Eine Neue Art von Strahlen / On a New Kind of Rays W.C. RÖNTGEN (Roentgen) 28dec1895

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EINE NEUE ART
VON
STRAHLEN.

VON

DR. W. RÖNTGEN,
Ö. O. PROFESSOR AN DER K. UNIVERSITÄT WÜRZBURG.

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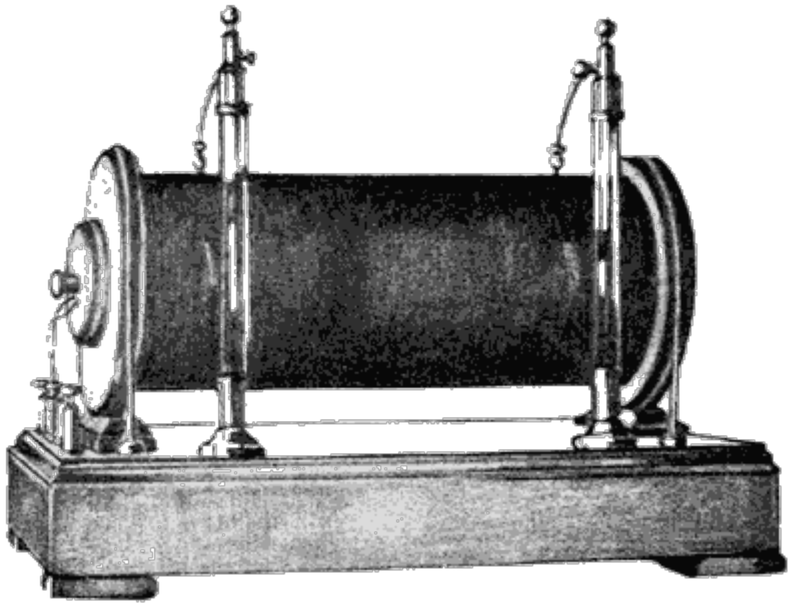
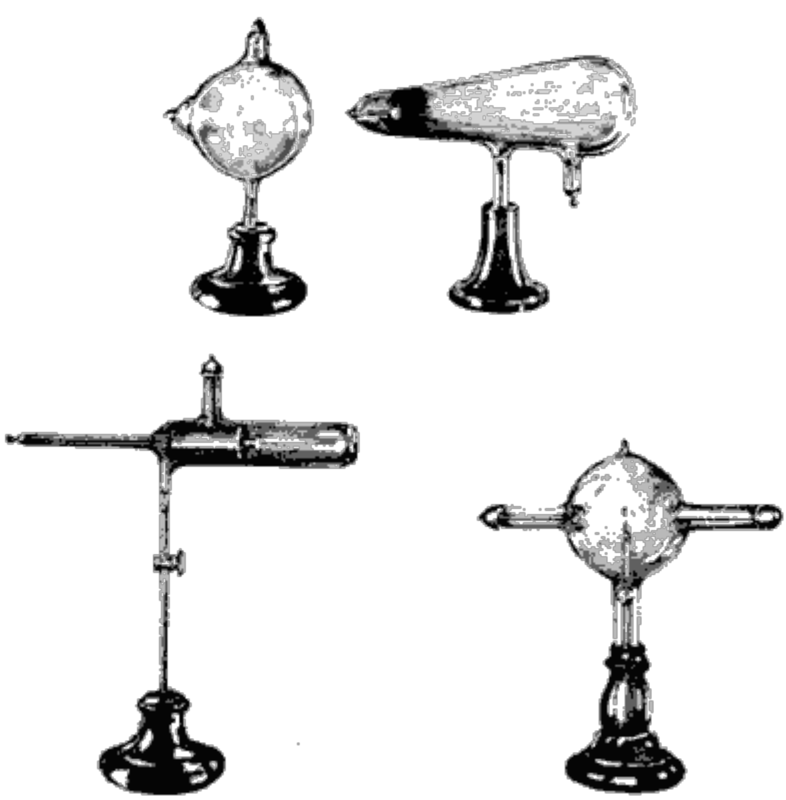


.. a fairly large Ruhmkorff induction coil .. .



"... a Hittorf vacuum tube, a sufficiently evacuated Lenard or Crookes

December 28, 1895

W. C. Röntgen: On a New Kind of Rays
(Preliminary Communication)

* *This new translation* [by Otto Glasser] *of Röntgen's first communication varies somewhat from one made by G. F. Barker in 1896.*

1. If one passes the discharges of a fairly large Ruhmkorff induction coil through a Hittorf vacuum tube, a sufficiently evacuated Lenard or Crookes tube, or a similar apparatus, and if one covers the tube with a rather closely fitting envelope of thin black cardboard, one observes in the completely darkened room that a piece of paper painted with barium platinocyanide lying near the apparatus glows brightly or becomes fluorescent with each discharge, regardless of whether the coated surface or the other side faces the discharge apparatus. The fluorescence is still visible at a distance of 2 m from the apparatus.

One easily convinces oneself that the cause for the fluorescence emanates from the discharge apparatus and from no other point in the circuit.

2. Observing this phenomenon one is immediately struck by the fact that the black cardboard cover, which stops visible or ultraviolet rays from the sun or the electric arc, transmits an agent that can produce active fluorescence, and one would therefore wish to investigate first whether other materials also possess this same property.

One soon finds that all materials are transparent to it, although differing widely in degree. I present a few examples. Paper is very transparent[1]: I observed that the fluorescent screen still glowed brightly behind a bound [illegible] double pack of Whist cards; the eye can hardly detect a single card held between the apparatus and the screen.-Also a single sheet of tinfoil is hardly perceptible; only after several layers have been placed one on top of the other does one see the shadow distinctly on the screen.-Thick blocks of wood are also very transparent; pine boards 2 to 3 cm thick absorb only very little.-A plate of aluminum about I S mm thick reduced the effect considerably but did not make the fluorescence disappear entirely.-Sheets of hard rubber several centimeters thick also let rays pass through.[2] Glass plates of equal thickness act differently depending upon whether or not they contain lead (flint glass); the former are much less transparent than the latter.—If one holds the hand between the discharge apparatus and the screen, one sees the darker shadows of the bones within the much fainter shadow picture of the hand itself.—Water, carbon disulfide, and several other liquids, when examined in mica containers, were found to be very transparent.-I have not been able to determine that hydrogen is definitely more transparent than air.—Fluorescence still may be clearly detected behind plates of copper, silver, lead, gold, or platinum, but only if the plates are not too thick. Platinum 0.2 mm thick is also transparent; silver and copper plates may even be thicker. Lead 1.5 mm thick is practically opaque and on account of this property was frequently used. -A stick of wood having a square cross section (20 by 20 mm) and one side painted white with lead paint acts differently depending upon how it is held between apparatus and screen; although there is practically no effect if the direction of the x-rays is parallel to the painted surface, the stick throws a dark shadow if the rays have to pass through the painted surface.-In a manner similar to that of the metals themselves, their salts, either solid or in solution, may be arranged according to their transparency.

1. "Transparency" of a material I define as the ratio of

> > screen under identical conditions without interposition of the material.
> >
> > 2. For the sake of brevity I should like to use the term "rays," and to distinguish them from others I shall use the name "x-rays." (See no. 14.)

3. The experimental results cited, as well as others, lead to the conclusion that the transparency of various substances assumed to be of equal thickness depends primarily upon their density: no other property, at least not to the same extent, is as conspicuous as this one.

