ON THE EFFECT OF THE MEDIUM ON GAS ION MOBILITY

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Abstract

Effect on the mobility of air ions of adding varying amounts of CO_2, H_2, water vapor, C_2H_2, C_2H_4, Cl_2 and NH_3 to the medium.—In this paper results are given showing the effect on the mobility of adding foreign gases to the air through which the ions move. The conditions were such as to permit the use, at least initially, of identical air ions. It is shown that adding CO_2 and water vapor to the air diminishes the mobility but adding hydrogen increases the mobility. The results also indicate that the change in the mobility is due to the change in the medium and not to a change in the ions. It is however found that increasing the relative humidity gives a larger proportion of initial or 1.87 ions indicating that H_2O simplifies the final positive air ion. It is also shown that a trace of acetylene gives rise to an ion which has a mobility only slightly less than the initial air ion. It was also found that when acetylene remains in air a body is formed which when it becomes charged has a lower mobility.

Results are also given showing that adding ethylene and chlorine to the air has no effect on the mobility within the time of observation used whereas a trace of ammonia results in the formation of a single positive ion of the same mobility as that of the negative ion which is not affected.

THE speed with which an ion moves through dry air at normal pressure and temperature under the action of an electric field depends upon the charge carried by the ion and on the complexity of its structure as regards aggregation of molecules. All singly charged molecules have practically the same mobility as the mass plays only an insignificant part. The speed with which a given ion travels depends also upon the nature of the gaseous medium through which it moves. In this paper are given a number of results showing the effect upon the mobility of changing the nature of the medium by adding foreign gases in varying amounts. The method used

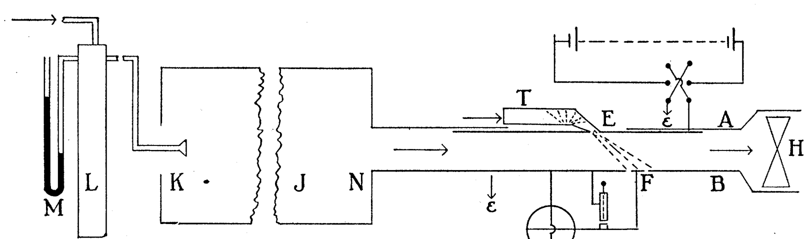

Fig. 1. Arrangement of apparatus.

consisted in passing ions of a definite character across a stream of the air to which the foreign gas had been added. The arrangement of the apparatus is shown in Fig. 1. The ions were produced in the tube T and at E they entered the air stream where they were forced across the stream by the field between the plates A and B to the electrode F, the downstream distance of which could be altered. The current to F plotted against the downstream distance of F gives a curve the position of the maximum of which depends upon the mobility. The air stream between the plates A and B due to the fan H, was taken from a large mixing tank J into which it entered from the room through an opening at K. The speed of the stream was of the order of 500 cm/sec. The foreign gas was added to the air near K and in passing through the tank J was mixed with the air. The effect on the mobility, of adding the gas in varying amounts, was noted.

Experimental Results

Effect of adding CO_2. CO_2 from a commercial supply cylinder was passed into the steel cylinder L where the pressure was measured by means of the gauge M. From this cylinder the CO_2 passed through a metal tube which was kept at a temperature such that the CO_2 was at room temperature when it entered the chamber J at K. A buffer plate was placed across the tube so as to insure a more complete mixing of the CO_2 with the air.

