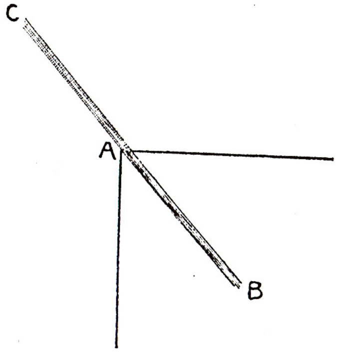
LXXXIII. *Rays of Positive Electricity.*
By Sir J. J. Thomson *.

I FIND that the investigation of the Positive Rays or Canalstrahlen is made much easier by using very large vessels for the discharge-tube in which the rays are produced. With large vessels the dark space around the cathode has plenty of room to expand before it reaches the walls of the tube; the pressure may therefore be reduced to very low values before this takes place, and in consequence the potential difference required to force the discharge through the tube at these low pressures is much lower than when the tubes are smaller. It is possible with large tubes to work with much lower pressures than with small ones, and at the lower pressures phases of the phenomena of the positive rays come to light which are absent or inconspicuous at higher pressures. With small tubes and therefore comparatively high pressures, when the arrangement used to investigate the rays is that described in my former paper (Phil. Mag. [6] xviii. p. 821, 1909), *i. e.* when the rays passing from a hole in the cathode through a long narrow tube fall on a phosphorescent willemite screen after passing through superposed magnetic and electric fields, the appearance on the screen is as follows.

Fig. 1.



The bright spot A which marks the place where the undeflected rays strike the screen is drawn out by the magnetic and electric forces, producing respectively vertical and horizontal displacements, into a straight band AB (fig. 1) of fairly uniform intensity; there is also a fainter prolongation AC of the band in the opposite direction to AB due to rays which carry a negative charge. The velocities and the values of e/m for the rays can be determined by measurements of this band. For if y and x are the vertical and horizontal deflexions of a ray striking the screen at P, then the velocity of this ray is equal to $c_1 y/x$ and the value of e/m to $c_2 y^2/x$, where c_1 and c_2 are constants depending on the strengths and positions of the electric and magnetic fields. I have shown (Phil. Mag. *loc. cit.*) that the velocity of the rays in this case is practically independent of the potential difference between the electrodes in the discharge-tube, and that we could increase the potential difference from 3000 to 40,000 volts without appreciably increasing this velocity. With small tubes the appearance I have just described is often the only effect to be observed even when the pressure is reduced close to the point at which it ceases to be possible to force the discharge through the tube.

When large discharge-tubes are used a much greater variety of effects can be observed. I have used tubes with a volume as large as 11 litres; these, however, are somewhat difficult to procure and not very convenient to work with. I have found flasks having a volume of 2 litres, such as are used for boiling-point determinations, large enough for most purposes.

A uniform and sensitive phosphorescent screen is of great importance as there is often a considerable amount of detail to be made out, and some of it too faint to be visible unless the screen is a very good one. My assistant Mr. Everett has lately succeeded in making very uniform screens by grinding the willemite into exceedingly fine powder, then shaking the powder up in alcohol and allowing it to settle slowly from the alcohol on to a flat glass plate; when the deposit has reached the requisite thickness the rest of the suspension is drawn off and the deposit allowed to dry; when dry it sticks quite firmly to the plate, and the deposit is much more uniform than that obtained by the method I formerly used of dusting powdered willemite on a glass plate smeared with water glass. The screens soon lose their sensitiveness if bombarded by the rays, and when any fine detail has to be made out it is advisable to use a new screen or a part of the screen not previously bombarded by the rays.

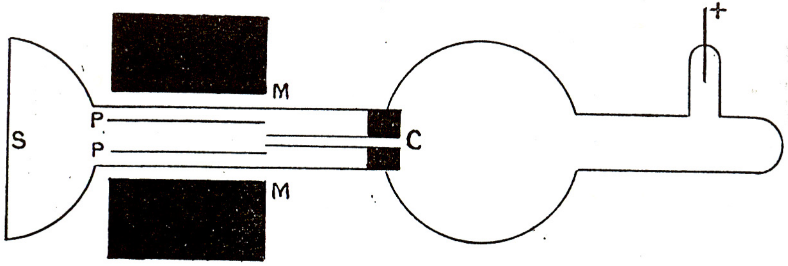
The discharge-tube is shown in section in fig. 2 (p. 754). The perforated cathode C protrudes well into the tube, the rays pass through the hole in the cathode through the fine tube

---

* Communicated by the Author. Read at the meeting of the British Association, Sept. 1, 1910.

