SOME EXPERIMENTS WITH KATHODE RAYS.[1]

THE extensive employment of the focus form of Crookes' tubes as the most efficient known means of generating X-rays, has rendered advisable the more complete investigation of the kathode ray discharge in tubes of this description.

Hitherto, the usual method of investigating the characteristics of a kathode ray discharge apart from its mechanical properties, and beyond what is visible to the unassisted eye, has been by allowing the rays to fall upon a screen of some brightly fluorescent material, such as glasses of various descriptions, or screens covered with fluorescent salts. With all of these the maximum amount of fluorescence appears to be produced by such comparatively weak kathode rays, that in some cases the special effects produced by the more powerful rays seem to be more or less entirely masked, while the well-known phenomenon of the fatigue of fluorescent substances, when exposed to the more active rays, conduces to the same result.

Surface Luminescence of Carbon when exposed to Kathode Rays.

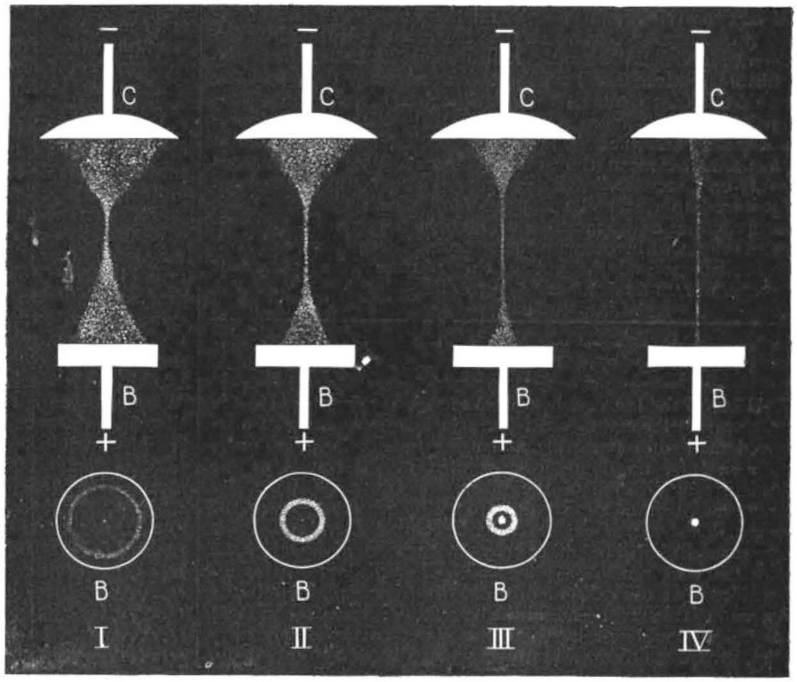
I have found in some cases that by replacing the usual screen, made of or covered with fluorescent material, by one of ordinary electric light carbon, much appears which was previously invisible. When a concentrated stream of powerful kathode rays are focussed upon a surface of carbon in this manner, a very brilliant and distinctly defined luminescent spot appears on the surface of the carbon at the point of impact of the rays, the remainder of the carbon remaining black. This luminescent spot seems to have a very close relation to the fluorescent spots on glass and on other fluorescent materials under similar influence. The effect is evidently a purely surface effect, as when the kathode stream is rapidly deflected by means of a magnet, the luminescent spot on the carbon moves with no perceptible lag. Further, though, as is also the case with glass, the whole of the carbon becomes gradually heated to a considerable extent if much power be employed for a long period of time, these luminescent spots are instantaneously produced on carbon of very considerable brilliancy with but a comparatively low power. Again, just as glass is known to become fatigued under the influence of kathode rays, so that after a time it refuses to fluoresce so brightly as before, so carbon is similarly fatigued, though only after having been very strongly acted upon. Carbon, like glass, also recovers its property of giving a surface luminescence to some extent, though it does not seem to entirely recover, at any rate, at all rapidly.

