



Electro-optic observation on various liquids

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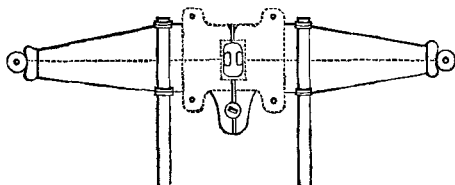
[FIFTH SERIES.]

AUGUST 1879.

XI. *Electro-optic Observations on various Liquids.* By JOHN KERR, LL.D., *Free Church Training College, Glasgow*.*.

IN two short papers which were published some years ago, I showed how I had succeeded in inducing a power of double refraction in glass, carbon disulphide, and several other dielectrics, by the application of electric force†. In this paper I propose to offer some notes of a later and more extended series of experiments on the same subject. The methods applied are, for the most part, much the same in principle now as formerly; but my means of observation have been greatly amplified and improved, chiefly by assistance from the Government Fund. I begin with the construction of the most important part of the apparatus.

1. *New Plate Cell.*—This piece is represented in the adja-



cent diagram. It is made of a block of carefully selected

* Communicated by the Author.

† "On a new Relation between Electricity and Light," *Philosophical Magazine*, November and December 1875.

plate glass, $\frac{3}{4}$ of an inch thick, 8 inches long, and originally, for convenience in boring, about 4 inches wide. The first step in the construction is made with steel drill and turning-lathe. Two fine holes, about $\frac{1}{10}$ of an inch wide, are drilled right through the block, one parallel to its length, and the other crossing the former at right angles in the centre of the piece. Each of the borings is parallel to, and equidistant from, the two plate-faces.

The plate is now reduced to a more convenient width, one inch of it (as it stands in the diagram) being ground away at the top from end to end, and similarly one inch at the bottom, except that a piece with sensibly square section is left projecting below the plate, round the vertical boring as axis. The plate is also made to taper at each end, as in the diagram, though this is not essential.

Two other borings are now made, each through the plate, at right angles to the plate-faces. One is a tunnel, concentric with the plate, shaped as in the diagram, about an inch in height, and $\frac{5}{8}$ inch in width, and leaving a good margin of polished plate-surface all round its mouths; the other is a slightly tapering hole through the projecting piece mentioned above, into which is fitted afterwards a stopcock of glass, which is easily worked by hand so as to open and close the vertical boring. The sides of the tunnel are carefully finished; they are sensibly plane, and perpendicular to the long boring and to the plate-faces. In these and the following operations, the polish of the plate is preserved with care, for which purpose the surfaces are permanently guarded by a shell of hard varnish.

The electric terminals within the tunnel are two balls of brass, originally spherical, and a quarter inch in diameter. Two thin shafts of brass pass from the ends of the block through the long borings, and are screwed firmly into the balls. Round the outer end of each of the shafts is a pierced plug or washer of india-rubber; outside of this is a perforated disk of brass, of rather smaller diameter than the washer, and well rounded, which moves freely along the shaft; and outside of each disk is a brass ball of $\frac{1}{2}$ inch diameter, which screws onto the end of the shaft. To provide for the insertion of conducting wires into these outer balls, two fine holes are bored through each of them, along diameters perpendicular to each other and to the shaft. The outer balls are screwed along the shafts until the washers are very strongly compressed. To prevent all possibility of leakage at the junction of inner balls and block, each of the long borings has been widened a little at the inner

end into a conical funnel; each of the inner balls also has been backed by a zone of lead.

At this stage of the construction, when the small spheres were seen to be symmetrically and securely placed in the tunnel, they were taken out, and very carefully flattened in the turning-lathe, so as to present approximately plane but still well rounded faces to each other; and they were then electroplated with a shell of silver as thick as writing-paper. As the balls lie finally in the cell, their least distance from each other is exactly $\frac{1}{8}$ inch.

The cell is closed by two panes of the finest plate glass, about $\frac{1}{16}$ inch thick, and 2 inches square, which are simply kept upon the plate faces of the block by pressure. The press is made of two small planks of mahogany, shaped as shown by the dotted lines in the diagram, and connected at the corners by four square-headed screw-nails, each provided with a bat's-tail nut; but in working the cell, I find two diagonally opposite screws quite sufficient in most cases. Between the planks and glass are two thin sheets of india-rubber cloth, these, as well as the planks, being channelled neatly in continuation of the tunnel.

The whole piece is supported by two fine pillars of glass, which are firmly fastened to the block by coils of silk thread. The pillars terminate below in a solid wooden stand. When the cell is in position on the experimental table, the two faces of the plate of liquid are vertical, and the axis of the electric field, or the straight line joining the centres of the inner balls, is horizontal.

