IMAGE EVALUATION TEST TARGET (MT-3)

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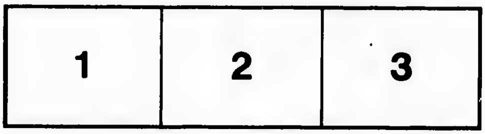
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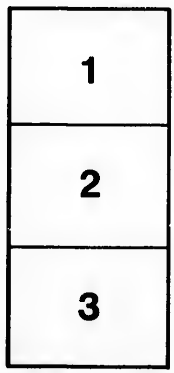
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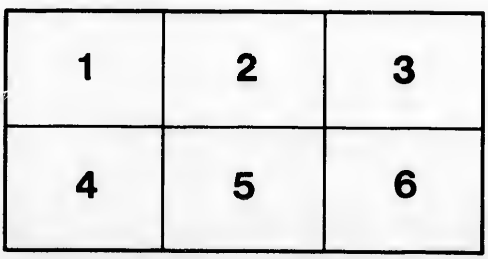
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SOME EXPERIMENTS ON THE X-RAYS

By JOHN COX, M.A.

AND

HUGH L. CALLENDAR, M.A.

Professors of Physics, McGill University, Montreal.

XI.—*Some Experiments on the X-Rays.*

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(Read May 28, 1896.)

A few days after the arrival of the news of Röntgen's discovery, on Feb. 7th, the first application of the method to surgery in the McDonald Physics Building, was made by the photographic location of a bullet in the leg by Professor Cox. This photograph, together with another of a hand, taken by Messrs. King and Pitcher on the same day, has been described and figured in the Montreal Medical Journal for March, 1896.

The tube used for taking this photograph was the phosphorescent lamp tube of Puluj, which has been widely used in Germany for the same purpose. Out of a collection of upwards of fifty Crookes tubes, obtained from Messrs. Geissler in 1894, this tube alone was found to retain a sufficiently perfect vacuum for the purpose of X-ray photography. The exposure required in the case of the hand was 45 minutes at a distance of 8 inches. Some of the other tubes were found to give faint results, but they were too weak to be of any practical use.

Shortly afterwards we received a copy of Nature, of Jan. 23rd, containing an account of some experiments by Swinton, who stated that much better results could be obtained by the use of the Tesla coil oscillating discharge. On trying this method, we found that several of the tubes in which the vacuum was bad, gave much brighter fluorescence than with the Ruhmkorff discharge, but the definition of the shadows with any of the ordinary tubes was inferior owing to the double kathode. We also found that the oscillating discharge had a very marked tendency to perforate the tubes. Several of our Geissler tubes were temporarily damaged in this way, with the oscillating discharge, whereas we had no such mishap with the direct discharge, although using a ten-inch spark.

With a view of overcoming these and other difficulties, upwards of 30 tubes of different patterns were devised and constructed by Professor Callendar, both for the direct and the oscillating discharge. Incidentally a number of anatomical and other photographs, including several surgical cases, were taken with these tubes, and most of the experiments of Röntgen and other observers were repeated and verified. These observations were interesting at a time when some physicists imagined that the rays proceeded from the anode, or that they could be concentrated and brought to a focus by a glass bell-jar, but the main facts with regard to the X-rays are now so firmly established as to need no further corroboration of this kind. We ultimately abandoned the use of the oscillating discharge, as we found that with the direct discharge a greater amount of power could be employed, and more brilliant effects secured, without risk of perforating the tube. The one-electrode method of Tesla, though attended with less risk of perforation, appeared to require a very extravagant expenditure of power.

The tubes in which the kathode rays were allowed to impinge on the glass walls were liable to a serious defect. If the X-radiating surface were large, as in the maltese cross tube of Crookes, a large volume of rays could be produced, giving brilliant effects, and readily visible through the human body, but permitting very poor definition. If on the other hand, the glass surface were made small, in order to secure good definition, very little power could be applied without melting the glass. Aluminum windows were tried, following Röntgen, but could not be made permanently air tight. Such devices as the use of a continuous air-blast, or of oil or water for cooling the tube, besides being troublesome, were open to obvious objections. All these difficulties were met by the discovery of the "Focus Tube."

Application of the Focus Tube.—The use of the focus tube represents the greatest practical advance which has been made on the method of Röntgen. The tube is one of the usual Crookes series, in which the kathode rays are concentrated by means of a concave electrode on a plate of platinum. It is generally used to illustrate the production of heat by the kathode rays. It was discovered that this focus was a very powerful source of X-rays, which proceeded in straight lines through the glass, and were capable of casting very sharp shadows, since they proceeded from a very small focal point. We found the first illustration of this tube, as applied to X-ray work, in the British Medical Journal, of March 21, 1896.