That the density, however, is not the only determining factor is proved by the following experiments. I studied the transparency of plates of almost equal thickness made of glass, aluminum, calcite, and quartz; although the density of these substances is approximately the same, it was quite evident that calcite was considerably less transparent than the other materials, which all reacted very much the same. I have not noticed a particularly strong fluorescence of calcite, especially as compared with glass (see no. 6).

4. As the thickness increases all materials become less transparent. In order to find a possible relation between transparency and thickness, I made photographs (see no. 6) in which the photographic plate was partly covered with a number of layers of tinfoil in a step-like arrangement; a photometric measurement will be made when I have a suitable photometer.

5. Platinum, lead, zinc, and aluminum were rolled out in sheets of such thickness that all appeared nearly equally transparent. The following table contains the measured thickness in millimeters, the relative thickness referred to that of the platinum sheet, and the density.

Density

Pt	0.018 mm	1	21.5
Pb	0.05 mm	3	11.3
Zn	0.10 mm	6	7.1
Al	3.5 mm	200	2.6

These values show that by no means is the transparency of different metals equal if the product of thickness and density is the same. The transparency increases much more rapidly than the product decreases.

6. The fluorescence of barium platinocyanide is not the only detectable effect of x-rays. First it must be mentioned that other substances also fluoresce, such as, for example, the phosphorescent calcium compounds, uranium glass, ordinary glass, calcite, rock salt, and so forth.

Of special significance in many respects is the fact that photographic dry plates are sensitive to x-rays. One is able to make a permanent record of many phenomena whereby deceptions are more easily avoided; and as a control I have, whenever possible, recorded every relatively important observation that I saw on the fluorescent screen by means of photography.

Here, the property of the rays of penetrating almost unhindered thinner layers of wood, paper, and tinfoil is very advantageous; in the lighted room one can expose the photographic plate, which is enclosed in a cassette or wrapped in paper. On the other hand, as a consequence of this property one should not leave undeveloped plates near the discharge apparatus for any length of time if these plates are protected merely by the ordinary cardboard box and paper.

The question remains whether or not x-rays are directly responsible for the chemical action upon the silver salts of the photographic plate. It is possible that this action is due to the fluorescent light which, as indicated above, is

"Films," by the way, may be used equally as well as glass plates.

That x-rays are also able to produce a heating action I have not yet proved experimentally; yet one may well assume that this effect exists, since the fluorescent phenomena prove that x-rays may be transformed and since it is also evident that not all of the impinging x-rays leave the material unaltered.

The retina of the eye is insensitive to our rays; the eye brought close to the discharge apparatus registers nothing, although, according to common experience, the media contained in the eye must be sufficiently transparent to the rays.

7. After I had recognized the transparency of various relatively thick materials, I was anxious to learn how x-rays behaved when passing through a prism, that is, whether or not they were refracted by it. Experiments with water and with carbon disulfide in mica prisms having a refracting angle of approximately 30 degrees did not show any refraction either on the fluorescent screen or on the photographic plate. As a control the refraction of light rays was observed under the same conditions; the refracted images on the plate were found to be located about 10 and 20 mm. respectively from the nonrefracted.—With hard rubber and aluminum prisms, also of a refracting angle of about 30 degrees, I have obtained images on the photographic plate in which one might possibly detect a refraction. However, this is very uncertain, and if refraction does exist, it is in any case so small that the refractive index of the x-rays in these substances could not be more than 1.05 at the most. Also on the fluorescent screen I was unable to observe any refraction in this instance.

Experiments with prisms of denser metals have not as yet produced any definite results owing to their low [illegible] transmitted rays.

Considering these facts on one hand and on the other the importance of the question whether or not x-rays can be refracted when passing from one medium into another, it is reassuring that this question can be investigated in a different manner without the aid of prisms. Finely pulverized substances in sufficiently heavy layers scatter the impinging light and because of refraction and reflection let pass only a small amount of it; now, if the powders are equally as transparent to x-rays as the coherent substance is-provided that equal masses of each are used-, it follows that neither refraction nor regular reflection takes place to any appreciable degree. Such experiments were carried out with finely pulverized rock salt, with fine silver powder produced electrolytically, and with zinc dust such as is frequently used in chemical investigations; in all cases no difference in the transparency between powder and coherent substance could be detected, neither with the fluorescent screen nor with the photographic plate.

That one cannot concentrate x-rays with lenses is self-evident from the foregoing; indeed a large hard rubber lens and a glass lens were ineffective. The shadow picture of a round rod is darker in the center than at the edge; that of a tube, filled with a substance more transparent than the material of the tube itself, is lighter in the center than at the edge.

8. On the basis of the preceding paragraph the question in regard to the reflection of x-rays may be considered solved in the sense that a noticeable regular reflection of the rays from any of the examined substances did not take place. Other experiments, which I shall omit here, lead to the same result.

However, one observation must be mentioned, which at first seems to be contradictory. I exposed to x-rays a photographic plate that was protected from light by black [illegible] apparatus; the sensitive layer with the exception of a small free space was covered with polished sheets of platinum, lead, zinc, and aluminum in a star-like arrangement. On the developed negative one can clearly perceive that the blackening under the platinum, the lead, and particularly under the zinc is denser than under the other areas; the aluminum had exerted no effect. It seems, therefore, that the three named metals reflect the rays; however, one may conceive of other causes for the stronger blackening, and in the second experiment, in order to be sure, I placed a piece of thin aluminum foil, which is not transparent to ultraviolet rays but is very transparent to x-rays, between the sensitive layer and the metal plates. Since essentially the same result was again obtained, a reflection of x-rays from the aforementioned metals is proved.

If one adds to this fact the observation that powders are equally as transparent as coherent materials and furthermore that materials having rough surfaces have the same effect upon the transmission of x-rays as polished substances as described in the last experiment, one comes to the conclusion that, although, as stated before, a regular reflection does not take place, materials react to x-rays as do turbid media to light.

Since, moreover, I could not detect any refraction when x-rays pass from one medium into another, it appears that they move with equal velocity in all materials, specifically in a medium that is present everywhere and in which particles of matter are embedded. These particles form an obstacle to the propagation of x-rays, which in general is the greater the denser the respective substance.

9. Therefore the arrangement of particles within the material may possibly influence its transparency; for instance, a piece of calcite of a given thickness may vary in transparency depending upon whether the rays pass through it in the direction of its axis or at right angles

given a negative result.

10. It is well known that Lenard, in his beautiful experiments on Hittorf's cathode rays passing through a thin aluminum foil, came to the conclusion that these rays are phenomena in the ether and that they are diffused in all materials. Regarding our rays we can make similar statements.

In his recent publication Lenard determined the absorption of cathode rays in different materials, and, among others, for air of atmospheric pressure he found it to be 4.10, 3.40, and 3, i o, all relative to i cm, depending upon the rarefaction of the gas in the discharge apparatus. In my experiments, judging from the discharge voltage estimated from the spark gap, I was dealing usually with rarefactions of approximately the same order of magnitude and only occasionally with higher or lower ones. With L. Weber's photometer—I do not have a better one-I succeeded in comparing in atmospheric air the intensities of the fluorescent light of my screen at two distances from the discharge apparatus-about 100 and 200 mm respectively—and I found in three experiments, which were in very good agreement, that they were inversely proportional to the squares of their respective distances between screen and discharge apparatus. Therefore air absorbs a much smaller portion of transmitted x-rays than of cathode rays. This result is also in entire agreement with the previously mentioned observation that the fluorescent light may still be observed at a distance of 2 m from the discharge apparatus.

In general other substances have properties similar to air: They are more transparent to x-rays than to cathode rays.

