THE MEAN FREE PATH OF THE ALKALI IONS IN DIFFERENT GASES

By Ralph Brandreth Kennard

Abstract

Retardation and neutralization of caesium and sodium ions in traversing hydrogen, helium and argon.—With caesium ions of 90 volt velocity in hydrogen there is very little neutralization or scattering of the ions even when their path is twenty times the mean free path for a xenon atom in hydrogen. There is a loss of velocity of 1.3 volts per collision. Similar phenomena were observed in helium. Caesium rays of 35 volts velocity in hydrogen are slowly weakened by neutralization or scattering. Sodium ions of 455 volt velocity are also weakened in hydrogen, but the free path for a collision that removes the ion from the bundle is 26 times that of a neon atom in hydrogen. In argon, caesium ions of 90, 35 and 20 volt velocities are rapidly neutralized with a free path only 3.4, 2.6 and 2.3 times that of a xenon atom in argon.

VARIOUS experiments have been made on the scattering and the loss of velocity of positive rays in passing through a gas. J. Koenigsberg and J. Kutschewski[1] experimented with H^+ ions in H_2, O_2 and He, with He^+ in He, and O^+ in O_2, at velocities equivalent to 30,000 to 50,000 volts. They conclude from their observations that the loss of velocity is less than 0.5 percent and that there is little if any scattering. G. P. Thomson,[2] working with H^+ ions at 10,000 volts, in various gases at different pressures found that there was considerable small angle scattering. A. J. Dempster[3] made experiments on the absorption of H^+ ions in helium at from 14 to 1000 volts. Little if any retardation was observed, but considerable scattering of the bundle of protons was found at high pressures. The above experiments were made on relatively light ions, and generally at high velocities. The following experiments have been made with Na^+ and Cs^+ at much lower velocities, and data have been obtained on the neutralization and the slowing up of these rays in different gases.

The method of positive ray analysis developed by Dempster[4] was used in these experiments. The sources of ions were alkali metal catalysts kindly supplied by C. H. Kunsman.[5] This material was placed in a small furnace heated externally by a coil of resistance wire, and insulated with alundum cement. A furnace was chosen in preference to a platinum strip because the material is all at one potential, and also because the larger quantity gives a longer life and greater stability in the emission. For caesium, with the furnace half full, a useful life was obtained of over 100 hours. The furnace,

[1] J. Koenigsberg and J. Kutschewski, Ann. d. Physik **161,** 37 (1912).
[2] G. P. Thomson, Proc. Royal Soc. **102,** 197 (1922).
[3] A. J. Dempster, Phil. Mag. **13,** 115 (1926).
[4] A. J. Dempster, Phys. Rev. **11,** 316 (1918).
[5] C. H. Kunsman, Jour. Ind. & Eng. Chem. **17,** 971 (1925).

A, was made positive with respect to the electrodes B and C which were grounded, B direct, and C through a galvanometer. Electrodes B and C were brass disks with a 5 mm hole in the center across which a few fine wires were stretched in order to get a more uniform electrical field. The beam of

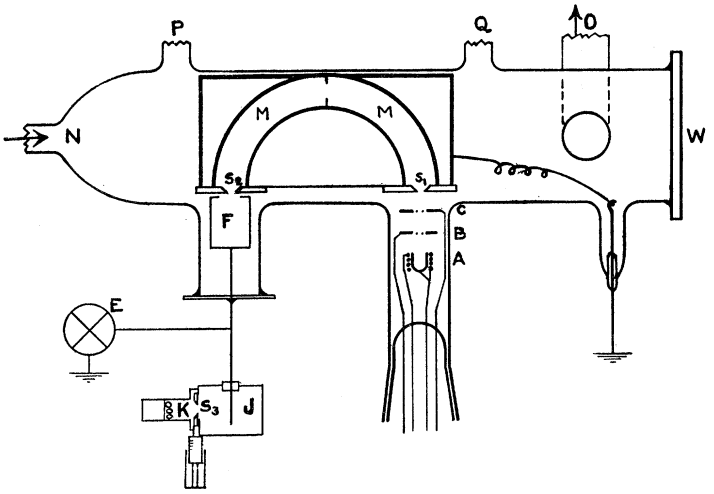

FIG. 1

positive rays was thus approximately parallel before entering the magnetic field, M, through the first slit S_1. In the magnetic field the beam was bent through 180° emerging through the slit S_2 into a Faraday chamber F. The current from the positive rays which entered F was measured by balancing