We were fortunate in possessing a very fine focus tube, with a bulb five inches in diameter, and a very large concave electrode. The tube was opened, and the platinum plate bent at a more convenient angle, and the tube then sealed and re-exhausted. The results were found to be far superior in clearness and density to any of those obtained with the glass tube. The original platinum plate, however, was so thin that a hole was melted through it. The limit of power which can be applied to these tubes depends on the size and thickness of the platinum plate. The larger and thicker the plate, the greater the power that can be dissipated without overheating the plate and spoiling the tube. With our particular coil and tube, the limit appears to be between 60 and 70 watts on the primary. The stage of greatest X-ray efficiency is a little beyond the stage of greatest heat production,

Method of Exhausting Tubes.—The method which we adopted for exhausting the tubes may perhaps be worth mentioning, as we found it to be very expeditious, and it does not appear to be generally known or employed. On first exhausting a tube, the chief difficulty is generally to get rid of the last traces of gas from the electrodes and the walls of the tube when high vacua are required for X-ray work. If this gas is not thoroughly removed, the vacuum is liable to subsequent deterioration. The method which we adopted for this purpose consisted in maintaining a continuous discharge through the tube, during the process of exhaustion, by means of an *alternating* current applied to the induction coil, the strength of the current being so regulated as to heat the electrodes of the tube as much as possible without melting them or causing a deposit on the glass. The effect of the current was simultaneously to heat the walls of the tube sufficiently to dry them very completely without any risk of cracking the glass, as may often happen if the tube is artificially heated by means of a Bunsen flame. Starting with a five inch bulb, wet and dirty from the blowpipe, we were able in this manner to raise it to an X-ray vacuum in from half an hour to an hour.

The pump which we generally used for exhausting the tubes, was a five-fall Sprengel of German make, which had been fitted in the laboratory with a vacuum trap for drying the mercury, and with an automatic arrangement for returning the mercury to the upper reservoir. At its maximum rate of working, this pump took only ten or fifteen minutes to raise a five inch bulb from one millimetre to a sparkless vacuum, if the electrodes had been previously freed from gas by the method above described. We found it preferable to the Geissler form of mercury pump, as it permitted the vacuum to be varied *continuously*, and to be maintained at any desired point. We also used, on several occasions, an automatic Geissler pump of the Max Stuhl pattern.

Phenomena presented by the Focus Tube.—The phenomena presented by this tube in action, have frequently been described, but the published descriptions do not altogether agree with our experience. According to one account which we received, the kathode rays were regularly reflected in a small pencil from the platinum plate, and formed a minute focus point on the glass, from which the X-rays proceeded. On exhausting our focus bulb for the first time, we found on the contrary that a whole hemisphere of the glass surface on the side exposed to the kathode rays reflected from the platinum, became brilliantly and almost uniformly phosphorescent. We further verified, by taking a pin-hole photograph, that practically the whole of the X-radiation came from the focus point on the platinum plate, and passed directly through the glass without further diffusion. According to a statement by Professor Lodge, which we observed at a subsequent date, the X-radiation is rendered more brilliant by connecting the platinum plate to the anode, and is diminished in intensity by allowing the plate to become red hot. We have not been able to observe these effects, and are inclined to attribute them to change in the vacuum, or to some other peculiarity in the tubes used by Lodge.

We have found it a matter of great importance for obtaining clear and brilliant photographs, to remove the least trace of water vapour from the tube. The presence of water vapour has the effect of making the focus point much less sharp, and the sparking very irregular. The phosphorescence of the glass is much less brilliant, with occasional sectorial flashes from the back of the kathode. Shadows of bones on the fluoroscope are much less clearly defined, and appear to be nearly as transparent as the flesh. If much water vapour is present, the platinum plate appears to be more highly heated for the same power. than if the air in the tube is dry. The vacuum at the sparking limit, appears to be much higher, as measured by the McLeod gauge, ·002 to ·005 mm. as compared with ·010 to ·030 mm. for dry air, but these figures, owing to the extreme slowness of diffusion, and the absorption of water vapour by the phosphoric anhydride in the pump, do not necessarily represent the actual vacuum existing in the tube. That these effects are to be attributed to the presence of water vapour, is rendered probable by the fact that they are always observed on exhausting a new tube, if precautions have not been taken to dry it, and that they disappear if a small quantity of dry air is admitted and the tube re-exhausted. The presence of water may also be verified by spectroscopic observations.

We have observed these appearances in X-ray tubes of various makers. They have generally been explained by other observers as being due to X-rays of different kinds, or to different degrees of vacuum, or to different kinds of discharge. No doubt these explanations are often true. An increase in the vacuum certainly increases the relative transparency of the bones, and the effects are often considerably modified by any change in the character of the discharge. But so far as our experiments go, the presence of water vapour is a much more serious source of disturbance, and affords in many cases a much more likely explanation of the irregularities.

Method of Operating.—For the sake of more completely investigating the effects with different gases, and under different conditions, we have preferred to keep the tube permanently connected with the pump. Incidentally this method possesses the advantage that it is possible to work the tube continuously at its point of highest efficiency for any length of time. With a good vacuum, and a powerful discharge, the air in the tube appears to get used up so rapidly that the spark soon refuses to pass otherwise than outside the tube. With a sealed tube, it is generally necessary to stop at intervals and warm the tube. We found it preferable, however, to supply small quantities of dry air occasionally through a tap connected with the pump. On one occasion, the tube was operated almost continuously in this manner for nearly two hours, including one exposure of over an hour without any intermission. The admission of air was so adjusted that the discharge took an alternative path by a six inch gap in air once in every five or ten discharges. It was not possible to keep the proportion quite constant, but a very fair average was maintained. A little air was admitted every one or two minutes. The character of the discharge, and the X-radiation appeared to be nearly unchanged throughout. The intensity was, if anything, greater at the end of the exposure. At the end of the exposure, however, the pressure of the air in the tube was found to have increased to nearly the same extent as if the air admitted to the tube had all accumulated in the tube, and had not been used up by the discharge or occluded by the walls as is generally supposed. This would appear to imply that the production of kathode rays is due in part at least to some change in the constitution of the gas in the tube, and is not merely a question of the degree of vacuum.

