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1897.
and
\[ C = c_c \left( \frac{R_1}{R} \right) e^{\frac{1}{R} \left( 1 - \frac{1}{R} \right)} \ln \frac{1}{R} + \frac{1}{R} \ln (R_k \ln \lambda) \]
\[ \frac{2 \frac{2}{R} - \frac{1}{m} \frac{\cos \pi}{\sin \pi} \ln \frac{R \left( R \cos \left( \frac{\pi}{m} \sin \lambda \frac{R}{R} \right) \right)}{\lambda} - \frac{1}{L} \lambda} \]
\[ \text{where } m \text{ is } m \text{ as before.} \]

Now, in § 885, equations (44) (57) I have given the V and C solutions in terms of functions of the first wave, and have shown how to carry on the formula to any extent in § 884 in another way. The succeeding waves are obtainable by change of argument, as explained above. Therefore we may equate the wave solutions to (44) and (45) respectively, and derive a fresh batch of equations which are integrals of the same kind. But as they are all included in the equations of (44) (45) to the wave formulas, we need not go far in elaborating them. Considering only the first wave, \( t = \infty \) in (44) makes

\[ V = c_m e^{2 \pi i R} \left( \cos \left( \frac{\pi}{m} \sin \lambda \right) \right) \frac{d}{d \lambda} \]

\[ \text{equivalent to (57) § 885, with } w = \omega. \]

To be continued.

**DISASSOCIATION OF ATOMS.**

**By Professor W. F. Fitzgerald.**

On Friday evening, April 80th, Prof. J. J. Thomson delivered a very interesting discourse on cathode rays. Anything he brings forward as the result of his mature judgment deserves consideration at the hands of the scientific world. In this discourse he expresses his judgment that atoms are divisible into very much smaller parts, and that they are so divided in cathode rays. The greater part of the discourse is a description and illustration of the work of the pioneers in the investigation of cathode rays and of a series of most interesting observations and experiments by himself. The experiments he had been making of the discharge of a battery, the apparent continuity of cathode rays, the apparent gap in a metal plate, the reproduction of cathode rays by a metal plate, and the amount of light given off by cathode rays, are all connected with the production of cathode rays by an electric charge on a battery.

The first of these observations is explained as follows by his hypothesis of corpuscles into which the atoms are decomposed:

"We see, too, on this hypothesis, why the magnetic deflection is the same inside the tube whatever be the nature of the gas, for the carriers of the charge are the corpuscles, and these are the same whatever gas be used." Hence the hypothesis put forward is essentially Prout's hypothesis that all kinds of matter are formed from the same kind of corpuscles, and that this corpuscular nature of matter is of the same kind. The magnetic spectrum is explained by the suggestion that the corpuscular aggregates are not all reduced to their simplest form, and that two or more corpuscles in combination would be deflected to a different extent from single corpuscles. This is a very interesting suggestion, but it naturally suggests the difficulty, why the variety of aggregates into which the atoms are decomposed should be independent of the nature of these atoms. One would, a priori, expect that different atoms would decompose into different aggregates, unless, of course, they were all entirely decomposed, which Prof. J. J. Thomson cannot hold, as this would destroy his explanation of a spectrum.

Perchance he holds that in the dark space, which he shows reason to think does not conduct electricity, the atoms are completely dissociated, and that the aggregation that occurs subsequently depends on the electromagnetic character of the field and possibly on the density of the corpuscles. This would make the number of one atom matter to another for us to be at all sure that each molecular impact of a charged atom on one side of a brass plate may not produce a corresponding emission of a cathode ray on the other side. There seems, however, that even when a battery is producing cathode rays, and there is too little known about the inner nature of conduction and the transference of electricity through a gas as in any way difficult to believe that the mass of a solid.

