THE DISCHARGE OF

ELECTRICITY IN GASES

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PREFACE

THE discoveries made during the last fifty years concerning the discharge of electricity through gases and the determination of the close relationship between the phenomena of this discharge and the recently studied properties of the radioactive substances have opened new fields for experiment and speculation.

The prediction of Faraday, that the study of the electrical discharge in gases might eventually lead us to a more thorough understanding of the nature of matter and electricity, is being gradually realized. Thus the existence in the chemical atom of much smaller particles, which propably are the same in all substances may now be looked upon as an established fact. The structural character of electricity also is, at the present day, more than a mere hypothesis.

Moreover this discharge has already proved of more than purely scientific interest. The mere mention of the mercury-arc lamp and of the mercury-arc alternating-current rectifier will be enough to show the practical use now made of some of the properties discovered The mercury-arc rectifier, which has been put on the market quite recently, bids fair to take a very prominent place among rectifying devices on account of its efficiency and convenience in handling.

To Professor Daniel W. Shea I desire to acknowledge my indebtedness and express my sincerest gratitude for his indispensable assistance and able direction in the study of the bewildering amount of literature on this subject. I also gratefully acknowledge my obligations to Professor Jno. J. Griffin for the instruction received in the department of Chemistry.

gradual changes that take place in the electric discharge as the pressure of the air decreases. At normal pressure, the electric strain may be released in two different ways:—if the distance between the electrodes is not too great for the available potential, the spark discharge occurs; in this discharge itself the spark proper and the discharge through the surrounding electrified air have to be distinguished; if the distance between the electrodes is increased the sparking becomes less frequent and is accompanied by a brush discharge, till the latter finally becomes the only noticeable phenomenon.

If the electrodes are inclosed in a vessel from which the air may be exhausted, the phenomena are the same as those described above as long as the pressure is not reduced below a definite value. After this there is a gradual change in the character of the discharge. The brush disappears and a luminous "Stream Discharge" reaching from one pole to the other sets in. If the pressure is lowered still more, a bluish glow first appears at the kathode and a pinkish light then begins to surround the anode. This light gradually extends towards the kathode though it never reaches the negative light. This last mentioned phenomenon was styled by Faraday the "Dark Discharge" owing to the dark space that always separates the two lights. Here is his own description of this interesting discovery:—(1) "I will now notice a very remarkable circumstance in the luminous discharge accompanied by negative glow, which may, perhaps,be correctly traced hereafter into discharges of much higher intensity. Two brass rods, 0.3 of an inch in diameter, entering a glass globe on opposite sides, had their ends brought into contact, and the air about them very much rarefied. A discharge of electricity from the machine was then made through them, and whilst that was continued the ends were separated from each other. At the moment of separation a continuous glow came over the end of the negative rod,

(1) l. c. p. 490, No. 1544.

the positive termination remaining quite dark. As the distance was increased, a purple stream or haze appeared on the end of the positive rod, and proceeded directly outwards towards the negative rod; elongating as the interval was enlarged, but never joining the negative glow, there being always a short dark space between. This space of about one tenth or one twentieth of an inch, was apparently invariable in its extent and position relatively to the negative rod; nor did the negative glow vary. Whether the negative end were inductric or inducteous, the same effect was produced. It was strange to see the positive purple haze diminish or lengthen as the ends were separated, and yet this dark space and the negative glow remain unaltered."

Faraday had never carried his vacuum very high. The idea of studying the discharge at the lowest obtainable pressure naturally suggested itself. Masson (1) attempted to pass an electric discharge through a barometric vacuum but failed to obtain any results, whence he concluded to the non-conductivity of an absolute vacuum. In a later paper (2) he brought further proof for this opinion. The first one to remark the resolution of the positive light into layers was W. R. Grove (3) who had also noticed the dark space observed by Faraday and had discovered, in addition, that under certain circumstances the latter may disappear. Quet (4) obtained the same striation of the positive light and described anew the different phenomena of the discharge, showing that it was disruptive and that it was possible to effect a complete disappearance of the positive light for a certain distance of the electrodes.

B. VALVE-TUBE AND FUNNEL TUBE.

The study of the elctric discharge in rarefied gases was given

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(1) C. R. 7, p. 671. Pogg. Ann. 46 pp. 487. 39.
(2) Ann. de Ch. et de Phys. 15, p. 486. 1868.
(3) Phil. Trans. 1852. Pogg. Ann. 93. p. 492. 1854.
(4) Pogg. Ann. Ergzb. 4. p. 507. 1854.

a greater impetus by the advent of M. Gaugain (1) who discovered that in a vacuum-tube with two electrodes whose sizes are very unequal, a current is transmitted in one direction much more easily than in the other. He called this tube "œuf-soupape" or "soupape électrique", from its valve-like action. According to his view, the closing current of an induction coil was always allowed to pass with much greater ease than the opening current. He also studied the nature of the layers and concluded that they are a phenomenon of matter.

Gaugain's views regarding the real nature of the occurrences in his valve-tube were challenged by P. Riess, who showed, in a series of papers, (2) that the phenomenon was to be traced to the direction of the current and not to the fact that it was either an opening or a closing current. He formulated the law that an induced current after traversing the valve-tube, deflects a magnet in the same manner as a current flowing from the large to the small electrode, or in other words, that the resistance offered by the tube is greater for currents which make the small electrode their anode than for those in which the anode is the larger surface. The same subject was studied by Feddersen (3) and Knochenhauer, (4) neither of whom found results favoring Gaugain's views.

Another form of tube resembling the previous one in its effects is what is known as the "Funnel-tube", namely, a vacuum-tube divided into several compartments by funnel-shaped obstructions which leave only a narrow opening between the several parts. These tubes were first made by Geissler in 1858 and subsequently perfected by Holtz. The nature of the effects occurring in them was studied by J. C. Poggendorff. (5) But

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(1) C. R. 40. p. 640, & Pogg. Ann. 95 p. 163. 1855.
(2) Pogg. Ann. 96. p. 177. 1835. 120, p. 513, 1863. 136, p. 31, 1869.
(3) Pogg. Ann. 115, p. 336, 1862.
(4) Pogg. Ann. 126, p. 228, 1866. 129, p. 78, 1866.
(5) Pogg. Ann. 134, p. 1. 1868.

before giving the results of his investigations, it may be well to mention that, in 1859, J. Pluecker (1) had noticed the peculiar behavior of obstructions in a tube, producing what he called "recurring currents". He again touched upon the same subject in 1861, (2) stating that if the current flows from a wider to a narrower part, there is a partial recurring of the current towards the anode. Poggendorff found that these tubes also offer a greatly different resistance with different connections: the resistance is always smaller when the points of the funnels are directed towards the anode. At the end of these same points there appeared a dark space from which a cone of light extended in the direction of the next funnel. From these several observations it became clearly evident that the funnel points were behaving somewhat like a kathode. With the aid of this tube Poggendorff detected a peculiar influence exerted by a rise of temperature on the striation of the positive light: namely that if one of the central compartments was heated, the striae of the adjoining compartments increased in number and brilliancy. The explanation of this phenomenon would present no difficulty were it not for the fact that it persisted for weeks, even after the cooling of the tube in ice.

C. STRIATION.

During this period a certain amount of attention was also devoted to the conditions giving rise to striation. As we have already noted the pioneer observer of the phenomenon was W. R. Grove. V. S. M. Van der Willigen (3) was the first to produce it by means of the influence-machine both with and without a condenser in circuit, (4) thus removing one more of the supposed differences between frictional and induced electricity.

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(1) Pogg. Ann. 107, p. 87. 1859.
(2) Pogg. Ann. 116, p. 29, 1861.
(3) Pogg. Ann. 98, p. 494, 1856. 99, p. 175, 1856.
(4) Pogg. Ann. 113, p. 511, 1861.

It was learned that striation was brought about by the insertion of a resistance (1) into the outer circuit; which resistance might be that of an air-gap, a metallic resistance, a wet twine, etc. Striation was also influenced by the application of heat, by mere touching of the tube and by connecting one of the electrodes with the earth. (2) The distance between the striae was shown to be some function of the diameter of the tube (3) and of the pressure therein. (4) All these observations about striation refer to the positive light, but it must be noted that some striation was also observed in the negative glow. (5)

D. INFLUENCE OF A MAGNET ON THE ELECTRIC DISCHARGE.

In 1849, A. De la Rive (6) noticed that if one of the electrodes of a vacuum-tube was magnetised, the electric light rotated around the pole of the magnet. This interesting and suggestive discovery seems to have passed unobserved. Several years later, the fact that a magnet does really exert some influence on the electric discharge was again discovered by J. Pluecker, (7) who found that the general behavior of the electric light under the influence of a magnet is apparently similar to that of a wire carrying a current and free at one end. The behavior of the positive light is different from that of the negative:—while the former is brought together into a cone, the latter rotates around a magnetic curve. If the tube is subjected to the influence of a magnet of sufficient strength, the positive light may be bent back towards the anode, causing a negative glow to appear at

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(1) Paalzow, Pogg. Ann. 112, p. 567, 1861. Poggendorff, Pogg. Ann. 134, p. 17, 1868. Holtz, Poog. Ann. 170, p. 555, 1878.

(2) Poggendorff, Pogg. Ann. 134, p. 43, 1868. P. Riess, Pogg. Ann. 104, p. 321, 1858.

(3) Pluecker, Pogg. Ann. 103, p. 101, 1858.

(4) Waltenhofen, Pogg. Ann. 126, p. 527, 1865.

(5) J. Pluecker, Pogg. Ann. 103, p. 92, 1858.

(6) Pogg. Ann. 104, p. 129, 1858.

(7) Koelnische Volksztg. July 22, 1857. Pogg. Ann. 103, p. 88, 1858.

the latter. (1) De la Rive (2) again called attention to his early experiments and repeated them. He also ascertained (3) that under the influence of a magnet the layers in the positive light become more brilliant and that the so-called dark space (4) may be made luminous. Generally the magnet was found to increase the resistance in the tube.

F. SPECTROSCOPIC STUDY OF THE LIGHT IN VACUUM-TUBES.

The discovery by J. Pluecker (5) in 1858 of the fact that each gas gives a special spectrum when fluorescing under the influence of the electric discharge in a vacuum-tube, created a new branch in spectrum analysis. This discovery, as its author himself foresaw, was to prove of great technical and scientific usefulness. The first scientific conclusion he deducted from it was the non-luminosity of the electric discharge through rarefied gases, the light being entirely due to ponderable matter under the influence of the current. (6) The difference between the spectra of the same gas near the kathode and the anode was described by F. W. Dove. (7) These spectra were studied by Van der Willigen, (8) Waltenhofen (9) and many others, but most of the work is only incidentally connected with this subject.

G. FACTORS OF THE DISCHARGE.

PRESSURE AND CURRENT.—Gaugain (10) remarked an increase

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(1) Pogg. Ann. 107, p. 77, 1859.
(2) Pogg. Ann. 104, p. 129, 1858.
(3) Ann. de Ch. et de Phys. 10, p. 159, 1867.
(4) Ann. de Ch. et de Phys. 20, p. 103, 1870
(5) Pogg. Ann. 104, p. 113, 1858.
(6) Pogg. Ann. 107, p. 497, 1859.
(7) Pogg. Ann. 104, p. 184, 1858.
(8) Pogg. Ann. 106, p. 526, 1859.
(9) Pogg. Ann. 126, p. 535, 1865.
(10) C. R. 40, p. 640.

of current coinciding with an increase of vaccum. A. Morren (1) made a more careful study of this subject and learned that the relation between current-intensity and gas-pressure was not a simple one. The curve which would represent this relation (pressure being represented along the X-axis, and current on the Y-axis) would, with high but decreasing pressures, at first rise very slowly till the gas pressure had reached as low as 2-4 mm, according to the nature of the gas; with a further decrease of pressure the curve would rise very rapidly up to a maximum which occured at about 0.7-1mm, after which it would again quickly decrease.

DISCHARGE POTENTIAL.—In 1834 Harris (2) had shown that the quantity of electricity required to obtain a discharge in rarefied air varied directly as the distance between the electrodes for a determined gas pressure and also directly as the gas pressure for a given distance between the electrodes. From this he concluded that the smallest charge could not be retained on a conductor in a sufficiently high vacuum. Matteucci (3) accepted the same theory. But in 1839 Masson (4) failed in his attempts to produce a discharge through a high barometric vacuum. Gassiot also obtained vacua which did not allow the discharge of an induction coil, hence the conclusion already drawn by Faraday that a perfect vacuum was a perfect non-conductor seemed to be justified. The relation between the gas pressure and the discharge potential was investigated more thoroughly by Waltenhofen (5) who demonstrated that this potential depended not only on the pressure of the gas but also on the nature and the shape of the electrodes. From his several experiments he con-

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(1) Ann. de Ch. et de Phys. IV, 4, p. 325, 1865.
(2) Phil. Trans. p. 243, 1834.
(3) Ann. de Ch. et de Phys. III, 28, p. 385, 1850.
(4) C. R. 7, p. 671.
(5) Pogg. Ann. 126, p. 527, 1865.

cluded that for very high vacua, a high potential is required only to start the discharge and not to maintain it. On the strength of this he advanced the theory that the electric discharge could really be propagated through vacua which are considered as perfectly impervious to electricity, thus rejecting the several proofs adduced in support of the hypothesis that a perfect vacuum was a non-conductor. Karl Schultz (1) also observed a minimum of discharge potential for certain gas pressures, above and below which the required potential rises slowly at first but with a gradually increasing velocity. He also investigated the effect of the dimensions of the tube on the discharge potential and found that the latter increases as the cross-section decreases and that it becomes greater as the length of the air column increases for all pressures above 1 mm. Below these pressures the discharge potential does not seem to be influenced by the length of the tube.

A. De la Rive (2) noticed the different changes of temperature near the kathode and the anode, but this manifestation of energy was studied more closely by Poggendorff. (3) In the Bakerian lecture of 1858, J. P .Gassiot (4) also alluded to the special development of heat at the kathode and attributed it to the overcoming of a large resistance near this electrode. As a further proof of the presence of this large resistance he brought forward the fact that metal is projected from the surface of the kathode, i. e. the so-called "Zerstaeubung".

H. EFFECTS OF THE DISCHARGE.

The strong green or blue fluorescence caused on glass under certain circumstances was observed by J. Pluecker (5) and P.

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(1) Pogg. Ann. 135, p. 249, 1868.
(2) Ann. de Ch. et de Phys. 8, p. 437, 1866.
(3) Pogg. Ann. 138, p. 642, 1869.
(4) Pogg. Ann. 119, p. 131, 1863.
(5) Pogg. Ann. 103, p. 88, 1858. -104, p. 113, 1858.

Riess (1) and attributed by them to the negative light. Pluecker also noticed that whenever the negative light was brought to the walls of the tube it produced this vivid fluorescence. Another curious and important phenomenon of fluorescence was described by H. W. Dove, (2) namely, that uranium glass and barium-platinum cyanide fluoresced intensely when placed in close proximity to the tube. Had he examined more deeply into the nature of the phenomenon, it can hardly be doubted that he would have anticipated the discovery subsequently made by W. Roentgen, because this fluorescence was in all probability an effect of the X-rays.

