WHAT ARE THE X-RAYS?

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IT is now three years since Röntgen, professor of physics at Würzburg, published an account of his discovery of the so-called X-rays. The scientific journals of the world were immediately flooded with articles describing investigations of the remarkable phenomenon. In the year 1895–96 there were at least one thousand of these articles. During the past year this number had dwindled to less than one hundred; and the leading scientific periodical in Germany, Wiedemann's "Annalen der Physik und Chemie," has just published Röntgen's original article, as if in irony of the futile attempts of the army of investigators to extend the work of the original discoverer. Röntgen seems, indeed, to have anticipated subsequent workers in many points. He found that the so-called rays could not be bent or refracted like ordinary light-rays in passing from air to a denser medium; and, apparently with the firm conviction that he had discovered a new manifestation of light-radiation, and since he could not discover reflection and refraction of these rays, he asks: "Are these rays an evidence of longitudinal vibrations of the ether?"

Now, we know that the light-waves move up and down in the ether of space with a motion which is transverse to the direction of their propagation. This transverse motion is like the rise and fall of the waves of the sea. A ship rises and falls with such transverse motion, and does not move to and fro in the direction of propagation of the waves. Such a to-and-fro or longitudinal movement has never been discovered in the case of light, and the suggestion of Röntgen immediately awakened the utmost interest among scientific men. If the X-rays are due to a longitudinal movement in the ether, their absence of reflective and refractive power can be explained. No advance, however, has been made in connecting the mysterious phenomenon with longitudinal movements in the ether, and the general trend of scientific opinion is toward the belief that the X-rays are extremely short waves of ultra-violet light, less than one hundred-thousandth of an inch in length; and no miscroscope now made could show such waves to the eye; for it is barely possible to separate lines which are one hundred-thousandth of an inch apart. I have said that the general belief is that the X-rays are due to a wave motion in the ether. The experiments, however, which I am about to describe lead me to believe that in the X-ray phenomena we have really two classes, so to speak, of phenomena—one an electrical polarization of matter in space, and another a manifestation of light at surfaces where the electrical polarization is converted into ordinary fluorescent and phosphorescent light. According to this electrical hypothesis, one should not expect to observe reflection and refraction of the electrical rays in the ordinary sense, and one should expect to treat the light observed where the X-rays strike just as one treats ordinary fluorescent and phosphorescent light.

Let us first consider what we mean by electrical polarization, electrical induction, phosphorescence, and fluorescence. In the magnetic needle we have a body which possesses two poles—a south pole and a north pole. The needle is thus said to be polarized. If we had an infinite number of such needles, without sensible weight, we could stretch a chain from the earth to the sun, and we could call this a polarized chain of particles the subtle vibration of which, under certain conditions, could form a medium of physical communication between a distant body and the earth. Such a polarized chain can also be formed by electrical polarization and induction. If we suppose that the earth and the sun are both electrified, then an infinite number of pith-balls, without sensible weight, existing in space between the earth and the sun, would arrange themselves by electrical polarization and induction, also in invisible polarized chains, between these bodies, and the direction of these chains would constitute invisible lines of electric force. The slightest quiver in these chains or lines of force would constitute an interchange of energy through illimitable space. When these lines of force become sufficiently in-

tense, and when they undergo a rapid change at the surface of certain substances, these substances exhibit fluorescent or phosphorescent light. We are familiar with phosphorescence in the case of the brimstone match, and we can perceive fluorescence in kerosene oil by looking at the surface of this oil obliquely.

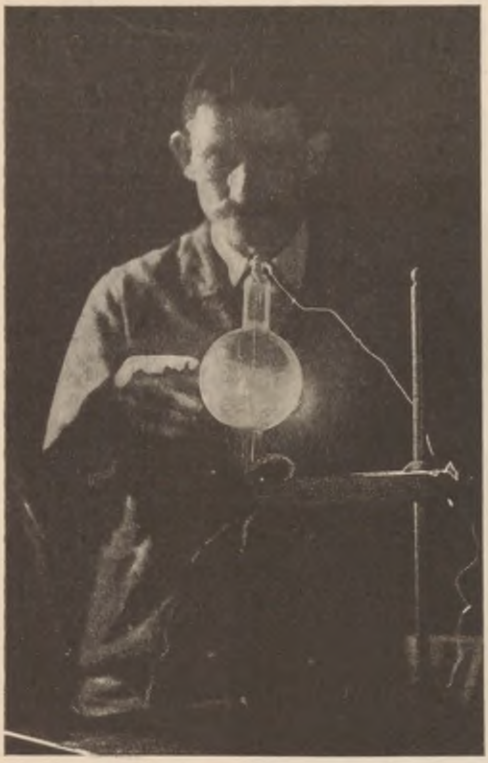

FIG. 1.

