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LI. The electrical conductivity of the æther

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manganin wire in our tests ; but in order to be sure that our fine short wires had not been overheated, we constructed a five-ohm resistance of four strands of coarse manganin wire about 0.25 millim. diameter and 3.5 metres long. This was stretched upon each side of a thin vulcanite plate to avoid self-induction, but it allowed essentially the same number of oscillations to pass as did the short fine wire. A short german-silver wire, with a very high temperature-coefficient, showed a conductivity only a very little less ; thus the error from the heating of the wire may be neglected.

In order to show that common electrolytic polarization does not interfere with the accuracy of our method, we measured with the help of our 20,000 volt storage-battery and condensers the resistance between two bright platinum plates similar in size to the copper ones described above in a cupric sulphate solution. This was found to be four ohms, and after plating the electrodes with copper the resistance remained unchanged. Kohlrausch's method gave no satisfactory result with both electrodes free from copper, but when both were plated it indicated a resistance of 3.9 ohms.

Our method may therefore be a useful one for the approximate determination of conductivities in cases where impurities or polarization render Kohlrausch's method unsatisfactory. For accuracy, of course pains must be taken to develop all the photographs in the same fashion, and in general to arrange the conditions of the exposure alike in all cases.

Our conclusion that the conductivity of electrolytes is *not* greatly affected by great changes in current-strength only emphasizes all the more strongly the conclusion of our last paper, that the conductivity of gases is very much affected by changes in the current-strength.

Harvard University,
March 8, 1897.

LI. *The Electrical Conductivity of the Æther.*

By JOHN TROWBRIDGE*.

THE electrical conductivity of the æther has been maintained by Edlund and has been apparently disproved by various recent investigations—notably those of Prof. J. J. Thomson†. The latter writer, in his treatise entitled ‘Recent Researches in Electricity and Magnetism,’ also remarks, p. 98 :—“Again, if we accept Maxwell’s Electromagnetic

* Communicated by the Author.

† Roy. Soc. Proc. vol. xlv. 1888, p. 290.

Theory of Light, a vacuum cannot be a conductor or it would be opaque, and we should not receive any light from the sun or stars."

The experiments which have been made hitherto on this subject have been conducted with comparatively feeble electrostatic forces. By means of a storage-battery of 10,000 cells in connexion with a Planté rheostatic machine* I have studied the resistance of highly rarefied media under disruptive discharges, and I am led to the conclusion that with a sufficiently powerful electrical stress, what we term a vacuum can be broken down, and that the disruptive discharge during its oscillations encounters very little resistance. In the case of a highly exhausted Crookes tube I have measured this resistance and find it in the special case I considered less than three ohms.

My experiments lead me to the conclusion that the chief resistance is encountered at the surface of the electrodes, and that when this is overcome the *æther* offers little resistance. The method I have employed seems to me to be a very useful one for the study of electrical discharges. It may be termed the damping of the additional Spark Method, or the comparison of resistances by the estimation of the damping of electrical oscillations†. The electrical circuit is provided with two spark-gaps. One of these is placed in a gas, or under the conditions which are to be examined, while the other is photographed according to Feddersen's method by a revolving mirror. With cadmium terminals this method enables one to estimate the resistance of a spark in air or in rarefied media to one half an ohm.

Having at my command a battery giving a voltage of twenty thousand, with an internal resistance of only one quarter of an ohm per cell, and capable therefore of giving a very powerful current, I first studied the behaviour of Crookes tubes which were connected to the terminals of this battery. I found that no Röntgen rays could be obtained with a voltage of twenty thousand. On heating the Crookes tubes, they were filled with a pale white light, which showed very faint bands in the green when examined by the spectro-scope. Then the entire strength of the battery appeared to be manifested in the tubes, the electrodes became red-hot—the medium broke down and offered no resistance to the current of the battery. This white discharge showed even at its culminating point no Röntgen rays. I then employed

* *Comptes. Rend.* t. lxxxv. p. 794, Oct. 1877.

