Philosophical Society of Glasgow.

1895-96.

Dr. J. T. BOTTOMLEY, F.R.S.,

The Right Hon. LORD BLYTHSWOOD,

AND

Dr. JOHN MACINTYRE, F.R.S.E.,

ON

The Röntgen X Rays, or the New Photography.

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[FROM THE *PROCEEDINGS* OF THE PHILOSOPHICAL SOCIETY OF GLASGOW.]

THE NEW PHOTOGRAPHY.

On the Röntgen X Rays, or the New Photography. By Dr. J. T. Bottomley, F.R.S.; the Right Hon. Lord Blythswood; and Dr. John Macintyre, F.R.S.E.

[Read before the Society, 5th February, 1896.]

Three papers on different branches of the subject of the X rays of Professor Röntgen, of Wurzburg, were communicated to the Society at the meeting held as above.

I.—Dr. J. T. Bottomley on the Discoveries of Hertz, Lenard, and Röntgen.

I have been asked to open this joint-communication from Lord Blythswood, Dr. Macintyre, and myself, and to say a few words on the subject of the discharge of electricity through vacuum tubes, and particularly on such parts of the subject as may be considered to have led up to the wonderful discovery by Professor Röntgen, which, within the last few weeks, has taken the scientific world, and even the general public, by storm.

The beautiful luminous phenomena which accompany the passing of an electric discharge through a vessel, which has been almost completely evacuated of air, have long been known; and, indeed, I myself have had the pleasure, on more than one occasion, of calling the attention of the Society to some of them.

When a discharge is passed through air of ordinary density, it generally passes as a spark or as a "brush" discharge, with more or less disturbance of a somewhat violent kind, and in an obviously discontinuous manner. If the points between which the discharge is taking place are within a glass tube, the effect is still the same. But if now the air is withdrawn gradually from the tube by means of one of the modern air pumps, with which we can obtain a very complete vacuum, we observe a very interesting set of phenomena as the process of evacuating the tube goes on. When the pressure of the air in the tube is reduced to about 1mm. or 0.5mm., the sparking character of the discharge entirely disappears, and the tube is filled with a beautiful glow of light, the colour of which depends on various circumstances—partly on the condition of the vacuum, partly on the nature of the gas which filled the tube originally and of which a residue still remains in the tube, and partly on the kind of glass of which the tube is made.

On carrying the process of pumping the air out of the tube still further, a very remarkable state of matters supervenes, which was discovered by Crookes, and which is the foundation of all the radiometer phenomena with which the name of Crookes is connected. When there is left within the tube not more than, say, one-millionth of the original quantity of air, and when the pressure of the air that is left has been reduced to a corresponding extent, the particles of the residual air become comparatively free to move about without being in incessant mutual contact and collision. They are then shot off from the negative electrode, or cathode as it is called, and they fly with great velocity through considerable distances—several centimetres, perhaps—before they chance to strike other particles, or to hit upon the side of the tube, or on any solid which may be within the tube. Any one particle may, of course, very soon strike something in its flight, but on the average many particles move through long straight paths without encountering an obstacle or meeting another particle. I have had the pleasure of showing some of these phenomena in this room, and only refer to them now because it is necessary to bear them in mind in considering the further developments of this matter which recent investigation has brought to light.

I must now call your attention to the contributions to this subject of the late Professor Hertz, and of his friend and pupil, Dr. Lenard. In a very remarkable paper, published in 1892, Hertz described what he called the "Passage of Cathode Rays through Thin Metallic Layers." He showed that the interposition of a thin layer of gold leaf, for instance, in the path of the cathode rays,* does not stop them. A thin plate of mica acts as a perfect screen to these rays, although the mica is quite transparent to ordinary light, while a thin plate or layer of gold, silver, tin,

* It is difficult to find language to use in this connection, because there exists at present a controversy as to the nature of the cathode discharge into which it would be impossible for me to enter here.

