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Graphical Methods of Recording Positive Ions

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GRAPHICAL
METHODS OF RECORDING
POSITIVE IONS

-by-

J.ohn DONALD HENDERSON

A thesis submitted to the Graduate Division
of the University of North Dakota in
partial fulfillment of the
requirements of the
degree
of
MASTER OF SCIENCE

* * *

Grand Forks, North Dakota
May 22, 1933

This thesis, presented by Mr. J. Donald Henderson, in partial fulfillment of the requirements for the degree of Master of Science, is hereby approved by the Committee on Instruction in charge of his work.

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ACKNOWLEDGMENT

The writer wishes to express his gratitude to Dr. John L. Hundley, Professor of Physics at the University of North Dakota, for the suggestion of this problem, for his assistance in constructing the apparatus, and for his valuable suggestions pertaining to the work.

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INTRODUCTION

In 1886 Goldstein shile studying electrical discharges in gases at low pressures used a perforated cathode in some of his experiments. In such a discharge tube there is a region that glows brightly just in front of the cathode, the color of the glow depending on the gas in the tube. With his perforated cathodes Goldstein noticed this glow in the form of streamers of light continued behind the perforations, unless the cathode was thick and the openings perpendicular to its surface. This seemed to indicate that a stream of particles of some sort was traveling toward the cathode during the discharge. Goldstein called these "canalstrahlen", which English writers wrote as "canal rays". A little later J. J. Thompson did a great deal of work with these rays and after finding that they normally carry a positive charge of electricity, he gave them their present name of "positive rays". Today the term positive rays applies to any stream of ions in the gaseous form which are carrying positive charges of electricity.

During the last part of the nineteenth century work had already been done with streams of electrons in an attempt to determine the ratio between their charge and their mass, so similar experiments were conducted with positive rays. Since these particles are relatively heavy, large forces are needed to change their paths; but just before 1900, Wien[1] succeeded in deflecting them with magnetic and electrostatic fields. His attempts to measure

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[1] Wien, Verh. d. Phys. Gesell., 17, (1898).

the ratio of e/m did not give very good results due to imperfect apparatus and methods. About 1908 Sir J. J. Thompson[1] began his work with positive rays. He carried on many experiments over a period of years but here again poor apparatus and undeveloped technique gave poor and sometimes incorrect results. The next man of importance to work along this line was F. W. Aston[2]. He made a great contribution to physical chemistry by using positive rays in the study of isotopes. It is a method, the sensitivity of which is appreciated when we learn that by it, traces of elements are found in samples known to contain the element in proportions of less than one part in 10,000 and probably less than one part in 100,000.

Thus before 1915 positive rays had been discovered and some of their properties examined; some values for the ratio of their charge to their mass had been measured for different elements; and it had been proved that they were of practical use in chemical analysis as made with a mass spectrograph. But even yet many of their characteristics have not been studied and consequently it is not known just how much further study of these rays may reveal in regard to the construction and properties of the individual atoms of the various elements. In fact, as yet there is no complete satisfactory theory of their production either in a gaseous discharge such as Goldstein studied or in their emission from hot filaments.

At present most work is being done with positive rays emitted by filaments and perhaps the best theory of this emission is that given by Langmuir and Kingdon[3]. In brief, this is as follows. If

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1. Thompson, J. J., Rays of Positive Electricity and Their Application to Chemical Analyses, Longman, Green, and Co. (1921).
2. Aston, F. W., Isotopes, Chap. III, Edward Arnold and Co. (1924)/
3. Langmuir, D. and Kingdon, K.H., <u>Science</u>, 57, 58 (Jan.12, 1923).

a filament is coated with some substance, e.g. caesium, upon heating this filament it is surrounded by a cloud of caesium vapor. Because of their thermal motion some of the caesium atoms in this cloud will come in contact with the filament. Then if the electron affinity of the filament is greater than that of the caesium, the caesium atom will be robbed of its outer or valence electron and will become a positively charged caesium ion which may be drawn away from the filament by applying a suitable difference of potential between the filament and a plate. However, the electron affinity of the filament depends not only on its material, but also on the proportion of the surface covered by the coating, which in turn depends on the temperature of the filament. In general the smaller the fraction of the filament covered with the coating, the greater is its electron affinity. Therefore when the filament is heated and more and more of the coating evaporates, a place is reached where the electron affinity of the filament is greater than that of the caesium atom and every caesium atom that strikes the filament loses an electron and leaves as a positive ion. After this point is reached, further increase in the temperature of the filament has no effect on the rate of emission of the positive ions. The rate of emission then depends only on the vapor pressure of the vapor surrounding the filament, or in other words, on the number of atoms striking the filament each second.

H. E. Ives[1] and R. A. Nelson[2] have each made studies of the

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[1] Ives, H. E., Bell Telephone Lab. Bul., Reprint B-182 (Feb. 1925).

[2] Nelson, R. A., Rev. Scientific Instruments, 2, 173-179 (March, 1931).

emission of different ions under different conditions and their findings agree quite well with this theory.

Then there was an attempt to work out an expression for the emission of positive ions that would correspond to the well known electron emission equation

$$I = AT^2 \epsilon^{-\frac{\phi e}{kt}}$$

where ϕ represents the electronic work function. Bridgman[1] started this work. It was later carried on by Lloyd P. Smith[2] who developed theoretical mathematical expressions for this emission; he ran into some things which were contrary to experimental results but which were required by his theory. As a result we have no satisfactory equation for the emission of positive rays, even though we do know considerable of the facts and conditions governing their emission.

