

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXLI.

APRIL, 1896.

No. 4

THE Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal*.

THE FRANKLIN INSTITUTE.

Stated Meeting, held Wednesday, February 19, 1896.

JOS. M. WILSON, President, in the chair.

THE RÖNTGEN RAYS.

BY EDWIN J. HOUSTON, PH.D., AND A. E. KENNELLY, SC.D.

The announcement of a scientific discovery has seldom produced so intense an excitement throughout the civilised world as has that made in December last, by Professor W. C. Röntgen, of Wurzburg, Bavaria, concerning his ability to obtain a photograph of the bones of an animal through its living integument. His announcement, indeed, has created so intense an excitement and enthusiasm, that, although the discovery is practically only a few weeks old, yet his experiments have been repeated in all parts of the world.

The authors have been requested, by the Franklin Institute, to present to its members a *résumé* of the facts that

are known concerning Röntgen's discovery, as well as of some of the theoretical explanations which have been offered in connection therewith.

The paper in which Professor Röntgen announced his discovery was addressed to the Wurzburg Physico-Medical Society in December last.

Professor Röntgen describes in this paper the method he adopted for obtaining the peculiar form of radiant energy, now generally known as the Röntgen rays, and for which he proposed the provisional name of X rays. On passing the discharge from a large Ruhmkorff coil through a suitably exhausted tube of the Hittorf, Lenard, or Crookes type, a peculiar effect, invisible to the eye, is produced in the region outside the tube. This effect, however, can be rendered visible by the fluorescence excited in a paper screen, painted with a solution of barium-platino-cyanide. In vacuum tubes of the type referred to, the passage of the proper discharge is attended by the production of rays, called cathode rays; that is, rays projected in straight lines from the cathode, or negative electrode, of the vacuum tube.

It was observed by Crookes that these cathode rays were not produced to an appreciable degree until a certain high vacuum was reached. Crookes showed, by his experiments that, in so high a vacuum, matter could be regarded as existing in a fourth state or condition, to which he gave the name of the *radiant* or *ultra-gaseous state*. The highly rarefied matter contained in these vacua is capable of producing characteristic effects when subjected to heat or electrification. For example, when an electric discharge is passed through the residual atmosphere in the tubes, the molecules are shot off in rectilinear paths from the cathode, and wherever they strike the walls of the glass tube, or suitable bodies placed in the tube, they produce a faint fluorescent light. Crookes showed that these cathode rays were capable of being deflected from their original rectilinear paths by the action of a magnet. They thus behave in conformity with the view that they consist of streams of negatively charged molecules, the deflecting action being merely a particular kind of electro-magnetic action, well

seen in the deflection of a voltaic arc by a magnet, or in the electro-magnetic motion of the armature of the electric motor.

Hertz discovered that the cathode rays readily pass through thin films or screens of mica, or even of metal. He showed that, in fact, metallic films were even more transparent to the cathode rays than films of mica. For example, when such metallic screens were interposed in the vacuum tube between the cathode and the glass walls on the tube opposite the cathode, fluorescence was still developed in portions of the tube which would have corresponded to the shadow of the screen, had it been opaque.

Lenard, at one time an assistant of Hertz, took the matter up, and showed that fluorescence could be produced by the cathode rays outside the glass vacuum tube. For this purpose, he placed a small window of aluminum in the walls of his vacuum tube, so that the stream of cathode rays would impinge upon this window. A change of some sort appeared to occur at the window. While in the tube, the rays proceeded along straight lines, unless deflected by a magnet; outside the window they preserved rectilinear paths, but radiated in all directions from the window as a source.

These rays, produced outside the vacuum tube by the cathode rays within the vacuum tube, may be called the Lenard rays.

In common with the cathode rays, the Lenard rays possess the power of producing fluorescence in fluorescent substances upon which they impinge. They differ from the cathode rays in the fact that, in the air, they are visible to the eye as a faintly glowing stream or pencil, which rapidly diminishes in intensity, at comparatively short distances from the window. All the effects of the Lenard rays became lost at a distance of a few centimeters from the window, so rapid is their absorption in the air or other media. Hydrogen was found to be the least absorptive, that is, the most transparent medium; but hydrogen, under great pressure, becomes more opaque. Lenard showed that many of the metals are partially transparent to his rays, and that sensi-

tive photographic plates, or films, are quickly blackened by their influence. In fact, Lenard took shadow photographs of opaque or semi-opaque bodies, by interposing them in the path of the rays before they impinged upon the sensitive photographic plate held in a light-tight box, provided with an aluminum cover or slide. Lenard found that the opacity of different substances to his rays varied, approximately, with their density.

In the paper before referred to, Röntgen announced that, when a suitably exhausted vacuum tube is placed under a cover of blackened pasteboard, fluorescent effects can be obtained, not merely at a distance of a few centimeters, but even at a distance of 2 meters, in air. He employed for this purpose a paper screen painted with a solution of barium-platino-cyanide. The Röntgen rays, unlike the Lenard rays, are invisible to the eye, even close to the vacuum tube. No window is necessary in the vacuum tube to produce the Röntgen effect, although Röntgen has produced the effect through an aluminum window. As in the case of the Lenard rays, the Röntgen rays are radiated in rectilinear paths in all directions from the portions of the walls of the tube subjected to the bombardment of the cathode rays.

It will thus be seen that a similarity exists between the Lenard and the Röntgen rays, so far as their method of production is concerned. In each, the source of the rays is to be traced to the impact of the cathode rays upon the walls of the vacuum tube in which they are produced. In each, the rays possess the power of exciting fluorescence in suitable bodies on which they impinge; in each, they possess the power of passing through substances opaque to ordinary light, the opacity in each case increasing apparently with the density, although not in direct proportion.

The Röntgen rays appear to differ from the Lenard rays in the fact that they are not so readily absorbed by air or other media. If no absorption existed, the intensity of the rays would, of course, diminish as the square of the distance from their source. Röntgen claims that he has observed that this rate of diminution in the intensity of his rays does exist within the limits of observational error. This peculi-

arity of the Röntgen rays has greatly enhanced their practical value.

It will be seen, therefore, that the difference between the Lenard and the Röntgen rays is not marked. The difference appears to be one of degree rather than of kind. There is, however, at least one difference in the rays under discussion. Lenard found that his rays are not appreciably deflected by a magnet when passing through air, but that deflection does occur when his rays were allowed to traverse a highly exhausted chamber. Röntgen mentions that, up to the present time, he has not been able to produce any deflection of his rays by a magnetic field. This has been confirmed by Dr. Oliver Lodge. Röntgen is also experimenting with the action of an electrostatic field, but we believe he has not, as yet, announced any result.

The curious fact pointed out by Röntgen, in the paper before referred to, of the ability of his rays to produce, upon a sensitive photographic plate, photographs of the shadows of, say, the bones of the hand, in the living subject, has naturally caused great popular excitement and interest. There can be no doubt that this fact will prove of great value to the surgeon, especially if, as would seem probable, means are perfected for the production of these rays with increased power.

Röntgen states, as a result of observation, that his rays are apparently incapable of reflection, refraction or interference. If refraction does exist, it must be of very limited amount. These facts have led Röntgen to suggest that his rays are not light in the ordinary physical sense of the term; that is, that they do not consist of a transverse vibration propagated in the ether, according to electro-magnetic laws, but that possibly they may be a longitudinal motion propagated in the ether, a condition which Prof. S. P. Thompson has happily named "ultra-violet sound," and which others have called "ethereal sound" and "longitudinal light."

The details of the method for producing Röntgen rays do not appear yet to have been published by Prof. Röntgen. Physicists, however, have very generally reproduced them, although thus far the shadowgraphs obtained in this coun-

try do not present the sharpness and depth which apparently characterise Prof. Röntgen's shadowgraphs.

