PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Cathode Rays and Some Analogous Rays

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Phil. Trans. R. Soc. Lond. A 1897 **190**, 471-490
doi: 10.1098/rsta.1897.0023

XII. *Cathode Rays and some Analogous Rays.*

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Received May 10,—Read June 17, 1897.

1. *On the Electrostatic Deflection of Cathode Rays and the Production of Negative Cathodic Shadows.*

In the experiments first to be described, the aim of the research was primarily to discover whether, and in what way, the shadow cast by the so-called cathode ray* was affected by the physical state of the object interposed between the cathode and the tube-wall, or other opposing surface capable of luminescing under the stimulation of the ray.

A pear-shaped Crookes tube, depicted in fig. 1, was made, having as an electrode at its smaller end a flat disk, A, of aluminium. At opposite sides of the bulb were introduced transversely two short cylindrical electrodes, B and C, of aluminium wire. These were mounted, as usual, on platinum wires, which were fused into the aluminium and sealed in through the glass wall of the tube. This tube was exhausted until the stage was reached at which all the pale internal nebuloid patches of luminous gas had disappeared, and the tube showed the yellow-green surface luminescence characteristic of soda-glass. When A was used as cathode, Röntgen rays were emitted from the glass at the opposite end of the tube, but the exhaustion was only just sufficient for this purpose, the emission ceasing when the tube became warmed with prolonged discharges. At this particular stage of exhaustion the tube was sealed off. It was in that stage of exhaustion in which it exhibited, in the luminous patch opposite the cathode, a singular unstable creeping luminosity, flickering in dendritic forms suggestive to the casual observer of splashes. The phenomenon has frequently been observed in Röntgen tubes, and is the subject of further notice in § 3 below. Throughout the entire research the electric source employed was an Apps induction coil capable of yielding sparks 25 centims. long, but with the break ordinarily adjusted so as to yield sparks up to 8 or 10 centims. only in length.

When the flat electrode, A, of this tube was made the cathode, shadows of B and

* The term ray is used here and throughout in the most general sense, not as in any way postulating a wave-propagation.

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C were projected upon the tube-walls. As is usual in such tubes, these shadows were quite well defined and were surrounded by the usual margin of brighter luminescence. When B and C were made cathodes, while A was made anode, each cathode was observed to produce an oval luminescent patch upon the tube-wall around its own region. When B and C were both made anodes, being connected together by an external wire, their shadows were both quite small and narrow, considerably less than the geometric shadow, being only about 6 millims. long and 1 millim. broad. Nor were they rectangular in shape (fig. 2), but somewhat tapered to a point; and beyond the tip of each appeared a more luminous point in the splashing luminescence on the glass wall. If B was alone anode, while C was disconnected, the shadow of C was full-size, and of nearly rectangular shape; while the shadow of B (the anode) was somewhat smaller, and showed at its end a flickering luminous spot at b (fig. 3).

Fig. 1.

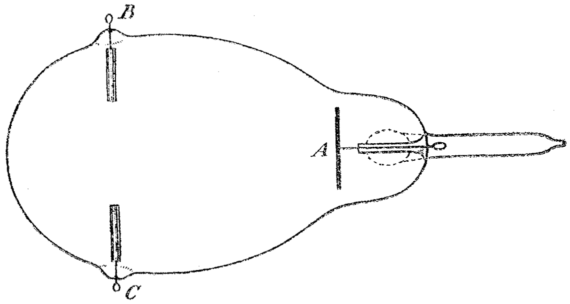


Fig. 2.

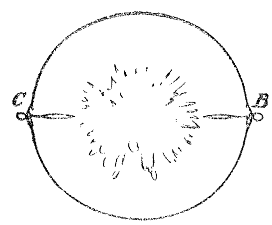
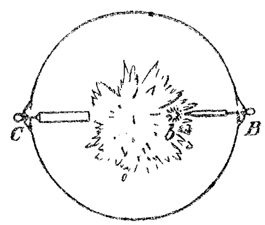


Fig. 3.



When B was connected to A so that both A and B were cathodes, C being anode, the shadow of B swelled out to an oval shape, some 22 millims. long and 18 millims. wide. The shadow of C was enlarged similarly if B was made anode, and C joined to A as cathode. The size of this oval shadow was found to depend on the nature of the connexion to the cathode. By introducing a bad conductor, such as a piece of damp wood or a highly exhausted vacuum tube into the conducting line, between the cathode and the electrode casting the shadow, the size of the shadow could be varied from normal dimensions up to the full oval. When either B or C was thus made cathode, the anode shadow shrank up altogether and disappeared, though the luminous spot at c or b remained.

When A was made anode, and B and C both cathodes, each was, as remarked above, surrounded by an oval luminous patch on the glass wall; which patch was brighter than the rest of the surface of the bulb, and was outlined with a still brighter marginal line. If B was disconnected, or its continuity with the cathode impaired by introducing a bad conductor, the patch surrounding it shrank, while that surrounding C expanded. If B was joined to the anode the patch surrounding it disappeared. When, as in fig. 4, B and C were joined through a rod of wood, to which the cathode wire from the coil was brought, the sizes of the two patches could be varied by sliding the wire along the wood. That patch expanded toward which the cathode wire was moved, while the other patch contracted.

The first conclusion to be drawn from these observations was that *the size of the cathodic shadow of an object depends upon its own electric state.** *If it is positively electrified the shadow contracts, if negatively the shadow expands.* The same result was found to occur when the electrification of the object was produced independently by use of an influence machine.

Fig. 4.

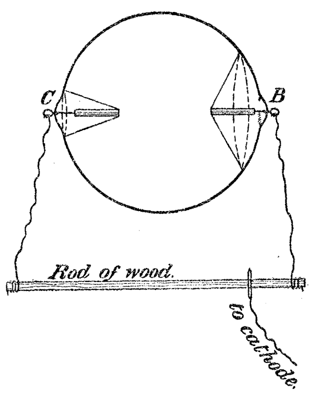


Fig. 5.

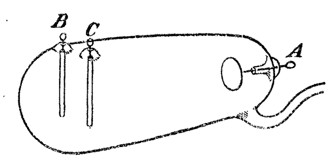
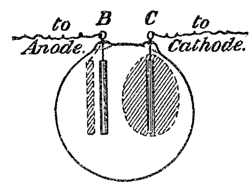


Fig. 6.