In some tubes constructed by Geissler, the gas still retained some fluorescence or "after-glow" after the discharge had been stopped. This peculiar effect was extensively studied during this period. The first to offer an explanation was E. Becquerel, (3) who assigned the presence of oxygen as the cause of the phenomenon. Riess (4) ascribed it to sulphuric acid gas. H. Wild (5) believed it was produced by the oxidation of sulphur after the discharge. A. Morren (6) attacked Becquerel's opinion and showed that pure oxygen would not give any after-glow; he found that if oxygen contained but slight traces of nitrogen it would fluoresce. E. Sarazin (7) attributed the after glow to chemical causes, and particularly to the formation of ozone. From his experiments, he thought himself justified in concluding that no other gases but pure oxygen and oxygen-compounds are able to give this fluorescence. This same view was confirmed by A. De la Rive, (8) in whose laboratory most of Sarazin's experiments had been performed.

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(1) Pogg. Ann. 104, p. 321, 1858.
(2) Pogg. Ann. 113, p. 511, 1861.
(3) C. 48, p. 404, 1859.
(4) Pogg. Ann. 110, p. 523, 1860.
(5) Pogg. Ann. 111, p. 621, 1860.
(6) C. R. 53, p. 794, 1865.
(7) Ann. de Ch. et de Phys. 17, p. 501, 1869.—19, p. 191, 1870.
(8) Ann. de Ch. et de Phys. 19, p. 191, 1870.

Two more effects of the discharge brought to light during this period deserve to be mentioned:—

1) Its effect on a photographic plate. This was discovered by H. W. Dove in 1861. (1) The fact that he obtained a well defined shadow of a piece of uranium glass shows that he had no ordinary light effect.

2) The fact that as the discharge continues through a gas, the latter becomes more rarefied. (2) This change of vacuum was attributed to a combination of oxygen with other gases or solids in the tube.

(1) Pogg. Ann. 113, p. 511, 1861.
(2) Pluecker, Pogg. Ann. 105, p. 67, 1858.

CHAPTER II.

SECOND PERIOD.— FROM HITTORF TO LENARD.

The publication in 1869 of W. Hittorf's first paper on the electrical conductivity of gases (1) may be rightly looked upon as the beginning of a new period in the study of this subject. Heretofore there had been more or less casting about and a lack of definiteness; but henceforth a more systematic study of the discharge of electricity through gases was instituted. Observations were more accurate, new facts were discovered, their theoretical bearing was discussed and a successful attempt was made to analyse some of the more complicated phenomena. All this was due mainly to the efforts of such men as W. Hittorf, E. Goldstein, the two Wiedemanns, Sir W. Crookes, J. J. Thomson and several others.

I.— W. HITTORF.

Faraday had already described the appearance of the electric discharge in rarefied gases. Although many experimenters intervened between him and Hittorf, the latter may be looked upon as continuing the former's work, for he prefaced his first paper by an extensive extract from Faraday's Experimental Researches and then pursued his own investigations on similar lines but under more favorable conditions. These allowed him to get a higher E. M. F. and higher vacua, thanks to the improvements made in the Rhumkorff coil and

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(1) Pogg. Ann. 136, p. 1, 1869.

the mercury pumps constructed by Geissler. By the aid of these new appliances, he noted (1) that as the gas pressure became lower than 2mm of mercury, there was a rapid change in the phenomena observed by Faraday. The glow on the kathode soon extended itself not only over greater portions of this electrode but also throughout the surrounding space driving back all the while the reddish light towards the anode. Both lights became striated with a concavity towards the positive pole. But in the mean time the three parts of the discharge noted by Faraday, namely, the positive light, the dark space and the negative glow still remained in the tube. While the number of striae in the positive light was variable, depending on the size of the tube, the quantity of available electricity, the nature and pressure of the gas, etc., the layers in the negative light on the other hand exhibited a remarkable constancy. They were always three in number. Directly on the kathode there appeared a narrow band of light which sometimes was very faint; beyond this there was a still darker but well defined band, which is now called the Hittorf or kathode dark space; at the end of this band begins what is called more particularly the negative light or glow.

It may be noted here that the kathode dark space has been called by some writers the "dark space" without any further specification; this is misleading as the term was first and still is generally applied to the region between the positive and the negative light.

At the highest vacua obtainable by Hittorf during this period, the positive light disappeared completely and the negative glow filled the whole tube. A very important characteristic of this negative light is its rectilinear propagation in a direction normal to the surface of the kathode, the position of the anode exercising no influence on its path. This property was aptly

(1) Pogg. Ann. 136, p. 6, 1869.

illustrated by a tube wherein the kathode pointed away from the anode, in which case the negative light travelled directly to the end of the tube opposite the positive pole. By placing a solid or liquid in the path of this light, a well defined shadow was thrown on the opposite wall of the tube, whence Hittorf concluded that the path of the glow was bounded by any solid which it happened to strike and that there was never any deviation from the rectilinear transmission. (1) This statement concerning the ending of the negative light on striking any solid was considerably modified by later experimenters: by E. Goldstein (2) and H. Hertz (3) in particular.

Another property of this negative light which has been very important in the study of the subject is its power to produce fluorescence on substances which may fluoresce under the influence of light. Thus if this negative glow is brought to the walls of the tube there is a vivid fluorescence; the color of the latter is bluish for lead glass and a very bright green for sodium glass. The light may be brought to the walls of the tube in several ways:—by giving the kathode such a shape or position as will lessen the distance from the walls to its surface, by evacuating to such a degree as will allow the negative light to fill the whole tube or, finally, by subjecting the tube to the influence of a magnet. Hittorf found that in this last case the negative light behaves like a stream of negatively electrified particles moving from the kathode to the anode.

Besides noting these general facts he made quantitative experiments to investigate the conditions prevailing in the tube. He first studied the conductivity of the gas and reached the conclusion (4) that the maximum of conductivity does not

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(1) Pogg. Ann. 136, p. 8, 1869.
(2) Wied. Ann. 11, p. 832, 1880.
(3) Wied. Ann. 45, p. 28, 1892.
(4) Pogg. Ann. 136, p. 30, 1869.

depend on the gas-pressure alone but also on the dimensions of the tube and the shape of the kathode. The conductivity increased until the pressure had been reduced to a certain value beyond which it decreased rapidly. In fact he was able to reach vacua through which the highest E. M. F. then at his command could not send an electric current. The source was a 42 cm. coil, which was put at his disposal in Paris. But he soon discovered that the conductivity was not uniform throughout the different parts of the tube. He was able to state that with decreasing gas-pressure, the resistance in the positive layers diminishes, while that in the kathode light and particularly that near the kathode increases. The application of heat to the kathode decreases this resistance very sensibly: thus, if this electrode was heated to white heat a few Bunsen cells were enough to maintain a constant current through a highly evacuated tube. (1)

The negative light itself also greatly increases the conductivity of a gas not only in the direction of its propagation but also in all other directions. (2)

The current-intensity likewise has an effect on conductivity. Hittorf (3) ascertained that the conductivity of a gas varies proportionately to the current-intensity and, in a later paper, (4) he stated more particularly that in the positive light the conductivity increases proportionately to the intensity of the current for a constant gas-pressure. Studying the fall of potential in the tube, he found that the difference of potential between any two cross-sections of the positive light does not depend on the current-intensity. (5)

The fall of potential at the kathode is always very great. (6)

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(1) Wied. Ann. 21, p. 90, 1884.
(2) Wied. Ann. 7, p. 553, 1879
(3) Wied. Ann. 7, p. 622, 1879.
(4) Wied. Ann. 20, p. 705, 1883.
(5) Wied. Ann. 20, p. 705, 1883.
(6) Wied. Ann. 21, p. 90, 1884.

This great potential-gradient is accompanied by an excessive heating effect on the kathode, causing the so-called "Zerstaeubung" of the latter. Hittorf even performed some experiments to show that this heat is sufficient to account for the rotation of the Crooke's radiometer.

II.— E. GOLDSTEIN.

Hittorf had generally used the term "Glimmlicht", (which may be rendered by "Negative glow" or "light") in connection with the main phenomenon which he studied in rarefied gases. By this he meant an action which is propagated from the kathode in the nature of a ray; "strahlenartig". (1) E. Goldstein calls the same phenomenon the electric ray of the kathode light, "der elektrische Strahl des Kathodenlichtes", (2) and later,simply "the kathode rays," which name passed into general use. He found that Hittorf's statement viz. that the kathode rays ended wherever a solid was put in their path, had to be modified. The kathode rays, under these circumstances, do not merely end and produce fluorescence but they are "differentiated", (3) this differentiation taking place both at the substances which did and those which did not fluoresce.

Allowing kathode rays to impinge on one of these non-fluorescing substances afforded the most convenient method of studying this new kind of rays or this modification of the primary kathode radiation. The path of the new ray is rectilinear and it forms every possible angle with the surface from which it issues. The modified ray ressembles the more refrangible light not only in its rectilinear propagation but also by its power of exciting fluorescence. This was shown by several interesting experiments, for instance:—a beam of parallel kathode rays was allowed to enter a tube sufficient in

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(1) Pogg. Ann. 136, 223, 1769.
(2) Wied. Ann. 11, p. 833, 1880.
(3) Wied. Ann. 11, p. 833, 1880.

length to prevent the rays from reaching its farther end. No fluorescence could in this case be noticed in the tube. If a fluorescing screen was then placed anywhere in the path of the kathode rays, fluorescence immediatly appeared not only on the screen but also on the walls of the tube. It was found that this modification of the kathode rays was not connected with any particular density of the gas or strength of the electrical discharge.

Another important point brought out by the work of Goldstein is the fact that in the much discussed funnel-tubes or any similar devices, the narrower part which points towards the anode acts as a secondary kathode. 1) The rays which it emits as well as all the other phenomena are the same as at an ordinary kathode but "quantitativ gemildert". Goldstein gave these devices many forms for the purpose of a thorough investigation and called them secondary kathodes.

Early in his work he had already deemed himself justified in speaking of rays in connection with the positive light. He pursued the study of these rays by constructing a tube bent several times at right angles, thus preventing the kathobe rays from reaching beyond the first bend. Nevertheless he found fluorescence at each succeeding bend and if a solid was put in the path of the discharge towards the kathode a shadow was produced, while if placed in the path towards the anode it did not effect the fluorescence. From this Goldstein concluded that the rays in the positive light are, like the kathode rays, directed from the kathode to the anode. Like the same rays also they produce fluorescence, are propagated rectilinearly and end at a solid wall whereon they produce a new source of the same kind of rays. A discovery made the following year by E. Wiedemann (2) shows that the effects on which Goldstein based these

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(1) Berl. Monatsber. p. 279, 1876.—Wied. Ann. 11, p. 836, 1880.
(2) Wied. Ann. 10, p. 236, 1880.

conclusions may, at least in part, be ascribed to some other cause. Wiedemann was working with a tube on which, opposite the kathode and beyond the anode, there was a narrow attachment bent at some distance from the main tube. When the current passed, fluorescence appeared not only at the bend which could be reached by a straight ray coming from the kathode but also at the very end of the bent tube. Goldstein had discovered the deflection of the kathode rays when they pass near a second kathode in the tube. (1) E. Wiedemann explained his results as a new instance of deflection, due to the static electricity gathered at the bend by the striking of part of the kathode ray. Goldstein however proved that this was not a case of deflection but of reflection and thus had the honor of again discovering a new property of the kathode rays. He found that this reflection was diffuse like that of light from a non-polished surface.

He also made a very extensive and interesting study of the effects produced by different shapes of the kathode on the images which they cast on the opposite walls of the tube. (2) The most important results of his experiments are the fact that kathode rays may cross one another and that their path is not always rectilinear, being modified either by mutual repulsion or by an action emanating from different parts of the kathode. E. Wiedemann (3) showed later on that the first of these two explanations could not be admitted because the apparent repulsion still took place if one of the rays was cut off; thus the cause of the effect had to be traced to the kathode itself.

In connection with the striated discharge, Goldstein (4) demonstrated that the distance between the layers is a function of the diameter of the tube and of the gas-pressure. Though

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(1) Berl. Monatsber. p. 285, 1876.—Wied. Beibl. 4, p. d832, 1880.
(2) Wied. Ann. 15, p. 246, 1882.—15, p. 254, 1882.
(3) E. Wiedemann & H. Ebert, Wied. Ann. 46, p. 158, 1892.
(4) Wied. Ann. 15, p. 277, 1882.

he could not find the exact expression for the latter function, he succeeded in showing that Sir W. Crookes was wrong in supposing it to be $\frac{1}{\rho}$ where ρ represents the density of the gas.

In his earlier papers, Goldstein (1) had already noticed that the regular kathode could be replaced in a tube by any substance perforated with a number of small holes. Somewhat later,(2) while working whith a kathode of this nature, he discovered near the kathode some rays not deflected by a magnet. From the place of their origin he called them "Canal Rays".

III.—Other Observers.

Although Hittorf and Goldstein did the most important work during this period, they are far from being the only ones who labored in this extensive and interesting field. There are even some whose work received much greater notice than theirs, Sir William Crookes for instance. This was due partly to the fact that the discoveries of Crookes were of a kind that readily appealed to the popular mind; whereas the others were too abstruse to receive general attention.

The impossibility of giving a detailed analysis of the work of all the experimenters makes it advisable to group their many observations under different headings. This will avoid all unnecessary repetitions and at the same time give a more general view of the subject under consideration.

The observed facts may be grouped into four classes:—

1. The general phenomena and the properties of the discharge.

2. The factors of the discharge and their mutual relations. Under this heading will be grouped the conductivity of gases,

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(1) Wied. Ann. 11, p. 832, 1880.
(2) Berl. Sitzungsber. 37, p. 691, 1886.

the discharge-potential, the fall of potential in the different parts of the tube, the current-intensity, the influence of the gas-pressure and the size, shape and nature of the electrodes.

3. The external causes that influence the discharge or the accompanying phenomena, such as resistance, heat, a magnetic field, an electric field, ultra-violet light, etc.

4. The effects of the discharge and of the different rays produced in a vacuum tube, such as mechanical, chemical and optical effects, secondary radiation, etc.

1. GENERAL PHENOMENA AND PROPERTIES.

The general appearances in the tube and the various characters capable of being assumed by the discharge again claimed a certain amount of attention. They were studied under slightly altered circumstances but the results failed to reveal anything new, hence it will be sufficient to make but a mere reference to them. (1)

During this period the question as to whether the electrical discharge was continuous or intermittent in character was extensively considered. G. Wiedemann and R. Ruehlmann, (2) while studying the light in the tube by the use of a heliometer, reached the conclusion that the discharge was always intermittent. The same view was held by E. Wiedemann, (3) E. Goldstein, (4) Warren de la Rue and H. Mueller, (5) and E. Fernet. (6) But Hittorf (7) and Hertz (8) showed rather definite-

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(1) O. Lehmann. Wied. Ann. 11, p. 686, 1880.—22, p. 305, 1884. Warren de la Rue and H. Mueller. Proc. Roy. Soc. 35, p. 292, 1883. Crookes. Chem. News. 39, p. 155, 1879.-63, 1891. C. Chree, Proc. Phil. Soc. Cam. 7, p.222, 1891.