Apparent form of the Kathode Ray Discharge in a Focus Tube.

As is well known, in tubes of the ordinary focus type with a single spherical concave kathode, the rays coming off normally to the kathode surface appear to converge in more or less of a cone to a focus, and if the vacuum be not too high, to diverge again immediately in another cone upon the other side of the focus. At higher vacua the rays, after passing the focus, do not appear to diverge again at once, but seem to form themselves into a description of thread which connects the convergent and divergent cones, and is longer or shorter according as the vacuum is higher or lower. The focus, or perhaps more correctly, the point at which this thread commences, seems always to be more distant from the kathode than the centre of curvature of the latter, but the variation in this respect seems to be less and less the higher the exhaustion. This is no doubt due to the mutual repulsion of the rays, and accords with the assumption that the rays consist of charged particles, which travel more and more rapidly the higher the exhaustion. Probably for the same reason, kathodes that are only slightly concave, focus further in proportion beyond their centres of curvature than do deeply concave kathodes, for the same vacuum.

Apparent Hollowness of the Divergent and Convergent Cones of Rays.

When the divergent cone is thrown upon a thin platinum disc, as in the ordinary focus tube, and sufficient electric power—say, from a 10-in. Ruhmkorff coil—is employed, the platinum quickly attains to a red heat. With platinum, either the whole disc becomes uniformly heated, or in the event of the diameter of the cone of rays where it strikes the platinum being small compared with the area of the platinum, that portion of the platinum covered by the base of the cone becomes uniformly heated to a higher temperature than the remainder. This is as much as can usually be seen with platinum, though rather more is sometimes visible with aluminium; but if instead of either metal the disc is made of ordinary electric-light carbon, I have found that the luminescent portion of the carbon, instead of comprising the whole disc, or consisting of a uniformly heated circle, will in some cases take the shape of a brilliantly luminescent and apparently white



FIGS. 1–4.

hot ring, with a well-defined dark, and seemingly quite cold, interior. As the dimensions of the cone of rays are increased or decreased by decreasing or increasing the vacuum, the luminescent ring will be found to increase or decrease correspondingly in diameter, at the same time being brighter when small than when large. Further, when the ring is very small it will usually have a very brightly luminescent central spot, with a dark intervening portion between this spot and the ring, and when the vacuum is further increased the ring will gradually close in upon the spot until only the latter remains.

Figs. 1, 2, 3, and 4 show diagrammatically these hollow effects for four different degrees of vacuum, 1 being the lowest and 4 the highest exhaustion. The upper portion of each of these figures represents the general appearance of the kathode discharge between the spherical concave aluminium kathode C at the top, and the carbon anti-kathode B at the bottom. Beneath each of the elevational views of the kathode discharge will be found a plan view of the carbon anti-kathode, showing for each condition of vacuum the effect of the kathode discharge upon the carbon anti-kathode, in forming a brightly luminescent hollow ring, gradually decreasing in diameter as the vacuum is increased, until it centres on a point, as already mentioned.

[1] Abstract of a paper by A. A. C. Swinton, read before the Royal Society, March 11.

It may further be remarked that the diameter of the luminescent ring may be increased or diminished, or finally reduced to a point, without altering the degree of vacuum, by moving the anti-kathode away from or towards or finally into the focus of the kathode stream, the appearance of the ring in each of these cases being practically similar to those shown in the figures for a uniform distance with varying vacuum. Similarly it may be shown that the converging cone of rays between the kathode and the focus produce hollow rings upon a carbon anti-kathode exactly as does the diverging cone of rays. When the anti-kathode surface is not at right angles to the line of the discharge, the ring, in place of being circular, takes the proper form of a conic section. The holding of a magnet near the tube distorts the ring from a circular shape and moves its position on the carbon.

From these experiments it appears that both the diverging and converging cones of kathode rays act as though they were not of uniform density throughout their sections, but, at any rate, in some instances as if they were completely hollow.