Tube [No. G 4], (fig. 5), was constructed to verify the above results. It also had three electrodes, one a slightly convex disk, A, at one end, the other two, B and C, short cylindrical wires inserted transversely to the tube, near together, and parallel to one another. The degree of exhaustion of this tube was made rather higher than that of the preceding. When electrode A was made cathode, shadows of B and C were cast on the broad end of the bulb. If B and C were both made anodes their shadows were slightly narrower than the geometric shadow, and became extremely well defined. When B was left as anode and C connected to the cathode through a rod of wood or through another vacuum-tube of high resistance, the shadow of C at once swelled out to an oval shape (fig. 6), while that of B was shifted a little sideways, as if repelled from B. If A was made anode and C cathode, a shadow of B was thrown upon the side wall of the tube. If then B was made anodic, by connecting it to A through a rod of wood, its shadow thinned down and became more brightly marginate. If B was made cathodic, by similarly joining it to C, its shadow widened out to an oval patch, while at the same time an oval shadow of C was cast on the opposite wall. By varying the resistance in the connexions, in the way described above, for the first-mentioned tube, the sizes of these two oval shadows could be varied, one enlarging when the other diminished. While the disk A was thus serving as anode, it also cast a shadow of itself upon the smaller end of the tube. This shadow shifted slightly sideways according as B or C was cathode.

* Crookes, in 'Phil. Trans.,' 1879, Part II., p. 648, has alluded to the widening of a cathode shadow, and to the production of a penumbra under an unsteady electrification of the object casting the shadow.

When B and C acted jointly as cathodes the shadow of A occupied a mean position; but under no circumstances were two shadows of A seen, or any appearance of overlapping shadows. These effects were repeated, using an influence machine to electrify the wires casting the shadows. A dry pile, ordinarily used to charge gold-leaf electroscopes, proved inoperative. It acted merely as a high resistance.

Tube [No. G 8], (fig. 7), has three small lateral disk electrodes, A, B, and C, and a central electrode D of aluminium wire, about 2 millims. thick. Electrodes A and B being connected as cathodes, and C as anode, the shadows of D were about of the geometrical size. The exhaustion was at this stage such that a spark would just pass in an alternative path between blunt points about 7 millims. apart.

When the wire D was made anodic its shadows at once became narrower. When is was made cathodic its shadow widened enormously, being about 16 millims. wide, with an ovate end.

When A and C were made cathodes, and B and the wire D anodes, there were produced two narrow shadows at *a* and *c* respectively, opposite the two cathodes. As the pump was worked, and the exhaustion increased, these shadows grew narrower, becoming mere lines, with a brighter spot of luminescence above the tip of each. Then the upper parts of these linear shadows closed up entirely, so that instead of presenting each, as at first, a dark line about 1 millim. broad, emarginate with a luminous edge, each now presented the appearance, except at the base, of a narrow bright luminescent line. At this stage the exhaustion was such that a spark would just not pass at a gap of 18 or 19 millims. in the alternative circuit. As exhaustion proceeded further, the luminescence on each edge began to overlap; and finally the shadows became two *bright* linear strips each about 1·5 millim. broad. The spark-gap at this stage, when the tube was sealed off, was 30 or 32 millims.

In this tube, then, the effect of making anodic the object which casts the shadow was to produce a deflexion of the cathode rays into the geometric shadow, even to overlapping; the result being to produce *negative shadows*, that is to say, shadows which appear bright upon a less bright background. It also appeared that *the enlargement of a shadow when the object is made cathodic, and the diminution of the shadow when the object is made anodic, both depend upon the degree of exhaustion of the tube; and both are augmented by raising the degree of exhaustion.*

These two effects are, however, unequal. The enlargement when cathodic exceeds by many times the diminution when anodic, under identical conditions of exhaustion and excitation of the tube.

These observations furnished an explanation of the luminous spot observed in tube (fig. 3) at the ends of the shadows of the lateral electrodes, and of the tapering form of those shadows when the electrodes were anodic. The surface when anodic deflects the cathode rays into the geometrical shadow; and, having been deflected, they continue in a new direction. As the surface of the bulb where the shadow falls is curved, the rays that cast the tip of the shadow have to travel a longer distance than those near the base of the shadow, which consequently becomes distorted to the extent of producing at the tip an overlap, with a luminous or negative shadow at that part, whilst the remainder of the shadow is of the usual dark or positive sort.

The preceding observations, and particularly the observation of the lateral shifting of the shadow of the wire B in tube [No. G 4], (fig. 6), when the parallel wire C was made cathodic, establish the following point :—*Cathode rays are capable of being deflected electrostatically; being apparently strongly repelled from a neighbouring cathodic surface, and less strongly deflected towards a neighbouring anodic surface.* Though no precise experiments were made to determine the shape of the path of a deflected cathode ray which passes near an anodic or a cathodic point, the observa-

Fig. 7.

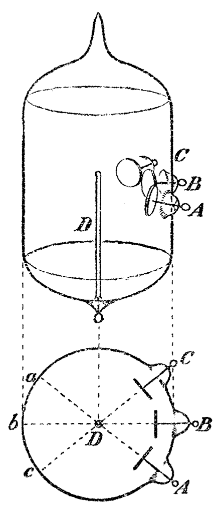


Fig. 8.

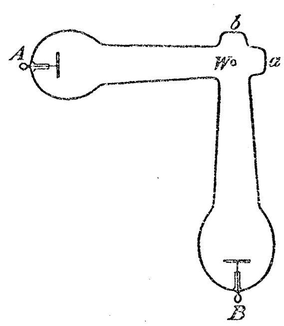
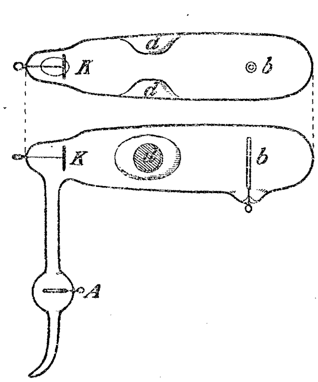


Fig. 9.



tions appeared to indicate a hyperbolic path. Incidentally, these experiments in which two shadows of one object were simultaneously produced from two cathodes, as in the case of tube [No. G 4], (fig. 7), described above, prove that two cathode beams are capable of passing through or penetrating one another, just as two beams of light will. This was further demonstrated by a special tube [No. G 6], (fig. 8), which has two arms at right angles, each ending in a bulb containing a small disk cathode. The object, an aluminium wire inserted at the point where the axes of the two arms intersect one another, cast two shadows, one on each of the tube-walls respectively opposite to the two cathodes. If one of these shadows was first produced alone no shifting of its position was seen when the second cathode was connected up to cast the second shadow.