The supporting pillars, as well as the ends of the cell-block, are covered with a thick shell of lac varnish.

I think that I have now mentioned every thing essential to the cell, except a small stopper of glass, which, at the beginning of each experiment, is dropped into the mouth of the vertical boring. It prevents the entrance of stray particles of dust, and is of use also in restraining evaporation when the cell is charged with a very volatile liquid. This plate cell is far superior to the old one described in the second of my former papers; it gives finer optical effects, and is ever so much more easily handled.

2. Working of the Cell.—To charge the cell with a liquid, I always use a small filtering funnel drawn out into a fine end, which passes along the upper boring, quite through the roof of the tunnel, leaving a narrow surrounding space for escape of air. When the charge of liquid is found to be not sufficiently clean, the cell is emptied at once by turning the lower cock, and is then charged again from the bottle as before; and

a good many repetitions of this operation are sometimes required before the charge is sensibly free from specks of solid matter.

When the cell has to be charged with a new liquid, the press is unscrewed, the planks and panes are removed, the faces of the block are cleaned, two clean panes are laid against the mouths of the tunnel, and held there while the cell is thoroughly rinsed with a proper solvent. The panes are removed, the faces of the block are again cleaned, two clean panes are placed as before, and the rinsing is repeated. Half-a-dozen thorough rinsings with ether and alcohol are generally sufficient to prepare the cell perfectly for any new liquid.

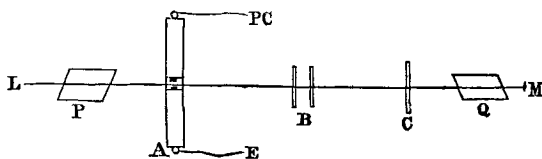
3. *Optical Compensator of Strained Glass.*—In the following experiments, I require continually to introduce definite and very faint birefringent actions at some point between polarizer and analyzer. The pieces which I employ for this purpose are perfectly rectangular slips, all cut out of one carefully selected plate of glass $\frac{1}{16}$ of an inch thick, and all of the same dimensions, width $\frac{3}{8}$ of an inch, length 7 inches. When such a slip is extended, it acts upon the transmitted light as a positive uniaxal with axis along the line of tension; and when it is compressed it acts as a negative uniaxal with axis along the line of compression. These optical actions are in most cases very definite and sensibly pure, though perhaps never perfect as the actions of good natural crystals.

4. *Hand Compensator.*—This is one of the slips (3), worked by hand in the manner described in my former papers. It is held between the first and second Nicols, immediately in front of the latter, with its faces perpendicular to the ray, and its length inclined at 45° to the plane of polarization. Kept steadily in position, it is strained by an effort of hands or fingers at each end, the axes of the couples applied being parallel to the ray, so that one edge of the slip is extended and the opposite edge compressed. According to the statement already made in (3), the extended and compressed parts of the slip act respectively as positive and negative uniaxals with axes parallel to the edges. When the glass is chosen with ordinary care, and preserved from any considerable changes of temperature during the observation, these optical actions are (to sense) perfectly pure, tension of one slip being always totally neutralizable by parallel compression or perpendicular tension of another slip.

5. *Fixed Compensator.*—This is one of the standard slips (3), which hangs freely in a constant vertical position from a purposely constructed stand. To give the required effect of

double refraction, the slip is simply stretched along its length by weights attached to its lower end. The arrangements for this piece were somewhat troublesome, but not such as to require a particular description. There is no cement used in its construction. The glass is attached to the stand above, and to the weights below, by double bands of thin leather, which are folded on the two ends of the slip, and kept adherent to the glass by small blocks of wood and light clamping-pieces of brass. The fixed compensator thus constructed acts very well up to a tension of sixteen pounds; and beyond this I have not yet gone.

6. *Arrangement of the Pieces.*—The optical effects obtained are sensibly modified by very small changes in the source of light, and in the positions of the pieces; but I shall not dwell upon these variations here, as they were noticed at some length in the second of my former papers. In all cases, the acting ray is horizontal, undeviated through its whole course, and about a foot distant from the table which supports all the pieces. Of the various arrangements tried, the following is, I think, the best upon the whole. The diagram shows all the pieces in horizontal section through the ray LM, L being the source of light, and M the observer's eye. L is a flat paraffin-



flame presented edgewise; P is the polarizing Nicol; A is the dielectric cell (1), having its outer balls connected by copper wires, one with the prime conductor and the other with earth; B is a couple of stationary compensating plates of glass (3), hanging vertically, and mounted so as to admit of the attachment of stretching weights to one or the other or both (5); C is a neutralizing plate which is sometimes required in measurements and in the more delicate observations; Q is the analyzing Nicol. The distance PQ is from 40 to 60 inches. The hand compensator is not shown in the diagram; when used, it is held between the pieces C and Q.