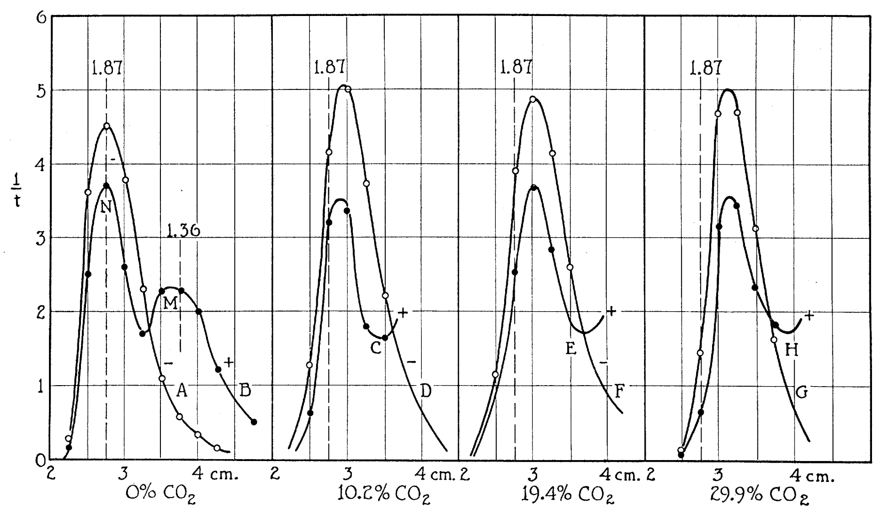

Fig. 2. Showing how CO_2 diminishes the mobility.

The ions were produced, by means of the alpha-rays from polonium, in the air passing through the tube T from the room. The rate of flow of the air between the plates A and B was determined with an anemometer. The rate of flow of the CO_2 at the pressures indicated by the gauge M was determined with a gasometer. The percentage of CO_2 was computed from these two rates.

The results obtained are shown graphically in Fig. 2. Curves A and B were obtained when only air passed through the tank J. Curve A is for the negative ion and as usual has only a single maximum which appears at a down-stream distance of 2.75 cm, and corresponds to a mobility of 1.87

cm/sec per volt/cm. Curve *B* is for the positive ions and has a maximum *N* due to the initial positive air ion at 2.75 cm, the same as for the negative ion, and a maximum *M* at 3.75 cm which corresponds to a mobility of 1.36 cm/sec per volt/cm, and is due to the final positive air ion. The age of the ions in this case was such that a portion of the initial positive ions had transformed into final ions as indicated at *M*. Curves *C* and *D* show the position of initial positive and negative maxima when 10.2 percent of CO_2 is added to the air in the mixing tank. The vertical dotted line shows the positions of the maxima in the case of air only. Curves *E* and *F* are for a 19.4 percent mixture and curves *G* and *H* for a 29.9 percent mixture. It is thus seen that a decided lowering of the mobility takes place as more CO_2 is added. In Fig. 3 is shown graphically the variation of the mobility with percent of CO_2 added.

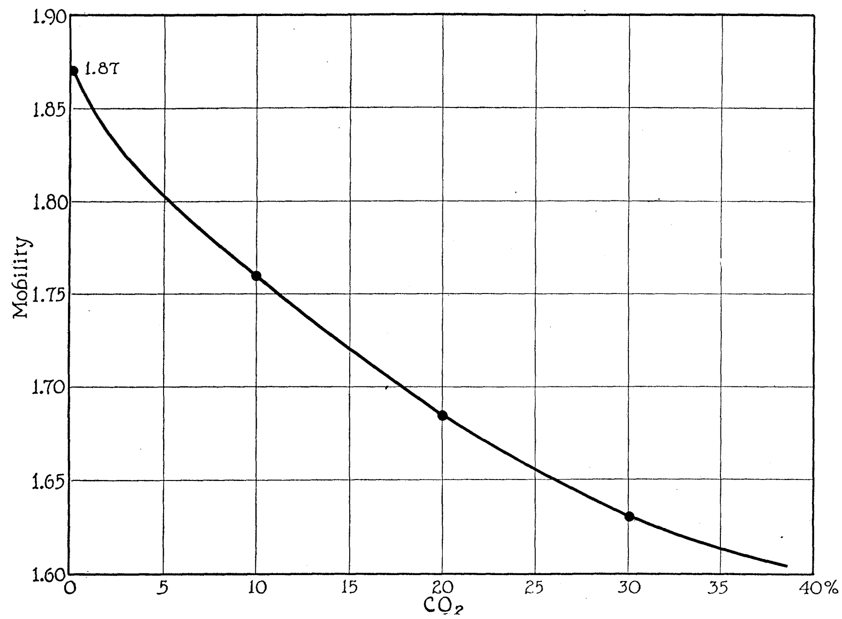

Fig. 3. Variation of mobility with percent of CO_2 in the medium.

