Hill

Gas Analysis By Positive Rays.
GAS ANALYSIS BY POSITIVE RAYS

BY

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THESIS

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Committee on Final Examination*

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GAS ANALYSIS BY POSITIVE RAYS.

I. History and Nature of the Positive Rays.

Positive rays, or Kanal Strahlen as they are often called, were discovered by Goldstein in 1886. The negative rays or discharge of electrons through a partial vacuum had been known for several years. These negative rays constitute the natural discharge between electrodes, however, and they are always easy to get. Compared with the positive rays, they do not need so high a vacuum and are ordinarily more easily seen due to their peculiar phosphorescence on several gases and crystaline substances.

If we take a discharge tube and reduce the pressure to 0.01 mm mercury or less, a dark space will be seen in front of the cathode, its size and shape depending upon the containing vessel. Around the cathode under such conditions, the rays will appear a more or less reddish colored discharge. It was this discharge that Goldstein was attempting to analyze when he discovered the positive rays. The tube used by Goldstein is shown in Fig. 1. A long glass tube was used with the anode at one end and the cathode at the middle. The cathode was made of a disc of metal and filled the tube at that point. As the tube is constructed at present both electrodes are made of aluminum. The anode may be merely a wire and may be at the end or in a nipple at the side. Goldstein bored holes through the cathode with diameters small compared to their lengths. He then found that small reddish rays shot backwards in
straight lines and he called these "Kanal Strahlen" since they streamed through these small channels. (Sir J.J. Thomson has suggested the name of "positive Rays", and both names are used at present, one probably as much as the other.) Goldstein found that the rays gave a peculiar phosphoresence, very different from the negative discharge, and it was evident at once that they were of a different character. Residual air gave a yellowish colored phosphoresence, hydrogen a rose color, and it has since been found by Thomson that helium gives a bright red and neon a brilliant red. The rays also have a phosphoresence peculiar to themselves on glass, lithium, etc. On willimite, one of the natural silicates of zinc, they give a deep green. Since this substance is easily prepared in a thin or layer on glass, mica, it furnishes a means for studying the rays.

Goldstein, however, did not give much theory concerning the rays and it was left to J.J. Thomson to really prove what they are. It was sometime after the rays were discovered before it was known that they could be deflected by a magnetic field. Only weak fields are necessary to give large deflections of the negative discharge and since such fields did not seem to affect the positive rays, it was concluded that they were free from magnetic action. Later it was found that they could be deflected by powerful fields and the difference between the two in this respect became evident when the true nature of the rays was discovered. Thomson found that he could deflect the beam with a powerful field. He found that the deflection varied with the potential applied at the terminals of the discharge tube, and also with the gas in the tube. He deduced from this that the rays must be particles with a small charge and a high velocity. The mass would probably be large, also, as compared to that of the electron, the latter having a mass of about $1/1700$. 
of the mass of the hydrogen atom. Since the deflection depended upon the gas in the tube, he argued that they were probably atomic in size with a positive charge attached. No elementary positive charge has ever been isolated, however. They always seem to be associated with matter or molecular structures only, and so their formation is explained by the loss of a negative charge or electron from the atom or molecule. The expression "positive charge" is equivalent to the above.

Now if the rays are positively charged particles, where and how are they formed? Thomson has given the following explanation. The rays really form in the region of the dark space in front of the cathode. It is certainly evident that they do not form on or near the cathode for they would not leave it. It is also evident that they do not form around the anode. No trace of them is found there which would give such a volume of the rays as it is possible to get. Their formation according to Thomson's theory is as follows. A molecule or atom under normal conditions carries a given number of charges or electrons which give it a zero or neutral potential. For some reason, the atom or molecule at rest in the region of the dark space may lose one or more negative charges and so suddenly become positively charged with respect to the cathode. Just how this happens is only theoretical of course, but the mechanical impact theory, that the electrons shot out from the cathode free the charges, seems to be the best accepted. If the vacuum is high enough, these positive carriers fall freely towards the cathode, gaining very high velocities. Here they appear as a reddish glow. If the cathode is perforated, their momentum carries them through and they stream out in rays behind. The length of these streams depends upon the vacuum and potential used. With very low pressures they may be detected at distances of 40 or 50 cm. A photographic
plate or phosphoresence screen may be used at such a distance to detect and study the rays.