At present it seems that main interest has shifted to the properties and effects of these rays. A study of the actions of positive rays under various circumstances may lead to a better understanding of the properties and actual make-up of the various individual atoms. Perhaps the aid these rays have already given in chemical analysis in the study of isotopes is only a fraction of what may be gained by further study.

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1. Bridgman, P. W., Phys. Rev., 27, 173 (1926).
2. Smith, L. P., Phys. Rev., 35, 381-395 (Feb. 15, 1930).

STATEMENT OF PROBLEM

Of course some means of recording these rays is essential. Since they carry a positive charge of electricity it is possible to detect and make quantitative measurements of them with the aid of electrical measurements. However, if possible, it would be desirable to have a graphic or visible record of these rays. It seems that as yet only photographic plates have been used for this purpose. These plates give clear traces where the positive rays strike, but they have many limitations and are very inconvenient in some types of apparatus. Therefore Dr. John L. Hundley suggested that I find whether or not methods somewhat similar to those used to record electrons by Percy H. Carr[1] at Iowa State College might be used in recording positive rays.

The problem then was to find some means whereby permanent graphic or visual traces of positive rays could be obtained without the difficulties and inconvenience encountered in the use of photographic plates. It was desirable to examine a number of substances but lack of time prevented an extensive study of any one material. Besides, it would be useless to spend a lot of time determining just how good a certain substance was for recording positive rays and then on further search to find another material that was so much better for that purpose that the first would never have any practical value in recording the rays. Thus in this problem all

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[1] Carr, Percy H., A New Method for Recording Electrons, Review of Scientific Instruments, 1, 711-743 (1930).

effort was toward examining a number of materials so as to determine their relative merit. Careful quantitative measurements of the absolute sensitivity of the various ones were left for future work.

THE APPARATUS

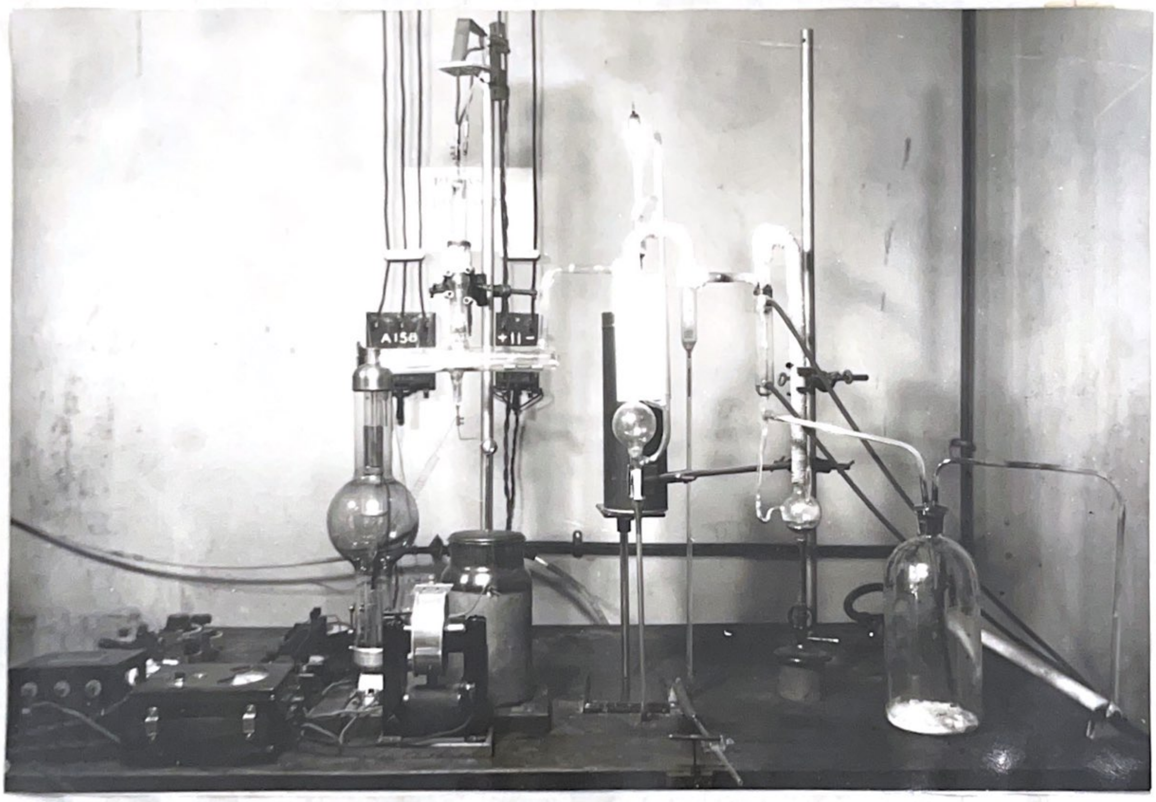
Since no work along this line had been done previously in this department, there was no apparatus on hand. Therefore everything had to be designed and constructed as needed. This meant that all parts had to be as simple as possible and some very desirable features had to be omitted entirely.

The apparatus was arranged as shown in Fig. 1. A description of the construction of the different parts and their fundtion will now be given in detail.