It should, however, be noted that these hollow effects appear only to be obtained with fairly short focus kathodes, such as are usually employed in X-ray focus tubes, that is to say, with kathodes whose diameter is large as compared with their radius of curvature, so that the rays converge and diverge rapidly to and from the focus. With comparatively flat, long focus kathodes the cones do not show any signs of being hollow, and produce a uniformly luminescent spot upon the carbon of larger or smaller diameter, according to the conditions of vacuum and the position of the screen.

For instance, while kathodes 1·125 inches diameter and 0·708 inch radius of curvature gave in the manner described distinctly hollow convergent and divergent cones, a kathode 1 inch diameter and 1·5 inches radius of curvature gave convergent and divergent cones that appeared to be uniformly solid under all conditions.

On the other hand, with rays from flat kathodes brought to a focus by magnetic means, both convergent and divergent cones are found to produce hollow ring effects.

The Rays cross at the Focus with no Rotation.

In order to investigate the kathode rays in a focus tube still further, and more especially in order to discover whether the various rays from the kathode cross one another at the focus, or diverge again without crossing, and also in order to discover whether there is any twist or rotation of the rays, similar to what has been observed in the case of rays focussed by magnetism, a tube was constructed similar to that used in the previous experiments, with a carbon anti-kathode which was also the anode, fixed at the opposite side of the focus from the kathode, with the focus about equally distant between it and the kathode. The peculiarity of this tube consisted in the fact that a sector of the aluminium kathode, equal to one-eighth of the total area of the kathode, had been entirely removed, as shown at C, Fig. 5. It was expected that on using this tube, with the proper degree of vacuum to form a well-defined ring on the anti-kathode screen, that a portion of the ring, corresponding with the amount of the kathode cut away, would be found wanting; and that by the position of this gap in the ring it would be possible to ascertain whether the rays crossed at the focus, and whether there was any rotation. What actually was observed is shown for three different conditions of vacuum in Fig. 5, B being for the highest, and B″ for the lowest vacuum. As will be seen, the expected gap in the ring was obtained, but with the unexpected addition that the dimensions of this gap, instead of being only one-eighth of the circumference of the ring, was seven-eighths of the circumference. In fact, the amount of ring shown corresponded not with the seven-eighths of the remaining kathode surface, but with the one-eighth of the kathode that had been removed. The portion of ring that did appear was of a length corresponding exactly to the arc of the removed sector of the kathode, according to its greater or lesser nearness to the centre with different conditions of vacuum; and as the portion of ring was in each case exactly in line with the portion of kathode that had been cut away, it would appear that there is no rotation of the kathode beam as a whole, that the rays do cross at the focus; and, further, that when the hollow convergent cone is, as it were, split in this manner, some unexplained action, similar in effect to the existence of a circular surface tension, causes the gap to widen out and the remaining portion of the ring-shaped section of the cone to contract correspondingly, without, however, altering its diameter.

In order to further investigate the matter another tube was made, in which the concave kathode was complete; but the interior of the tube was furnished with a small movable piece of aluminium, which by shaking could be moved up and down the tube between the kathode and anti-kathode, and which, while not quite reaching the centre of the tube, would fill up very nearly one quarter of the circular sectional area of the latter.

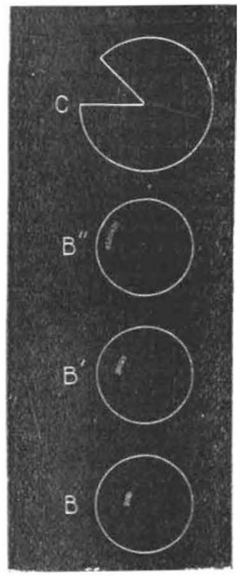


Fig. 5.

With this arrangement of tube, with the aluminium obstacle placed just at the focus, as shown in Fig. 6, the point of the obstacle just missing the kathode rays, a complete ring was formed on the carbon anti-kathode. On moving the obstacle slightly into the divergent cone, exactly one quarter of the ring on the anti-kathode failed to appear, as shown in Fig. 7, and on the obstacle being further moved in the same direction, the result was not altered.