There can hardly be any doubt that Lenard is right in his contention that gases are far too transparent for the hypothesis that cathode rays are simply projected molecules to account for the phenomena. At the same time it
would require a very full discussion of the effect of increased velocity in diminishing the effective size of atoms to be quite sure what it would happen. If we take two bodies in collision when they come so close that their paths are deflected, say 10deg., it is quite evident that they must approach more closely in order to in this sense collide when their relative velocity is large than when it is small. The variation is enormous if the law of force be the inverse square of the distance. If charged atoms may act according to this law. If so it seems at least possible that the effective size of these rapidly moving charged atoms, both as regards another and as regards the residual gas, may be different from that of the ordinary molecules that constitute the gas. It may also be that the laws of impacts of spheres do not apply even approximately to the actions of molecules polarized by an electric force. The action may be transmitted from molecule to molecule, not by any impact, but by the advent of a charged atom enabling one of the constituents of the molecule it is approaching to obey the electric force and dart off in the line or nearly the line of the approaching one. This would account for rays being transmitted long distances in straight lines.

An hypothesis seems also possible on the lines of Grothus, chains being formed under the action of the cathode rays or under the action of Röntgen rays due to the impacts of cathode rays on the molecules. In fact, there seems an "embarrass de richesse" in the possible explanations of the transparency of media to cathode rays with supposing that we can account for the presence of a possible method of transmutation of matter. This latter is by far the most interesting hypothesis, and it is very much to be hoped that Prof. J. J. Thomson's hypothesis is true.

As regards the calculation of the ratio of the numerical measure of the mass of the corpuscle to the electric charge it carries, there are two suggestions that can be made in respect of it. The first is that we are dealing with free electrons in these cathode rays. This is somewhat like Prof. J. J. Thomson's hypothesis, except that it does not assume the electron to be a constituent part of an atom, nor that we are dissociating atoms, nor consequently that we are on the track of the alchemists. There seems every reason to suppose that electrons can be transferred from atom to atom without all destroying or indeed sensibly changing the characteristic properties of the atom: that in fact there is a considerable analogy between a charged sphere and an atom with an electron charge. If this be so, the question of course arises, how far can an electron jump in going from atom to atom? Why not the length of a cathode, say, or at least from molecule to molecule along it, or anyway in nearly straight lines along it? In this case, the mass calculated may be the effective mass of the electron, and that will depend on its size as an electric charge, and as Dr. Lodge has pointed out, in the corresponding case of Zeeman's observation the resultant size is quite feasible. If it be so we should have this further interesting result. We can calculate how much nearer the electrons must be in 2HCl than in HH and CCl if the heat of combination be due to this approach. This gives a maximum size for an electron if they preserve their individuality. Knowing the size of the electrons, and assuming it to stay constant, we could calculate what the change in the effective inertia of the electrons must be, due to their being nearer together in 2HCl than in HH + Cl2. This would give us a possible reason why the mass of matter may change when it changes its chemical constitution. Of course we had time to worry out the calculation, but it is evident that the change in effective inertia would be a very small part of the total inertia of the matter: yet it may be within our powers of measurement. If there is no change, then either the size of the electrons changes in such a way as to compensate exactly for the change in the elementary continuous force, or else the inertia we are dealing with is not the effective inertia of electrons.

The other suggestion is that Prof. J. J. Thomson is quite wrong in assuming that nearly all the bombarding molecules give up charges to the cylinder, or what comes to much the same thing, that he is wrong in thinking that all the rays are stuck there, and that only a few of them escape into the surrounding gas. Suppose that only a thousandth part of the molecules entering the cylinder gave up charges to it, and that the rest were either uncharged or were driven out by the entering cases, and not scattered near the tube, so that they quietly gave up their charges, then the energy of these 999 would be attributed to the few that give up their charges, and this naturally leads to an abnormally small mass and an extraordinarily great velocity for these molecules. The velocity that Prof. J. J. Thomson now attributes to the corpuscles in cathode rays is 1 1/2 x 107; the second, which is only one-twentieth of that of light, a velocity that would penetrate anything, and is enormously greater than what his own direct observations of cathode rays give. This latter, when introduced into the equation—

\[ m \cdot v^2 = \frac{1}{2} \cdot M \cdot v^2 \]

for values of \( m \) corresponding approximately to that usually received for the mass of an atom. Hence this recent investigation coupled with his former one would lead to the conclusion that only a small part of the projected atoms give up their charge to the cylinder, either because they take it out again with themselves, or because only a small proportion of the bombarding atoms are charged. In any case, there does not seem anything necessary to be inferred from these experiments and the case Zeeman investigates. In this latter case it would seem most improbable that the moving electric charge that originates the light vibrations should carry the whole atom along with it in its insurances. It would seem much more likely that an extremely minute deformation of the atom would accompany the insurances of the charge, so that Zeeman's result is what one would naturally expect, and the only remarkable thing about it seems to me to be that such a large proportion of the matter accompanies the ether incursions. In his case it may quite possibly be that the inertia is that of the electron and not of the matter at all.