The vacuum system: In such work a good vacuum is essential so that, first, the mean free path of the molecules in the system will be great enough that nearly all the atoms leaving the filament will travel as far as the receiving plate without suffering a collision and, second, that the system be as free from undesirable impurities as possible.

The vacuum system was arranged as shown in the diagram. A Cenco Hyvac was used as a forepump for a mercury diffusion pump constructed by Dr. Hundley. In order to redueeewater vapor in the system to a minimum, a tube containing calcium chloride and a gallon bottle with a layer of phosphorus pentoxide on the bottom were placed between the two pumps. The large bottle served another purpose, that of sort of a vacuum "reservoir"; that is, when it was quite well evacuated by the forepump this pump could be stopped and the mercury pump could pump gas into this large bottle for some time before its back pressure built up enough to hinder the operation of the mercury pump. Consequently even though the mercury

THE APPARATUS



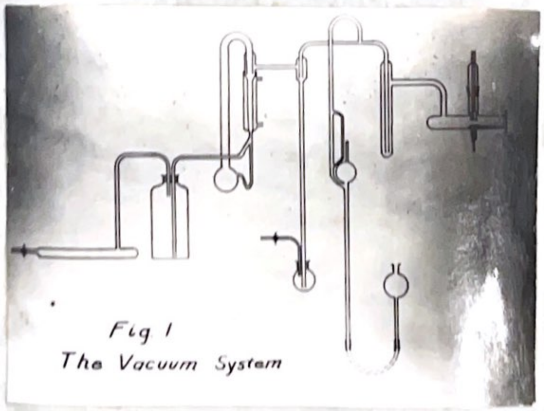


Fig I
The Vacuum System

pump was kept going during all the experiments, it was necessary to keep the forepump going only part of the time.

Between the mercury pump and the rest of the system was a mercury seal. This was put in to isolate the foresystem and thus keep many undesirable gases and vapors out of the main part of the apparatus. Although this seal was not absolutely necessary, it was well that it was inserted because there was an ordinary greased stop cock in the foresystem and upon standing for some time the pressure in this part of the apparatus did increase.

The pressure was measured with a McLeod gauge. During all trials this registered 10^{-6} cm. of Hg or less, but this does not measure the pressure due to the mercury vapor, which is equal to the vapor tension of the mercury at the existing temperature. To minimize this, a mercury trap was used. Ice and salt served as a cooling agent most of the time. This mixture when placed in a thermos bottle would maintain a temperature in the neighborhood of fifteen degrees below zero Centigrade for over two days. Part of the time concentrated hydrochloric acid was added to the ice and salt mixture and then the temperature was between twenty and thirty degrees below zero. However, even at $-10°$ C. the mercury vapor pressure is reduced to 6.06×10^{-5} cm. of Hg and under these conditions the mean free path as found by the formula

$$L = \frac{1}{\sqrt{2}\,\pi N \sigma^2}$$

where L is the mean free path, N the number of mol./c.c., and σ the diameter of the molecule, is equal to 23.67 cm.

Since the distance between the filament and the receiving plate was only three centimeters, a study of the distribution of the free paths and the number of molecules whose paths exceeded a certain distance poimts out that at least 88% of the molecules leaving the filament in the proper direction to pass through the slit actually reach the receiving plate before suffering a collision. Thus although it would be desirable to have a still lower pressure, this arrangment produced a pressure that was satisfactory.

The filament assembly: All the filaments used were cut from a sheet of platinum foil. They were fastened to the leads by means of iron clamps which made it comparatively easy to replace filaments when they burned out. Then to get a narrow, well defined trace on the receiving plates an aluminum collimating cylinder was used. This cylinder was two centimeters long and the slit in it was .05 centimeters wide and .6 centimeters long. The filament was approximately 1.5 millimeters directly above the slit.

In order to be able to remove the filament assembly it had to be in a tube fitted with a ground glass joint. Also it was necessary to seal three lead-in wires in this tube, two for the filament and one for the cylinder, and these seals cannot be made too close to the ground joint. This necessitated long (approximately 20 centimeters) lead wires because it was desirable to have the collimating cylinder quite close to the receiving plate. These long lead wires gave considerable freedom of movement to the filament and the cylinder. Then to align this filament and slit and keep them in line till the apparatus was in place caused very much trouble. At times the alignment would be good while the apparatus was cold but when heated unequal expansion of the parts would force the filament to one side. Finally the two filament clamps and the lead to the cylinder were all fastened in a piece of glass and thus held in their proper relative positions and no further trouble in alignment was experienced.

The filaments were in the form of narrow ribbons and at first they were put in place with their broad side toward the slit. One time when the filament was slightly to one side, i.e. the edge of the filament was directly over the slit, an appreciably larger current through the slit resulted. Then the filament was turned through an angle of ninety degrees and mounted with its edge toward the slit. This arrangment gave a noticeably larger current. Later it was found that a filament in the form of a helix gave a steadier positive ion current of about the same size and the filament had a longer life.

The filament was heated by a direct current drawn from a six volt storgge battery. The current needed to heat the filament to the proper temperature depended on the dimensions of the filament and was adjusted to suit the filament with the aid of a rheostat connected in series with the filament and battery. In most cases the current needed was between 0.5 and 1.0 ampere.

