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XLVII. *On some Experiments with Röntgen's Radiation.*
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THE experiments to be described were performed during April and May of this year, and were made with the object of elucidating the nature of the radiation. It was thought that the following possible explanations should be tested:—

1. The radiation consists of a swarm of material particles projected through the glass of the generating tube. Electrical changes taking place at the glass surface are invoked to explain the differences between Röntgen's and Lenard's rays.
2. The radiation consists of an "æther wind." Æther is sucked through the glass towards the source of radiation and then blown outwards. The question as to whether the radiation observed by Röntgen is the expression of the motion of æther to or from the source remaining open.
3. The radiation consists of æther vortices moving to or from the source.
4. The radiation consists of æther waves: that is waves of regular or irregular æther motions.
5. The radiation consists of electromagnetic waves of either

* Communicated by the Physical Society: read November 13, 1896.
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very small wave-length or having longitudinal components. This is probably a special case of (4)—at least if we are to look to the æther to explain electricity and magnetism dynamically.

6. The radiation is a phenomenon of a new order entirely unconnected in any way with anything in our past experience.

Source of Radiation.

Being thrown entirely on our own resources for means of production of the radiation—all the Crookes's tubes in our possession being almost useless—we arrived at the form of tube shown in fig. 1. These tubes are easily made; the surface

Fig. 1.

opposite to the kathode being spherical, can be made very thin, and the electrodes are kept well apart. The kathode is best made very nearly plane—if concave it will easily fuse the thin glass against which its rays are projected; we have lost many tubes from this cause. We have found that the bulb may be conveniently about three or four centimetres in diameter and the main tube as little as 1.5 to 2 cm. in diameter. The expansions round the electrodes are intended to obviate local heating, for it is not always easy to prevent oscillatory discharges and consequent “kathoding” from the “anode.” The chief merits from our point of view, however, were that the tubes were very easy to make out of comparatively small glass tubing. Their volume is small, so that they can be exhausted quickly, and they give very intense action. In fact one tube—the bulb of which ultimately fused under the

influence of the kathode-discharge—gave quite as intense if not more intense radiation than a “focus”-tube made in our laboratory, which appeared to act perfectly, so far as we could judge.

Experiment to test Hypothesis 1.

When a vacuum-tube is prepared with electrodes of aluminium-wire whose ends are about 1 centimetre apart, and exhausted until the discharge will rather jump across three or four centimetres of air between balls of 1.5 cm. diameter than pass in the tube, it is generally noticed that the discharge, when forced to pass by the tube, goes rather more easily in one direction than the other. By placing a spark-gap with spherical electrodes in parallel with the exhausted tube and properly adjusting the distance of the balls from one another, it is easy to so arrange matters that the sparks pass mostly by the spark-gap when the current is in one direction and by the tube when it is reversed. An arrangement of this kind is exceedingly sensitive to small changes of pressure in the exhausted tube. In the experiment to be described, the spark-gap was generally so adjusted that when the coil-commutator was in one position the whole of the discharge passed over the gap—only the faintest glow being discernible in the tube in a dark room. When the current was reversed, however, the discharge was about equally divided between the gap and the tube. No very delicate adjustment of the gap seems to be necessary, at all events when the discharges follow each other rapidly.

Having thus obtained a means of testing the vacuum in a discharge-tube more rapidly and probably much more delicately than by any kind of gauge, we thought it worth while to try whether Röntgen's rays would project particles into the exhausted tube. If hypothesis (1) be correct, then particles must be carried into the exhausted tube if it is thin enough to be transparent; and if in addition it contains a piece of platinum-foil which stops the radiation, the particles would also be stopped; also if the particles are not wholly entangled in the platinum, some change in the vacuous state of the tube is to be expected.

A tube about 12 cm. long and 1.5 cm. in diameter, and having a bulb about 4 cm. in diameter in the middle of its length, was prepared of German glass. It was provided with electrodes fused in from either end, and extending to within 1 cm. of each other in the centre of the bulb. A bit of platinum-foil lay in the bulb, and the tube was fused on to a Sprengel pump through about a metre of tubing some millimetres in

internal diameter. A phosphorus-pentoxide tube was included just above the fall-tube. The whole apparatus, including the pentoxide tube, was repeatedly heated by a Bunsen burner and exhausted until the discharge preferred to pass through 3 cm. of air-gap rather than through the tube. So sensitive, however, was this means of testing the vacuum that for the first few days, despite frequent heatings and pumpings, the vacuum would not remain constant for more than some minutes. After about a fortnight of heating and pumping, however, the vacuum became so steady that the change in twelve hours, which was sufficient to entirely stop the discharge in the spark-gap, could be rectified by the fall of at most 50 drops of mercury in the fall-tube—*i. e.* by about 30 seconds' pumping. The change of vacuum occurring during an hour could still be easily detected by testing with a current in alternate directions.