In conclusion, I may express a hope that Prof. J. J. Thomson is quite right in his by no means impossible hypothesis. It would be the beginning of great advances in science, and the results it would be likely to lead to in the near future might easily eclipse most of the other great discoveries of the nineteenth century, and be a magnificent scientific contribution to this Jubilee year.

**CATHODE RAYS.**

**BY PROF. J. J. THOMSON, F.R.S.**

The first observer to leave any record of what are now known as the Cathode Rays, seems to have been Plücker, who in 1859 observed the now well known green phosphorescence on the glass in the neighborhood of the negative electrode. Plücker was the first physicist to make experiments on the discharge through a tube, in a state anything approaching what we should now call a high vacuum: he owed the opportunity to do this to his fellow-townman Geissler, who first made such vacua attainable. Plücker, who had made a very minute study of the effect of a magnetic field on the ordinary discharge which stretches from one terminal to the other, distinguished the discharge which produced the green phosphorescence from the ordinary discharge, by the difference in its behaviour when in a magnetic field. Plücker scribed these phosphorescent patches to currents of electricity which went from the cathode to the walls of the tube and then for some reason or other retraced their steps.

The subject was next taken up by Plücker's pupil, Hitdorf, who greatly extended our knowledge of the subject, and to whom we owe the observation that a solid body placed between a pointed cathode and the walls of the tube cast a well defined shadow. This observation was extended by Goldstein, who found that a well marked, though not very sharply defined shadow was cast by a small solid body placed near a cathode of considerable area; this was a very important observation, for it showed that the rays casting the shadow came in a definite direction from the cathode. If the cathode were re-
placed by a luminous disc of the same size, this disc would not cast a shadow of a small object placed near it, for though the object might intercept the rays which came out normally from the disc, yet enough light would be given out sideways from other parts of the disc to prevent the shadow being at all well marked. Goldstein seems to have been the first to advance the theory, which has attained a good deal of prevalence in Germany, that these cathode rays are transversal vibrations in the ether.

The physicist, however, who did more than any one else to direct attention to these rays was Mr. Crookes, whose experiments, by their beauty and importance, attracted the attention of all physicists to this subject, and who not only greatly increased our knowledge of the properties of the rays, but by his application of them to radiant matter spectroscopy has rendered them most important agents in chemical research.

Recently a great renewal of interest in these rays has taken place, owing to the remarkable properties possessed by an offspring of theirs, for the cathode rays are the parents of the Röntgen rays.

I shall confine myself this evening to endeavouring to give an account of some of the more recent investigations which have been made on the cathode rays. In the first place, when these rays fall on a substance they produce changes physical or chemical in the nature of the substance. In some cases this change is marked by a change in the colour of the substance, as in the case of the chlorides of the alkaline metals. Goldstein found that when exposed to the cathode rays changed colour, the change, according to E. Wiedemann and Ebert, being due to the formation of a sub-chloride. Elster and Geitel have recently shown that these substances become photo-electric, i.e., acquire the power of discharging negative electricity under the action of light, after exposure to the cathode rays. But though it is only in comparatively few cases that the changes produced by the cathode rays shows itself in such a conspicuous way as by a change of colour, there is a much more widely spread phenomenon which shows the permanence of the effect produced by the impact of these rays. This is the phenomenon called by its discoverer, Prof. E. Wiedemann, theroluminescence. Prof. Wiedemann finds that if bodies are exposed to the cathode rays for some time, when the bombardment stops the substance resumes to all appearance its original condition; when, however, we heat the substance, we find that a change has taken place, for the substance now, when heated, becomes luminous at a comparatively low temperature, one far below that of incandescence; the substance retains this property for months after the exposure to the rays has ceased. The phenomenon of theroluminescence is especially marked in bodies which are called by Van't Hoff solid solutions; these are formed when two salts one greatly in excess of the other are simultaneously precipitated from a solution. Under these circumstances the connection between the salts seems of a more intimate character than that existing in a mechanical mixture. I have here a solid solution of CaSO₄ with trace of MnSO₄, and you will see that after exposure to the cathode rays it becomes luminous when heated. Another proof of the alteration produced by these rays is the fact discovered by Crooke's that after glass has been exposed for a long time to the impact of these rays the intensity of its phosphorescence is less than when the rays first began to fall upon it. This alteration lasts for a long time, certainly for months, and Mr. Crookes has shown that it is able to survive the heating up of the glass to allow of the remaking of the bulb. I will now leave the chemical effects produced by these rays, and pass on to consider their behaviour when in a magnetic field.