The principal difference between fluorescence and phosphorescence resides in this: phosphorescent bodies glow in the dark after having been exposed to light (even a piece of ordinary paper is phosphorescent), while fluorescent substances in general cease to exhibit light in the dark.

Now the X-rays excite both fluorescence and phosphorescence very powerfully, and when they were discovered many investigators endeavored to discover them in ordinary sunlight, and in the electric light, which also excites these states. These attempts were failures. Nevertheless, many believe that ordinary sunlight is due to the conversion of the electrical energy of the sun, transmitted across the ninety millions of miles of space by electrical polarization or induction, into intense fluorescent and phosphorescent light, by an agency similar to that of the X-rays.

I mention this bold hypothesis to show how far-reaching the mysterious phenomena of these rays appear to many minds. These rays are produced by electrical currents, and the question also arises, Are they given off from our telegraph- and telephone-wires when messages fly over these wires—not sensibly, but even in a minute degree? The experiments which I am about to describe were instituted for the purpose of studying the effect of the X-rays on the electrical polarization of matter which I have endeavored to describe. If we could stretch a telegraph-wire between the earth and the sun, and send powerful currents of electricity over it, could we fill the extremely rarefied space around the wire with X-rays? Would they be given off from every element of such a conductor when the electrical charge in the conductor was made to fluctuate? Since it is impossible to realize such an experiment, I resolved to imitate the conditions as nearly as possible in the laboratory. To do this required the expenditure of enormous electrical force. Instead of stretching a wire from the earth to the sun, I narrowed, so to speak, the distance between these bodies to six inches, and, inclosing a wire of this length in a glass vessel, I imitated the vast region of rarefied space by pumping out the air from this vessel. This was the form of vessel in which I studied the manifestation of the X-rays. The electrical apparatus used for the production of the intense electrical forces is probably the most powerful that has ever been used to study these rays. Electric discharges varying in length from one inch to eight feet can be studied by its means. The source of the electricity consists of ten thousand storage-batteries; and the effect of this battery is so heightened that an electric force of over two million volts can be obtained. The ordinary electric-arc street-lamp is generated by means of an electric pressure of less than one thousand volts. The energy in the X-rays, however, does not manifest itself by a dazzling light. Its light-manifestation is a weird yellow glow which barely enables one to obtain a photograph of the tube in which it is generated. Its energy is shown by the extraordinary activity which is given to small particles of matter. By means of the electric discharge of high pressure or electromotive force one can see through timbers a foot thick, and also see the beating of the human heart through the flesh.

Immediately on sending such powerful discharges through the form of vessel I have

described, I discovered that the rays were generated from every point of the six inches of wire. They made the walls of the tube gleam with a weird, fluorescent light, and, penetrating to the outer air, enabled me to detect their presence by photography. Our flight of imagination in picturing a telegraph-wire stretching from the earth to the sun, giving forth mysterious rays into space, has therefore a basis of fact.

The continuous wire tube may have various forms. One of the most interesting, from a scientific point of view, is a spherical bulb through the center of which runs a straight, continuous wire at the center of which is a little mirror of aluminum. When a powerful electric discharge is sent along this wire at a certain stage of the vacuum in the tube, the mirror reflects a beam like a search-light to the walls of the tube, and the point where this beam strikes glows with a phosphorescent light and emits the X-rays. Moreover, if one should stand on an insulated stool (Fig. 1), and touch with the finger this spot on the outside of the bulb, one could reflect back another search-light of X-rays to the opposite side of the bulb, and throw a shadow of the mirror and the wire on the inside of the bulb. This shadow can be thrown to one side or the other, according to the position of the touching finger. These so-called search-lights contain the X-rays, for they show all the manifestations of the latter, such as their power to pass through thin sheets of aluminum, to produce light in fluorescent substances, and to exhibit the skeleton of the hands. Now these effects can be produced by making the continuous wire either positive or negative—that is, by making it either an anode, the way in, or a cathode, the way out. We have hitherto thought of the cathode rays as a phenomenon of the cathode—that is, of the terminal in a Crookes tube by means of which the discharge is conducted out of the tube; and we have never spoken of anode rays. My experiments show conclusively that the term "cathode rays," which are accompanied by the X-rays,—the latter probably being a heightened manifestation of the former,—is only a limited name for a more general phenomenon which I am tempted to call electrostatic rays. The anode rays have all the qualities of the cathode rays; they are not, however, so powerful.