Under these circumstances, experiments were made by urging Röntgen tubes to their utmost, almost in contact with the bulb of the exhausted tube, and directing their radiation on to the platinum-foil. Though many very active tubes were fused or otherwise destroyed, yet during an hour's action on several occasions no change of vacuum in the exhausted tube could be detected when due allowance for the slight progressive deterioration was made.

This experiment was repeated several times, and a tube which had successfully exhibited the fluorescence of a screen of tungstate of calcium through an aluminium plate 7 mm. thick to an entire audience, was melted down in the operation; but no effect whatever was observed.

Professor Wright, of Yale, has given some reasons for thinking that Röntgen rays when passing through gold-leaf carry particles (of gold?) off with them; so that if a positive effect had been obtained in the experiment described it would not have been quite conclusive; neither is the negative effect observed conclusive against *any* particles being carried forward; it only shows that the particles so carried (if any) either refuse to behave as gaseous particles, or are exceedingly few in number.

The experiments of Professor Minchin which are now available have, however, rendered the solid particle theory so unlikely that it is hardly worth while pushing the investigation further—at all events until much more powerful appliances are to hand. In case the experiment appears worthy of repetition, we would call attention to the fact that it appears desirable to use specially purified phosphorus pentoxide in the drying-tube; for the presence of the vapour of phosphorus

or its lower oxide fouls the mercury when impure pentoxide is heated.

Experiments made to test whether Röntgen's Radiation is associated with æther currents in any way.

With regard to hypothesis (2) Michelson has put into our hands a comparatively simple method of obtaining the interference of two beams of light which may be used for detecting the presence of æther currents by their influence on the velocity of light travelling through the moving æther.

The arrangement employed in fig. 2 was made use of for

Fig. 2.

the purpose of determining whether Röntgen's radiation is associated with æther movements.

In this arrangement the light from L is divided into two beams at A which travel round from mirror to mirror in opposite directions, eventually reaching the telescope T. When the adjustment is correct, interference-bands are seen on looking into the telescope.

In this experiment it was estimated that a shift of the bands equal to one tenth of the width of a single band, or a widening of the bands by one fifth of the same amount,

could not have escaped our notice. In some experiments the Röntgen tube was placed so that the line of kathode discharge made an angle of about 30° with the path BC, and in others made an angle of 90° with the same line. No disturbance of the bands could be detected when the coil was started or while it was working, which shows at once that within the limits of accuracy imposed by the experimental conditions, the Röntgen radiation is unaccompanied by æther streams. This conclusion refers, of course, only to air, and it therefore appeared desirable to make an additional experiment, replacing the air by a substance of greater density. Pure benzene was selected as a suitable liquid, and a glass tank 16.4 cm. long, and several centimetres wide and deep, was placed in the path BC. The radiating tube, which was placed above the free surface of the benzene, was arranged to radiate on to the path in all directions, and in some cases was actually immersed in the benzene so that its active surface was in the field of view of the telescope.

No disturbance of the bands commencing when the coil started, and stopping when it stopped, was ever detected, though a great many excellent observations were made. Of course, effects due to the heating and electrification of the glass can be easily distinguished from those we are in search of in view of their persistence after the coil is put out of action. The tube employed gave quite visible fluorescence by barium platinocyanide at a metre's distance and through aluminium .7 mm. thick. We can get an idea of the order of the minimum æther velocity which could be detected by this means. The path BC being some 25 cm. long, we will suppose that only 10 cm. of it are influenced by the tube and that the radiation is along the path. The sensitiveness of the method was the same whether we employed air or benzene.

A shift of the bands amounting to a fifth of the distance from band to band would be produced by an æther velocity sufficient to change the time of passage of light over the path by one tenth of a period. As sodium light was employed, we may call this

$$5.9/3 \times 10^{-16} \text{ seconds.}$$

But the time required for light to travel over ten centimetres in air is about

$$1/3 \times 10^{-9} \text{ seconds ;}$$

or the velocity is not changed by the radiation by more than six parts in ten million, say. This is about 177 metres

per second, so that the conclusion to be drawn from the experiment is that the Röntgen radiation is not associated with æther velocities greater than, say, one fifth of a kilometre per second, or about a thousand times less than that of kathode rays as measured in a vacuous tube by Prof. J. J. Thomson (Phil. Mag. vol. xxxviii. p. 364).