First, let us consider for a moment the effect of magnetic force on the ordinary discharge between terminals at a pressure much higher than that at which the cathode rays begin to come off. I have here photographs (see Figs. 1 and 2) of the spark in a magnetic field. You see that when the discharge which passes as a thin bright line between the terminals is acted upon by the magnetic field, it is pulled aside as a stretched string would be if acted upon by a force at right angles to its length. The curve is quite continuous, and though there may be gaps in the luminosity of the discharge, yet there are no breaks at such points in the curve into which the discharge is bent by a magnet. Again, if the discharge, instead of taking place between points, passes between flat discs, the effect of the magnetic force is to move the sparks as a whole, the sparks keeping straight until their terminations reach the edges of the discs. The fine thread-like discharge is not much spread out by the action of the magnetic field. The appearance of the discharge indicates that when the discharge passes through the gas it manufactures out of the gas something stretching from terminal to terminal, which, unlike a gas, is capable of sustaining a tension. The amount of deflection produced, other circumstances being the same, depends on the nature of the gas; as the photographs (Figs. 3 and 4) show, the deflection is very small in the case of hydrogen, and very considerable in the case of carbonic acid; as a general rule it seems smaller in elementary than in compound gases.

Let us contrast the behaviour of this kind of discharge under the action of a magnetic field with that of the cathode rays. I have here some photographs (Figs. 5, 6 and 7) taken of a narrow beam formed by sending the cathode rays through a
tube in which there was a plug with a slit in it, the plug being used as an anode and connected with the earth, these rays traversing a uniform magnetic field. The narrow beam spreads out under the action of the magnetic force into a broad fan-shaped luminosity in the gas. The luminosity in this fan is not uniformly distributed, but is condensed along certain lines. The phosphorescence produced when the rays reach the glass is also not uniformly distributed, it is much spread out, showing that the beam consists of rays which are not all deflected to the same extent by the magnet. The luminous patch on the glass is crossed by bands along which the luminosity is very much greater than in the adjacent parts.

These bright and dark bands are called by Birkeland, who first observed them, "the magnetic spectrum." The brightest places on the glass are by no means always the terminations of the brightest streaks of luminosity in the gas; in fact, in some cases a very bright spot on the glass is not connected with the cathode by any appreciable luminosity, though there is plenty of luminosity in other parts of the gas.

One very interesting point brought out by the photographs is that in a given magnetic field, with a given mean potential difference between the terminals, the path of the rays is independent of the nature of the gas; photographs were taken of the discharge in hydrogen, air, carbonic acid, methyl iodide, i.e., in gases whose densities range from 1 to 70, and yet not only were the paths of the most deflected rays the same in all cases, but even the details, such as the distribution of the bright and dark spaces, were the same; in fact, the photographs could hardly be distinguished from each other. It is to be noted that the pressures were not the same; the pressures were adjusted until the mean potential difference was the same. When the pressure of the gas is lowered, the potential difference between the terminals increases, and the deflection of the rays produced by a magnet diminishes, or at any rate the deflection of the rays where the phosphorescence is a maximum diminishes. If an air break is inserted in the circuit an effect of the same kind is produced. In all the photographs of the cathode rays one sees indications of rays which stretch far into the bulb, but which are not deflected at all by a magnet. Though they stretch for some two or three inches, yet in none of these photographs do they actually reach the glass. In some experiments, however, I placed inside the tube a screen, near to the slit through which the cathode rays came, and found that no appreciable phosphorescence was produced when the non-deflected rays struck the screen, while there was vivid phosphorescence at the places where the deflected rays struck the screen. These non-deflected rays do not seem to exhibit any of the characteristics of cathode rays, and it seems possible that they are merely jets of uncharged luminous gas shot out through the slit from the neighbourhood of the cathode by a kind of explosion when the discharge passes.

