THE EFFECT OF WATER VAPOR ON THE MOBILITY OF GASEOUS IONS IN AIR

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Abstract

In this paper additional results are given which indicate that an H_2O molecule gives up an electron to the final positive air ion and thus forms an H_2O^+ ion of a greater mobility. Results are also given showing that the reciprocal of the mobility bears a linear relationship to the humidity.

IN AN earlier paper[1] attention was called to the effect of water vapor on the mobility of gaseous ions. It was there shown, as found earlier by Tyndall and Grindley,[2] that the mobility of the positive and negative ions in air diminishes as the amount of water vapor is increased. It was also there shown that when water was added to the air the number of initial positive ions (mobility 1.87) was increased at the expense of the number of final positive ions (mobility 1.36). In this paper results obtained under more favorable conditions are given which confirm the above. The arrangement of the apparatus was as shown in Fig. 1.

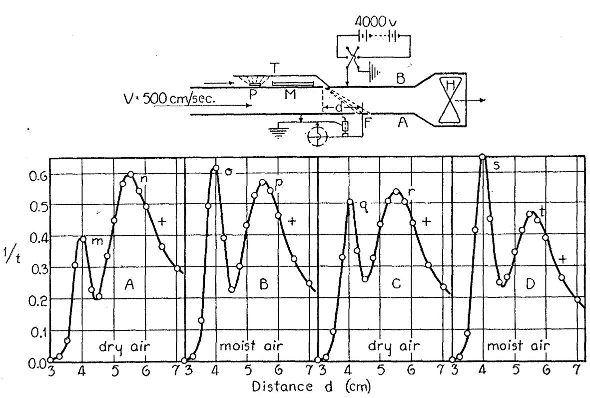

Fig. 1. Showing apparatus used and the increase in the number of initial positive ions when H_2O is added.

Air was drawn between the plates A and B which formed the bottom and top of a rectangular tube having ebonite sides. The distance between plates A and B was 3.5 cm. The width of this tube was 5 cm and its length 70 cm. The fan was driven by means of a cream-separator worm connected by a link belt to a synchronous motor. The speed of the air was of the order of 3000 cm/sec. The potential between plates A and B was of the order of 5000 volts and was obtained from a storage battery. The ions were pro-

[1] Erikson, Phys. Rev. **30**, 343 (1927).

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

duced in the side tube *T* by means of a polonium plate at *P*, the position of which determines the age of the ions. *M* is a trough designed to hold water for humidifying the air.

Results Showing the Effect of Water on the Relative Number of Initial and Final Positive Ions

The polonium plate *P* was placed so as to give comparable numbers of the initial and final positive ions.

Curve *A*, Fig. 1, was obtained with no water in the trough *M* and normally dry air passing through the apparatus. The ordinates are proportional to the currents to the electrode *F* and the abscissae are the corresponding downstream distances of the electrode *F*. The maximum at *m* is for the initial positive ion (mobility 1.87 cm/sec per volt/cm) and maximum *n* is for the final positive ion (mobility 1.36 cm/sec per volt/cm).

Water was then placed in the trough *M*. The conditions otherwise remaining identical. The water, through evaporation, passed into the on-coming air stream containing the ions. Curve *B*, Fig. 1, was obtained under these conditions. The maximum *o* is for the initial positive 1.87 ion and the maximum *p* is for the final positive 1.36 ion. The rise in the maximum *o* shows that there was a marked increase in the number of initial ions, whereas the drop in the maximum *p* shows that the number of final positive ions decreased.

The positions of the polonium plate *P* and the trough *M* were then interchanged so that the trough was on the upstream side of *P*. In this case therefore the humid air was ionized. Curve *C*, Fig. 1, was obtained when there was no water in the trough. Maximum *q* is for the initial positive ions and *r* for the final positive ions. Water was then placed in the trough *M* and the curve *D*, Fig. 1, was obtained. The rise in the maximum *s* shows that again there was a marked increase in the number of initial positive ions and the lowering of the maximum *t* shows that there was a decrease in the number of final positive ions. No change was observed in the negative ion.

Interpretation

In earlier publications[3] the author has expressed his conviction that the initial positive 1.87 ion is one molecule large and that the final positive 1.36 ion is two molecules large. On this basis the above results mean that water increases the number of one-molecule ions at the expense of the two-molecule ions. The action no doubt is that a water molecule gives up an electron to the two-molecule air ion thus forming a one molecule H_2O positive ion. This process should be possible as the ionization potentials of nitrogen and oxygen are of the order of 16 volts, whereas the ionizing potential of H_2O is of the order of 13 volts. On the other hand recent results by Smyth and Stueckelberg[4] indicate the reverse process in the case of H_2O^+ and O_2. Since there are indications that O_2 has an ionization potential also of the order of

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

[4] Smyth and Stueckelberg, Phys. Rev. **32**, 779 (1928).

12 volts and since the final positive air ion is a double molecule complex of nitrogen or oxygen, it is not clear that the interpretation given above is in conflict with the results referred to.