2. *Electrostatic Deflexion of Cathode Rays by Conductors protected by Glass.*

In the preceding experiments the objects used for giving shadows were of metal, their electrified surfaces being exposed directly to the residual gases in the tube, and to the cathode rays. It was desirable to ascertain whether any such effects were produced when the conducting surface was shielded from direct action by the interposition of a non-conducting layer of glass. Attempts to deflect the cathodic shadows by holding charged bodies outside the tubes led to no definite result. In some cases it was possible by laying the finger on the outside of the tube to produce slight displacements, particularly if the cathode pole of the coil was earthed at the time, so that the finger acted cathodically. Tube [No. G 17], (fig. 9), was constructed to test this point. It is of a pear shape, with a small disk cathode, *k*, at one end, and an anode, *a*, in the side tube by which the bulb was connected to the pump. A wire, *b*, to cast a shadow, was inserted near the broad end, and two dimples or depressions, *d*, were impressed into the sides, leaving an internal distance of about 5 millims. between their faces. These depressions were covered externally with tinfoil. The wire *b* gave a shadow the size of which varied, as in previous experiments, according as the state of the wire was neutral, anodic, or cathodic. On each side of this shadow appeared a shadow of the dimple *d*. When the metal coatings of the two dimples were made cathodic, the space between their shadows decreased slightly. When made anodic, there was no measurable increase in the space between their shadows. When one was made anodic and the other cathodic, their shadows appeared to shift slightly as from the cathode side, and the shadow of the wire *b* was very slightly shifted in the same sense.

Tube [No. G 16], (fig. 10), was of a vertical pear shape,* with a small disk cathode of about 6 millims. diameter inserted at the side, and a similar disk anode at the bottom. Through the top was inserted a narrow glass tube, closed at the bottom, open at the top to receive mercury. This tube cast the usual shadow on the opposite wall, and gave identical shadows when empty and when filled. A wire was then inserted into the mercury to enable it to be electrified. At low degrees of exhaustion the shadow remained unchanged in size, whether the mercury thread within it was neutral, anodic, or cathodic. But, as the exhaustion was increased, a point was reached at which, almost suddenly, sensitiveness set in, and the size of the shadow became variable, contracting very slightly when the mercury was made anodic, expanding enormously when made cathodic. It was noticed that this change from the non-sensitive to the sensitive state occurred at the stage of exhaustion at which the "splash" phenomenon appeared on the bulb-wall opposite the cathode. It was also noticed that the sensitiveness depended upon the conditions of excitation, being greater when the break of the coil was lightly adjusted, so as to operate the coil with the spark-gap at 3 millims., than when tightened up to operate with the spark-gap at 15 or 20 millims. or more.

Several tubes were made of the general form of [No. C 2], (fig. 11), having a small disk cathode at one end, an anode in a side tube, and, as object to cast shadows, a tube containing mercury. These mercury tubes were made of several different

* This tube, and the succeeding one, were exhibited at the evening gathering of the Royal Society, October, 1896.

sizes and of different thicknesses of glass. All showed the same general set of phenomena. At low exhaustions there was little or no electrostatic deflexion by a glass-protected electrode, whether cathodic or anodic. But, at the stage of exhaustion where splashing sets in, the electrostatic deflexion of the shadow made its appearance, with resulting enlargement if the object were made cathodic. In several cases the mercury tube pierced, the mercury slowly oozing in minute drops into the bulb. When this had occurred, the shadow of the drop was electrostatically sensitive at exhaustions lower than that which was necessary to render sensitive the shadow of the glass-protected thread of mercury; the shadow assuming in consequence a grotesque nodular form.

It appears, then, that *the electrostatic deflexion of cathode rays by an electrified object is dependent upon the surface of that object, as to whether that surface is or is not conductive;* and that *for objects protected by a non-conducting layer there is a certain minimum stage of exhaustion below which they cause little or no electrostatic deflexion of the rays.*

3. *The "Splash" Phenomenon.*

Many CROOKES tubes show the phenomenon already twice alluded to, in which the glass surface opposite the cathode appears to be "splashed" by the cathodic discharge; creeping dendritic forms of an unstable kind appearing in the luminescence of the glass. This "splash" phenomenon is independent of the kind of glass used. It occurs with soda-glass, lead-glass, and uranium-glass tubes. It does not occur

Fig. 10.

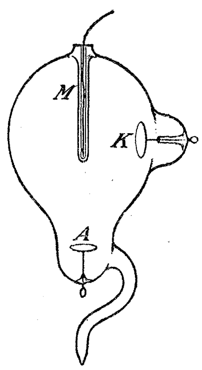


Fig. 11.

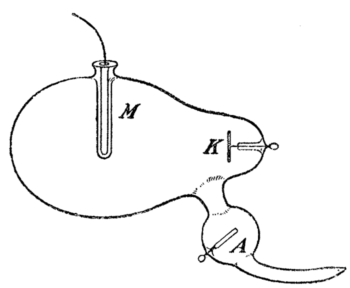
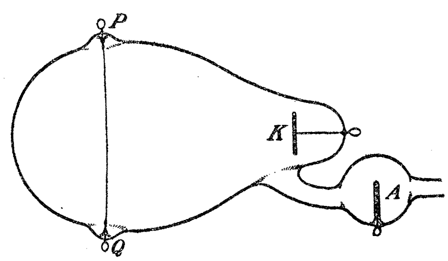


Fig. 12.



on an anticathodal surface of metal, nor, apparently, on an anticathodal glass surface, coated internally with plaster of Paris, or with powdered scheelite. It occurs at a particular stage of exhaustion a little below that needed for the production of RÖNTGEN rays, and at the stage, previously considered, at which there is a rapid increase in the electrostatic sensitiveness of the cathode rays. The dendritic forms assumed by the splash strikingly resemble the LICHTENBERG'S figures (of the positive kind), but are in general less fine-grained. The spreading of the "splashes" is affected by electrostatic influences; they spread on the inner surface of the tube toward an anodic point, whether that point be internal or external to the glass wall. If a single "splash" is produced by a solitary discharge from the coil, the external surface of the tube at the part splashed shows an electrostatic state of charge evidenced by the adherence of dust.* The explanation of the phenomenon appears to be the following:—At this stage of exhaustion, the first portion of a cathodic discharge electrifies the inner surface of the glass where it strikes, giving it a negative charge, or making it temporarily cathodic. The presence of this cathodic charge electrostatically affects the next-advancing portion of the discharge, and causes it to strike the glass a little on one side, so further distorting the ray. This may occur in any direction from the central point and will obviously present an instability; the "splash" creeping outward from the centre, first in one direction, then in some other, ramifying as it spreads, and fading out almost as fast as it is formed.

4. *Cathode Shadows of Hot Wires.*

After the experiments described in § 2, in which threads of mercury in fine closed glass tubes were used to cast shadows, others were made to test the effects of electric currents passing in the object which casts the shadow. A tube was constructed resembling fig. 11, but having the bulb traversed by a narrow glass tube which opened to the air at both ends. This was filled with mercury, and connected to a small battery to pass currents through it. No effect was noticed that depended either on the direction or the strength of the current.

