THE EXISTENCE OF HIGH MOBILITY IONS.[1]

By Oswald Blackwood.

Synopsis.

Existence of Positive Ions of Abnormally High Mobilities in Air.—Contrary to the conclusions of other observers, Nolan has reported what he believes to be indications of the presence in ionized moist air of ions of eight different mobilities ranging from one to seven times the normal value. *A repetition of Nolan's experiment*, however, with duplicate apparatus, has led to an explanation of his anomalous results. In his experiment, ions generated in a small shielded space next the lower plate of a long condenser, are carried by an air current into the electric field where the mobility is determined by a blast method. At first curves similar to Nolan's were obtained, but the irregularities interpreted as due to different groups of ions were removed when precautions were taken to insure a uniform blast of air. Then it was discovered by the author that in spite of a lead shield between the emanation tubes emitting the ionizing rays and the measuring chamber, there was, contrary to Nolan's assumption, a volume ionization in that chamber, due probably to secondary x-rays from the lead, which accounted for his results. When these secondary rays were eliminated by substituting polonium as the source of ionization the mobility came out normal.

Introduction.

The existence of small ions of very high mobility is indicated in several papers by Nolan,[2, 3] who finds a value *seven times* greater than normal. Furthermore, he detects in the ionization from radioactive bodies not *one* but *eight* widely separated sizes of ions. In so far as the writer knows, these results are at variance with the investigations of all other workers[4] who agree in assigning to the negative ion in dry and moist air mobilities 1.8 and 1.5 cm./sec. respectively. In particular, the normal value has been reported recently by Erikson[5] using a method closely resembling Nolan's.

The author has repeated the experimental work in detail, and in addition finds that the curves are capable of another interpretation and that, when certain precautions neglected by Nolan are taken, the method indicates the existence of but one size of ion of normal mobility.

Method.

The apparatus is fully described in Nolan's paper.[2] It consists of a shallow box 10 cms. in depth fitted with two condenser plates. The

[1] An abstract of this paper was read by title at the December meeting of the American Physical Society.

[2] Proc. Royal Irish Academy, XXXV. (A), p. 38 (1920).

[3] Ibid., XXXIII. (A), p. 9 (1916). Proc. Royal Society, XCIV. (A), p. 112 (1918).

[4] Proc. Camb. Phil. Soc., IX., p. 401. Phil. Trans., A, 195, p. 193. Annale de Chemie et de Physique, XXVIII., 289. Proc. Nat. Acad., II. (1916), 345.

[5] Phys. Rev., XVIII., p. 100 (1921).

upper (electrometer) plate is 35 cms. long and is surrounded by an earthed guard ring. The lower plate may be given any desired potential. Ionization is produced in the small trough Z below a lead shield (See Fig. 3, Z) the source being several tubes of radium emanation lying on the floor of the trough. A current of air traverses the apparatus carrying ions from Z into the condenser. When the electric field is zero these ions are carried forward horizontally. As the field is increased step by step the stream is curved upward more and more until, at a critical voltage, it is forced into contact with the upper plate and the electrometer current jumps from zero to its maximum value. In practice owing to recombination, diffusion, turbulence of the air stream, as well as other factors, the ideal curve should not be realized.

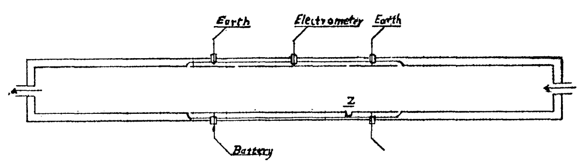

Fig. 1.

The mobility of the ions can be calculated from $u = vb^2/LV$ where V is the critical voltage at which ions begin to reach the plate, u is the ionic mobility, v the velocity of the air stream, b the vertical distance between the plates and L the plate length.[1]

Discussion of Results.

One of Nolan's typical current voltage curves for air saturated with water vapor is shown in Fig. 2. It will be noted that the curve does not cross the X axis at 14 volts as it should (1) if ions of normal mobility were present, and (2) if all the ions were produced at Z. Nolan interprets the fact that small voltages are sufficient to drive ions to the plate on the hypothesis of high mobilities. Furthermore, he explains the *eight* "nicks" or "steps" ($a \cdots f$, Fig. 2) as indicating the presence of eight different sizes of ions.