To sum up, positive rays are atoms or collections of atoms which have lost one or more electrons and when generated in a discharge tube, fall towards the cathode, gaining very high velocities. Due to their momentum they fall through the perforated cathode and appear as positive rays or "Kanal Strahlen" behind it.

Thomson studied these rays during the period 1907 to 1912 and developed an apparatus which he claims may be used for gas analysis. The object of this thesis is to reproduce Thomson's apparatus, making such changes as seemed the better for the purpose in hand, having in mind its adaptability to a practical method of gas analysis in this laboratory. Since the apparatus constructed in this laboratory differs so little from Thomson's, only a description of the apparatus as developed here will be given with the accompanying theoretical discussion.

II Theory Upon Which the Apparatus is Based.

If we take a discharge tube similar to the one used by Goldstein and have a single opening through the cathode, a pencil of rays will be projected backwards. These may be seen and studied by means of a phosphoresence screen at a suitable distance behind the cathode. If a powerful magnetic field is brought up, the rays will be found to deflect at right angles to the flux and in a direction in which positive carriers would naturally deflect. If an electrostatic field is also produced, it gives a deflection of attraction or repulsion, depending upon which plate is considered. If the two fields are therefore made parallel we get the deflections at right angles to each other. They will be considered parallel in the following discussion. The magnitude of the deflections depends upon the
strength of the two fields, the mass of the particles, the charge carried, the velocity of the particles, and the distance through which the deflection takes place. Of these factors, the charge and mass are separately difficult of determination; however, the ratio of the charge to the mass, $e/m$, and the velocity are comparatively easy to determine if the two fields and the constants of the apparatus are known. We know that the unit charge is a constant and that a molecule or atom will have an integral number of these, i.e. one, two, three, or four, and so on. The deflection depends upon the ratio of the charge to the mass, $e/m$. Thus if we can determine the ratio, we can substitute the values of charge equivalent to one, two or three charges and solve for the mass. The kind of gas may then be identified by the mass of its molecule. The elementary charge has been determined as $4.8 \times 10^{-10}$ c.g.s., e.s.u. of electricity.

1. The Magnetic Deflection and its Equation.

To get $e/m$ it is necessary to set up the equations for the two deflections and solve them simultaneously to eliminate the velocity. Suppose then that we first consider the magnetic deflection. The particle will be shot out in a horizontal direction, say along the $x$-axis. We shall place the magnetic plates coterminus with the electro-static plates so that the two have lines of force in a horizontal plane, perpendicular to the velocity of the positive rays.

If we make this the magnetic $z$-axis, the deflection will be along the $y$-axis. The particle has an initial velocity, $v$, which is practically constant in the $x$-direction if we make the deflection small. This velocity will be $dx/dt$. We may set the magnetic force
equal to the mechanical force and so have the equation,

$$ma = m \frac{d^2y}{dt^2} = Hev = He \frac{dx}{dt}. \quad (1)$$

Integrating this equation, we have,

$$m \frac{dy}{dt} = \int_0^t eH \frac{dx}{dt} \, dt = \int_0^x eH \, dx. \quad (2)$$

The limits of integration of the second member are 0 to t and these are changed to 0 to x in the last member since the particle has the position, x, at the time, t, and starts from the origin.