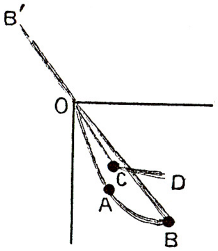
and then travel between the poles MM of an electromagnet and the parallel plates PP which are connected with a battery

Fig. 2.



of small storage-cells; the rays after being deflected fall on the willemite screen S. With a tube of this kind the appearance on the screen as the pressure is gradually reduced is as follows, the rays being exposed to both magnetic and electric forces. At the highest pressure at which the phosphorescence is visible, the phosphorescent patch covers a considerable area, the left hand (the least deflected) boundary being fairly well defined while the other boundary is hazy. As the pressure is still further reduced we get the appearance shown in fig. 1; this persists for a considerable range of pressure, but as the pressure is still further reduced bright spots as described in my paper (Phil. Mag. [6] xiii. p. 561, 1907) begin to appear, while the luminosity appears to divide into two portions, the appearance being that represented in fig. 3.

Fig. 3.



The luminous band, which at the higher pressures was the sole representative of the phosphorescent, can still be seen in its old position though it is not so bright as when the pressure was higher, the negative continuation of it still persists. As the pressure is still further diminished this part of the phosphorescence with its negative accompaniment gets fainter and fainter but does not alter in position, showing that the

velocity of the rays producing it is independent of the potential difference between the electrodes, finally when the pressure is very low it looks like a faint nebulous band over which brighter patches are superposed.

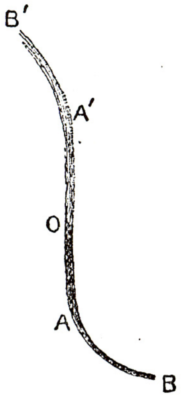
The relations between the positive and negative portions of the phosphorescent figures when the pressure is low are very interesting. The lower, more deflected portion has frequently two bright spots A and B for each of which $e/m=10^4$: one at A which gradually moves, as the pressure is diminished, along a parabolic path to O, the position of the undeflected spot; the other, not quite so definite, at B, a point on the phosphorescent band which has survived from the higher pressure. The negative portion at these low pressures is not a replica of the positive portion as it was at the higher pressures, but remains unaltered in shape and position as the pressure diminishes, getting gradually fainter. There is no trace on it of the spot A; the spot B is, however, visible at B′, and the luminous band BB′ can be traced as a straight strip occupying the same position as it did at higher pressures when it was the only part of the phosphorescence visible.

There is nothing on the negative side corresponding to the portion OCD on the positive, or at any rate if it exists it is so very much fainter, that I have never been able to satisfy myself of its existence, even when the negative part OB′ was quite bright.

I think there is exceedingly strong evidence to show that the straight band of phosphorescence which alone is seen at higher pressure and which lingers on with diminished intensity when the pressure is reduced, has a different origin from the phosphorescence which shows itself as bright spots on an isolated streak of phosphorescence, and which is due to rays whose velocity, unlike that of those producing the first kind of phosphorescence, depends upon the potential difference between the electrodes.

Such evidence is afforded by the following experiments, the first of which shows the complete symmetry between the positive and negative parts of the first kind of phosphorescence, and also that much of this kind of phosphorescence is due to secondary rays produced after the primary rays have passed through the cathode. In this experiment, the magnetic and electric fields, instead of being as in the previous experiments arranged so that when a particle was exposed to a magnetic force it was simultaneously exposed to an electric one, were made to overlap. The poles MM of the electromagnet were pushed nearer the screen so that they extended on the screen side beyond the parallel plates PP which produced the electric field. With this arrangement a particle, after leaving the space between the plates, enters a region where it is exposed to magnetic but not to electric forces, *i. e.* when it is deflected vertically but not horizontally. In this case the appearance presented by the phosphorescence patch at the pressure, when under normal circumstances it would be as represented in fig. 1, is shown in fig. 4.

Fig. 4.

