ART. XXXVII.—*The Electrical Conductivity of the Ether*;
by JOHN TROWBRIDGE.

I STATED in the April number of this Journal that my experiments have led me to the conclusion that the chief resistance in overcoming the apparent resistance of a highly rarified medium is encountered at the surface of the electrodes (*uebergangsschicht*) and that when this is overcome the ether 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 rarified 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 behavior 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 spectroscope. 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 the Planté rheostatic machine. This apparatus, I think, has not received sufficient attention from physicists. In connection 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 discharging 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

* Damping of Electrical Oscillations on iron wires, *Phil. Mag.*, Dec., 1891. Also *American Journal of Science*, April, 1897.

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 hundred 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 appearance 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 it in a rapidly revolving mirror. The photograph showed at least ten oscillations with a period of about one ten-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 rarified 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 horse power, acting for one millionth of a second. I employed also a Crookes tube with an aluminum mirror of about two centimeters focus. The resistance of this tube to the discharge was the same as that in which the mirror had a focal length of six centimeters. Incidentally, there seems to be no advantage in shortening the distance between the cathode 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 additional 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. Rhigi 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 rarified air at the point when long ribbon light white disruptive discharges can be obtained. This point is at about 100^{cm} 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, which have a resistance of from 2 to 3 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 secondary 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, aluminum, 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 secondary 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^{cm}. I was interested to observe whether 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 centimeter. 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

* Rhigi ovo Cimento (2), 16, p. 97, 1876; De la Rue and Hugo Muller, Phil. Trans., 169, Pt. 1, p. 93, 1878.

direction of the latter. Is it possible that, the ether being already under a magnetic stress, the addition of a powerful electrostatic stress serves to suddenly break down the ether? 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 rarified 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 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. 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 ether breaks down and becomes a good conductor.

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