The curves described by the cathode rays in a uniform magnetic field are, very approximately at any rate, circular for a large part of their course; this is the path which would be described if the cathode rays marked the path of negatively electrified particles projected with great velocities from the neighbourhood of the negative electrode. Indeed all the effects produced by a magnet on these rays, and some of these are complicated, as for example, when the rays are carried up into spirals under the action of a magnetic force, are in exact agreement with the consequences of this view.

We can, moreover, show by direct experiments that a charge of negative electricity follows the course of the cathode rays. One way in which this has been done, is by an experiment due to Perrin, the details of which are shown in the accompanying figure (Fig. 6). In this experiment the rays are allowed to pass inside a metallic cylinder through a small hole, and the cylinder, when these rays enter it, gets a negative charge, while if the rays are deflected by a magnet, so as to escape the hole, the cylinder remains without charge. It seems to me that to the experiment in this form it might be objected, that though the experiment shows that negatively electrified bodies are projected normally from the cathode, and are deflected by a magnet, it does not show that when the cathode rays are deflected by a magnet the path of the electrified particles coincides with the path of the cathode rays. The supporters of the theory that these rays are waves in the ether might say, and indeed have said, that while they did not deny that electrified particles might be shot off from the cathode, these particles were, in their opinion, merely accidental accompaniments of the rays, and were no more to do with the rays than the bullet has with the flash of a rifle. The following modification of Perrin's experiment is not, however, open to this objection: Two co-axial cylinders (Fig. 9), with slits cut in them, the outer cylinder being connected with earth, the inner with the electrometer, are placed in the discharge tube, but in such a position that the cathode rays do not fall
upon them unless deflected by a magnet; by means of a magnet, however, we can deflect the cathode rays until they fall on the slit in the cylinder. If under these circumstances the cylinder gets a negative charge when the cathode rays fall on the slit, and remains uncharged unless they do so, we may conclude, I think, that the stream of negatively-electrified particles is an invariable accompaniment of the cathode rays. I will now try the experiment. You notice that when there is no magnetic force, though the rays do not fall on the cylinder, there is a slight deflection of the electrometer, showing that it has acquired a small negative charge. This is, I think, due to the plug getting negatively charged under the torrent of negatively electrified particles from the cathode and getting out cathode rays on its own account which have not come through the slit. I will now direct the rays by a magnet, and you will see that at first there is little or no change in the deflection of the electrometer, but that when the rays reach the cylinder there is at once a great increase in the deflection, showing that the rays are pouring a charge of negative electricity into the cylinder. The deflection of the electrometer reaches a certain value and then stops and remains constant, though the rays continue to pour into the cylinder. This is due to the fact that the gas traversed by the cathode rays becomes a conductor of electricity, and thus, though the inner cylinder is perfectly insulated when the rays are not passing, yet as soon as the rays pass through the bulb and the air between the inner cylinder and the outer one, which is connected with the earth, becomes a conductor, and the electricity escapes from the inner cylinder to the earth. For this reason the charge within the inner cylinder does not go on continually increasing: the cylinder settles into a state of equilibrium in which the rate at which it gains negative electricity from the rays is equal to the rate at which it loses it by conduction through the air. If we charge up the cylinder positively it rapidly loses its positive charge and acquires a negative one, while if we charge it up negatively it will leak if its initial negative potential is greater than its equilibrium value.

