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A NEW FORM OF CATHODE DISCHARGE AND THE PRODUCTION OF *X*-RAYS, TOGETHER WITH SOME NOTES ON DIFFRACTION.

PRELIMINARY COMMUNICATION.

By R. W. Wood.

IF accurate measurements are to be made of diffraction bands produced by the *x*-rays, it seems probable that very narrow slits, and a very intense and minute radiating source must be used. The focus tube has the disadvantage that the radiation is given off from a surface of considerable size, and is not very intense *per unit of area*, which is what is required for diffraction work. What we need is something that bears the same relation to the focus tube that the arc-light bears to a large flame. After considerable experimenting I have succeeded in finding a method of producing the rays by what appears to be a new form of cathode discharge, which manifests itself as a bright blue arc between two minute balls of platinum in a very high vacuum.

The advantage of the method is that a very small bulb can be used, an inch or less in diameter (of interest to those bent on getting a tube into the human body and lighting it up from within), which yields a radiation intense enough to show the bones of the forearm distinctly, from a source about the size of a small pin-head. *Per unit of area* of the radiating surface, I find the radiation to be between ten and twenty times as intense as with the best focus tubes. This statement I base on photographs made of the two sources by means of a pin-hole 0.2 mm. in diameter.

I have not yet succeeded in producing a "total radiation" as intense as the large focus tubes yield, where the source is a plate of considerable area, but the method seems more rational than that of focusing the cathode rays on a platinum target, and I think it not unlikely that the development of a very powerful tube is possible on the lines indicated in this paper.

The apparatus is shown ½ natural size in Fig. 1. The small bulb is blown on the top of a tube 80 cm. long, which dips into a jar of mercury. Within this tube is another, bent into a U at the bottom, one arm projecting out of the mercury. A conducting wire runs through this, and is attached to a platinum wire sealed through the glass at the top.

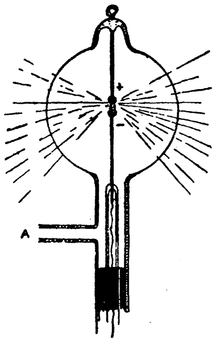

Fig. 1.

The arrangement is the same as that devised by the writer for determining the temperature variations in the stratified discharge, by means of a sliding bolometer, and will be better understood by referring to Vol. IV, No. 3, of the Physical Review (Fig. 4). This rather complicated arrangement is not necessary at all, but it facilitates adjustments within the tube, and has been used thus far.

The electrodes are two platinum wires carrying small platinum balls, about 1.5 mm. in diameter, easily made by fusing the wire in the electric arc. One is fixed and the other can be moved up and down by means of the inner tube which supports it. The bulb is exhausted through the side tube *A*, which communicates with a mercury pump.

Starting with the balls about 5 mm. apart, the tube is exhausted (first clamping the projecting arm of the U) until, on passing a discharge through it, the green luminescence due to the cathode rays is very pronounced. The balls can be pushed within a millimeter of each other without producing any apparent change, the cathode rays being given off from the entire surface of the wire and ball.

If now a large spark gap be introduced into the external circuit, the green luminescence disappears as does also the bluish negative light, and the discharge passes between the balls in the form of a minute and brilliant blue arc. I use the word "arc" because on close inspection the discharge resembles an arc rather than a spark. It is intermittent of course. From the surface of the anode ball on which this arc plays, the x-rays emanate with great intensity.

I have been using a large 12-plate Wimshurst machine, which seems to work better than a coil. A good deal depends on the conditions: the platinum balls must be adjusted to the maximum striking distance (usually about 1 mm.). If they are too close together, the radiation is feeble. The external spark gap must also be adjusted carefully: if it is too short or too long, the arc disappears, we get the usual diffuse cathode rays, and the x-radiation vanishes except for the feeble effect from the glass.

When everything is just right, the little arc burns away steadily without interruptions, except the rapid periodic ones, and the anode radiates precisely as the positive carbon in the arc-light.