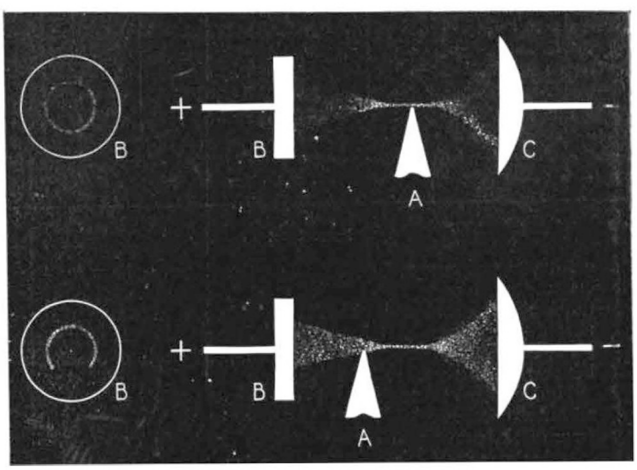


Fig. 6, 7.

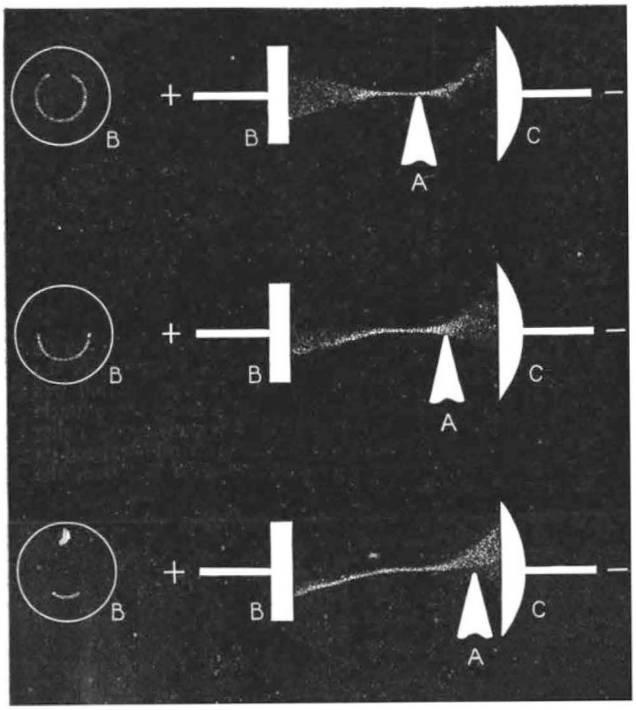
As in each of the latter two cases there was no displacement of the gap in the ring, the above showed that there is no rotation of the divergent kathode cone.

Experiments were next tried with the aluminium obstacle, moved so that its point just entered the converging cone of kathode rays, when a small portion of the ring was cut out; but on the opposite side, as shown in Fig. 8, this confirming the previous experiments, which showed that the rays cross one another's paths at the focus without rotation. Upon moving the aluminium obstacle a little nearer to the kathode, so that its point entered still further into the convergent kathode beam, one-half of the ring disappeared, as in Fig. 9, while, when the obstacle—which, it should be remembered, blocked only one-quarter of the circular area of the tube—was brought close up to the kathode, only about one-quarter of the ring remained, as in Fig. 10.

Further experiments were tried with the aluminium obstacle both in the divergent and convergent cones, but with the tube exhausted to different degrees of vacuum, when it was observed that when the obstacle was in the divergent cone, a portion of the ring was cut off exactly proportional to the angle subtended by the sides of the obstacle; while when the obstacle was placed in the convergent cone, a much larger proportion of the ring was cut off in each case, this being much more marked with a high vacuum, when the diameter of the ring was small, than with a low vacuum, when the diameter of the ring was large.