It is of interest to know if the observed change in the mobility is in this case due to a change in the ions or to the change of the medium only or both. Evidence bearing on this question is offered by the character of the shifts observed. In Fig. 4 curves *A* and *B* are for air only. Curve *A* shows one negative ion and curve *B* shows the initial positive ion and the final positive ion and the proportion of each. Curves *C* and *D* are the corresponding curves in the case of air plus CO_2. It is seen that the curves *C* and *D* are similar to the curves *A* and *B*, not only in width but also in the relative amounts of the initial and final positive ions. This could not possibly be the case if there were a change in the nature of the ions. If the ion changed in going from *E* to *F*, Fig. 1, the curve would broaden out instead of shifting as a unit, as is observed. Furthermore, if a change in the ions takes place it is quite inconceivable that the relative amounts of the two positive ions would remain unaltered. It seems therefore that the conclusion must be that the ions remain unaltered and that the change in the mobility is due, in this case, only to the altered medium which interposes a greater resistance to the motion of the ions. This increase in the resistance to motion is probably due to an increase in the specific inductive capacity of the medium. The charge of the ion exerts a greater polarizing action on the surrounding medium when CO_2 is added to the air.

Effect of adding hydrogen to the medium. The procedure in this case was similar to that in the case of carbon dioxide. The hydrogen from a commercial supply cylinder was admitted to the cylinder *L*, Fig. 1. It was then allowed to discharge through *K* under a pressure of 7 cm. This gave a mixture of about 12 percent of hydrogen.

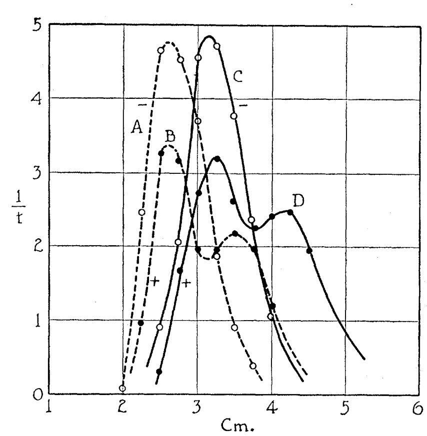

Fig. 4. Showing that the mobilities of all ions present are changed by the same amount.

The results obtained are given in Fig. 5. Curves *A* and *B*, Set (a), are for air only and curves *C* and *D* are for the 12 percent hydrogen-air mixture. It is thus seen that the presence of hydrogen increases the mobility by about 20 percent. It is also seen that the mobilities of both the initial and final positive ions are increased by the same percent and that the increase of the mobility of the initial positive ions is the same as the increase in the case of the negative ion. It is also seen that the proportion of initial and final positive ions is not appreciably altered. In this case therefore as in the case of CO_2, the change is due to the medium and not to a change in the ion.

The greater height of the curves for the hydrogen-air mixture (Curve *CD*) is due to the greater slope of the ionic stream. In order to test this point the downstream distance of the electrode *F*, Fig. 1, was kept constant and the potential between the plates *A* and *B* varied. Curves (b), Fig. 5, show the results. Curves *E* and *F* are for air only and curves *G* and *H* are for the 12 percent hydrogen-air mixture. It is seen that there is no significant alteration in the altitude of the curves.

Effect of adding water vapor to the medium. Tyndall and Grindley[1] observed the effect of moisture on the mobility in air and found that the mobility diminished as moisture was added. In their case the air and the moisture were in a closed vessel as the alternating field method was used. The changed medium in which the mobility was measured was thus also the medium in which the ions were produced by the rays.