The authors have successfully obtained Röntgen rays by the use of a large induction coil excited directly by storage cells through an interrupter, the secondary terminals of the induction coil being led directly to the terminals of the Crookes tube. In this case the cathode is the source of cathode rays in the tube, and the surface of the glass, opposite to the cathode, where fluorescence is produced, is the source of the Röntgen rays. We have found, however, as others have done, that by far the best results are obtained by using a high-frequency discharge through the Crookes tube. This is conveniently done by exciting the primary of the induction coil from a 50-volt alternating-current circuit, such as is employed for supplying incandescent lamps on commercial alternating-current circuits, at, say, 15,000 alternations per minute. The secondary terminals of the induction coil are led to a battery of Leyden jars through the primary coil of a Tesla induction coil immersed in oil. The secondary terminals of the Tesla coil are then connected directly to the Crookes tube. Under these conditions torrents of high-frequency discharges pass between the discharging knobs of the induction coil, which are separated to a distance of, perhaps, 5 millimeters, the frequency being determined by the capacity and inductance of the Leyden jar circuit, including the Tesla primary. These high-frequency discharges induce, in their turn, high-frequency and high-tension discharges in the Crookes tube. In such cases both electrodes of the Crookes tube are alternately cathodes, and the glass wall opposite to each electrode becomes fluorescent, and, therefore, the source of Röntgen rays.

The practical difficulties in connection with the production of the Röntgen rays arise from the fact that the Crookes tubes, as ordinarily constructed, are not designed to stand the molecular bombardment of the cathode rays, when of fairly great power, for any considerable length of time. Since the ordinary Röntgen shadowgraphs require exposures lasting, usually, half an hour, and sometimes several hours, a great liability exists to excessive heating of the

tubes and the destruction of their vacua. Indeed, at times, the heat produced by the molecular bombardment of the cathode rays is sufficient to melt the glass walls of the tubes, as the authors, most probably in common with others, have ascertained to their loss.

Since the high-frequency discharges obtained by the use of a Tesla coil are not characterised by such marked heating effects, either at the walls of the tubes or in the electrodes, they are greatly to be preferred for producing shadowgraphs. Independently of this, however, they appear to produce a more powerful image. Possibly the velocity with which the molecules are projected from the cathode, or their number, or both, are increased.

A simple form of Tesla coil may be made by winding a primary of about eighty turns of No. 19 A. W. G. cotton-covered copper wire over a glass tube about $\frac{3}{4}$ inch in diameter, and inserting this inside a slightly larger glass tube, over the surface of which has been wound a secondary of about 400 turns of about No. 31 A. W. G. fine silk-covered copper wire. The coil is then immersed in some high insulating oil, such as rosin oil.

In the shadowgraph of such portions of the human body as, for example, the hand, the bones cast the most marked shadows, and the surrounding tissues produce shadows intermediate in intensity. The density of the shadow which is cast upon the plate depends apparently upon the total quantity of matter which the rays have to traverse. Thus, a short passage through a dense substance produces the same depth of shadow as a long passage through a rare medium. In order to obtain sharp definition, the use of a diaphragm is recommended. An iron or lead plate provided with a suitable aperture, and placed between the tube and the photographic plate, is suitable for the purpose.

A photographic copy of a shadow photograph obtained by Röntgen, of a human hand, is here presented on the screen. It will be observed that the shadows cast by the bones are much darker than those cast by the cartilages, sinews, muscles, veins, arteries or integuments.

It is stated by Prof. Silvanus P. Thompson that distinct

shadow photographic effects have been produced by the ordinary arc light, so that it would appear that some Röntgen effect is produced by the voltaic arc.

It has recently been discovered by Prof. Pupin and others that, in order to obtain the cathode rays in a vacuum tube, it is not necessary to employ electrodes within the tube itself; but if pieces of tinfoil are placed outside the vacuum tube, and the terminals of the high tension coil are connected therewith, discharges are produced in the vacuum tube by electrostatic induction. These discharges produce fluorescence in the tube, and the fluorescent glass is again the region of Röntgen rays.

This would appear to show that the Röntgen rays are produced by molecular bombardment by the molecules of the residual atmosphere of the high vacuum, and that the metallic cathode is only to be regarded as an auxiliary means for producing this bombardment.

Prof. J. J. Thomson has recently made the extremely important discovery that the Röntgen rays tend to discharge an electrified body on which they impinge, and this whether the charge of the body be positive or negative. Prof. Thomson finds that a charged body constitutes a more sensitive test for the presence of the Röntgen rays than is afforded by either a sensitive photographic plate or a fluorescent screen. This effect takes place whether the charged body be covered by a layer of paraffine, sulphur or vulcanite. In other words, as Professor Thomson points out, *the remarkable fact exists that an insulating layer becomes electrically leaky while being traversed by the Röntgen rays.*

Hitherto no means have been known, beyond mere thermal influence, for altering the electrical insulating power of solid materials by radiant energy of any character. The discovery of this property of effecting electric discharge makes the ray far more wonderful and important to physicists than its property of penetrating opaque solids as displayed in shadowgraphs.

The degree of exhaustion in the vacuum tube, which is the source of the Röntgen rays, appears to be that required for rectilinear molecular bombardment. Edison has shown,

experimentally, that below a certain exhaustion the Röntgen effect is negligibly small, while above a certain exhaustion the intensity of the effect again decreases. In general, it may be said that a vacuum which produces a bluish violet light on the passage of the discharge is too low to produce the Röntgen effect. The best results are obtained when little or no discharge is visible within the tube, but the walls are rendered fluorescent with a peculiar greenish tinge. This is usually obtained at about one-millionth of an atmosphere.

Since the Röntgen effect is evidently due to molecular bombardment, and varies with the degree of the vacuum, it would appear that good experimental work can be conducted, both by ascertaining the best degree of vacuum in tubes containing rarefied air, and by ascertaining whether gases other than air will produce, in such tubes, better results.

It would appear that the Röntgen rays must be either a material propagation or an ethereal propagation.

A material propagation would require either that ordinary matter be projected rectilinearly as a whole along the rays, or that some disturbance in matter is projected along them.

The burden of probability seems to be against the assumption that the Röntgen rays consist of a material propagation, since they not only traverse opaque, dense substances, but also appear to be unaffected by a magnet. Assuming, therefore, that the Röntgen rays are an ethereal propagation, they must either consist of a translatory movement of the ether, or of some disturbance propagated along it. Such a disturbance would, probably, have to be periodic or vibratory. The vibrations might be transverse, or they might be longitudinal to the path of the ray. Physical science is acquainted with transverse ethereal vibrations, such being, in fact, electro-magnetic vibrations, or ordinary light. These vibrations differ in their frequency, and, hence, in their wave lengths, but are not known to differ in their speed through free ether. In the ether within material substances their velocity of propagation is reduced, as is evidenced by their refrangibility. This is true of all known transverse vibra-

tions from the lowest frequency, far below the red, produced by the discharge of a Leyden jar and detected only by electrical methods; through the higher-frequency waves, still in the infra-red and constituting direct heat; throughout the limits of the visible spectrum, and beyond the violet in that frequency which is detectable only by chemical or by electric eyes. The marked characteristics of these transverse vibrations are their refrangibility, their reflectibility and their possibility of interference; characteristics which are all apparently wanting in the Röntgen rays.

It would, therefore, appear that the Röntgen rays are not transverse vibrations of the ether. If they are, they do not appear to lie within the range of frequency hitherto explored, a range extending from about 100,000 to about 1,000,000,000,000,000 (a quadrillion) waves per second. There is reason to believe that if they have a wave length, this wave length is long compared with that of visible light, since they pass through appreciable distances of gross matter, distances measured in centimeters or hundredths of a meter, rather than in microns or millionths of a meter. Such waves would correspond to dark heat waves, in the infra-red.

It is known that ultra-violet light possesses the power of discharging a negatively charged body upon which it falls directly, while, as Prof. J. J. Thomson has discovered, the Röntgen rays can discharge bodies either positively or negatively charged, even while imbedded in a layer of highly insulating material.