Only three different positive ions were examined, namely, sodium, potassium, and lithium. When sodium ions were desired, the filament was coated with cryolite $[Na_3AlF_6]$; for potassium the coating was orthoclase $[KAlSi_3O_8]$; and for lithium, spodumene $[LiAl(SiO_3)_2]$ was used on the filament.

To cause the positive ions to move toward the receiving plate an accelerating voltage must be applied between the filament and the collimating cylinder. This was effected by grounding the cylinder and making the potential of the filament approximately 180 volts positive through the use of four "B" batteries. With this arrangment and the filament at the proper temperature, a positive ion current of 10^{-7} amperes was easily obtained.

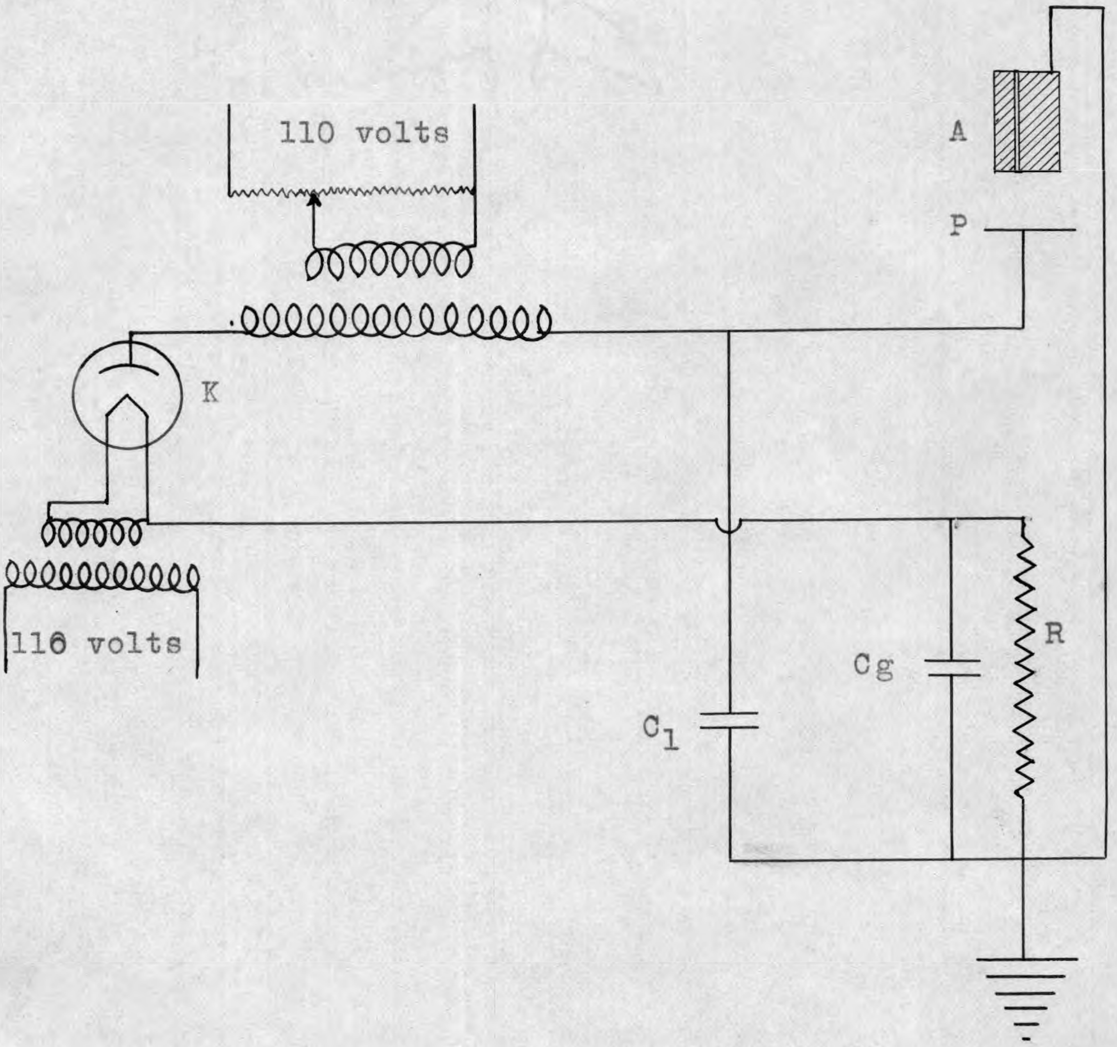
The speed with which the positive ions travel through the slit depends on the voltage between the filament and the cylinder. However, the amount the speed of the ions can be increased by increasing this voltage is limited by the physical characteristics. of the apparatus. Still it was desirable to study the effect higher speeds might have on the ease of recording the positive rays. To accomplish this an additional accelerating potential was applied between the collimating cylinder and the receiving plate.

Large direct voltages are not readily obtained so an alternating voltage was tried. Of course this would cut out half of the positive rays and besides, when the potential was reversed and the plate positive, the plate would attract any electrons that happened to be present. Both these things were very undesirable, and it was decided to rectify the voltage.