Now \(dy/dt = dx/dt \, dy/dx = v \, dy/dx\), since \(dx/dt = v\) except for a small error due to the deviation from the x-axis, and this error is negligible. Therefore equation (2) may be written,

$$mv \frac{dy}{dx} = \int_0^x He \, dx. \quad (3)$$

Therefore \(\int mv \frac{dy}{dx} = mvy = \int_0^L (\int_0^x He \, dx) \, dx. \quad (4)$$

Integrating the right hand member by parts, we have,

$$mvy = L \int_0^L He \, dx - \int_0^L Hex \, dx. \quad (5)$$

$$= L \int_0^L (L - x)H \, dx. \quad (6)$$

A difficulty arises here due to the fact that \(H\) is an unknown function of \(x\), and so a direct method of integration cannot be used. A close approximation may be gotten by considering that the magnetic field exists only between the poles of the magnet, since the air gap is small. Thomson, however, has given a method by which the integral may be solved if the apparatus is built to fit the conditions imposed. This condition is that the particle be affected by the magnetic field over the distance, \(x = 0\) to \(x = L\), only. \(L\) is the distance from the base of the cathode to the screen where the deflection is measured. It is easy to shield against magnetic fields and in this case does not cause a complicated apparatus. The deflec-
tion of the particle depends only upon the total flux passed through and not upon the distribution of the flux. Suppose we take a coil, triangular in shape, of length L and base small compared to the depth of the pole pieces of the magnet. The shape of the coil is shown in the accompanying diagram, Fig. 3. The base, CD, will be placed at the origin, or point of projection of the particles and E will be at the screen.

Let N be the total flux passing through the coil and let H be the average field strength.

Then \[ N = \int_0^L H (AB) \, dx \] (7)

And from similar triangles,

\[ \frac{(AB)}{(CD)} = \frac{(AE)}{(DE)} = \frac{L - x}{L} \] (8)

Therefore \( (AB) = \frac{L - x}{L} \) (9)

and \[ N = \int_0^L H \left( \frac{L - x}{L} \right) (CD) \, dx \] (10)

or \[ N = \int_0^L \frac{L - x}{L} (CD) \, dx \] (11)

Solving for the integral,

\[ \int_0^L H (L - x) \, dx = \frac{NL}{(CD)} \] (12)

This is the integral found in the original equation. The solution of the integral, therefore, seems to depend upon the total flux, the length of the triangle, and the base of the triangle for this special case. It will be evident immediately, however, that one other condition has been imposed upon the field. The field is much stronger between the poles and probably does not decrease as a straight line curve as we leave the poles. For a given deflection of
the beam it is also evident that the integral remain a constant no
matter what the value of the base of the triangle. The ratio of the
total flux to the base of the triangle is therefore a constant. This
means that the surfaces of equal field strength are practically
concentric spheres with centers at the poles of the magnet and that
the sides of the triangle, as the base changes, remains allright
angles to these surfaces. The base of the triangle must, of course,
remain small to do this.

Substituting in (6) from (12) we have,

\[ mvy = \frac{eNL}{(CD)} \]  

(13)

or \[ v = \frac{eNL}{(CD) my} \]  

(14)

N may be determined by either a fluxmeter or a ballistic gal-
vanometer method, using a triangular coil as suggested above. The
method of calibration will be considered later.

2. The Electro-static deflection and Equation.

The electro-static field is to be made parallel with the magnetic
by making the plates coterminus. This gives the electro-static de-
flexion at right angles to the magnetic so that the deflection will
be along the z-axis. Let Z be the electric force parallel to this
axis. Equating forces again, we get the equation,

\[ m \frac{d^2z}{dt^2} = eZ \]  

(15)

If the deflection is small we may again consider the velocity con-
stant along the x-axis and let \( v = \frac{dx}{dt} \) so that,

\[ \frac{d^2z}{dt^2} = \frac{d^2z}{dx^2} \frac{dx^2}{dt^2} = v^2 \frac{d^2z}{dx^2} \]  

(16)

Therefore \[ mv^2 \frac{d^2z}{dt^2} = eZ \]  