After allowing the tube to rest for three hours, the vacuum was found to be almost unchanged, but no kathode rays were produced until the discharge had been passed for nearly a quarter of an hour. Similar phenomena were observed on other occasions after prolonged exposures. It is possible that the apparent increase of pressure may have been really due to the removal or decomposition of aqueous vapour by the discharge, but we could not find any direct evidence that this was the case. A similar increase of apparent resistance is observable in most tubes during the first few minutes of the passage of the discharge. In many cases the resistance ceases to increase after a short time, and the tubes will run continuously without change for half an hour or more. In the case of sealed tubes, if air-tight, the original state of the vacuum may be restored by heating, or by an alternating current.

Anatomical Photographs.—With the focus tube, there is now no difficulty in taking photographs of any of the joints or extremities, which are capable of showing the nature of any injury due to fracture or dislocation or the presence of foreign bodies, just as clearly as if the bones themselves were exposed to view. In taking photographs through the thicker and more solid parts of the trunk, however, there are still difficulties, owing to the fact that the bones appear to be much less opaque as compared with the flesh when tested by rays of sufficient intensity to pass through a considerable thickness. Plenty of light gets through, and it is possible to obtain extremely dense negatives with an exposure of ten or fifteen minutes, but it appears that the rays undergo a kind of filtering process in passing through the upper layers, and that those which survive extinction longest, penetrate bone and flesh alike with more nearly equal facility. It is fortunate, however, that bullets, buttons, and other metallic objects, are so much more opaque than bone or flesh as to be very readily distinguished in any part of the body.

It is probable that many improvements remain to be made in this direction by the use of suitable fluorescent screens in conjunction with the photographic plate, or of suitably stained or loaded emulsions.

There is little evidence at present of any kind of selective absorption, but if any phenomenon of this nature exists, as in the case of ordinary light, it should be possible to find some fluorescent substance which was particularly sensitive to the rays which are specially absorbed by bone. We did not ourselves make any experiments worth mentioning in this direction, because it happened that the photographic plates which we first used, Stanley, sensitometer 50, appear to give results which from all accounts were at least equal to those which were obtained elsewhere with the aid of fluorescent screens. The following list, comprising the more difficult cases which we have attempted, will serve to illustrate the possible applications of the method.

Bullet in brain of child, aged 12. The bullet and the hole by which it entered are clearly shown in a photograph with an exposure of nine minutes. The bullet was faintly visible on another plate with an exposure of three minutes. It was found to have settled down nearly in the centre of the brain.

Broken hip joint. An exposure of fifteen minutes was allowed for this case, as the subject was a man of solid build. The head of the thigh bone was found to have been broken off and twisted round. The foramina and other details of the pelvis are clearly shown. The negative is so dense that it takes more than half an hour to print in bright sunshine.

Drainage tube in lung. This was a case of a small drainage tube of ebonite, No. 9 catheter, which was lost in the lung eleven years ago. Owing to its thinness and to the comparative transparency of ebonite, the tube was a somewhat faint object, but was quite unmistakably visible in the negative.

Fracture of skull. The subject had been gored by a bull two years previously, and had lost one eye and part of the bone of the orbit. He had lately become subject to fits. The negative showed a vague white shadow in the neighbourhood of the gap in the skull, which may have been due to a piece of displaced bone, or to some bony growth. The indications are too indefinite, however, to be of much use in diagnosis.

Pus cavity in lung. In this case the diagnosis from the ordinary methods was very uncertain. A cavity, however, was very clearly indicated as a dark shadow in the negative. If the cavity had been full of pus at the time, it would have been indicated as a lighter patch, the transparency of liquid being less than that of lung tissue when distended with air.

Stone in kidney. Some of the typical symptoms were absent in this case. The X-ray negative showed a faint white patch in the region of the kidney.

In addition to the above, which include the more difficult medical cases, a very large number of simpler cases of fractures, etc., of the extremities were taken, as well as photographs of various parts of the healthy body including the skull and trunk.

Exposure and Development.—In taking photographs through the trunk, we found that little or nothing was gained by prolonging the exposure beyond ten minutes or a quarter of an hour. A longer exposure appeared to give a flat over-exposed result, in which the fainter differences of transparency were, to a great extent, obliterated. For the same reason we found it best to use a fairly strong developer, in order to strengthen the contrast as much as possible. We generally used rodinal of strength 1/10, and continued the development for ten minutes on the average. In many cases the negatives were subsequently intensified with bichloride of mercury in order to heighten the effect. In some cases this method was found to bring out slight differences of density which were otherwise too faint to be appreciated.

The X-ray photograph differs from that produced by ordinary light, in that the action of the X-rays extends through the whole thickness of the film, whereas that of ordinary light is confined to the surface. The photographic film is very opaque to the actinic rays of the spectrum, but is very transparent to the X-rays, which are capable of penetrating many successive films without apparent weakening. It is therefore necessary to continue the development until the action has extended through the whole thickness of the film. It is also evident that greater density may be obtained by using thick films, and that the time of exposure might be enormously reduced if it were possible to discover a sensitive film capable of absorbing the whole energy of the X-radiation in a single thickness. Some advertisers claim to have reduced the time to less than one-hundredth in this manner, but so far as we can discover their results do not appear to be in any way superior to those which we have obtained with ordinary plates.