To do this a type KR-1 kenotron made by the General Electric Company was used. This kenotron was placed in the circuit as shown in Fig. 2. One terminal of the secondary of an 8000 volt transformer was connected to the plate of the kenotron and the other terminal to the inside of a Leyden jar, which in turn was connected to the receiving plate in the apparatus. The outside

FIGURE II

HIGH VOLTAGE RECTIFIER



A - Collimating cylinder
Cg - By-pass condenser
C_1 - Leyden jar
R - Resistor
K - Kenotron
P - Receiving plate

of the Leyden jar was to keep the potential of the receiving plate more constant. This was possible because the current to the receiving plate was so extremely small. The transformer was designed to produce 8000 volts in the secondary when 110 volts were applied across the primary. Therefore, to get smaller voltages the primary was connected to a potentiometer arrangement whereby the primary voltage could be varied from 0 to 110 volts, which would cause a corresponding range of voltages in the secondary. It should also be remembered that the voltages just mentioned are effective values and with the Leyden jar arrangement the potential of the receiving plate should stay at the maximum value, which is the square root of two times the effective value.

The filament of the kenotron was heated by alternating current obtained from the 110 volt mains through a suitable step-down transformer.

The electrical recording of the rays: The problem was to find a graphic means of recording positive rays, but for detection of such rays and to check the intensity of the beams, it was desirable to have some electrical device for their measurement.

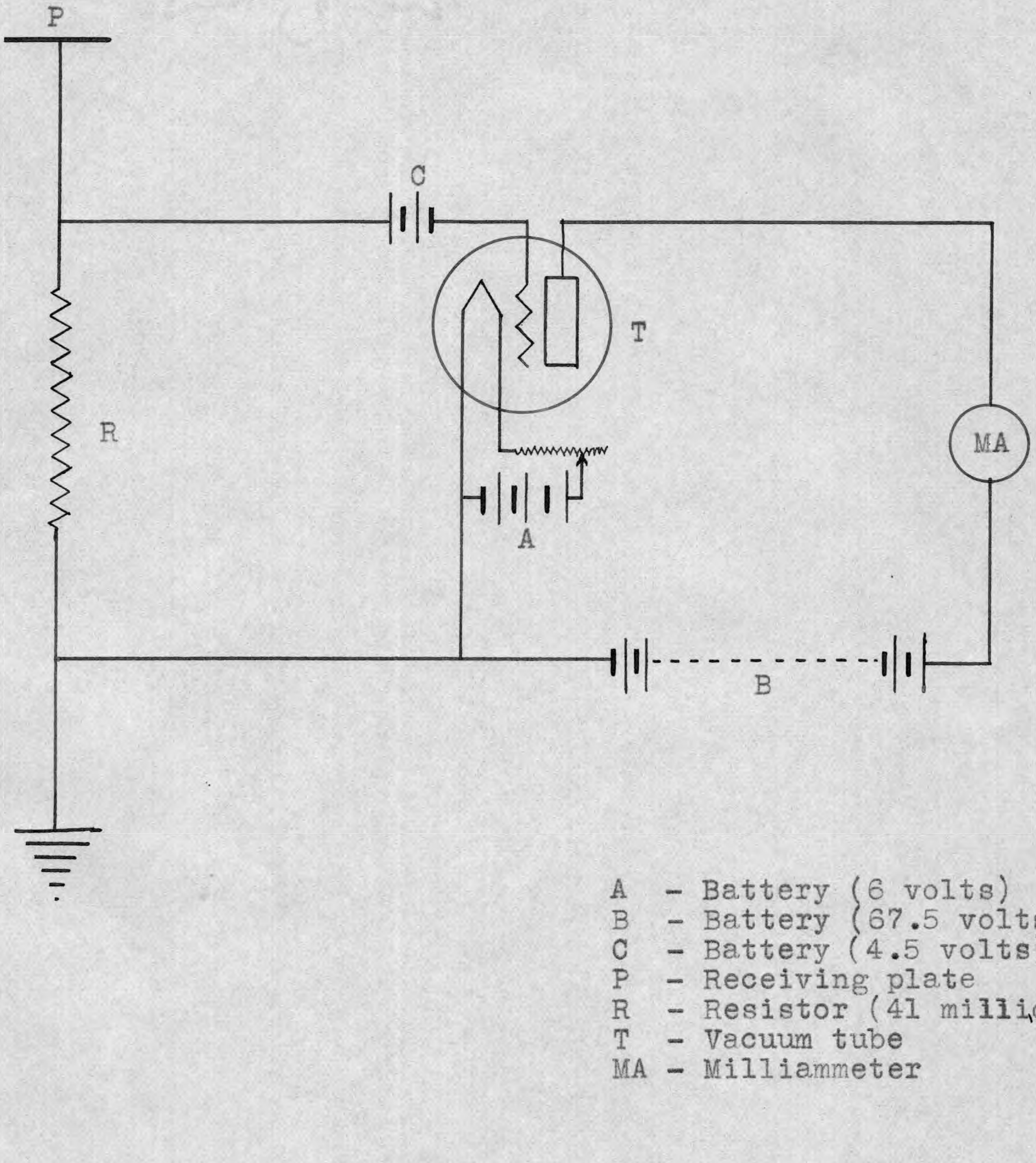
At first a Zeleney electroscope was used because of its great sensitivity and the ease with which it may be used. This is very satisfactory as far as detection is concerned, but for quantitative measurements the electroscope would have to be calibrated and even then it would not be very satisfactory. Besides, as was described abve, in part of the work a transformer was used to get large accelerating potentials and when the transformer was in operation it was impossible to use the Zeleney electroscope.