Another rather curious analogy between the discharge and the carbon arc is that the anode ball is eaten away to a shallow crater, while on the surface of the cathode is built up a dense, hard deposit of very brilliant metallic platinum. The appearance of the balls under the microscope, after a five-hour passage of the arc, is shown in Fig. 2. They are not visibly heated by the discharge, though at times showers of red-hot sparks are given off, which bounce about inside the bulb, and pour down into the barometer tube. The surface of the anode, where it has been eaten away, is pitted and corrugated but very brilliant: the built-up mass on the cathode has a similar appearance, but the rest of the surface is dull and without luster.

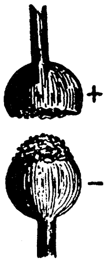

Fig. 2.

Another curious action of the arc is, that if it be made to play on the edge of a piece of platinum foil (used as anode), the edge is sharply crimped or turned up towards the cathode. In one tube in which the radiating anode was a small horizontal plate of platinum 0.5 cm. square, on the center of which the arc played, the plate was bent into an arc of perhaps 60° concave towards the cathode. Although there is a strong attractive force between the anode and cathode (shown by the flying together of the balls if they are side by side), it does not seem to be sufficient to explain this action: moreover, the plate is not heated even to redness. The effect is such as would be produced if the surface on which the arc played was put in a state of tension, but as this surface is the one that is continually cut away by the discharge, it is difficult to imagine how such a state could be produced. A similar bending or crimping of the anode sometimes takes place in focus tubes.

I have already alluded to the spark showers which sometimes take place within the tube. On one occasion after running the current in one direction for several hours, I reversed it suddenly and observed a phenomenon which I have never seen surpassed in point of beauty in any of the various forms of vacuum tubes. From the anode there shot out two intense yellow beams resembling those of search lights shining through a mist (Fig. 3). The edges of the beams were as sharply defined as I have indicated in the drawing, and the closest scrutiny showed them structureless. Where they struck the wall of the bulb they apparently splashed off, and were somewhat brighter than at points midway between the source and the wall. The bulb was about 10 cm. in diameter, and the electrodes were shaped like those in Fig. 8, which will be alluded to later. The appearance of the beams was unlike anything that I have ever seen in a vacuum tube, and the only explanation that I could think of was that they might be caused by minute particles of heated platinum thrown off from the anode, too small to be perceived individually by the eye, but collectively presenting the appearance of a ray of light in smoky air. Subsequent events showed that beyond a doubt this was the

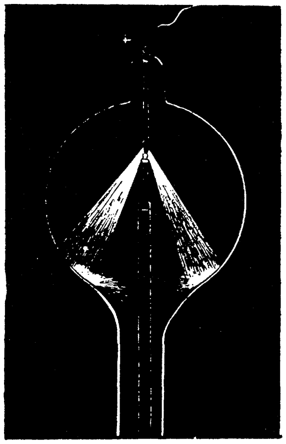
Fig. 3.

true explanation, for in a few minutes a close examination revealed the presence of bright lines in the rays which became more and more distinct, until no doubt remained that the yellow beams were in reality blasts of red-hot metallic particles which, at the outset, may have been of nearly molecular dimensions.

The phenomenon is undoubtedly caused by the rapid cutting away of the built-up deposit on the electrode to which I have already alluded, as I have observed it only when that electrode which has served for some time as cathode is suddenly made anode. The deposit built up by the arc, though apparently as hard and solid as the rest of the ball, is probably a dense aggregation of very minute particles, which is rapidly undermined and torn to pieces when the current is reversed. As we get deeper down into the mass, the projected particles become larger, until their individual trajectories can be seen; and the luminous beams become transformed into the common spark shower.

The behavior of these beams in a powerful magnetic field may be worth investigating, though it is doubtful if any effect would be found.

To return now to the tube shown in Fig. 1. By means of the pin-hole I photographed the radiating surface on a plate wrapped up in several thicknesses of black paper and obtained an image which is shown slightly magnified in Fig. 4. It will be seen that the under surface of the ball gives out most of the rays, while a few come from the wire: this, together with the fact that the extreme top of the bulb shines with a green light, leads me to think that the little arc is a very dense bundle of cathode rays, a few of which get around the ball and impinge, some on the wire and some on the glass. I have also noticed that particles of aluminum oxide on the upper surface of the anode ball, where no rectilinear rays from the cathode could possibly reach them, glow with a rich red color, while the arc plays between the balls, a fact which can only be explained by supposing that the cathode rays curve around and envelop the + electrode in the vicinity of the arc. If the balls are pushed nearer together, an aureole a centimeter or more in diameter surrounds the arc, which is bluish white with