Dr. Lodge has shown that when polarised ultra-violet light strikes such a negatively charged polished plate, it is most effective in producing discharge when striking at an angle, instead of perpendicularly, and, consequently, the discharge may, perhaps, be effected by a longitudinal component of the impact. This seems to favor the supposition that the Röntgen rays are longitudinal ethereal vibrations.

The material substances with which we are familiar, and which are capable of transmitting vibrations transversely to the direction of propagation, are also capable of transmitting longitudinal vibrations. The fact that longitudinal

vibrations in the ether have hitherto remained undiscovered has caused no little inconvenience in the framing of hypotheses concerning the action and properties of the ether. If ether resembles material substances, its velocity of propagation for longitudinal vibrations would be much greater than that of its velocity of propagation for transverse vibrations; consequently, for any given frequency of vibration, the wave length would be greater than that of light waves.

Summing up, then, while it is far too early to form a reliable conclusion concerning the nature of the Röntgen rays, such evidence as does exist would appear to favor the theory of longitudinal vibrations in the ether.

Whatever may be the future of the Röntgen rays, so far as their practicable applicability or scientific value is concerned, great praise must be accorded to Professor Röntgen for the exceedingly interesting and important contribution he has made to this branch of molecular physics.

LABORATORY OF HOUSTON & KENNELLY,

FEBRUARY 16, 1896.

DISCUSSION.

DR. A. E. KENNELLY.—Having contributed to the paper of this evening, I have very little to add to what has already been stated in it; but a few remarks upon the possible future of the Röntgen rays may be admissible at the present time.

The future may be regarded from a practical and also from a theoretical point of view. There can be no doubt that the Röntgen rays, which render indirectly visible to the eye the bones and interior tissues of the body, must be of great value to the surgeon, anatomist and biologist. It only remains to strengthen and develop these rays in order to extend their range of application. The rays lie, at present, under the troublesome disability of absence from bending or focussing by reflection or refraction. It may be that indirect means may be employed to overcome this difficulty.

From a theoretical point of view the subject is full of interest. Its investigation cannot fail to increase our knowl-

edge of molecular physics and the physics of the ether. Should the rays prove to be of a nature hitherto unrecognised and unknown, an entirely new channel of communication with the unknown world is opened up. I cannot but believe that the great interest which has been bestowed upon this fascinating subject all over the civilised world indicates more than a mere passing fancy or tribute to the most recent scientific passion, that it points to a general effort on the part of the entire civilised community to become acquainted with the new manifestation of Nature, which has, for years, been clamoring at the doors of our senses for recognition, and that it indicates a consciousness that we have before us a most potent agent to aid us in wresting from Nature her secrets in the invisible domain. We all know that advances in sciences are made in epochs, or wave-like periods of activity. May we not hope that this wave of public interest is one whose crests shall lead us to fortune?

I think it would be most fitting that a vote of thanks should be offered to the scientific worker in Bavaria, whose labors have been so fortunately crowned with success, and I beg to propose that such a vote of thanks be extended to Professor Röntgen, by this meeting, for the interesting and important work which we are discussing this evening.

[This motion was numerously seconded, and, on being put to vote, was adopted unanimously.—THE SECRETARY.]

PROF. ELIHU THOMSON.*—From my experiments it appears that the cathode rays are produced only when the vacuum in the Crookes tube is such that little or no light, other than that arising from fluorescence of the glass, is given out. A degree of exhaustion somewhat higher than this stops the electric discharge, while a somewhat lower vacuum, although giving abundant fluorescent light on the glass walls, gives, also, an illumination of the residual gas in the interior, and no cathode rays.

While using one of my tubes, it was noticed that, during the passage of the discharge, the vacuum continually im-

* Correspondence.

proved, and soon became so high as not to permit the discharge to pass at all. This was doubtless due to the fact that one electrode was of platinum instead of aluminum, and that the platinum was carried from it to the sides of the tube and deposited there as a smoky layer. This finely divided metal absorbed the residual gas and so far completed the exhaustion as to prevent the passage of the discharges, even when of very high potential. In this connection it may be mentioned that the vacuum in an ordinary incandescent lamp commonly improved during the use of the lamp. I have found old, discarded lamps, with worn-out or broken filaments, to have excellent Crookes vacua, and sometimes vacua through which no discharge would pass, while new lamps are rarely to be found with so high exhaustion. The reason of the change in the vacuum in this case is doubtless the absorption of residual gas by the film of carbon or soot deposited gradually on the interior of the bulb in the old lamp.

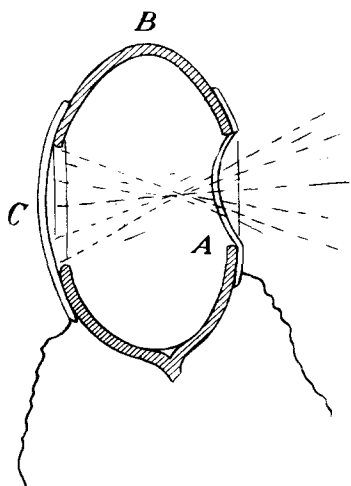
These old lamps may, in fact, when provided with thin aluminum caps outside the glass bulb, give rise to cathode rays when excited inductively by an apparatus giving alternating currents of high frequency.

It appears to me probable that a Crookes tube, provided with a side tube containing potassium hydrate, and exhausted to the highest possible vacuum, will present advantages as a generator of Röntgen rays; for, by warming the hydrate, the degree of vacuum may be controlled or adjusted to that proper for obtaining the best effects.

In order to render it possible to use a large amount of energy in excitation, to the end that the vigor of cathode rays emanating from the apparatus may be made a maximum, it may be possible to construct tubes like the accompanying sketch, where *B* is the vacuum bulb having two openings or windows opposite each other. One of these, as *C*, is capped with a cup of sheet aluminum, cemented on, and having a surface concave to the vacuous interior. The other opening, *A*, would be capped by a very thin cover of aluminum, made, for strength, convex to the interior space. Cap *C* would be made the cathode and *A* the anode. The

rays would converge near *A* within the bulb, then diverge through *A* in passing out into the air. If the whole bulb, except the window *A*, be immersed in oil in a surrounding box, the outside insulation, as well as the cooling of the tube under vigorous excitation, is provided for.

The current best adapted for the development of cathode rays would naturally be a continuous current of from 50,000 to 100,000 volts. Its strength would be made as great as the tube or bulb itself could bear without injury. It is difficult, however, to obtain such currents, while it is very easy to obtain, with simple, cheap apparatus, high-frequency, high-potential alternating currents, which, while not so effective as continuous currents, may be had of any power.



Cathode rays may be detected, as is well known, either by the photographic plate, or by their power of exciting fluorescence. It is conceivable that a simple instrument, such as a blackened tube, having a screen with fluorescent material near one of its open ends, and a sight-hole at the other, might, for practical purposes, be superior to the photographic plate, inasmuch as the exploration de-

sired would be accomplished in a short time and with changing directions of transmission of rays. In this case, of course, no permanent record would be made.

A third method of detection of cathode rays is based on their power to cause discharge of electrified surfaces. An electrified body, connected with an electroscope for indicating its charge, if exposed to the cathode rays, is at once discharged. Recent experiments made at the Massachusetts Institute of Technology have, it is reported, shown that this electrical test will instantaneously detect the rays that have passed through a thick brass plate (about $\frac{1}{2}$ inch) and very heavy plates of vulcanite.

There can be little doubt that means will soon be found for greatly accelerating the making of shadow pictures by cathode rays. Were it possible to produce plates sensitive only to the rays absent in sunlight or ordinary artificial light, it would follow that the taking of the impression could be carried on in a light room with an uncovered plate, and the development of the same carried on without a dark room.

There is yet, of course, much to be learned concerning the real nature of the rays and their relations to ordinary light and heat rays. I incline to the opinion that it is not necessary to consider the cathode rays as differing in kind of ether vibration from light waves, until it is proven that electro-magnetic waves of very high pitch must, of necessity, undergo reflection and refraction at surfaces.