(2) Pogg. Ann. 145, p. 235, 1872.

(3) Wied. Ann. 10, p. 245, 1880.

(4) Wied. Ann. 12, p. 101, 1881.

(5) Ann. de Ch. et de Phys. 24, p. 461, 1881.—Phil. Trans. 169, p. 225 1878.—C. R. 86, p. 1072, 1878.

(6) C. R. 90, p. 680, 1880.

(7) Wied. Ann. 7, p. 553, 1879.

(8) Wied. Ann. 19, p. 782, 1883.

ly that a battery discharge through gases was not to be looked upon as discontinuous any more than if it occurred through an entirely metallic circuit.

J. T. Bottomley (1) described the property of a vacuum tube to act like a condenser when held in one hand or surrounded by a conductor.

The discharge in the tube is propagated with a finite velocity. This was already studied by Wheatstone. J. J. Thomson (2) also investigated this velocity and determined its value for the propagation of the positive light towards the kathode. This value was found to be about half that of the velocity of light, viz. 1.6×10^{10} cm/sec.

Most of the other observations refer to the kathode rays and their effects, mainly to fluorescence. Crookes (3) described the apparent mutual deflectibility of two kathode rays and the peculiar phenomenon known as the tiring of the glass, a property which prevents the glass from fluorescing with the same intensity after having been exposed for some time to the influence of the kathode rays. This tiring is very persistent.

Spottiswoode and Moulton (4) obtained peculiar shadow effects which they explained as interference of the kathode rays.

2. FACTORS OF THE DISCHARGE.

The resistance of a gas was shown by G. Wiedemann (5) to be independent of the cross-section of the column of gas. Warren de la Rue and Hugo Mueller (6) found that there is no

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(1) Nat. 23, p. 218, 1880.
(2) Proc. Roy. Soc. 49, p. 84, 1891.
(3) Chem. News, 39, p. 155, 1879.
(4) Wied. Beibl. 8, p. 73, 1884.
(5) Pogg. Ann. 158, p. 53, 1876.
(6) C. R. 86, p. 1072, 1878.

relation between the E. M. F. and the current-intensity in rarefied gases. Hittorf (1) also reached the same result and, with regard to the positive light in particular, stated that the difference of potential between any two cross-sections does not depend on the intensity of the current. He drew the conclusion that the conductivity in the positive light increased proportionately to the current-intensity.

The question concerning the conductivity of a complete vacuum was again discussed during this period. J. Puluj (2) thought that a vacuum would be a conductor and that the resistance of high vacua is due to the electrostatic charge on the walls of the tube. According to Edlund also, there is no resistance in a vacuum. But to this, K. Krayewitsch (3) objected that in extreme vacua the discharge-potential again varies with the distance between the electrodes and that highly evacuated funnel-tubes still show a great difference of conductivity with different connections.

The distribution of resistance in the tube is far from being uniform. It is found mostly near the electrodes and mainly on the kathode, as shown by Hittorf, (4) Warren de la Rue and Hugo Mueller (5) and E. Goldstein. (6) The last named author stated very clearly that the real resistance in a highly evacuated tube is on or in close proximity to the kathode surface. This resistance can be reduced in several ways:—one is by using a kathode which can be heated to white heat; another ingenious method adopted by Goldstein was to use an inverted U—tube on whose electrodes some cadmium was placed. If the exhaustion was too high, the discharge again took place as soon as a

(1) Wied. Ann. 7, p. 573, 1879.—20, p. 729, 1883.
(2) Sitzungsber. der Wien. Akad. der Wiss, 2te Abt. 85, p. 871, 1882.
(3) Rep. der. Phys. 19, p. 118, 1883.
(4) Wied. Ann. Jubelb. p. 430, 1874.
(5) Proc. Roy. Soc. 35, p. 292, 1883.
(6) Wied. Ann. 24, p. 79, 1885.

little of the cadmium had been evaporated by heating, although cooling devices, whose efficiency was tested by the spectroscope, were used to confine the vapor to the immediate neighborhood of the kathode.

This great resistance at the kathode means a rapid fall of potential in the same region: under this aspect it was also studied by A. Righi. (1)

The conductivity of gases in general began to receive considerable attention during this period. E. Becquerel (2) had found that gases begin to be conductors of electricity when they become red hot. G. Wiedemann (3) extended this discovery by finding that the heating of a tube considerably lowers the amount of electricity necessary for a discharge.

R. Blondot, (4) characterized the conductivity of hot gases as galvanic. The conductivity of flames also was investigated by W. Hittorf, (5) A. Macfarlane and D. Rintoul, (6) Mascart (7) and Angelo Nob. Emo. (8) In the same article the last mentioned author treated likewise the conductivity of damp air, which subject was also taken up by Macfarlane and Rintoul. (9)

In many respects the resistance of gases is different from that of solid or liquid conductors. The smallest electro-motive force is sufficient to set up a current in a solid conductor, whereas to obtain a current in gases, the electric tension at the electrodes must first attain a definite value, which varies with the nature, density and temperature of the gas. G. Wiedemann

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(1) Nuovo Cim. 8, p. 93, 1880.
(2) Ann. Ch. Phys. (3) 39, p. 377, 1853,
(3) Pogg. Ann. 158, p. 68, 1876.
(4) C. R. 92, p. 870, 1882.
(5) Wied. Ann. Jubelb. p. 430, 1874.
(6) Proc. Ed. Roy. Soc. p. 567, 1882.
(7) C. R. 95, p. 917, 1882.
(8) Riv. Scient. Ind. Firenze, 15, p. 67, 1883.
(9) Proc. Ed. Roy. Soc. p. 801, 1882.

and R. Ruehlmann (1) studied this potential and found that a higher one was required to start the discharge at the positive than at the negative electrode. It was also investigated by Macfarlane acting alone (2) and in connection with R. Simpson (3) and P. M. Playfair. (4) W. Hittorf held the view that some finite potential was always required to set up a current in a gas. But A. Schuster (5) attacked this opinion, maintaining that the smallest electro-motive force is sufficient to bring about this current. The fact, that in reality a very great electromotive force is required, would be due merely to the resistance at the electrodes. If this could be obviated, the current, it was supposed, would pass readily. A means of doing away with the electrodes was found by J. Moser (6) who succeeded in exciting a tube by the induction produced in the tube itself. Contrary to the expectations of many, high vacua resisted this current as well as the ordinary electrode current. J. J. Thompson (7) also studied this new way of obtaining a current in a vacuum tube; curiously enough he never succeeded in obtaining any striation by this method.

The electricity necessary for the current may also be supplied by influence as had already been shown by Pluecker. (8) This was again treated by J. T. Bottomley, (9) apparently without any knowledge of Pluecker's work.

E. Wiedemann (10) studied the effect of varying the distance between the electrodes at constant pressure; he succeeded in

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(1) Pogg. Ann. 145, p. 235, 1872.
(2) Ed. Roy. Soc. Trans. 28, p. 633, 1877.
(3) Ed. Roy. Soc. Trans. 28, p. 673, 1877.
(4) Ed. Roy. Soc. Trans. 28, p. 679, 1877.
(5) Proc. Roy. Soc. 42, p. 371, 1887.
(6) C. R. 110, p. 397, 1890.
(7) Electrician, 27, p. 139, 1890.—Phil. Mag. 32, pp. 321, 445, 1891.
(8) Pogg. Ann. 107, p. 81, 1859.
(9) Electrician, 28, p. 463, 1892.
(10) Wied. Ann. 20, p. 756. 1883.

arranging his apparatus in such a manner as to allow him to vary the distance between the electrodes continuously. As the anode moves towards the kathode the positive layers do not change their position but disappear one after the other as the anode enters them. When the last layer has disappeared and the anode has entered the dark space, a brush appears on the latter. This brush is bent back when the negative glow is entered. As soon as the kathode dark space is reached, the negative light appears back of the kathode and fluorescence is seen on the glass behind the same.

3. EXTERNAL INFLUENCES.

Some new facts were discovered concerning the influence of a magnet on the electric discharge and the kathode rays. J. J. Thomson (1) verified those already known, particularly those dealing with the production of striation in the positive light and found, moreover, that the place at which the negative glow appears on the electrode is changed by a magnet. W. Spottiswoode and J. F. Moulton (2) discovered the interesting fact that under some circumstances, the kathode rays are brought to the walls of the tube, not at one particular spot but at a whole series of them, as was proved by the fluorescence; in their case the magnet was put close to the kathode.

Pluecker (3) had already described the effects that take place in the tube when the walls are touched by the hands of the operator. When the finger or some other conductor is brought near the tube, the light therein is generally attracted but sometimes repelled. Pluecker thought he could trace this difference to the nature of the gas and the special form of the tubes. But this was shown to be wrong by Edm. Reitlinger and Alph. von

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(1) Proc. Camb. Phil. Soc. 5, pt. 6, p. 391, 1886.
(2) Proc. Roy. Soc. Lon. 32, p. 388, 1881.
(3) Pogg. Ann. 104, p. 121, 1858.

Urbanitzki (1) who named the double phenomenon "electro-attraction" and "electro-repulsion" respectively. They found that the effect depended mainly on the pressure of the gas. At high pressures there was electro-attraction, but by gradually lowering the pressure a point was reached where no effect was noticed; at all points below this, electro-repulsion occurred. The effect is influenced, moreover, by the current-strength and by resistance inserted in the circuit. It is of an electric nature and preceded by some other effect due to influence, as the conductor is brought near the tube, but it cannot come from the presence of free electricity since it is not produced by a charged non-conductor.

Another result brought about by approaching a conductor is the production of a new kathode at the very place where the tube is touched. This was noticed by K. Domalip. (2) W. Spottiswoode and J. F. Moulton. (3) The two last named authors also observed that this new kathode showed a dark space and possessed the other properties of an ordinary kathode.

4. EFFECTS OF THE DISCHARGE.

HEATING—G. Wiedemann and R. Ruehlmann (4) learned that the heat produced by a current in rarefied gases varies directly as the current-intensity and not as the square of this same current-intensity, as required by Joule's law for solid conductors. Subsequently G. Wiedemann (5) studied the heating effect of the current more extensively. The heat produced on capillary tubes increases as the gas-pressure in-

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(1) Wiener Anz. p. 100, 1877.—Wied. Ann. 10, p. 574, 1880.—13, p. 670 1881.

(2) Sitzungsber. der K. Boehm. Akad. der Wiss. July, 2d, 1880.

(3) Proc. Roy. Soc. 29, p. 21, 1879.—Phil. Trans. 1879, 1880.

(4) Pogg. Ann. 145, p. 237, 1872.

(5) Pogg. Ann. 158, pp. 55, 252, 1876.

creases, but somewhat more slowly. The heating on any cross-section of a long or small capillary tube is almost the same between large limits of the respective lengths of the tube. Tubes of different inner but same outer diameter receive nearly equal quantities of heat, but the temperature is not equal in the several parts of the same tube:-that in the dark space being notably lower than that of the brighter parts. From his studies of the heat effects in rarefied gases, E. Wiedemann (1) reached the following conclusions: — The spectrum given by the light in a vacuum tube is not necessarily due to high temperature; a spectrum may be obtained even at temperatures below 100°C. If these statements are referred to the average temperature of the gas at any place in the column of light, they are, no doubt, true. But from this it would be wrong to conclude that a light-emitting atom or other small particle of gas does not exceed these temperatures. The low values given by E. Wiedemann contrast rather strongly with those given later by Paalzow and Neessen, (2) who found that the temperature in rarefied gases ranged between 10 000° and 100 000° under the influence of the electric discharge. Wiedemann also found that the passing from the band spectrum to the line spectrum requires 128 300 calories per gram for hydrogen, and in connection with this that the heat of dissociation of the hydrogen molecule is 126 000 G. D. units of heat. The study of the relative temperature of the different parts of the

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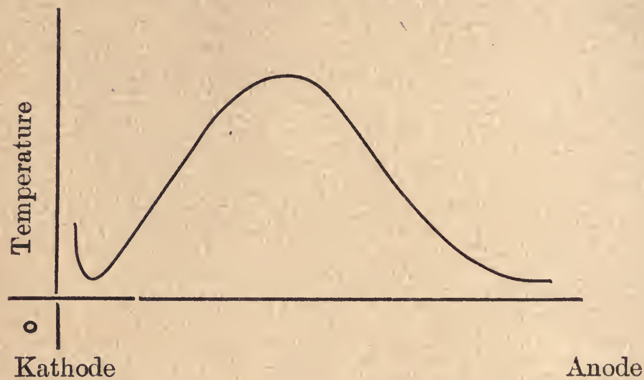
(1) Wied. Ann. 5, p. 500, 1878.—6, p. 298, 1979.—10, p. 202, 1880.—20, p. 756, 1883.

(2) Verh. der Ges. D. Näturf and Aerzte, 63 Vers. zu Bremen, p. 51, 1890.

tube gave the general results represented by the following curve:—



Immediately near the kathode the temperature is very high; but this part of the curve could not be traced very accurately. The maximum always falls well within the kathode light and consequently its position depends on the extension of this light.

D. Goldhammer (1) learned that the total heat developed under the influence of the electric discharge depends in a great measure on the current-intensity but not on the gas-pressure whereas the relative temperature of the electrodes depends on the gas-pressure. As this pressure is increased, the temperature at the kathode at first becomes equal to and then larger than that at the anode. This heating of the electrodes was also studied by A. Naccari and G. Guglielmo. (2)

The heat developed by the striking of kathode rays may become intense enough to melt glass and platinum. (3)

The kathode rays produced in high vacua give rise to a vivid

(1) Journ. der Russ. Phys.—Chem. Ges. 6, p. 325, 1884.

(2) Nuovo Cim. 17, p. 1, 1885.—Atti della R. Acc. di Torino, 20, p. 263, 1885.

(3) W. Crookes, Chem. News, 39, p. 155, 1879—H. A. Cunningham, Nat. 19, p. 458, 1879.

fluorescence on the glass of the tube and in many substances. This was explained by Crookes (1) as due to the impinging of radiant matter; by Goldstein (2) as a result of the ultra-violet light produced by the kathode rays; by Puluj (3) as coming from an action of the ether carried along by the moving particles on the ether on the surface of the fluorescing bodies.

The spectrum given by these fluorescing substances is generally continuous but Crookes (4) found that some of the rare earths give a band spectrum. On this observation he founded a new branch of spectrum-analysis.

In some cases, the continued impinging of the kathode rays on a fluorescing substance causes a distinct change of color; in others different spectra may be given by the same substance. Crookes claimed for these bodies a different fluorescence in different vacua. But E. Wiedemann (5) showed that all the facts could be easily explained by a change in the physical or chemical condition of the body; for instance, by the loss of water of crystalization which would naturally increase with the vacuum.