11. Another very remarkable difference between the behavior of cathode rays and of x-rays lies in the fact that, despite many attempts, I have not succeeded in obtaining a deflection of the x-rays by a magnet, even in very strong

So far, the deflection by means of a magnet has been considered a property peculiarly characteristic of cathode rays; it is true that Hertz and Lenard observed that there are different kinds of cathode rays "which can be differentiated from one another by their production of phosphorescence, by their absorption, and by their deflection by a magnet," but a considerable deflection was found in all their investigations, and I do not believe that one should give up this characteristic feature without good reason.

12. According to experiments made especially for this purpose it is certain that the area on the wall of the discharge apparatus that shows the strongest fluorescence must be considered the main point of emission of x-rays, which radiate in all directions. Therefore, the x-rays proceed from that area where, according to the reports of several investigators, the cathode rays impinge upon the glass wall. If one deflects the cathode rays within the discharge apparatus by means of a magnet, one observes also that the x-rays are emitted now from another area, namely, from the terminating point of the cathode rays.

This is another reason why x-rays, which cannot be deflected, cannot be simply cathode rays that have been transmitted or reflected without being changed by the glass wall. The greater density of the glass outside the discharge tube cannot, according to Lenard, be made responsible for the great difference in deflection.

I therefore come to the conclusion that x-rays are not identical with cathode rays, but that they are produced by the cathode rays in the glass wall of the discharge apparatus.

13. This production takes place not only in glass but also in aluminum, as I was able to observe with an apparatus

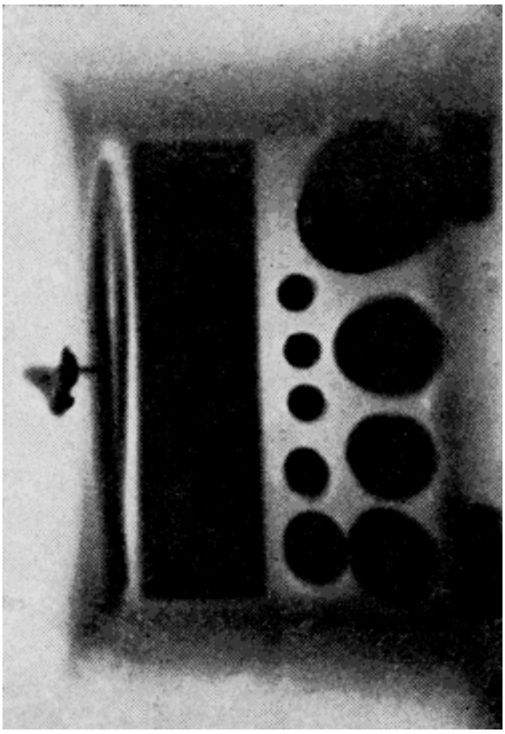
substances are to be examined later.

14. I find the justification for using the name "rays" for the agent emanating from the wall of the discharge apparatus in the very regular formation of shadows that are produced if one brings more or less transparent materials between the apparatus and the fluorescent screen (or the photographic plate).

I have observed and sometimes photographed many such shadow pictures, the production of which is occasionally very attractive; for instance, I have photographs of the shadows of the profile of a door separating rooms, in one of which the discharge apparatus was placed and in the other the photographic plate; of the shadows of the bones of the hand; of the shadows of a concealed wire wound on a wooden spool; of a set of weights enclosed in a small box; of a compass in which the magnetic needle is entirely surrounded by metal; of a piece of metal whose inhomogeneity becomes apparent with x-rays; and so forth.

That x-rays are propagated in straight lines is further proved by a pinhole photograph that I was able to make of the discharge apparatus enclosed in black paper; the picture is weak but unmistakably correct.

". . . shadows of the hones of the hand; of a set of weights enclosed in a small box . . ."



". . . shadows of a compass in which the magnetic needle is entirely surrounded by metal;
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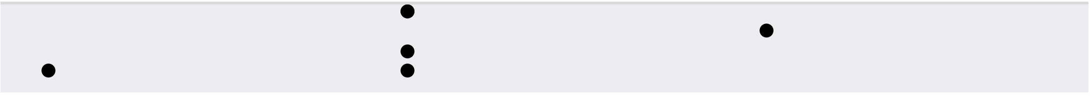
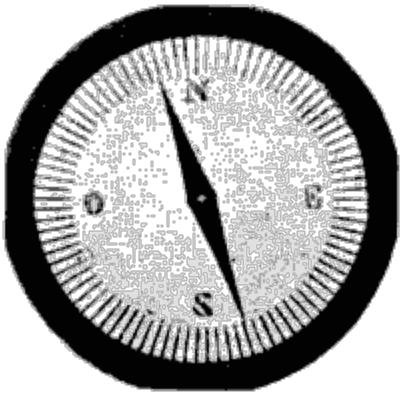
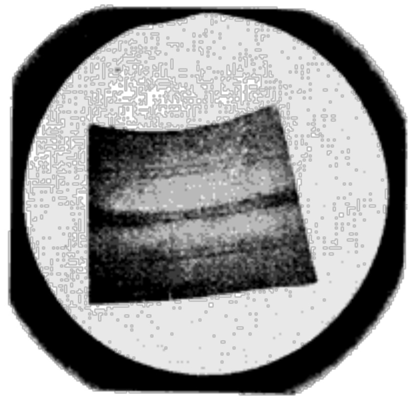


15. I have often looked for interference phenomena of x-rays but unfortunately without success, possibly only because of their low intensity.

16. Experiments to determine whether or not electrostatic forces can affect x-rays have been started but as yet are not finished.

17. If one asks oneself what x-rays-which cannot be cathode rays-really are, at first, misguided by their lively fluorescence and chemical effects, one might perhaps think of ultraviolet light. However, one is immediately confronted with rather serious considerations. For, if x-rays were ultraviolet light, this light should have the following properties:

(a) that, in passing from air into water, carbon disulfide, aluminum, rock salt, glass, zinc, and so forth, it suffers no noticeable refraction;

(b) that it cannot be regularly reflected to any noticeable extent by these substances;

(c) that, therefore, it cannot be polarized by any of the ordinary methods;

(d) that no other property of the material influences its absorption as much as its density.

ultraviolet rays behave entirely differently from the infrared, visible, and ultraviolet rays known at present.

I have not been able to arrive at this conclusion and have sought for another explanation.

Some kind of relation seems to exist between the new rays and light rays, at least as is indicated by the formation of shadows, by fluorescence, and by chemical effects, which are common to both types of rays. Now it has been known for a long time that, besides transversal light vibrations, longitudinal vibrations in the ether can also occur and must even exist according to the opinion of several physicists. It is true that their existence has not yet been definitely proved and that therefore their properties have not yet been investigated experimentally.

Could not, therefore, the new rays be due to longitudinal vibrations in the ether.

I must confess that during the course of investigations I have favored this thought more and more, and I therefore take the liberty of expressing this theory here, although I am perfectly aware that the explanation offered requires further confirmation.

Würzburg. Physikal. Institut der Universität, Dec. 1895.

March 9, 1896

W. C. Röntgen: On a New Kind of Rays (Continued)

** This new translation* [by Otto Glasser] *of Röntgen's second communication varies somewhat from one made by G. F. Barker in 1896.*

should like to present at this time some new results in the following.

18. At the time of my first publication I knew that x-rays are able to discharge electrified bodies, and I suspect that in Lenard's experiments it was also the x-rays and not the cathode rays, transmitted unchanged by the aluminum window of his apparatus, that produced the effects upon electrified bodies at a distance. However, I waited until I could present incontestable results before publishing my experiments.