(17)
Integrating twice we get,

\[ z = \frac{e}{mv^2} \int_0^L (\int_0^x zdxdx) dx \]  

\[ = \frac{e}{mv^2} B, \text{ where } B = \int_0^L (\int_0^x zdxdx) dx. \]  

(20)

\( Z \) is a function of \( x \) as was \( H \) in the previous case and must be solved by imposing a condition upon the electro-static field. The condition is taken care of by the apparatus again. We may determine \( f(x) \) in the equation, \( Z = f(x) \), for the special case that the field exists only between the plates. This is accomplished, except for very small end corrections, by putting the plates very close together. The end correction is negligible as far as results are concerned in this experiment but may be calculated if desired. Thus we make \( Z \) a constant along the length of the plates and zero over the rest of the path. Therefore if \( b \) is the length of the plates,

\[ f(x) = \text{a constant from } x = 0 \text{ to } x = b, \]

and \( f(x) = 0 \) from \( x = b \) to \( x = L \).

Considering equation (20) we find upon integrating and substituting limits of integration,

\[ B = Zb(L - b/2), \text{ all of which are measureable quantities.} \]

Substituting this value of \( B \) in equation (19) we get,

\[ z = \frac{e}{mv^2} (L - b/2)Zb \]  

(21)

\[ \text{or } v^2 = \frac{e}{mz} (L - b/2)Zb. \]  

(22)

\( e/m \) is the quantity desired and may be gotten by eliminating \( v \) from the equation by means of the equation for the magnetic deflection as all the rest of the quantities in both equations are measureable.

The magnetic equation is

\[ v = \frac{e/mv^2 NL}{(cd)}. \]  

(23)
From this by squaring both sides of the equation,

\[ v^2 = \frac{e^2 N L^2}{m^2 y^2 (CD)^2} \]  

(24)

Therefore from (22) and (24) we have,

\[ \frac{e}{mz} (L - b/2)Zb = \frac{e^2 N^2 L^2}{m^2 y^2 (CD)^2} \]  

(25)

and

\[ \frac{e}{m} = \frac{Zb/2 (L - b/2)y^2/N^2 L^2 (CD)^2}. \]  

(26)

It was found necessary to make the values of \( L \) slightly different for the two fields and so the working equation becomes,

\[ \frac{e}{m} = \frac{Zb/2 (L_e - b/2)y^2/N^2 L^2_m (CD)^2}. \]  

(27)

Similarly, by eliminating \( e/m \), the value of \( v \) may be gotten. \( Z \) is expressed in volts per cm. \( x 10^3 \) to get c.g.s. units.

Equation (27) is the working equation and it is easily seen that it is not necessary that the two fields be at right angles but it is necessary that the angle between the fields be known. The construction of the apparatus and the calculation of results are both made easier by having them at right angles, however.

III The Apparatus.

In any exhibition or demonstration of positive rays, it is necessary of course to follow the general plan of Goldstein's apparatus. A few modifications and additions are necessary, however, if the positive ray tube is to be used as a means of gas analysis. From the discussion above it is evident that the rays must be shielded from magnetic disturbances, except over the distance \( x = L \); That powerful fields must be used in order to get measurable deflections; that the deflections should be at right angles to each other; and finally that the opening through which the beam passes must be a
Plate I

Photograph of Apparatus.
very small tube in order that accurate measurements may be made. The rest of the details are immaterial except for ease of manipulation, convenience for evacuation, etc. as will be seen from the following description.

