens and polarised in a plane inclined to the horizontal at 45°. The vapour or the cloud is introduced into a horizontal tube, which contains in many experiments interior plates connected with the source of electricity. The tube is closed by plates of thin coverglass; two side tubes served resp. for the introduction and for the egress of the vapours. The analysing Nicol, of course, follows after the tube.

The double refraction to be observed is so small that special means are necessary for observing and measuring it. Between the polariser and the tube we introduce a horizontal bar of glass, perpendicular to the beam of light[1]). Near the middle of its length the strip is supported by two small glass cylinders and subjected to a small flexure. It is therefore in a condition of strain and double refraction. Between crossed nicols there is revival of light, especially near the edges of the bar, while near the middle a horizontal band remains dark. It seams superfluous to comment upon the optical theory of the strained glass bar, which is rather simple and moreover given in many text-books. The most refined investigation made with the strained bar, is probably Lord RAYLEIGH'S, when discussing the question whether motion through the aether causes double refraction.[1])

The position of the band is determined by two horizontal wires inclosing it, and disposed close to the bar. If a double refracting substance, with horizontal and vertical principal directions, is introduced into the beam a motion of the band occurs, upwards or downwards, depending upon the sign of the double refraction.

The sensitiveness of the method can be changed within rather wide limits. It is increased, 1. by diminishing the loads at the ends of the bar, 2. by increasing the distance of the supporting cylinders. We are thus enabled to choose the sensibility according to circumstances.

The absolute value of the amount of double refraction was determined, at least for higher values, by means of a carefully constructed compensator of SOLEIL—BABINET. By its means the displaced band can be moved until it is again in its original position. The compensator is so mounted that it can be easily introduced into or removed out of the beam. For very small values of the double refraction it seems appropriate to use a second strip instead of the compensator, and to restore the original conditions of the field of view by a

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

flexure of this second bar in a suitable direction. We have not yet had occasion to try this method systematically.

In order to determine the sensitiveness of the method a thin vertical glass plate was introduced in the course of the light and the weight determined necessary to cause a marked shifting of the band. During this operation the compensator of SOLEIL—BABINET is removed. The constant determining the influence of one sided pressure on double refraction is measured in a separate experiment. The glass bar and the compensator are then used simultaneously. The difference of phase just perceptible was in our case $6.10^{-5}\,\lambda$.

4. The cloud of sal-ammonia was made in an anteroom, preceding the observation tube. The two gases, hydrochloric acid and ammonia, were introduced under slight pressure after being partially dried. After passing the observation tube the cloud escaped in the free atmosphere. The density of the cloud and the magnitude of its constituting particles could be chosen by regulating the ratio of the two gases.

The source of electricity was either an electrostatic machine or a transformer, allowing potentials between 1000 and 10000 Volts being used.

The question whether there is dichroism or double refraction (see § 2) could now be settled immediately. By dichroism a rotation of the plane of polarisation will occur, and therefore a *fading* of the dark band and not a displacement must take place. Double refraction shows itself by a displacement alone. Our first experiments with the sal-ammonia cloud at once made it clear that only double refraction is operative. The effect was nearly proportional to the square of the electric intensity.

If a transformer is used then a displacement of the dark band must take place as well; it can be easily calculated. The direction of the displacement of course depends upon the nature of the substance under consideration.

5. The results of our measurements will be given later on. The sign of the KERR-effect in the sal-ammonia cloud is opposite to that of ordinary glass.

6. We also tried to determine the relation of the specific values of the effects in the sal-ammonia cloud and in large crystals of salammonia. The latter were never faultless. Perhaps this circumstance accounts for the very small specific action found for a

separate crystal. The result seems too striking to be accepted without further evidence. Or would it be possible that the mobility of the particles in the large crystal is considerably reduced?

7. The experiment of § 4 proves very clearly that in the case of the KERR-effect there is a direct action of the field and not one due to a mechanical pressure from the condenser plates.

8. Besides clouds of sal-ammonia in different degrees of dilution, we have made observations with some other clouds; details will be given later. They were obtained by heating of substances in some cases, in others by chemical processes, among which we count also the process generating TYNDALL's actinic clouds. In some of our experiments we made use of dust clouds, the substance under review being first reduced to very fine powder and then blown by a current of air between the condenser plates. It is easy to obtain clouds in this manner with glass powder and with different salts of tartaric acid. The effect of a glass cloud is, as is to be expected, in the same sense as that of the original glass.

9. The method, resumed in § 3, and especially the combined use of a glass bar and a compensator of SOLEIL-BABINET (or of a second bar previously gauged), can be used to ascertain sign and magnitude of the KERR-effect of very small quantities of fluids. With condenser plates of only a few square millimeters' area and with voltages of a few hundreds Volts the KERR-effect in nitrobenzene is easily observed.

In order to obtain quantitative results a condenser of some extension in the direction of the beam is necessary. The greatest difficulty in all experiments on electric double refraction give the optical perturbations caused by heating effects from the part of the electric field, which interfere very seriously with observation. The time of observation must therefore be reduced as much as posible. The following mode of operation is advisable. Let the shift of the band be compensated as accurately as possible with the field on. Then put the field off. The band then is shifted again. It is now easily controlled whether the compensation was exact, by putting on the field for one moment. The time necessary to ascertain whether or not the dark band jumps back just inside the two horizontal wires is very short.