Another tube [No. C 4], (fig. 12), was made, having a thin bare platinum wire stretched across the bulb between inserted terminals, P, Q. This wire gave as its shadow in the cathode rays a fine black line, bordered by the usual margin of brighter luminescence. On sending through the wire a current from a small insulated battery of accumulators no effect was observed until the current had been so far increased as to make the wire red hot, when its shadow was observed to be rather wider at the end by which the current left than at the end by which it entered. On reversing the direction of the current, this effect also changed direction. If, under these circumstances, the wire was made anodic as a whole by connecting the insulated battery, or any part of its circuit, to the anode pole of the coil, the shadow of the wire at once changed to a luminous line (a negative shadow, in fact, as described in § 1 above), which showed no change on reversing the battery, and which was unaltered whether the current is on or off. On similarly making the wire cathodic, its shadow expanded to some 6 millims. wide; and again, no effect was perceptible on reversing the current, though, apparently, the wire when hot

* A similar observation has been made by VILLARI ('Rendiconti della R. Accademia dei Lincei,' vol. 5, May 17, 1896), who has investigated the external electrostatic state of RÖNTGEN tubes and GEISSLER tubes by the use of electroscopic powders.

yielded a slightly larger shadow than when cold. But this could not be determined with certainty.

5. *Attempts to Concentrate Cathode Rays.*

The concentration of cathode rays by the use of concave cathodes to focus the beam dates from the classic researches of CROOKES.* In the experiments now made it was sought to concentrate the rays by other means. The first of these means was reflexion from the surface of a non-conductor—glass—at a small grazing angle. A tube [No. G 20], (fig. 13), was prepared, within which was suspended by platinum links an inner funnel of glass, about 47 millims. long, having an internal diameter of 12 millims. at the larger, and 8 millims. at the smaller end. The suspension

Fig. 13.

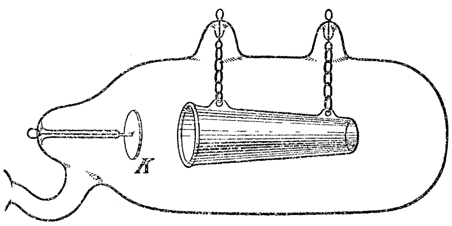


Fig. 14.

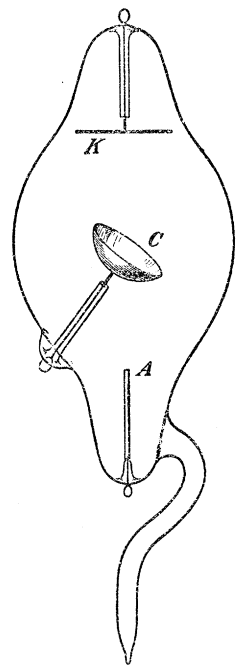
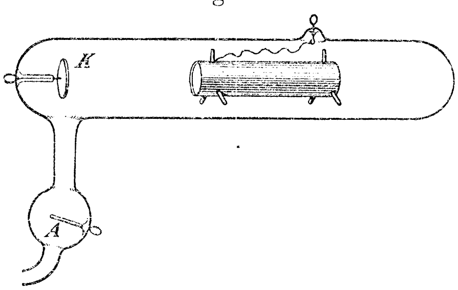


Fig. 15.



permitted the funnel to be swung aside by tilting the tube. This tube was exhausted to the point at which RÖNTGEN rays are but just emitted, the emission ceasing when the tube was warmed. To the eye there was no apparent difference in the brightness of the yellow-green luminescence of the anticathodal end of the tube whether the funnel were present or absent. The funnel itself cast a broad annular shadow, but it produced no difference in the brightness of the central patch within. On examining, by the aid of luminescible screens of platinocyanide of barium or of scheelite, the emission of RÖNTGEN rays from this central patch, no difference was perceptible in the luminosity, whether the funnel was absent or present. It did not concentrate the cathode rays.

* 'Phil. Trans.,' Part I., 1879, p. 142.

In the experiments made with tube [No. G 17], (fig. 9), described above, when the two external coatings of foil were made cathodic, no increase of brightness had been observed in the patch of luminosity on the end of the bulb, in spite of the narrowing of the luminous space between the two lateral shadows.

A tube [No. C 24], (fig. 14), was constructed, having a flat cathode, K, opposite to which was inserted obliquely, as an anticathode, a concave cup, C, of aluminium. A third electrode, A—an aluminium wire—was inserted at the further end of the bulb as anode. The cathode discharge was directed against this concave anticathode, at various degrees of exhaustion up to the highest when no spark could be sent through the tube. At no stage, however, was there any appearance, either by internal cones of rays, or by any special spot of luminescence on the glass wall, or by the evidence of a luminescible screen applied outside, of any concentration by the concave anticathode of rays of any kind.

Another tube [No. C 9], (fig. 15), was constructed, having an internal cylindrical tube of silver supported at each end by three projecting feet. This was not found to concentrate cathode rays that were passed along its axis. When it was itself made anodic its shadow was more sharply defined. But, when it was made cathodic, so far from any concentration being produced on the cathode rays directed along its axis, there appeared a new set of phenomena which are described below in § 8.

Another attempt to concentrate the rays by passing them along the axis of a helix of iron wire within the bulb, while a current traversing the wire produced a longitudinal magnetic field, is also narrated below. It also failed to produce any concentration of the cathode rays.

6. *Comparison of Cathode Shadows with* RÖNTGEN *Shadows. Production of Internal or Paracathodic Rays.*

In order to be able to compare together ordinary cathode shadows and the shadows produced on external luminescent screens by RÖNTGEN rays a number of tubes were constructed, having wires or other objects introduced for the purpose of casting shadows. One of these tubes was described at the meeting of the British Association at Liverpool.* A somewhat simpler tube [No. M 12] is depicted in fig. 16. It consists of a pear-shaped bulb having a concave cathode, C, focussing upon an oblique anticathode,† A, at its upper end. A lateral tube into which the upper end of the pear-shaped bulb is united has an aluminium wire, B, inserted as an object to cast shadows. This aluminium wire, about 3 millims. in diameter and 17 millims. long, is mounted upon a platinum wire fused in through the tube-wall.

At fairly low degrees of exhaustion the wire B casts a shadow upon the tube-end

* 'British Association Report,' 1896. See also 'Electrical Review,' p. 417, September 25, and p. 432, October 2, 1896.

† The term *anticathode* signifies an object upon which cathode rays are directed, as against a target. See 'Nature,' March 12, 1896, p. 437.

p, when C is made cathode. It is immaterial whether B or A serves as anode, or whether an anode in a bulb in the exhausting-tube is used. The shape and position of this shadow, which is dark against the yellow-green luminescence of the tube-wall, indicate distinctly that it is cast by rays proceeding from A. This quasi-cathodic shadow is cast by rays proceeding from A, even when A is anode, and under conditions which preclude the possibility of an oscillatory discharge. No shadow is produced if the cone of cathode rays proceeding from C is diverted by the influence of an external magnet from falling on the anticathode A. It is therefore clearly due either to cathode rays reflected at A, or to some other rays, resembling cathode rays, which are originated at A under the impact of the cathode rays from C.* Specular reflexion of cathode rays is not known to exist, and has not been observed in any of these tubes. No trace is seen of any blue cone or beam that might be a geometrical prolongation of the reflected cathode cone or beam. If reflexion is here operative, it is diffuse, not specular. But if specular, it differs from ordinary specular reflexion in two respects: (1) the shadows have no penumbra but are sharply defined, even though the anticathode surface is relatively large; (2) the distribution of the rays differs from that of ordinary specular reflexion.