The characteristics of cathode rays appear to be the same in many respects as those of ultra-violet light; both effect chemical decompositions, both cause fluorescence and phosphorescence, and both provoke discharge of negatively-electrified bodies.

May not cathode rays, therefore, be ordinary transverse electro-magnetic waves in the ether, as are light waves, but of such high pitch, relatively thereto, as to be beyond the vibration period of atoms in the molecules of ordinary matter; and that, as a consequence of such high pitch, they can neither be reflected nor refracted, but can travel through bodies in the assumed free ether between the molecules?

It might easily be that, when obstructed by the molecules, absorption takes place from internal refraction or reflection, and absorption would then depend on the amount of matter traversed, as measured by its density and thickness.

It is true that the crude view thus presented may involve changes in our ideas concerning the true causes of ordinary reflection, refraction and dispersion of light. At all events, the new discovery will, in my opinion, become a mighty weapon for attacking anew the problem of the relations between what is called gross matter and the universal ether. We may be able to make one further step towards

unifying the Universe, as when it be shown that in all probability the chemical elements, as we know them, are but modifications in the ether, in somewhat the same way that polymeric bodies depend, in structure, upon modifications of much simpler atomic groupings.

PROF. A. E. DOLBEAR.*—It is remarkable what an amount of photographic activity has been induced by Prof. Röntgen's announcement. The physical laboratories of the world appear to have well-nigh dropped everything else in order to duplicate that work and ring the changes on it, and the experimenters are daily besieged by the multitude of reporters from the daily press, anxious to be the first to describe whatever is done. The utility of it is what gives it its chief interest to the public, as it very properly should, for there is now no foreseeing what great importance it may presently have. To the scientific man, as such, the interpretation of the phenomenon is of first importance, and here the question very properly arises: Is this discovery so radically new as it appears, and is there any reason for assuming the existence and activity of rays or ether waves of a different kind from any heretofore known?

As to the first, it has certainly been known by myself for nearly four years that photographic action would take place in the dark through the activity of waves set up by electric discharges in the air. In 1892, I made a profile of a five-pointed iron star on a photographic surface when the latter was separated from the sparks by the top of a table an inch in thickness, and ordinary light in other ways was excluded. I had expected it from thinking upon the theory of photographic action and of ether waves. I did not publish anything about it at the time, because I came across, somewhere, a scrap saying that the same thing had before been accomplished by another, I do not remember by whom or when. However, I published, in April, 1894, an article in the *Cosmopolitan Magazine*, a copy of which I attach with this,† which

* Correspondence.

† "For a long time it was believed there were three different kinds of ether waves, known as heat, light and actinic rays. The latter were supposed to be the ones that produced the chemical action on photographic plates, while

will show that the knowledge of the fact and the explanation, such as it was, was already in my possession. *Cosmopolitan Magazine* articles have to be prepared two or three months before the date of publication, and that article was written more than two years ago.

There was nothing said about X rays, or cathode rays, for the very good reason that, so far as my experiments

light consisted of rays of a different kind, capable of affecting the eye. It was discovered, however, that the same rays which can produce vision can also heat a body, and also do photographic work; and what any ray can do depends upon the kind of matter it falls upon, so that all rays have similar characteristic properties. This discovery makes it plain that there is no peculiar kind of ether waves which can be called light, as distinguished from other kinds of ether waves. What is called light is a physiological phenomenon, and has no existence apart from eyes. So well assured is this, that the serious proposal is made to banish the word 'light' from physics.

"The sensitive coating upon a photographic plate is an unstable chemical compound, which may be broken up by mechanical pressure, by heat, or by ether waves. The proper wave length for a given plate depends upon the nature of its surface. The tanning of the skin, the darkening of newly laid shingles, the coloring upon apples and other fruit, is a photographic process, as can be shown by shielding them from the sun's rays.

"It has long been known by photographers that pictures may be taken with ether waves much too long to be seen by the eye, if some other substances are used in place of the simple silver salts in common use.

"Since it has been shown that ether waves of all lengths have an electromagnetic origin, it has been apparent that all the effects of light can be duplicated with suitable electric apparatus. Lay a coin like a half-dollar on a plate of glass, and let a few sparks from an electric machine fall on it. Remove the coin and the glass surface will not appear to have been affected; but if it be breathed on, the image of the coin will at once be seen, and that it is really engraved on the glass surface is evident, for it will not easily rub off. If a piece of photographic paper takes the place of the glass, it will have the imprint of the coin made upon it. It is not needful to have the sparks fall upon the coin, for, if it be enclosed in a dark box brought near to an electric machine having short sparks passing between its knobs, the ether waves set up by the latter will be sufficiently short to affect the photographic surface, which may be developed afterwards in the ordinary way.

"So it is actually possible to take a photograph of an object in absolute darkness with the ether waves set up by working an electric machine. Not much has yet been done in this direction, but it is a new clew to chemical possibilities, and one may confidently look forward to the time when the qualities and colors of surfaces of many things will be changed to suit the taste by an application of electric waves of suitable length to bring about the proper chemical reactions, and an electric machine may become a necessary adjunct to the apparatus of the photographer."—*Cosmopolitan Magazine*, April, 1894

went, only ordinary means and apparatus had been employed, and there had been found no necessity for assuming that the work done necessitated other kinds of waves than such as I supposed myself to employ. Dr. W. J. Morton, of New York, and others, have lately reported similar experiments, which corroborate the proposition that vacuum tubes, as such, have little to do with the phenomenon.

As to what was generally known about the fundamental principles, it may be said that it was not new to photograph by waves either too short or too long to be visible. Photography can go on wherever fluorescence is possible, and ultra-violet waves have long been known to be effective for that purpose. Dr. Draper, fifty or more years ago, got photographic effects in the region beyond the red; and Captain Abney, in England, long ago photographed the whole spectrum a long way above and below the visible part. Hence, photographing with invisible rays, either long or short, is not new.

After Hertz's work was published everyone has known that ether waves set up by electric action were initiated in the discharges of Leyden jars and condensers in general, and that the wave length depended on their capacity; also, that such discharges always set up phosphorescent and fluorescent action in gases and solids; that is, relatively long waves were capable of producing phosphorescence.

That such waves, invisible to the eye, were capable of passing easily through bodies opaque to visible or certain definite wave lengths, has been known for many years. Iodine in bisulphide of carbon is opaque to the eye, but very transparent to other waves, and Tyndall raised bodies to incandescence by such passed through that medium. He called the phenomenon *calorescence*. Afterwards, Bell showed that vulcanite was similarly transparent, while Hertz proved that stones, wood, etc., were transparent to waves set up by electric discharges.

All this shows that the data for supposing that such shadow photography as we now have, even to the distinctions between bone, muscle and bullet, were common knowledge.

What Röntgen did was to take a picture of his hand, showing the bones. If he had taken a picture in a similar way of a coin only, the interest in the experiment would have been small until some one had done *that particular thing*. It is that which has pushed the matter to its prominence, and rightfully so, for it has given photography a new field, which, though lying close at hand before, had not been entered on the physiological side, and which promises practical applications of great value.

As to the interpretation that may properly be given, or attempted, it may be too early to do more than believe very gently. It is evident that a phenomenon involving phosphorescence, fluorescence, photography, transparency and opacity, long and short waves, their origins and properties, is tolerably complicated; but for myself, I should say that every effort should be made to find the explanation with the transverse waves we know, and take the longitudinal wave only as the last resort. When one reflects upon the well-known phenomenon, fluorescence, that it is not only the transforming of short waves to longer ones, as in eosin, but also the transforming of long waves into shorter ones, as happens with chlorophane, which changes waves much longer than the red rays into emerald-green waves. Hence, it is entirely within proper bounds to expect that rays made too long to be appreciably refracted can act upon a phosphorescent body so as to produce waves capable of doing photographic work.

Again, there does not appear to be any good reason for thinking that an electric discharge can produce among atoms and molecules particular movements and resulting waves different in kind from other agencies, say heat, for instance; and if so, the same rays found in electric discharges in the air, and from Crookes tubes, are to be found in other sources of light as well, differing perhaps in degree, but not otherwise.