That the initial air ion is similarly affected is of course fully as probable. This however can not be detected because only one-molecule bodies are involved thus giving rise to no change in mobility. Since all one-molecule ions have practically the same mobility in air, the ions H_2O^+, N_2^+ or O_2^+ can not be distinguished by mobility measurement.

Results Showing the Effect of Humidity in the Air on the Mobility of the Negative Air Ion

The essential part of the apparatus was the same as shown in Fig. 1. A large chamber was placed at each end of the tube as shown in Fig. 2. These were connected above so as to permit recirculating the air. Arrangement was made so that a dry bulb and a wet bulb thermometer could be inserted at Q in order to determine the amount of H_2O in the air.

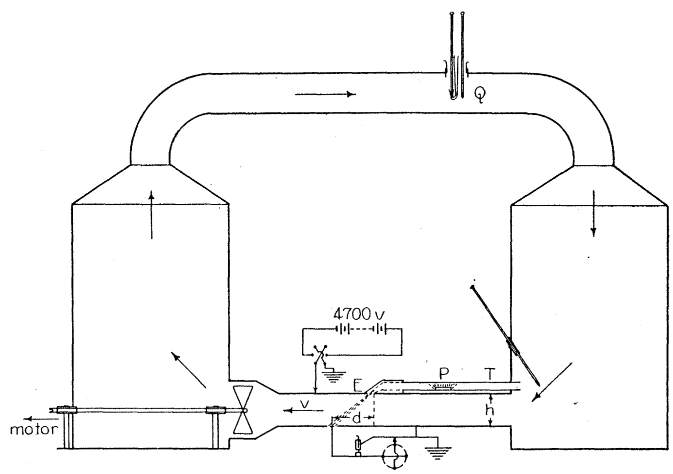

Fig. 2. Showing apparatus used in determining the effect of humidity on the ionic mobility.

As the mobility, in this case of constant air pressure, depends upon the temperature of the air it was necessary to keep the temperature from changing. This did not introduce a serious difficulty as the normal running equilibrium temperature was used which was about 5° higher than room temperature. The humidity was increased by approximately the desired amount by placing the required volume of distilled water in a copper boiler and evaporating it to dryness, allowing the vapor to pass into the apparatus.

The results are shown graphically in Fig. 3. The ordinates are the downstream distances (d) of the center of gravity of the curves obtained for each humidity. These are the average of the abscissae for all the points which are one centimeter apart on each curve.

The expression for the mobility is $k = h^2v/Vd$ or $d = h^2v/Vk$, where h is the distance between the plates, v the speed of the air, and V the potential between the plates.

Since d is proportional to the reciprocal of the mobility k, Fig. 3 shows that the relation between the humidity and this reciprocal of the mobility is linear. In terms of the quantities involved the expression for the mobility is $k = h^2v/V(lm + d_0)$ or $k = a/(lm + b)$, where d_0 is the distance at zero humidity,

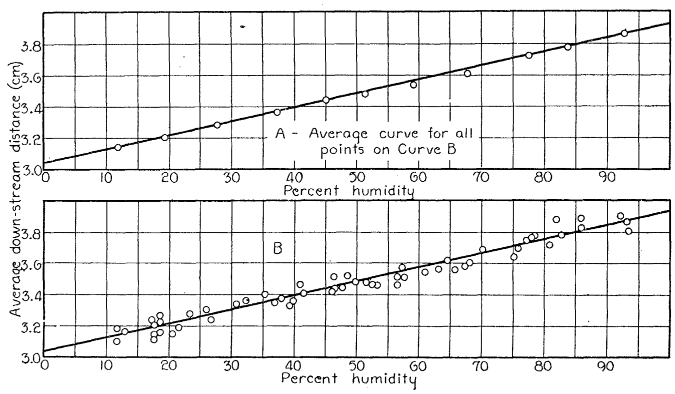

Fig. 3. Showing the linear relation between the percent humidity and the reciprocal of the mobility of the negative ion.

and m is the absolute humidity. This therefore agrees with Blanc's[5] law which may be expressed by the relation $k = a_1/(nc + b_1)$, where a_1 and b_1 are constants and c is the partial pressure.

Blanc's law is derived on the basis that the resistance to the motion of an ion is the sum of the resistances of the different gases present and that these partial resistances are proportional to the partial pressures and to the reciprocal of the mobility of the ion in these gases.

The linear relationship in this case apparently shows that the water vapor offers an independent resistance to the motion of the negative ion or in other words that the resistance to motion of water vapor is similar in character to the resistance introduced when CO_2 or H_2 is added to the air.

The author wishes to thank the Executive Committee of the Graduate School of the University of Minnesota for its financial aid in this research.

Physical Laboratory,
University of Minnesota.
July 30, 1928.

[5] A. Blanc, Jour. d. Physique **7,** 825 (1908); S Loeb, Phys. Rev. **32,** 86 (1928).