Since it was desirable to have a measure of the positive ion current at all times, a vacuum tube arrangement suggested by Mark Scarff, department mechanician, was devised. The positive ions upon reaching the receiving plate build up a positive potential on it which would be neutralized by a flow of electrons from the ground if the plate were grounded. Therefore a resistor of 4.19×10^7 ohms resistance was placed between the ground and the receiving plate. Then when a current flows through this high resistance, even though the current be small, the voltage drop across the resistance is appreciable. Now the plate current in the three electrode vacuum tube is very sensitive to changes in the grid voltage, so the voltage drop across the grid-leak was impressed on the grid of a vacuum tube in the circuit shown in Fig. 3 and the effect on the plate current was noted. The only purpose of the "C" battery shown in the diagram was to keep the potential of the grid always slightly negative. Then the effects of different grid voltages on the plate current were actually determined by experiment although they might have been found quite accurately from the characteristics of the vacuum tube as published by the manufacturer. With this knowledge and by measuring the plate current in the vacuum tube, one could compute the voltage drop across a known resistance. The current may be found by a simple application of Ohm's law. This current is equal to the positive ion current reaching the receiving plate.

When the transformer-kenotron apparatus was in use, a con-

FIGURE III

ELECTRICAL RECORDING DEVICE



A - Battery (6 volts)
B - Battery (67.5 volts)
C - Battery (4.5 volts)
P - Receiving plate
R - Resistor (41 million ohms)
T - Vacuum tube
MA - Milliammeter

denser was placed in parallel with the grid-leak to allow any alternating current from the kenotron circuit to reach the ground without passing through the grid-leak and thus affecting the recording device.

The receiving plates: It was desirable to make a number of exposures without opening the apparatus for each one and it was also desirable to have only one exposure on each plate. This brought up the problem of moving the plates while they were in the apparatus. It was found that if the plates had iron bases, they could be moved about in the apparatus with the aid of a small electro-magnet. Usually five plates were put in the apparatus at one time and it proved convenient to have the alternate plates of nonmagnetic material. If they were all magnetic, when one was moved, the rest followed due to the induced magnetism in the plates, but with every alternate one non-magnetic they could be moved about individually with ease.

RECORDING THE POSITIVE RAYS GRAPHICALLY

A number of methods of attempting to record these rays suggest themselves. First, the positive ion current may be allowed to flow long enough to make a deposit on the receiving plates heavy enough to be seen. Second, some substance might be used on the receiving plates with which the positive ions would react chemically to produce a readily visible color change. Third, after the plates are exposed they might be treated or "devloped" with some chemical to make the traces of the positive rays visible. Fourth, the ions might be accelerated to such velocities that their bombardment would produce a noticeable change in the surface of the receiving plate. All of these methods were tried; some of them were found useless and others were fairly satisfactory in recording sodium, potassium, and lithium positive rays.

Visible deposits: Attempts to get visible deposits were made on various plates. With clear glass no traces were found even after long exposure. It was though that this might be due to the fact that it was impossible to ground the glass. In that case a positive charge is built up on the plate which would repel other positive charges and thereby prevent a compact definite deposit. Then similar plates were sputtered with silver, which left a very thin uniform coating of silver and made the plates conducting so that they might be grounded. These plates also proved to be unsatisfactory.

Then various metal plates were tried. Before using, these plates were rubbed down with fine emery paper, then polished on a polishing wheel, and finally polished with rough. In some cases the plates were washed in alkali and acid solutions, but this washing made no apparent difference in the results obtained. No traces were deposited on copper, phosphor-bronze, brass, iron, or aluminum. Slight traces were found on tin and zinc. Easily visible traces were found on nickel and silver but only after exposures of over an hour and a half. (Where the sinsitiveness of plates is spoken of in terms of length of exposure necessary, the positive ion current is 9.54×10^{-8} ampere and the accelerating voltage six thousand volts.) At that there is some question as to whether these deposits consist only of the alkali metal; there is always some mercury present and since the alkali atoms have a great affinity for mercury, perhaps the deposit is made up of mercury also. Therefore, while this method then might be used, it is relatively insensitive.

Sensitized plates: Only positive ions from the alkali group were used in this experiment, so a search was made for some substance or compound with which the ions would react producing a marked color change. Such compounds are apparently very few and none was found which appeared practicable for the purpose at hand. Then it was thought that if a plate were coated with an indicator, exposed to positive rays, and held in water vapor, the base formed by the alkali and water vapor would cause a color change in the indicator. No results were obtained by applying indicators to the plates after they had been exposed and removed from the apparatus, so it seemed desirable to have the indicator on the receiving plate while exposed to the positive rays. The number of indicators that may be used in this manner is very limited because the high vapor pressure of most of them makes their use impossible in a vacuum system.

Phenolphthalein seemed to satisfy the technical requirements and it was used in a number of trials. The phenolphthalein was finely powdered and put on the plates which were then placed in the apparatus. After exposures of different lengths, the plates were removed and held in water vapor. No satisfactory results were obtained in any of the trials.

Use of developers: It seems that many of the metals may be used to record traces of alkali positive rays, especially if the rays are traveling with considerable velocity. However, the results found with the different metals vary a great deal.