Crookes and Hittorf obtained the condition of vivid fluorescence only at very high vacua and in, the opinion of the former especially, these high vacua where matter became radiant were absolutely required. In connection with this it may be interesting to note that D. Goldhammer (6) began to obtain the same conditions at pressures ranging from 1.2 to 0.9 mm of mercury.

A peculiar case of fluorescence was found in the so-called after-glow of some gases, which had already been extensively

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(1) Chem. News, 39, p. 155, 1879.

(2) Wien. Ber. 80, 1879.

(3) Wien. Ber. 81, April 15, 1880.

(4) Chem. News, 47, p. 261, 1883.— Radiant Matter Spectroscopy. Phil. Trans. 1883-1885.

(5) Wied. Ann. 9, p. 157, 1880.

(6) Jour. der Russ. Phys.—Chem. Ges. 6, p. 325, 1884.

studied in the previous period. Since then some attempts had been made to prove that this effect was due to secondary discharges from the walls of the tube; but E. Warburg (1) showed that the older explanation, which attributed it to a chemical action, was still more satisfactory.

MECHANICAL EFFECTS.—A. de la Rive (2) succeeded in rotating a pair of vanes mounted in a vacuum tube by directing the discharge on them with the aid of a magnet. Six years later Sir W. Crookes (3) illustrated the same property of the kathode rays by several striking experiments. But it must be remarked here that, although the so called bombardment may contribute to the rotation, it is not the only cause of it. Thus W. Hittorf (4) showed that the heat produced on the radiometer-vanes is of itself sufficient to cause rapid rotation. Moreover the phenomenon is still complicated by an electrostastic action between the charged walls of the tube and the radiometer itself. Another arrangement of these experiments, made both by Crookes and Puluj, (5) is to make the wheel of the radiometer the kathode of the discharge by covering every alternate side with a fluorescing screen so that the kathode rays will be produced only on the opposite sides. But this is still more complicated than the previous one since the heat produced on the walls of the tube by the impinging kathode rays is again a new cause influencing the rotation.

CHEMICAL EFFECTS.—Many chemical compounds undergo changes when subjected to the influence of an electric discharge through gases; but it is hard to determine how far these changes are due to purely electrical causes since there cannot be any doubt that the intense heat caused by the electric discharge

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(1) Arch. de Gen. 12, p. 504, 1884.
(2) Ann. de Ch. et de Phys. 29, p. 207, 1873.
(3) Phil. Trans. p. 152, 1879.
(4) Wied. Ann. 21, p. 125, 1884.
(5) Radiant Electrode Matter. Phys. Soc. Reprint of Memoirs. p. 275.

and particularly by the kathode rays is a great factor in chemical change in general.

In a very great number of gases the more complex molecules are broken up into simpler ones and quite frequently into the simplest possible. But conversely, if a mixture of different gases is exposed to the discharge, chemical combination may take place between them. These several changes are not confined to gases, but may also be effected in solids with which the gases come into contact: thus a chemical action has sometimes been noticed on the constituents of the glass-walls and the electrodes of a vacuum tube.

A third action of a chemical nature is seen in the frequent changing of oxygen to ozone. Phosphorus is similarly affected.

Moreover there is evidence of a transfer of gases from one electrode towards the other; this often assumes an electrolytic character and may cause a different degree of vacuum in the different parts of the tube.

CHAPTER III

THIRD PERIOD

The interest during this period centers mainly around the kathode rays and the several causes that bring about the conductivity of gases. The nature of the former was largely discussed, their properties were studied in a masterly way by Ph. Lenard, their effects and particularly secondary radiation and Roentgen rays opened new fields for investigation. The stupendous amount of the literature on this general subject during this period will not allow of more than a passing reference to most of the work. Physicists all over the world have investigated the laws governing the discharge of electricity through gases; they have tried to build up a theory which would account for all known facts and have investigated many new phenomena.

This chapter will be devoted mainly to the historical review of the question of conductivity and to the study of kathode rays. In the latter part, the work of Lenard will receive special attention on account of its importance.

I. CONDUCTIVITY OF GASES.—IONIZATION.

A.—INFLUENCE OF ULTRA-VIOLET LIGHT ON GASES.

In studying the resonance-phenomena between very rapid electric oscillations, H. Hertz (1) accidentally discovered that

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(1) Wied. Ann. 31, p. 983, 1887.

one spark greatly facilitated the formation of another. He traced the effect to ultra-violet light and expressed the desire that this subject should be studied under simpler conditions. This wish received the response that such an important discovery deserved. Eilhard Wiedemann and H. Ebert (1) were the first to publish the results of their investigations. Ultra-violet light may facilitate the discharge in the proportion of 2:1. The greatest effect is noticed when the kathode is illuminated; the illumination of the anode gives much smaller results and when the action of the ultra-violet light is confined to the intervening gas by carefully excluding reflection, the effect does not take place. The active light lies mainly beyond the visible spectrum but for carbon dioxide the maximum effect was obtained with the wave-lengths between the G and K lines. The part of the arc which proved most effective is that on or in the immediate vicinity of the positive carbon. The effect was explained as a sympathetic action between the ultra-violet light-waves and the very short wave-lenghts which, in their theory, are the kathode rays. Experimenting with different metals and liquids they found that, when the kathode is a substance which readily absorbs ultra-violet light, the effect is greatest: thus among the ordinary metals the most effective was found to be platinum. Pure water produced little effect, whereas solutions showed a result in proportion with their absorptive power. Aniline dyes, which readily absorb ultra-violet light, produce very strong effects.

Hallwachs (2) studied the question from another standpoint and thus discovered what has been known ever since as the "Hallwachs Effect". A negatively charged body is rapidly and in some cases almost instantaneously discharged under the in-

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(1) Wied. Ann. 33, p. 241, 1888.—35, p. 209, 1888.
(2) Wied. Ann. 33, p 301, 1888.—34, p. 731, 1888.—37, p. 666, 1889.

fluence of ultra-violet light. Hallwachs has definitely established that this effect is due to ultra-violet light and that it occurs at the surface of the charged body. If a positively charged body is put into the path of the light, the loss of electricity is scarcely observable but if the body is not electrified, it will acquire a small positive charge. This is owing to the negative electricity liberated under the influence of the ultra-violet light. Whilst working with electrified liquids, the same experimenter confirmed E. Wiedemann and H. Ebert's conclusion that there is a direct relation between the absorptive power of a body for ultra-violet light and the rate of discharge.

Other important work was done in this line by A. Righi, (1) Stoletow (2) Elster and Geitel, (3) Lenard, (4) Hoor, (5) and many other physicists. (6) The principal facts brought out

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(1) C. R. 106, p. 1349, 1888.—107, p. 559, 1888.—Jour. de Phys. 7, p. 153, 1888.—Rend. della R. Acc. dei Lincei, 4, p. 16, 1888.—6, p. 185, 1888.—Exner Rep. 25, p. 185, 380, 1889.—Atti del R. Ist. Ven. 7, 1889.—Mem. Bol. 9. 1888.—10, p. 85, 1890.

(2) C. R. 106, p. 1149, 1888.—106, p. 1593, 1888.—107, p. 91, 1888.—108, p. 1241, 1889.—Jour. der Russ. Phys.—Chem. Ges. 21, p. 159, 1889.—Jour. de Phys. 9, p. 468, 1890.—Bull. Soc. Fr. de Phys. p. 202, 1890. — Phys. Rev. 1, p, 721, 1892.

(3) Wien. Ber. 97, p. 1175, 1888. — Sitzungsb. der Wien. Ak. Math.—Naturw. Cl. 99, p. 1008, 1891.—Wied. Ann. 38, p. 40, and 497, 1889.—39, p. 321, 1890.—41, p. 161, 1890.—42, p. 564, 1891.—43, p. 225, 1891.—44, p. 722, 1891.—46, p. 281, 1892. 48, p. 625, 1893.—52, p. 432, 1894.—55, p. 684, 1895.—57, p. 24 and 401, 1896.—62, p. 599, 1897.

(4) Lenard and Wolf, Wied. Ann. 37, p. 443, 1889.—Lenard, Wien. Ber. 108, p. 1648, 1889.

(5) Wien. Ber. 97 p. 719, 1888.—Exner Rep. 25, p. 105, 1889.

(6) Bichat and Blondlot, C. R. 106, p. 1349, 1888. Bichat, C. R. 107, p. 557. 1888. Arrhenius, Wied. Ann. 33, p. 638, 1888. Borgmann, C. R. 108, p. 733, 1889. Branly, C. R. 110, p. 751 and 898, 1890.—116, 741, 1893.—114, p. 68, 1892.—120, p. 829, 1895.—Lum. El. 41, p. 143, 1891.—Jour. de Phys. 2, p. 300, 1893. Precht, Wied. Ann. 49, p. 150. 1893. Cantor, Wien. Ber. 102, p. 1188, 1893, Warburg, Wied. Ann. 59. p. 1, 1896. — Drude Ann. 5, p. 811, 1901. Simon, Wien. Ber. 104, p. 565, 1895. Jaumann, Wied. Ann. 62, p. 396, 1897. G. C. Schmidt, Wied. Ann. 62, p. 407, 1897.—64, p.

by this study are the following:—The effect may be produced by any source of light that will furnish ultra-violet rays. Those rays that cause the discharge are always absorbed but the absorption is not necessarily accompanied by the discharge. The effect of polarized light depends to a great extent on the position of the plane of polarization, showing two maxima and two minima. The minima occur when the plane of polarization coincides with that of incidence for the ray of light. The maxima occur for positions which differ from the previous ones by an angle of 90 degrees.

The loss of electricity is also greatly influenced by the physical condition of the surface experimented on, being greater for highly polished surfaces. The surfaces themselves are attacked and sensibly roughened by the action of ultra-violet light. This phenomenon led to the almost general belief that the discharge was brought about by the so-called "Zerstaeubung" of the electrode. Ph. Lenard (1) did not look upon this as probable and began a series of experiments to discover the true nature of this action of the shorter wave-lengths of light. He first constructed a tube with a quartz window that allowed the ultra-violet light to strike one of the electrodes. This electrode was made of sodium amalgam and could be charged to any desired potential. The opposite electrode was of platinum. After the platinum electrode had been charged negatively by casting a beam of ultra-violet light on the sodium amalgam, it was taken out and tested for sodium in the spectroscope. Although 3×10^{-7} mg. of

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708, 1898. Henry, Proc. Cambr. Phil. Soc. 9, p. 401, 1898. Buisson, C. R. 127, p. 224, 1898.—130, p. 1298, 1900. Zeleny, Phil, Mag. 45, p. 272, 1899 Rutherford, Proc. Cambr. Phil. Soc. 9, p. 401, 1898. Schweidler, Wien Ber. 107, p. 881, 1898.—108, p. 273, 1899. J. J. Thomson, Phil. Mag. 48, p. 547, 1899. Merritt and Stewart, Phys. Rev. 11, p. 230, 1900. Guthe, Drude Ann. 5, p. 818, 1901. Kreusler, Drude Ann. 6, p. 398, 1901.—6, p. 412, 1901. E. Ladenburg, Drude Ann. 12, p. 558, 1903.

(1) Drude Ann. 2, p. 359, 1900.

sodium may easily be detected in this way, not the slightest trace of it was noticed on the platinum. Another proof against the Zerstaeubung theory clearly appears from the fact that if the kathode is charged anywhere from 1 to 45,000 volts, the coulombs discharged per second represent a constant quantity of about 22.5×10^{-10}. By inserting a screen with a hole in the centre between the kathode and the antikathode, he still obtained negative electrification on the latter from the beam of rays that could reach it. Applying a magnet to this beam, he saw he could deflect it in such a manner as to cause electrification solely at the place to which it had been deflected. From this he concluded that ultra-violet light produces kathode rays on negatively electrified bodies which it discharges. The velocity of these kathode rays is smaller than that of those produced in an ordinary vacuum tube and changes with the potential to which the kathode is charged. The following table gives some of the values:—

Charge of the kathode in — volts.	Velocity.
607	0.12×10^{10} cm per second.
4 380	0.32×10^{10} " " "
12 600	0.54×10^{10} " " "

The maximum velocity of the rays obtained by this method was 10^8 cm per second.

Ultra-violet light has also a direct effect on gases, serving to make them conductors by producing in them what Lenard has styled "Electric Carriers". This process is more generally known as "Ionization" and was studied by Arrhenius, (1) Branly (2) and especially by Ph. Lenard.

Lenard (3) was the first to find that the very short wavelengths between 0.00014 mm and 0.00019 mm produce fogging,

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(1) Wied. Ann. 33, p. 638, 1888.
(2) C. R. 110, pp. 751, 898, 1890.— 120, p. 829, 1895.
(3) Drude Ann. 1, p. 486, 1900.— 3, p. 298, 1900.

form ozone and make the gas through which they pass a good conductor. The best source of these rays is incandescent hydrogen though they are also contained in an aluminium spark gap, the arc-light and the rays of the sun. A positively charged body placed near the path of these rays is rapidly discharged. This discharge is accelerated if the air acted on by ultra-violet light is directed towards the electrified body. Under the influence of this light both positive and negative carriers are produced. The initial velocity of the latter is much greater than that of the former and according to Lenard's estimate ranges from 10^7 to 10^8 cm per second.

B.—INFLUENCE OF HEAT ON CONDUCTIVITY.

The increase of conductivity by heat, which had been known and investigated during the previous period, still continued to receive a considerable amount of attention. (1) In connection with this subject it was learned that all gases may be classified under two general heads, viz.: 1. Those that conduct with difficulty even at the highest temperatures, as air, nitrogen, carbon dioxide, ammonia, and the vapors of sulphuric acid, of tin and of mercury. 2. Those that readily allow the passing of a current, such as the halogens, hydriodic acid, hydrobromic acid, hydrochloric acid, sodium chloride and potassiun chloride. The cause of this diversity of behavior is probably the decomposition of the second class of gases and vapors into electric carriers. Those of the first class are simply broken up into less complicated molecules which take part in the transfer of electricity only by convection.

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(1) J. J. Thomson, Phil. Mag. 29, p. 359, 1890.— 29, p. 441, 1890. Branly, C. R. 114, p. 831, 1892.—114, p. 1531, 1892. Braun, Zeitschr. fuer Phys. Chem. 13, p. 155, 1894. Pringsheim, Wied. Ann. 55, p. 507, 1895. Merrit and Stewart, Phys. Rev. 7, p. 129, 1899. J. Stark, Wied. Ann. 68, pp. 931 and 942, 1899. Die Elektrizitaet in Gasen, Leipzig, 1902. Arrhenius. Wied. Ann. 42, p. 18, 1891.

Lenard (1) calculated the velocity of the positive carriers or ions in a flame (2) and found that for lithium it was 108 cm per second for 1 volt/cm. His method did not show any evidence of negative carriers probably on account of their high velocity. This was computed by M. Mareau (3) and shown to be greater than 1200 cm/sec. per volt/cm.

C.—INFLUENCE OF KATHODE RAYS ON CONDUCTIVITY.