Stereoscopic X-Ray Photographs.—In locating a small object in the thicker parts of the body, it is often necessary to know the depth at which it is situated. Various more or less complicated methods have been proposed for accomplishing this. The majority of the proposed methods turn on securing a pair of photographs either taken in different directions, so that the coordinates of the object may be deduced, or else taken from slightly different points of view, so that they may be combined into a single stereoscopic picture.

We have found that the same result may be more simply and accurately attained in a single photograph in the following manner. A photograph is taken in the ordinary way but with a rather shorter exposure than usual. The tube is then moved through a carefully measured distance, generally one or two inches, and another exposure is taken on the same plate without moving either the plate or the patient. The distance of the focus point from the plate is also measured. On developing the plate, the shadows of the bones, etc., are found to be double. The distance of any object from the plate, when the photograph was being taken, may be very readily deduced by measuring the distance on the plate between the edges of the two corresponding shadows.

We applied this method in the attempt to locate a pin which had been accidently swallowed by a schoolboy. As a reference mark, a small ring of No. 20 copper wire was placed over the umbilicus. Two expoures of ten minutes each were given on the same plate, and the tube was shifted an inch and a half between the two, in a horizontal direction. The patient was lying on his back on the plate, which was at a distance of about 26 inches from the focus. The shadows of the pelvis and other bones all show sharp and double edges. The shadows of the fine copper ring, cast through the viscera and spine, at a distance of eight inches from the plate, are so sharp that the diameter of the wire can be measured. The pin, however, was not found on the plate; either because it was not there, or because it was kept moving by the respiration or the peristaltic action of the intestines.

Magnetic Experiments.—The only certain point of difference in kind at present recognized as existing between the kathode rays as investigated by Lenard and the X-rays of Röntgen, is that the latter are not deflected by a magnet to any appreciable extent. The Röntgen rays far surpass the Lenard rays in point of penetrative power, but the difference here is one of degree only. According to Lenard, kathode rays differing in intensity, according to the degree of vacuum, differ also in their penetrative power, and in the extent to which they are deflected by a magnet. It appeared, therefore, quite a tenable hypothesis that the X-rays were really of the same nature precisely as the kathode rays, but that they consisted of that part only of the kathode radiation which was able to survive reflection from the platinum plate and transmission through the glass, and were consequently less liable to subsequent absorption or deflection.

With our focus tube (owing to the care taken in adjusting the platinum plate, and the consequent minuteness of the focus point, which was less than two milimetres in diameter), we were able to obtain extremely sharp shadows at a considerable distance from the tube and the object casting the shadow. It was therefore easy to verify the statement of Röntgen to a high degree of accuracy. We also attempted to reproduce the experiment of Lafay, who states that he obtained a deflection of the X-rays if they were passed through an electrified plate. We did not, however, succeed in obtaining any positive evidence of such an effect.

It occurred to us that the X-rays might be more amenable to magnetic deflection in a vacuum than in air outside the tube. With this idea we tried the effect of approaching the magnet very close to the tube with the direction of its lines of force tangential to the boundary of the intense green fluorescence covering one half of the walls of the tube on the side exposed to the reflection from the platinum plate. The boundary of this green fluorescence was observed to bulge in or out according to the direction in which the magnet was presented, precisely as if caused by rays having the same properties as ordinary kathode rays, although proceeding from the platinum plate, and not direct from the kathode. On making simultaneous observations with the fluoroscope and with the photographic plate, we found that the boundary of the X-radiation outside the tube, which under ordinary conditions coincides exactly with the plane of the platinum plate, was also deflected by the magnet, but in the opposite direction to the boundary of the green fluorescence. This effect was verified on several occasions in various ways, the deflection amounting in some cases to half an inch on the photographic plate at a distance of eight inches from the tube.

We conclude from these observations that the rays causing the brilliant green fluorescence of the glass, were probably identical with ordinary kathode rays, and were reflected by the platinum according to the same law of diffuse reflection as the X-rays. This observation is of some interest as establishing a point of similarity between the X-rays and kathode rays. The other observation would however appear to show that the two are distinct. The fact that the boundary of the X-radiation appeared to be deflected, is probably to be explained by a slight shift of the focus point on the platinum plate, which was not perfectly plane. This explanation receives support from the fact that the shadow of the magnet itself as seen in the same photographs, is not perceptibly double. Further, the sharpness of the boundary both before and after deflection in each case, would appear to lend support to the view that the kathode and X-rays are of two distinct kinds, sharply separated in properties, rather than rays of the same kind, differing only in degree, and connected by a continuous series possessing intermediate properties in the way of penetration and magnetic refrangibility. We might, therefore, still suppose the kathode rays to be streams of radiant atoms, even if the X-rays were proved to be of the nature of a wave motion in the æther.