DR. JOSEPH W. RICHARDS.*—Since the shadow pictures are made through substances ordinarily considered opaque,

*Correspondence.

it has been assumed that the *light* rays have nothing to do with casting the shadow. It should be remembered, however, that substances are only *relatively* opaque. Strong sunlight shows the bloodvessels in the ear, even the veins in the hand. Even metals are translucent if in thin enough films. Magnetic iron oxide, the most opaque of all substances, is translucent when crystallising between leaves of mica. There is no substance known to science which is absolutely opaque, even to ordinary light rays.

We know that heat rays can pass through substances opaque to ordinary light. Can we not readily imagine a *thermo-graph*, made on a plate very sensitive to heat rays, placed behind a screen cutting off ordinary light? Substances would cast shadows on such a plate in proportion to their transparency or opacity to radiant heat.

Coming now to the X rays, I believe they act on an analogous principle. It is said that they are difficult of refraction. If this is so, may it not be because they are so far below the ultra-red rays that their index is so small as to have escaped observation? The very long waves of Dr. Hertz passed through wood, etc., like the X rays, but he refracted them by a huge prism of pitch. There seems to me to be many points of resemblance between Dr. Hertz's rays and these X rays.

Metals have the highest known indices of refraction for light rays. Allow me to suggest that *metallic* lenses (as of aluminum) may enable the X rays to be refracted and focussed.

Glass is said to intercept or weaken the X rays. Possibly the glass bulb of the Crookes tube, therefore, weakens the effect. If the bulb were made of celluloid, or some other available material transparent to the rays, heightened effects could be obtained.

A rigid search will probably result in the discovery of films more sensitive to these X rays than even our most instantaneous light plates. It is not only possible, but even probable, that there exist such compounds, the use of which would give us *quick* plates for the X rays.

There is no reason why the X rays cannot be generated

on a much greater scale than heretofore, and thus more striking results be obtained. Experiments with other metals than aluminum in the discs may result in showing that the effects are modified by the kind of electrode emitting the rays.

PROF. GEO. A. HOADLEY.—Having seen several statements in the newspapers quite recently that Röntgen photographs could be obtained in the electrostatic field of a Holtz machine, I have thought it might be of interest to show that the effects thus produced are not due to the Röntgen rays.

The first two lantern slides, which I show you, were made from negatives obtained by placing a coin upon a photographic plate, wrapping the two in several thicknesses of black paper, and placing them between the knobs of the machine, when they are at the proper distance to produce the brush discharge.

At all points where the coin was in contact with the plate, the effect of the discharge is seen showing the lettering, figures and date, while around the edge is a rim of minute radiating lines.

The third slide shows the effect of the condenser spark on both sides of the plate, the one on the rear side being much less distinct than the one on the film.

MR. W. N. JENNINGS.—I had the honor of showing, in this hall, six years ago, the image of a silver dollar, made in precisely the same way as those now shown; also a spark taken on the plate direct. These photographs I also used in connection with my lecture before the Institute last April, and explained fully, at the time, how the pictures were produced. I make this statement now for Professor Hoadley's information, and merely to place the matter on record.

MR. JOHN CARBUTT.—Naturally, the announcement of Professor Röntgen's discovery of photographing the invisible, with what he terms X rays, attracted my attention, the more so as I saw that a new field had been opened for the use of dry plates. The length of exposure required particularly interested me, and I therefore commenced experiments to produce, if possible, a plate that should be

more sensitive to these X rays than the ordinary rapid plate. The tests made on these new plates which I have prepared have enabled me to reduce the exposure from one hour to twenty minutes, when making a shadowgraph of the human hand. Professor Goodspeed, of the University of

3



6

Copy of picture made with one of Carbutt's Spécial "Röntgen Ray" Plates (exposure, 21 minutes). 1-2, flat steel keys $\frac{1}{16}$ inch thick; 3, leather purse with steel clasp, containing coins and disk of aluminum; 4, sheet of glass; 5, aluminum rod $\frac{1}{4}$ inch thick; 6, imitation diamond pin.

Pennsylvania, kindly placed at my disposal the Crookes tube and coil with which he had made his experiments. Placed on the box holding the X ray dry plate was a purse containing a number of coins, including a disc of aluminum;

alongside of the purse were two flat steel keys; below these a piece of ordinary window glass; in the center, beside this, an imitation diamond pin; and, on the lower right-hand corner, a piece of rod aluminum. Two exposures were made, one of twenty-one minutes and the other thirty minutes; the negatives were at once developed, using my "J. C. Tabloid Developer." The plates developed up in the normal time usual to a fully exposed plate, and the results were pronounced by Professors Goodspeed and Richardson superior to any they had obtained, even with a much longer exposure. The transparency now on the screen shows that the X rays obliterated the leather of the purse and passed through the aluminum disc and the piece of glass in about the same ratio.

PROF. CHAS. F. HIMES.—I made some experiments with Crookes tubes and a coil giving 7-inch sparks, but with negative results, which I attributed to the absence of the peculiar rays from the light I employed. Thereupon, I turned to sunlight as possibly containing some similar form of energy transmissible through substances opaque to visible light, and made the following experiment: A thick piece of ebonite was placed in an ordinary photographic plate-holder, and upon it a Carbutt "Eclipse" plate, separated from the ebonite by strips of heavy cardboard. Several pieces of black paper were placed upon the plate, and then the felt-covered hinged back was fastened in. The ebonite was then exposed to bright sunlight, partially covered with a ring of sheet brass having a central circular aperture of about $\frac{3}{4}$ inch. After an exposure of twenty minutes, prolonged development gave no apparent result. An extreme exposure of three hours and a half was then made at midday in bright sunshine, and less prolonged development gave the unexpected result of a dark ring on a light ground with a light center, or a positive. Regarding this as a reversal by over-exposure, another exposure of forty-five minutes was made, which, upon development, gave a negative or light ring on dark ground with dark center.

I do not say that Röntgen rays are involved, but this experiment proves at least this much—that there is a form of

energy in the sunlight, transmissible through ebonite, and, perhaps, through other opaque substances, and which, perhaps, is also present in other sources of light. I have not been able, however, to detect them in magnesium light. As the plates were separated from each other by the thickness of the cardboards, and the temperature at the time was near 0° F., the result seemed only explicable by the transmission of the rays by the vulcanite. A similar exposure to rays from a warm iron plate gave no developable effect, although the vulcanite became sensibly warm.

It will be *apropos* here to recall the oft-cited experiment of Abney, of photographing with the rays from a tea-kettle as having some interest in connection with the subject of this evening's paper.

The photographs so-called were simply shadowgraphs. A card with perforations was held above the sensitive plate, and a hot tea-kettle placed above the card, and, after a short exposure, the plate, upon development, showed spots of the shape of the perforations. But a much more remarkable experiment, made by this investigator at the same time, more than ten years ago, was the photographing of the carbon points of an arc light through a piece of vulcanite with an ordinary lens, in about thirty seconds.

I regard as the most suggestive feature in connection with these experiments, that Abney was illustrating and emphasising the possibility of imparting peculiar kinds of sensitiveness to bromide of silver by suitable treatment, and thus of obtaining photographs by ultra rays, and that he was calling attention to the particular modification he had produced. The transmissibility of rays through vulcanite was an incident. It seems to me that much of the progress of the new photography must lie in the direction of the production of films peculiarly sensitive to these so-called X rays. All recent progress in photography has been in the direction of the preparation of films responsive to any peculiar demand, and it is a matter of great gratification to learn that Mr. Carbutt has already recognised this new field for his activity, and that there is every reason to hope, from his known success in meeting all demands hitherto made upon

him, and his character as an indefatigable experimenter, that he will be able soon to furnish us X ray plates that will permit the use of sources of light more readily available.