7. *Conduct of an Observation.*—The pieces are brought most conveniently into the line LM in a certain order of succession. The piece first placed is the polarizer P: it is laid carefully with its principal section at 45° to the horizon—that is, at 45° to what is afterwards the axis of the electric field. The ana-

lyzer Q is then laid so as to suit the observer's eye, and is turned into the position of perfect extinction ; and this being done, the two Nicols are left untouched, if possible, till the end of the experiment. The cell A, with conducting wires led from its outer balls to prime conductor and earth respectively, is now put in position under direction from the observer, who sits at the polariscope, and restores the light by the use of the hand compensator. When A is well placed, the line LM is perpendicular to the plate-faces of the cell, and the object restored by the hand compensator is a fine streak of light, passing midway between the balls in the cell, and projecting well above and below them. When this has been done once for all, the cell is left unmoved throughout the experiment. The fixed compensator B, containing either one plate or two, is now placed carefully, so that the line LM passes through the centre of each plate in a direction perpendicular to its faces. The last piece C is not required always, but only when the purity of initial extinction in the polariscope has been in any degree lost by the introduction of A or B ; it is a piece of common plate, the more irregular in temper the better, about $\frac{1}{8}$ of an inch thick, fixed in a movable stand ; its modes of application and action are precisely the same as those of the larger neutralizing plate described in my first paper. When things have been thus arranged, the cell is charged with clean liquid (2), the observer sits at the polariscope, and, the initial extinction being still unimpaired, the electric machine is set in motion.

Definite Chemical Compounds.

8. *Carbon Disulphide as a Dielectric.*—My first trial of the new cell was with this liquid, which is much the best dielectric yet discovered. The arrangements and procedure are exactly as described in the last two articles; the cell is charged with perfectly clean carbon disulphide, and the initial extinction is perfect. A small movement of the machine, one turn or less, gives a very fine restoration of the light in the polariscope. As the potential rises, the light increases steadily till it is quite brilliant ; but if a spark be taken upon the knuckle from the prime conductor at any point in this process, the phenomenon vanishes instantly.

9. *Character of the Optical Effect.*—The preceding experiment is repeated, with the addition of the hand compensator (4). The compensating slip is put in position with its length horizontal, and the initial extinction is found to be unimpaired ; the light is then restored steadily by electric action, and the slip is successively stretched and compressed with forces in-

creasing continuously from zero. Horizontal tension is found to strengthen the effect of electrical action in every case, while horizontal compression, with similarly perfect distinctness and regularity, weakens the effect down to sensibly pure extinction. When the electric action is feeble, a certain small compression of the compensator extinguishes the electrically restored light as a whole, or simultaneously in all its parts; but when the action is intense, the axial part of the field requires a greater compression than the outer parts, and the extinction-phenomena take the form of two dark bands, which will be particularly described immediately.

When the plane of polarization of the light rendered by the first Nicol is either horizontal or vertical, either parallel or perpendicular to the lines of force, and the second Nicol is at pure extinction, the effects of electrization are evanescent; if they do appear, they are irregular in character and trifling in quantity.

There is certainly no rotation of the plane of polarization in the present case; for when the light restored by electric force is tried by small rotations of the second Nicol in contrary directions from the position of initial extinction, it is found to be similarly and equally affected by the two movements.

The action of dielectrified carbon disulphide upon transmitted light is therefore similar to that of *glass extended in a direction parallel to the lines of force*: it is a sensibly pure case of what is known in optics as a *uniaxially birefringent action*, the axis being *parallel* to the lines of force, and the action *positive*. Of two component vibrations, which are polarized in planes respectively *parallel* and *perpendicular* to the lines of force, the *latter* is relatively *retarded*.

10. *Carbon Disulphide as an Insulator*.—To test the insulating power of this and other liquids, I compare the striking-distance of the prime conductor when the wire connecting it with the cell is in position and out successively. When the cell is charged with carbon disulphide the result is decisive. All the pieces being placed as in the experiments just described, the machine is worked at an ordinary rate, and sparks are drawn from the prime conductor on the knuckle, or on a metallic ball connected with earth; the wire from prime conductor to cell is then removed, and sparks are again drawn from the prime conductor now simply insulated. I have seen very little perceptible difference (if any) between the two cases, the sparks being of much the same density and length when the connecting wire is in position and when it is out.

