LXXV. On charging through ion absorption and its bearing on the earth's permanent negative charge

George C. Simpson B.Sc.

To cite this article: George C. Simpson B.Sc. (1903) LXXV. On charging through ion absorption and its bearing on the earth's permanent negative charge , Philosophical Magazine Series 6, 6:35, 589-598, DOI: [10.1080/14786440309463060](https://doi.org/10.1080/14786440309463060)

To link to this article: <http://dx.doi.org/10.1080/14786440309463060>

Published online: 15 Apr 2009.

Submit your article to this journal [↗](#)

Article views: 2

View related articles [↗](#)

Citing articles: 2 View citing articles [↗](#)

Its activity is probably about 100 times that of uranium. The divergence of the leaves begins to be perceptible about three hours after complete discharge, and the full divergence is attained in about twenty hours. For lecture purposes it would be better to have a more active preparation, so that the complete cycle would be gone through in the course of an hour. If the apparatus is sealed off from the pump it will be available for exhibition at any time. But very complete exhaustion is necessary.

The α rays of radium, which are deflected by a magnet in the opposite sense to the β rays, should carry a positive charge. I have attempted to detect this by the same method. A brass strip, carrying an aluminium leaf, was supported on a quartz rod, and itself supported in turn a small dish, on which a radium preparation was spread. The whole was arranged in a vessel connected to earth, and exhausted. No deflexion was, however, obtained. In order to test the insulation a charge was given to the brass strip, causing the aluminium leaf to diverge. But even at the best vacuum which the Toepler-pump could produce, the charge was lost in an hour. The ionization produced in gases by the α rays is so strong that even at the lowest pressure of the mercurial pump it prevents the detection of the charge carried by these rays.

LXXV. *On Charging through Ion Absorption and its Bearing on the Earth's Permanent Negative Charge.* By GEORGE C. SIMPSON, B.Sc., 1851 Exhibition Scholar, Owens College*.

OF the numerous theories for the permanent negative charge on the earth's surface none has been so generally accepted by geophysicists as that due to Elster and Geitel, which ascribes the phenomenon to a charging of the surface through absorption of ions from the surrounding atmosphere. The explanation given by H. Geitel in his Hamburg address ("Ueber die Anwendung der Lehre von den Gasionen auf die Erscheinungen der atmosphärischen Electricität," published by Vieweg & Sohn, Braunschweig, 1901) was as follows:—Zeleny has shown (Phil. Mag. xlv. p. 120, 1898) that when insulated conductors are in contact with Röntgenized air they become negatively charged in consequence of the greater mobility of the negative ions. This charging has a limit which is reached when the field set up is strong enough to make the number of positive and negative ions which reach the surface equal, by increasing the velocity towards the

* Communicated by the Author.

conductor of the positive ions and decreasing the velocity of the negative ones.

As the air in contact with the conducting surface of the earth is always ionized one would expect the same process to take place in the atmosphere; *i. e.* the earth to gradually become charged until such a field is set up in the atmosphere around it that an equal number of positive and negative ions reach the surface in a given time. If this process takes place on the free surface it will do so to a much greater extent in all places where there is a protection against the earth's normal field, so that in all places having a covering of vegetation the absorption of negative ions will go on unhindered.

Others have found it necessary to enlarge this simple theory of Elster and Geitel. C. T. R. Wilson ('Nature,' vol. xlviii. p. 104, 1903) postulates a wind as necessary to remove the positive ions from the neighbourhood of the surface, and Riecke (*Nachrichten der k. Ges. der Wissensch. zu Göttingen, Math.- und Phys.-Klasse*, 1903, Heft 2) has considered that a greater proportion of negative than of positive ions which strike the surface may be absorbed, and so he introduces a special coefficient of absorption.

On the whole, it may be said that Elster and Geitel's theory has held its own; but, as recognized by Geitel in his address, it has the weak point of being based upon an experiment which has given a different result when repeated by Villari.