&c., perfectly opaque to ordinary light, permits the cathode rays to pass through with tolerable freedom. The experiments of Hertz were carried on within the vacuum tube, but later, Lenard, at the instance of Hertz, carried out some important further experiments in which the cathode rays were obtained *outside* the tube, and their properties carefully examined. Lenard constructed a tube in which the end opposite to the cathode was closed, not by glass sealing, but by a metallic cap of brass, or other suitable metal; and in this cap a minute hole was cut. The hole was covered with a small piece of excessively thin aluminium foil, which would have been far too thin and weak to form the cap, but which, when used simply as a cover for the minute hole in the brass cap which I have described, was strong enough to withstand the pressure from the air without, and thus allowed a vacuum to be formed within the tube. With a tube constructed in this way, and with an extreme exhaustion of the tube, Lenard was able to find rays outside the tube in the vicinity of the little aluminium window, and to examine the properties of these rays. He found that they could be made easily visible if caused to fall on small pieces of paper sensitised with luminous paint; and with the help of screens thus constructed, he was able to trace the paths of the rays, and to study them. He found that different bodies are very differently transparent to the rays, and showed that many bodies quite opaque to ordinary light transmit them with great freedom. Thus, wood and all the metals permit them to pass, and some bodies much more freely than others. The denser the substance the more does it obstruct the passage. For instance, lead is nearly opaque to them, while one of the materials which transmits them easiest is the very light metal aluminium. One more property which Lenard found I must refer to. It is well known that the cathode stream of particles is deflected in a very remarkable way by a magnet. This was shown by Crookes, following the older experimenters on the subject. Lenard showed that the rays which have come out of the vacuum tube through the aluminium window are similarly affected. This, as we shall see, is of great importance in considering the most recent discoveries, of which I have now to give you a very brief account.

Five weeks ago came the startling announcement that Professor Röntgen, of Wurtzburg, had been able to obtain radiations from the vacuum tube which could pass through great masses of solid and commonly-called opaque matter, and which could be detected at great distances, and which, in fact, were not at all of the almost microscopic character of the rays investigated by Lenard. These rays have the property of acting very powerfully on certain fluorescent salts, and particularly on the salt known as platino-cyanide of barium. With a screen covered with this salt Röntgen has found the rays passing through a book of more than 1,000 pages, and at a distance of one or two metres from the tube. He also finds that they act with great power on ordinary dry photographic plates. He has been able to make shadow photographs of objects, which are opaque to these rays, through wood and through plates of aluminium which are very transparent to them. But perhaps the part of his discovery which has excited universal attention and astonishment is this, that the rays are differently affected by different parts of the animal body. The bones are much more opaque to the rays than the flesh and muscles. Thus, Röntgen has been able to produce a photograph of a human hand in which the bones are clearly shown, while only a faint image is given of the surrounding flesh. Through the kindness of Lord Kelvin, I shall be able to show you a series of original photographs by Professor Röntgen himself, which accompanied a copy of his original paper; and which, with the paper, reached Lord Kelvin a few days before the end of the year, and constituted the first announcement in this country, so far as I know, of this wonderful discovery. Lord Blythswood and Dr. Macintyre will also be able to show you results of their repetitions of Röntgen's experiments.

Röntgen has investigated very carefully the properties of these new rays, which he has provisionally termed X rays, on account of want of knowledge at the present time of their true nature. He has compared the transparency of various bodies for the rays, and, it appears, so far as has yet been discovered, that density is the main property which regulates transparency. It is not possible to say yet, however, whether or not the rays may be, by some means, broken up, and whether there may be in different bodies a quality corresponding to the *colour* of ordinary transparent substances. Bodies like wood, paper, and all sorts of organic substance, seem extremely transparent. Every one of the metals is more or less transparent, but the lighter the substance the more transparent it is. Thus, while aluminium and zinc are highly transparent, the bodies which are least transparent are lead, platinum, and the other heavy metals. Such want of transparency as there is appears to correspond with that which we ordinarily meet with in muddy water, or in water which has had a little milk mixed with it.

So far as has yet been found, the rays are not refrangible. Röntgen has tried with lenses and prisms of various kinds but has not been able to detect any signs of refraction. Neither has he been able to detect any signs of true reflection. With regard to this latter point, however, some experiments of Lord Blythswood lead us to think that perhaps definite and true reflection may yet be found. It is to be remembered that the subject presents great difficulties because of the almost complete transparency of the bodies, from the surfaces of which reflection might be observed.