I present this fact prominently, because it has an important bearing on the interpretation of the electro-optic experiment

(8). It would be rash to assert that there is no considerable discharge of electricity through the cell in the course of that experiment. On the contrary, I think that when the wires are in position and the machine working, there is a certain quantity of convective discharge through the liquid. But the present observation shows, to a certainty, that the shell of bisulphide in the cell, though not more than one eighth of an inch thick, is able to keep the two inner balls at a large difference of potentials, a larger difference than would be supported under similar conditions by more than an inch of air. The liquid is therefore a good insulator; and the restoration of the light by electrization is due, in all probability, to electrostatic inductive action through the liquid. Up to this point I have merely given a revision of observations made long ago with the old plate cell, and published in the second of my former papers.

11. *Extinction-bands in CS₂*.—The cell is charged with clean carbon disulphide, and the pieces all stand as in the diagram of (6), the principal section of the first Nicol being inclined at 45° to the horizon, and the second Nicol being at pure extinction. The correctness of the arrangements is tested by a repetition of the electro-optic experiment with the hand compensator (9). Matters being thus arranged, I begin now by attaching a weight of some pounds, say eight or nine, to one of the fixed compensating slips B (6). The experiment begins thus with a strong permanent restoration from extinction in the polariscope, the restoration being due to vertical tension of glass, which is here optically equivalent to horizontal compression of glass, and therefore optically contrary to the electric action (9). It should be remembered that the object now restored in the polariscope is a fine vertical streak of flame-light, passing through the centre of the electric field, not encroaching on either ball, but projecting well above the balls, and also well below. Things being thus prepared, the observer sits at the polariscope, and the machine is worked at a moderate rate.

The first thing observed is a broad horizontal band, very dim and ill-defined, which crosses the flame in the axial part of the electric field. As the potential of prime conductor and inductive ball rises, the band comes out more and more definitely, and darkens by degrees till it is perfectly black, every trace of that part of the flame having disappeared. As the potential still rises the flame begins to reappear in a faint speck or patch at the centre of the band. The patch brightens and widens gradually till the one band along the axis is clearly broken up into two, lying symmetrically on opposite sides of the axis,

and concave to each other. As the potential still rises, the bands move symmetrically outwards from the axis, dividing the flame into three large segments which are sensibly of equal brightness. And when the electric action is at the strongest, near spark-discharge through the liquid, the bands cross the flame at points very little, if so much as, outside of the cylinder which envelops the two balls. The bands are still intensely black and well-defined where they cross the flame; and they are quite distinct in their whole course, as fine arches resting on the two balls, and spanning the intermediate field. When the machine is stopped, and the potential falls to zero more or less slowly, the optical effect passes through the same phases, but of course in reversed order.

12. This fine experiment presents a case of what is known in optics as the cross duplication of positive uniaxal plates, the axis of the compensating slip being vertical, and that of the liquid plate horizontal. The birefringent action of the dielectric plate is not uniform either in time or space, but increases in time at any given point of the field as the potential rises, and diminishes at each instant regularly in space, outwards from the axis of the electric field; and this consideration affords a sufficient general explanation of the form and phases of the phenomena. When the flame is divided by the bands into three segments, the light of the middle segment is restored by predominance of electric action in the liquid plate, while the light of the extreme segments is still restored by predominant action of the compensating plate of glass. I think the following variation of the experiment worth mentioning as an additional illustration of this view.

The extinction-bands being formed as in (11), and kept stationary in the outer parts of the electric field by constant motion of the machine, I introduce the hand compensator, and apply a horizontal compression beginning at zero. As the compression rises gradually to a large intensity, the arched bands move in gradually towards the axis of the field, until they coincide in one band, which finally disappears. If the compression be suddenly relieved at any point in this process, the arches come into view again at once in their old positions. Like effects are obtained by a strong downward pull upon the weight which is attached to the fixed compensator.

13. These extinction-bands, obtained by electric action against the tension of the fixed compensator, improve in all respects with every increase of tension and corresponding increase of potential. Against a tension of one pound or two, the bands are moved into the outer parts of the field by a comparatively feeble electric action, and they are wide and

dim and not well defined, although they present all the essential features of the phenomenon clearly enough ; but against a larger tension of twelve pounds to sixteen, the bands are beautifully distinct, narrow, sharply defined, and very black. Some elementary electro-optic measurements with this liquid will be described afterwards ; in the meantime I shall merely ask the reader to notice the large range of measurable optical effect here obtained, and with such a small cell, from a tension of one pound or less in the fixed compensator up to a tension of sixteen pounds.