Fig. 16.

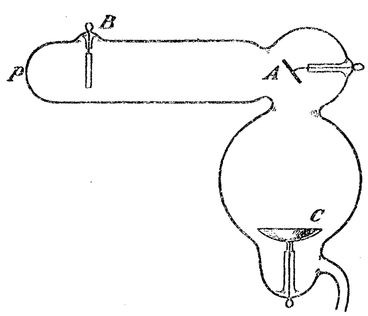
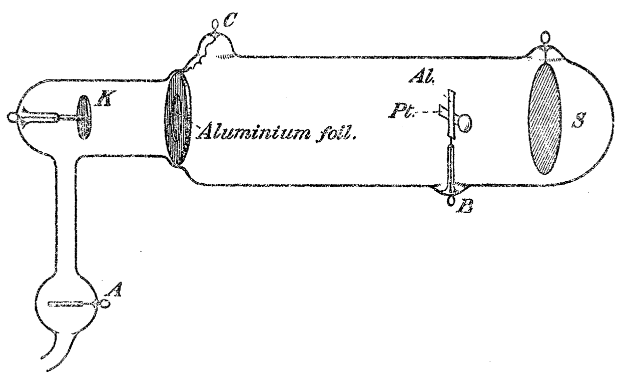


Fig. 17.



The shadow of B thus thrown on the tube-wall at p can be observed at a degree of exhaustion quite insufficient to excite RÖNTGEN rays; it can also be observed up to the highest exhaustion. Like the shadow of ordinary cathode rays, it can be deflected by a magnet placed over the tube between the object and the tube-end. It is also susceptible to electrostatic deflexion; the shadow expanding when B is made cathodic, contracting slightly when made anodic. The colour of the luminescence of the glass under the impact of these rays is identical with that produced by ordinary cathode rays.

If, now, a luminescible screen of platino-cyanide of barium, or one of scheelite, is

* This conclusion was reached by WIEDEMANN and EBERT as the result of experiments yet unpublished. See their paper "Ueber elektrische Entladungen," in the 'Sitzungsberichte der Physikal.-med. Societät zu Erlangen,' December 14, 1891.

held outside the tube near p, there will appear upon it, if the exhaustion is sufficiently high, a second shadow cast by the Röntgen rays; the size and position of this shadow being such as to indicate that it is cast by rays which have their point of origin also at A, and which have traversed the glass wall of the tube. If no perturbing magnetic or electrostatic influences are present, these two shadows lie geometrically on the same lines projected from A as origin. Both are sharply defined; the internal one more so than the external one. But the external shadow due to Röntgen rays does not shift when a magnet is placed between B and p. Neither does the external Röntgen shadow change its shape or size when B is made anodic or cathodic. If the shadows are simultaneously observed it will be seen that one and the same object, illuminated from one and the same point of origin, is capable of casting two shadows of different shape in different directions at the same time. It is clear that there are present two kinds of rays, which differ in their deflectibility by magnetic and by electrostatic forces, and in their power of penetrating glass.

These internal rays which are deflectible are not, however, ordinary cathode rays. Cathode rays proper, at a sufficiently high exhaustion, possess the characteristic property of exciting Röntgen rays wherever they impinge upon solid, or as Roiti has shown,* upon liquid matter. These internal rays fail to exhibit, either at high or low exhaustion, any trace of this property. There are produced, as is shown below, under certain conditions, some other internal rays, which also differ from ordinary cathode rays. Hence it becomes necessary to distinguish the different species by adopting an appropriate nomenclature. The ordinary cathode rays may be called *ortho-cathodic*; while the internal rays described above, which are emitted along with Röntgen rays at the surface of the anticathode, may be termed *para-cathodic*.

The emission of these para-cathodic rays demands especial attention. They may be observed in any Röntgen ray tube of the focus type. As pointed out by the author,† in April, 1896, the emission of Röntgen rays from the surface of a plane anticathode follows a distribution entirely different from that of the emission of any known kind of light. It does not follow Lambert's law of the cosine, the intensity remaining nearly uniform right up to a grazing angle, where it abruptly ends. This is demonstrated by photometric measurements made on the luminosity of a barium platino-cyanide screen placed near to the bulb. As viewed in such a screen the emission of Röntgen rays is confined to the region in front of the plane of the anticathode; the whole hemispherical space in front being filled with them, while the whole hemispherical space behind is devoid of them;‡ a sharp delimitation

* Mem. Accad. Lincei, s. V., vol. 2, July, 1896.

† 'Comptes Rendus,' *loc. cit.* See also 'Philosophical Magazine,' August, 1896, p. 156, and 'Proc. Royal Institution,' May 8, 1896.

‡ This is the state of things when the exhaustion is sufficient. But the author has many times observed, and has put on record ('Comptes Rendus,' *loc. cit.*) the circumstance that during exhaustion, and at the stage at which Röntgen rays just first appear to be emitted, they are emitted from both

between brightness and darkness (as viewed in the screen) occurring in the plane of the anticathodal surface. As was pointed out in a communication to the Physical Society,* and often since noticed by other observers, a similar oblique delimitation is visible in the yellow-green luminescence upon the walls of the bulb. At the time it was supposed that this internal luminescence extending over the region traversed by the Röntgen rays was caused by them on their way through the glass wall of the bulb. That they are not due to Röntgen rays may be, however, readily shown. If a magnet-pole be brought close to the bulb near the delimiting edge of the patch of luminescence upon the glass, that edge is seen to be distorted. It is due therefore to rays that possess magnetic deflectibility. It is also possible to produce an electrostatic distortion of this delimiting edge. But if with a barium platino-cyanide screen one observes the corresponding delimiting edge of the Röntgen ray emission in the same oblique plane, one finds that it undergoes neither electrostatic nor magnetic deflexion. A small displacement in some cases to be noticed is due to want of exact complaneity of the anticathode surface, and to a displacement by the magnet of the focus of the incident (ortho-)cathodic beam.

It therefore appears that from the anticathode surface there are emitted simultaneously with the Röntgen *rays, and with a similar abnormal lateral distribution, para-cathodic rays which differ from the* Röntgen *rays in respect of their power of penetration, as well in being electrostatically and magnetically deflectible. They also differ from the* Röntgen *rays in being emitted at a lower degree of exhaustion than is necessary for the production of the former, and from ordinary (ortho-)cathodic rays in not exciting* Röntgen *rays where they impinge on a solid surface.*

From the similarity in the abnormal distribution of the para-cathodic rays and of the Röntgen rays, it may be inferred that the physical processes concerned in their emission at the anticathode are similar.