Experiment to test whether Röntgen Rays produce any change in æther affecting the velocity of light.

An experiment (fig. 3) was arranged on Michelson's

Fig. 3.

principles. In this case the sodium light from *L* is divided at the partially silvered mirror *A*, one beam travelling to *C* and thence to *T*, the other travelling to *B* and thence back to *T*. The path *AC* is operated upon by the tube, and the path *AB* is screened by a heavy cast-iron screen. The active

surface of the tube is brought up to the path CA, and the Röntgen radiation allowed to traverse it in a variety of directions from parallelism to normality, and is even thrown on to the mirror at C. For experiments on benzene, troughs of that liquid as similar as possible are inserted in both paths, the one in the path AB acting merely as a compensator. This experiment is much more difficult than the one previously described, and the benzene requires to be well stirred if good definition is required. In the experiments in air a shift of the bands by $\frac{1}{50}$ of the width of a band could be observed, while in benzene a change of about half the distance from band to band only could be seen. A widening of the bands to about half the above amounts could have been detected in each case. When the benzene was used the fringes were unsteady, and opportunities for observation had to be waited for. Of course, when the active surface of the Röntgen tube dipped into the benzene so as to appear in the field of view of the telescope great disturbances due to thermal and electric changes became visible. These, however, did not appear instantaneously on starting the coil, nor did they disappear on stopping it. In no case was any real effect observed.

The chief interest of this experiment lies in the fact that if the Röntgen radiation consisted of longitudinal æther waves, *i. e.*, waves of longitudinal æther displacement, some effect was to be expected. If the waves are long compared with the path AC (the path AB being screened) a widening of the fringes, or in the extreme case a total disappearance of the fringes, is to be anticipated. This can easily be realized by blowing an organ-pipe in the neighbourhood. If the waves are short compared with the dimensions AC then all will depend on the azimuth of the tube, or rather on the inclination of the Röntgen-ray path to the path of the light rays. This appears from the fact that whole waves would produce no effect in the case contemplated—everything would depend on the fractional parts of the waves included in or projected on AC.

The conclusion to be drawn from the experiment is that neither in air nor benzene are the light-transmitting properties of the æther interfered with. The limits of observational accuracy are of the same order as in the case of Experiment II.

Action of Röntgen's Rays on a Selenium Cell.

It so happened that one of us was engaged early in the year in experimenting with photo-resistance cells made of selenium which had been laboriously purified and which was probably as pure as any that has ever been obtained. Contrary to expectation, such cells showed a quite normal light-

sensitiveness whether the electrodes were of platinum or of aluminium. The cells were made according to the directions given by Mr. Shelford Bidwell* in his paper read before the Society last year—the only difference being that purified selenium was employed.

The result of a good many observations was to show that a certain selenium cell with platinum electrodes was acted on to about the same extent and in the same direction whether it was exposed to the radiation of a "standard" candle at a distance of three metres, or to the Röntgen radiation at a distance of ten centimetres and passing through 7 mm. of aluminium and about 3 mm. of wood. The tube was working so as to cause visible fluorescence in a barium platino-cyanide screen—not of quite the best quality—at a distance of rather over a metre in a room nearly but not absolutely dark. This is of course a very rough way of stating the degree of activity of the tube, but when the experiments were made Professor Minchin's work had not reached us, and consequently the simple scale of tube intensities which it implies was not available.

In order to test whether the action of the light differed in kind from that of the Röntgen radiation two experiments were made—in one the rate of resistance-recovery of the selenium cell was carefully studied and compared with the rate of recovery of the cell after exposure to candle-light; in the other tests were made in the hope of discovering that a permanent electromotive force was established by the radiation, and that it persisted after the radiation was cut off. Neither of these experiments led to positive results. The rate of change of resistance during the twenty seconds of exposure to Röntgen's radiation was, so far as could be seen, exactly the same as when the candle-flame was substituted at the proper distance. The recovery curves, extending over about half an hour, were also very similar on the whole (several tests were made), though both curves themselves exhibited great irregularities.

In order to obtain effects as little complicated as possible by previous history the sensitive cell was kept in circuit on the bridge, and was traversed by the testing current for two or three days before the observations.