Action of X-Rays on Selenium.—Among the negative results which we obtained, there are some perhaps which deserve mention. A selenium cell was prepared by Professor Cox, consisting of copper wire wound on a plate of mica, and annealed in the usual way. The resistance of the film, when measured with a megohm and a Thomson-Varley slide box, was found to be nearly ten megohms. This somewhat high value was probably due to the thickness and small size of the selenium film. It proved, however, to be very fairly sensitive to ordinary light, and, what was more important, to have an extremely constant resistance, and to return very quickly to the original value when the disturbing influence was removed. With the galvanometer which we used, a light of one candle power at a distance of one metre was found to give a deflection of thirty scale divisions. The deflections were so consistent that the cell would have made a very fair photometer. The battery used was a single cell of a silver chloride testing battery, and the variations of resistance were observed by the bridge method using the slide box and wire megohm.

The same selenium cell was exposed at a distance of three inches from the tube to the most powerful X-radiation which we could produce, but no effect whatever could be observed. The sensitiveness to light was tested both before and after exposure several times, but no change could be detected. It may be necessary to remark that the selenium was protected from the light and from the electric discharge by a double thickness of one-mil aluminum foil, which though absolutely opaque to light, did not cast a perceptible shadow on the fluoroscope when tested by the X-rays. The screen of foil was connected to earth and to one pole of the galvanometer. It is necessary to emphasise these precautions as it appears that other observers have obtained positive results by neglecting them. The galvanometer which we used was adjusted to give a deflection of 1 scale division for 1 volt through 50,000 megohms. It had a resistance of 110,000 ohms, and a period of 15 seconds.

Electrostatic effects of the X Rays—Within a short time of the publication of Röntgen's discovery, it was shown by J. J. Thomson that the X-rays possessed the same properties as the kathode rays of Lenard, of discharging an electroscope, however, carefully insulated. He expressed this result by saying that any substance through which the X-rays passed, was rendered for the time a partial conductor. The behaviour of paraffin wax in particular was given as an instance of this effect. The time of discharge of an electroscope or of a small condenser has been suggested as a means of measuring the intensity of the X-radiation at various distances and under various conditions. Some very surprisingly exact proofs of the law of the inverse square were obtained in this manner by some French physicists.

It appeared from some of our photographs, that the X-rays were not diffused from the platinum plate according to the same law as obtains in the case of the diffuse reflection of ordinary light. We endeavoured to use the discharge method for measuring the intensity of the rays diffused in different directions. We found, however, that it was not possible to operate the tube at a perfectly constant intensity, and the rate of discharge itself did not appear to be always uniform even if there were no apparent change in the tube. It therefore occurred to us to try whether with a very sensitive galvanometer the leakage current itself might not be directly observed. For this purpose we constructed small condensers of very thin aluminium foil and paraffined paper. The foil was so thin that the X-rays were able to penetrate a thickness of a quarter of an inch of condenser with little absorption. We hoped in this manner to be able to obtain readings with greater rapidity and accuracy, and also to be able to use a balance method for comparing the intensities of the radiation in different directions simultaneously.

The condensers thus made were inclosed in a screen of aluminium foil connected to earth, in order to protect the galvanometer from the direct effect of the electrification due to the discharge. Four condensers were made of different sizes and capacities. Some trouble was experienced at first in making the leakage sufficiently small. When this difficulty was overcome, and a small condenser had been made of suitable capacity and sufficiently free from leakage, it was found that the effect to be observed, although measurable, was very transient. The X-rays apparently did not render the dielectric a conductor so long as they were passing through it, but produced only a temporary effect equivalent to an absorption current. We did not, however, determine whether the absorption were actually increased by the incidence of the rays, our main object being to test a method of measurement of the intensity of the rays, which the experiment proved to be impracticable, or at least to have no advantages over the electrometer method.

Absorption of X-Rays by Liquids.—We incidentally made a few experiments on the absorption of the X-rays by different liquids and solutions of different thicknesses. The liquids to be compared were inclosed in four vertical lead pipes with thin ebonite bottoms, which were filled with the liquids to the desired depths, and placed on a photographic plate beneath the focus tube. It was not of course possible with a photographic plate to obtain accurate photometric measurements of the coefficients of absorption. The comparative results, however, would be correct, and might be expected to give valuable information with regard to the degree of penetration and the time of exposure required for taking anatomical cases. The object photographed in each case was a small hole in a lead plate placed over the top of each tube. The shadow of this hole showed as a small and sharp circular spot on the plate.

We found the opacity of water to be much greater than we had expected. Our expectation, however, was probably biassed by the great transparency of water to ordinary light. As a rough estimate, the coefficient of absorption of water for X-rays, appeared to be at least a hundred times greater than for light. It appeared to be much more opaque to the X-rays than paper, wood, leather, or other dry fibrous material of an organic nature.

The absorption was considerably increased by the presence of acids or salts, in proportion to the strength of the solution. The opacity did not appear to depend upon the electrical conductivity, but rather on the atomic weight of the metallic constituent of the salt. For instance, a weak solution of copper sulphate was much more opaque than a similar solution of sulphuric acid, although the conductivity of the copper sulphate was much less.

In no case could we detect any evidence of any diffusion of the rays as by passage through a turbid medium. The kathode rays investigated by Lenard showed this effect of diffusion in a very marked manner in atmospheric air. Some observers have stated that they found the same effect with the X-rays. It is possible that an effect of this kind might be found in the case of a fluorescent liquid.