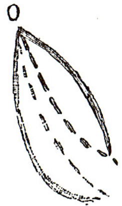


There is now a vertical portion OA due to rays which have been deflected vertically but not horizontally, *i. e.* which have been acted upon by magnetic but not by electric forces, and which must therefore have been produced between the ends of the parallel plates and the screen. Connected with the vertical piece OA there is a curved part AB due to rays which have been deflected by the electrostatic as well as the magnetic forces. The rays falling on the portion of AB near to A have been produced inside the parallel plates close to the end next the screen, and have only been exposed to the electric force for a small portion of their path. As we approach B the corresponding rays have been produced nearer the cathode, while the rays at the very end were already produced before the space between the plates was entered, for we find that the end B of the phosphorescent patch is in the same position as where the fields of action of the magnetic and electric forces were coincident.

If we reverse both the electric and magnetic forces so as to bring the negatively charged particles on to the part of the screen previously occupied by the positive ones, we find that the phosphorescent band due to the negative rays is an exact reproduction in shape, size, and position of that due to the positively charged particles.

If this experiment is repeated when the pressure has been reduced to the stage when the phosphorescence splits up into two bands as in fig. 3, the contrast between the behaviour of the two bands is very instructive. The lower band (*i. e.* the one where the magnetic deflexions are the greatest) is bent in the way we have just described, and is below the position it occupied when the magnetic and electric fields were coincident. The upper band on the other hand is bent in the opposite way and is above the position it occupied when the fields coincided. The appearance of the phosphorescence is represented in fig. 5, where the dotted lines show the positions of the bands when the magnetic and electric fields coincide, the continuous lines their position when the magnetic field is pushed forward towards the screen. The shape of the lower band can be explained as we have seen by supposing that it is due to secondary rays which are continually being produced as the undeflected rays travel from the cathode to the screen. The configuration of the upper band can be explained by supposing that it is due to primary rays coming through the cathode, and that these are not recruited by secondary rays, but on the other hand gradually get neutralized by combining with negative corpuscles. For if this were the case the rays which strike the screen near O are not, as in the previous case, rays which have been produced near the ends of the electric and magnetic fields, but are rays which have been neutralized soon after entering these fields. As the deflexions of such rays are due to the forces which act on the charged particle immediately after it leaves the tube and enters the space between the plates, the effect of pushing the magnetic field forward away from the tube will be to diminish the magnetic force on these particles while the electric force is unaltered: this will clearly tend to make the luminous band more nearly horizontal than it was before the magnets were pushed forward, and we see from fig. 5 that this is just the effect produced.

Fig. 5.



The upper band also differs from the lower one in not having, so far as I have been able to observe, any negative portion connected with it.

The difference between the properties of the rays which constitute the two bands is also shown by the following experiment. Two systems of magnets and parallel plates instead of one are placed between the cathode and the screen, the fields in these could be excited separately. The deflexion due to the magnet next the cathode is horizontal, that due to the magnet next the screen vertical. The electric fields are at right angles to the corresponding magnetic fields. Suppose that the magnetic field nearest the cathode is excited, the phosphorescent patch will be drawn out into a horizontal line, the most deflected portion of which, B, will be due to particles which were charged when they passed through the cathode. Now let the magnet next the screen be excited, the appearance on the screen is as in fig. 6; those rays which were charged when they passed through the first field and were deflected by it are still further deflected along the line BC, but in addition to this the stream of neutral particles as it passed between the two magnets has produced new secondary rays and these are deflected along OA. Thus all the rays which were charged when they passed through the cathode are found on the line BC, while OA consists exclusively of those which have been produced or which have acquired their charge after they left the first magnet. If now we put on the electric field in the system next the screen, we find that, at low pressures, the portion BC, which consists of rays charged when they passed through the cathode, is broken up into the two bands of which we have been speaking, and which were seen when only one system of electric and magnetic forces was used. On the other hand, the band OA, due to rays which were produced nearer the screen than the first magnet, does not bifurcate but consists of only one branch for which the maximum value of $e/m = 10^4$. The appearance of the phosphorescence is shown in fig. 7.

Fig. 6.

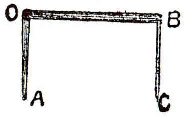
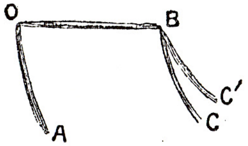


Fig. 7.