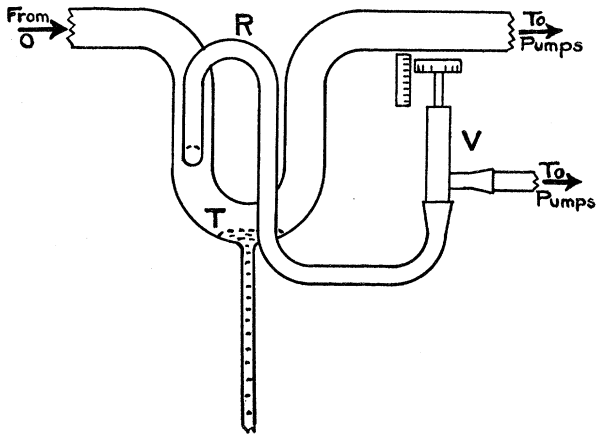

FIG. 2

the positive current by a negative current from an ionization chamber, J.[4] The current in this chamber was proportional to the opening between J and K which contained tubes of radium E, the width of this opening being controlled by micrometer screw reading to 0.01 mm. The current in J could

also be varied by changing the position and the number of radum E tubes in K, three standard arrangements being used.

Gas from a reservoir passed through a very fine capillary, a stop-cock, and a liquid air trap, and entered the system at N. The gas left at O, and passed through a liquid air trap to the pressure control system shown in Fig. 2 and thence to the mercury pumps. When the inflow of gas at N, Fig. 1, was stopped and the trap T, Fig. 2, left open, pressures as low as 10^{-5} mm were obtained. For higher pressures the gas was allowed to flow into the system and the mercury in the trap T was raised so as to force the gas through R and the choke valve V. This valve consisted of a slightly tapered plunger which could be raised or lowered in a cylinder by rotating a divided head. It was found that settings of the head corresponded to definite pressures so that it was possible to duplicate pressures at will. P and Q (Fig. 1) are joined together and lead past an ionization gauge through a liquid air trap to a Macleod gauge. The ionization gauge was used for convenience to indicate when a constant pressure had been reached, and to show any pressure variation that might take place in the course of a set of observations, the Macleod gauge being used as the final measure of all pressures.

In the beginning of a run the freshly filled furnace was heated, at low pressure, and under running conditions, for ten or more hours in order to get a steady emission. The pressure was then adjusted to the desired value and, after the iron in the magnet had been brought into the cyclic condition for a weak field, the current through the second slit was observed for a series of increasing magnetic fields. Although the emission current as measured by the galvanometer connected to C (Fig. 1) was kept constant throughout the readings, the emission of caesium or sodium would not remain constant if the composition of the emission current varied during the course of an experiment. It was found necessary to make an observation of the peaks of the curves when more than one ion was present, in order to reduce the readings to a constant emission of the particular ion under investigation.

Three phenomena may determine the form of the curves observed when gas is present; neutralization of the positive particles, retardation of the rays, and scattering. The positive ions finally observed may also have been subjected to the last two influences simultaneously. If neutralization were the only phenomenon occurring at collisions between the ions and the gas molecules, the curves observed would be weakened as gas is introduced, but would not be broadened or displaced to different values of the magnetic field. A scattering of the rays at collisions would broaden the curves to both higher and lower values of the magnetic field, and in addition would weaken the bundle since the scattering would deflect rays to the sides as well as in the plane in which the magnetic deflection occurs. If retardation occurred alone without neutralization or scattering, the curves would be shifted to smaller values of the magnetic field, and in this case the areas of the curves would remain the same, since the ions are not deflected to the sides. There are thus definite characteristics for identifying the two cases of pure neutralization or pure retardation.

The results of the observations with sodium ions of 445 volts velocity in hydrogen are shown in Fig. 3. The curve observed at the lowest pressure agrees with the curve calculated[4] on the assumption that the beam of ions at S_2 is of the same width as the width of the slit S_1. As gas is introduced the number of ions received is diminished and the curves are spread, mainly to the side of lower magnetic fields. This can be accounted for by the retardation of some of the rays when gas is introduced. There is also possibly some scattering at the higher pressures. Although the three effects cannot be clearly distinguished in this case, it is of interest to note that the combined action of all three is very ineffective in preventing the ions from reaching the second slit, when compared with what we might expect from the kinetic gas theory. The number of ions, N, traversing a distance $x=11.2$ cms at a