14. *Benzol* (C_6H_6).—This liquid also had been already examined thoroughly in the old cell. When tried in the new cell it acts as a very good insulator (10), and gives excellent optical effects of the same kind as those of carbon disulphide (9). It requires no measurements, and very little observation, to show that this liquid is far inferior to the former in intensity and range of effect. Benzol does give the extinction-bands clearly ; but they are never so fine as in CS_2 ; and I think that I have never seen the bands clearly separated in benzol against a tension of more than two pounds in the fixed compensator. Still the electro-optic action is very fine, pure, and perfectly regular. The light restored from pure extinction by electric action in the cell is always extinguished perfectly by compression of glass in a direction parallel to the lines of force, and always strengthened by tension in that direction.

15. *Toluol* (C_7H_8).—This liquid is very like benzol in its more patent physical properties ; like benzol also, it is a very good insulator, and gives a good optical effect of the same kind as CS_2 under electric action. In the only two careful trials that I have given to this liquid, I found it particularly difficult to obtain a pure initial extinction ; and although this may have been caused by some unnoticed and accidental derangements of the solid parts of the apparatus, I suspect it was rather due to some faint specific action of the liquid. In other respects I could not observe any clear difference between toluol and benzol, the effects being equally regular and pure, of exactly the same kind, and of much the same intensity and range. The light restored from good extinction in the polariscope by electric action in the cell was always extinguished perfectly by horizontal compression or vertical tension of glass. The extinction-bands also were clearly developed in toluol, as in benzol, against a small tension in the fixed compensator.

16. *Xylol* (C_8H_{10}).—This liquid also is very like benzol in odour and appearance ; and it acts very similarly in the plate cell, both as an insulator and in electro-optic experiment. From

the difficulty of cleaning it, I found it not a good liquid to work with. After many rinsings of the cell, the electrified balls were still connected by visible chains of particles; and although the larger particles fell to the bottom of the cell in a little time, and the desired effect came out very clearly, still the liquid was hardly ever purely transparent, but generally somewhat misty or faintly speckled. With this one drawback, xylol acted perfectly well in the electro-optic experiment (9). The optical effect was clearly stronger than that of benzol. The extinction-bands were well developed against a tension of two pounds. The light restored by electric action was always extinguished perfectly by horizontal compression of glass.

17. *Cumol* (C_9H_{12}).—This compound is somewhat viscous, and not nearly so volatile as the preceding liquids. The only sample of it that I have worked with is of a faint yellowish colour, but purely transparent. When tested in the usual way, it acts as a good insulator (10). The optical effect of electric force is of the same kind in cumol as in the former liquids, and is equally regular and pure, being always neutralized perfectly by horizontal compression or vertical tension of glass. This liquid is likely to hold an important place in electro-optics: it is in all respects very easily managed as a dielectric; and after CS_2 , which it follows indeed at a large interval, it gives an optical effect more intense and of longer range than any other liquid yet examined. Against a tension of four pounds in the fixed compensator, the extinction-bands are developed almost as finely in cumol as in CS_2 .

When the electric action and the compensating strain are intense, the bands appear to assume a peculiar form in cumol. Returning to the experiment described in (12), where the two compensators were applied in combination with an intense electric action on CS_2 , it will be remembered that the effect of a strong compression of the hand compensator was to bring the bands in towards the axis of the field, where they finally coincided in one axial band. In cumol the effect takes a different form. As the bands approach the axis, they become largely inclined to each other, converging from the outer parts of the surface of the inductive ball towards the intersection of the axis of the field with the surface of the opposite ball. A contrary form of effect was observed in xylol, where the bands diverged from the axial part of the surface of the inductive ball towards the outer parts of the opposite ball. Other liquids gave traces of similar variations, but none so distinctly as the two that I have mentioned. Although I have not made a particular study of these phenomena, but have merely noticed them carefully in passing, I cannot believe

them to have been accidental. They seem rather to indicate some specific differences between the several liquids, probably with reference to the distribution of electric force.

18. *Cymol* ($C_{10}H_{14}$).—Colourless, transparent, and very distinguishable from benzol by its agreeable odour. It is an excellent insulator, and acts very similarly to benzol in electro-optic experiments, giving an optical effect of exactly the same kind, equally regular and pure, and of much the same intensity and range. The light restored by electric force in cymol is always extinguished perfectly by compression of glass in a direction parallel to the lines of force.

19. *Terebene* ($C_{10}H_{16}$).—When the cell is charged with my only specimen of this liquid, the arrangements being otherwise as in the fundamental electro-optic experiment (8, 9), I find, contrary to expectation, that the light is rotated and sensibly dispersed in its passage through the cell; still there is a good approximate initial extinction got between the red and blue. The liquid acts as a very good insulator, the sparks from prime conductor having apparently the same density and length when the connecting wires are in and out of place (10). In terebene, electric force evidently strengthens the light from approximate extinction in the polariscope; and this effect is clearly weakened by horizontal compression of glass, and clearly strengthened by horizontal tension. The effect is not nearly so strong as in the members of the benzol series; but it is certain, and certainly of the same kind. My former observations on oil-of-turpentine with the old plate cell were at least as satisfactory as these on terebene.