† "Damping of Electrical Oscillations on Iron Wires" (*Phil. Mag.* Dec. 1891).

the Planté rheostatic machine. This apparatus, I think, has not received sufficient attention from physicists. In connexion with a large battery it is very efficient and it enables one to form an estimate of the high electromotive force that one employs in the study of the Röntgen rays. I have slightly modified the form of the machine as it is given by Planté. The main principle consists in charging leyden-jars in multiple and then discharging them in series. The proportion of the length of spark to the number of jars is very close. Knowing the electromotive force of the battery which charges the jars we can estimate the voltage necessary to produce sparks of different lengths. I speedily found that at least one hundred thousand volts were necessary to produce the Röntgen rays, and they were produced more intensely as I increased the voltage, certainly to the point of five thousand volts.

In order to ascertain whether the discharges through the Crookes tubes when the Röntgen rays were apparently produced most strongly were oscillatory, I first placed a Geissler tube in the circuit with the Crookes tube and carefully observed the appearances of the two electrodes of the Geissler tube. They were quite alike and indicated an oscillatory discharge. I then replaced the latter tube by a small spark-gap and photographed the spark in a rapidly revolving mirror. The photograph showed at least ten oscillations with a period of about one millionth of a second with the Crookes tube and the circuit I employed. Furthermore, applying the method of estimating resistances by the method of damping, I found that the resistance of the rarefied medium was less than five ohms. The energy, therefore, at the moment of the emission of the Röntgen rays was not far from three million horsepower acting for one millionth of a second. I employed also a Crookes tube with an aluminium mirror of about two centimetres focus. The resistance of this tube to the discharge was the same as that in which the mirror had a focal length of six centimetres. Incidentally, there seems to be no advantage in shortening the distance between the kathode and the anode by employing a mirror of short focus. Struck by the fact that the distance between the electrodes did not appear to make any appreciable difference in the resistance of the Crookes tube, I replaced the latter by a spark-gap of six inches in length in air, and photographed the spark in another gap in air in the same circuit. This latter gap was one quarter of an inch. The photographs showed on an average the same number of oscillations whether the secondary spark-gap was six inches in length or one inch in length. I found

moreover, that on increasing the electromotive force the resistance of the sparks in air decreased. By quickly drawing apart the terminals of my large battery I can produce a flaming discharge in air of about three feet in length. Righi has also observed the same phenomenon with sparks from an electrical machine. We see that no increase in resistance results. I then placed the secondary spark-gap in a receiver and studied the resistance offered by rarefied air at the point when long ribbon-like white disruptive discharges can be obtained. This point is at about 100 millim. pressure. The resistance of such discharges of about six inches in length in a receiver containing air at this pressure is two or three ohms more than sparks of one quarter of an inch in air; the latter have a resistance of from two to three ohms. On measuring by the above method the resistance of sparks of different lengths in the receiver at this pressure, no difference in resistance could be perceived between a spark of six inches in length and one of three inches in length.

The secondary spark-gap was next placed in a chamber of air which was compressed to four atmospheres. This amount of compression made no difference in the resistance to the disruptive discharges. The additional spark was also obtained in hydrogen gas generated by electrolysis at atmospheric pressure, and no appreciable difference in resistance between this gas and air was noticed. The length of spark which could be obtained with a given voltage was somewhat more in hydrogen than in air. It was interesting, in the next place, to determine by this method whether differences in the material of the spark-gaps made any difference in the resistances observed in the case of disruptive discharges*. I accordingly employed terminals of platinum, iron, aluminium, brass, cadmium, and zinc, and could perceive no difference. Moreover, any difference of resistance between spheres and between pointed terminals, or between a point and a plane, seemed to be inappreciable. With powerful discharges such differences, if they exist, apparently disappear. The additional spark was next placed in a heated flame. It is well known that the spark-length can be thus greatly increased. On photographing a spark in an additional gap the resistance appeared to be slightly increased in the flame; doubling the length of this spark, however, made no change in the resistance that was encountered in the heated medium. The phenomenon was exactly analogous to that observed in the receiver exhausted to 100 millim. I was interested to observe whether

* Righi, *Nuovo Cimento* (2) xvi. p. 97 (1876); De La Rue and Hugo Müller, *Phil. Trans.* clxix. pt. i. p. 93 (1878).