Referring to my own unsuccessful experiments with the Crookes tube, I should state that such a result ought to have been anticipated. The tube employed was the so-called shadow tube of the set, and was an excellent one for the purpose for which it was designed, but the cross of aluminum, which produced a shadow on the fluorescent ground of the tube, almost constituted a test for effective rays and indicated the almost complete absence of any that would pass through aluminum under the conditions present in the tube. Other shadow tubes giving less perfect shadows might furnish more of the active rays.

MR. JAMES WILSON.—The paper just read has described very thoroughly the effects and peculiarities of the Röntgen or X rays. A description of the Crookes tube, in which these rays are generated, might aid a little in the discussion of the mystery.

In 1884, when the Franklin Institute held its great Electrical Exhibition, Mr. Chas. H. Richardson and myself had the care of the exhibit of electrical and scientific instruments of Queen & Co. In that space we had a dark room to show Geissler and Crookes vacuum tubes. This experience and years of handling and testing Crookes tubes, when received and sold, enabled us to become more or less familiar with Professor Crookes' theories of "Radiant Matter," or, as he termed it "The Fourth State of Matter."

I, therefore, venture to offer a theory that will partially explain the cause and some of the peculiarities of the mysterious X rays, that have been so ably treated in the paper just presented by Drs. Houston and Kennelly. In December, 1878, Dr. Wm. Crookes described before the Royal Society of Great Britain his various experiments, to prove that there is a state of matter beyond the gaseous, in which the molecules of matter, having so much more space to move freely, have their mutual attractions altered, thereby giving the same chemical material new physical properties, making it as much different from a gas as a gas differs from a liquid,

or a liquid from a solid. For example, two atoms of hydrogen and one atom of oxygen combined chemically form one molecule of water. These water molecules may be arranged together in the form of solid ice, liquid water, or gaseous steam, the difference being one of pressure, or temperature, or both.

In a gas the molecules can move freely among themselves, having lost much of their mutual attraction or cohesion.

At the ordinary pressure of the atmosphere, 15 pounds per square inch, if a vibration or motion is imparted to a molecule of a gas, it can move only an exceedingly small distance without striking another molecule. Dr. Crookes found that, when the pressure was removed, each molecule could then move a considerable distance without striking another; and that, under the influence of an electrical discharge or vibration, they acted differently from when in the gaseous state.

When a glass tube, having metal electrodes sealed through the glass, is partly exhausted, and placed near a Holtz glass-plate electrical machine, or in the secondary or tertiary circuit of an induction coil in operation (potential of 20,000 to 50,000 volts), there is a stream of light, usually violet, from one electrode to the other. At about $\frac{1}{1000}$ of an atmosphere exhaustion, the stream of light seems broken into numerous stratifications of light and darkness, and although the negative end of the tube is always brightest, there is a space close to the metal of the negative electrode where there is no light. Dr. Crookes explained the dark spaces between the stratifications and around the negative pole as the "*mean free path of the molecules*;" i. e., the average distance that a molecule could move without a collision with another molecule.

At low exhaustions, no matter how the tube be bent, the discharge or stream of light goes from one electrode to the other, and if the tube be brought near a magnet, the stream of light is attracted or repelled, as though it were a conductor carrying a current of electricity. If the exhaustion be increased, the dark space about the negative

electrode grows larger, until it fills the entire tube. At an exhaustion of about the $\frac{1}{1000000}$ of an atmosphere, there is no stream of light from one electrode to the other. The stream of light meant collision of molecules; now the molecules can move the entire length of the tube without collision; where they strike the glass, they set the *molecules* of the glass into vibration, producing a fluorescent light, the color depending on the composition of the glass. The molecules move in straight lines from the surface of the negative electrode (cathode), no matter where the positive pole be placed. If the glass tube be curved or bent, the flying molecules will not turn the corner. If the negative electrode, or cathode, be in the form of a flat plate, the molecules will fly from it in parallel lines; if it be concave, like a saucer, they will fly from it to a focus; if there be two cathodes, the streams of molecules from each repel each other. Dr. Crookes' explanation is, that as the molecules floating in space come in contact with the electrically-charged plate (cathode), each one becomes similarly charged and is repelled, and, there being no resistance to their motion, they fly with great velocity. A few are deflected by collision with other molecules coming slowly toward the plate. Others strike the glass without collision with other molecules, thus producing the greatest effect on the glass at one spot directly opposite the negative electrode. If any substance be placed in the path of the molecules between the negative electrode and the glass, a shadow of the substance will appear on the glass. If the substance be capable of fluorescence, it will glow with a characteristic color, when placed in the path of the molecules—a diamond glowing with a light equal to that of a candle. If the cathode be made concave, and a piece of platinum foil be placed at the focal point, it will be heated white-hot and fused, showing that the energy of the bombarding molecules can be changed into heat. If a magnet be brought near the tube, the focal point can be deflected, and a hole melted in the tube. If a light wheel with vanes be placed in the tube, and the flying molecules allowed to strike against the vanes, the wheel will revolve rapidly. These flying molecules, whose direc-

tion depends so much on the form of the negative electrode, have been called *cathode rays*. The X or unknown rays, that are capable of affecting a sensitive photographic plate through substances that are opaque to light, seem to start from the fluorescent surface of the glass, the greatest effect being produced on the photographic plate, when this is placed opposite the part of the glass subject to the greatest bombardment. From the fact that the rays inside the tube can be deflected by a magnet, and the X or unknown rays outside the tube cannot be so deflected, it is assumed that there are no X rays inside the tube, and, of course, there are no cathode rays outside of the tube. X rays seem to differ from all other forms of energy, except in one particular—they act on a photographic plate like light waves.

The question is, what are they? A ray of light is affected by a powerful magnetic field. The paper of the evening explains that the principal difference between Lenard rays and Röntgen or X rays is, that the Lenard rays are affected by a magnetic field, and the Röntgen rays are not. The suggestion that they are longitudinal vibrations in the ether only adds to the mystery, because the existence of the *ether* itself has never been proven, it being itself merely an imaginary X quantity adopted to supply the missing link needed to make the wave theory of light plausible.

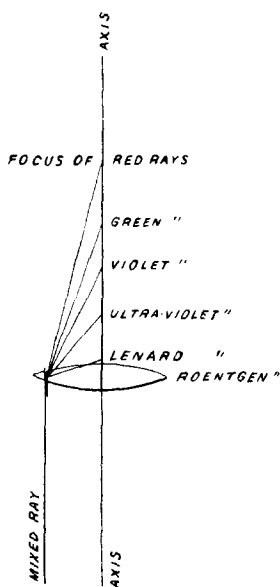
Accepting Dr. Crookes' theory of what happens inside the Crookes' tube, I hold with those who think that the Röntgen and Lenard rays are both similar to light rays, and are ultra-violet light, and that they bear the same relation to ordinary light that harmonics or overtones do to a fundamental sound. The accepted theory of fluorescence is, that the fluorescing substance receives waves of a certain rate of vibration, and transforms them into waves of a different rate of vibration, usually changing short, rapid waves, into longer, slower waves, and, in some instances, the reverse. If a beam of light from a slit be passed through a prism, and the spectrum thrown on the wall, we can readily note about where the red begins and the violet ends. If a piece of paper painted with a solution of quinine be placed beyond where the violet ends, what before was darkness

now appears light; part of the invisible ultra-violet light has been made visible, because the quinine changed the rate of vibration low enough to bring it into the range of what our eyes are capable of seeing. If we had eyes adjusted to be sensitive to these rapid rates of vibration, we might be able to see the ultra-violet light without the use of quinine, or any fluorescing substance, and even X rays might be visible.