It is of interest in this case to know if the change observed was due to the change in the medium through which the ions moved or if it was due to a change in the ions. The same apparatus described above could be used for this purpose. The most satisfactory method for introducing the moisture was to increase the relative humidity of the air in the room. In order not to change the air in which the ions were produced the tube T, Fig. 1, was

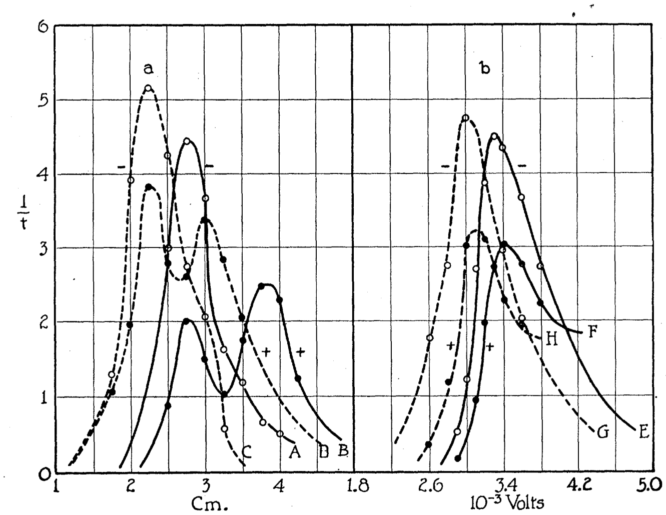

Fig. 5. Showing the effect on the mobility of adding hydrogen to the medium.

connected to a three-inch pipe which passed into the adjoining room. The unchanged ion from T thus passed into the moist medium at E, thus permitting a separation of the effect of the moisture in the medium from the ionizing process. As an alteration in the temperature of the medium at constant pressure produces a detectable effect, it was necessary to keep the temperature of the room constant. The procedure therefore was to raise the temperature of the room to 29°C and obtain a set of curves with normally dry air. The humidity in the room was then raised by evaporating water keeping the temperature constant at 29°. A set of curves under the new condition was then obtained.

The results are shown in Fig. 6. Curves A and B, Set (a), are for a relative humidity of 25 percent and C and D are for a relative humidity of 65 percent. Curve E is for the negative ion when the humidity was again 27 percent and shows the return to the normal mobility value.

[1] Tyndall and Grindley, Proc. Roy. Soc. **A110**, 358 (1926).

The curves in set (b), Fig. 6, were obtained under conditions similar to those for set (a). Here however the voltage between plates A and B was changed instead of changing the downstream distance of F, Fig. 1. The full curves F and G are for normally dry air and curves H and I are for air of 65 percent humidity. It is thus seen that the effect of water vapor is to diminish the mobility as found by Tyndall and Grindley.[1] The question of interest is: To what extent is this change in the mobility due to a change in the ions.

The sharpness and similarity of the negative curves indicate that there has been no change in the negative ion and that the change in the mobility of the negative ion is due to the change in the medium. The presence of water vapor in the medium increases the resistance to the motion of the negative ion. In the case of the initial and final positive ions there is also a corresponding decrease in the mobility. The presence of water vapor in the medium thus retards the motion of the initial and final positive ions by the same amount as it retards the negative ion.

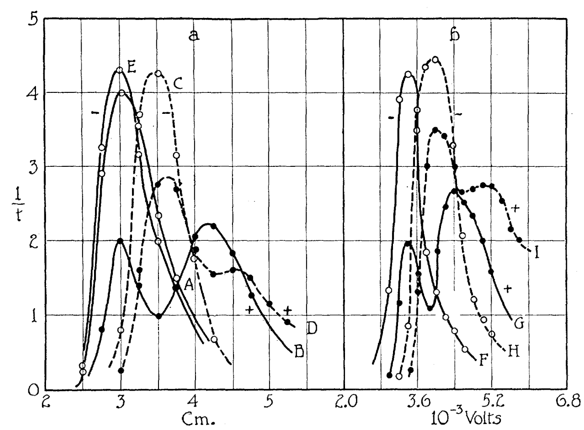

Fig. 6. Showing effect of water vapor on mobility.

An interesting effect here comes into evidence when it is noted that the relative number of initial and final positive ions is altered by a change in the humidity, and, strangely, that the number of initial ions is greater at the higher humidity. This has the apparent effect of slowing up the transition of the initial positive ion into the final ion, an effect observed by Tyndall and Grindley.[1] Mrs. Valasek[2] met with it in her work on the time of transition of the initial into the final air ion. The writer has also met with it on a number of occasions and has been greatly puzzled by it. The effect is as if the final positive ion in the presence of water vapor simplifies back to the initial ion state.