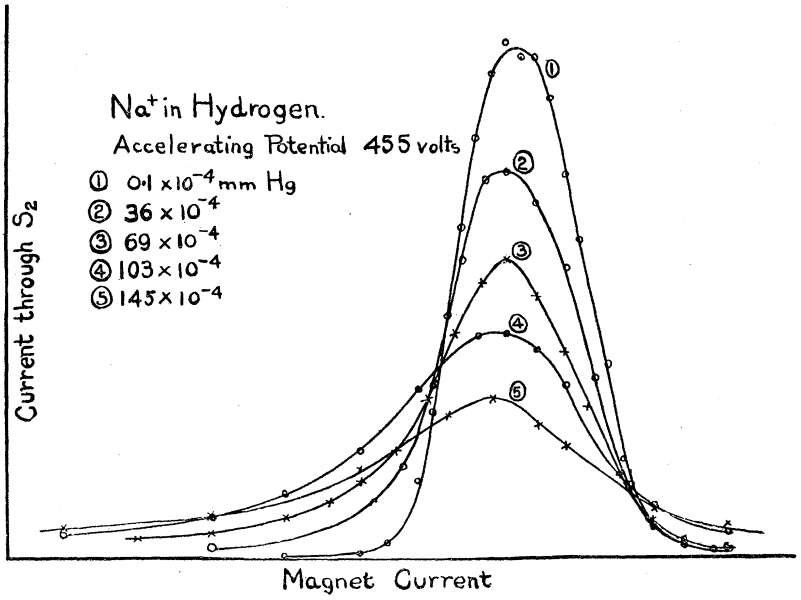

FIG. 3.

pressure of p mms would be expected to decrease with pressure according to the formula $N=N_0e^{-xp/760\lambda}$, where λ is the mean free path, reduced to atmospheric pressure, that the ion traverses before being removed from the group considered. The total number of ions given by the area under the first three curves decreases according to the formula with $\lambda=52\times10^{-5}$ cms. If we consider the maxima of the curves to give the number of ions which have not suffered neutralization or scattering we have for these $\lambda=27\times10^{-5}$ Assuming a radius for the sodium ion equal to that given by the kinetic theory for the neon atom, we find that the mean free path for a collision reduced to atmospheric pressure is only 2×10^{-5} cms. The free paths just deduced from the weakening by neutralization and scattering of the sodium ions in hydrogen are thus from 13 to 26 times as long as the kinetic theory free paths.

It is also of interest to note that the slight shift of the maximum of the curves in Fig. 3 corresponds to a very small loss of velocity even though the

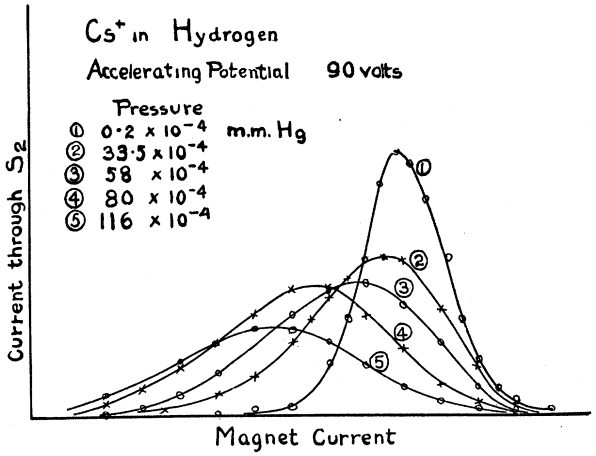

FIG. 4.

ions in curve 5 make 10.7 collisions in traversing this path. The shift at a pressure of 0.01 mm corresponds to a velocity decrease equivalent to 4 volts, or less than one percent.

