

at which the conductivity dies away also shows that the drops must settle down exceedingly slowly, so slowly that they take some days to fall through 1 metre; from this we may conclude that the diameter of the drop cannot greatly exceed 10^{-5} cm. If each little drop gets surrounded by a layer of positive electricity then, just as in the case of the wire, the drop might emit cathode-rays which would ionize the air in its immediate neighbourhood; thus each little drop would act as a centre of ionization, and thus make the air a conductor. The formation of a layer of positive electricity outside the drop is what we should expect if any chemical combination went on between the water of the drop and the oxygen of the air leading to the formation of such a compound as H_2O_2 , for, in forming this compound, the water would combine with a negative oxygen ion and not with a positive one; thus from the layer of oxygen outside the drop the water would pick out the negative and leave the positive ions, this would lead to the production of the coating of positive electricity round the drop required to make it act as an ionizing agent.

The drops of water as well as acting as producers of ions would also act as traps to catch ions moving through the air in which they are suspended; they thus tend to reduce the conductivity, because when an ion gets attached to one of these drops, it is as it were anchored to it, and only moves with great difficulty; in some cases the presence of drops of water diminishes the conductivity of the gas instead of increasing it: thus I found that squirting a steam-jet into either of the tanks A or B materially diminished the saturation-current through the tank.

The ordinary polarization of the electrodes in the electrolysis of liquids is usually explained by the existence of a layer of electrification close to the surface of the electrode, thus the polarized electrode resembles in this respect the electrified wire and the small drop of water on the preceding theory. I therefore thought it of interest to see whether a polarized electrode, when taken out of the electrolytic cell, would ionize the gas. Two platinum plates or wires were immersed in a solution of sulphuric acid of about the maximum conductivity, and a current of from 1 to 5 amperes sent from one electrode to the other for about an hour; the electrodes were then taken out, washed with distilled water, and dried with filter-paper; they were then placed in tank B and the saturation-current through the tank when these were used as electrodes measured. It was found that the one which had been used as the negative electrode (*i. e.* the one against which the hydrogen was

liberated) now gave considerably higher currents than before the electrolysis, in some cases twice the current, while the positive electrode gave the same current as before. On first charging up the negative electrode positively, there was frequently a very large current for a short time, which was not repeated on the second charging, as if there were some positive ions loosely attached to the electrode which got driven away; the smaller increase to which I have alluded lasted for about half-an-hour. The amount of the increase varied a good deal; in one or two experiments there was no change in the current. The experiments with liquid electrolytes are more ambiguous than those with gases, as there is the possibility of some acid adhering to the plate and not getting entirely removed by the washing and drying, and then setting up some chemical action. Against this explanation we have the fact that the increase only occurs with one electrode—the negative, not with the positive—so that if it is due to the chemical action it must be caused by something produced at the negative terminal and not at the positive. Hydrogen peroxide seemed to me the most likely substance, so I immersed a platinum plate in a strong solution of H_2O_2 , and washed and dried it in the same way as the electrodes. I found, however, in this case no change in the current through the tank B.

I have much pleasure in thanking my assistant, Mr. E. Everett, for the help he has given me in these experiments.

June 1902.

XL. *On the Influence of Convection on Optical Rotatory Polarization.* By J. LARMOR*.

THE postscript (this volume, p. 220) to Lord Rayleigh's account of his decisive determination that the orbital motion of the Earth is without influence on the rotatory polarization produced by quartz, has brought to my notice the recent paper by Prof. H. A. Lorentz there quoted.

The fundamental character of Lord Rayleigh's negative result may be illustrated by reference to Prof. Lorentz's *Versuch einer Theorie . . .*, p. 119 (1895), where the opposite conclusion is considered as not unlikely in view of the formal possibilities that are open. But the main object of this note is to entirely admit the demur made by Prof. Lorentz, that my criticism ('*Æther and Matter*,' p. 214) of his calculation of rotational effect, there given, is not well founded. The conclusion which I had reached was in fact that for light of given absolute wave-length the optical rotation would be

* Communicated by the Author.

independent of the Earth's motion, if the form of the constitutive relation which connects electric polarization with electric force, for the material medium, is not altered by its convection; but, not reflecting that reversal of the direction of light in a moving medium alters its wave-length, a hasty inference was made that this negative deduction represented the negative experimental result long ago announced as probable by M. Mascart.