I have lately made some experiments which are interesting from the bearing they have on the charges carried by the cathode rays, as well as on the production of cathode rays outside the tube. The experiments are of the following kind: In the tube (Fig. 10) A and B are terminals. C is a long side tube into which a closed metallic cylinder fits tightly. This cylinder is made entirely of metal except the end furthest from the terminals, which is stopped by an abonite plug, perforated by a small hole so as to make the pressure inside the cylinder equal to that in the discharge tube. Inside the cylinder there is a metal disc supported by a metal rod which passes through the abonite plug, and is connected with an electrometer, the wires making this connection being surrounded by tubes connected with the earth so as to screen off electrostatic induction. If the end of the cylinder is made of thin aluminium about 1/60 of a millimetre thick, and a discharge sent between the terminals, A being the cathode, then at pressures far higher than those at which the cathode rays come off, the disc inside the cylinder acquires a positive charge. And if it is charged up independently the charge leaks away, and it leaks more rapidly when the disc is charged negatively than when it is charged positively; there is, however, a leak in both cases showing that the gas between the cylinder and the disc. As the pressure in the tube is diminished the positive charge on the disc diminishes until it becomes unappreciable. The leak from the disc when it is charged still continues, and is now equally rapid, whether the original charge on the disc is positive or negative. When the pressure falls so low that cathode rays begin to fall on the end of the cylinder, then the disc acquires a negative charge, and the leak from the disc is more rapid when it is charged positively than when it is charged negatively. If the cathode rays are pulled off the end of the cylinder by a magnet, then the negative charge on the disc and the rate of leak from the disc when it is positively charged is very much diminished. A very interesting point is that these effects, due to the cathode rays, are observed behind comparatively thick walls. I have here a cylinder whose base is brass about 1 mm. thick, and yet when this is exposed to the cathode rays the disc behind it gains a negative charge, and leaks if charged positively. The effect is small compared with that in the thin aluminium base, but is quite appreciable. With the cylinder with the thick end I have never been able to observe any effect at the higher pressures when no cathode rays were coming off. The effect with the cylinder with the thin end was observed when the discharge was produced by a large number of small storage cells, as well as when it was produced by an induction coil.

It would seem from this experiment that the incidence of the cathode rays on a brass plate as much as 1 mm. thick, and connected with the earth, can put a residuated gas shielded by the plate into a condition in which it can conduct electricity, and that a body placed behind this screen gets a negative charge, so that the side of the brass away from the cathode rays acts itself like a cathode though kept permanently to earth. In the case of the thick brass the effect seems much more likely to be due to a sudden change in the potential of the outer cylinder at the places where the rays strike rather than to the penetration of any kind of waves or rays. If the discharge in the tube was perfectly continuous the potential of the outer cylinder would be constant, and since it is connected to earth by a wire through which no considerable current flows, the potential must be approximated by a small potential of the earth. The discharge there cannot be continuous; the negative charge must come in gusts against the ends of the cylinder, coming so suddenly that the electricity has no time to distribute itself over the cylinder so as to shield off the inside from the electrostatic action of the cathode rays; this force penetrates the cylinder and produces a discharge of electricity from the far side of the brass.

Another effect which I believe is due to the negative electrification carried by the rays is the following: In a very highly exhausted tube provided with a metal plug, I have sometimes observed, after the coil has been turned off, bright patches on the glass; these are deflected by a magnet, and seem to be caused by the plug getting such a large negative charge that the negative electricity continues to stream from it after the coil is stopped.

An objection sometimes urged against the view that these cathode rays consist of charged particles, is that they are not deflected by an electrostatic force. If, for example, we make, as Hertz did, the rays pass between two plates connected with a battery, so that an electrostatic force acts between these plates, the cathode ray is able to traverse this space without being deflected one way or the other. We must remember, however, that the cathode rays, when they pass through a gas, make it a conductor, so that the gas acting like a conductor screens off the electric force from the cathode ray; when the plates are immersed in the gas and a definite potential difference established between the plates, the conductivity of the gas close to the cathode rays is probably enormously greater than the average conductivity of the gas between the plates, and the potential gradient on the cathode rays is there-
fore very small compared with the average potential gradient. We can, however, produce electrostatic results if we put the conductors which are to deflect the rays in the dark space next the cathode. I have here a tube in which inside the dark space next the cathode two conductors are inserted; the cathode rays start from the cathode and have to pass between these conductors. The stream of conductors is independent of the density and chemical composition of the gas outside the tube, though it varies very much with the pressure of the gas inside the tube. The cathode rays could be started by an electric impulse which would depend entirely on what was going on inside the tube; since the impulse is the same, the momentum acquired by the particles would be the same; and as the intensity of the path only depends on the momentum, the path of these particles outside the tube would only depend on the state of affairs inside the tube.