The great interest which belongs to this question of the origin and maintenance of the earth's negative charge led me to undertake a series of experiments to find the conditions under which a conductor can become charged, and to what extent, in consequence of ion absorption. The chief work which has so far been done on this subject is that of Zeleny, Townsend, and Villari, the result of which may be summed up as follows. Zeleny found that when air which had been ionized by means of Röntgen rays was passed along a tube, metals over which it streamed became negatively charged. From this and other experiments he drew the conclusion that when positive and negative ions *are in an electrical field* the negative ions move through the neutral molecules of air quicker than the positive ones, *i. e.* they have a greater mobility. Townsend (Proc. Roy. Soc. lxx. p. 192, 1899, & lxxvii. p. 122, 1900) worked from another point of view. He assumed that positive and negative ions may be looked upon as the constituent parts of two separate gases. With this assumption the following is the process to be expected

when a mixture of ordinary air with positive and negative ions moves along a tube. Every ion which strikes the conducting wall is absorbed, this leaves an ion-free space within molecular distances of the wall, into this space positive and negative ions diffuse by the ordinary laws of gas diffusion. The greater the coefficient of diffusion the more ions will reach this space, and so a greater absorption of ions will take place during the passage of the mixture along the tube. By measuring the ratio of the quantity of positive ions in a given mass of gas before and after it had passed along tubes of different length, Townsend was able to calculate the rate of diffusion of positive ions, similarly for negative ions. The values of the coefficient of diffusion obtained by this method agreed very well with Zeleny's number for the "mobility."

Villari (*Phil. Mag.* [6] i. p. 535, 1901), contrary to Zeleny, found that metals exposed to a stream of ionized air became positively or negatively charged according as the air streamed over them with great or little friction.

Starting with the work carried so far, my first experiments were directed to finding an explanation for the apparent disagreement between Zeleny's and Villari's results. In order to do this it was necessary to repeat their experiments, but this was done by a slightly altered method. A straight tube 40 cms. long was connected to a box in which air could be ionized by means of Röntgen rays and then passed along the tube.

The tube was composed of four pieces: the first connected to the box being of glass and 10 cms. long, the second a metal tube 5 cms. long, the third a glass tube 20 cms. long, and finally another metal tube 5 cms. long. It was then found that when ionized air was passed through the tube the metal piece nearest the box became charged negatively, the one at the far end positively. This showed that for the first few moments after leaving the place of ionization the air gave up a negative charge, while later on it gave up a positive charge. This agrees with Zeleny's experiment, for the metal he used was situated so near the place where the air was ionized that it was passed over during the time the

air was giving up a negative charge. It also agrees with Villari's experiments ; but in order to see this the arrangement of his apparatus must be considered.

In order to obtain a good insulation Villari placed the metal to be examined in the end of a glass tube 30 cms. long. Sometimes this metal consisted of a few filings or pieces of wire, at others the whole end of the tube was filled with tightly packed filings or strips of metal. He then found that when only a little metal was in the end it became negatively charged, while the tightly packed metal obtained a positive charge. A connexion between friction and charge appeared obvious. But in reality the friction itself had directly nothing to do with the phenomenon. The reason for the different charges being that as Villari worked *with a constant pressure driving the air through the tube*, the air took longer to reach the metal when there was much friction to overcome than it did when there was little. In the latter case the air reached the metal during the time it was giving up a negative charge ; in the former this state had been passed, and a positive charging of the metal was the consequence. That this is the real explanation could be easily shown with my arrangement of the experiment, for on placing a plug of cotton-wool in the far end of the tube and keeping the same pressure in the box as before, the first metal tube which had always before become negatively charged became positively charged. That is, a positive or negative charge could be given to the metal tube by simply increasing or decreasing the time taken for the ionized air to reach it quite independently of the friction with which the air passed over the metal itself ; in fact, the positive charge in my experiment was obtained when the air passed over the metal with the smaller friction, this being exactly contrary to Villari's result.