To make a comparison with sound, for the purpose of illustration, go to a piano and hold a key down softly without striking the string, then strike suddenly the octave higher; the first string will be set in vibration by the second, and will give a mixture of the sound of its own fundamental tone, and that of the octave higher and its overtones. This phenomenon might be called fluorescence in sound, the relative effect being the same as fluorescence in light. The left or lower end of the piano keyboard may be compared with the red, and the upper or right end, with the violet, of the spectrum. Beyond the piano keyboard limits, there are tones to which our ears cannot respond in unison; beyond the spectrum there are light vibrations our eyes cannot appreciate. When the different instruments in an orchestra, in tuning, sound in succession the key-note of A, it is easy to distinguish and name the instrument that makes the sound, yet they all sound A. The difference is called, in acoustics, *timbre*, meaning the difference in number and particular overtones sounded by each instrument in addition to the fundamental or key-note.

Most large orchestras have two or three kettle-drums, a membrane screwed over a copper kettle and tuned to give one particular fundamental note only. If we drop pebbles or sand on it, or if we could provide a membrane that would not absorb water and stretch out of tune, we could place it out in a shower of rain and get the musical note and its overtones, the same as if pounded with drumsticks. The action of the Crookes tube and the kettle-drum may be compared. The bombarding molecules of air strike the glass as the globules of rain strike the membrane of the drum; the membrane is

tuned to one fundamental note, and has its overtones or harmonics, one, two, three, five, etc., octaves higher, with some fifths and thirds, all mixed, together giving the characteristic sound of a drum. The glass molecules are tuned, so to speak, in the case of the Crookes tube made of ordinary German glass, to the key of G, or green light, and, when set in vibration by the bombarding air molecules, give forth the fundamental green which we see. The overtones or harmonics being some octaves, thirds and fifths above, are Lenard and Röntgen rays of ultra-violet light, Röntgen or X rays



being possibly some octaves higher than Lenard rays. The reason that aluminum gives off X rays apparently without fluorescence may be due to the fact that the molecular fundamental light tone of aluminum may be itself beyond the violet; that is, its fluorescence is beyond our eye limit.

If light be a transverse vibration of molecules, there is no reason why wave motion should stop abruptly at violet, or an octave beyond violet light. Mathematically considered, wave motion should continue until it merged into a straight line or infinity. We might assume that when transverse vibrations became exceed-

ingly small they would merge into longitudinal vibrations, which would be represented by a straight line when compared with a wavy line, representing transverse vibrations. The ultra-violet or harmonic theory may also explain why they have not been refracted. (See accompanying sketch.)

The focus of the red rays, passing through a lens or prism, are always refracted farthest from the lens; the violet rays are brought to a focus much nearer the glass; the ultra-violet would be still nearer, and the Lenard and Röntgen rays would possibly not get out of the glass; they would be absorbed. If a very thin lens of long focus were tried with

sufficient force of rays to penetrate to the focal distance in air, some Röntgen rays might be found between the violet focus and the lens; or, if a lens were made of a very light material, whose density and composition would have nearly the same relation to X rays that glass or water has to light waves, the X rays might be refracted. Air seems to obstruct the passage of X rays, which means that their energy is absorbed in trying to start the air molecules vibrating at an X ray rate, or some octaves lower; therefore, any substance placed around the Crookes tube, which is capable of vibrating at an X ray rate, or an octave near it, should transmit X rays freely.

If a Crookes tube be made, similar to the form in the communication of Prof. Elihu Thomson, and on the side of it from which the X rays are to emerge another lens-form tube be blown—this extra lens-form chamber to have a Geissler-tube vacuum—it is probable that the rays would be partly refracted, sufficient to concentrate them.

From what we know of the sun as a source of energy—of heat, light and electricity—Röntgen rays are, undoubtedly, shed upon us in great quantity; and as the air obstructs and absorbs some of those given off by the Crookes tube, possibly most of the X rays from the sun are absorbed before they reach the earth. A fluorescing substance may yet be discovered that will harmonise more readily with X ray vibrations from the sun than anything yet known, reducing their rate of vibration sufficiently near that of violet light, after passing through substances opaque to ordinary light, to permit us to see them. There will then be no need of Crookes tubes. The sun will do the part of the induction coil and cathode, the higher atmosphere will be similar to the interior of the Crookes tube, and the lower atmosphere will act the part of the fluorescing glass. We will try to do the rest.

If it can be proven that X rays are vibrations similar to those of ultra-violet light, but more rapid, the name X rays, instead of being the algebraic sign for the *unknown*, may mean that their proper place in the spectrum is where the Fraunhofer line *X* would be; line *A* being in the extreme

red end, *D* in the yellow, *E* in the green, *H* in the violet, *I*, *J*, *K*, and so on to *X*, beyond the violet.

The assumption that X rays are longitudinal vibrations in the ether may be harmonised with the ultra-violet light theory, by premising that X rays are *caused* by longitudinal vibrations in the ether; for, if this imaginary ether be perfectly homogeneous, filling all space, the vibrations started by the sun may be longitudinal until they reach our atmosphere, where they may be transformed into other forms of vibration, electric, heat, light, and X or Röntgen vibrations.

Of course, statements like these, made in an extemporaneous discussion of such a profound scientific mystery, must be regarded merely as suggestions. Practical investigators will, I believe, soon discover new facts sufficient to establish a theory that can be proven experimentally, and enable mankind to more thoroughly utilise this latent force of Nature.

MR. A. E. OUTERBRIDGE, JR.—Mr. President, I came to this overflowing meeting, only to look, to listen, and to learn something of this strange discovery, respecting the precise nature of which there is at present so much speculation and vagueness of ideas.

I did not expect to be able to contribute any information to this symposium; but while listening to the address of Drs. Houston and Kennelly, my mind reverted to a memorable occasion, nearly eleven years ago (which some of those now present can, no doubt, recall), when the famous physicist, Sir William Thomson, now Lord Kelvin, during the electrical exhibition held under the auspices of the Franklin Institute, gave, at the Academy of Music, a most enlightening lecture upon "the wave theory of light."

This address made a profound impression upon my mind, and gave me a new intellectual comprehension of the scientist's mathematical conception of the nature of light waves, propagated through the luminiferous ether, as distinguished from sound waves, travelling through the air, and also indicated a possible though unknown analogy. I can vividly recall in my mind's eye, at this instant, the moving diagram upon the screen, exhibiting these two distinct forms of wave motion, and although I cannot now

repeat the precise words then used by the lecturer, the substance of his remarks was, as I recall them, that the propagation of waves of light through the ether was explainable only on the theory of *transverse* displacement; the propagation of sound waves, on the other hand, is due to alternate condensation and rarefaction of the grosser air, rarefaction succeeding condensation at intervals, of course, of half the wave lengths, making longitudinal waves.

Then—becoming enthusiastic over his subject—forgetting for the moment the so-called “popular” nature of his address and his audience—discarding his written notes—he gave a momentary glimpse, to those who could keenly and understandingly follow his intellectual flight into these higher ethereal regions of the inmost (perhaps prophetic) thought of the astute philosopher; and he exclaimed somewhat as follows:

“What is this thing we call the luminiferous ether?”

“It is the one thing in all nature we are sure of; that is, the reality and the substantiality of the luminiferous ether.

“I have shown you the diagram of transverse waves of light; may there not also be *longitudinal* waves in this ether, having unknown powers, of which, at present, we have no conception? I am not prepared to say that it is so—this is little more than a scientific dream of mine; yet we cannot say that the luminiferous ether is *not* capable of longitudinal vibration; indeed, I cannot conceive of its incapability, if it be in the least degree compressible; and, while I do not venture to make an assertion at this moment that we will have a new development of force in the future that will be explainable on the theory of longitudinal vibrations of the ether, I think some of us now present may live to see that, though I may not.”

While I believe that I have, in the main, correctly recalled these fleeting expressions, unfortunately not recorded at the time, you must not, of course, hold Lord Kelvin responsible for the accuracy of my unaided memory.