The rays in their passage through the liquid, certainly appeared to undergo a kind of filtering process. In passing through the last millimetre of the solution, a much smaller proportion of the surviving rays were absorbed than in the first millimetre. The weakening of the rays was, however, much more rapid than in simple proportion to the thickness. Doubling the thickness of the layer in all cases appeared to diminish the intensity by much more than half, but the ratio of reduction appeared to vary to some extent, according to the intensity of the source as well as the thickness of the layers considered.

Velocity of the X-Rays.—We made some direct attempts to measure the velocity of the X-rays, thinking that if they really consisted of streams of electrified atoms, as some physicists imagine, the velocity might turn out to be of measurable magnitude. As it happens, we have only succeeded in establishing an inferior limit for the velocity, which is practically a negative result, like the result of so many other experiments on these rays, but it may be of value so far as it goes.

Since the X-rays are not amenable to reflection or refraction, the problem is not capable of so complete a solution as in the case of light. The only property, in fact, which we were able to use for the purpose of the experiment, was that of absorption by a metallic screen. The method adopted was somewhat analogous to that used by Fizeau in the case of light, but with certain modifications necessitated by the different properties of the rays.

The rays were made to pass between the teeth of two rapidly revolving wheels fixed on a rigid axis at a distance of a metre apart. If the time occupied by the rays in traversing the distance between the wheels were an appreciable fraction of the time of one revolution of the wheels, certain aberration effects would evidently be introduced, the magnitude of which would depend upon the velocity of the rays. We were restricted to a distance of the order of a metre, both on account of the necessary lightness and rigidity of the connecting shaft, and because of the impossibility of obtaining a parallel beam of rays which could be transmitted over greater distances without too great a loss of intensity. The wheels were made nearly a metre in circumference, and we found it possible to drive them at a speed of 25 revolutions per second without appreciable vibration. Assuming that it would be possible to observe an aberration displacement of one-fifth of a millim. on the circumference, we might expect to obtain some effect provided that the velocity did not exceed 100 kilometres per second.

Construction of the Apparatus.—The wheels were made of brass one-sixteenth of an inch thick. The discs were flattened and turned true on a suitable hub, and were then soldered together at the edges so that the radial slots to be cut in the edges might exactly correspond. The slots were each a sixteenth of an inch wide, and half an inch deep, and numbered one hundred. The metal left between the slots was nearly four times the width of a slot. This proportion of slot to space was necessary in order to secure a total eclipse, because the rays necessarily formed a conical pencil. When the slots had been cut, the discs were separated, and fixed on a brass tube axis, at a distance of a metre apart, with the corresponding slots in each on a line parallel to the axis of rotation. This precaution was essential for the method which we proposed to adopt, because although the slots were cut on a very good milling machine, it is doubtful whether the accuracy of the division would have been sufficient to make each pair of slots give exactly similar effects unless they had been simultaneously cut.

The brass tube carrying the discs, was fitted with steel pivots turning in suitable bearings in the end of a long wooden box, which was covered with tin plate and at the ends with thick sheet lead. The X-rays were admitted at one end of the box through a small tube fitted with a lead cap. After passing through a pair of corresponding slots in the two wheels, they were observed by means of a small fluoroscope, or by means of a small camera, each protected by a double thickness of aluminum foil, at the other end of the box.

The adjustment and setting of the apparatus in each case could be very easily and exactly performed by the aid of common light. In this manner we tested the exact correspondence of the slots, which was found to be very satisfactory, and also the steadiness of the apparatus when driven at a high speed.

With this apparatus it was possible to use three different but closely related methods, for the attempt to measure the velocity. These methods may be called (1) the method of Aberration, (2) the method of Total Eclipse, and (3) the method of Partial Eclipse. The methods all gave the same result, but of the three the third method appeared to be the most satisfactory.

(1) *The Method of Aberration.*—For the application of this method, the axis of observation was aligned by optical observation of the small red-hot focus point on the platinum plate, in such a manner that the focus point was just visible through a pair of corresponding slots when the latter were in the centre of the field of view. The distance from

the focus point to the nearer wheel was 50 cm., and the diam. of the focus point was about 1·6 mm., being as nearly as could be judged the same as the width of one of the slots in the wheels. Under these conditions, it was plain that the appearance presented on the photographic plate, if the wheels were slowly rotated, should be that of an umbra 1·6 mm. in width, fringed on either side by a penumbra of the same extent. More exactly, if b is the width of a slot, and c the diam. of the focus point, the width of the umbra should be $2b-c$, and the total width of the band including penumbra $2b+c$. This, in fact, proved to be the case. The effect of aberration should have been to shift the bands in the direction of rotation by a displacement equal to the distance turned through by the wheels during the time taken by the rays to traverse the interval between them. By means of a horizontal slot a little less than a quarter of an inch wide in a brass plate, it was possible to expose one half of the plate while the wheels were turning very slowly, and the other half at the highest speed. Exposures were made for one minute intervals alternately on the two halves in order to eliminate the effect of any possible change in the discharge, or in the relative positions of the focus tube and box. In general, each half was thus exposed for five minutes. No displacement could in any case be detected, using a circumferential velocity of 25 metres per second.