Fig. 5 gives the general plan for the apparatus. It was constructed during the first semester, 1915 and 1916, and set up early in the second semester. Except for a few changes, the whole of the apparatus is merely a reproduction of Thomson's and in most cases these are not important. Looking at the diagram, the large bulb is the discharge tube, with the anode to the left marked + and the cathode to the right, -. The bulb is made of a three liter flask. By making it large, the discharge passes at much lower potentials when a high vacuum is reached. This tends to prevent sparking and so prevents puncturing the glass. The anode is removable by means of the ground joint and this permits the small capillary tube to be taken out of the cathode whenever that is desired. At the top of the bulb is a tube by which the unknown gas may be admitted, and from the neck of the flask, a tube leads to the camera side so that evacuation is made easier. The anode is merely a small aluminum wire with a small aluminum disc on the discharge end. The other end of the wire is fused to a platinum wire which is in turn fused through the glass tube at the end. The cathode is fastened to the other end of the tube by means of a wax joint (Bank of England Wax). It is a heavy iron cylinder about 10 cm. long and is fastened at the other end to a brass casing, also about 10 cm. long. This casing fits between the magnetic poles and is shown in the diagram in red ink. It is waxed to a glass tube which increases in size as it leaves the joint and at a distance of about 30 cm. opens into the tube containing the plate holder. A ground joint between the magnetic field and the
plateholder makes the system more flexible and permits its being taken down more easily when necessary. The pump is connected to this end of the tube as indicated. The plateholder is a thin aluminum box which allows the plate to slide up and down inside and is of sufficient size that a plate long enough for two exposures may be used. Thus a plate may be shielded until an exposure is desired. A plate 5x7 cm. is allowed for one photograph. At the back of the opening in the plateholder is a willimite screen, which gives a convenient method for adjusting the beam. The plate is operated by means of a winch through a ground joint at the top as shown. A charcoal bulb is seen in the diagram but it was not used as a molecular pump was available.

The cathode (Fig. 6) is not so simple as the anode for it must be constructed to take care of the special conditions introduced in order to integrate the equation for the magnetic deflection. The rays must be shielded from magnetic disturbances until they enter the deflecting field. To properly shield the beam, the cathode is made of a heavy, soft-iron, cylinder with a small cylindrical hole along the axis, and an aluminum tip at the end from which the discharge takes place. A lip at this end allows the neck of the flask to fit into a bed of wax and so make an air tight joint. In Fig. 6 A represents the soft-iron shield, B the aluminum tip, and C the brass cylinder holding the capillary tube, D. The brass cylinder fits
accurately inside the soft-iron shield and holds the capillary tube on the axis of the system by means of brass plugs. Small openings are bored through these plugs to allow the air to escape easily. The base of the cathode is turned down to fit into the rubber cap that insulates it from the brass casing. The diameter of the capillary tube is about .3mm. Better accuracy may be gotten with a smaller tube but it is much more difficult to get the beam to affect the photographic plate.

In the space between the magnetic poles it was necessary to place some dielectric which would withstand powerful fields, or to

![Diagram](image)

place some non-magnetic substance which could be insulated. An ebonite box was first tried but after trying for about two months to get of brass and hold a vacuum, it was discarded for a similar one shown in the diagram (Fig. 7). Thomson used a rubber plate as a containing wall or at least his description would seem to indicate such, and he mentions no trouble with it. In the present case the ebonite proved very unsatisfactory, however. Attempts were made to wax over the rubber with soft wax and later with Bank of England wax but the rubber still seemed to be a perpetual source of gas. When the apparatus was finally taken down, it was found that at a corner of the electrostatic plates, the ebonite was badly disintegrated. This was probably due to an arc or to ozone formed by the small arc. The brass casing
was then made and was immediately found to hold a vacuum much better than the rubber. Rubber insulation was used between it and the cathode but in this case did not form a part of a containing wall or a wax joint and so did not affect the vacuum. In Fig. 7 the magnetic poles are shown as the shaded portion imbedded in the sides of the casing and the electro-static plates as the shaded portion inside and parallel with the magnetic plates. The brass is shown in black outline, unshaded, the rubber in shaded red, and the glass in unshaded red. The electro-static plates are made of soft iron and since they face with the magnetic plates, give a small air gap. The actual gap is 1.1 cm. The face of the electro-static plates is 3 cm. by 1.7 cm. and are 1.5 mm. apart. The rest of the dimensions may be gotten from the Fig. as it is drawn to exact size.