These seem to be obtainable only if the observations are made in a room that not only is protected completely from the electrostatic forces emanating from the vacuum tube, from the conducting wires, from the induction apparatus, and so forth, but also is closed against air that comes from the region of the discharge apparatus.

Accordingly I had a box built of zinc plates soldered together, which is large enough to accommodate me and the necessary instruments and which is completely airtight with the exception of an opening that could be closed by a zinc door. The wall opposite the door is to a large extent covered with lead; at a place near the discharge apparatus, which is set up outside the box, an opening 4 cm wide is cut out of the zinc wall and its lead cover, and this opening is in turn made air-tight with a thin sheet of aluminum. Through this window the x-rays can enter the observation box.

Now I observed the following:

(a) Positively or negatively electrified bodies set up in air are discharged if they are irradiated with x-rays; the more intense the rays, the more rapid the discharge. The intensity of the rays was estimated by their effect upon the fluorescent screen or upon a photographic plate.

conductors or insulators. Moreover, so far I have not been able to find a specific difference in the behavior of different bodies with regard to the rate of discharge, nor in the behavior of positive and negative electricity. Yet it is not impossible that small differences exist.

(b) If an electrified conductor is not surrounded by air but by a solid insulator, e.g., paraffin, the irradiation of it has the same effect as moving a grounded flame over the insulating cover.

(c) If this insulating cover is surrounded by a tight-fitting grounded conductor, which like the insulator must be transparent to x-rays, the radiation exerts upon the inner electrified conductor no effect detectable with the available means.

(d) The observations cited under a, b, c indicate that air that is irradiated with x-rays has acquired the property of discharging electrified bodies with which it comes in contact.

(e) If this is really the case and in addition if the air retains this property for some time after being exposed to x-rays, it should be possible to discharge electrified bodies that themselves are not directly irradiated by x-rays simply by conducting irradiated air to them.

One can be convinced of the validity of this conclusion in different ways. I should like to describe one experimental set-up, although it is not the simplest one.

I used a brass tube 3 cm wide and 45 cm long; a few centimeters from one end of the tube, part of its wall was cut away and replaced with a thin sheet of aluminum; through the other end a brass sphere, fastened to a metal rod and insulated, was sealed air-tight into the tube.

an exhaust apparatus; when suction was applied, air that passed the aluminum window on its way through the tube flowed around the brass sphere. The distance from window to sphere was over 20 cm.

I set this tube up inside the zinc box so that through the aluminum window of the tube the x-rays could enter perpendicularly to its axis and so that the insulated sphere lay in the shadow beyond the range of these rays. The tube and zinc box were connected to each other; the sphere was connected to a Hankel electroscope.

It was then observed that a charge either positive or negative given to the sphere was not influenced by the x-rays as long as the air remained at rest in the tube, but that at once the charge decreased considerably if irradiated air was drawn past the sphere by strong suction. When a constant potential from a storage battery was applied to the sphere and when irradiated air was continuously sucked through the tube, an electric current was produced just as if the sphere had been connected to the tube wall by a poor conductor.

(f) The question arises in what manner air can lose the property given to it by x-rays. Whether in time it loses the property itself, that is, without coming in contact with other bodies, is still unsettled. However, it is certain that a brief contact with a body that has a large surface and is not necessarily electrified may render the air ineffective. If, for example, one placed a sufficiently large stopper of cotton so far into the tube that irradiated air must pass through the cotton before it reaches the electrified sphere, the charge of the sphere remains unchanged; even while suction is applied.

If the stopper is placed in front of the aluminum window, one obtains the same result as without cotton; a proof that

observed.

Wire screens have an action similar to cotton; however, the screen must be very fine, and many layers must be put on top of one another if the irradiated air passing through them is to be made ineffective. If these screens are not grounded, as has been assumed so far, but are connected to a source of electricity of constant potential, the observations have always been what I anticipated; however, these experiments have not yet been completed.

(g) If the electrified bodies are placed in dry hydrogen instead of air, they are also discharged by x-rays. It seemed to me that the discharge in hydrogen proceeded somewhat slower; however, this is still uncertain because of the difficulties in obtaining equal intensities of x-rays in a series of consecutive experiments.

The method of filling the apparatus with hydrogen very likely precludes the possibility that the denser layer of air originally present on the surface of the bodies could play an important role in the discharge.

(h) In highly evacuated spaces the discharge of a body struck directly by x-rays proceeds much more slowly-in one case, for example, about seventy times more slowly—than in the same vessels when they are filled with air or hydrogen of atmospheric pressure.

(i) Experiments have been started on the behavior of a mixture of chlorine and hydrogen under the influence of x-rays.

(j) Finally, I should like to mention that one must often accept with caution the results of experiments on the discharging effects of x-rays in which the influence of the surrounding gas has not been taken into account.

19. In some cases it is advantageous to insert a Tesla

Ruhmkorff coil. This arrangement has the following advantages: First, the discharge tubes are less liable to be punctured and heat up less; secondly, the vacuum, at least so far as my home-made tubes are concerned, keeps for a longer time; and, thirdly, some apparatus produce more intense rays. Some tubes that were evacuated too little or too much to work satisfactorily on the Ruhmkorff coil alone functioned satisfactorily with the use of the Tesla transformer.

The question arises-and I should like, therefore, to mention it without contributing anything to its solution at present-whether x-rays can also be produced by a continuous discharge from a source of constant potential or whether fluctuations of the potential are absolutely necessary to produce them.

20. It is stated in paragraph i3 of my first communication that x-rays can be produced not only in glass but also in aluminum. In continuing the investigations along these lines no solid body could be found that was not able to produce x-rays under the influence of cathode rays. I also have found no reason for liquid and gaseous bodies' not acting in the same manner.

However, quantitative differences in the behavior of different bodies have been found. For example, if one lets cathode rays fall upon a plate, one half of which consists of a 0.3 mm platinum sheet and the other half of a i mm aluminum sheet, one observes on the photograph of this double plate taken with a pinhole camera that the platinum emits considerably more x-rays from the front side where it has been struck by the cathode rays than the aluminum emits from the same side. From the rear side, however, hardly any x-rays are emitted from the platinum but relatively many from the aluminum. In the latter, rays have been produced in the front layers of the aluminum and have

One can easily arrive at an explanation of this observation, but it might be advisable to learn about some other properties of the x-rays first.

However, it should be mentioned that the observed facts also have a practical significance. According to my experience up to now, platinum is best suited for the production of x-rays of highest intensity. For several weeks I have used with good success a discharge tube with a .concave mirror of aluminum as cathode and a platinum foil as anode, which has been placed in the focus of the cathode and inclined 45 degrees in relation to the axis of the mirror.

21. In this apparatus x-rays are emitted from the anode. From experiments made with apparatus of various shapes I must conclude that, insofar as the intensity of x-rays is concerned, it does not matter whether these rays are produced at the anode or not.

Especially for experiments with alternating currents from a Tesla transformer a discharge apparatus is being built, in which both electrodes are concave aluminum mirrors, whose axes form a right angle; in their common focus a platinum plate is placed that receives the cathode rays. A report on the usefulness of this apparatus will appear later.

Finished: March 9, 1896
Würzburg. Physikal. Institut d. Universität.

March 10, 1897

W. C. Röntgen: Further Observations on the Properties of X-rays (Third Communication)

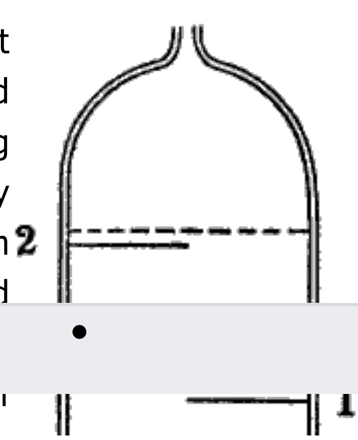
communication varies somewhat from one made by G. F.