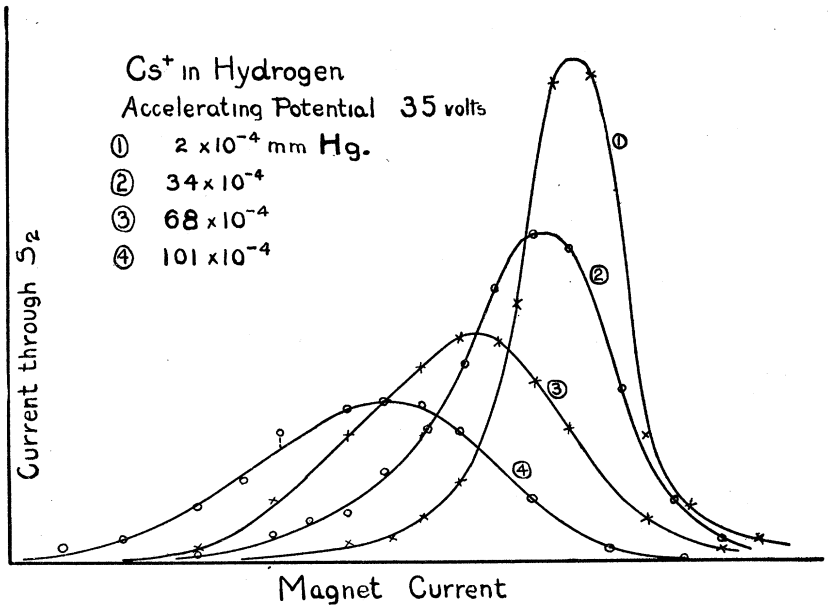

FIG. 5.

With caesium ions quite different phenomena were observed. Whereas with sodium the peaks of the curves (Fig. 3) lie one under the other, with

caesium in hydrogen, the curves (Figs. 4 and 5) spread out in the direction of smaller magnet currents as the pressure is increased. The areas under the first four curves in Fig. 4 are the same, showing no change with increasing pressure. The curve for the highest pressure was not corrected for a change in the relative intensity of the caesium ions. We may then conclude that caesium ions of 90 volt velocity are retarded only, and not neutralized or scattered in passing through hydrogen. With 35 volt rays in hydrogen (Fig. 5) a small decrease in area was observed. The curves for 90 volt rays in helium (Fig. 6) were not corrected for changes in the relative intensity of the caesium rays, but they show the shift of the rays to slower velocities.

In the case of the pure retardation shown by 90 volt caesium rays in hydrogen (Fig. 4) we may estimate the number of collisions made by the

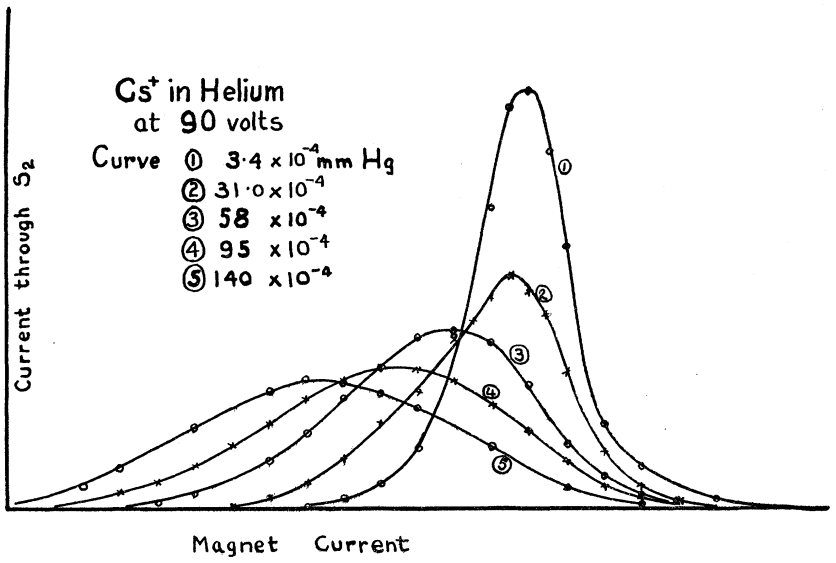

Fig. 6.

ions at the highest pressures. Assuming the diameter of the caesium ions to be the same as that of the xenon atom we find a kinetic theory free path of 5.25 mms at 1.16×10^{-2} mms pressure. Thus the ions giving the fifth curve of Fig. 4 have suffered 21.4 collisions in completing their path of 11.2 cms. The decrease in area of the curves for the 35 volt caesium rays in hydrogen indicates that about 1/5 of the ions are lost by neutralization or scattering after 12 collisions. The results in helium are similar to those in hydrogen although it was not possible in this case to make an exact correction for the emission current. The shift of the maximum of the 90 volt caesium curve in hydrogen would be caused by a loss of velocity corresponding to about 1.3 volts per collision.