This brings Zeleny's, Townsend's, and Villari's results into line, for the process which leads to the charging may be considered as follows :—Imagine a small part of the stream of air separated from the rest, and follow it in its course along the tube. When it first enters, the negative ions, on account of their greater mobility, move quicker than the positive ions into the neighbourhood of the walls where they are absorbed. As this leaves a greater volume-density of positive than of negative ions behind, a state will soon be reached at which the greater number of positive ions balances the greater velocity of diffusion of the negative. Up to the point in the tube where this takes place the air has been giving up a negative charge to all bodies over which it streams ; at the

point itself no charge is given up. The state of balance is, however, not maintained, for the ratio of positive to negative ions rapidly increases owing to the recombination of the positive and negative ions to build neutral molecules. From this point onwards more positive than negative ions reach the wall—a positive charging of the remainder of the tube being the result. Thus the negative charging found by Zeleny and the positive one found by Villari are both due to the same cause, viz. the greater rate of diffusion of the negative ions.

Having explained these experiments by assuming different coefficients of diffusion for the two kinds of ions, the question arises—are we justified in assuming, as Townsend has done, that positive and negative ions act as molecules of two separate gases mixed with the ordinary unionized gas from which they are formed, as such obeying Avogadro's law, and having different coefficients of diffusion quite independently of their electrical properties? Although Townsend has used this assumption in interpreting the results of his experiments, the ions in those experiments were not free from their electrical properties, for when an ion comes into the neighbourhood of the solid wall of a tube, it induces there an opposite charge, and under the influence of the field so formed moves towards the wall. But Zeleny showed that in a given field negative ions have a greater velocity than positive ones; hence the negative ions will move quicker than the positive ones toward the wall, so producing the apparently different coefficients of diffusion.

Thus we are not able to say, from Townsend's experiments, that negative ions really have a greater coefficient of diffusion than positive ones in the same sense that we say two gases have different coefficients of diffusion. Realizing that the only way to settle the point is to isolate a mass of ionized air and then to investigate the rates of diffusion of the two kinds of ions into the surrounding unionized air, an attempt was made to find a method of doing this. Vortex rings gave a simple means. A box from which vortex rings could be sent out was placed above a Röntgen tube so that the air within could be strongly ionized—a lead covering prevented the rays from ionizing the air in the room. On tapping the elastic side of the box, when the Röntgen tube was in action, a mass of ionized air was sent out into the unionized air of the room. In order to investigate the effect of diffusion the rings were directed into a gauze cage connected to an electrometer and properly protected against outside electrical fields. When the cage was 20 cms. from the orifice from

which the rings came, no charge could be observed on the rings entering the cage; but on reducing the distance between the orifice and cage a distinct positive charge was obtained from the rings. Thus during the time (about a tenth of a second) the ionized rings had been passing through the unionized air on their way to the cage, a diffusion of the ions had taken place; but as the rings entered the cage with a positive charge we may safely say that the negative ions had diffused away the more rapidly. The fact that there was no charging of the cage when the rings had to travel further than 20 cms., showed that within one-fifth of a second both positive and negative ions had entirely diffused away. In this way it was possible to show directly that negative ions have a greater coefficient of diffusion than positive ones.

Two interesting observations showing charging as a result of ion absorption must be here described. The first was observed when working with the ionized vortex rings. It was then found that when the box from which the rings were sent out had been filled with tobacco-smoke in order to make the rings visible they entered the cage with a negative instead of a positive charge.

The second observation was as follows:—Fine white sand was allowed to run out of a metal funnel into a saucer some distance below. As a result of the friction between the metal and the sand, the latter was positively charged. A ring wrapped round with cotton-wool soaked in spirits was now so placed that the stream of sand passed through it on its way from the funnel to the saucer. On lighting the spirits the sand passed through a ring of flame. It was then found that the sand carried a negative charge to the saucer. At first it was thought that this change in sign was due to a change in the frictional electricity, owing to the funnel becoming hot, but that this was not so could be seen by removing the flame, when at once the positive charge returned although the funnel had had no time to cool.