Barker in 1897.

1. If one places an opaque plate between a discharge apparatus[1] that emits intense x-rays and a fluorescent screen in such a way that the shadow of the plate covers the entire screen, one can still detect a luminosity of the barium platinocyanide. This light can even be seen if the screen lies directly upon the plate, and one is at first inclined to think that the plate is transparent. However, if one covers the screen lying on the plate with a heavy plate of glass, the fluorescent light becomes much weaker and disappears entirely if instead of a glass plate one places the screen in a cylinder of lead-foil 0.1 cm thick, which is closed at one end with the opaque plate and at the other by the head of the observer.

The phenomenon described may have been produced by diffraction of rays of very long wavelength or by the fact that x-rays are emitted from substances surrounding the discharge apparatus, notably from the irradiated air.

> 1. All the discharge tubes mentioned in the following communication are constructed according to the principle given in paragraph 20 of my second communication (Sitzunsber. d. phys.-mediz. Gesellschaft zu Würzburg, Jahrg. 1895). I obtained a great number of them from the firm of Greiner and Friedrichs in Stützerbach i. Th., to whom I wish to express publicly my thanks for putting abundant material at my disposal gratis.



The latter explanation is the correct one as can be easily demonstrated with the following apparatus, among others. Figure 1 represents a very thick-walled glass bell jar, 20 cm high and 10 cm wide, which is closed and

and 2 are inserted circular segments of

lead sheets, which are somewhat larger than half the cross section of the jar and which prevent the x-rays that enter the jar through an opening

Fig. 1.

in the zinc plate, which is covered with a celluloid film, from travelling in a straight line to the space above lead disk 2. On the upper side of this lead disk is fastened a small barium platinocyanide screen, which almost fills the entire cross section of the jar. This cannot be hit by direct rays nor by those which have undergone a primary diffuse reflection on a solid substance (for example, the glass wall). The jar is filled with dust-free air before each experiment.—If one lets x-rays enter the jar, first, so that they are all stopped by lead screen 1, one does not yet see any fluorescence near 2; only when the jar is tipped so that direct rays can also enter the space between 1 and 2 does the fluorescent screen show an illumination of the half not covered with lead disk 2. If the jar is then connected to a water aspirator, one notices that the fluorescence becomes gradually weaker as the evacuation progresses; if air is readmitted, the intensity increases again.

Since now, as I found, mere contact with air that has just been irradiated does not produce any noticeable fluorescence of the barium platinocyanide, one must conclude from the experiment described that air emits x-rays in all directions while it is being irradiated.

If our eye were as sensitive to x-rays as it is to light rays, a discharge apparatus in operation would appear to us like a light burning in a room that is uniformly filled with tobacco smoke; perhaps the color of the direct irradiation and that coming from the air particles would be different.

I have not yet been able to answer the question as to whether the rays that are emitted from irradiated substances are of the same kind as those impinging upon

phenomenon similar to fluorescence is the cause of these rays; that the rays coming from the air also are effective photographically can easily be proved; as a matter of fact, this effect is even noticeable sometimes in a manner disagreeable to the observer. To guard against this, which is frequently necessary, especially for longer exposure times, one must enclose the photographic plate in suitable lead containers.

2. For comparing the intensity of the radiation of two discharge tubes and for several other experiments I used an arrangement that is fashioned after the Bouguer photometer, and that I shall also simply call a photometer. A rectangular sheet of lead, 35 cm high,150 cm long, and 0.15 cm thick, is placed vertically at the center of a long table and supported by boards. On each side of it is placed a discharge tube which can be moved along the table. At one end of the lead strip a fluorescent screen[2] is attached in such a way that each half of it receives perpendicularly the rays from only one of the tubes. In these measurements one adjusts to obtain equal intensity of the fluorescence in both halves.

Some remarks on the use of this instrument may be made here. First, it must be stated that adjustments are frequently very difficult to make because of the inconstancy of the source of radiation; the tube responds to each irregularity in the interruption of the primary current, such as occurs with the Deprez and notably with the Foucault interrupter. It is therefore advisable to make repeated adjustments.

2. In this and in other experiments Edison's fluorescent screen has proved very useful. This consists of a box similar to a stereoscope, which can be held light-tight against the head of the observer and whose cardboard end is covered with barium platinocyanide. Edison uses tungstate of [illegible] prefer the latter for several reasons.

Secondly, I should like to indicate the factors that govern the brightness of a given fluorescent screen which is bombarded by x-rays in such rapid succession that the observing eye can no longer detect the intermittence of the radiation. This brightness depends upon (1) the intensity of the radiation emitted from the platinum plate of the discharge tube; (2) very probably the kind of rays that fall upon the screen, since not every type of radiation causes the same degree of fluorescence (see below); (3) the distance of the screen from the point of emission of the rays; (4) the absorption of the rays on their way to the barium platinocyanide; (5) the number of discharges per second; (6) the duration of each single discharge; (7) the duration and the strength of the afterglow of the barium platinocyanide; and (8) the radiation originating in materials surrounding the discharge tube and falling upon the screen. In order to avoid mistakes one should always remember that in general these conditions are similar to a comparison of the fluorescent action produced by two intermittent light sources of different colors which are surrounded by an absorbing envelope and placed within a turbid-or fluorescent--medium.

3. According to paragraph 12 of my first communication[3] the part of the discharge apparatus that is struck by cathode rays is the point of emission of x-rays which spread out "in all directions." Now it is interesting to learn how the intensity of the rays varies with the direction. For this investigation the sphere-shaped discharge apparatus with smoothly polished plain platinum plates upon which the cathode rays fall at an angle of 4S degrees are the most suitable. Even without additional instruments one can recognize from the uniformly bright fluorescence of the hemispherical glass wall above the platinum plate that there are no very great variations in the intensities in different directions and that therefore *Lambert's* law of emission

3. Sitzungsberichte der physik.-mediz. Gesellschaft zu Würzburg. Jahrg. 1895.

In a more accurate test the intensity of the radiation emitted in different directions from several tubes was examined with the photometer; furthermore for the same purpose I have exposed photographic films bent in the shape of a semicircle (radius *25* cm) with the platinum plate of the discharge apparatus as its center. In both procedures, however, the variation in thickness of different areas of the tube wall becomes very disturbing, since it causes x-rays proceeding in different directions to be absorbed to different degrees. However, it seems entirely feasible to equalize the thickness of the glass through which the rays pass by interposing thin glass plates.

The result of these experiments is that the radiation through an imaginary hemisphere with the platinum plate as its center is practically uniform almost to its very edge. Only when the angle of emission of the x-rays reached about 8o degrees could I detect the beginning of a decrease in the radiation, but even this decrease is still relatively small, so that the main variation in the intensity occurs between 89 and go degrees.

I have not been able to observe a difference in the kind of rays emitted a different angles.