I understand that Prof. Lorentz assents to, or at any rate admits as probable, the application of the principle (which rests indeed on a development in the molecular direction of his own previous analysis), that uniform convection does not affect the constitution of a permanent material system formed of groups of electrons or material ions that interact by electrodynamic agency alone; except in so far that, instead of the ordinary time, we must refer the convected system to a new time-variable, the "local time" of Prof. Lorentz. The constitutive relations of a rotational medium, as well as all properties depending on extinction of light, form a case in point. Considering radiation propagated in the direction of the axis of the rotational quality of the medium, say the direction of x , the relation between the material polarization $(0, g', h')$ and the electric force $(0, Q, R)$ in its undulations is expressed ('Æther and Matter,' p. 211) in the form

$$g' = \frac{K-1}{4\pi c^2} Q + \frac{1}{4\pi c^2} \left(\epsilon_1 \frac{\delta}{dt} + \epsilon_2 \frac{d}{dx} \right) R,$$

$$h' = \frac{K-1}{4\pi c^2} R - \frac{1}{4\pi c^2} \left(\epsilon_1 \frac{\delta}{dt} + \epsilon_2 \frac{d}{dx} \right) Q,$$

in which the coefficient ϵ_2 represents the structural and ϵ_1 the magnetic type of rotation. When the material medium, instead of being at rest, is being convected in the direction of x with velocity v , this structural relation should thus remain true when for t is substituted the local time t' (*loc. cit.* p. 168) equal to $t - \frac{v}{c^2}x$, so that every function $\phi(x, t)$ becomes $\phi\left(x, t - \frac{v}{c^2}x\right)$; this keeps $\frac{d\phi}{dt}$ unaltered, but changes $\frac{d\phi}{dx}$ into $\left(\frac{d}{dx} - \frac{v}{c^2} \frac{d}{dt}\right)\phi$. Thus the effect of the convection will be to maintain the coefficient of magnetic rotation $\epsilon_1 \frac{\delta}{dt}$ unaltered, but to change the structural coefficient $\epsilon_2 \frac{d}{dx}$ into the mixed type $\epsilon_2 \frac{d}{dx} - \epsilon_2 \frac{v}{c^2} \frac{d}{dt}$; and the equation of electric constitution of the medium being thus modified, the rotation produced by it remains unaltered by convection. This is, in

fact, merely a paraphrase of Prof. Lorentz's argument (*Proc. Amst. Acad.* April 19, 1902).

The conclusion to be drawn from Lord Rayleigh's result may thus be held to stand as before, that in the more complex circumstances of rotational media as well as in ordinary optical propagation in matter, the ions or electrons that form the connexion between the matter and the æther interact in all their relations according to laws of purely electrodynamic type.

The single principle that electrification is of atomic character, with or without a distinct material basis, so that when the medium is convected the ions belonging to it exert the ordinary electrodynamic influence of moving charges, suffices to abolish all first-order effects of uniform convection on the electric and optical properties of material media; rotational optical phenomena being therein included. It is only when the absence also of second-order effect of uniform convection has to be accounted for that more questionable hypothesis must enter. It appears to be established that, if it could be granted that the molecules of matter are constituted entirely on an electric basis, no second-order effects either electric or optical would arise. Such an electric basis of matter implies that, an ordinary molecule being made up somehow of a group of ultimate atoms describing steady orbits round each other after the manner of a stellar system, the mutual actions of these ultimate atoms, as also their inertia, are wholly electrodynamic, and are thus really resident in the interconnecting æther in which the atoms constitute mere singular points or centres of strain. If this hypothesis could be admitted,—and no independent reason can be assigned for its validity, except that fundamental presumption of simplicity which we are not unaccustomed to find justified in physical analysis,—the negative second-order optical observation of Michelson and Morley would be explained. Electric effects of the second order would also be absent; and there appears to be one such (an outcome of a suggestion of FitzGerald's) which would otherwise exist, that in Prof. Trouton's hands will probably furnish an independent experimental test*.