These rays are not found to be polarised by any of the ordinary means, and this fact has given rise to the conjecture that they may possibly be not of the nature of light waves at all. In waves of light the wave motion is transverse to the direction in which the light is being propagated; but we are familiar with waves also which are not transverse, and in which the movements of the particles are in the direction of propagation of the disturbance. Such are the waves of sound. Röntgen, in his paper, puts forward the suggestion that possibly the rays which he has discovered are longitudinal waves, of extremely short wave lengths, set up and propagated in the so-called luminiferous ether.

Lastly, Röntgen has found that these rays are not affected by the presence of a magnet. This is of great importance, because, as you will remember, I explained that the radiations with which Hertz and Lenard dealt are conspicuously affected by the magnet, and this last-mentioned property of the rays discovered by Röntgen seems to show that the Röntgen rays and the Lenard rays are different in kind.

I need hardly say that much yet remains to be done in the examination of this wonderful new subject. In the course of the next few weeks, or months, we may expect to know a great deal more about it than we can at all claim to know this evening.

II.—Lord Blythswood's Account of his Experiments.

His Lordship remarked that Dr. Bottomley having given an eloquent preface as to what was known with regard to the X rays, he was himself glad to bring before the Society a notice of some experiments which he had conducted in his own laboratory at Blythswood. For some time past he had been forced to believe that the haloid salts exposed on a sensitive plate were acted on by an electric spark, and that, in fact, they were acted on more decidedly than would be the case with the same length of exposure to ordinary sunlight. Photographs of such sparks, taken in the five-hundred-thousandth part of a second, were what photographers spoke of as "over-exposed." In the autumn and winter of 1895 his Lordship had repeated the experiments of Herr Lenard, and produced the "brush" discharge through a thin plate of aluminium from a high vacuum into the open air. From the experiments referred to, he was led to believe that photographs could be obtained between the poles of a powerful Wimshurst induction machine, which he had some time previously made for himself. He found that such was the case, and photographs had been taken between the poles of his induction machine in light-tight boxes (which were exhibited). At the suggestion of Lord Kelvin, in order to make quite certain that the pictures produced were not an electrical effect, he used a thick zinc box, which was provided with an aluminium window. This box was placed between the poles of the machine, with metal objects, such as watch wheels, placed close to the photographic plate, under the aluminium window. The box was carefully "earthed," and the photographs came out clearly and well. This result seemed to be quite conclusive that the X rays could be produced in the open air by an electrical discharge of high tension. His Lordship did not pretend to say that this method was as good as that with a vacuum tube for what had been called "shadow photographs," but the interest lay in the fact that a vacuum was not necessary. He had produced good photographs in carefully-closed metal boxes, fitted with aluminium windows. These boxes were placed between the poles of the induction machine, carefully "earthed." The positive pole of the machine was also well "earthed." The object of all those arrangements was to prevent any probability of the photographs being produced by discharges inside the metal box, and the result seemed to be quite conclusive that without a vacuum tube the X rays could be excited in the open air.

III.—Dr. Macintyre on the production of Shadow Photographs.

When the interesting subject of the Röntgen rays was first mentioned in the newspapers of this country, the description of the apparatus to be employed suggested great complications.

One read of ten to twenty thousand volts alternating current, Tesla coils with twelve Leyden jars, ten inches spark induction coils, and very highly exhausted Crookes' tubes. With the current from the street electric main supplied from the 100-volt circuit in Glasgow, it was quite evident that transformers for such work could not be made either portable or inexpensive. As these considerations were of great importance in surgery, I thought it advisable to make a series of experiments with much simpler apparatus, and the result has been attended with some success. In to-night's demonstration I will show the apparatus, and project upon the screen a number of the photographs taken.

The apparatus consists of a small secondary battery, giving eight volts and six amperes; an induction coil, lent by Professor Jamieson; a very small Tesla coil, made by Messrs. Baird & Tatlock; and a Crookes' tube, which was selected from the stock of Mr. Otto Müller, of Glasgow. With these one is able to demonstrate all the ordinary phenomena of photography of objects through wood, aluminium, black cardboard, &c., &c.

APPARATUS REQUIRED.