It was for the same reason that exposures were limited to 20 seconds, for the rate of recovery of resistance with the cell employed was very slow. On one occasion when an accidental exposure for several minutes to Röntgen's radiation

* *Phil. Mag.* vol. xi. p. 233.

was made the cell had by no means recovered four hours afterwards.

The resistance of the sensitive cell employed was reduced from 1209 ohms to 1185 ohms in 20 seconds by the radiation under the conditions mentioned. The testing battery consisted of two "Obach" cells, and the bridge was made up of two equal arms of 1000 ohms each—the selenium and the variable arm. We mention this in case it may ever turn out that the effect depends on the testing current.

With regard to the electromotive force which it was supposed might be set up. The cell was kept at rest and undisturbed for three days before the final trial; it was placed three centimetres from the active tube, which was, as before, in a metallic box, together with the coil. The tube was shut off from the cell by an aluminium plate $\cdot 7$ mm. thick.

A very sensitive high resistance galvanometer in our possession, which has been described in a paper read before the Royal Society but as yet unpublished, was employed to test for any electromotive force which might be set up. An exposure to the radiation was made while the cell was in series with the galvanometer, and it was found that the cell always exhibited a small electromotive force whether it was exposed to the rays or not. This prevented the test from being very sensitive, but in no case was any electromotive force attributable to the radiation discovered, though if a voltage of 10^{-7} volts had come into operation its effect could probably not have escaped observation.

At the time these experiments were made we were uninformed as to the discharging action of the rays, which has since been so copiously studied. As soon as we saw an account of some of this work we felt that the change of resistance of the selenium cell was no longer an isolated phenomenon to be worked out by itself, but must be studied in conjunction with the similar phenomena observable in other substances, and it is for this reason that the experimental work was not extended so as to include other cells.

These notes may, perhaps, be summed up as follows:—

- (1) It is easy to make a Röntgen tube of great activity by the most elementary glass-blowing.
- (2) The Röntgen radiation does not consist in the projection of gaseous matter, or if it does the amount of such matter involved is extraordinarily small.
- (3) The Röntgen radiation does not consist in the projection of æther streams having a velocity above a couple of hundred metres per second: this is true whether the radiation takes place in air or in benzene.
- (4) The properties of æther regarded as determining the

velocity of electromagnetic waves are not greatly changed (*i. e.* not at all within our experimental limits) by the Röntgen radiation, and this applies alike together in air and in benzene.

(5) A selenium cell composed of platinum electrodes and highly purified selenium is affected by Röntgen radiation to an extent which is comparable with the effect produced by diffused daylight.

(6) No permanent or temporary electromotive force is set up in a selenium cell by the Röntgen radiation.

XLVIII. *On the Diurnal Periodicity of Earthquakes.* By CHARLES DAVISON, *Sc.D., F.G.S., Mathematical Master at King Edward's High School, Birmingham**.

1. **W**ITHIN the last seven years, two important memoirs have appeared dealing in part with the diurnal periodicity of earthquakes. In a paper published in 1889, M. de Montessus de Ballore † considers the question from a negative point of view, his object being to show that the diurnal period is apparent rather than real. More recently, in 1894, Prof. F. Omori ‡, in a valuable investigation on the after-shocks of earthquakes, points out that there are various periodic fluctuations in their decline of frequency, three of the periods being a day or less in length. I will first give a brief summary of the methods and conclusions of these two writers before proceeding with the immediate object of this paper, which is to subject the records used by them, or similar records, to the more rigid process of harmonic analysis.

2. M. de Montessus's statistical inquiries are based on a great catalogue of more than 45,000 earthquakes. The separate entries being of unequal value, he divides them into seven classes, according to the nature of the district and the mode of record. The first six classes include all registers obtained without instrumental aid, the seventh those of the Italian geodynamic observatories. For every region of each class he gives the total number of shocks during each hour of the day. Representing by d the number of shocks occurring in the twelve day-hours (6 A.M. to 6 P.M.), and by n the number in the twelve night-hours (6 P.M. to 6 A.M.), he then evaluates the ratio d/n for each region. For the first group, excluding the fifth or volcanic series, the mean value of d/n

* Communicated by the Author, with some alterations, after being read before the Royal Society on March 5, 1896.

† "Études sur la répartition horaire diurne-nocturne des Séismes et leur prétendue relation avec les culminations de la lune." *Arch. des Sc. phys. et nat.* vol. xxii. 1889, pp. 409-430 and tables.

‡ "On the After-shocks of Earthquakes." *Journal of the Coll. of Science, Imp. Univ. Japan*, vol. vii. 1894, pp. 111-200.