(2) *Method of Total Eclipse.*—For the application of this method, a brass tube was fitted along the axis of observation between the two wheels. The ends of this tube were closed by discs having slots cut in them of the same width and size as those in the edges of the wheels. The slots in the ends of the tube were set very close to those on the wheels, and accurately parallel to them. The end of the tube nearest to the photographic plate, was provided with a screw adjustment, by which it could be shifted in a direction at right angles to the slots, while at the same time the parallelism of the slots was maintained as accurately as possible.

If the position of the tube was adjusted so that any part of the slot in the end of the tube nearest the X-ray focus, was open at the moment when a slot in the wheel coincided with the slot in the tube at the other end, the image obtained on the photographic plate was an exact outline of the whole width of the slot in the end of the brass tube nearest to the plate. By the aid of ordinary light it was very easy to make the adjustment so that one slot just began to open at the moment when the other closed. Under these conditions, the two slots were never open together, and the light was just totally eclipsed. A movement of a thousandth of an inch in the screw adjustment, was sufficient to restore a very appreciable amount of light. It was therefore very necessary that the slots in the wheels should be cut to correspond as accurately as possible. Fortunately this had been foreseen, and the cutting of the slots was found to be sufficiently exact, when tested in this manner.

The total eclipse having been adjusted in such a manner that the slot at the camera end was just on the point of opening at the moment when the other closed, five minute exposures were taken alternately as before at a low and high speed on the two halves of a plate for the space of more than an hour. Both halves of the plate developed perfectly clear. The setting was so fine that if the velocity of the rays had been less than 200 kilometres per second, some light must certainly have been restored by the rotation.

(3) *The Method of Partial Eclipse.*—The method of total eclipse, if the setting were sufficiently fine, afforded perhaps the most delicate test of the velocity of the X-rays. At the same time, it was so far unsatisfactory that it gave only a perfectly clear plate showing no record whatever of the time and trouble spent in producing it. If the velocity had been measurably small, it could have been determined by this method, either by observing the width of the band of light restored at a given speed of rotation, or by observing the speed required to reproduce the total eclipse at the other side of the slot. To secure this latter result with our apparatus at a speed of 25 revolutions per second, the velocity of the X-rays must have been as low as 7 kilometres per second, or not more than about 20 times the velocity of sound. That we had succeeded in reproducing the eclipse, was a possible, though not a likely, interpretation of our failure to secure any result by the total eclipse method. The intensity of the rays is of course excessively weakened by the distance, and more particularly by the passage through so many fine slots. The failure to affect the plate might have been attributed to lack of intensity of the rays, or to want of proper alignment on the focus point. We therefore used the most powerful radiation which we could produce without melting the platinum plate, and we verified the setting of the axis on the focus point both before and after the exposure.

In repeating the experiment on two subsequent occasions, we adopted the method of partial eclipse. The tube was set so that the near slot had already opened by about half a millimetre or one-third of its width at the moment when the far slot closed. The shadow of the slot obtained in this way on the plate, would be conclusive evidence with regard to the alignment and the sufficiency of the exposure. The velocity of the rays, if measurable small, could also be measured by the widening of the shadow.

The method of partial eclipse was tried in this manner on two occasions with exposures of upwards of half an hour. The photographic image obtained was a sharp narrow band half a millimetre wide, corresponding exactly with the setting of the slot. The two halves of the band, corresponding to the exposures at the high and low speed respectively, coincided so exactly that no break could be detected at the point where they met. The edge of the band was so well defined, and the band itself so narrow, that a widening of a quarter of a millimetre, corresponding to an X-ray velocity of 100 kilometres per second, could not fail of being readily detected. In fact, the lower limit of the velocity so far as may be judged from the evidence of these experiments, is in all probability not less than 200 kilometres per second.

While these experiments cannot be regarded as proving that the X-rays do not consist of electrified atoms, as some physicists supposed at the time when experiments were undertaken, they at least appear to render it more improbable than was at first supposed. Such a stream of atoms in air at atmospheric pressure, might be expected to suffer diffusion or absorption like the kathode or Lenard rays. The velocity found is so many times greater than ordinary molecular velocities, as to appear improbable even for an electrified atom. It is in the highest degree improbable that such atoms could penetrate solid bodies with the facility shown by the X-rays. The inference is either that the propagation of the X-rays is a process of exchange, if propagated by the aid of material particles, or much more probably that it is some kind of wave motion in the ether, of a frequency too great to suffer regular refraction or reflection. It is interesting to compare the present result with the lower limit of 314·4 kilometres per second given by Helmholtz in 1871 for the velocity of propagation of electrical oscillations. The application of more refined methods to the X-rays, may succeed in showing that this velocity is the same as that of light.

Physiological Effects of the X-Rays.—It was natural to try whether the X-rays produced any effect upon the retina or the skin or parts of the body exposed to their action. Positive results have been claimed in many cases though not by any observers of much repute. As stated by Röntgen, we could not detect that the retina was sensitive to the smallest extent to the most powerful X-radiation which we could produce. This shows that the pigment of the retina does not fluoresce appreciably under the influence of the X-rays, as it does under the influence of the ultra violet rays of the spectrum. The X-rays have also been credited with producing blisters and peeling of the skin, and falling out of the hair. We have not observed these effects in the most prolonged exposures. It is evident, however, that such effects might be produced by the electric sparks from the tube, if it were placed too close to the skin, as is sometimes done with the object of shortening the exposure. The direct light from the tube also contains a proportion of ultra-violet rays which are known to produce blistering if sufficiently intense.