7. *Sifting of Cathode Rays.*

It has long been known that cathode rays at different stages of exhaustion of the tube, and excited under different electromotive forces, differ in character from one another. The changes in magnetic deflectibility during the process of exhaustion, noticed by Crookes,† are familiar. The cathode rays observed outside the Crookes tube, by Lenard,‡ differ from those within in several physical respects, and also apparently from one another under different conditions of production. Wiedemann and Ebert in particular have dwelt on the heterogeneity of cathode rays, and

front and back of the anticathode, which, as viewed edgeways in a luminescent screen, appears a a dark line between two dim luminous regions. See also a case recorded in § 7 below.

* 'Proc. Physical Society of London,' June 12, 1896, and 'Philosophical Magazine,' August, 1896.

† 'Philosophical Transactions,' 1879, Part I., p. 160.

‡ Wiedemann's 'Annalen,' vol. 51, p. 225, 1894.

on the operation * of the deflecting magnet in separating the different elements of a bundle emitted simultaneously at a cathode. The remarkable success of LENARD in transmitting cathode rays through a window of aluminium leaf into the open air naturally suggested the possibility of partially separating within the tube itself the constituents of a heterogeneous cathode beam, by interposing screens or films to sift out the less penetrating from the more penetrating parts.

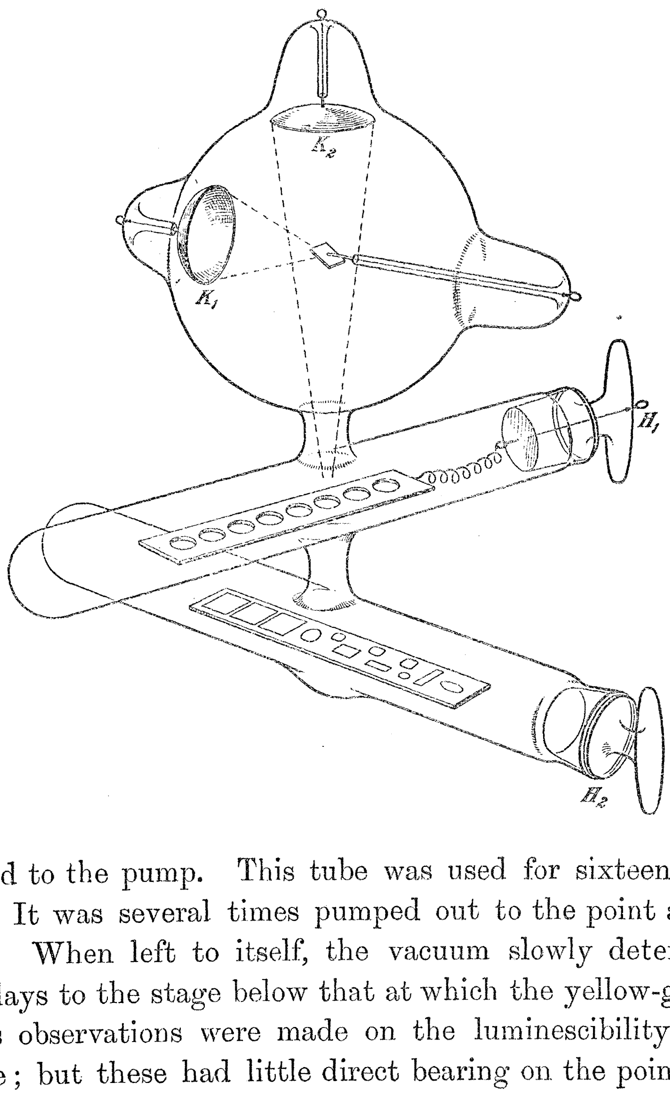
Accordingly, a tube [No. G 19], (fig. 17), was prepared, having at one end a small disk cathode, K, of aluminium, and an aluminium wire anode, A, in a bulb in the lateral exhausting tube. An interior luminescible screen, S, of mica coated with scheelite was inserted near the far end of the tube, and in front of this was erected, upon a conducting support, as an object to cast shadows, a cross, one arm of which was of aluminium foil, another of platinum foil, whilst the third was of platinum upon which a globule of glass was fused. Near the cathode the tube was fashioned with a shoulder, into which loosely dropped a ring of lead, carrying a diaphragm of aluminium foil. A platinum wire, C, inserted through the glass, enabled this ring and diaphragm, when in place, to be connected up to anode or cathode if desired. The ring and diaphragm being removable by tilting the tube, ordinary cathodic shadows could be produced for comparison. The tube was exhausted in the usual way to a high degree, and sealed off the pump. When the diaphragm was shaken out of its seat to allow a clear passage of the cathode rays, the shadows of the object upon the screen, S, were very sharp and distinct, and all parts of the shadow were equally dark. When the diaphragm was replaced, there was a shadow also, provided either B or S was earthed, or connected to the anode through a resistance, or made itself the anode. If C (the diaphragm) was connected to the cathode, the shadow became more brilliant, but with so rapid volatilization of lead, or of occluded gases, that this connexion was only possible for a second or two. The shadow was in all cases deflectible by the magnet, and appeared to be more readily deflected if the magnet was applied over the region between the diaphragm and the object than if applied between the cathode and the diaphragm. Although the diaphragm fitted fairly well in its seat, which was lined with aluminium foil, and permitted no direct cathode discharge around its edges, there was a distinct luminescence of the glass at the far end of the bulb around the edges of the mica screen, which cast a well-defined, dim shadow. The colour of this luminescence was the usual yellow-green, but there was a singular dark-orange luminescence over the end of the bulb where screened by the mica disk. When the aluminium diaphragm was connected to the cathode, and the platinum support of the mica screen was connected to the anode, a similar orange luminescence appeared in the neighbourhood of the cathode, K, during the brief moments that the operation could be continued. Further reference is made below to this second species of luminescence.

* *Op. cit.* This dispersion was also observed by the author in May, 1896, see 'Proc. Oxford University Junior Scientific Club,' May 26, 1896.