The writer has felt for some time that the effect was due to a more ready attachment to a water cluster on the part of the final ion. The heavy ion thus formed being carried downstream out of reach of the measurement

[2] Leila M. Valasek, Phys. Rev. **29**, p. 542 (April, 1927).

and thus giving an apparent increase in the ratio of the initial to the final ion. The fact, however, that the height of the maximum for the initial ion increases with the humidity rather precludes this interpretation as this indicates that there is an actual increase in the number of initial ions. If it is the final positive ion which is simplified by the water the effect would have to take place when the ion entered the moist air at E, Fig. 1, and would thus have to be of a rapid order. That such rapid changes may take place at E is borne out by the results for acetylene to be described presently. In the case of water vapor it is as though its presence loosened the electrical bond between the two molecules of the final positive air ion.

Effect of adding acetylene to the medium. In the case of acetylene it had previously been found[3] that the initial and final positive air ions disappeared and that a positive acetylene ion was formed which is distinctive in that it has a slightly lower mobility in air than the negative air ion and therefore may be recognized. It was therefore decided to add acetylene to the air in J, Fig. 1, and observe to what extent a transfer at E is detectable. The results obtained are shown in Fig. 7.

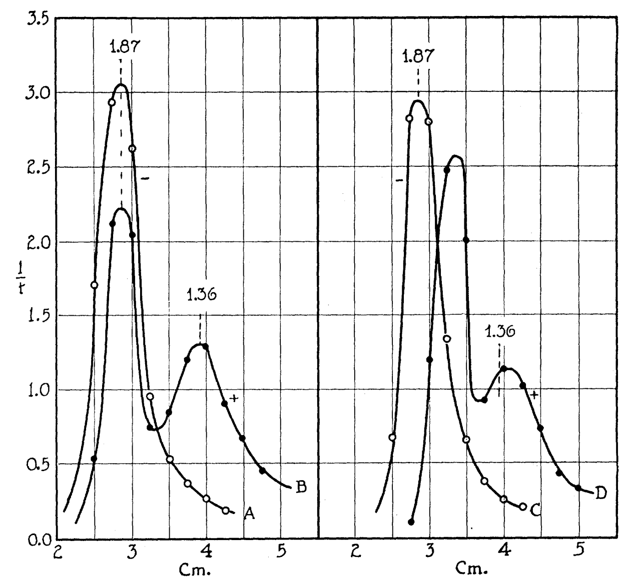

Fig. 7. Showing effect on mobility of adding 0.01 percent acetylene to the medium.

Curves A and B were obtained using air without the acetylene and curves C and D when acetylene was mixed with the air in tank J. It is thus seen that while the negative is not changed in position, the first maximum of the positive has shifted to the normal position of the positive acetylene ion as found in the investigation on acetylene.[3] It is also seen that the initial positive ions have changed completely and that the final ion has also changed, but by a smaller amount. That the position of the final 1.36 ion has not

[3] Erikson, Phys. Rev. **28**, p. 372 (August, 1926).

changed, however, is significant. The writer feels that what takes place here is that the acetylene molecule gives up an electron to an air ion forming a positive acetylene ion. This ion behaves as if it has a slightly greater polarizing action and thus meets with a slightly greater resistance to motion.

The above shows that the effect of the acetylene at E is sufficiently rapid to permit of its detection. The amount of acetylene added was of the order 0.01 percent indicating the great sensitiveness of the effect. This amount was too small to alter the medium sufficiently to change the mobility as in the case of CO_2.

Anomalous effect in the case of acetylene. In working with acetylene it was found that the results were not the same, if the acetylene gas were admitted to the air at K, the far end of tank J, Fig. 1, as the results obtained when the acetylene was admitted at N, a point near the inlet to the apparatus. The results are shown in Fig. 8. Curves A and B are for air without the acetylene.