The writer has duplicated Nolan's apparatus in detail and has repeated his measurements using several different air velocities. The curves re-

[1] At the critical voltage V the ions are displaced through the vertical distance b cm. between the plates while the air stream carries them through a horizontal distance L. The electric field (potential gradient) being V/b and the vertical speed Vu/b, the time to move through the condenser is

$$t = \frac{b}{Vu/b}.$$

Also, $t = L/v$. Therefore, $u = b^2v/LV$.

semble those of Nolan in that they pass through the origin, showing that small fields are sufficient to drive ions to the plate. They also have "nicks" or "steps" but these are not repeatable and are probably due to lack of constancy in the motion of the gasometers used to force air through the apparatus. After these gasometers were replaced by a constant-speed rotary pump the curves showed no irregularities. They show no evidence, therefore, of the existence of separate, distinct groups or sizes of ions.

The first inkling of an explanation of the form of the curve not involving the assumption of high mobilities came when the air stream in the ion box was reversed in direction. If all the ions were really produced in the shielded space Z, as Nolan assumed, this procedure should reduce the galvanometer current to zero, since the reversed air stream carries the ions *away* from the condenser. In fact, however, the current decreased only one third. Most of the ions, therefore, are produced in the main volume of the condenser.

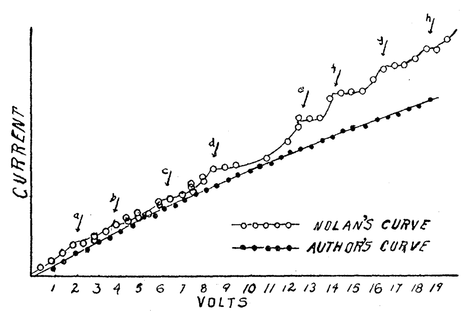

Fig. 2.

The distribution in still air of this general ionization has been studied as follows. A wire screen of 1 cm. mesh was placed horizontally between the two condenser plates. (See Fig. 3, X.) It was charged to the

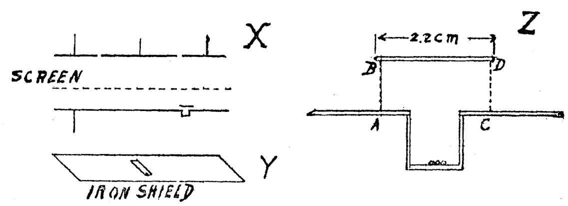

Fig. 3.

same potential as the lower plate so that no ions produced below it should be driven to the electrometer. The potential of the screen was given a sufficiently high value to drive all ions above it to the electrometer plate. The current was found to be directly proportional to the distance between the screen and plate. This indicated a uniform vertical distribution of the ionic density. Therefore, the ionization near the electrometer plate is as great as that in the lower part of the condenser. This being the case, an explanation of the experimental curve is simple. Ions are driven to the upper plate by small fields not because the ions have *high mobilities, as Nolan assumed,* but because they are generated in *immediate proximity* to it.

Source of General Ionization.

With the purpose of discovering the source of this general ionization, its horizontal distribution in still air was investigated. The wire screen described above was replaced by a grounded sheet of iron which was fitted with an aperture four cm. wide. (See Fig. 3, *Y*.) This sheet of metal shielded the electrometer plate from all ions which were not generated immediately below the slit. Keeping the electric field constant, the sheet was shifted horizontally so as to successively uncover all portions of the upper plate. The electrometer currents for the various positions show that more than one third of all the ions are produced at distances from the ion trough *Z* greater than 10 cm.

In order to investigate the absorption of the rays causing the general ionization, the window *CD* (Fig. 3, *Z*) was blocked with a lead plate while *AB* was covered with a paper screen found to be equivalent to .001 cm. thickness of aluminium foil. This shield decreased the ionization about 50 per cent. Replacing the paper by a sheet of lead 1 mm. thick reduced it to zero. Since the window *CD* is shielded from direct radiation, and since the paper was adequate to prevent diffusion of ions into the main chamber, by elimination it seems probable that the general ionization was due to secondary Roentgen radiation from the lead walls of the trough at *Z*. While this radiation is doubtless relatively feeble, the volume of air penetrated by it is at least one hundred times that of the volume at *Z* which is subject to direct radiation.