20. *Amylene* (C_5H_{10}).—Colourless, transparent, and excessively volatile. Tested in the usual way, it acts as an excellent insulator; long sparks from the prime conductor, or from connected ball of the cell, do not sensibly diminish in length or intensity when the earth-ball of the cell is touched by earth-wire or knuckle. In the electro-optic experiment, as for CS_2 (8, 9), amylene acts very finely, and in the same way as each of the preceding hydrocarbons, the effect of electric action from extinction in the polariscope being always neutralized perfectly by horizontal compression of glass. Against a weight of one pound on the fixed compensator (11), electrization develops the extinction-bands faintly, and moves them into the outer parts of the field; but against a weight of two pounds, the effect of the strongest electric action attainable falls far short of extinction at the centre of the electric field. Amylene stands, therefore, between benzol and terebene.

21. *Valeric Acid* ($C_5H_{10}O_2$).—Tested in the usual way, this liquid is not a good insulator. Sparks from the prime

conductor are very much shortened and attenuated when the connecting-wires are placed ; and if the earth-wire be detached from the cell, the earth-ball of the cell (with shaft projecting a little way out of it) gives crackling discharge into the air whenever the machine is worked vigorously. In one careful trial of the electro-optic experiment, as for CS_2 , I obtained a continuous restoration from pure extinction in the polariscope. The effect was extremely faint, but perfectly regular, and was neutralized by horizontal compression of glass. In several following trials I could not recover this phenomenon regularly. I have little doubt that the effect is real ; but it is one of the faintest that I have ever observed.

22. *Carbon Dichloride* (C_2Cl_4).—Transparent, colourless, and a very good insulator. Under electric action, as in the preceding experiments (8, 9), carbon dichloride restores the light from extinction in the polariscope. The effect is pure and regular, and is neutralized perfectly by horizontal compression of glass. The extinction-bands are well separated in this liquid against a weight of three pounds on the first compensator (11). Carbon dichloride stands, therefore, somewhat above benzol.

As this liquid was expensive, and as there was only a small quantity of it at hand, I had to be satisfied with charges that were not quite clean. As the experiment proceeded, the impurities were apparently dissolved or absorbed in some way, and the plate improved remarkably in its optical action. Changes of the same kind were observed in some other liquids, but in a less degree.

23. At this point I may mention some apparently trivial phenomena which I observed repeatedly in the course of the preceding experiments. On one occasion, when the cell was charged with CS_2 , the liquid had been allowed to evaporate until its free surface was nearly as far down as the tops of the balls. At the instant when the machine was set in motion, the surface of the liquid was deformed ; over the centre of the field there was a hump raised which, by its form and position, reminded me of the arched extinction-bands (11). As long as the electric force was kept at a moderate and approximately constant intensity, I could not detect any sure appearance of motion in the hump. Similar effects, though not so large, were obtained in benzol, also in carbon dichloride and other liquids. In cumol the hump was apparently as high as in CS_2 ; but it was accompanied by vigorous movements in the liquid, apparent currents from ball to ball along and through the hump. In xylol the effects were very intense ; the movements were more violent than in cumol ; and when only a large bubble of

air was left in the top of the cell, it was drawn downwards by the commotion of the strongly electrified liquid, and was broken up into many small bubbles, which danced rapidly through the field, and prevented all regular optical effect.

The impression conveyed by the phenomenon in the case of CS_2 was that of a simply statical arrangement of the dielectric, a concatenation of electrically polarized particles of the liquid along the curved lines of force, the electric action being intense enough to overpower, so far, the gravitation of the particles. In the case of cumol the impression was different; the hump may have been produced, at least in part, by the strong convection-currents which always accompanied it. Not that there is any real inconsistency between these views; for there may evidently be a regular file-arrangement of particles, kept up continually, or, rather, incessantly renewed, along the curved lines of force, while there are gross currents of liquid passing incessantly between the balls.

24. *Nitrobenzol* ($\text{C}_6\text{H}_5\text{NO}_2$), *new electro-optic action*.—This oily liquid, though yellowish in colour, is very purely transparent. Tested in the usual way, it acts as a good conductor (10). When the two connecting-wires are in position, and the machine is worked vigorously, no sensible spark can be drawn from the prime conductor, no movement can be detected in the liquid, nor any trace of the hump (23). And, accordingly, in the electro-optic experiment arranged and conducted as for CS_2 (8), nitrobenzol gives no trace of optical effect, the extinction in the polariscope being as pure when the machine is worked at the hardest rate as when it is at rest. But it requires only a small change of the conditions to give a large effect.