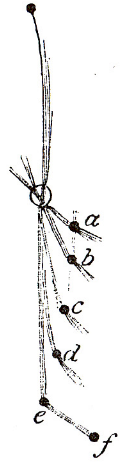


I have hitherto spoken only of two bands, but when the pressure is low there seem with these large tubes to be parabolic bands corresponding to every gas in the tube. By using very sensitive screens I have been able to detect the bands corresponding to hydrogen, helium, carbon, air, oxygen, neon, and mercury vapour. The appearance on the screen when there are several gases in the tube is almost like a spectrum, and I think this effect may furnish a valuable means of analysing the gases in the tube and determining their atomic weights. There is a band on the screen corresponding to a value of e/m about $\frac{1}{7} \times 10^4$, due to the air in the tube; the arrangement I was using was not suitable for applying the most intense magnetic fields and I could not detect that this spot was double, with one constituent corresponding to the atom of nitrogen, the other to the atom of oxygen. When CO was put into the tube, however, the band in this region was clearly double although the constituents were very close together, one constituent I suppose corresponding to oxygen the other to carbon.

One interesting feature in these experiments is that the bright spots on the bands are all in the same vertical line, showing that the electrostatic deflexion is the same for them all, and therefore that this energy of the particles which form the bright spots corresponding to the different gases is due to a fall through the same potential difference. The velocity of the rays forming these bright spots varies with the potential difference between the electrodes.

The bright spots come I think from the negative glow at the outer boundary of the dark space; they are weakened by any arrangement which prevents the portion of the negative glow straight in front of the cathode having free access to the cathode. Thus, if the anode A is a disk placed in front of the cathode, the spots do not appear unless the anode is pushed back so as to be outside the dark space; the continuous band due to the secondary radiation is, however, well developed when the anode is put forward.

Fig. 8.



Another interesting feature of these bright bands is that some of them have negative tails connected with them while others have not. This is shown in fig. 8, which represents the appearance in a tube containing mercury vapour, air, helium, and hydrogen; *a*, *b*, *c*, *d*, are the spots corresponding to these substances, the spot *f* is on the part due to secondary radiation: it will be noticed that this secondary radiation has a negative tail, there are no tails corresponding to the lighter elements, but the air and mercury bands have a well developed tail.

The details of the measurements of the values of e/m for the different elements are given at the end of this paper; it may be noted here, however, that with the exception of hydrogen all the charged particles of the different gases seemed to be atoms and not molecules of the gas. In working with the heavier atoms it is desirable to have very intense magnetic fields, otherwise the magnetic deflexion is very small. I am making arrangements for experiments in which the magnetic forces will be much greater than those I have hitherto used.

The preceding considerations show I think that we may divide the positive rays into the following classes :—

1. The undeflected rays, *i. e.* rays which are not affected by electric or magnetic forces; we cannot determine directly the velocity or the value of e/m for these rays.

2. Secondary rays produced by the rays (1). As the rays of the first type pass through a gas and collide against the molecules they produce secondary rays; whether they do this by splitting up themselves or by dissociating the molecules against which they strike, is uncertain. The rays of this class have a constant velocity 2×10^8 cm./sec. roughly; whatever may be the potential difference between the electrodes, they have a constant maximum value of $e/m = 10^4$. At the higher pressures and when the discharge-tube is small, these rays predominate and swamp the others; they get fainter and fainter as the pressure is reduced below a certain amount. We shall call the rays of this type secondary positive rays.

3. Rays characteristic of the gases in the tube. These are seen at low pressures, they produce bright spots on the screen; with each spot a thin parabolic band of luminosity is connected, the separate bands forming a kind of spectrum characteristic of the gases in the tube. The velocity of these rays depends on the potential difference between the electrodes, and the value of e/m is inversely proportional to the atomic weight of the gas from which they are derived. Their kinetic energy is that due to the potential difference between the negative glow and the cathode, in a mixture of gases the electrostatic deflexion of the rays from each gas is the same.

The retrograde rays which start from the cathode and travel away from it in the same direction as the cathode rays belong to classes (1) and (2). I have never seen the bright spots characteristic of class 3 in the retrograde rays.

In addition to the positively charged rays there are negatively charged ones of type 2 and in some cases of type 3. The different gases show great variations in the brightness of the negative tails connected with the rays peculiar to the atoms of the element, some elements show the negative tail readily while I have never seen it with others.

If we suppose that the undeflected rays are formed by the recombination of positive and negative particles and that these by collision with the molecules of the gas through which they pass form rays of type (2), either by splitting up themselves or by dissociating the molecules against which they strike, we can explain why the velocity of these rays should be independent of the potential difference between the electrodes in the tube. For in the first place, the positive and negative charges will not unite unless their relative velocity falls below a certain value which does not depend upon the strength of the electric field, and in the next place if the velocity were less than a limiting value they would not dissociate themselves nor could they dissociate other molecules by collisions when moving through a gas. The first condition gives a superior limit to the velocity, the second an inferior one; and both are independent of the strength of the electric field.