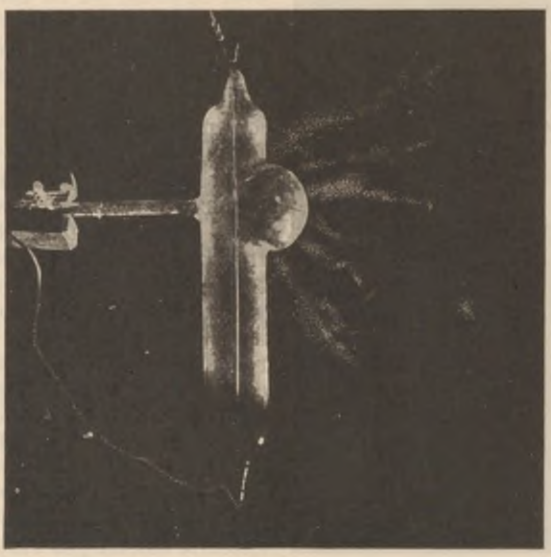

FIG. 2.

It is highly important that the investigator of the phenomena of the X-rays should himself exhaust the Crookes tubes, and should study their manifestations at different stages of the rarefied medium in which they are produced. The effects produced by electricity in such tubes as the air is gradually withdrawn are very beautiful. At first there is a bright pink glow which fills the entire tube; then there are cloud-like masses of white light, which float like feathers through the tube; then comes a yellow fluorescent light which makes the whole interior of the tube luminous. This last effect is produced by the cathode and anode and X-rays, or by what I prefer to call the electrostatic rays. For a time there was a long discussion in regard to the source of the X-rays. Some maintained that they came only from the cathode, others that they proceeded from the anode, and others that they emanated from any surface where the cathode rays struck. My experiments show that the contestants were like those who are said to have disputed whether a shield was gold or silver. Each contestant saw only one side of the shield. In truth, one side of it was gold and the other silver. There are anode rays as well as cathode rays, and either produce by electrical induction a manifestation in any desired direction. This inductive effect is shown by touching the Crookes bulb containing the continuous conductor with

the insulated finger or with an insulated piece of metal.

The continuous wire tube has shown that lines of electric force radiate from the surface of a conductor in a rarefied medium, and produce the X-rays at every point of this conductor. This is true whichever way the electric current flows in the conductor; with such a tube the distinction of cathode rays disappears, and we have a more general manifestation of X-rays.

While trying a great variety of forms of tube, I came across many interesting manifestations of electrification outside the tubes. One of these is of practical interest to surgeons and physicians; for I obtained what is called the X-ray burn by electrification when there were no X-rays which could be detected. I say by electrification, for the burn was evidently produced by the impinging of the electrostatic lines of force on the skin of the hand. The latter was exposed to the neighborhood of a tube containing a continuous conductor such as is shown in Fig. 2. At a certain stage in the vacuum, before the X-rays could be distinguished, peculiar forked brush discharges proceeded from the tube; and these discharges, impinging on the skin, produced the peculiar so-called X-ray burn, which often results from exposure to the X-rays. The skin shows a peculiar red tint, especially after exposure to the cold; it is extremely irritable, and after about three weeks the surface peels. The effect is like that of a severe sunburn. These forked brush discharges can pass through sheets of glass half an inch thick, and leave their impression on photographic plates which are carefully insulated from the ground, and which are shielded from all light in plate-holders. When these photographic impressions (Fig. 3) are examined they resemble in a striking manner the centers of disturbance on the burnt hand when the latter are examined with a microscope. The photographs resulted from minute electrical discharges on the surface of the plate, and the burn was also in this case, and probably in all cases, due to similar discharges on the skin.