The explanation of these two observations is the same. The smoke ring on leaving the box consists of a mass of carbon particles mixed with negative and positive ions. The sand on falling through the flame carries with it a quantity of the highly ionized gas of the flame. Thus in both cases we have to do with a mixture of material particles with positive and negative ions. As soon as this mixture enters ordinary air diffusion takes place, but the ions in the middle of the mass have to diffuse through the material particles. We may consider the process as being similar to a diffusion

through a number of narrow tubes, so that if any ions pass out, as Townsend's experiments have shown, there is bound to be an excess of positive ones. The material particles are thus left behind with a negative charge. That this is the process by which the charge is obtained, and not that the sand and smoke leave the place of ionization negatively charged, was proved by the fact that it was possible to collect the positive ions which, streaming away from the sand, left it negatively charged. To do this a cylinder of metal was so placed that the sand passed through it immediately on leaving the flame. The positive ions diffusing out of the stream of sand were caught by the cylinder, which at once showed a positive charge. No charging of the cylinder could be detected when the sand passed through it without first passing through the flame.

In all the experiments so far described, we have obtained a charge as the result of ion absorption; but it has in every case been accompanied by the removal of air from the action of a strong ionizer to a place where diffusion could come into play. In the atmosphere such a removal does not take place, for we have strong reasons to believe that the natural ionization in the atmosphere is mainly due to a radioactive gas which the air carries with it; therefore none of the cases described above can be directly applied to the problems of atmospheric electricity. Even the charging of the metals in Zeleny's experiments, which has been used as the foundation of Elster and Geitel's theory, has no parallel in the atmosphere, for in Zeleny's experiments the air was first removed from the ionizer, then, as a result of diffusion, the charge appeared. Zeleny's experiments do not prove that an insulated conductor in air which is *constantly and uniformly* ionized will become negatively charged. Experiments which will now be described show that such an insulated conductor does not become negatively charged.

When working with a quadrant electrometer it was necessary to lead a long copper wire to it from apparatus a considerable distance away. In order to protect this wire from electrostatic induction it was led through a long wooden box covered on the outside with earth-connected tinfoil. It was then found that the wire although insulated became positively charged when left for any considerable time to itself. In order to see whether this charge had anything to do with the material of the wire, the copper one was replaced by one of zincd iron: this latter became negatively charged. To investigate the effect more thoroughly, a large cage, one and a half metres long and one metre high and wide, was

made of zincd iron wire netting. Inside this cage different metals were hung on an insulating support and then connected by a wire of the same material to an electrometer outside. The metal to be investigated was first connected to the earthed cage and a zero reading of the electrometer taken; then, on insulating, it was found that the metal began to become charged, until in a little over an hour a steady deflexion of the electrometer-needle showed that the charging had ended. The final voltages obtained varied in sign and amount from metal to metal, being as follows :—

Copper ...	+·70 volt.	Lead	+·23 volt.
Iron	+·46 „	Magnalium...	—·28 „
		(magnesium aluminium)	
Tin	+·25 „	Sodium	—·70 „

It will be seen at once that these numbers are practically those of the volta difference of potential between the different metals and zinc. The zincd iron cage and the metal within form the poles of a battery with the slightly ionized air between acting as the electrolyte. The only effect of greatly increasing the ionization of the air by means of Röntgen rays was to increase the rate at which the final charge was obtained, the charge itself remaining unaltered. Thus we see that Zeleny's results do not apply to conductors in the ionized air of the atmosphere—at least with the air at rest, air in motion will be considered later. A conductor in ionized air must be looked upon as a conductor in an electrolyte, the charge it obtains being determined by its position in the volta series and not by the mobility of the ions. It is easy to see that a conductor in ionized air at rest will not become “charged negatively until it produces in the surrounding air an electrical field strong enough to neutralize the difference in the mobility of the ions.” Consider a space filled with ionized air, there being an equal number of positive and negative ions in a cubic centimetre. Now imagine a conducting sphere suddenly placed in the middle of the space. For the first instant more negative than positive ions will reach it and be absorbed, but the corresponding positive ions are all within molecular distances of the sphere so that no field can be set up outside the immediate neighbourhood of the surface. There may be something of the nature of a double layer at the surface, but its presence cannot be experimentally observed, for all conductors have the same layer. We must accept then, as the result of both theory and experiment, that in air at rest there is no tendency for an insulated conductor to become charged negatively as a result

of the difference in the mobility of the ions. We can also no longer accept the theory that in all places protected against the formation of an electrical field, such as within conductors, there is a continual stream of negative ions out of the air, for the positive ions which this would leave behind are all within molecular distances of the surface, so hold an equal quantity of negative electricity as a "bound charge," no electricity being able therefore to appear as a free charge.