heating the spark in the primary of a Thomson-Tesla transformer produced any marked change in the high-tension spark of its secondary. It was evident that it was detrimental. The high-tension sparks immediately ceased to jump at the extreme sparking-distance of the terminals. Following this train of thought I next placed a spark-gap of the primary of the above-mentioned transformer between the poles of a very powerful magnet, giving a field of certainly ten thousand lines to the centimetre. It is well known that when such a field is excited, the primary spark appears to be blown out with a loud report and a great increase of length of spark is obtained in the secondary of the transformer. Applying the same method, I photographed the spark of the additional spark-gap and found no difference in resistance whether the magnetic field was excited or not : or when the spark jumped across the magnetic lines or in the direction of the latter. Is it possible that the æther being already under a magnetic stress, the addition of a powerful electrostatic stress serves to suddenly break down the æther? It is well known that a blast of air imitates the action of the magnetic field. It probably does so by blowing out the voltaic arc which tends to form. It may be that the electrodynamic repulsion compels the spark not to follow, so to speak, the voltaic arc and its current of heated air. The loud report may indicate a sudden stress in the medium, and in the case of the Crookes tube the highly rarefied medium within it would effectually prevent our hearing a similar report.

I next placed the primary spark of the Thomson-Tesla transformer near a Crookes tube which was giving out the Röntgen rays. I could not perceive any mutual effect. The effect, moreover, of ultra-violet light on the resistance of sparks in air could not be detected.

The method I have outlined enables one to form an estimate of the energy incident upon the production of the Röntgen rays. It can also measure with greater accuracy than has been possible hitherto the resistance of sparks in air and different media. It shows conclusively that the discharge in a Crookes tube at the instant when the Röntgen rays are being emitted most intensely is an oscillatory discharge. In popular language, it can be maintained that a discharge of lightning a mile long, under certain conditions, encounters no more resistance during its oscillations than one of a foot in length. In other words, Ohm's law does not hold for electric sparks in air or gases. Disruptive discharges in gases and in air appear to be of the nature of voltaic arcs. Each oscillation can be considered as forming an arc. It is well known

that a minute spark precedes the formation of the voltaic arc in air. The medium is first broken down and then the arc follows the drawn apart carbons. I believe that this process occurs also in a vacuum, and that absolute contact is not necessary to start the arc. My experiments lead me to conclude that under very high electrical stress the æther breaks down and becomes a good conductor.

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LII. *On the Effect of Capacity on Stationary Electrical Waves in Wires.* By W. B. MORTON, M.A.*

WHILE working recently at stationary electrical waves in wires produced in Blondlot's manner, I was led to make some measurements on the effect produced when a capacity is inserted at a point of the secondary circuit. The positions of the successive nodes were explored in the usual way by a bridge, the indicator being a vacuum tube which was placed across the wires and which showed a maximum of brightness when the bridge was at a node. When two opposite points of the parallel secondary wires were joined to the plates of a small air condenser, the effect was to bring closer together the nodes on the two sides of the condenser, the amount of this shortening of the apparent half wave-length depending on the position of the inserted capacity. The effect was nil when the condenser was at a node, and maximum when it was midway between two nodes. This influence of the increased capacity of the wires is of course of the same nature as the shortening of the wave-length when the wires pass from air into a dielectric liquid. Drude and others have made use of this way of measuring directly the index of refraction of different liquids for the electric waves; but the influence of an isolated capacity does not seem to have been much studied. Salvioni has published † some measurements on the effect of capacity inserted at a point between the end condenser and a bridge. When the second condenser was put in it was necessary, in order to restore resonance, to alter the distance of the plates of the end condenser. Von Geitler ‡ got rid of the reflected waves by using a terminal resistance

* Communicated by the Physical Society: read April 9, 1897.

† *Rend. Acc. Linc.* 1892, pp. 250-253; *Wied. Beibl.* xvii. p. 485.

‡ *Wied. Ann.* xlix. pp. 184-195 (1893); cf. Barton and Bryan, *Proc. Phys. Soc.* xv. p. 23.