The Convergent Cone at Higher Vacua.

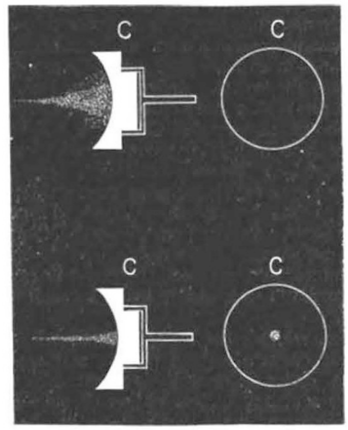
The carbon anti-kathode screen was found useless for investigating the convergent cone of kathode rays at anything but a very low vacuum, by the reason of the well-known difficulty in



FIGS. 8–10.

getting any discharge to pass when the distance between the electrodes is less than the thickness of the dark space; and for the further reason that if the anti-kathode screen was not connected to the anode, it became itself negatively charged, and acted as an additional kathode when brought into the space between the kathode and the focus.

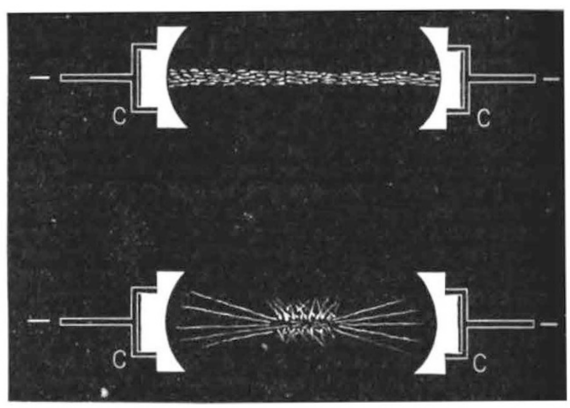
Under these circumstances, it was thought that possibly some additional information might be obtained with regard to the form of the convergent cone at high vacua, by making the concave kathode itself of carbon. A tube was therefore constructed having a concave carbon kathode, the diameter of which was 1 inch, and the radius of curvature 0·75 inch. The appearance of the kathode with this tube is shown for a fairly high vacuum in Fig. 11, in which the kathode itself is shown in section, so as to let the form of the discharge be better seen. As will be observed under this condition of vacuum, which was too high to show any divergent cone, the cone of convergent rays appears to be contracted in diameter at its base, and to come off from the central portion of the kathode only, the remaining surface of the kathode being apparently inactive. This was found to be still more the case at higher vacua, as will be seen from Fig. 12, which shows in a similar manner the form of the kathode discharge in a tube exhausted to a very high vacuum. In this case, as will be observed, the whole of the kathode rays appear to come off from a very small spot in the centre of the kathode. Further, that this small spot is, at any rate, the source of most, if not all, activity, was evident from the fact that it became luminescent exactly in the same manner, but in a less degree, than had previously been observed with a carbon surface upon which kathode rays were concentrated. Whether this surface luminescence of the kathode carbon, at the point where the kathode rays leave it, is due to the violent tearing away of particles of carbon, or to some other cause, it is difficult to say; but the fact that at high vacua the kathode rays come of entirely



FIGS. 11, 12.

—or, at any rate, almost entirely—from only a very small portion of the centre of the kathode, explains the observed fact that, within limits, large kathodes have no advantage over small kathodes in X-ray tubes.

During the carrying out of the above experiments with a carbon kathode, very bright sparks were occasionally seen coming off the kathode and passing through the focus, and it was consequently thought that possibly by placing two concave carbon kathodes facing one another, such particles, by being caused to rebound backwards and forwards continuously between the two, might render the form of kathode stream visible at very high vacua when the stream itself becomes otherwise invisible.



FIGS. 13, 14.