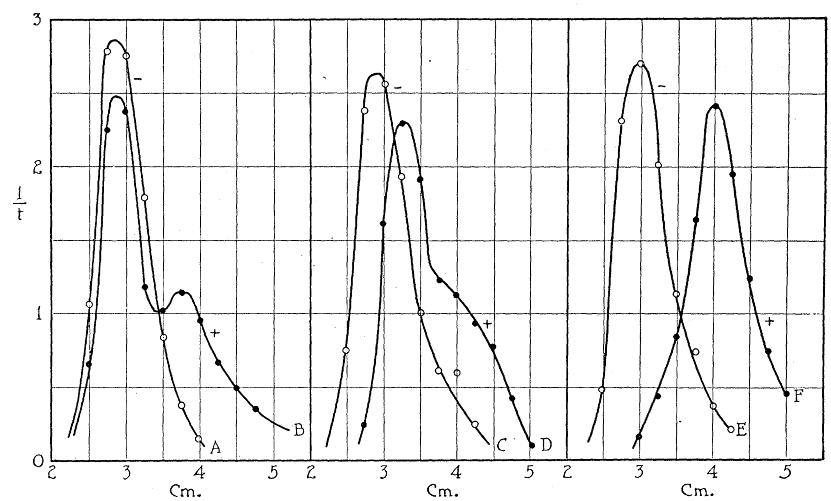

Fig. 8. Showing effect of allowing acetylene to remain in air a greater length of time.

Curves C and D were obtained when acetylene was admitted at N about 15 cm from inlet to tube AB. Curves E and F were obtained when the acetylene was admitted at K, the remote end. It is thus seen that a gradual change takes place when acetylene remains in the air. When acetylene is first admitted to the air the acetylene molecules are free and will give up an electron to the positive air ions thus forming a one molecule positive acetylene ion which, as shown by curves CD, Fig. 8, and as was found in the earlier investigation,[3] appears to have a mobility a little less than 1.87, the mobility of the negative and initial positive air ions. It is seen from curves E and F, Fig. 8, that acetylene unites with the air forming a body which upon becoming charged through contact with the positive air ions at E, Fig. 1, manifests itself as a 1.36 or two-molecule ion.

Effect of adding ethylene, chlorine, and ammonia to the air. In these cases a glass tube 4 meters long and 6 cm inside diameter was substituted in place

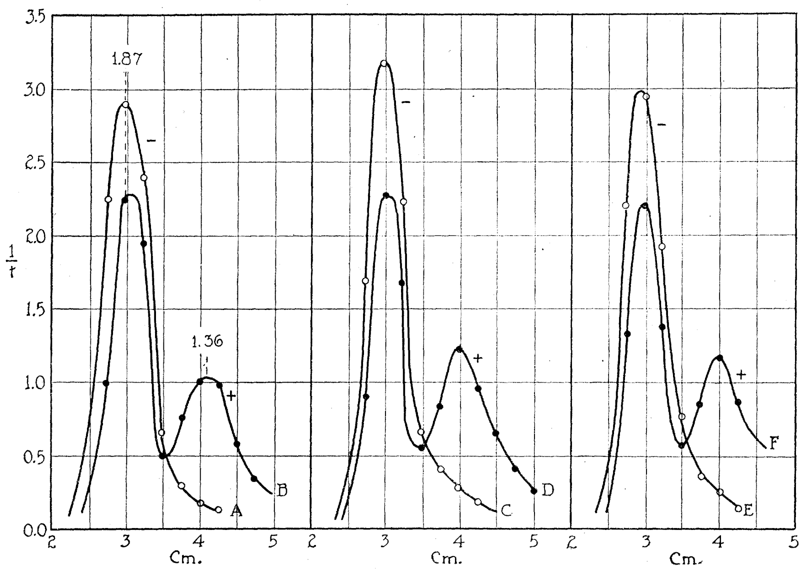

Fig. 9. Showing no effect in adding ethylene to the medium.

of the metal tank *J*, Fig. 1. The gases were admitted at the near end and at the remote end of this tube. The results in the case of ethylene are shown in Fig. 9. Curves *A* and *B* are for air only. Curves *C* and *D* were obtained when the ethylene gas was admitted at the near end, and *E*, *F*, when admitted at the far end. The amount of ethylene added was the same as in the case of acetylene. It is seen that no effect is obtained.