The ionization of a gas under the influence of kathode rays was studied chiefly by Ph. Lenard, (4) Des Coudres, (5) E. Wiedemann and G. C. Schmidt, (6) Arnold, (7) McClennan, (8) Townsend (9) and Durac. (10)

The absorption of the kathode rays is, according to Lenard, proportional to the mass-lengths of a gas. Its effect is an ionization which remains in the gas for some time. McClennan proved this ionization to be the same in all gases at the same density. From this Lenard concluded that there is a relation between the absorption of the kathode rays and the conductivity resulting therefrom. Durac found that the number of pairs of ions produced in 1 cm of gas at 1 mm pressure is 0.43 for one kathode quantity. This is about one fiftieth of the value that had been previously given by Townsend.

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(1) Drud Ann. 9, p. 642, 1902.

(2) cfr. also K. Wesendonck, Wied. Ann. 66, p. 121, 1898. J. A. McClelland Phil. Mag. 46, p. 29, 1898. H. A. Wilson, Phil. Trans. Roy. Soc. Lond. 192, p. 499, 1899.

(3) C. R. 134, p. 1575, 1902.

(4) Wied. Ann. 56, p. 255, 1895.—63, p. 253, 1897. Drude Ann. 12, p. 449 1903.

(5) Wied. Ann. 62. p. 143, 1897.

(6) Wied. Ann. 62, p. 468, 1897.—66, p. 330, 1898.

(7) Wied. Ann. 61, p. 327, 1897.

(8) Zeitschr. f. Phys. Chem. 37, p. 513, 1901.

(9) Phil. Mag. 1, p. 198, 1901.—3, p. 557,—1902.—5, p. 389, 1903.

(10) Phil. Mag. 4, p. 29, 1902.

This ionization of the gas by kathode rays has furnished a consistent explanation of many of the phenomena that occur in vacuum tubes, mainly with regard to the striated and the non-striated positive light, the different dark and luminous layers of the discharge near the kathode, etc. These different phenomena will be discussed in the subsequent chapter; thus a mere reference to the theoretical work done along this line will be sufficient at this place. (1)

D.—INFLUENCE OF ROENTGEN RAYS ON CONDUCTIVITY.

The ionization of a gas may be brought about directly by Roentgen rays and indirectly by the so-called secondary radiation which they produce.

The direct ionization by Roentgen rays was one of the first properties of these rays observed by their discoverer. (2) This property was so evident that Roentgen believed himself justified in questioning Lenard's work on ionization by kathode rays. The degree of ionization depends greatly on the intensity of the rays and is proportional to the pressure of the gas.

The secondary rays produced at the surface of any body on which Roentgen rays impinge, are generally better ionizing agents than the primary rays themselves on account of their higher coefficient of absorption. Ever since the day of the discovery of these rays they have been largely used as a primary or secondary source of ionization and studied as such. (3)

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(1) J. J. Thomson, Phil. Mag. 50, p. 278, 1900.—1. p. 368, 1901. Stark, Phys. Zts. 2, p. 664, 1901.—Drude Ann. 3, p. 237, 1900. —5, p. 110, 1901.—7, p. 426, 1902. Townsend, Nat. p. 340, 1900.—Phil. Mag. 1, p. 198, 1901. Townsend and Kirkby, Phil. Mag. 1, p. 630, 1901.

(2) Wied. Ann. 64, p. 12, 1898.—Sitzb. Wuerzb. Phys. — Med. Ges. 1895. Beitrag.

(3) Roentgen, Wied. Ann. pp. 12, 18, 1898. Righi, C. R. 122, pp. 376, 601, 1896.—Rend. della R. Acc. dei Lincei, 5, p. 342, 1896.—Mem. Bol. 5, p. 723, 1896. J. J. Thomson, Proc. Roy. Soc. 59, p. 274, 1896.—Proc. Cambr.

E.—INFLUENCE OF THE BECQUEREL RAYS ON CONDUCTIVITY.

The so-called Becquerel rays, (1) which are a complexus of very different rays, are emitted by the radioactive substances. From such substances as are naturally radioactive, bodies have been separated which exhibit this phenomenon in a marked manner. These are actinium (separated by Debierne), polonium and radium (separated by the Curies). Of these the most active is radium whose rays are divided into the α, β and γ rays which are distinguished by their penetrating power and their deflectibility. The α rays are the least and the γ the most penetrating. The γ rays are not deflected by a magnet; the β rays are easily deflected and the α rays only with difficulty and in a direction opposite to that of the β rays. The γ rays closely resemble those discovered by Roentgen; the β rays are negatively electrified particles traveling with great velocity and hence may be looked upon as kathode rays. The α rays carry a positive charge. On bodies where the Becquerel rays strike they produce a secondary radiation. (2) The primary

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Phil. Soc. 10, p. 10, 1898.—Id. and McClelland, Proc. Cambr. Phil. Soc. 9, p. 129, 1896.—Id. and Rutherford, Phil. Mag. 42, p. 392, 1896.. Rutherford, Phil. Mag. 43, p. 241, 1897.—Id. and McClung, Proc. Roy. Soc. 67, p. 245, 1900. Perrin, C. R. 122, pp. 186, 716, 1896.—Jour. de Phys. 5, p. 350, 1896.—6, p. 425, 1897.—Ann. de Ch. et de Phys. 11, p. 496, 1897. Winkelmann, Wied. Ann. 66, p. 1, 1898. Sagnac, C. R. 125, pp. 168, 230, 942, 1897.—126, pp. 36, 467, 521, 887, 1898.—127, p. 46, 1898.—128, pp. 300, 546, 1899.—Jour. de Phys. 8, p. 65, 1899.—Id. and P. Curie, C. R. 130, p. 1013, 1900.—Jour. de Phys. 1, p. 13, 1902. Townsend, Proc. Cambr. Phil. Soc. 10, p. 217, 1900. Dorn, Arch. Neerl. 5, p. 595, 1900. J. A. Cunningham, Proc. Cambr. Phil. Soc. 11, p. 431, 1902.

(1) H. Becquerel, C. R. 122, 1896.— 128 and 129, 1899.— 130 and 131, 1900. G. C. Schmidt, Wied. Ann. 65, p. 141, 1898. P. and S. Curie, C. R. 1898, 1899, 1900, 1901 and 1902.—Id. and Bemont, C. R. 127, p. 1215, 1898. Rutherford, Phil. Mag. 47, p. 109, 1899. Debierne, C. R. 129, p. 593, 1899.— 130, p. 906, 1900. Giesel, Wied. Ann. 69, p. 91, 1899.—Phys. Zts. 1, p. 16, 1899.—Ber. Chem. Ges. 33, p. 1665, 1900.

(2) H. Becquerel, C. R. 128, p. 771, 1899.—129, p. 716, 1899. — 132, pp. 371, 734, 1286, 1901.

as well as the secondary rays have many interesting properties, but here we are only concerned with their power to produce ionization in gases. This ionization is always an effect of absorption and is different for the different kinds of rays. It usually follows the same general laws as the other rays heretofore studied. (1)

F.—CHEMICAL SOURCES OF IONIZATION.

Chemical reactions are very often accompanied by ionization in the gases which enter into combination. In combustion we may have the double process of direct ionization of the burning gases and their electrification by a solid introduced into the flame. (2)

The discharge of an electrified body by moist air which had been in contact with phosphorus is also in all likelihood due to ionization resulting from a chemical action. (3)

Chemical decomposition by electrolysis or otherwise may also give rise to ionization. Thus Townsend (4) has proved that the rapid evolution of hydrogen from sulphuric acid and iron causes the gas to assume a positive charge, leaving the solution oppositely electrified. He likewise found positive charges

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(1) H. Becquerel, C. R. 122, pp. 559, 689, 762, 1086, 1896.—123, pp. 856, 1896.— 124, pp. 438, 800, 1897. G. C. Schmidt, Wied. Ann. 65, p. 141, 1898. Rutherford, Phil. Mag. 47, p. 109, 1899. Strutt, Nat. 61, p. 539, 1900.— Proc. Roy. Soc. 68, p. 126, 1901. Elster and Geitel, Wied. Ann. 69, p. 673, 1899. M. Cantor, Drude Ann. 9, p. 452, 1903. McClelland, Phil. Mag. 8, p. 67, 1904. —p. 230, Febr. 1905.

(2) Svante Arrhenius, Wied. Ann. 42, p. 18, 1891. Smithels, Dawson and Wilson, Proc. Roy. Soc. 64, p. 142, 1899. H. A. Wilson, Phil. Trans. 192, p. 499, 1899. McClelland, Phil. Mag. 46, p. 29, 1899. Warburg, Drude Ann. 2, p. 304, 1900. Marx, Drude Ann. 2, p. 768, 1900.

(3) Bidwell, Nat. 55, p. 6, 1897. Barus, Phys. Rev. 10, p. 257, 1900. Amer. Jour. of Sc. 11, p. 237 and 310, 1901.—Phil. Mag. 1, p. 572, 1901—2, p. 40, 1901.

(4) Proc. Cambr. Phil. Soc. p. 244, 345, 1897.— Phil. Mag. 45, p. 125, 1898.

on chlorine and oxygen after their liberation. The rapid electrolytic dissociation of sulphuric acid leaves hydrogen with a positive charge whereas oxygen does not show any electrification. This difference is easily explained by the fact that the liberation of oxygen is not a primary but a secondary electrolytic reaction. The following equations show one of the ways in which sulphuric acid may be electrolyzed and explain the different behavior of the two gases that are evolved.

$$H_2SO_4 = H_2 + SO_4$$
$$2H_2O + 2SO_4 = 2H_2SO_4 + O_2$$

G.—IONIZATION OF LIQUIDS BY "ZERSTAEUBUNG".

The anomalous electrification of air near water-falls had been known for a long time. Lenard (1) showed that when water or mercury is allowed to drop on a metallic plate, the liquid becomes positively electrified and the surrounding air shows negative electrification. Lord Kelvin (2) obtained a similar result by allowing air to bubble through water. The Zerstaeubung of pure water in air seems to produce only the negative carriers or ions in the latter, while the slightest trace of a solvent in the water causes both kinds of carriers to appear. The velocity of the positive ions produced by pure water is given by Karl Kaehler (3) as 4.17 cm/second per volt/cm.

This subject has received a good deal of attention quite lately. (4)

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(1) Wied. Ann. 46, p. 584, 1892.

(2) Lord Kelvin, McClean and Galt, Brit. Ass. Rep. 1894.—Proc. Roy. Soc. Lond. 57, p. 335 and 436, 1895.

(3) Drude Ann. 12, p. 1119, 1903.

(4) Elster and Geitel, Wied. Ann. 47, p. 496, 1892. Wesendonck, Wied. Ann. 47, p. 529, 1892.—51, p. 353, 1894. J. J. Thomson, Phil. Mag. 37, p.

II.—PHENOMENA CONNECTED WITH THE DISCHARGE.

During this period some new and important facts were discovered such as the production of Roentgen rays from kathode rays which was described by Professor Roentgen of Wuerzburg in 1895. The most important work however consists in a closer study of previously known phenomena. Thus, Lenard published his papers on kathode rays which were honored and deservedly so by many scientific associations. For among all the important work done in the busy physical laboratories of our days, that of Lenard stands out as a model of accurate investigation and of scientific thought.

The other important kind of rays, named by Goldstein "canal rays", also received their share of attention, mainly from their discoverer and Willy Wien.

A.—KATHODE RAYS.

We have already seen how a discovery made by H. Hertz led to the extensive study of the effects of ultra-violet light on gases. It likewise was another discovery of his that enabled Lenard to bring the kathode rays out of the kathode tube and thus study them under a great variety of conditions unobtainable in the discharge tube.

Hertz (1) noticed that the walls of a vacuum tube still fluoresced if a thin sheet of gold leaf or aluminium foil were interposed between them and the kathode. The fluorescing spot thus obtained changed its position under the influence of a magnet and showed all the other characteristics of the

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341, 1894.—4, p. 352, 1902. Usener, Ztschr. fuer Phys. Chem. 18, p. 191, 1895. F. Himstedt, Ber. der Naturf. Ges. Freib. im Breisgau, April, 1903. Pacini, Atti della R. Acc. dei Lincei. 13, pp. 559 and 617, 1904. A. Schmaus Drude Ann. 9, p. 224, 1903.

(1) Wied. Ann. 45, p. 28, 1892.

fluorescence produced by kathode rays. Thus it seemed to be proved that kathode rays could traverse a thin sheet of metal.

Lenard fully appreciated the importance of this discovery and set to work to utilize it. He finally succeeded in constructing a tube with an aluminium window thin enough to allow the kathode rays to go through, yet strong enough to stand the atmospheric pressure and to keep a perfect vacuum. The aluminium which he used was 0,003 mm thick.

His first studies of the rays thus obtained were published under the title:- "Ueber Kathodenstrahlen in Gasen von atmosphaerischem Druck und im aeussersten Vacuum." (1) The fact that up to then kathode rays could only be obtained and studied between pressures which scarcely exceeded the range of 1 mm is sufficient to suggest the full significance of this title. The work of Lenard is very extensive and practically covers the whole subject, so that an analysis of it together with references to and an occasional addition from that of other experimenters will be sufficient to give a complete view of the subject.

1. PATH OF THE KATHODE RAYS.—The path of the kathode rays is generally rectilinear but it may be modified by intervening obstacles and by electric and magnetic fields.

Thus the kathode ray issues from the aluminium window not only normally but at every angle from 0 to 90 degrees, and in gases it suffers diffusion at all higher pressures. (2) This diffusion increases with increasing pressure of the gas and is always greater for slow rays than for more rapid ones. This general law holds for solids as well as for gases. The latter ab-

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(1) Ber. der Berl. Akad. p. 3, 1893.—Wied. Ann. 51, p. 225, 1894.

(2) Lenard, Wied. Ann. 51, p, 225, 1894. See also: Goldstein, Wied. Ann. 51, p. 622, 1894.—67, p. 84, 1899. W. Kaufmann, Wied. Ann. 69, p. 95, 1899. Stark, Phys. Ztschr, 2, p. 233, 1900. McLennan, Ztschr, fuer Phys. Chem. p. 513, 1901. Seitz, Drude Ann. 6, p. 1, 1901.

sorb the rays and thus shorten their path. This absorption is the same for equal mass-lengths of all substances. The extent of a certain kind of rays was found to be 2 cm in air of 760 mm pressure and 10 cm for hydrogen at the same pressure. For all gases at the lowest obtainable pressure, (0.000009 mm or about 1/85000000 th of an atmorphere) this path was found to be limited only by the end of the observation tube which was 150 cm long.

The absorption is not always the same but varies greatly with the conditions in the kathode tube; thus showing that kathode rays of different velocities must exist.

PATH OF RAYS IN A MAGNETIC FIELD.(1)—A bundle of kathode rays traveling through a magnetic field in a direction perpendicular to the lines of force is deflected. This deflection is not uniform for the whole beam of rays as appears from the fact that the rays are separated into a so-called magnetic spectrum, some being but slightly and others considerably deflected. This again shows that the kathode rays are not all alike; their velocities vary and probably may assume any values from 0 to a certain maximum which, according to Lenard, lies between 0.67×10^{10} and 0.81×10^{10} cm per second. i. e. less than 1/3 of the velocity of light. The deflection of the kathode rays is largely dependent on the gas-pressure in the kathode tube but is in no wise affected by the nature or the pressure of the gas in the observation tube.