With this view, a tube was made with two concave carbon kathodes, similar to those employed in the last experiment, were placed exactly opposite one another. The anode was placed in an annex, and the two kathodes were connected together by means of a wire outside the tube. At a very high exhaustion, this tube gave very beautiful effects, and showed clearly the form of the kathode discharge at a degree of exhaustion when it is usually in itself quite invisible. Immediately on the current being turned on and the discharge passing, a straight and thin stream of bright golden coloured particles of apparently incandescent carbon passed between small luminescent spots at the centres of each kathode, as shown in Fig. 13. This did not last for more than a second, when owing, no doubt, to the rapid fall of vacuum the appearance changed to that shown in Fig. 14, and the incandescent particles of carbon could be seen passing backwards and forwards along the convergent and divergent cones of kathode rays, which, at the lower vacuum, proceeded from both kathodes, and spluttering in the centre, where the particles going in opposite-directions collided. This appearance lasted for some seconds, becoming gradually fainter as the vacuum fell. By re-exhausting the tube with the pump, however, the original appearance shown in Fig. 13, as also the appearance shown in Fig. 14, could be produced as often as desired. Apparently the particles of carbon become heated to incandescence either by the action of the kathode rays upon them while they are flying through space, or by their friction in passing through the residual gas, and possibly by their mutual collisions, for in the stage shown in Fig. 14, when the kathodes themselves show no luminescence the flying particles appear to be most intensely luminescent when in the centre of the tube. It may be mentioned that after this experiment had been repeated several times, the glass of the tube became perceptibly blackened, which, taken with the fact that a similar tube with kathodes of aluminium showed no stream of bright particles, goes to show that the particles consist of carbon torn off the surfaces of the kathodes.

The Production of X-Rays.

In order to ascertain whether it is necessary that the kathode rays should fall on solid matter in order to produce X-rays, another tube was constructed, similar in all respects to the last, with the exception that the two kathodes were made of aluminium.

It was thought that with this tube the opposing streams of kathode rays might possibly produce X-rays at the point where they met. This does not, however, appear to be the case, as though this tube, when exhausted to so high an extent that the alternative spark in air leapt fully eight inches, gave X-rays in considerable quantity, these rays appear to come entirely from portions of the glass of the tube that were covered with green fluorescence, and not at any rate appreciably from the central point between the two kathodes, where the opposing streams of kathode rays would meet one another.

It seems, therefore, that X-rays can only be produced by kathode rays when these strike solid matter.

No doubt this matter must also be positively electrified.

THE INSTITUTION OF NAVAL ARCHITECTS.

THE annual spring meeting of the Institution of Naval Architects was held last week in the hall of the Society of Arts, under the presidency of the Earl of Hopetoun, President of the Institution. The meeting extended over the 7th, 8th, and 9th of April. The following is a list of the papers read :—

"Recent Trials of the Cruisers *Powerful* and *Terrible*," by A. J. Durston, Engineer-in-Chief to the Royal Navy.

"Water-tube Boilers in War Ships," by Rear-Admiral C. C. P. Fitzgerald, R.N.

"A Mechanical Method of Ascertaining the Stability of Ships," by A. G. Ramage.

"On the Fighting Value of certain of the Older Ironclads if Re-armed," by Captain Lord Charles Beresford, R.N.

"The Application of the Compound Steam Turbine to the Purposes of Marine Propulsion," by the Hon. Charles Parsons.

"On the Use of the Mean Water Line in designing the Lines of Ships," by A. G. Ramage.

"The Accelerity Diagram of the Steam Engine," by J. Macfarlane Gray.

"Acetylene and its Probable Future Afloat," by Prof. Vivian B. Lewes.

"Nickel Steel as an Improved Material for Boiler Shell Plates and Forgings," by William Beardmore.

"Application of Electrical Transmission of Power in Marine Engineering and Shipbuilding," by F. von Kodolitsch.