Although the constitution of a molecule has not been systematically elucidated on this purely æthereal hypothesis any more than it has on any other, an increasing tendency to consider it as a working scheme may be remarked†. And in this connexion it may be noticed that there is no necessity for restricting the singularity in the constitution of the æther to

* See Trouton Trans. Roy. Dub. Soc. vii. (1902); also FitzGerald's 'Scientific Papers,' pp. 557, 566, lxi.

† E. g. Planck, *Berlin. Sitzungsberichte*, xxiv. p. 486 (1902).

be a mere point; the region of misfit (to borrow an expressive term from Prof. Osborne Reynolds) might, if necessary, have definite extension and structure. Hypotheses of this type are most naturally (indeed, as it seems to me, unavoidably) expressed in terms of an æther which is only locally disturbed by each moving ion; so that a congeries of connected atoms like the Earth does not push it along bodily and establish any finite flow. But there may be philosophers who prefer not to employ the term æther at all, who are satisfied with a colourless phenomenology, and who manage to escape the consideration of the possibility of an æther whose parts maintain their positions notwithstanding the motion of matter through it, by saying merely that if a certain scheme of formal relations between variables which are symbols of things unknown is altered in a certain formal way, probably originally suggested by the use of dynamical analogies such as have been referred to, the scheme will continue to group the facts under the wider conditions, and they would thus feel freed from any necessity of considering images or models, probably imperfect, of things which being outside ourselves we cannot intrinsically know.

Cambridge, August 7, 1902.

XLI. *The Cause and Nature of Radioactivity.*—Part I. By E. RUTHERFORD, M.A., D.Sc., Macdonald Professor of Physics, and F. SODDY, B.A. (Oxon.), Demonstrator in Chemistry, McGill University, Montreal*.

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I. *Introduction.*

THE following papers give the results of a detailed investigation of the radioactivity of thorium compounds which has thrown light on the questions connected

* Communicated by the Authors. Accounts of these researches, during the progress of the investigation, have already been given to the London Chemical Society.

with the source and maintenance of the energy dissipated by radioactive substances. Radioactivity is shown to be accompanied by chemical changes in which new types of matter are being continuously produced. These reaction products are at first radioactive, the activity diminishing regularly from the moment of formation. Their continuous production maintains the radioactivity of the matter producing them at a definite equilibrium-value. The conclusion is drawn that these chemical changes must be sub-atomic in character.

The present researches had as their starting-point the facts that had come to light with regard to thorium radioactivity (Rutherford, Phil. Mag. 1900, vol. xlix. pp. 1 & 161). Besides being radioactive in the same sense as the uranium compounds, the compounds of thorium continuously emit into the surrounding atmosphere a gas which possesses the property of temporary radioactivity. This "emanation," as it has been named, is the source of rays, which ionize gases and darken the photographic film*.

The most striking property of the thorium emanation is its power of exciting radioactivity on all surfaces with which it comes into contact. A substance after being exposed for some time in the presence of the emanation behaves as if it were covered with an invisible layer of an intensely active material. If the thoria is exposed in a strong electric field, the excited radioactivity is entirely confined to the negatively charged surface. In this way it is possible to concentrate the excited radioactivity on a very small area. The excited radioactivity can be removed by rubbing or by the action of acids, as, for example, sulphuric, hydrochloric, and hydrofluoric acids. If the acids be then evaporated, the radioactivity remains on the dish.

The emanating power of thorium compounds is independent of the surrounding atmosphere, and the excited activity it produces is independent of the nature of the substance on which it is manifested. These properties made it appear that both phenomena were caused by minute quantities of special kinds of matter in the radioactive state, produced by the thorium compound.

The next consideration in regard to these examples of radioactivity, is that the activity in each case diminishes regularly with the lapse of time, the intensity of radiation at each instant being proportional to the amount of energy remaining to be radiated. For the emanation a period of

* If thorium oxide be exposed to a white heat its power of giving an emanation is to a large extent destroyed. Thoria that has been so treated is referred to throughout as "de-emanated."