In order to aid in insulating the electro-static plates, it was decided in the case of the brass casing, to remove the plates farther from the cathode. This introduces a small change in the working equation, however, which should be mentioned. In the discussion the length, "L", of the path was first considered the same for both deflections but since the value for the electro-static deflection must be measured from the base of the plates and the value for the magnetic from the base of the cathode, the two must be considered different. Equation (27) was written to take care of this.

IV Calibration of the Magnetic Field.

From the theory it is seen that the total flux passed through, the base of the calibration coil, and the length of the coil, must be known. The length of the coil is fixed by the distance from the cathode to the screen which is 33.5 cm. The base of the triangle was made about 6 mm. This is considerably smaller than the width of the electro-static plates. The coils used were made of wood and rub-
ber as a base and wound with number 40, silk insulated, copper wire. The core must be made fairly accurate, of course. Shellac was used to hold the wire on the form.

An attempt was first made to use this coil with a fluxmeter which would read the flux directly but the method was not sensitive enough and the constants for such a method could not be determined easily. A ballistic galvanometer method was finally decided upon, the set-up being shown in Fig. 8. An air coil, a, was wound on a glass rod with length large compared to its diameter so that the flux could be calculated. This was then connected to a source of current as shown. A reversing switch allowed the circuit to be broken, thus changing the flux. The secondary, b, was then connected in series with the galvanometer and triangular coil and this circuit must be kept constant if the calibration constants are to be used continuously. The number of turns on b was 100.

With such a set-up, K may be determined for the calibration circuit such that \( N = K\theta \) per turn, and with this constant the flux of the magnetic field may be determined, since it makes no difference what part of the circuit is cut by the flux.

Now to get the working equation, let \( \theta' \) be the deflection of the galvanometer, and \( K' \) the constant such that,

\[ K'\theta' = N' = \text{flux cut in the air coil.} \]

By calculation, \( N' = 4\pi naI/L \)
or \( K' = 4\pi naI/L\theta' \).

But this is the constant for 100 turns on the secondary and the value of \( K'' \) for one turn is,

\[
K'' = 100 K' = (4\pi naI/L\theta')100.
\]

If \( K'' \) is the constant giving the flux per turn for the circuit, and if the triangular coil has \( n' \) turns, then the constant for the calibration coil is,

\[
K = K''/n'
\]

and \( K\theta = K''\theta/n' \).

This is the working equation which may be put in better form by substituting from the equation for \( K'' \) above. The equation therefore becomes,

\[
K = K''/n' = (4\pi naI/L\theta'n')100.
\]

The actual value of \( K \) may be determined and used as long as the circuit is kept constant in resistance so that the damping factor of the galvanometer is not changed. All that is necessary to calibrate the magnetic field is to suddenly remove the coil so that it cuts the flux, read the angle, \( \theta \), and multiply by the constant. By drawing a curve for the flux plotted against current in the magnet coils, the field is calibrated so that the flux may be read at any time by merely knowing the current, so long as the magnets have not been disturbed since calibrating.

The magnet used to produce the field was a large Dubois, electro magnet with special pole pieces to fit the apparatus. A special soft iron is used in the pole pieces and core of the magnet so as to get a high permeability and small hysteresis effect. This really makes the curve method of calibration possible, for the curve is a straight line except for very small currents. The follow-
Data for the determination of K.

<table>
<thead>
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<th>Current</th>
<th>Deflection-θ</th>
<th>Mean of θ</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps.</td>
<td>Right</td>
<td>Left</td>
<td></td>
</tr>
<tr>
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<td>7 mm</td>
<td>7.1 mm</td>
<td>7.05 mm</td>
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<tr>
<td>8.</td>
<td>3.9</td>
<td>4.4</td>
<td>4.35</td>
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<td>4.3</td>
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<td>5.35</td>
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<td>13.9</td>
<td>6.6</td>
<td>6.8</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Mean K = \[ \frac{1208.3}{12} \]

Constants for the apparatus:

\[ n = 259 \text{ turns}, \]
\[ L = 33.3 \text{ cm}, \]
\[ r = .755 \text{ cm}. \]

Calibration of the magnetic field.