On account of the described distribution of intensity of the x-rays, images from the platinum plate observed either upon the fluorescent screen or upon the photographic plate by means of a pinhole camera-or with a narrow slit--must be more intense the greater the angle between platinum plate and screen or photographic plate, provided that this angle does not exceed 8o degrees. I was able to confirm this conclusion by means of suitable arrangements which permitted comparisons of images obtained simultaneously

In optics we encounter in the case of fluorescence a similar distribution of intensity of emitted radiations. If one adds a few drops of fluorescein solution to water in a rectangular tank and if one illuminates the tank with white or violet light, one observes that the brightest fluorescence proceeds from the edges of the slowly dropping threads of fluorescein, that is, from those parts where the angle of emission of the fluorescent light is greatest. Mr. Stokes on the occasion of a similar experiment has already explained that this phenomenon is due to the fact that rays which excite fluorescence are absorbed to a much greater extent by the fluorescein solution than is the fluorescent light itself. Now it is most remarkable that also cathode rays, which produce x-rays, are absorbed by platinum to a much greater extent than are x-rays, and the postulate suggests itself that a relationship exists between the two phenomena-the transformation of light into fluorescent light and of cathode rays into x-rays. However, at present no definite evidence for such an assumption exists.

Also the observations on the intensity distribution of the rays emitted from the platinum plate have a certain significance with respect to the technic of producing shadow pictures with x-rays. According to the statements made previously it is advisable to place the discharge tube in such a position that the rays used to produce the picture leave the platinum at the greatest possible angle, although it should not be much greater than 80 degrees; in this way one obtains the sharpest picture possible, and if the platinum plate is very plain and if the tube has been constructed so that the oblique rays do not have to pass through a glass wall considerably thicker than do the rays that are emitted perpendicularly to the platinum plate, then the radiation falling upon the object in the described arrangement does not suffer a decrease in intensity.

screen placed perpendicular to the rays directly behind the material to that of the screen under identical conditions without interposition of the material. Specific transparency of a substance will be used to indicate the transparency relative to the unit thickness of the substance; this is equal to the *d*th root of the transparency when d is the thickness of the traversed layer measured in the direction of the rays.

Since my first communication I have used mainly the photometer described previously to determine the transparency. A plate of the substance to be investigated--aluminum, tin, glass, and so forth-was placed in front of one of two equally bright fluorescent halves of the screen, and the difference in the brightness thus produced was then matched, either by increasing the distance between the discharge apparatus and the uncovered half of the screen or by bringing the other one closer. In both cases the correctly determined ratio of the squares of the distances of the platinum plates of the discharge apparatus from the screen before and after adjustment of the apparatus represents the desired value for the transparency of the interposed substance. Both methods led to the same result. After adding a second plate to the first, one finds in the same way the transparency of that second plate to the *rays* that have already passed through the first.

The described procedure presupposes that the brightness of a fluorescent screen is inversely proportional to the square of the distance from the source of radiation, and this is only true if, first, the air does not absorb or emit any x-rays and, secondly, if the brightness of the fluorescent light is proportional to the intensity of the radiation for rays of the same kind. Now, the first condition certainly is not fulfilled, and it is doubtful whether the second one is; I therefore first 'convinced myself by experiments, as already described in paragraph 10 of my first communication, that

Considering the fact that x-rays are also emitted from irradiated substances, it should also be mentioned that, first, no difference could be detected with the photometer in the transparency of an aluminum plate, 0.925 mm thick, and of thirty-one aluminum foils, each 0.0299 mm thick stacked on one another‾31 times 0.0299 equals 0.927; and, secondly, that the brightness of the fluorescent screen was not noticeably different when the plate was placed directly in front of the screen or at a greater distance from it.

The result of these transparency experiments for aluminum is as follows:

Transparency to perpendicularly impinging rays	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 2**
Of the first s mm thick Al plate	0.40	0.45		0.68
Of the second s mm thick Al plate	0.55	0.68		0.73
Of the first 2 mm thick Al plate		0.30	0.39	0.50
Of the second 2 mm thick Al plate		0.39	0.54	0.63

From these experiments and from similar ones with glass and tin we arrive first at the following conclusion: If one assumes that the investigated substances are divided into layers of equal thickness, placed perpendicularly to the parallel rays, one sees that each of these layers is more transparent to the transmitted rays than the previous one, in other words: The specific transparency of a substance increases with its thickness.

This result is in complete agreement with what one observes on the photograph of a tinfoil ladder, as mentioned in paragraph 4 of my first communication, and used to wrap the plates, are sometimes very noticeable.

5. If two plates of different substances are equally transparent, this equality may not persist if the thickness of the two plates—but nothing else—is changed in the same ratio. This fact *may* be proved most simply with two scales, one of platinum and one of aluminum, placed side by side. For this purpose I used platinum foil, 0.0026 mm thick, and aluminum foil, 0.0299 mm thick. When I brought this double scale in front of the fluorescent screen or of a photographic plate and directed rays upon it, I found in one case, for example, that a single platinum layer was as transparent as a sixfold aluminum layer; however, the transparency of a twofold platinum layer was not equal to that of a twelvefold but to a sixteenfold aluminum layer. With another discharge tube I found that 1 platinum equals 8 aluminum and 8 platinum equals 90 aluminum. These experiments prove that the ratio of the thicknesses of platinum and aluminum of equal transparency is the smaller the thicker the respective layers are.

6. The ratio of the thicknesses of two equally transparent plates of different materials depends upon the thickness and the material of that substance-for instance, the glass wall of the discharge apparatus-that the rays must penetrate before they reach the respective plates.

In order to prove this conclusion-which is not unexpected according to statements made in paragraphs 4 and 5—one may use an arrangement that I call a platinum-aluminum window, which, as we shall see, is also useful for other purposes. It consists of a rectangular piece of platinum foil (4.0 cm by 6.5 cm), 0.0026 mm thick, which is glued to a thin paper screen and in which are punched 15 round holes, 0.7 cm in diameter, arranged in three rows. These little windows are covered with tightly fitting little disks of aluminum foil, 0.0299 mm thick, carefully stacked in such a

the second, and so forth, and finally fifteen disks in the fifteenth. If one places this arrangement in front of the fluorescent screen, one observes very clearly, particularly if one uses tubes that are not too hard (see below), the number of aluminum disks having a transparency equal to that of the platinum foil. This number will be called briefly the window-number.

In one case, when using direct radiation, I obtained the window-number 5; when a plate 2 mm thick made of ordinary soda glass was then interposed, the window-number obtained was 10; thus the ratio of the thicknesses of platinum and aluminum foil of equal transparency was reduced to one-half when I used rays that had passed through a glass plate 2 mm thick instead of rays that came directly from the discharge apparatus, q.e.d.

The following experiment should also be mentioned here. The platinum-aluminum window was laid on a small package containing twelve photographic films and was then exposed; after development the first film lying under the window showed the window-number 10, the twelfth the number 13, and the others in proper sequence all the steps from 10 to 13.

7. The experiments described in paragraphs 4, 5, and 6 refer to the changes that the x-rays emitted from a discharge tube undergo in passing through different substances. It will now be proved that for one and the same substance and the same thickness traversed the transparency may be different for rays emitted from different tubes.

For this purpose the values for the transparency of an aluminum plate 2 mm thick for rays produced in different tubes are given in the following table. Some of these values have been taken from the first table in section 4.

of evacuation of the gas content and in the discharge potential consequent to this; tube i requires the lowest, tube 5 the highest, discharge potential, or, as we shall say for the sake of brevity: Tube i is the softest, and tube 5 is the hardest. The same Ruhmkorff coil-directly connected to the tubes-, the same interrupter, and the same primary current were used in all cases.

All the many other materials that I investigated behave similarly to aluminum: All of them are more transparent to rays of a harder tube than to rays of a softer tube.' This fact seems to me worthy of special attention.