An attempt was next made to eliminate secondary radiation and realize experimentally the intense, localized ionization which Nolan assumed to exist in his apparatus. The ionizing agent used was polonium which emits only alpha rays. The specimen was equivalent in ionizing power to about 1/40 mg. of radium bromide. With an air velocity of 4.1 cm./sec., several current-voltage curves were determined of which Fig. 4, *A*, is typical. This curve has only one break in slope corresponding to a critical voltage 7.5 and a mobility 2.15 cms./sec. It will be noticed that a considerable number of ions are driven to the plate at voltages less than 7.5. This was attributed to turbulence of the air stream and to secondary radiation. To decrease the former the height of the ion box was reduced fifty per cent., thus increasing the ratio of length to cross section. To lessen secondary radiation the shield over *Z* was lowered 5 millimeters thus decreasing the size of the openings through which the radiation might pass. Using the modified ion box only two curves were determined. (See Fig. 4, *B*.) The intercepts are much more sharply defined than in the case of the preceding curve. The com-

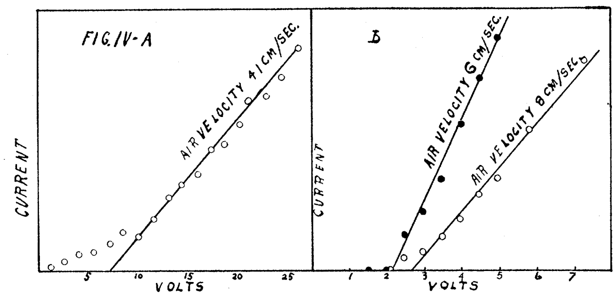

Fig. 4.

puted mobilities, 1.96 and 2.13 cm./sec. are respectively within 30 and 42 per cent. of the accepted value for moist air. The agreement is not close, but it is sufficient to show that the method indicates the existence of only *one size* of ion of approximately normal mobility.

Summary.

1. Nolan has presented evidence indicating the existence of several sizes of high-mobility ions.

2. The writer, after duplicating the apparatus, finds no evidence for the existence of several groups.

3. General ionization, proved to exist in the tube, is adequate to explain the experimental curves. It is not necessary, therefore, to assume the existence of high mobility ions.

4. After eliminating general ionization, the method gives approximately the mobility value found by other workers.

Note Added October 10, 1922.

Further evidence as to the existence of the ions of high mobility has been reported by Nolan and Harris.[1] After adopting a more accurate alternating-field method, *they find no trace of the mobile ions*. The writer believes that this confirms his own results, but Nolan and Harris explain the failure to detect the ions on the assumption that in the new apparatus the ions recombine before reaching the electrometer plate. They write as follows:

"We think that the explanation lies in the one radical difference between the two methods. In the air-current method the ions of one

[1] Proc. Royal Irish Acad., Sect. A, XXXVI., p. 31, 1922.

sign are almost immediately separated from those of opposite sign and for practically all their path in the measuring vessel are moving through air free from other ions. In the alternating-field method the ions are in contact with one another for some time in the space above the perforated plate. The time that an ion spends in this space will depend upon the value of the field there, the distance from the place where it is formed to the perforated plate, and its mobility. . . .

"It seems to us reasonable to suggest that the alternating-field method fails to reveal the faster ions because they have disappeared by recombination. The older method does reveal them because the chances of recombination have been reduced to a minimum."

This explanation will be shown to be quite inadequate since the ions in the older method are by no means "immediately" removed from those of opposite sign. Indeed, the time available for recombination is actually much greater in the older apparatus. In this method the ions are produced in the space immediately below a lead plate 2.2 cms. wide (Fig. 1, *Z*), and are not subject to the electric field and, consequently, are not separated from those of opposite sign until they have moved forward an average distance of at least 1.1 cms. The air velocity being 6 cm./sec., the time available for recombination is at least 1/5 second. In the newer apparatus the ions after being produced in a box 4 cms. high are driven downward toward a perforated plate through which they pass into the condenser proper. Until they reach this plate they are in contact with ions of opposite sign and are subject to recombination. The mean distance to the plate is thus 2 cms., the field strength was 4 volt/cm. and the time available for recombination for the three fastest ions (mobilities 12, 7, and 4 cm./sec.) would be respectively 1/24, 1/14, and 1/8 seconds. Thus the times available for recombination were respectively 1.6, 3, and 5 times greater in the older apparatus than in the new.

After failing to detect the ions in moist air, Nolan and Harris next introduced a new condition by drying and, using the new apparatus, found an abundance of faster ions. These results, however, must be regarded with caution since they are quite opposite to those of Loeb,[1] who also used an alternating-field method. He dried the air so thoroughly that free electrons were detectable for several days, but found no trace of abnormally mobile ions.

THE UNIVERSITY OF PITTSBURGH,
DEPARTMENT OF PHYSICS,
PITTSBURGH, PA.

[1]PHYS. REV., XVIII., p. 89, 1921; XVIII., p. 633, 1916. Nat. Acad. Sci. Proc. (6), p. 435, 1920.