It was natural to imagine that the X-rays might possess germicidal properties similar to those of ultra-violet light. That this is not the case, however, has been shown by the agreement of the negative results of many competent observers. With the assistance of Dr. Wyatt Johnston, we submitted cultures of typical bacilli in jelly to the action of the most intense X-radiation which we could produce for upwards of an hour at a distance of three inches from the tube. Parts of the cultures were shaded from the X-rays by slips of thick lead. The whole of the cultures were screened from the electrical discharge and from the ultra-violet rays by means of thin aluminium foil. It is not improbable that the neglect of this precaution, which is not generally mentioned, may account for some positive results which have been obtained. The cultures on which we experimented, developed in the normal manner without showing any trace of the action of the X-rays.

Description of Plates.

The accompanying illustrations refer to the case of the cavity in the lung mentioned on page 174. By way of contrast, a similar photograph of a healthy lung is given in Plate II. Both photographs are reduced about two-thirds from the original negatives. The cavity in Plate I is bounded above and below by the shadows of the ribs, and on the outer side by the shadow of the scapula. On the inner side its margin is less sharply defined. The cavity is shown by an extremely dense black patch in the original negative, and remains white after most of the other detail has vanished in the printing. The differences of density in the negative are, in fact, so great, that it is practically impossible to reproduce them by any process of printing. In printing these negatives sufficiently to show the cavity, the fainter detail of the spinal column is wholly lost, and, yet, the cavity is far less clearly shown than in the original. In reducing the plates it was necessary, first, to print them on ordinary silver paper, then to obtain a reduced negative by the wet process, which was printed on the zinc plate. Since it is possible to obtain X-ray negatives of almost any degree of density, it is very likely that it will be found possible to print direct from the original negative in many cases, and thus to avoid the excessive loss of detail incidental to repeated copying.

PLATE I.—CAVITY IN LUNG.

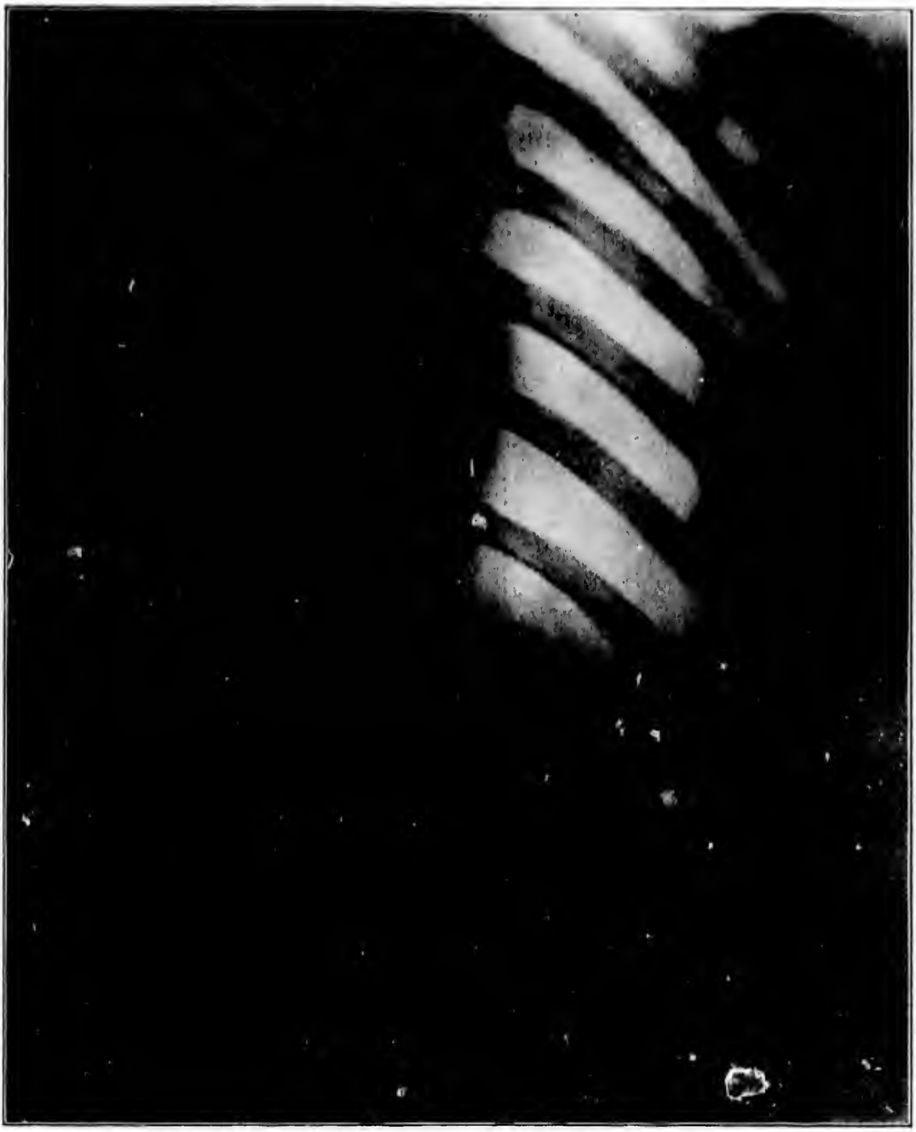

PLATE II.—HEALTHY LUNG.