The first connecting-wire, that from prime conductor to cell, being kept always in position, the earth-wire is detached from the second outer ball of the cell, and the observer at the polariscope brings up his knuckle slowly towards the latter ball till a spark passes, the longer and denser the better. At the instant of the spark (that is, at the instant of abrupt discharge of the prime conductor through the liquid) there is a strong restoration from extinction in the polariscope, not a mere spark, nor a vague illumination, but a true restoration of the old object, bright and clear and well outlined, as in many of the former observations, though apparently instantaneous as the spark itself.

As the knuckle is brought up slowly to contact with the ball, the restorations in the polariscope succeed each other more rapidly, and become individually fainter. The light is by-and-by sustained continually, but never without a sen-

sible flicker; and it becomes fainter and fainter on the whole as the length of the spark diminishes. A little before the spark vanishes, the restorations disappear to sense; and from this point up to contact of ball and knuckle, and afterwards, the action of the machine is without sensible effect in the polariscope. I have made some additional observations on this form of effect; but, to prevent confusion, I reserve them for a little.

25. *Bromtoluol* (C_7H_7Br).—In its electro-optic relations, this liquid resembles carbon disulphide and benzol on the one hand, and nitrobenzol on the other, giving the two kinds of effect clearly, though not intensely. Tested in the usual way, it acts as an imperfect insulator. When the connecting-wires are in position, the sparks from the prime conductor are greatly attenuated, and are reduced in length from an inch or more to about an eighth of an inch.

When bromtoluol is examined electro-optically in the same way as CS_2 (8), the electric action gives a continuous restoration from pure extinction in the polariscope. The effect is not strong; but it is quite certain, and certainly of the same kind as in CS_2 , being neutralized perfectly by horizontal compression of glass. And, again, when the discharging train from the prime conductor through cell to earth is interrupted at any point by an air-interval, there is a good restoration in the polariscope at the instant of each spark, the effect being apparently of the same kind as that observed in nitrobenzol, though not nearly so strong. Bromtoluol is an inconvenient liquid to work with, partly from the very irritating, onion-like action of its vapour on the observer's eye, and partly from the difficulty of getting a clean charge—a difficulty that I have not once overcome perfectly.

26. *Trial of other Liquids for the Nitrobenzol Effect.*—Carbon disulphide, carbon dichloride, terebene, and most of the other liquids already mentioned were all examined carefully in the same way as nitrobenzol (24). The optical effects accompanying discharge were either insensible, or of the kind noted in the two following cases.

Amylene.—The sparks obtained from the earth-ball were very short and attenuated, and were accompanied by distinct restorations in the polariscope. The restorations were far from instantaneous, each of them rising sensibly to a maximum intensity, and then sensibly falling. The effect improved in strength as the knuckle approached the ball till the length of the spark reached zero; and then the effect was to sense continuous, and certainly at its greatest intensity.

Benzol.—The sparks from earth-knob to knuckle were very

short, not more than an eighth of an inch, when those from the prime conductor were about an inch. The sparks were accompanied by an almost continuous effect in the polariscope, which improved as the knuckle approached the ball. At contact of ball and knuckle the optical effect was continuous, and certainly at its greatest intensity. In these two liquids, and in all the other insulators that gave any distinct effect, the phenomenon was apparently of the same kind through its whole progress, and very unlike that obtained from nitrobenzol.

27. *Stannic Chloride* (SnCl_4).—I was sorry to find, on trial, that my method is quite inapplicable in the case of this interesting compound, one of the best insulators known among liquids. Still the trial ought to be described, as it gave me a good glimpse of what I believe to be a new fact. The liquid was let into the cell as rapidly as possible, through filtering-paper and funnel. During this brief exposure to the air, which was unfortunately rather moist at the time, the liquid gave off a dense white cloud of suffocating fumes. The liquid, as it rose in the cell, was fairly transparent; but above it there lay a deep shell of dense white froth. The charging of the cell was completed in several seconds. The most of the froth had run over the mouth of the vertical boring, and was rapidly wiped away; but some of it had evidently dissolved in the liquid, giving it a uniformly milky or misty appearance, deadening the transparency without seriously impairing it. As all the pieces had been already put in final position for the electro-optic experiment (8, 9), the second Nicol was now turned at once to good extinction, and the machine was set in motion. At the first turn of the plate there was a vivid restoration in the polariscope, stronger a great deal (such at least was my impression at the time) than any thing of the kind that I had yet seen, even in the case of CS_2 . The hand compensator was immediately applied in the usual way (4), but without a trace of the ordinary effect: the light restored by electric force was not sensibly weakened either by horizontal tension or by horizontal compression. This result was so unexpected, and, indeed, so extraordinary, that I had to spend a little time in making sure there was no mistake. Trying other means, I soon found that the effect of electric force was neutralized, either perfectly or very nearly, by a definite rotation of the second Nicol through a small angle; and up to this point I am very confident of the facts.