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(1) Lenard, Wied. Ann. 51. p. 225. 1894.—52, p. 23, 1894.—56, p. 255, 1895. Birkeland, C. R. 123, p. 492, 1896.—126, p. 228, 1898. Deslandres, C. R. 125, p. 373, 1897.—126, pp. 997, 1323, 1897.—127, p. 1210, 1898. Wiechert, Wied. Ann. 69, p. 739, 1899. J. J. Thomson, Phil. Mag. 44, p. 293, 1897.—48, p. 547, 1899.—Proc. Cambr. Phil. Soc. 9, p. 243, 1895.—10, p. 49, 1900. Braun. Wied. Ann. 60, p. 552, 1897.—65, p. 368, 1898. W. Kaufmann, Wied. Ann. 61, p. 544, 1897.—65, p. 431, 1898. E. Wiedemann and Wehnelt, Wied. Ann. 64, p. 606, 1898. W. Wien, Wied. Ann. 65, p. 440, 1898. Strutt, Phil. Mag. 48, p. 478, 1899. H. A. Wilson, Proc. Cambr. Phil. Soc. 11, p. 179, 1901.

PATH OF RAYS IN AN ELECTRICAL FIELD.(1)—If the path of the kathode rays is perpendicular to the lines of force, it becomes curved towards the positive plate. This deflection is directly proportional to the fall of potential in the field and inversely to the square of the ray's velocity. This law supplies one of the most convenient methods of measuring the velocity of kathode rays.

If the electric field is parallel to the direction of transmission, it exerts a force tending to change the velocity of the kathode rays. This change is positive if the kathode ray is directed oppositely to the lines of force and negative if it travels along them; or in other words, the kathode rays are attracted by and accelerated in the direction of a positive plate, whereas they are retarded if they are propagated in the direction of a negative plate. The most convenient way of showing this property of the kathode rays is to allow them to pass through an opening in the centre of two condenser-plates and then to observe the change in their magnetic deflectibility. The velocity of kathode rays may be accelerated in an electric field to fully 1/3 that of light.

2. EFFECTS OF THE KATHODE RAYS.—One of the most noticeable effects of the kathode rays is the fluorescence (2) they produce in many substances. In addition to the facts already known with regard to this property Lenard showed that the bluish light observed in vacuum tubes is nothing but the fluo-

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(1) Lenard, Wied. Ann. 64, p. 279, 1898.—65, p. 504, 1898. Goldstein, Wied. Ann. 48, p. 787, 1893.—Ver. der Phys. Ges. 2, p. 142, 1900.—3, p. 192, 1901. E. Wiedemann and H. Ebert, Wied. Ann. 46, p. 158, 1891. E. Wied. and G. C. Schmidt, Wied. Ann. 60, p. 510, 1897. E. Wiedemann, Wied. Ann. 63, p. 246, 1897.—67, p. 714, 1899.—Id. and Wehnelt, Fort. der Phys. 2, p. 811, 1898. J. J. Thomson, Phil. Mag. 44, p. 293, 1897.—48, p. 547, 1898. E. Schneider, Inaug. Diss. Erlangen, 1903.

(2) Wied. Ann. 51, p. 225, 1894.

rescence of the gas under the influence of the kathode rays which in themselves are completely invisible. These rays also produce fog-nuclei in gases traversed by them, (1) and charge negatively all bodies within their path. This is the case even when the vacuum is so great as to offer too much resistance for the ordinary transfer of electricity. Similarly kathode rays carry their negative charge through dielectrics which, under ordinary circumstances, isolate very well.

3. KATHODE RAYS FROM ULTRA-VIOLET LIGHT.—After having proved that ultra-violet light that is absorbed on a negatively charged surface produces kathode rays thereon, Lenard (2) began to study these rays which, on account of their much smaller velocity, offer advantages not possessed by the ordinary kathode rays. The study of these phenomena gradually led him to change his views with regard to the kathode rays. At first he had been inclined to consider these rays as waves in the ether but through his experiments with ultra-violet light, he came to the conclusion that the kathode rays are nothing but the path of the free elementary quantities of negative electricity. Under ordinary circumstances this electricity is bound to matter but when the ultra-violet light is absorbed at the surface of a body, the vibrations of the elementary quantities are increased until these quantities finally break away from matter and travel into space because of their own velocity and the action of some external force; this force is generally in the nature of an electrical field. If this field exerts a retarding force of sufficient intensity, the electrical quantities may be brought back to the charged surface which under these circumstances will show no loss of electrification. The production of negative electrical quantities is always accompanied by the production of an equal number

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(1) Wied. Ann. 64, p. 279, 1898.

(2) Drude Ann. 2, p. 359, 1900.—3, p. 298, 1900.—8, p. 149, 1902.—12, p. 449, 1903.—12, p. 714, 1903.

of carriers of positive electricity. The velocity of these is generally much smaller than that of the negative carriers. When a gas is ionized by kathode rays of a velocity less than that corresponding to –11 volts, there is no evidence of positive carriers on account of their possessing no velocity in this case. The positive carriers are of the same order of magnitude as atoms and molecules and are most probably the atoms or molecules of the gas.

In connection with this it may be interesting to give Lenard's views on the different quantities with which we are dealing in physics. According to him, four things are always to be distinguished:—

1. The atoms of chemistry. These constitute matter.

2. Ether, that hypothetical substance which transmits light electricity, etc.

3. Electrical quantities. They are not material although coming out of matter. The path of these quantities of negative electricity constitutes the kathode rays.

4. Electrically charged atoms, or carriers of electricity.

It must be noticed however that many physicists apply the term ion to the quantities under the two last headings and that many do not admit the existence of these "free" electrical quantities. According to them, the quantities of negative electricity which constitute the kathode rays are bound to a small fractional part of the atom. Lenard does not suppose this splitting up of the atom. According to Lord Kelvin and Helmholtz, we must admit the structural nature of the atom but its splitting up is not concluded from their discussions.

From a later paper by Lenard may be seen what is to be understood by chemical atoms or matter. The atoms are groups of "dynamides" having in all probability the same extension and inertia for all substances. They are electrical fields of force, their true radius is exceedingly small and the space between the several dynamides is very large in relation to the space occupied. If the dynamides in a cubic metre of platinum could be crowded together so as not to leave any intervening space, they would not occupy more than one cubic mm. In one of his last papers (1) he says that a pair of elementary electrical quantities in rapid rotation would be the simplest conception of a dynamide, or of part of it, thereby showing that he perhaps no longer regards the splitting up of the atom as an impossibility.

All these views are not mere speculation. They are an attempt to account for the absorption of kathode rays of different velocities (2) and the diverse other facts concerning them. The most important of the facts that led to the preceding views are the following:- The effective radius of the component parts of the atom is variable. For rapid kathode rays the absorption is proportional to the density of the absorbing medium, and is in no wise influenced by either its chemical or its physical constitution. The diffusion and the secondary radiation follow the same law.

4. REFLECTION OF THE KATHODE RAYS.—The only important property of kathode rays not thoroughly studied by Lenard is their reflection from solid surfaces. Consequently the facts concerning this phenomenon will be taken from the work of other experimenters. (3)

This reflection depends largely on the velocity of the kathode rays. For very slow rays it is small; with increasing velocity it increases up to a certain maximum, from which it drops

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(1) Drude Ann. 12, p. 714, 1903.

(2) Lenard, Drude Ann. 12, p. 714, 1903. R. J. Strutt, Nat. 61, p. 539, 1900. H. Becquerel, C. R. 130, p. 206, 1900.—130, p. 809, 19.0. P. and S. Curie, C. R. 130, p. 647, 1900.

(3) Starke, Wied. Ann. 66, p. 49, 1898.—Drude Ann. 3. p. 75, 1900. Campbell Swinton, Phil. Mag. 48, p. 132, 1899. Austin and Starke, Drude Ann. 9, p. 271, 1902. Segny, C. R. 122, p. 134, 1896. Swinton, Proc. Roy. Soc. 64. p. 377, 1899. Villard, C. R. 127, p. 223, 1898.—130, p. 1010. 1900. Seitz, Drude Ann. 6, p. 1. 1901. Stark, Phys. Zeitschr. 3, p. 161, 1902.

again and approaches a nearly constant value for all higher velocities.

The angle of maximum emanation, i. e. the angle formed by the incident rays and the direction of maximum emanation is different for different substances.

The phenomenon of reflection is always complicated and consequently difficult to study quantitatively since the reflection is accompanied by a secondary emission which can not well be separated from the reflected rays.

When the kathode rays undergo reflection as well as diffusion, their velocity is generally decreased and they are less homogeneous than they were before incidence. (1)

5. CHARGE OF THE KATHODE QUANTITIES: e/m.— The value for the charge e, carried by an ion in electrolytes has been determined by electrochemists as 1.29×10^{-10} electrostatic units. Several authors have also established the charge of an ion in gases by means of the ionization obtained through Roentgen rays or ultra-violet light. The mean of the values that were reached is 6.5×10^{-10}. This is at least in the same order of magnitude as that obtained from electrolysis and, considering the uncertainty of the methods used, the unit charge of an ion may be looked upon as a universal constant.

The relation of charge to mass, e/m, in the kathode rays was investigated by many experimenters. Their first results were widely divergent but the latest computations are in closer agreement. The most reliable determinations are probably those given below:–

J. J. Thomson, (1897)	$1—1.43 \times 10^{7}$	C. G. S.	Units.
Ph. Lenard. (1899)	1.15	"	"
Kaufmann, (1901)	1.86	"	"
Sarke, (1903)	1.85	"	"

(1) E. Gehrke, Drude Ann. 8, p. 81, 1902.—8, p. 480, 1902.

From these results and from the preceding ones about the charge of one of the ions the apparent "mass" of one of the kathode quantities may be obtained if we assume that their charge is equal to that of the ions. On this assumption it has been found to be more than 1 000 times smaller than that of a hydrogen atom. But the most recent work of the best physicists seems to require a much smaller mass for those particles.

All attempts to determine the relation of charge to mass in the elementary negative quantities of the kathode rays, or in other words, the specific charge of those quantities, have been carried out with the greatest care especially during the past few years. Despite this results so widely different have been obtained that their disagreement could no longer be considered as being between the reasonable limits for errors of observation: thus for instance, W. Wien found 0.3×10^7 and Simon 1.865×10^7. A closer investigation of the subject revealed the fact that for lower velocities of the kathode rays, this relation was constant or nearly so, whereas for greater velocities it varied. The following values given by Kaufmann show these variations:—

V. of Kathode Rays in 10^{10} cm/sec.	2.36	2.48	2.59	2.72	2.83
e/m in 10^7 C. G. S. U.	1.31	1.17	0.975	0.77	0.65

Since from other considerations we may assume that the electric charge e is a constant, we are compelled to admit that the mass of the kathode quantity varies. This apparent increase in mass becomes especially evident when the velocity of light is being approached by the kathode rays.

B.—ROENTGEN RAYS.

When kathode rays of sufficient velocity fall upon a metallic or other solid surface, their energy is partially transformed into a much more penetrating form of radiation.

The new rays were first studied by Roentgen (1) who called them "X-Rays" on account of their unknown nature. Goldstein's "Differentiated Rays" which were studied in an earlier chapter may have been partly Roentgen rays; but they included certainly also reflected kathode rays whereas Goldstein does not make any distinction between several kinds of differentiated rays. So Roentgen is rightly known as the discoverer of the rays which bear his name although he certainly was not the first to observe effects produced by them.

The main characteristics of these rays are:—their behavior in a magnetic field, their penetrating power, their ionizing and fluorescing properties. A magnet has no influence on them and they do not suffer any refraction. Their penetrating power is determined almost entirely by the density of the body on which they impinge. The vivid fluorescence which they cause and their effect on photographic plates have proved of no small practical usefulness.

C.—CANAL RAYS. (2)

As the kathode rays are the path of free negative electrical quantities, so the canal rays are the path of positive electrical quantities or positively electrified particles.

The velocity of the latter is generally much smaller than that of the kathode quantities but it is considerably increased when

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(1) Sitzb. der Wuerzb. Phys.-Med. Ges. 1895. Beitrag.

(2) Goldstein, Wied. Ann. 64, p. 38, 1898.—Verh. der D. Phys. Ges. 3, p. 205. 1901.—4, p. 228, 1902. W. Wien. Verh. der D. Phys. Ges. p. 165, 1897.—p. 10, 1898.—Wied. Ann. 65, p. 441, 1898.—Drude Ann. 5, p. 421, 1901.—8. p. 244, 1902.—9, p. 660, 1902.—Phys. Zeitschr. 3, p. 440, 1902. Schuster, Proc. Roy. Soc. 47, p. 557, 1890. Arnold, Diss. Erlangen, 1897.—Wied. Ann. 61, p. 325, 1897. E. Wiedemann and G. C. Schmidt, Wied. Ann. 62, p. 468, 1897. G. C. Schmidt, Drude Ann. 9, p. 703, 1902. Villard, C. R. 126, p. 1564, 1898. Wehnelt, Wied. Ann. 67, p. 421, 1899. Ewers, Wied. Ann. 69. p. 167, 1899. Townsend, Phil. Mag. 6, p. 598, 1903.

the positive particles traverse the rapid fall of potential at the kathode. There they produce the fluorescence which is generally known as the first kathode layer. If the kathode is not continuous they proceed through and beyond the openings as canal rays because of the velocity acquired in the kathode fall. It is in this manner that canal rays are usually produced.

They are not deflected by a magnet so easily as are the kathode rays. This deflection is opposite to that of the latter and separates the canal rays into several groups, showing that the positively electrified particles which constitute them have masses of different orders of magnitude. There may be other kinds of rays in this group of canal rays besides those defined by the order of magnitude of the particles which constitute them. Thus E. Goldstein, (1) basing his division on the color of the fluorescence produced by them and on their different methods of propagation, thinks that what is commonly known as "canal rays" is a complex of at least five different kinds of rays.

These conclusions are not astonishing in view of the careful work of Willy Wien, (2) who showed conclusively that the canal rays are very different in different gases and described the difficulties he encountered in his efforts to obtain pure gases in his discharge tubes on account of the occluded gases constantly given off by the kathode.

From his experiments it seems probable that while the canal rays approximately retain their initial velocity, the relation of charge to mass is a variable one for the same particle. The values of this relation vary from 0 to 36 000, the latter being for canal rays in hydrogen at a discharge-potential of 9 000 volts. It also seems probable that the canal rays are produced from the gas in the tube, since in highly exhausted tubes they are

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(1) Verh. der D. Phys. Ges. 4, p. 228, 1902.
(2) Drude Ann. 8, p. 244, 1902.—9, p. 660, 1902.

entirely absent while kathode rays are still in evidence: these are produced from the negative electrode.

Canal rays as well as kathode rays are influenced by an electrostatic field. When the rays are parallel to the lines of force they are either retarded or accelerated, the former taking place when they travel with the lines of force, the latter when they travel against them. In a field that is perpendicular to their path of propagation they are deflected towards the negative plate.