The ratio of the thicknesses of two equally transparent plates of different materials was also found to be dependent upon the hardness of the discharge tube used. One can recognize this immediately with the platinum-aluminum window (paragraph 5); using a very soft tube one obtains, for example, the window-number 2, while for very hard but otherwise identical tubes a scale, reading up to number 15, is not even sufficient. This means that the ratio of the thicknesses of platinum and aluminum of equal transparency is the smaller the harder the tubes are which emit the rays or-considering the result mentioned above-the less absorbable the rays are.

The different behavior of rays produced in tubes of different degrees of hardness is also evident, of course, in the familiar shadow pictures of hands, and so forth. Using a very soft tube one obtains dark pictures in which the bones are not very prominent; when a harder tube is used, the bones become clearly visible in all details, while the soft parts are weak in comparison, and with a very hard tube one obtains only weak shadows, even of the bones. From this observation one learns that the choice of the tube to be used must depend upon the nature of the object to be pictured.

8. It must also be mentioned that the quality of radiation

emitted from one and the same tube depends upon different circumstances. As the investigation with the platinum-aluminum window shows, this is influenced: (i) by the manner in which the Deprez or Foucault interrupters functions in connection with the induction apparatus, that is, by the course of the primary current. Here must be mentioned the frequently observed phenomenon that some of the discharges in rapid succession produce x-rays that are not only particularly intense but that also are distinguished from others by their absorbability. (2) By a spark gap connected in series in the secondary circuit of the discharge apparatus. (3) By inserting a Tesla transformer in the circuit. (4) By the degree of evacuation of the discharge apparatus (as was mentioned previously). (5) By various, not yet sufficiently understood, phenomena in the interior of the discharge tube. Several of these factors deserve to be discussed in a little more detail.

4. On the behavior of "non-normal" tubes see under 8.

5. A good Deprez interrupter functions more uniformly than a Foucault interrupter; the latter, however, makes better use of the primary current.

Transparency	Tube 1	Tube 2	Tube 3	Tube 4	Tube 2	Tube 5
For rays falling perpendicularly upon an aluminum plate 2 mm thick	0.0044	0.22	0.30	0.39	0.50	0.59

If we take a tube that has not yet been used nor even evacuated and connect it to the mercury pump, we shall noticed by a feeble light on a nearby fluorescent screen. A spark gap connected in parallel with the tube registers sparks a few millimeters in length, the platinum-aluminum window shows very low numbers, and the rays are very absorbable. The tube is "very soft." Now if a spark gap in series or a Tesla transformer is inserted,' more intense and less absorbable rays are produced. I found for instance in one case that by increasing the spark gap in series the window-number could gradually be brought from 2.5 up to 10.

(These observations prompted me to wonder whether x-rays might not be obtainable even at still higher pressures by using a Tesla transformer. This is indeed the case: Using a narrow tube with wire-shaped electrodes I could still obtain x-rays when the pressure of the enclosed air amounted to 3.1 mm of mercury. If hydrogen was used instead, the pressure could even be higher. I was not able to determine the lowest pressure at which x-rays can still be produced in air; at any rate, it lies below 0.0002 mm of mercury, so that the range of pressures within which x-rays may altogether be produced is already now a very large one.)

> > > 6. That a spark gap connected in series acts similarly to a Tesla transformer I was able to point out in the French edition of my second communication (*Archives des Sciences Physiques,* etc., de Genève, 1896); in the German publication this comment was omitted by an oversight.

As a result of further evacuation of the "very soft" tube—connected directly to the induction coil—the radiation becomes more intense, and a larger percentage of it passes through the irradiated material: A hand held in front of the fluorescent screen is more transparent than before, and higher window numbers are obtained with the

connected in parallel must be increased in order to let the discharges pass through the tube: The tube has become "harder." If one evacuates the tube still more, it becomes so "hard" that the spark gap must be increased to beyond 20 cm, and now the tube emits rays to which the materials are exceedingly transparent: Heavy iron plates 4 cm thick, when investigated with the fluorescent screen, were still found to be transparent.

The behavior of a tube on the mercury pump connected directly to the induction coil, as described above, is normal, but deviations from this norm, which are caused by the discharges proper, occur frequently. Sometimes the behavior of the tubes is altogether unpredictable.

We have thought that the hardening of a tube is produced by continued evacuation with the pump, but it may also occur in a different way. A medium hard tube that has been sealed off the pump will gradually become harder by itself —unfortunately, as regards the duration of its usefulness—even when it is used correctly for producing x-rays, that is, when discharges are passed through it that do not or only faintly cause the platinum to glow. A gradual self-evacuation takes place.

With such a tube that had become very hard I obtained a very beautiful photographic shadow picture of the double barrel of a hunting gun with cartridges in place, in which all details of the cartridges, the internal faults of the damask barrels, and so forth, could be recognized very distinctly and sharply. The distance between the platinum plate of the discharge tube and the photographic plate was 15 cm, the time of exposure twelve minutes-which is comparatively long because of the smaller photographic effect of the less absorbable rays (see below). The Deprez interrupter had to be replaced by the Foucault interrupter. It would be interesting to construct tubes permitting the use of still higher discharge potentials than has been possible thus far.

The reason for the hardening of a tube that had been sealed off the pump was given above as self-evacuation caused by discharges; however, this is not the only cause, since changes taking place on the electrodes also have the same effect. What they consist of, I do not know.

A tube that has become too hard can be made softer by admitting air, sometimes also by heating the tube or reversing the direction of the current, and finally by sending very strong discharges through it. In the last case, however, the tube has for the most part acquired other properties than those described above: It sometimes requires, for example, a very high discharge potential and yet emits rays of a relatively low window-number and great absorbability. I do not wish to discuss further the behavior of these "nonnormal" tubes.-The tubes constructed by Mr. Zehnder with an adjustable vacuum, since they contain a small piece of charcoal, have been very serviceable to me.

The observations described in this paragraph and others have led me to the conclusion that the composition of the rays emitted from a discharge tube equipped with a platinum anode depends primarily upon the duration of the discharge current. The degree of evacuation, the hardness, plays a role only because the form of discharge current depends upon it. If one is able to produce that form of discharge which is necessary for the production of x-rays by any form whatever, x-rays can also be produced even for relatively high pressures.

Finally it is worth mentioning that the quality of the rays produced by a tube is either not at all or only slightly changed when the strength of the primary current is altered considerably, provided that the interrupter functions the same in all cases. On the contrary the intensity of the x-rays is found to be proportional within certain limits to the strength of the primary current, as is demonstrated by the following experiment. The distances from the discharge

barium platinocyanide screen was barely noticeable amounted to 18.1 m, 25.7 m, and 37.5 m when the strength of the primary current was increased from 8 to 16 to 32 amp. The squares of those distances are in nearly the same ratio as the corresponding currents.

9. The results described in the last five paragraphs were obtained directly from the respective experiments mentioned above. If one surveys the sum of these individual results, one arrives, partly guided by the analogy that exists between the behavior of optical rays and x-rays, at the following impressions:

(a) The radiation emitted from a discharge apparatus consists of a mixture of rays of different absorbability and of different intensity.

(b) The composition of this mixture depends essentially upon the time relationship of the discharge current.

(c) The rays which are selectively absorbed by various substances differ for different materials.