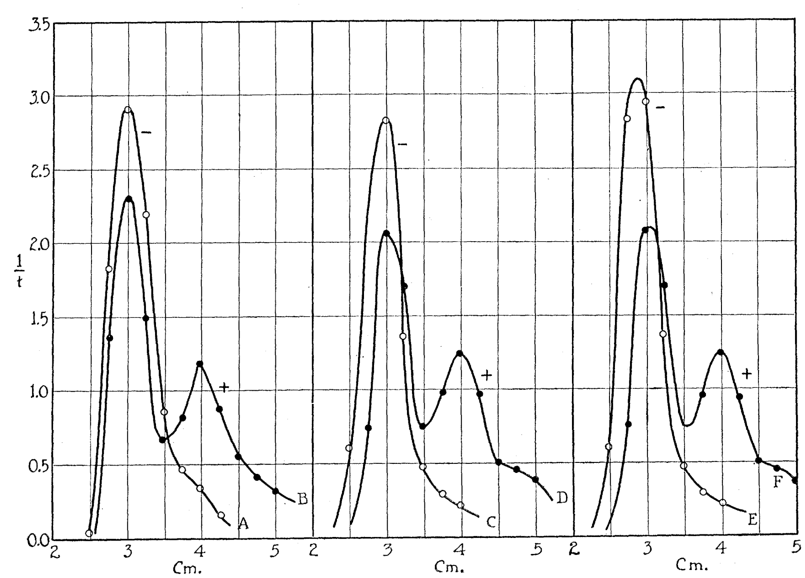

Fig. 10. Showing no effect in adding chlorine to the medium.

In Fig. 10 are given the curves obtained when chlorine is added. *A* and *B* are for air only, *C* and *D*, with the chlorine admitted at the near end, and *E* and *F* at the remote end. Here again there is no change unless the slight increase in the negative is significant.

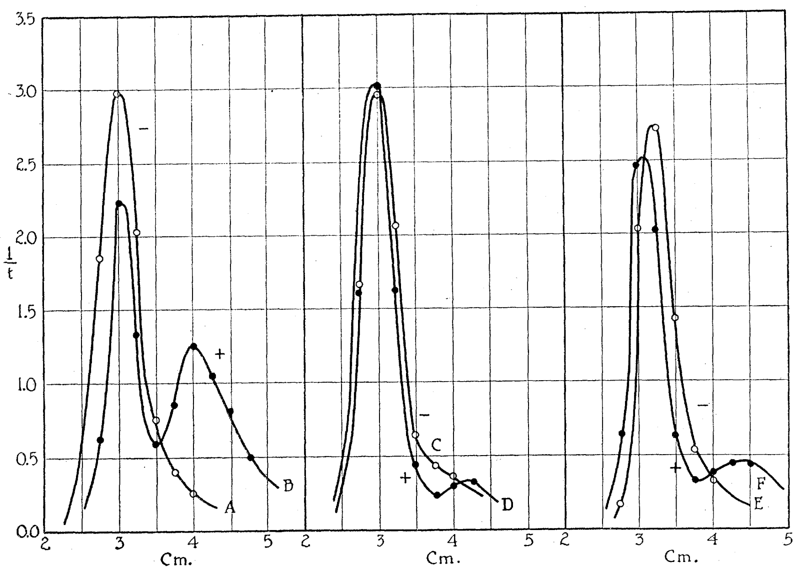

Fig. 11. Showing effect of adding ammonia to the medium.

In Fig. 11 are given the results of adding ammonia to the air. Curves *A* and *B* are for air only, *C* and *D* for ammonia admitted at the near end, and *E* and *F* at the remote end. Here a decided effect is obtained similar to the effect with acetylene.[3] The final positive air ion has disappeared and a single positive ion of the same mobility as the negative air ion is obtained. This has the effect as in the case of acetylene of increasing the positive ion mobility. This effect of ammonia was first observed by Loeb.[4] This effect is as if the ammonia simplifies the final positive air ion or that an ammonia molecule gives up an electron to the positive air ions and thus itself becomes a one molecule positive ion.

It is to be observed that the mobility of the negative ion is slightly decreased when the ammonia has been in the air from the remote end indicating that a slight change has taken place.

Physical Laboratory,
University of Minnesota.
June 11, 1927.

[4] Loeb, Nat. Acad. of Sci. **12**, p. 677 (Dec., 1926).