Fig. 4.

platinum electrodes and bright green with copper. There are a number of points about the arc that require investigation. I find that it can be produced to a less degree between the cathode and a metal plate insulated on a glass stem, the anode being below. This suggests that oscillations may be set up, and it may be possible to construct a vibrator for short waves in some such way. The spectrum of the arc and its behavior in the magnetic field are also worth investigating. Most of the light comes from a film on the anode, which is sometimes yellowish, though usually blue. A more complete study of the nature of the discharge and the distribution of the cathode rays about it will be made in the near future.

Reference to Fig. 4 shows us (considering that the ball is but 1.5 mm. in diameter) that the chief source of the rays is an exceedingly narrow horizontal line, especially if the ball has been somewhat cut away, and we might therefore expect some diffraction phenomena to show themselves on the edges of shadows of objects thrown by such a source. This I find to be apparently the case. If a piece of fine copper wire 0.2 mm. in diameter be fastened horizontally on the outside of the bulb opposite the balls, and another wire vertically, making a +, the horizontal wire, which is parallel to the narrow radiating source, throws a sharp shadow on a plate 40 cm. away, while the vertical wire throws scarcely any shadow at all.

The shadow of the wire, which is of course light on the photographic plate, has a dark border, darker than the rest of the surface which receives the whole radiation, and there seems no other way of explaining this increased blackening on the edge of the shadow than by interference. Shadows of a wire mounted within the tube also showed this dark border. The distance of the wire from the radiating source was about 1.5 cm., and the plate was about 40 cm. from the wire, so that the shadow of the wire was nearly half a centimeter wide, a magnification of about 20 diameters: in spite of this it was in most cases sharply defined.

The dark border was only to be found *on one edge;* namely, the one towards the radiating anode. The other edge appeared slightly lighter than the rest of the shadow, somewhat as indicated in Fig. 5. If the upper ball was the anode, the dark border was on the upper side of the shadow; if, however, the lower ball was made anode by reversing the current, the light and shade were reversed. (Fig. 6: both exposures made on the same plate, one half of it being screened each time with a strip of lead.)

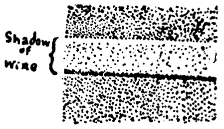

Fig. 5.

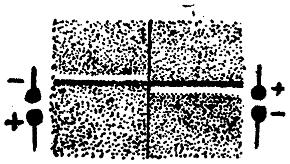

Fig. 6.

I see no way of explaining these effects except by diffraction or something analogous to it, for no half-shadows or penumbræ will account for the edge of the wire's shadow being darker than the rest of the plate which is exposed to the full action of the rays. There seemed at first sight to be no way of explaining the difference in the appearance of the two edges of the shadow; or in other words, why the edge of the wire towards the radiating surface should act differently from the one facing away from it. Some rotational element in the rays, such as would exist if they were vortex filaments in the plane of the wire, might cause them to be affected differently by the two edges, but such an explanation is hardly worth considering, at least on present evidence.

By combining diffraction with penumbral effects we might possibly get a similar result: reference to Fig. 4 shows that the radiation, though most intense from the under side of the ball, comes also to a less degree from the sides as the arc plays about over the surface.

Draw a figure showing the paths of two pencils of rays; a strong one from the under surface and a weaker one from a point above, and suppose the two edges of the wire's shadow thrown by the first pencil to have dark edges due to interference maxima. It will be seen that the feebler rays coming from the upper source will cast a shadow of the wire a trifle lower down than the first shadow, but will illuminate all the rest of the plate. If this shadow falls on the under dark band, it will tend to obliterate it, if the relative intensities are about equal; that is, if the darkening due to the rays from the upper source is about equal to the increased darkening due to interference. If the lower ball is made anode, the conditions are reversed, the feebler source being below the brighter, and we have the maximum on the upper edge of the shadow obliterated.