I shall now proceed to give the details of the measurements of the values of e/m and v. These constants were determined by measuring the magnetic and electrostatic deflexion of the rays. If y is the deflexion due to the magnetic force, e the charge on the particle and v its velocity,

$$y = \frac{e}{mv}\int_0^l (l-x)\mathrm{H}dx,$$

where x is the distance, measured along the undeflected ray, from the end of the tube through which the rays enter the magnetic field, H the magnetic force at the point x, and l the distance of the screen from the end of this tube. The value of $\int_0^l (l-x)\mathrm{H}dx$ was determined by measuring the magnetic induction through a triangular coil with its base at the end of the tube and its apex at the screen (see Phil. Mag. Nov. 1909). If n is the number of turns in this coil, d the base and l the perpendicular from the apex on the base, I the magnetic induction through the coil, then

$$\mathrm{I} = \frac{nl}{d}\int_0^l (l-x)\mathrm{H}dx\,;$$

hence if we know I we can deduce the value of the integral; the coil was made so narrow that for a given value of x the magnetic force was constant over the coil.

The induction was measured by means of a Grassot fluxmeter, using for the sake of greater accuracy the deflexions of a beam of light reflected from the back of the instrument instead of the usual index and scale.

The fluxmeter was standardized, (1) by measuring by means of it the induction through one of a pair of coaxial solenoids when a known current was broken in the other, the coefficient of mutual induction for these coils had been carefully determined by Mr. Searle; (2) by means of a Duddell induction-meter which had been standardized at the National Physical Laboratory and which was kindly lent to me by the Cambridge Scientific Instrument Co. The two methods gave results agreeing within less than 1 per cent.

With regard to the electrostatic deflexion we have to allow for the irregularity of the field near the edges of the plate; the case is one for which a complete solution is given by the Schwartzian transformation

$$\frac{dz}{dt} = \mathrm{C}\frac{t}{t+1} \quad \text{where } z = x+iy,$$

or

$$x+iy = \mathrm{C}(t-\log(1+t)+i\pi),$$

$$\frac{dw}{dt} = \frac{\mathrm{B}}{t+1} \quad \text{where } w = \phi+i\psi,$$

or

$$\phi+i\psi = \mathrm{B}\{\log(1+t)-i\pi\},$$

where $y = \mathrm{C}\pi$ is the equation to one plane and $y = -\mathrm{C}\pi$ to the other, $y = 0$ is the plane midway between them; ψ is the potential and ϕ the current function, $2\mathrm{B}\pi$ the difference of potential between the plates. The range of t over one of the semi-infinite planes and the plane midway between them is shown in fig. 9. t ranges from $+\infty$ to 0 on the upper, from $t = 0$ to -1 on the lower surface of the semi-infinite plate, and from $t = -1$ to $t = -\infty$ on the plane midway between the two plates.

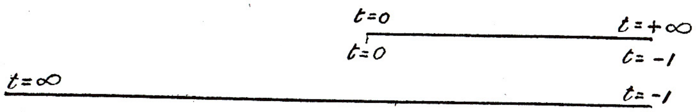


Fig. 9.

We shall suppose that the undeflected path of the particle is in this median plane. The equation of motion is

$$m\frac{d^2y}{dt^2} = \mathrm{Y}e,$$

or approximately

$$mv^2\frac{d^2y}{dx^2} = \mathrm{Y}e,$$

where Y is the electric force perpendicular to the plates,

$$\mathrm{Y} = \frac{d\psi}{dy} = \frac{d\phi}{dz}.$$

Hence

$$mv^2\frac{d^2y}{dx^2} = e\frac{d\phi}{dx},$$

hence

$$mv^2\frac{dy}{dx} = e(\phi_{\mathrm{P}}-\phi_0),$$

where $\frac{dy}{dx}$ is the value of $\frac{dy}{dx}$ at a point P; ϕ_{P} is the value of ϕ at P and ϕ_0 the value of ϕ at the place where the rays leave the narrow tube inserted in the cathode; the value of $\frac{dy}{dx}$ at this place is assumed to be zero. Hence if y is the displacement of the particle on the screen,