1. *The Source of the Current.*—It is difficult to say in a general sense what is the best source for such work, especially when we consider that portability is an essential element in surgical practice. Those who have the current supplied from the street mains have a considerable advantage, so long as the work is to be done in the laboratory; but Bunsen's and Grove's cells, giving the necessary voltage and amperes to excite the coil, can easily be obtained. In my own experiments I use the current from the main, but, given an induction coil requiring a certain voltage and ampere of current, one can easily obtain a primary or secondary battery sufficient for the purpose. Naturally, if cells be used, those which do not polarise rapidly are the best, and hence my choice of four ordinary E.P.S. cells, failing which, however, I have used a battery of the Bunsen type.

2. *The Transformer.*—This, the second part of the apparatus, is a very important one. Various kinds of transformers are at our disposal, but the common one is some form of induction coil. The one on the table gives a six inches spark, and where it can be obtained even a larger coil is of service.

3. *The Tesla Apparatus.*—I wish here to point out that the Tesla coil is not essential, but it is useful to those who are

employing a small induction coil, because of the increase of voltage and frequency of discharge which it produces. In the experiments under consideration I have used a small Tesla coil for this purpose, and it has answered admirably.

4. *The Crookes' Tube.*—Probably the most important part of the apparatus is a good Crookes' tube of high vacuum. The one which I have used with greatest success so far is the old form with four poles, but different patterns must be tried. Through the kindness, and acting upon the advice, of Dr. Bottomley, I am having a number of these made by Mr. Otto Müller, but we are so far in the experimental stage only. At present it is very difficult to get suitable tubes for this particular purpose, so that I was forced to make a selection of what could be found in the instrument-maker's stock.

With the apparatus which I have mentioned and described, all the ordinary phenomena spoken of in the journals may be demonstrated, and with it I have photographed coins through the ordinary camera slide, the shutter of which was three-sixteenths of an inch thick. I have also passed the rays through aluminium plates, cardboard, and wood.

PRACTICAL WORKING OF THE APPARATUS.

1. *Method of Placing the Object to be Photographed in Relation to the Sensitised Plate.*—Having selected the object to be photographed, it should next be placed as near as possible to the sensitised surface of the plate. If it be a flat object it may be placed directly in contact, so that a sharp picture may be obtained. On the other hand, certain objects cannot be placed in contact because of their thicknesses, and therefore it is better to enclose the sensitised plate between layers of thin material, such as wood or paper, which will prevent it being acted upon by ordinary light. Care should be taken, however, to place the object as near the plate as possible, and to remove the Crookes' tube to some distance from the plate.

2. *Where to Place the Object.*—The object should be placed between the tube and the sensitised plate, and by carefully watching the fluorescence of the tube, or by testing, photographically, one can discover where the greatest number of X rays are generated. For example, in the tube seen on the table the negative pole is placed directly upon, or in front of, the object to be photographed, and when the current is switched on a

greenish fluorescence on the glass is observed directly opposite the cathode. The object to be photographed is placed in front of or below this,—in other words, in the course of the X rays, so that these may be absorbed in their passage from the tube to the sensitive plate.

3. *Length of Exposure.* — This, of course, will depend upon many things—first of all, upon the current at our disposal, on the coil, on the number of interruptions per second, and particularly on the tube used ; and, lastly, on the character of the sensitive plate itself. At first my exposures were as long as forty minutes, but since then the time has been greatly reduced.

4. *Photographic Material.*—The most of my experiments have been made with Paget·XXXXX plates, but I have also used others. It is not unlikely, however, that a good deal yet has to be done in finding more suitable plates. In developing I have used hydrokinone, but with bromide paper of the ordinary iron solution. Beyond this the details are simply those of ordinary photographic work.

This art, of course, is in its infancy, and consequently every worker will meet with difficulties; but my experience has led me to think that they will be easily overcome. Indeed, our present difficulties may in the end be found to be an advantage, owing to the constancy of the factors which produce the picture, not as in the case of sunlight, which is constantly varying.

I feel quite confident that the apparatus will soon become very much more simple than can at present be conceived, and that before long a portable and comparatively inexpensive apparatus will be at the disposal of the surgeon.