The chemical effects of these rays generally consist in the dissociation and splitting up of more complex molecules in the gas which they traverse. When they acquire sufficient velocity the dissociation produced by them may assume an electrical character which is evidenced by secondary radiation and ionization.

III.—POTENTIAL PHENOMENA.

1. FALL OF POTENTIAL. (1)

The general behavior of the fall of potential was carefully studied during this period. As might have been expected, the potential gradient was found to be very different in the three main parts of the discharge:- the positive light, the dark space and the negative glow. The maximum fall is always in the dark space near the kathode, the minimum in the negative glow. At the anode there is also a great fall followed by a much smaller value. Within the unstriated posi-

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(1) Graham, Wied. Ann. 64, p. 49, 1898. Skinner, Wied. Ann. 68, p. 752, 1899.—Phil. Mag. 50, p. 563, 1900. G. C. Schmidt, Drude Ann. 1, p. 625, 1900. H. A. Wilson, Phil. Mag. 49, p. 505, 1900. Wehnelt, Drude Ann. 7, p. 237, 1901. J. Stark, Drude Ann. 5, p. 89, 1901. H. Starke, Verh. der D. Phys. Ges. 5, p. 364, 1903. D. Rudge, Proc. Cambr. Phil. Soc. 12. p. 155, 1903. N. S. Taylor, Phys. Rev. p. 321, May, 1904. R. S. Willows Phil. Mag. 9, p. 370, 1905. Townsend, Phil. Mag. 9, p. 289, 1905.

tive light there is no change in the potential gradient but if the tube presents striations, the fall of potential curve is a succession of relative maxima and minima. The former begin at the beginning of the bright layers, i. e. at the bright part nearest the kathode; the latter are found towards the end of the layers, i. e. in the dark part nearest the anode.

In the dark space the potential gradient rises gradually in the direction from the kathode to the anode, sometimes showing small maxima and minima.

2. KATHODE FALL. (1)

The difference of potential between the kathode and the beginning of the negative glow is called "Kathode fall." It decreases very rapidly in the kathode dark space but this decrease does not always obey the same laws. As long as the negative glow can extend itself symmetrically over the surface of the electrode, the kathode fall is normal, but as soon as this negative glow is forcibly restricted to surfaces smaller than those which it would naturally tend to cover, the kathode fall becomes abnormal. The normal fall is independent of the current-intensity but varies with the pressure and the nature of the gas. When the negative light is prevented from extending freely, the potential fall at the kathode increases with increasing current. The relation between these two quantities is represented by one branch of a parabola.

The normal kathode fall is not influenced by the pressure of the gas but when the kathode fall becomes abnormal it

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(1) Paalzow and Neessen. Wied. Ann. 56, p. 700, 1895. Capstick, Proc. Roy. Soc. 63, p. 356, 1898. E. Wiedemann, Wied. Ann. 67, p. 714, 1899. Strutt. Proc. Roy. Soc. 65, p. 446, 1900. G. C. Schmidt. Drude Ann. 1, p. 625, 1900. Heuse, Drude Ann. 5, p, 670, 1901. Wehnelt, Drude Ann. 7, p. 237, 1902. Skinner, Phil. Mag. 2, p. 616, 1901. E. Riecke, Drude Ann. 4, p. 592, 1901. J. Stark, Phys. Zeitschr. 3, pp. 88, 165, and 274, 1902.—Drude Ann. 12, p. 1, 1903.—12, p. 31, 1903. Cunningham, Phil. Mag. 4, p. 684, 1903.—9, p. 193, 1905.

increases slowly at first and then rapidly as the vacuum becomes higher.

Finally it may be noticed that heating the kathode considerably decreases the potential gradient, and that a weak transverse magnetic field somewhat lowers the kathode fall, while a strong field makes it rise rapidly. On the contrary if a magnetic field is parallel to the kathode rays, it does not influence the kathode fall.

CHAPTER IV.

THEORY OF THE DISCHARGE.

1. VOCABULARY.

Unfortunately there is still in this branch of physical science a confusing variety of terms without any universally recognized definition. Some terms are used to denote entirely different things, while inversely the same thing often has several appellations. The two words "ion" and "electron" which are certainly very extensively used, may serve as an illustration.

The term "ion" was first used by Faraday:- "Finally", he says speaking about electrolytes, "I require a term to express those bodies which can pass to the electrodes, and I propose to distinguish such bodies by calling those anions which go to the anode of the decomposing body; and those passing to the kathode, kations; and when I have occasion to speak of these together, I shall call them ions. Thus the chloride of lead is an electrolyte, and electrolyzed evolves the two ions, chlorine and lead, the former being the anion, and the latter the kation." Here ion in its original sense means an atom or molecule carrying an electrical charge. It still retains this signification in electro-chemistry and is used in the same sense by a great many physicists in the subject now under discussion. But some authors define the ion as an elementary quantity of electricity which is not bound to a similar quantity of opposite sign. Thus they speak about molions, atomions and electronions, meaning an electrically charged molecule, atom or electron.

This word electron is defined by them as the elementary quantity of matter though it is still used by the majority of physicists in its original and more appropriate meaning, i. e. the elementary quantity of electricity.

To this must be added that, in order to avoid the confusion resulting from the use of these terms, other authors entirely dispense with them and employ only such terms as carry with them their own meaning: thus for instance Lenard speaks of electrical carriers and elementary quantities of electricity. This seems to be a better method than using the other words without going to the trouble of defining them but it has a drawback in this that it again introduces another set of terms into the subject. It would seem preferable to retain the words ion and electron, as has been done by representative physicists in the few last years, in their time-honored original meaning of electrically charged atom or molecule and elementary quantity of electricity respectively. It is this sense that will be given them throughout the following pages.

Since the structural character of the chemical atom may now be looked upon as definitely established, it would also be convenient to have a name for those extremely minute parts whose grouping constitutes the atom. Several terms have been suggested:- energon by Reuterdahl and dynamide by Lenard The latter word is founded on the strongly sustained hypothesis that these minute parts constitute electrical fields of force through the juxtaposition of a negative and a positive electron. The word corpuscle extensively used by J. J. Thomson would be an appropriate appellation were it not for the fact that this author uses it in a slightly different sense.

The term kathode ray is not interpreted in the same manner by all physicists. Some introduced a distinction between kathode and Lenard rays:- A kathode ray for them is the path.

of any particle that carries negative electricity whereas the Lenard ray is the one outside the kathode tube after all the particles larger than the electrons have been sifted out by the aluminium window. But there is no necessity for making this distinction, and we may, with the majority of physicists, define a kathode ray as the path of the negative electrons.

II.—EARLIER SYSTEMS.

This subject is relatively very recent and it is largely on this account that there is so much embarrassing confusion. Another potent factor in bringing it about is the variety of systems set up for the explanation of the facts that were gradually discovered. These systems are scarcely less numerous than the investigators, although quite frequently they differ only in some minor details.

One of the earliest theories was that advanced by G. Wiedemann, according to whom the molecules are electrified near the charged electrodes and then repelled according to well-known electrical laws. These molecules do not travel from one electrode to the other but by their impact on others they give them their charge which is thus transmitted until it is neutralized on meeting an opposite charge on molecules coming from the other electrode. Moreover if the gas may be dissociated electrolytically, the transfer of electrical energy may be accomplished by the separation, the convection and the reunion of ions as in the electrolytic process.

A somewhat similar theory was adopted by Sir W. Crookes and supplemented by a revival of Faraday's ideas concerning a fourth state of matter. Puluj proposed another theory in which the particles that effected the transfer of electricity were not the molecules of the gas but the electrode-dust thrown off from the kathode at a great velocity and carrying with it a strong negative charge.

Another class of hypotheses was based upon the supposition that the electric discharge was a phenomenon in ether. This view was favored by a great many careful experimenters. But gradually the electrolytic dissociation theory already proposed by G. Wiedemann gained ground, thanks to the efforts of such able defenders as Schuster, Giese, Elster and Geitel, J. J. Thomson and many others. To day all physicists seem to admit that gases may become conductors in an electrolytic sense and that consequently electricity may be conveyed through them by the migration of ions.

But this dissociation is insufficient to account for the phenomena that occur in rarefied gases. Moreover it could not possibly be applied to conductors of the first order, although it seems natural to suppose that whenever there is a current of electricity, whether in metals, electrolytes or gases, the essential nature of this current is always the same. The following theory which may be called the electron theory seems to offer a fundamental idea applicable to the several kinds of electrical conduction.

III.—ELECTRON THEORY.

A.—FOUNDATIONS OF THE ELECTRON THEORY.

The electron theory which may be defined as the theory of electric dissociation is founded on several branches of physical science, the most important of which is electricity itself. The ideas of scientists with regard to the nature of this important agent have gradually undergone a change. The single- and two-fluid theories were the earliest conceptions of electricity, but for many great physicists they were only a convenient mathematical expression which proved very efficient in the analytical treatment of the various problems connected with electrical forces.

By laying down the fundamental laws governing electrolysis, Faraday furnished the fundamental idea on which a new theory was soon to build up. The first of these laws is the one stating that "the chemical decomposing action of a current is constant for a constant quantity of electricity," or that "the chemical power of a current of electricity is in direct proportion to the absolute quantity of electricity which passes". From this it follows that the quantity of electricity which passes is the equivalent of and therefore equal to that of the particles separated. The second law states that "electro-chemical equivalents coincide with and are the same as ordinary chemical equivalents".

These laws suggest the idea that the electrical charge pertaining to any valency of an ion may be a fixed quantity having a separate existence, so that there may be atoms of electricity as well as of matter. Weber and Helmholtz were the first champions of this theory which was soon to supplant the older fluid-theories. But their views were deficient in as far as they failed to sufficiently account for the action of electricity beyond the space occupied by the small particles. By conceiving these electrons imbedded in the cosmic ether and surrounded by an electromagnetic field of force, this objection is completely removed, while at the same time the exigencies of atomistic structure are satisfied.

This view of electricity still leaves the question as to its real nature an open one. It may be a separate substance different from what is ordinarily called matter or it may simply be a localized condition of the ether. The latter hypothesis is certainly the one by which the transmission of electrical force through the ether would be most easily accounted for.

ZEEMAN EFFECT. — The electron hypothesis received a further development from two other important sources:– the kathode rays and the Zeeman phenomenon. As the former will be discussed later on it will be enough to state the main facts concerning the latter.

It is well known that incandescent gases in general give a line spectrum and that each line represents a definite period of vibration. But if the gas is subjected to a strong magnetic field, an important change takes place in the spectrum. When the propagation of the light which causes a certain spectrum line is in the direction of the magnetic force, this line disappears and in its stead two new ones appear at an equal distance from the position of the original line. When the field is perpendicular to the light-wave, there are in general three lines of which the middle one occupies the original position. In some cases these general phenomena are even more complicated, the D_1 line for instance yielding four new lines, while D_2 is resolved into six by a magnetic field.

A careful study of these phenomena revealed the fact that the new vibration periods are due to a negatively electrified particle, for which e/m is about 1000 times greater than for a hydrogen atom. Since we may assume that the electrical charge is equal in both cases, it will follow that the mass of the vibrating particle is very small and that the Zeeman effect is due to a magnetic influence on the negative electrons which possess a greater freedom of motion than the positive electrons. In the case of kathode rays this greater freedom results in a total liberation from the influences of the atom and of the positive electrons.

B.—APPLICATION OF THE ELECTRON THEORY TO THE DISCHARGE OF ELECTRICITY THROUGH GASES.

The foregoing views which to a great extent are only a statement of facts, furnish a new explanation for the conduction of electricity. In this new theory the negative electrons are looked upon as separable from the atom. They possess a certain freedom of vibration within the atom, which vibration may be increased by the absorption of radiant energy, by electrical tension, etc., to such an extent as to overcome the attraction of the positive electron and the rest of the atom. In such a case the negative electron breaks away from its former vibrating position and travels into space with a velocity that is determined by its own energy and the amount of exterior forces acting on it. At the same time the rest of the atom, which has now a positive charge, moves in the opposite direction. These motions or migrations constitute the electric current. The only difference between rarefied gases on the one hand and electrolytes and gases of a higher pressure on the other lies in the fact that in the former the negative electron may travel on for a great distance while in the latter, some atoms or molecules immediately condense on it, thus forming the electrolytic negative ions. In conductors of the first order conduction is similarly accounted for by a motion of electrons. We assume that in these solids there is always a number of free electrons which move in the interatomic space as soon as new electrons enter from any of the several sources of electricity. These free electrons might be both positive and negative, but since we have no sufficient evidence for admitting the separate existence of positive electrons, we may assume that the conduction is effected only by negative electrons. This hypothesis sufficiently accounts for all the known facts by assuming that when a negative ion is being deposited on the anode, it gives up its negative electron while a positive ion arriving at the kathode takes a negative electron from the kathode itself. For entirely metallic circuits, a current of electricity would be nothing but a motion of negative electrons in one direction.

Let us now apply the electron theory to the passage of electricity through rarefied gases with which we are mainly concerned.

Generally a gas contains some ions although their number may be very small. As soon as a difference of potential is established between the two electrodes, these ions move in opposite directions, thereby causing the weak current which is noticed long before the difference of potential becomes high enough to produce the well-known phenomena of the discharge.

This current is purely electrolytic in character and in consequence of the relatively greater velocity of the negative ions it produces a greater rarefaction near the negative electrode. As the difference of potential rises the vibration of the negative electrons on the kathode becomes more intense until it finally reaches a value which allows these electrons to break their connection with the atom. They are then thrown off from the kathode at a high velocity. By impinging on the atoms of the gas they produce other negative electrons and a corresponding number of positive ions.

FIRST KATHODE LAYER.—The initial path of these new carriers has every possible direction but all the positive ions are gradually bent back by the electrical field towards the kathode.

The great fall of potential near the latter gives them a velocity sufficient to produce a vivid fluorescence when their path is stopped by the solid electrode. This gives rise to the so-called first kathode layer.

KATHODE DARK SPACE AND KATHODE LIGHT.—The relative darkness of the next layer is due to the few impacts of the negative electrons on account of their high velocity and the relative scarcity of the positive ions. These impacts gradually increase in number up to a place well within the negative light. The negative electrons, like the positive ions, at first travel in every direction, but those which return towards the kathode, being gradually retarded by the rapidly increasing force acting against them, are finally stopped and repelled towards the anode. The third kathode layer is chiefly due to the secondary negative electrons. Its greater luminosity is accounted for by the larger number of impacts for slow electrons in a given cross-section; its sharp definition is a natural consequence of the rapidly increasing strength of the electrical field near the electrode, the point where this field will be able to destroy the oppositely directed velocities will be practically the same for all negative electrons. It may not be evident at first why the absorption of slower electrons should be greater than that of swifter ones in the same length of the gas-column, but this is a direct consequence of the concept of matter which underlies this theory. The atom has structure and its component parts are at least mainly, if not essentially, electric fields of force resulting from the juxtaposition of two electrons of opposite sign. In such a field of force the true radius of the component electrons and the efficient radius of the field are two different things. By true radius is meant the radius of the space occupied by the electrons while the term "efficient radius" denominates the radius of the electric field which is sufficient to completely counterbalance the velocity of a negative electron crossing it. This effective radius is naturally different for different velocities, and beyond it the negative electrons are merely retarded.