$$mv^2 y = \int_0^{-l} e(\phi_{\mathrm{P}}-\phi_0)dx,$$

$$= e\int_0^{-l}\phi_{\mathrm{P}}dx + el\phi_0,$$

where l is the distance of the screen from the end of the tube. Along the median plane

$$\frac{dx}{dt} = \frac{\mathrm{C}t}{t+1},$$

$$\phi_{\mathrm{P}} = \mathrm{B}\log(1+t);$$

hence

$$e\int_0^{-l}\phi_{\mathrm{P}}dx = e\mathrm{BC}\int\frac{t}{t+1}\log(1+t)dt$$

$$= e\mathrm{BC}\Big[(1+t)\log(1+t)-(1+t)-\tfrac{1}{2}\log^2(1+t)\Big]_0^{\mathrm{A}},$$

where A refers to the screen and 0 to the end of the tube.

Hence

$$\frac{mv^2}{e}y = \mathrm{BC}\Big[(1+t)\log(1+t)-(1+t)-\tfrac{1}{2}\log^2(1+t)\Big]_0^{\mathrm{A}} + \mathrm{B}\log(1+t_0)l.$$

If the distance of the end of the tube from the edge of the plates is a considerable multiple of the distance between the plates an approximate value of t_0 is -1.

Let $t_0 = -1 - \xi$, let b be distance from the end of the tube to the edge of the plate, then

$$b = \mathrm{C}(-1 - \xi - \log \xi),$$

an approximate solution is

$$\xi = e^{-\left(\frac{b+\mathrm{C}}{\mathrm{C}}\right)},$$

$$\log(1 + t_0) = -\left(\frac{b+\mathrm{C}}{\mathrm{C}}\right).$$

If d is the distance of the screen from the edge of the plate, t_{A} is given by the equation

$$-d = \mathrm{C}(t_{\mathrm{A}} - \log(1 + t_{\mathrm{A}})),$$

and when d is large compared with C, we can easily get a solution of this equation by successive approximation.

Two sets of plates were used in the course of the experiments. For one set 2·5 cm. long and ·2 cm. apart,

$$\mathrm{C}\pi = \cdot 1, \qquad l = 8\cdot 7,$$
$$b = 2\cdot 5,$$
$$d = 6\cdot 2,$$

for these we find

$$t_{\mathrm{A}} = -189\cdot 46 \log(1 + t_0) = -79\cdot 5,$$

this gives

$$y = \frac{e}{mv^2} \mathrm{X}\ 19\cdot 7,$$

where X is the potential difference divided by the distance between the plates.

For the second pair of plates, which were 5·0 cm. long and 3 cm. apart,

$$\mathrm{C}\pi = \cdot 15,$$
$$b = 5\cdot 0,$$
$$d = 3\cdot 7,$$
$$l = 8\cdot 7,$$

for them

$$t_{\mathrm{A}} = -73\cdot 42 \log(1 + t_0) = -105\cdot 7,$$

hence

$$y = \frac{e}{mv^2} \mathrm{X}\ 32\cdot 2.$$

We shall now proceed to consider the values of e/m for the different types of rays. First, with regard to the secondary rays. The values of e/m were measured when

there was a well-marked spot which was visible on both the positive and negative side (this is the spot f in fig. 8). When the conditions were most favourable to accurate measurements, it was found that increasing the potential difference between the plates from 100 to 200 volts increased the horizontal deflexion of the spot by 3 millimetres when the second system of plates was used. While an increase of 3 millimetres in the vertical deflexion was produced by increasing the current through the electromagnet by 1 ampere. The measurements of the magnetic induction by the fluxmeter showed that this increase in the current corresponded to an increase of $5\cdot 05 \times 10^4$ in the value of

$$\int_0^l (l - x)\mathrm{H}\,dx,$$

hence we have

$$\cdot 3 = \frac{e}{mv} \times 5\cdot 05 \times 10^3,$$

$$\cdot 3 = \frac{e}{mv^2} \times \frac{10^{10}}{\cdot 3} \times 32\cdot 2,$$

giving

$$v = 2\cdot 1 \times 10^8,$$

$$e/m = 1\cdot 24 \times 10^4.$$

It was found that the values of e/m for this spot always came out a little greater than 10^4, and as the spot was not quite at the extreme end of the straight band of phosphorescence due to the secondary rays, the value of e/m for the rays at the tip of this band would be still greater; for the tip the values of e/m ranged up to $1\cdot 5 \times 10^4$, but as the tip is somewhat ill-defined the values of e/m for it could not be measured with the same accuracy as when there was a spot. The larger values of e/m were more frequent for the negative secondary rays than for the positive ones; these larger values would be accounted for if some of the particles had acquired a double charge for part of their course.