The tube was opened and resealed to the pump in a vertical position, so that the diaphragm remained constantly in its seat. The electrode K was used as cathode, and the support S as anode, during the exhaustion, which was continued until the spark-gap in the alternative circuit could be increased to about 25 millims. There were now clear shadows of aluminium, platinum, and glass, all equally dark. But on allowing the discharge to pass for 8 or 10 seconds, during which time the exhaustion diminished, the shadow of the aluminium arm faded out, leaving those of the arms of platinum and glass as dark as before. At this stage of things a barium platino-cyanide screen, placed directly over the bulbous end of the tube, showed a faint luminosity, but no shadow of the cross could be distinguished. Exhaustion was carried gradually higher, until the spark-gap was 4 inches; but at no stage could the shadow of the platinum upon the mica screen be made darker than that of the aluminium without first letting the discharge pass for a few seconds. The glass walls of the tube showed yellow-green luminescence only on the lowest region between the cathode and the diaphragm, save a slight trace on the upper end of the tube, which also showed yellow-green. Yet, on examining the side of the tube with a barium platino-cyanide screen, it was found that RÖNTGEN rays were being emitted both above and below the diaphragm, the luminescence being almost as bright above as below. The place where the diaphragm lay across the tube was marked by a strong clean black line between two regions of almost equal luminosity. Hence it would seem that in this case the rays which produce the yellow-green luminescence are stopped by the aluminium diaphragm, whilst other rays pass through, which are competent both to cast an internal deflectible shadow upon a scheelite screen, and to produce RÖNTGEN rays, which cause luminescence outside the tube on a platino-cyanide screen.

To test the sifting action of aluminium foil more thoroughly, the tube [No. M 14], (fig. 18), was designed. The bulb is provided with two concave cathodes, one, K_1, at the side, to focus upon a small oblique anticathode of platinum at the centre, the other, K_2, at the summit, being larger and shallower, intended to focus past the anti-cathode to a point in the narrow aperture at the bottom of the bulb. The object of this design was to allow either ordinary (ortho-)cathodic rays to be thrown directly down from K_2, or by the use of the lateral cathode K_1 and the oblique target, to throw down RÖNTGEN rays, accompanied by para-cathodic rays. Below the aperture at the bottom of the bulb a horizontal glass tube, H_1, was fixed, and below this, with a short vertical neck intervening, a second horizontal tube, H_2, at right angles to the first. Each of these tubes was fitted at one end with a ground glass stopper, their other ends being closed. A platinum wire was sealed in through the stopper of H_1. Nitrate of silver was used as a cement to make the stoppers vacuum-tight. In the upper of the two horizontal tubes was laid a short slip of sheet-lead, having eight holes punched in it. These holes were covered with pieces of aluminium foil in various thicknesses, to act as screens or filters to sift the rays. In the experiments to be described only the thinnest of these filters was used; it was a leaf about 0·07 millim. thick. The leaden slip was itself connected by a thin spiral of platinum wire to the wire leading out through the stopper. Into the lower horizontal tube was introduced a similar loose slip of sheet-lead, carrying upon its upper surface a number of fluorescible materials: scheelite, ruby, jacinth, diamond, Iceland-spar, fluor-spar, calcium sulphide, zinc sulphide (SIDOT'S blende), and a preparation of calcium carbonate, containing in solid solution about $1\frac{1}{2}$ per cent. of manganese carbonate. The disposition of the two horizontal tubes at right angles to one another enabled the two lead carriers to be moved, by tapping, independently of one another, while the

Fig. 18.



tube was connected to the pump. This tube was used for sixteen consecutive days upon the pump. It was several times pumped out to the point at which RÖNTGEN rays are emitted. When left to itself, the vacuum slowly deteriorated, the tube relapsing in two days to the stage below that at which the yellow-green luminescence appears. Various observations were made on the luminescibility of the materials enumerated above; but these had little direct bearing on the point now in question. When K_2 was used to produce ortho-cathodic rays, all the materials named luminesced brightly, most of them doing so even when the state of exhaustion was too low for the production of the yellow-green luminescence of the glass. They all, also, luminesced, though less brightly, when K_1 was used to produce para-cathodic rays. A horse-shoe magnet, placed with its poles on either side of the neck joining the two horizontal tubes, deflected the rays. When the screen of aluminium foil was shaken into its place to intercept the rays, the luminescence of almost all the above-mentioned materials was stopped. The scheelite proved to be the most luminescible of them, but no effect was produced upon it at any exhaustion up to the highest, unless the screen was itself also made cathodic by joining the lead slide in H_1 through a resistance to the cathode pole. The luminescence of the scheelite under these conditions was faint, and the tint, instead of the usual bluish-green, was of a lavender colour. The magnet did not seem to affect the production of this luminescence. Under no circumstances did the ruby luminesce when the aluminium screen was present.

A narrow aperture was punctured with a penknife through one of the thicker screens in the lead slide, and the effect was observed of throwing ortho-cathodic and para-cathodic rays through this slit upon the luminescible materials below. If the screen was itself neutral or anodic the luminescent effects of the ray that traversed the screen were exactly the same in kind as those produced on the same materials when the screen was absent. With para-cathodic rays the effects were the same as those with ortho-cathodic, but fainter, and in the case of several materials, particularly the ruby, so faint as to be practically invisible. When, however, the perforated screen was made cathodic, somewhat different results followed. The cathode ray, which was thus filtered through a slit in a negatively electrified or cathodic screen, no longer produced an effect identical in kind; the luminescence was, in general, weaker, but the tints differed, being in general duller.

The action of the magnet on rays filtered through a narrow hole in the diaphragm was carefully observed, a patch of the leaden surface of the slide, H_2, coated with powdered scheelite, being used as a luminescent screen to watch the effects. The beam of cathode rays streaming downward from K_2, and falling upon the perforated screen, was intercepted save the small part which passed through the aperture. When this small beam entered the magnetic field between the magnet-poles it was spread out, as described by WIEDEMANN and EBERT,* and by the author,† several patches of luminescence appearing on the scheelite surface, where it was struck by rays of different degrees of deflectibility. The exhaustion was varied while the magnet remained in place, when it appeared that the deflexion of any given ray did not depend on the degree of exhaustion. But as the vacuum was carried to a higher point the more-deflected patches of luminosity died out, while the less-deflected patches persisted. This is not inconsistent with the observation of CROOKES,‡ who

* *Op. cit.*

† See *supra.* The above apparatus was made early in June, 1896, before the publication of the researches of M. BIRKELAND on the magnetic spectrum. The results were briefly described by the author at the British Association meeting in September, 1896.

‡ 'Phil. Trans.,' 1879, Part I., p. 160 ('The Bakerian Lecture,' Art. 577).

found the curved cathode beam across a tube to become straighter as the exhaustion proceeded. From these experiments it appeared :—

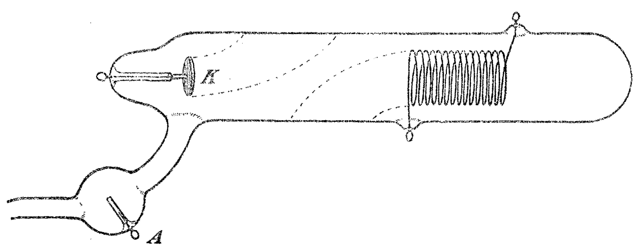
(1.) *That the various constituents of a heterogeneous cathode beam are emitted in various proportions at different degrees of exhaustion;* (2) *That in the cathode rays emitted at higher degrees of exhaustion there is a greater proportion of the less-deflectible rays;* (3) *That the least-deflecitble rays are those which most readily penetrate through a perforated screen when that screen is itself made cathodic.*

8 *Effect of a Negatively-electrified Screen on Cathode Rays, Double Fluorescence. Dia-cathodic Rays.*

Attention having been directed by previous experiments to the particular effects produced—notably in tube [No. M_{14}], (fig. 18)—by the interposition of a screen, which was itself made cathodic, other tubes were prepared to aid in examining these effects.