FIG. 3.

There is another remarkable phenomenon shown by the X-rays, which further supports my belief that these rays are a manifestation of an electrical disturbance in space. It is well known that an ordinary electrical current cannot pass through a vacuum. At a certain degree of extreme tenuity of the air or any gas the so-called vacuum stops electrical discharges, just as if a piece of glass should be interposed in an electrical circuit. If the X-rays illuminate such a vacuum, however, an electrical current can be made to pass with extreme ease over spaces which had completely stopped its flow. No effect of ultra-violet light with which I have been able to experiment can produce a similar effect. The phenomenon is an electrical one.

The phosphorescent effects produced by the X-rays also support the electrical theory. Whenever such rays strike certain crystals, the latter shine vividly in the dark. The X-rays can lead one to the spot where there is a Crookes tube entirely concealed from view behind a thick door, or behind timbers a foot thick. All that is necessary to discover such rays is a diamond ring and a darkened room.

As one approaches the hidden tube the diamond emits a lambent flame.

The phosphorescent effects produced by the X-rays can also, in certain notable instances, be produced by directly electrifying the phosphorescent bodies, even when the most intense ultra-violet light fails to produce any trace of phosphorescence.

Have we, then, answered the question, What are the X-rays? I believe that the experiments which I have described support the theory that there are really two classes of phenomena—one an electrical disturbance in a medium, another the conversion of this electrical disturbance into fluorescent and phosphorescent light at the surfaces of suitable screens or in the body of suitable crystals. My experiments certainly show that there are anode rays as well as cathode rays, and that both are subject to the well-known laws of electrical induction. One should not expect, therefore, that the electrical rays or lines of force should be reflected and refracted like waves of light. I believe that when we have answered the question, What are the X-rays? we shall be able to state more exactly than at present the relations between light and electricity. The question, therefore, has become one of the most important in physical science.

GALLOPS.

BY DAVID GRAY.

HIS FIRST RACE.

YOUNG Hatfield sat up in bed, and began groping for matches and the candle. He struck a light, and looked at his watch. It was half-past five. He drew a long breath, and tried to recall the nightmare from which he had just escaped. He had been riding somewhere over jumps. It was all vague and disordered at first. Then as he galloped faster and faster toward the fence, it grew clear and real—frightfully real. He was awake, but the crash of breaking rails still jarred in his ears. His heart was thumping with the dream-horror that had come as his horse's head and withers sank under him. He was breathing hard, and his knees felt weak. He had believed that he was dead.

He slipped out of bed, and threw open the shutters. The pines about the Oakdale clubhouse were sighing. Down the valley a southwest wind was herding successive ranks of low, wet clouds. In the first glimmerings of dawn the distant hills were only a darker shadow across the horizon. The gray fields in front of the club sloped dimly, and were lost in the mists on the bottom-lands. Hatfield stretched his arm out, and opened his hand to the wind.

"They 'll race," he muttered; "there 's no frost." He cuddled his hands in his pajama sleeves, and shivered. Then he closed the window, and jumped into bed.

Hatfield had left Forbes's dinner about two o'clock; therefore he needed sleep, but he knew that it was out of the question. His brain was in that stage of nervous alertness which results from champagne and much coffee, followed by an evening of Scotch and soda. His dream weighed upon him; there was a prophetic vividness about it which he could not shake off. He argued that the horse he was going to ride had run many steeplechases, and had never hurt any one. Forbes had told him that when he offered him the mount. Then an inner voice suggested that this was the more reason for avoiding that horse. Every horse will fall some day. His mind brought up instances of men killed in the hunting-field when mounted on their best. He had known an Englishman killed in that way the winter before. At the end of an hour he recognized the certainty that he was going to be killed, or at least badly hurt. He was not superstitious, but presentiments nowadays have a scientific recognition. He imagined how he would look in his coffin, and he wondered whether his mother would come over, or whether they would send him to her. His mother lived in Europe. Then he fell to thinking about the Girl who, at that moment, was asleep at the Alden Adamses', a mile up the road. He wondered if by any freak of thought-transference his dream had come to her.