So far we have considered air at rest, we must now ask what will be the effect of setting the air in motion. At first sight it would appear that as fresh air is always moving past the conductor more negative than positive ions would reach the surface, and as a surface layer of positive ions would be unable to form, a negative charging could be expected. But when we consider conductors in air as being electrodes in an electrolyte it is difficult to see how motion could affect the potential which they had taken up when the air was at rest. In order to put this question to the test of experiment, air was driven past insulated metals within the cage described above, by means of a fan attached to an electric motor. Although the wind so produced had a velocity greater than six metres a second no change could be observed in the charge which the metal had attained before the fan was set in motion. Thus when a piece of the same netting as that of which the cage was made was hung within the cage, the needle of the electrometer connected to it remained at zero with or without the fan in motion. When copper was used as the insulated metal it took a positive charge as described above, and this charge was the same whether the fan was in motion or not. The electrical state of the fan itself was then investigated by carefully insulating it from the axis of the motor, but no charging, except a very uncertain positive one, could be observed, although the fan, which was 50 cms. in diameter, produced a wind with the velocity stated above. It must be stated that an uncertain positive charge appeared also sometimes on the metals which were subjected to the wind, but as it never produced more than a tenth of a volt potential, and could not be obtained at will, no conclusion can be drawn from it. The result of this experiment favours the second method described above of considering what will happen when air is in motion, but does not disprove the former, all that can be said for certain is that a conductor has not yet been charged as a result of its motion relative to the *naturally* ionized air of the laboratory.

Although it has been impossible to charge a conductor by this method, yet a very great absorption of ions takes place

from air which comes into contact with a conductor. To show this the fan was placed within a large closed box ($50 \times 80 \times 140$ cms.). By means of an Ebert aspiration apparatus the ionization of the air within the box was determined before and after the fan had been set in motion. The results showed a great decrease in the ionization as a result of the air being continually driven into contact with the walls of the box. Before the fan started 0.4 electrostatic unit was found in a cubic metre of air; after it had been in motion ten minutes, and while it was still in motion, a determination showed that this quantity had been reduced to 0.1. As far as the Ebert apparatus was able to show, its accuracy not being greater than 5 per cent., there was the same number of positive as negative ions in both experiments.

Applying now these results to atmospheric electricity and the earth's negative charge, it would be rash to say that they disprove the theory of the permanent charge being due to ion absorption, but they show that the process which Elster and Geitel consider is taking place in the atmosphere is not substantiated by experiment. We are also brought face to face with the fact that as yet no conductor has been charged through absorption of ions from the naturally ionized air of the atmosphere (charging due to the volta effect being excepted), and until this is done we cannot consider the problem of the earth's negative charge as being solved by the "absorption of ions from the atmosphere."

In conclusion I would like to express my thanks to Prof. Wiechert for the helpful interest he has taken in this work, and for placing every facility at my disposal for making these experiments in the Geophysical Institute in Göttingen.

LXXXVI. *The Genesis of Ions by the Motion of Positive Ions in a Gas, and a Theory of the Sparking Potential.*
By JOHN S. TOWNSEND, Wykeham Professor of Physics,
Oxford*.

IN a paper published in the 'Electrician,' April 3, 1903, I gave an outline of a method by which some properties of positive ions may be investigated. The present paper contains a fuller account of the theory of the genesis of ions by positive ions and its application to experiments which have been made with air and hydrogen.

The theory is founded on the determinations of the conductivity which takes place between parallel plate-electrodes when ultra-violet light falls on the negative plate.

* Communicated by the Author.