Perhaps the most reliable and one of the clearest developers was a very thin film of moisture. If your breath were blown on an exposed plate, the moisture in your breath would condense in the form of a thin film on the plate. Then while this film is evaporating there is a distinct difference in the appearance of the unexposed and the exposed regions and at the instant just before this film disappears, the difference is very pronounced. A complete satisfactory explanation of this phenomenom has not been found. Apparently it is due to a difference in the condensation and evaporation of the water vapor on the different parts of the plate. This difference may be due to a deposit on the plates, or to a roughening of the exposed region from the bombardment by the charged particles, or perhaps to an etching effect of the positive rays. Whatever it is that causes these traces, this method was the most reliable graphic detector of positive rays found in this experimant. It brought out traces that could not be brought out in any other manner. The serious shortcoming of this method is the short life of the traces. This does not mean, however, that the trace will appear only once, because the trace will appear each time a film is condensed on the plate. Some of the plates have been exposed to the atmosphere for over six weeks and they still respond with clear traces when treated in this manner.

To get a permament trace, no one developer was found which would produce results onall plates. Something that was quite satisfactory for one metal might not work at all for another metal.

Silver: With exposures of two and one half hours or more this metal gives traces of positive rays without any development. Other plates which had been exposed fifty minutes or more but on which one could not distinguish between the exposed and unexposed regions were held in the iodine vapor above a warm beaker containing some iodine crystals. In a few minutes if there was not too much iodine vapor present, the unexposed regions of the plate became a dirty yellow, then blue, and finally nearly purple; the exposed region was unchanged in appearance, that is, bright silver in color. These traces are quite permanent. Some of the plates developed in this manner have been lying on a shelf for three months with no special protection, part of the time being in direct sunlight, and still the traces are very distinct although their edges are not as sharp and regular as they were when first developed.

Using mercury vapor in place of the iodine vapor it was possible in some instances to distinguish traces but then only with difficulty because the condensed mercury is the same color as the silver.

<u>Nickel</u>: It was again found that long exposures produced permament traces but they appeared in less time on the nickel than they did on the silver, that is, in about one and one half hours. Nickel seems quite sensitive to positive rays; traces that could be developed by condensed water vapor appear on plates exposed no longer than ten minutes. Still no satisfactory developer for nickel has been found. Mercury vapor develops traces to some extent but here again the lack of color contrast was discouraging. Iodine proved of no value as a developer on nickel; neither did fumes from the common acids. Therefore while nickel is the best material examined for the recording of positive rays without any form of development and while it is apparently quite sensitive to these rays, until some better developer is found, permament distinct traces may be obtained in less time on other metals.

<u>Zinc and tin</u>: The first traces discovered were on zinc plates which after exposure were held in hydrogen chloride vapor. At first the hydrogen chloride was obtained by heating concentrated hydrochlorid acid but later better results were obtained when hydrogen chloride was obtained directly from the reaction between sodium chloride and sulphuric acid. The plate was held just above

the beaker in which this reaction was taking place and the fumes attacked the unexposed region giving it a dull etched appearance, while the exposed portion remained bright and shiny. However, care had to be exercised because if the vapor was allowed to act too long, the whole plate took on a dull etched appearance. This could be avoided by placing the plate in ammonia gas when the development had reached the proper stage, because the ammonia would neutralize the acid and thereby stop theetching.

A possible explanation of the difference in the reaction on the different parts of the plate might be as follows. There would be a thin layer of the alkali atoms on the exposed region which would neutralize the first hydrogen chloride molecules striking this portion. On the rest of the plate the zinc would be attacked immediately. Thus, if the plates were held in the vapor just until all the layers of alkali atoms were used in neutralizing the acid, the zinc in the exposed region would still be unaffected while the etched appearance of the unexposed region would have reached a maximum. Any attempts toward further development caused the entire plate to assume a uniform dull appearance. This seems to support the idea that there was some kind of a protective coating on the exposed region.

Hydrogen bromide and hydrogen flouride were also tried as developing agents but they did not prove as satisfactory as hydrogen chloride. Mercury vapor gave very feeble results and iodine vapor gave none at all.

The results found on tin plates were nearly identical with those found on zinc, save that in general the tin is less sensitive. However, in one instance two brass plates were coated with tin by melting drops of tin laid on the brass. This gave a coating composed mostly of tin but its color was slightly yellow, indicating that it was alloyed with the brass to some extent. The traces found on these plates were as good or better than those found on zinc. However, in less than two months they disappeared entirely.

Faint traces were also produced on plates coated with ordinary half and half solder if hydrogen chloride or sulphuric acid vapor was used as a developing agent.

Brass: No consistent results were obtained with brass. On some plates fairly good traces could be developed with either mercury vapor or iodine vapor but the mercury vapor was the better of the two. On other plates under apparently identical conditions no traces at all could be found. No explanation of this inconsistency was discovered.

Copper: Here again the results were inconsistent. Traces were obtained in some instances and not in others. The only developer of any value found for copper was the fumes given off by boiling sulphuric acid and then only indistinct traces were found. Still in one instance very distinct traces were found on brass and copper. A brass plate and a copper plate were removed from the apparatus just after being exposed to a beam of sodium ions. No traces were visible and no attempt was made to bring out traces through the aid of developers. The plates were laid on a shelf and forgotten for a time. About a week later a faint trace was noticed on the copper plate and about two weeks later there were very distinct traces on both the copper and the brass. At present it is over two months since these plates were exposed and for the first month the distinctness of the traces increased with time and since then there has been no apparent change. The exposed region of the plates has maintained its original appearance while the remainder of the plate has become tarnished. It seems that if there was only a layer of sodium atoms on the plate, the exposed region would be the first to tarnish because of the great activity of the sodium, but this was found to be not true. However, sodium has a great attraction for mercury and since there is always some mercury vapor in the apparatus, the deposit on the plates may be an amalgam of sodium and mercury which resists the tarnishing. Of course, as a method of development this takes entirely too long, but it does give some information as to what may be happening on the plate.