When caesium ions pass through argon (98 percent pure) the curves in Fig. 7 are obtained. Here there is a rapid decrease in intensity as the gas

pressure is increased. The ions that remain positive do not suffer a marked loss of velocity. This is, however, to be expected as they have not made

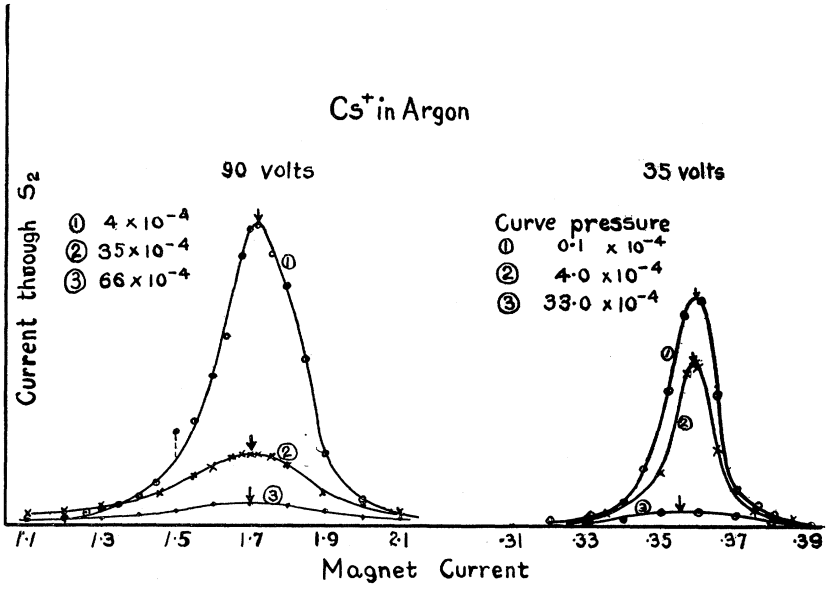

Fig. 7.

many collisions as in the case of the caesium ions in hydrogen. To determine the rate of decrease of the number of ions reaching the second electrode, the

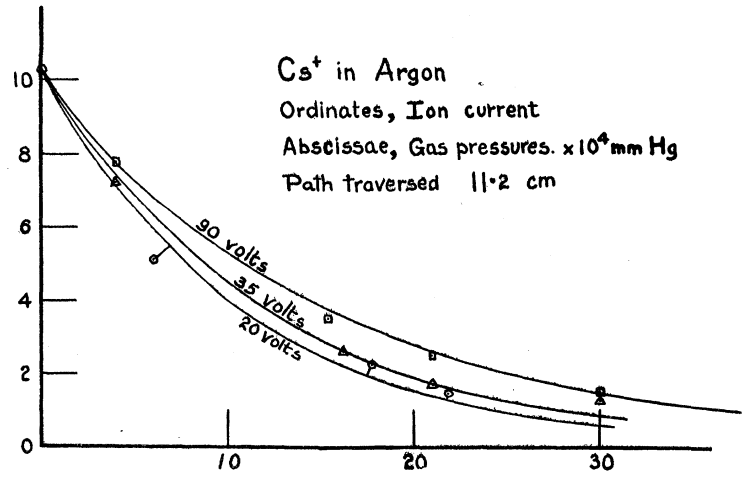

Fig. 8.

decrease of the maximum of the curve was observed. This gives an indication of the areas under the curves in Fig. 7 and may be made rapidly under con-

stant conditions. These observations are given in Fig. 8, and from the curves we may calculate a mean free path for the disappearance of the ion by neutralization or scattering. Reduced to atmospheric pressure we find 22.4×10^{-6} cms at 90 volts; 17×10^{-6} cms at 35 volts, and 15.3×10^{-6} cms at 20 volts. The kinetic theory free path for a rapidly moving xenon atom in argon is 6.5×10^{-6} cms, so that the above values are respectively 3.4, 2.6 and 2.35 times as long.

Experiments were also made on Rb^+ ions in H_2 and it was found that a loss of velocity occurred similar to that for Cs^+, but the work with Rb^+ was discontinued because an exact location of the peak of the curves was im-, possible. This was due to the presence of the two isotopes of Rb, 87 and 85 and of an ion of molecular weight 83, possibly $NaSiO_2^+$ from the alundum cement. All three ions could be separated at a low pressure and their weights determined by a comparison with sodium. The intensities of the two Rb isotopes corresponded exactly to that called for by the atomic weight.

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RYERSON PHYSICAL LABORATORY,
UNIVERSITY OF CHICAGO,
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