DARK SPACE.—The great production of negative electrons and positive ions within the negative glow results in a rapid rise of the potential gradient. The ionization decreases and finally ceases almost entirely, thus bringing about the dark space.

POSITIVE LIGHT.—The relative scarcity of electrons and ions due to this absence of ionization causes a decrease of conductivity and consequently another drop in the potential gradient. This difference of potential again accelerates the negative electrons and gives them energy enough to produce new ions and electrons by impinging on the atoms. The place where this new ionization sets in is the beginning of the so-called positive light. This light appears under two distinct forms:—the striated and the unstriated.

UNSTRIATED POSITIVE LIGHT.—If the ionization and the electrical forces in this part concur in producing negative electrons and positive ions of all velocities, these will continue producing an ionization whose amount will be practically the same for all cross-sections in the column of light. In this case there will be no appreciable difference in the potential gradient between any two points; as a result the luminosity of the gas will be nearly the same throughout the whole length of the positive light and the discharge will be unstratified.

STRIATION.—But if a majority of the electrons have, or acquire, nearly the same velocity, their mean free path will be the same. Within this free path very little ionization will take place and consequently a dark layer will be produced and the potential gradient will fall again. When they have reached the end of their free path, new electrons are produced in great numbers; this gives rise to a greater degree of luminosity and to an increase in the potential gradient. The luminous layer will be succeeded by a dark one, the latter again by a brighter one and so on until the anode is reached. This is the striated discharge. The fundamental idea underlying this explanation was first advanced by Goldstein who considered each brilliant layer of the positive light as the starting point of a new current. It appears readily how a new period of ionization really supplies the elements for a new current.

ANODE LAYER.—The conditions near the anode are mainly dependent on the state of ionization of the gas in its immediate neighborhood. If few electrons and ions are present there is a rapid change in the potential gradient, the velocity of the existing electrons is accelerated and these will produce ionization and a brilliant layer on the surface of the anode. If on the other hand this electrode is in the negative glow or in any part of the tube where there is a high conductivity, the anode fall is small, very little ionization is produced and the anode layer becomes faint or vanishes completely.

At the beginning of this discussion it was supposed that the increase of vibration which resulted in the separation of the electron from the atom, was due to the high potential at the kathode and that thus an electric current was established in the gas. This however is not the only cause that may produce the same result. If the kathode absorbs energy from ultra-violet light or an exterior source of heat, this energy passes to the electrons and increases their vibration Ultra-violet light is an electro-magnetic vibration propagated through the ether in very short wave-lengths. These vibrations excite a stronger activity in the negative electrons and give them sufficient energy to allow them to overcome the attraction of the positive electrons with which they are associated. These negative electrons then pass into the surrounding gas and thus bring about the discharge of the plate on which ultra-violet light is impinging. If this plate is not charged initially, the effect of ultra-violet light is still the same but in such a case the throwing off of negative electrons will result in leaving it with a positive charge. Heating the kathode has a similar effect because heat is a vibratory motion communicated to the electrons.

When a gas surrounding a charged body is directly ionized by an external agent such as ultra-violet light, kathode rays, Roentgen Rays, Becquerel rays, etc., the ions thus produced receive an acceleration from the electric field near the charged surface. The current thus established lasts as long as there are free ions in the gas. If the field is strong enough to increase the velocity of the ions to such a degree as to allow them to ionize more gas in their turn, a new current directly produced by the electro-motive force of the electrode is established. Hence as a general rule, currents may be divided into two main classes:- the dependent and independent currents. The dependent currents are those that consist entirely in the motion of ions produced by an external agent. The independent currents again are of two kinds:- completely so or only partially so. The former are established by the electro-motive force of the electrodes while the latter need the help of some exterior agent for beginning but are then maintained by the difference of potential between the electrodes.

C.—THE ELECTRON THEORY AND THE DIFFERENT KINDS OF RADIATION.

1. KATHODE RAYS.

Kathode rays are the path of negative electrons. This view is universally held to day with one unimportant exception. Some authors apply the term kathode ray to the path of any carrier of negative electricity, whether this carrier be an electron or an ion. It is only a question of words and it seems preferable to adopt the first definition because it is almost universally recognized.

For a long time, the most notable experimenters v. g. Hittorf, Hertz, Goldstein, Lenard (in the beginning of his work) and many others held an entirely different view. For them, a kathode ray was a process in the ether, pobably very refrangible ultra-violet light. The deflection of the ray by a magnet was explained by saying that it was an effect similar to the rotation of the plane of polarization. This at best was not a very clear explanation. These views naturally led to the conclusion that the kathode ray was merely a phenomenon accompanying the electric discharge without taking any part in it.

But gradually the electrical character of these rays was established, and they came to be looked upon as one of the most important factors of the discharge through their power to produce ionization.

The real nature of the electrons, those quantities which constitute the kathode rays is still under discussion. To explain them, one of two hypotheses must be admitted:–either the kathode quantity is part of the material atom with an elementary charge of negative electricity or it is this elementary quantity existing independently of matter. This second view has been held throughout this discussion. No convincing reason can be given against it. The strongest argument adduced by the adversaries of this theory is that it is an altogether new assumption. But this is likewise true of their own hypothesis for although radium emanation shows after some time the spectrum of helium, the faintest trace of which could not be previously detected, thus showing that some change had taken place in the atomic structure of the expelled gases, still these changes involve immense groupings of the elementary constituents of matter and do not justify the conclusion that one of those small parts with its negative charge, can be separated from the atom. An analogous case is found in the more complicated chemical molecules: when such a molecule is broken up by heat or otherwise, the resulting bodies are never one solitary atom and the former molecules with only a slight change, but new molecules are formed which represent a grouping that already existed in the first molecules. Thus oxalic acid for instance, may in several ways be broken up by heat, yielding carbon monoxide, carbon dioxide, water and formic acid, according to the following formulæ:—

$$(COOH)_2 = CO_2 + H.COOH$$

$$2(COOH)_2 = 2CO_2 + CO + H.COOH + H_2O$$

But no single atom ever breaks off, leaving the rest of the compound in an incomplete grouping.

By assuming that the electron is nothing but an elementary quantity of electricity, this difficulty is avoided. This is not the only advantage of the electron theory as exposed above. Another difficulty against assuming that there is a material mass connected with the elementary quantity of the kathode ray comes from the fact that we have no evidence of its mass unless it be in motion. Thus the highest charge on a conductor does not bring about the slightest difference in mass, nor is any transfer of mass ever noticed in a conductor of the first order through which a current is passing. This, in connection with the fact that the mass of an electron is a function of its velocity warrants the conclusion that this mass is entirely electro-magnetic in character. It is easy to see how self-induction and the resistance of the surrounding field against deformation by any external cause may sufficiently account for this apparent mass; for a rapidly moving electron is to all intents and purposes an electric current which, on account of the extremely small radius of its carrier, creates an intense field of force in its vicinity. Any force tending to deform the field will expend an energy that will be resisted by the electron. This inertia is sufficient to explain all the facts that have been observed up to the present.

A very interesting but complex phenomenon occurs when a kathode ray strikes a solid obstacle. In such a case the ray may be:– 1. transmitted, 2. reflected, 3. deflected, and 4. absorbed and changed into a new form of energy. These phenomena may all happen at the same time and several of them are always produced simultaneously. This behavior is easily explained by the electron theory.

Thin sheets of metal allow the kathode rays to pass through them because of the almost infinitesimal radius of the electron and the relatively large space between the small quantities whose grouping constitutes the atom as well as between the atoms and molecules themselves. But the electrons are at the same time subjected to the influence of the parts of the atom, which influence tends to destroy their velocity and to change their original direction. In fact kathode rays are retarded in going through an aluminium window and they issue from it in all directions.

But some electrons will impinge on the space really occupied by the obstructing body and because of their elasticity be reflected. This reflection will necessarily be diffuse because the surface on which they strike will always be rough for such small quantities as the electrons. This real reflection may be accompanied by something of a quite similar nature. Instead of striking against the solid parts of the substance, the kathode quantities may be gradually brought to rest and then accelerated in the opposite direction by the opposing field of force, since a body on which they strike becomes thereby negatively charged.

Deflection may also take place on account of this same negative charge, especially if the angle of incidence is great. This follows from the very nature of the electron viewed as an elementary quantity of negative electricity.

Ultimately, whenever the kathode rays impinge on a solid some of their energy is transformed. They may thus cause an increase of vibration and consequently heat and fluorescence. And again when they impinge on any particle, they will be suddenly stopped, at the same time throwing the particle out of its ordinary vibratory path. This will result in a stress in the ether and in a wave that may be characterized as an electro-magnetic pulse, since it is of very short duration. This phenomenon is known as the Roentgen ray. It is evident why the intensity of this ray should increase as the velocity of the producing kathode ray increases since the disturbance created in the ether will be more intense for greater velocities.

The Zeeman effect shows how light is probably due to the vibration of the negative electron around its point of rest. This vibration, i. e, the constant varying between the velocities O and a certain maximum, sends out into the surrounding ether a continuous train of electro-magnetic or light-waves. When the negative electron is suddenly stopped in its path by striking on a solid surface, the same sudden, or rather, a more sudden variation of velocity occurs, and consequently an electro-magnetic disturbance is propagated through the ether. After having been thus stopped, the electron may not return or may return with an acceleration quite different from what it had before arriving. If, therefore, we look upon a wave of light as produced by a regular full or half vibration, we will not be justified in calling the Roentgen ray a wave, since it lacks the regularity which this name implies: hence the name electro-magnetic pulse.

2. CANAL RAYS.

In discussing the first layer of the kathode light we assumed a continuous electrode. If this is not the case, some of the positively charged particles instead of impinging on the kathode, continue through the openings and by their high velocity are constituted canal rays. These rays may also be produced by accelerating the positive carriers in a strong electro-static field.

The nature of the canal rays is not known so well as that of the kathode rays owing partly to their more complex character. In kathode rays the so-called magnetic spectrum which is due to differences of velocity. But in canal rays there is also different deflectibility which can not be accounted for by different velocities. There are some rays that can not be deflected even by the strongest electro-magnets although their velocity is of the same order as that of those which are deflected.

Again, these rays show widely different values for their specific charge, e/m. This might be accounted for in two ways:- neutral atoms or molecules combine with the charged particle, the charge meanwhile remaining constant; or the mass remains constant while the charge varies. The latter hypothesis is the more probable owing to the general behavior of the rays. The electron theory offers a ready explanation of this. There is no reason to suppose that only one negative electron may be separated from the atom for all the electrons enjoy an equal freedom of motion and, consequently, it may happen that several of them are separated from the atomic group at the same time. But each negative elementary quantity of electricity that is thrown off makes it harder for the others to break their connection with the atom. As a consequence, a limited number can only be separated and, moreover, the atom positively electrified in this way will tend towards neutralization by combining anew with the negative elementary quantities which it may meet in its path. This accounts for the change of the specific charge of the rays during their propagation and for all their known properties:—

The rays that are not deflected are the path of those particles which have become completely neutralized before entering the electric or magnetic field applied to the tube. The several groups produced by a deflecting force are formed by such particles as retain an equal charge.

Finally, this recombination explains the fact that in very highly rarefied gases the current can pass much longer than could be expected from the computation of the number of molecules in the tube, for the gas is being constantly regenerated, thus rendering possible the production and transfer of new carriers, or in other words allowing the current to continue.

3. Becquerel Rays.

There are two differences between the Becquerel rays and those hitherto discussed but neither of them is essential. The one is quantitative while the other concerns their source. Quantitatively, Becquerel rays and in particular radium rays are generally stronger than the corresponding rays produced in an ordinary vacuum tube. Thus α rays correspond to canal rays. β rays are strong kathode rays or in other words, they are negative electrons of high velocity. γ rays show all the characteristics of "hard" Roentgen rays. But while canal, kathode and Roentgen rays are obtained from ordinary bodies under the influence of some well defined exterior agent such as strong heat, ultra-violet light, a high electro-motive force, etc., they seem to be emitted by the radioactive substances without the absorption of any external energy.

The production of the γ rays is explained on the same principle as that of the Roentgen rays which they resemble in every property. But here the negative electrons strike against the particles of the radium itself and being thus suddenly stopped, produce the same electro-magnetic pulse which is generally very intense on account of the high velocity of the β rays.

THE CONSTITUTION OF MATTER.

The study of the electric discharge through gases and more particularly that of the kathode rays has led to a new concept of the nature of matter. The existence of electrons both positive and negative, grouped so as to neutralize one another, while allowing at the same time the negative electrons more freedom of motion, has led physicists to ask the question whether there is anything else but these electrons. If all the properties of matter can be explained on such a supposition, it will be logical to admit that the so-called material atom is nothing but a group of electrons. Inertia can be explained very well as has been shown for the negative electrons. Moreover it is possible to conceive that the small parts of the atom composed of one positive and one negative electron rotating around a common centre possess an apparent mass quite different from that which would have to be attributed to each separately because the radius of the rotating double elementary quantity would be different from the sum of their two radii, and the rotation itself would constitute a very important factor of this inertia.

The systems of electrons, or whatsoever the component parts of the atom may be, are the same in all substances. This seems to be an inevitable conclusion from the law that the absorption of rapid kathode rays is directly proportional to the density of the absorbing medium without being influenced by any of the physical or chemical conditions which this medium may assume. A quantitative study of this absorption shows that the real radius of the impenetrable system of two electrons must be less than 0.3×10^{-10} mm, and that the relation between the volume of the atom and that of a system of electrons is less than 10^{-9}. But the efficient radius is always greater, and consequently the above law which practically states that the efficient radius is the same for equal mass-lengths of all substances, supposes that the strength of the electric field is the same for the component parts in all atoms. In other words, the study of kathode rays has taught us the probable unity of matter.

Even more than this, it leaves us to suppose that the one and only thing which exists as a substance in the physical world is the universal ether. The electrons may be nothing but a localized condition of this same ether and consequently matter itself would be another modification of the universal substance which fills all space. Thus a grand unity which may eventually even lead us to a better understanding of gravitation possibly the most mysterious force of nature, would be at last established in our concept of the physical world.

BIOGRAPHICAL.

Nicholas M. Wilhelmy was born in Bech, Luxemburg, February 23, 1880. His first education was received in the public school of the same place. His secondary instruction was begun at Differt, Belgium. In September 1896, he entered the noviciate of the Society of Mary at La Bousselaye, France, and the following year began to study philosophy in the scholasticate of the same Society at Paignton, South Devon, England. He came to the United States of America in September 1900, and continued his studies successively in the Marist College, Washington, D. C., and in Jefferson College, La., from which he was graduated in 1903 with the degree of Bachelor of Arts. He was ordained to the priesthood in June, 1904. After matriculating at the Catholic University of America in 1903, he followed the courses in physics and chemistry under the Faculty of Philosophy and that of applied mathematics in the School of Technology.

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CHAPTER IV.—THEORY OF THE DISCHARGE.