Other metals: Slight traces may be found on aluminum through the aid of condensed moisture or development in hydrogen chloride vapor. In either case long exposures are required and the traces are very faint. Aluminum proved to be the poorest of the metals examined for the purpose of recording positive rays.

Iron compares fairly well with most of the metals in its ability to give traces of positive rays. With forty-five minutes exposure, clear traces were seen when a thin film of water vapor was condensed on the plate. The disappointing feature with iron was the fact that no developer was found which would give permanent graphic traces which are easily visible.

Results with different ions: As was said before, only alkali ions, sodium, potassium, and lithium, were examined. All the findings given above hold equally well for sodium and potassium. No noticeable difference was found in the ease of recording either sodium or potassium. The recording of lithium positive rays was only attempted with a few of the metals and apparently they are as easily recorded as either sodium or potassium.

The effect of velocity on ease of recording: It was explained above how the apparatus was arranged so as to enable the use of accelerating voltages ranging from one hundred and eighty to eight thousand volts. This made it possible to examine, again only relatively, the effect of the velocity of the positive rays on the ease of recording them. It was found that the faster the rays were traveling, the easier it was to record them. For instance with silver using an accelerating voltage of 8000 volts, a trace was obtained in fifty minutes which was as distinct as a trace obtained in one hundred minutes using an accelerating voltage of only 180 volts. Similar results were found with most of the metals. With iron and copper no traces were obtained until accelerating voltages in the neighborhood of 5000 volts were used. Therefore there is no question but that it is easier to record the rays having the higher velocities.

Some comparative data: Since in this problem it was not attempted to make fine quantitative determination of the sensitivity of the different materials, only a small amount of data was taken alogg this line. However, one may gain some idea of the relative merit of some of the materials and developing agents from the results given in the following table. These results were obtained with positive rays of sodium. In the first column is given the metal from which the receiving plates were made; in the second, the accelerating voltage which was made up of two parts and designated by a summation, e. g. (180 + 5000) volts means that the voltage difference between the filament and the collimating cylinder was 180 volts and between the cylinder and the receiving plate the voltage was 5000 volts; in the third column, the developing agents are listed; and in the last is given the exposures necessary to insure traces. These exposures were measured in two ways, namely, in the length of time and in the quantity of electric charge striking the receiving plate. The second value has much the greater significance of the two in comparing sensitivities of different materials.

Material	Accelerating Voltage	Developing Agent	Exposure	
			Time	Micro coulombs per sq. cm.
Silver	180 + 0 volts	Iodine vapor	100 min.	8238
	180 + 8000 "	" "	50 "	4119
Nickel	180 + 0 volts	Water vapor	90 min.	7414
	180 + 6100 "	None	95 "	7826
	180 + 7100 "	Mercury vapor	75 "	6178
	180 + 7100 "	Water vapor	30 "	2472
	180 + 7100 "	Water vapor	10 "	824
Zinc	180 + 0 volts	Hydrogen chloride	90 min.	7414
	180 + 6100 "	" "	60 "	4944
Iron	180 + 6100 volts	Water vapor	65 min.	5354

PHOTOGRAPHS OF SOME TRACES

1

2

3

1. Silver plate developed in iodine vapor.
2. Silver plate developed by exposure to atmosphere.
3. Copper plate developed by exposure to atmosphere.

<u>Possible causes of the traces</u>: No satisfactory explanation of this phenomenon can be given at present. With long exposure the traces are deposits of the positive ions perhaps along with some mercury as was explained above. With shorter exposures, those requiring some type of development, there would be a light deposit, but there must be some other determining factors.

In this case there must be some change in the surface of the exposed region due to the bombardment of the ions. This is indicated by the difference in the ease of recording low and high speed ions; even though the same number of ions strike, the trace is much easier to detect when the rays have hit with a high velocity. Also since these metals have some vapor pressure, if the traces consisted only of a metallic deposit, one would expect the traces to "evaporate" if kept in a very low pressure for some time. No such effects were noticed in a couple of days of time so some plates were left in a vacuum for over three weeks with no apparent harm to the traces.

Therefore it seems that although the actual metallic deposit aids in producing the traces, the bombardment of the positively charged particles produces some change in the surface of the metal either chemical or physical. That is, the positive ions may combine with the material in the plates or they may merely roughen the surface so that it reacts differently when exposed to different gases or vapors.

To determine the exact cause, much more work has to be done with different kinds of rays and under as many different conditions as possible. As yet not enough data have been taken to justify any definite conclusions as to what is producing these effects.

CONCLUSION

Positive rays may be recorded graphically without the difficulties and inconvenience encountered with photographic plates. With long exposures, traces may be obtained on silver and nickel without the aid of developing agents. However, with proper developing agents traces may be obtained with much shorter exposures on silver, nickel, zinc, tin, copper, and brass.