To remove all chances of penumbræ a much narrower radiating source is necessary, and I made a great number of experiments to determine the best possible form to give the apparatus. I first tried a long narrow bulb with the platinum beads very close to the glass, and a slit .05 mm. wide fastened with wax to the outside just opposite the anode. This form, though giving excellent results at first, was very short lived and very apt to be punctured by the discharge. Better results were obtained with a form shown in Fig. 7. Over the mouth of a thistle tube was fastened with sealing wax a sheet of very thin aluminum plate, which served as cathode. The anode was a platinum bead which is pushed up until the arc plays between the plate and the ball; the x-rays coming from the ball pass through the aluminum plate, on which is fastened a narrow slit of copper or platinum. The chief advantage of this form is that the cutting away of the anode does not alter its position with reference to the slit, though the deposit of platinum on the aluminum plate soon lessens its transparency.

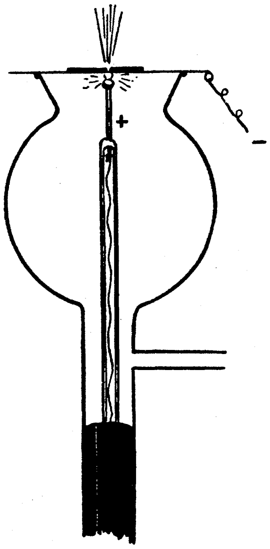

Fig. 7.

The best form found thus far is shown in Fig. 8. A rectangular plate of platinum foil is partially cut across with the point of a very sharp penknife: this makes a slit about 0.05 mm. wide with very uniform straight edges. The plate is soldered with gold to the wire carrying the cathode, which is a short piece of thick plati-

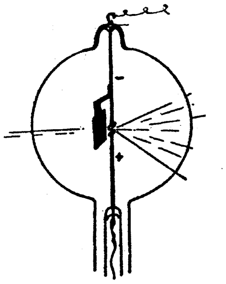

Fig. 8.

num wire mounted parallel to the slit. The anode is of similar form and is mounted on the movable rod, and the arc plays back and forth between the two cylindrical surfaces.

The diffraction slit, furnished with a micrometer screw, is placed at a distance of about 15 cm., as nearly as possible in the center of the beam which comes through the knife cut in the platinum plate (the proper position being found by means of a small screen of calcium tungstate), and the photographic plate behind this, at a distance of 25 cm. It is important that the electrode carrying the plate be made cathode, otherwise *x*-rays are given off in profusion from both its surfaces as shown by a pin-hole photograph.

I tried one other arrangement which promises to be even better than this, in that it furnishes radiations from a source 0.05 mm. in diameter without the use of a slit, which makes the position of the diffraction slit immaterial, providing it be only parallel to the source. This method is to allow the cathode arc to play upon a horizontal and tightly stretched bit of platinum wire 0.05 mm, in diameter, and gives beautiful definition while it lasts, but unfortunately the discharge cuts through the wire in ten or fifteen minutes.

I have designed a tube in which new wire can be continually fed to the arc, which I think may be better adapted to diffraction work than the one with the slit.

The images of the slits on the photographic plate give evidence of a maximum darkening on each edge. With a comparatively wide slit (0.2 mm.) the appearance is about as indicated in Fig. 9 (magnified). This was obtained with the plate at a distance of about 15 cm. from the slit. With a slit 0.05 mm. wide at a distance of 25 cm. the image was uniformly dark, but there was a very faint trace of a light border followed by a faint shadow. This looked more like true diffraction than any of the other results, and for comparison a plate was made under similar conditions with light. A rough calculation based on these two plates would indicate a wave length of about 0.00004 for the *x*-rays, a trifle less than one half that of Schumann's shortest light wave. I place very little confidence in this estimate, and in fact am not yet at all

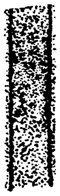

Fig. 9.

sure that we are dealing with true diffraction. There seems to be very strong evidence, however, that the rays do not pass by the edges of obstacles in rectilinear paths without suffering any change, although there remains a good deal of work to be done before any very definite statements as to just what happens can be made.

It does not seem to me to be unreasonable to suppose that there may be some action which is not identical with the interference of light and heat waves.

In conclusion, I wish to express my thanks to Professor Charles R. Cross for his great kindness in placing at my disposal the facilities of the Rogers Laboratory of Physics of the Massachusetts Institute of Technology.

Jamaica Plain, March 27, 1897.