For the spot e the magnetic deflexion for a current of 2 amperes through the electromagnet

$$\left(\text{value of } \int_0^l (l - x)\mathrm{H}\,dx = 1\cdot 1 \times 10^4\right)$$

was 4·4 millimetres, and for 200 volts an electrostatic deflexion of 3·5 millimetres. This gives

$$\cdot 44 = \frac{e}{mv} \times 1\cdot 01 \times 10^4,$$

$$\cdot 35 = \frac{e}{mv^2} \times \frac{2 \times 10^{10}}{3} \times 32\cdot 2;$$

or

$$v = 2\cdot 66 \times 10^8,$$

$$e/m = 1\cdot 16 \times 10^4.$$

The value of v for this spot depends upon the pressure in the tube. The spot d had the same electrostatic deflexion as e, so that the values of e/m for the spots d and e will be as the squares of the magnetic deflexions.

The corresponding magnetic deflexions for d and e and the square of their ratio is given in the following table:

Deflexion of *e*.	Deflexion of *d*	Square of ratio.
3·5	2·5	1·96
5·3	3·7	2·06
6·8	4·7	2·09
6·0	4	2·25
7·0	5	1·96

Thus the value of e/m for d is half that for e; hence if the charges are the same, the mass of the carriers producing the spot d is twice that of those producing e, hence we ascribe d to the hydrogen *molecule*.

The spot c is the helium spot, and the value of e/m as I showed in my earlier paper is $\frac{1}{4}$ that of the spot e.

We can compare the mass of the carriers for the spot b with those of d by comparing the magnetic deflexions, the following are corresponding values:

Spot *d*.	Spot *b*.	Square of ratio.
9·0	3·3	7·4
4·7	1·8	6·8
9·2	3 5	6 9
9·5	2·4	7·8
8·0	3	7·1

Thus if the charges are the same, the mass of the carriers of b is about seven times that of d; if, as we supposed, the carrier of d is the hydrogen molecule, then the carrier of b will be an atom either of nitrogen or oxygen. I am inclined to think that this is a double spot and will be resolved by the application of stronger magnetic fields.

When the air in the tube was replaced by CO there was a spot in approximately the same position as b, on increasing the field it was resolved into two with magnetic deflexions 6·0 and 5·3 millimetres; the square of the ratio of these deflexions is 1·28, the ratio of the atomic weights of O and C is 1·33, which agrees with the preceding value within the accuracy of the experiments. The spot a was compared with b, the corresponding magnetic deflexions are:

b.	*a*.	Square of the ratio.
5·0	1·5	11·1
5·0	1·3	13·6
	Mean	12·35

For mercury vapour the square of the ratio would have been 14 if the spot b were due to nitrogen, 12 if it were due to oxygen. The deflexion of the spot a with the magnetic force available was too small to admit of accurate measurement, but there can, I think, be little doubt that the spot a is due to mercury vapour. It disappears very quickly when liquid air is put around some charcoal in a side tube.

Thus we see that on the assumption that the charges are equal, we see that all the carriers with the exception of those for spot d are in the atomic condition; a very remarkable result, and one which has an important bearing on the dissociation of gases in the discharge-tube. It will be interesting to liberate the different elements from compounds of different types when they have different valencies, and from carbon compounds where the bands are different, and see whether the value of e/m remains unaltered.

The absence of the negative part of the phosphorescence indicates a reluctance on the part of the atoms of some gases to acquire a negative charge; this is also brought out by Franck's discovery that in some gases from which oxygen has been carefully excluded the velocity of the negative ion was very many times greater than when oxygen was admitted, while the positive ion was not affected. This indicates that negative corpuscle does not readily attach itself to the molecules of these gases.

I had occasion in the course of the work to investigate the secondary Canalstrahlen produced when primary Canalstrahlen strike against a metal plate. I found that the secondary rays which were emitted in all directions were for the most part uncharged, but that a small fraction carried a positive charge.

I have much pleasure in thanking Mr. F. W. Aston, of Trinity College, Cambridge, and Mr. E. Everett, for the kind assistance they have given me with these experiments.