The investigation by Lenard on the absorption of these rays shows that there is more in his experiment than is covered by this consideration. Lenard measured the distance these rays would have to travel before the intensity of the rays fell to one-half their original value. The results are given in the following table:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Coefficient of absorption</th>
<th>Density</th>
<th>Absorption Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (7mm. press.)</td>
<td>0.00149</td>
<td>0.0000000368</td>
<td>4.090</td>
</tr>
<tr>
<td>Air (076mm. press.)</td>
<td>0.0476</td>
<td>0.00000484</td>
<td>6.640</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.00182</td>
<td>0.00000183</td>
<td>2.780</td>
</tr>
<tr>
<td>Cl₂</td>
<td>0.00310</td>
<td>1.00000310</td>
<td>6.510</td>
</tr>
<tr>
<td>Glass</td>
<td>0.007810</td>
<td>0.0247</td>
<td>3.150</td>
</tr>
<tr>
<td>Alumina</td>
<td>0.007150</td>
<td>0.0270</td>
<td>2.650</td>
</tr>
<tr>
<td>Gold</td>
<td>0.002200</td>
<td>0.00105</td>
<td>2.070</td>
</tr>
<tr>
<td>Silver</td>
<td>0.005600</td>
<td>0.0193</td>
<td>2.880</td>
</tr>
</tbody>
</table>

We see that though the densities and the coefficient of absorption vary, and very much, yet the ratio of the two variables is a very little, and the results justify, I think, Lenard's conclusion that the distance through which these rays travel only depends on the density of the substance—that is, the mass of matter per unit volume, and not upon the nature of the matter.

These numbers raise a question which I have not yet touched upon, and that is the size of the carriers of the electric charge. Are they or are they not of the dimensions of ordinary matter?

We see from Lenard's table that a cathode ray can travel through air at atmospheric pressure a distance of about half a centimetre before the brightness of the phosphorescence falls to about one-half of its original value. Then the mean free path of a molecule of air at this pressure is about 10-6 cm., and if a molecule of air were projected it would lose half its momentum in a space comparable with the mean free path. Even if we suppose that it is not the same molecule that is carried, the effect of the obliquity of the collisions would reduce the momentum to one-half in a short multiple of that path.

Thus, from Lenard's experiments on the absorption of the rays outside the tube, it follows on the hypothesis that the cathode rays are charged particles moving with high velocities; that the size of the carriers must be small compared with the dimensions of the atoms or molecules. The assumption of a state of matter more finely subdivided than the atom of an element is a somewhat startling one; but a hypothesis that would involve somewhat similar consequences—viz., that the so-called elements are compounds of some primordial element—has been put forward from time to time by various chemists. The hypothesis is that all the elements were built up of atoms of hydrogen, and Mr. Norman Lockyer has advanced weighty arguments, founded on spectroscopic consideration, in favour of the composite nature of the elements.

Let us trace the consequence of supposing that the atoms of the elements are aggregations of very small particles, all similar to each other; we shall call such particles corpuscles, so that the atoms of the ordinary elements are made up of corpuscles and holes, the holes being predominant. Let us suppose that at the cathode some of the molecules of the gas
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get split up into these corpuscles, and that these, charged with electrical energy, and moving at a high velocity form the cathode rays. The distance these rays would travel before losing a given fraction of their momentum would be proportional to the mean free path of the corpuscles. Now, the things these corpuscles strike are other corpuscles, and not against the molecules as a whole; they are supposed to be able to thread their way between the interstices in the molecule. Thus the mean free path would be proportional to the number of these corpuscles; and, therefore, since each corpuscle has the same mass to the mass of unit volume—

that is, to the density of the substance, whatever be its chemical nature or physical state. Thus the mean free path, and therefore the coefficient of absorption, would depend only on the density; this is precisely Lenard's result.

We see, too, on this hypothesis, why the magnetic deflection is the same inside the tube whatever be the nature of the gas, for the carriers of the charge are the corpuscles, and these are the same whatever gas be used. All the carriers may not be reduced to their lowest dimensions; some may be aggregated of two or more corpuscles; these would be differentially deflected from the single corpuscle, thus we should get the magnetic spectrum.