The papers were mostly of a practical rather than of a scientific interest. Mr. Durston's contribution on water-tube boilers was a valuable record of the performance of the boilers in the two big cruisers lately added to the Navy. It may be said generally that the Belleville boiler has proved successful in these ships, and has done a little better than return-tube boilers of the type recently placed in the ships of Her Majesty's Navy. The fuel economy has been fair, 1·7 lbs. per I.H.P. per hour; whilst the weight of boiler and contained water was somewhat below that which has been generally reached in Navy return-tube boilers when run under easy conditions; but in some cases the boiler weights per I.H.P. of other war vessels have been lower than the figure—22 I.H.P. per ton—recorded of the two cruisers. In the long debate which followed the reading of the paper, it was stated that the Belleville boiler appeared to advantage in the *Powerful* and the *Terrible*, because it was compared with a type of boiler that was ill-designed. The general opinion of speakers, however, was that Mr. Durston had scored a great success, and deserved to be congratulated on his courage and perseverance. Admiral Fitzgerald discoursed on the advantages of the Belleville boiler from a tactical and strategical point of view. His opinion was altogether favourable to the new type of steam generator. Lord Charles Beresford, in his contribution, advocated the re-arming of certain old battle-ships with modern breech-loading guns, or else scratching them off the list of effective ships. The preponderance of naval opinion appeared to be in favour of the latter course. Mr. Ramage's paper described a mechanical method of ascertaining stability by means of wooden sections representing mean sections. The method is ingenious, but the principle is not altogether new.

The paper by Mr. Parsons had been looked forward to with great interest, as it was to describe a very wonderful boat, which was fitted with the author's steam turbines in place of ordinary engines. The *Turbinia*, as the boat is named, is 100 feet in length, 9 feet beam, and 44½ tons displacement. The original turbine engine fitted in her was designed to develop upwards of 1500 actual horse-power at a speed of 2500 revolutions per minute. The boiler is of the water-tube type for 225 lbs. per square inch working pressure with large steam space, and large return water legs, and with a total heating surface of 1100 square feet, and a grate surface of 42 square feet; two firing doors are provided, one at each end. The stokeholds are closed, and the draught furnished by a fan coupled directly to the engine shaft. The weights are remarkable, and certainly have never before been equalled for lightness in any practicable marine machinery. They are as follows :—

Main engines	3 tons 13 cwts.
Total weight of machinery and boiler, screws and shafting, tanks, &c. ...	22 tons
Weight of hull complete	15 tons
Coal and water	7½ tons
Total displacement	44½ tons

The great trouble, as might have been expected from the high rate of revolutions, was with the screws, and Mr. Parsons has only repeated the experience of Mr. Thornycroft with his destroyer, in finding that in all screws there is a limiting speed of blade, due to cavitation, depending upon the slip ratio and the curvature of the back. In order to throw light on this subject, the author had recourse to an ingenious device. Model screws were revolved in a bath of hot water heated to within a few degrees of the boiling point, and in order that the model screw should produce analogous results to the real screw, it was arranged that the temperature of the water and the head of water above the propeller, as well as the speed of revolution, should be such as to closely resemble the actual conditions and forces at work in the real screw, the object in heating the water being to obtain an increased vapour pressure from the water, so as to permit a representation of the conditions with a more moderate and convenient speed of revolution than would otherwise have been necessary. The screw was illuminated by light from an arc lamp reflected from a revolving mirror attached to the screw shaft, the light falling on the screw at one point only of the revolution. The shape, form, and growth of the cavities could be clearly seen and traced as if stationary. It appeared that a cavity or blister first formed a little behind the leading edge, and near the tip of the blade; then, as the speed of revolution was increased, it enlarged in all directions until, at a speed corresponding to that in the *Turbinia's* propeller, it had grown so as to cover a sector of the screw disc of 90°. When the speed was still further increased, the screw, as a whole, revolved in a cylindrical cavity, from one end of which the blades scraped off layers of solid water, delivering them on to the other. In this extreme case nearly the whole energy of the screw was expended in maintaining this vacuous space. It also appeared that when the cavity had grown to be a little larger