By this time the liquid had evidently deteriorated, not as an insulator, but as an optical medium; it had become in appearance faintly discontinuous, partly speckled and partly reticu-

lated, showing that the fine deposit was in course of agglomeration. Among other trials now made, the first Nicol was turned through a right angle, the second Nicol was turned into the position of best attainable extinction, and the electro-optic observation was repeated. Nothing like a good extinction was obtained in this case; but the effect of electric action was still considerable; and it was evidently and considerably weakened by a rotation of the second Nicol through a small angle, the direction of this rotation being contrary to that obtained in the first case. Several other charges of the cell were tried from the same bottle; but they were all speckled or gritty from the outset, and gave no distinct effect. As far as I can judge from memory and from imperfect notes taken at the time, I think that the optical action of electric force thus manifested in stannic chloride is to diminish the acute angle between the plane of polarization and the lines of force.

Such is the best account that I can give of an observation which was unavoidably hurried, confused, and unsatisfactory. The experiment is not one that I should like to repeat in the same form; it puts the instruments quite out of working order, and tends also to damage them permanently.

28. *Other Liquids tried, but without effect.*—Of these I may mention particularly chloride of sulphur, pentachloride of antimony, trichloride of phosphorus, tetrachloride of carbon, sulphide of allyl. These all acted as conductors (10), and gave no sensible effect in the polariscope under electric force (8). I should except sulphide of allyl, which gave good, though very faint, traces of the nitrobenzol effect (24). I have little doubt that the failure of most of the perchlorides was due to traces of water, for which these compounds have an intense attraction.

All the liquids mentioned up to this point were obtained as pure chemicals from the establishment of Burbidge and Farries.

Organic Liquids.

29. *Young's Paraffin Oil.*—Specific gravity .814, a trade sample of an illuminant, one of the lightest made, clear as water, and an excellent insulator. In the electro-optic experiment, as for CS_2 , this liquid gives a very fine, but faint effect: the light is well restored by electric force from pure extinction; and the effect is neutralized perfectly by horizontal compression of glass. In intensity and range of effect, this paraffin stands between amylene and terebene, but a good deal nearer the latter. An illuminating paraffin was tried long ago in the old plate cell, and with like effects, though much fainter.

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30. *Young's Paraffin Oil*, specific gravity .890, a trade sample of one of the heaviest lubricants made; brownish in colour, fluorescent, transparent, and a very good insulator. In electro-optic experiments the action of this paraffin is similar to that of the preceding, equally regular and pure, but remarkably stronger. The extinction-bands are as fine in this liquid as in cumol, if not finer. Against a weight of 4 pounds on the fixed compensator the bands are easily moved out beyond the balls; but against a weight of 7 pounds the axial band is barely, if so much as, divided. There is no other liquid that I have examined, except CS_2 , which is clearly superior to this heavy paraffin in strength and range of electro-optic action. I am not sure whether cumol should be placed above or below it.

Glasgow, July 1, 1879.

[To be continued.]

XII. *On Professors Ayrton and Perry's new Theory of the Earth's Magnetism, with a Note on a new Theory of the Aurora. By H. A. ROWLAND, Professor of Physics in the Johns Hopkins University*.*

SOME years ago, while in Berlin, I proved by direct experiment that electric convection produced magnetic action; and I then suggested to Professor Helmholtz that a theory of the earth's magnetism might be based upon the experiment. But upon calculating the potential of the earth required to produce the effect, I found that it was entirely too great to exist without producing violent perturbations in the planetary movements, and other violent actions.

I have lately read Professor Ayrton and Perry's publication of the same theory; and as they seem to have arrived at a result for the potential much less than I did, I have thought it worth while to publish my reasons for the rejection of the theory.

The first objection to the theory that struck me was, that not only the relative motion but also the absolute motion through space of the earth around the sun might also produce action. And to this end I instituted an experiment as soon as I came home from Berlin.

I made a condenser of two parallel plates with a magnetic needle enclosed in a minute metal box between them; for I reasoned that, when the plates were charged and were moved forward by the motion of the earth around the sun, they would then act in opposite directions on the enclosed needle, and so

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