I have endeavoured by the following method to get a measurement of the ratio of the mass of these corpuscles to the charge carried by them: A double cylinder with slits in it, such as that used in a former experiment was placed in front of a cathode which was curved so as to focus to some extent the cathode rays on the slit; behind the slit, in the inner cylinder, a thermal junction was placed which covered the opening so that all the rays which entered the slit struck against the junction, the junction got heated, and knowing the thermal capacity of the junction, we could get the mechanical equivalent of the heat communicated to it. The deflection of the electrometer gave the charge which entered the cylinder. Thus, if there are N particles entering the cylinder each with a charge e, and Q is the charge inside the cylinder,

\[ Q = N e. \]

The kinetic energy of these

\[ \frac{1}{2} N m v^2 = W, \]

where W is the mechanical equivalent of the heat given to the thermal junction. By measuring the curvature of the rays for a magnetic field, we get

\[ m = \frac{Q}{v^2}. \]

Thus

\[ m = \frac{Q}{v^2}. \]

In an experiment made at a very low pressure, when the rays were kept on for about one second, the charge was sufficient to raise a capacity of 1.6 microfarads to a potential of 16 volts. Thus

\[ Q = 2.4 \times 10^{-4}. \]

The temperature of the thermo junction, whose thermal capacity was 0.005 was raised 88 C. by the impact of the rays, thus

\[ W = 3 \times 10^4 \times 4 \times 2 \times 10^6. \]

The value of I was 260, thus

\[ m = 1.6 \times 10^{-1}. \]

This is very small compared with the value 10^{-1} for the ratio of the mass of an atom of hydrogen to the charge carried by it. If the result stood by itself we might think that it was probable that e was less than the atomic charge of atom rather than that m was less than the mass of a hydrogen atom. Taken, however, in conjunction with Lenard's results for the absorption of the cathode rays, these numbers seem to favour the hypothesis that the carriers of the charges are smaller than the atoms of hydrogen.

As is evident, it is not to be expected that the value of e/m, which we have found from the cathode rays is of the same order as the value 10^{-2} deduced by Zeeman from his experiments on the effect of a magnetic field on the period of the sodium light.

ADJUSTABLE X

BY A. A. G. NOL

The writer has discovered a method of constructing X-ray tubes somewhat different from those commonly described (see The Electrician, April 29th, page 15), which possesses distinct advantages.

The arrangement is as shown in the illustration. The essential features consist simply in mounting the cathode upon a sliding support, so that it can be moved axially to a very small extent in and out of a tubular neck, blown at one end of the glass bulb. When arranged in this manner, the exact position of the cathode is found to have an enormous influence upon the penetrating value of the X-rays produced. With a suitable and constant degree of excitation, if the cathode is placed as shown in full lines in the figure, X-rays of very high penetrating value are produced, while the small movement of about 0.5 inch required to place it in the position indicated by the dotted lines will suffice to reduce the penetrating value of the rays almost to nothing. Between these two extremes every grade of penetrating value is readily obtained by simply altering the position of the cathode within its limits of travel. If the tube be used in a horizontal position this can easily be done by merely tapping it at one end or the other, without removing it from its support, and the anti-cathode being a fixture, the point of origin of the X-rays remains in the same position.

The effect is evidently due to changes in the electrical resistance of the tube, which, as measured by the alternative spark in air is much highest when the cathode is in the position shown in full lines, i.e., which gives rays of the greatest penetration, and appears to be closely connected with the proximity of the cathode to the glass, which is greatest in the position just mentioned. This factor is evidently so important that it much more than neutralises the effect of the alteration to the distance between cathode and anti-cathode, which, as the writer has previously shown, has the result of increasing the penetrating value of the rays, and also the resistance of the tube, the nearer these two electrodes are together.

ELECTRICAL UTILISATION OF ST. LAWRENCE RIVER.

The existence of large waterfalls which can be economically developed may, in certain conditions, prove as valuable as coal-fields. These conditions are either that the waterfall shall be within reasonable distance of large centres of industry to which the power can be transmitted electrically with economy, or be located in a district to which the necessary materials can easily be transported for the manufacture electrically of chemical reagents used on a large scale. In this country very few water powers exist which can be described as large, compared with those found in other parts of the world; and even in Switzerland, where, perhaps, larger water Powers exist than in any other parts of Europe, the water powers are small compared to those to be found on various parts of the American continent. Of late the value of cheaply developed water powers has been realised in the United States, and from month to month we hear of these powers being developed and put to useful purposes. The developments at Niagara represent, of course, the largest that is to be expected in the water-power development, but there are many others also in the States of not inconsiderable size that have been put to useful work.