<table>
<thead>
<tr>
<th>Current</th>
<th>Readings- θ</th>
<th>Mean of θ</th>
<th>Flux</th>
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(Current decreased to see if flux is constant.)

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Flux same as above.
V Manipulation of the Apparatus.

The theoretical discussion would seem to indicate that the positive ray method is an easy method of gas analysis, at least for one with some experience with positive rays. The purpose of this thesis has been to determine if it were possible to develop a practical and permanent gas analysis apparatus. Thomson suggests in his monograph on "Positive Rays" that it would be comparatively easy to do this and from my own experience, I believe that it may be accomplished in any laboratory where the necessary accessory apparatus is available, such as vacuum pumps, liquid air, magnets, and source of potential for the electro-static field. The chief difficulty that I have found is to overcome some mechanical defects which prevent getting the necessary vacuum. Thomson mentions no experimental difficulties and hence to reproduce the apparatus it is necessary to overcome for oneself many of the difficulties which he encountered over a period of several years. The best working conditions are found with pressures of about .0001 mm mercury and it is necessary of course to have gas tight apparatus to get this. It is also best to have the camera end at lower pressure than the discharge end but this is accomplished by connecting the pump to the two sides as shown in the general diagram page 12. After such a pressure is reached, the walls of the tube, the anode, and the cathode should all be free from gas or the discharge will drive out this gas and lower the vacuum. The pumping system should be a very efficient one. An equivalent of the Gaede rotary pump, supplemented by liquid air or by a molecular pump should be available. Otherwise the work will be slow and unsatisfactory. I have found the Gaede rotary pump with the molecular pump a very efficient means for evacuating the tube and holding a working pressure.
Another difficulty of manipulation which should be mentioned here, is that of maintaining a continuous discharge potential, which is high enough to pass through the evacuated tube, and yet which may be well enough controlled to prevent piercing the glass walls of the discharge tube. For the best working conditions, a potential equal to a spark gap of 5 or 6 cm. in air is necessary. A large Klink-fuss coil operated on 110 D.C. by means of a Wehnelt electrolytic interrupter, was first used but this gave too much energy. The bombardment of the cathode rays on the anode and walls of the vessel, caused the evolution of gas which let the vacuum down. A small induction coil built by Max Kohl was finally found sufficient to give the rays.

The actual manipulation for the analysis of gas is comparatively easy after the vacuum is produced. The electro-static field is gotten from a set of small storage cells, giving a range of potential up to 2000 volts. These are connected to the plates through a water rheostat. A few volts across the magnet coil gives enough current to produce the field. It is very necessary, of course, that both of the fields be perfectly constant.