In tube [No. C 10], (fig. 19), there was inserted a helix, made of a dozen turns of bare iron wire, the ends of which were welded to platinum terminals passing through the glass. The cathode, K, was a flat disk; and there was an anode in a lateral bulb in the exhaust tube. The terminal turn of the helix, at the end nearest the cathode,

Fig. 19.

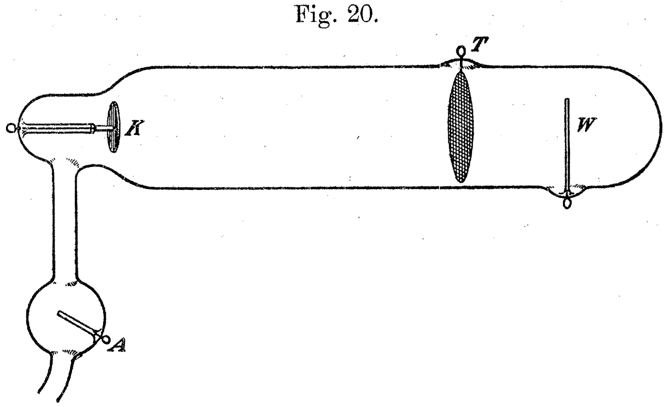


was brought down across the end face of the spiral, so that its cathodic shadow on the end wall of the tube appeared as a vertical diametral line across the circular outline of the helix. One purpose in constructing the tube thus was to test the effect of a longitudinal magnetic field upon the cathode rays. When a current was sent through the helix, the ampere-turns being about 140, and the intensity of the field nearly 60 C.G.S. units, the shadow of the diametral wire was rotated through about 20°. When the wire helix was made cathodic, the yellow-green luminescence of the glass was (as in the case also of tube [No. G 19], described above) confined to the portion of the tube between the cathode and the nearest end of the helix, no yellow-green luminescence being now produced on the tube end, and almost none on that part of the tube which covered the helix. But there now appeared a blue cone of rays proceeding from the inside of the further end of the helix, and extending thence to the far end of the tube. The tube-wall at this end now showed the dark orange luminescence which has been more than once alluded to in the preceding paragraphs as casually occurring. This phenomenon is a second species of fluorescence of the glass, and is always produced, provided the exhaustion be sufficiently high, when a cathode beam is directed against glass through a thin screen or through an aperture in a metallic screen which is itself made cathodic. This second fluorescence was examined with the spectroscope, when its light was found to consist simply of the D-lines of sodium.

The effect of an external magnet upon this tube was remarkable. When the horse-shoe was placed vertically, with its poles on either side, over the tube between the cathode and the helix, the yellow-green luminescence on the glass was driven into two portions; one, apparently due to rays proceeding from the cathode proper, being deflected up to the upper side of the tube; the other, apparently due to rays proceeding from the near end of the helix, being deflected down to the lower side of the tube. Or, on reversing the poles of the magnet, these deflexions were reversed. But in each case the blue cone proceeding from the far end of the helix appeared to be slightly deflected downwards. When the magnet was, however, brought down over the further part of the tube, so that its poles were one on each side of the tube, with the blue cone of rays between, the cone of rays was absolutely unaffected. That these rays were really rays of some kind was proved by the circumstance that they could cast shadows. A scrap of glass which accidentally remained inside the tube was observed to cast a shadow behind itself, none of the tawny fluorescence appearing in the shadowed portion.

To investigate the phenomenon further, tube [No. C 11], (fig. 20), was then made. Opposite the cathode there was introduced a screen of iron wire gauze, mounted upon

Fig. 20.



a platinum terminal, T, which passed through the glass. Between this screen and the tube-end was inserted a vertical wire, W, as an object to cast a shadow. If the gauze screen was made anode, or was left neutral, the usual sharp shadow of it was cast on the tube-wall by the (ortho-)cathodic rays, the whole tube being lit up with yellow-green fluorescence except where the lines of shadow fell. When the gauze screen was made cathodic that part only of the tube which was between the cathode and the screen showed the yellow-green tint, but, beyond the screen, there was the blue cone of rays, producing on the remainder of the tube the second, or dark-orange, fluorescence, as before, and in this second fluorescence the shadow of the wire could be seen upon the glass. This shadow was not displaced by a magnet held over the blue cone; it was, however, displaced if the magnet was held over the tube at the part where the yellow-green fluorescence showed itself between the cathode and the screen. The rays of this blue cone did not appear to be electrostatically sensitive, since the size of the shadow of the wire was not affected by electrifying the wire. Another feature which had been noticed with the preceding tube, but was exceedingly striking in the present one, was the difference in the situation of the two kinds of fluorescence. In the present tube, with its thin gauze screen, the two kinds of fluorescence met in the plane of the screen, and it was evident that while the fluorescence of the second, or dark-orange, kind was exactly confined to the inner surface of the glass, the fluorescence of the first, or yellow-green, kind was not so confined, but extended right through the glass. This seemed at first to be an optical illusion, but careful scrutiny proved it to be really so. It is most suggestive to find from spectroscopic evidence that both kinds of fluorescence are referable to the same element—the sodium of the glass employed. The circumstance that the rays last described should excite the emission of light giving a spectrum of so totally different a character, is itself sufficient to justify their being considered as different from the ordinary cathode rays. It is, therefore, proposed to distinguish them by the name *dia-cathodic rays.*

These observations may be summed up as follows :—

(1.) *When cathode rays fall upon a perforated metallic screen, which is itself made cathodic, or upon a tubular cathode, there emerge beyond the latter some rays, here termed dia-cathodic, which are incapable of exciting the ordinary cathodo-luminescence.*

(2.) *These dia-cathodic rays are not themselves directly deflected by a magnet.*

(3.) *They are capable of exciting a different kind of luminescence, the luminescent surface emitting light which, in the case of sodium glass, shows a gas spectrum.*

(4.) *They can cast shadows of intervening objects.*

[Note added November 7, 1897.—Recent further examination of the rays, here termed diacathodic, has shown me that they are very similar in their properties to, if not identical with, the "Kanal-strahlen," which GOLDSTEIN has found to be projected backward from cathodes. I have not yet been able to determine whether these diacathodic rays always accompany the ortho-cathodic rays or not. Observations on the yellow-green fluorescence of the first kind, made through revolving slits or in a rotating mirror, show that its colour changes before it dies away, becoming orange. This may be due to fatigue, however, and not to the greater persistence of emission of a different kind of ray.—S.P.T.]