This all-pervading (although purely hypothetical) luminiferous ether, an imponderable medium, unaffected by

gravity, so far as we know, having great rigidity and elasticity, the only conceivable material connecting link between ourselves and distant worlds, is now regarded by modern philosophers *as the key-note, or the fundamental principle, or genesis of all matter*; indeed, the greatest leaders of thought in this realm of pure science no longer hesitate to attribute all the varying properties of matter to "motion of molecules" of this universal medium. Lord Kelvin said, for example: "What we call matter may be only the rotating portions of something which fills the whole of space, *i.e.*, vortex motion of an everywhere-present fluid," and in his famous address at the Montreal meeting of the British Association* some years ago, he still further elaborated the same thought, and said: "It is scarcely possible to help anticipating, in idea, the arrival at a complete theory of matter in which all its properties will be seen to be merely attributes of motion."

At the present moment we are lost in a sea of speculation, regarding the nature of the new "X ray" shadowgraphs of Professor Röntgen, and in almost a nervous condition of excitement as to the possible future developments; but we have been led by these theoretical and mathematical studies up to a level of comprehension of their possibility.

A word in concluding may serve to explain Professor Himes' doubt as to the presence of X rays in the Crookes tube. He asks: If aluminum is transparent to these rays, why is a shadow cast upon the end of a tube by an aluminum cross interposed in the path of the cathode rays? I think an explanation is this: Aluminum is only comparatively, not absolutely, transparent to these rays. This is proven by the shadowgraphs of aluminum coins thrown upon the screen a few moments ago. Had the metal been *perfectly* transparent, the faint silhouette of the coin would not have appeared at all upon the sensitised plate.

The more intense fluorescent light at the end of the tube in those portions exposed to the full glare of the cathode rays (or to the unshielded bombardment of molecules) would

*Steps toward a Kinetic Theory of Matter. Proceedings B. A., 1884.

naturally disguise any fainter fluorescence which might otherwise be visible within the shadow of the cross, due to the impingement, within this penumbra, of fewer molecules; or, in simpler words, to the partial leaking through the aluminum cross of cathode or X rays.

The cross is pivoted on a hinge, and when it is thrown down, so that the entire end of the bulb is exposed to the cathode rays, behold! the image of a luminous cross appears on the glass bulb, shining much brighter than the surrounding portions of the fluorescent glass. This is commonly explained, by Professor Crookes and others, on the theory of "fatigue." May it not be due to normal fluorescence of the glass under full exposure, plus the fainter fluorescence caused by leakage of cathode rays, due to partial transparency or permeability of the aluminum?

The gradual fading of the cross from view is explicable upon either theory.

PROF. M. B. SNYDER.—It was far from my intention to have anything to say at this time regarding the important discovery of the action of these rays; but since I have been so cordially invited to participate in this discussion, a few observations may be allowable. The chief interest of Röntgen's admirable discovery lies, it seems to me, not in the proposed practical applications, however important those may come to be, but rather in the bearing it may have in forwarding more accurate theoretical conceptions of the whole question of radiant energy. While it is not desirable, in this discussion, to go into detail concerning any opinion regarding the theory of these phenomena, I may say that I have no manner of doubt that these Röntgen radiations do not require the supposition of the character of longitudinal vibrations. They are, in all probability, but a part of the vast series of electro-magnetic vibrations with which we are already acquainted in the magnetic, heat and light spectra. This would, of course, give them the character of transverse waves. The longitudinal vibration of the ether must be reserved, it seems to me, for gravitation itself. We do not, unfortunately, at the present time, possess a mechanical theory of the ether that is even fairly satisfactory, but

the indications, as developed by Lord Kelvin and others, suggest that there is nothing yet known that should prevent us from regarding these rays as a part of the vast electromagnetic gamut. Their refraction, reflection, and even polarisation, would then be a probable result of the future experiments.

An important element in the Röntgen experiment seems to be the transformation of energy that takes place at the surface of the tube, and this has suggested the reflection that we are in all likelihood laying too slight an emphasis upon the changes that take place in the solar radiations within our own atmosphere, changes that may be analogous to those we see in this experiment. The radiant energy of the sun is of one character in space, and of another character within our own atmosphere, just as the action within the Crookes tube is one thing, and that without it another. So, although this is not the time to moot and discuss the mechanical conceptions we should assume, it is, I hope, not beside the question to insist that, however fascinating the applications may be, it is in no less degree fascinating to attempt to provide for this new discovery a proper place in relation to the accepted scientific conceptions. It is even possible that the world-wide interest aroused by the experiments of Röntgen may expend itself in working out a truer conception of radiant energy than has as yet been at all deemed possible.

PROF. GEO. F. STRADLING.—From what I have been able to learn on the subject of this evening's paper, the observers disagree on some points. Professor Frost, of Dartmouth College, for example, finds that his rays found no difficulty in passing through crossed tourmalines; while Dr. H. C. Richards, of the University of Pennsylvania, finds that tourmaline is quite opaque to his rays. Röntgen regards aluminum as a good transmitter, while Professor Frost finds it to transmit poorly. May it not be that there is some marked difference in the rays, at present the subject of so much discussion and speculation? Perhaps one experimenter is using Lenard rays, the other Röntgen rays.

MR. CHAS. H. RICHARDSON.—Mr. President, I would like

to ask Prof. Houston a question. When using the Crookes tube connected, as he describes, to a Tesla high-frequency coil, which is connected to a Ruhmkorff induction coil, the latter charged from the street alternating current, is one pole or electrode distinctly negative, the same as when the Crookes tube is directly connected to the Ruhmkorff coil and energised from a battery, or do both poles give the cathode ray?

PROF. HOUSTON.—Each pole of the Crookes tube gives a cathode ray.

MR. RICHARDSON.—That is, the alternations are so rapid that each electrode appears as if it were the negative electrode?

PROF. HOUSTON.—Yes; there are two fluorescent surfaces of the tube, one due to each electrode.

MR. RICHARDSON.—Mr. President, in conclusion, I would like to make a statement. In one of the letters read to-night, I think from Prof. Thomson, is a suggestion of a visual apparatus for use with the X rays, consisting of a dark tube coated inside with some fluorescent substance which could be placed to the eye and directed towards the Crookes tube.

Such a tube has already been designed and made by Professor Magie, of Princeton University. The rough model consisted of one section of a spy-glass, with the lens removed, and one end covered with a piece of black card-board. The inner surface of this card-board disc was coated with barium-platino-cyanide.

When this apparatus was held to the eye and directed towards the sun, no light could be seen in it; but if pointed towards the active Crookes tube and held close to it, the card across the lower end lighted up with a light green hue, and any object opaque to the X rays, held between this tube and the Crookes tube, would cast a black shadow on the card.

I saw the outline of a key and also of the human finger. A gentleman present said he could see the outlines of the bones inside of the outlines of the finger, but I could only detect a heavier shadow in the center of the finger.

DR. KENNELLY.—I have listened, with great pleasure and interest, to the remarks that have been read this evening from different parts of the country, and made by different members of this audience. I think it would be evident, from the differences of opinion manifested in these remarks, that our present knowledge of the nature of Röntgen rays is very limited. I think, however, there can be no doubt that, with so many able workers in different parts of the world, engaged upon the investigation of these rays, it will not be very long before our knowledge of them will be greatly extended. The surprising feature about these rays is that they are produced under conditions which must have been present at any time during the last ten years to nearly every experimentalist in electricity. Nearly everyone having an induction coil and Crookes tube at his disposal has made those marvelous experiments by which Crookes has manifested the behavior of the cathode rays. Throughout all the trials and experiments of this sort, which have been made in this and other countries since the advent of the Crookes tube, these Röntgen rays have, in all probability, been developed, and have been patiently waiting for discovery. It is those things which lie immediately before our eyes that are often so hard to find.

Stated Meeting, December 18, 1895.

MR. JOS. M. WILSON, President, in the chair.

AUTOMOBILE VEHICLES.

BY PEDRO G. SALOM.

The subject of automobile vehicles is almost as old as the locomotive, and, indeed, may be said to be contemporaneous with the locomotive, as all automobile vehicles are, in the truest sense, locomotives. But the fundamental distinction between the two is that one is designed for operating on a rail, while the other is designed for operating on a road or pavement. With the advent of the steam engine, it was natural to suppose that the question of moving