Suppose then that we have obtained the required pressure. When the discharge passes, the positive rays fall backwards through the cathode and strike the center of the willimite screen. By regulating the two fields a part of the spot may be deflected within range of the photographic plate, and by lowering the plate, a photograph may be taken of both the central spot and the deflected beam. Then by reversing one of the fields, say the magnetic, a second photograph of the deflected beam may be taken with the central spot in the same position. By reversing the field, we get two measurements for the same deflection and the mean may be used. The time for an
exposure ranges from 10 minutes to 30 minutes or even more, depending upon the beam and the plate. If the plate is now developed, we shall see the central spot, and if the deflected beam has been of sufficient strength to affect the plate, a set of parabolic arcs will be found above and below and to one side of the center. These short arcs are connected to the central spot by means of faint lines. If the vacuum is not high enough to get rid of the effect, there may also be a faint set of parabolas on the other side. These are due to negative rays as may be seen by following out the direction of the magnetic field and the sign of the electrostatic plates. Thomson has found that very high vacuum gets rid of this effect. He also gives the following explanation of the photographs. The positive rays form in front of the cathode as explained above, and fall through the cathode, gaining a velocity great enough to carry them to the screen. Those particles, which retain their charges along the entire path, will be deflected most and will be found in the end of the parabola. Some may lose their charges and then gain them again before reaching the deflecting field, and all these will be found in the dense part of the parabolic arc. Some may, however, hold their charge over a part of the path through the deflecting field, and these will strike along some part of the curve connecting arc with the central spot. Some may even become negatively charged and be deflected in the opposite direction as explained above, but the number of these is usually small compared to the positive rays. The number of the parabolic arcs will depend upon the number of molecular structures present in sufficient quantities to affect the photographic plate. To determine the gas causing a given arc, therefore, choose corresponding points in the two arcs, measure their deflections, and
substituting in the equation, calculate $e/m$. $m$ may thus be gotten for one, two, three, etc. charges and the possible value chosen. One peculiar condition which the photographs secured by Thomson show, is that a gas under ionic conditions is far from the normal state. If we have a pure gas in the tube, as oxygen for example, we should expect an arc from the atom, one from the molecule, and probably one from the ozone molecule. Thomson has found all the combinations up to $C_6$, however. Many other examples may be found in Thomson's results which show that under ionic conditions, many combinations exist which are not normal compounds.

VI Discussion of the Practical Application of the Method.

So far it has not been possible to keep the apparatus working, except at short intervals of time, and so I have not been able to get any photographs that show the deflection. It has been possible to get the arcs clearly outlined on the willimite screen and even two distinct arcs have been seen at the same time. Several attempts have been made to photograph these but for some reason they did not affect the photographic plate, although exposures were made for periods of 10 minutes to 30 minutes. For the longer exposures the plate became considerably fogged. Just why the exposures failed to affect the plate, I am unable to explain at present, but one or two very probable reasons have been suggested. It seems most probable that the vacuum was not high enough, and also that the photographic plate may not be sensitive enough. Thomson mentions having trouble getting sensitive plates. The suggestion that the vacuum was not high enough seems the more plausible, since the effect on the screen was stronger and more clear-
cut with the best vacuum it was possible to get. The vacuum for
best working conditions could be gotten only by pumping without
the discharge passing. When the discharge was sent through, the
pressure increased considerably and naturally decreased the num-
ber of positive rays. Measurements could be taken on a willimite
screen of course, but not nearly so conveniently or accurately.
The above difficulties should be easily overcome, however. The
chief difficulty with leaks seems to be due to the metal-wax
joints and since they have held at times, they certainly
be made to hold permanently.

The purpose of this thesis, as has been stated above, was
to determine if the positive ray method could be made a practical
method. To draw any conclusions concerning this question, it will
be necessary to consider the advantages and disadvantages of the
method as well as the construction and manipulation of the appa-
ratus. From the theory it is seen that the method gives a qual-
itative study of the gas considered, especially for the study of the
elements present. Due to the fact that the ionic state changes the
normal combination of the elements introduced, it is not possible
to determine accurately the composite gas introduced, but the
elements may be determined and this is certainly worthwhile. The
method is also a direct method, which is a decided advantage. Fur-
ther it requires only a small amount of the gas analyzed. And
finally, a variation in the method may be introduced to make the
method quantitative. (The description of this may be found in
Thomson's Monograph on "Positive Rays", pages 56-7.) The diffi-
culty of construction and manipulation of the apparatus would seem
to me to be the only objection to the method. While it has not been
possible so far to keep the apparatus gas tight long enough to
get any definite results, the only trouble has been with mechanical difficulties that should be easily enough overcome. My conclusion so far would be that, if the accessory apparatus is available, it is possible to make the positive ray method a practical method of gas analysis.

References:


Rays of Positive Electricity- Sir J.J. Thomson.