(d) Since x-rays are produced by means of cathode rays and since both have common properties—such as production of fluorescence, photographic and electrical effects, and absorbability, the amount of which depends essentially upon the density of the irradiated material, and so forth—, the hypothesis is suggested that both phenomena are processes of the same nature. Without being willing to adhere unconditionally to this view I may state that the results in the last paragraphs tend to remove one difficulty which was opposed to that hypothesis. This difficulty exists on one hand in the great difference between the absorbability of the cathode rays studied by Mr. Lenard and that of the x-rays and, secondly, in the fact that the transparency of these substances for cathode rays follows a law in relation to the density of the substance other than

With respect to the first point, two facts should be considered. (1) We have seen in paragraph 7 that there are x-rays varying greatly in absorbability, and we know from the investigations of Hertz and Lenard that the different cathode *rays* also differ from each other in their absorbabilities; thus if the "softest tube" mentioned in paragraph 7 produced x-rays whose absorption does not in any way approach that of the cathode rays investigated by Mr. Lenard, there exist without doubt x-rays of still greater and, on the other hand, cathode rays of still smaller absorbability. It therefore seems entirely possible that in further experiments rays may be found which, as far as their absorbability is concerned, form a link between one type of ray and the other. (2) We found in paragraph 4 that the thinner the layer of an irradiated substance is the smaller its specific transparency. Consequently, if we had used in our experiments plates as thin as those of Mr. Lenard, we might have found values for the absorption of the x-rays that would have been nearer those of Lenard's.

With regard to the different influences of the, density of substances upon their absorption of x-rays and of cathode rays, it must also be stated that this difference is found to be the smaller the more easily absorbable the x-rays for this experiment are (paragraphs 7 and 8) and the thinner the irradiated plates (paragraph 5). Consequently the possibility must be admitted that this difference in the behavior of the two types of radiation, as well as the one mentioned previously, may be made to disappear by further experimentation.

Nearest in their absorbability are the cathode rays produced especially in very hard tubes and the x-rays, preferably emitted from the platinum plate, in very soft tubes.

10. In addition to exciting fluorescence x-rays also exert, as

and it is of interest to know to what degree these run parallel if the source of radiation is altered. I had to confine myself to a comparison of the two first mentioned effects.

The platinum-aluminum window is again very useful for this purpose. One of these was placed upon a wrapped photographic plate, a second was put in front of the fluorescent screen, and then both of them were placed at equal distances from the discharge apparatus. The x-rays had to traverse exactly the same media in order to reach the sensitive layer of the photographic plate and the barium platinocyanide. During the exposure I observed the screen and determined the window-number; after the photographic plate was developed, the window-number was also determined on it, and then both numbers were compared. As a result of such experiments no difference was observed when softer tubes were used (window-numbers 4 to 7); when using harder tubes it seemed to me as if the window-number on the photographic plate was slightly lower, but at most only one unit, than that determined with the fluorescent screen. However, this observation, although confirmed repeatedly, is still not entirely incontestable, since the determination of the high window-number on the fluorescent screen is rather uncertain. Absolutely certain, however, is the following result. If with the photometer described in paragraph 2 one adjusts a hard and a soft tube so as to produce equal brightness on the fluorescent screen and if one then substitutes a photographic plate for the screen, one observes, after the plate is developed, that that half which has been irradiated by the hard tube is considerably less darkened than the other half. The radiations which produce equal intensity of fluorescence have different photographic effects.

In judging this result one must not fail to consider that neither the fluorescent screen nor the photographic plate completely utilizes the impinging rays; both transmit many ordinary thickness of the sensitive photographic layer and of the layer of barium platinocyanide.

How very transparent the sensitive layer of the photographic plate is even for x-rays from tubes of medium hardness is proved by an experiment in which 96 films, one laid on top of the other, were placed 25 cm from the source of radiation and exposed for five minutes, the whole being protected against radiation from the air by a lead cover. A photographic effect can be clearly recognized even on the last one of them, while the first is hardly overexposed. Induced by this and similar observations I asked several manufacturers of photographic plates whether it might not be possible to produce plates that would be more adapted to photography with x-rays than the ordinary ones. The samples obtained, however, were not serviceable.

I have had many opportunities, as already mentioned in paragraph 8, to notice that very hard tubes require a longer time of exposure than medium hard ones under otherwise identical conditions; this is understandable if one remembers the result mentioned in paragraph 9, according to which all examined substances were found to be more transparent to rays emitted by hard tubes than to those emitted by soft tubes. That even with very soft tubes a long exposure is again required may be explained by the smaller intensity of the rays emitted by them.

If the intensity of the rays is increased by increasing the primary current (see paragraph 9), the photographic effect is increased in the same degree as is the intensity of the fluorescence; in this as well as in the case discussed previously, in which the intensity of the radiation of the fluorescent screen was altered by changing the distance of the screen from the source of radiation, the brightness of the fluorescent screen might be—at least approximately —proportional to the intensity of the radiation. A general

11. In conclusion may I be permitted to mention the following details. In a properly constructed, not too soft, discharge tube the x-rays are emitted principally from a point I to 2 mm large at which the platinum plate is struck by the cathode rays; however, this is not the only point of emission: The whole plate and a part of the wall of the tube emit x-rays, although to a much smaller extent.

Cathode rays really travel from the cathode in all directions; but their intensity is significant only near the axis of the concave mirror, and therefore the most intense x-rays are produced at the point where the axis meets the platinum plate. If the tube is very hard and the platinum thin, a considerable quantity of x-rays is also emitted from the rear of the platinum plate and, as the pinhole camera shows, again mostly from a point lying on the mirror axis.

Also in these hardest tubes the maximum intensity of the cathode rays could be deflected from the platinum plate by a magnet. Some experiences with soft tubes led me to investigate once more and with better instruments the question of the magnetic deflection of x-rays; I hope to be able to report on these experiments soon.—

I have continued the experiments mentioned in my first communication on the transparency of equally thick plates cut from a crystal according to different directions. Plates of calcite, quartz, tourmaline, beryl, aragonite, apatite, and barite were examined. Again no influence of the direction upon the transparency could be detected.—

The fact observed by Mr. G. Brandes that x-rays can produce a light sensation in the retina of the eye, I have confirmed. In my record book there is also a note, written at the beginning of November 1895, according to which I noticed in a completely darkened room near a wooden door, on the other side of which a Hittorf tube was placed, a [illegible] vision when discharges were sent through the tube. Since I observed this phenomenon only once, I thought it was subjective; the reason that I did not see it again lies in the fact that later on, other less evacuated tubes without platinum anodes were used instead of the Hittorf tubes. The Hittorf tube because of its high evacuation produces rays of small absorbability and because of its platinum anode, which is struck by cathode rays, produces very intense rays, all of which favors the production of the sensation of light as mentioned above. I had to replace the Hittorf tubes with others because all of them were punctured after a very short time.

With the hard tubes now in use the Brandes experiment may be easily repeated. A description of the following experimental procedure is perhaps of some interest. If one holds a vertical metal slit, a few tenths of a millimeter wide, as close to the open or closed eye as possible, and if one then holds the head, enveloped in a black cloth, near the discharge apparatus, one observes after some practice a weak and not uniformly bright strip of light, which according to the position of the slit in front of the eye has a different shape: straight, curved, or circular. By a slow motion of the slit in a horizontal direction one can progressively make these forms pass into one another. An explanation of this phenomenon is easily found if one considers that the eyeball is intersected by a laminated beam of x-rays, and if one assumes that x-rays can produce fluorescence in the retina.—

Since the beginning of my work with x-rays I have made repeated efforts to obtain diffraction phenomena with these rays; several times when using narrow slits, and so forth, I also obtained phenomena whose appearance recalled diffraction patterns, but when the conditions of the experimental arrangements were altered in order to check the correctness of the explanation of these images as being in a manner entirely different from diffraction. I cannot recall one experiment on the basis of which I could safely be convinced of the existence of diffraction of the x-rays.

Würzburg, Physik. Institut der Universität.
March 10, 1897