IONIZATION OF ARGON, NEON AND HELIUM BY VARIOUS ALKALI IONS

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Abstract

Caesium, rubidium, potassium, and sodium positive ions from Kunsman catalyst sources, and lithium ions from spodumene have been used to produce ionization in helium, neon, and argon. In most cases the ionization sets in between 100–150 volts and increases linearly to 750 volts, the highest potential used. Maximum ionization was produced in each gas by the alkali ion closest to it in atomic number.

PREVIOUS experiments have been reported[1] concerning the ionization of various gases by potassium positive ions of relatively low energies. The present paper deals with the ionization of helium, neon, and argon by a series of alkali ions representing a wide range of atomic weights from lithium to caesium. It was of interest to determine what relationship might exist be-

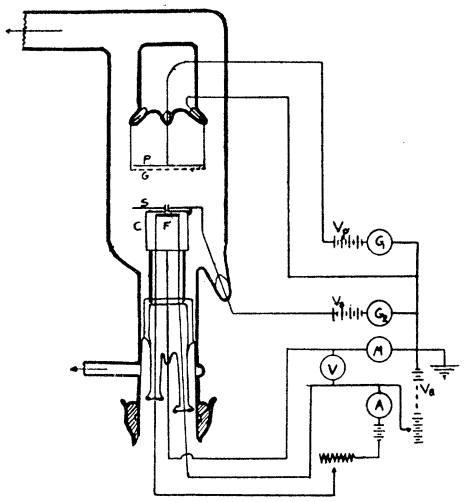

Fig. 1. Experimental tube and connections.

tween the various ionizing agents and the ionization which they produce in gases of different atomic weights. Some rather unexpected experimental results came to light which indicate that the field is fruitful for further investigation and explanation.

The method of measurement has been described in the previous papers. Referring to Fig. 1, it may be summarized briefly as follows. Positive ions

[1] R. M. Sutton, Phys. Rev. **33,** 364 (1929); Sutton and Mouzon, **35,** 694 (1930).

emitted from Kunsman catalyst sources by a hot coated platinum strip F are directed by the variable accelerating potential, V_a, through a small channel in the steel cathode C which completely surrounds the filament. Any ionization occurring in the gas between C and the grid G will produce an electron current I_s to the collector plate S which is connected to the high sensitivity galvanometer G_2. The initial positive beam (except for loss by scattering and the small fraction striking the grid) falls upon the upper plate P and is recorded as a positive ion current, I_p, by the galvanometer G_1. At each gas pressure used, the accelerating potential of the positive ions is varied in steps from zero to 750 volts. The ratio of currents, I_s^-/I_p^+, corrected for the small secondary emission of electrons from the grid, is taken as a measure of the ionization produced in the gas between S and G. The collector S and plate P are both maintained at small positive potentials to prevent the escape of elec-

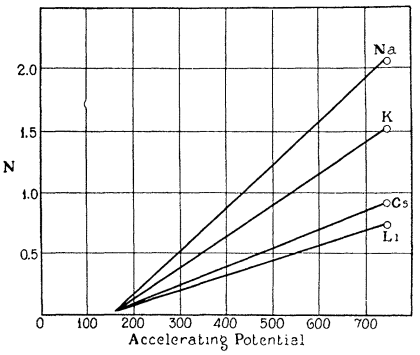

Fig. 2. N, number of neon ions formed per initial positive ion per cm path at 1 mm pressure.

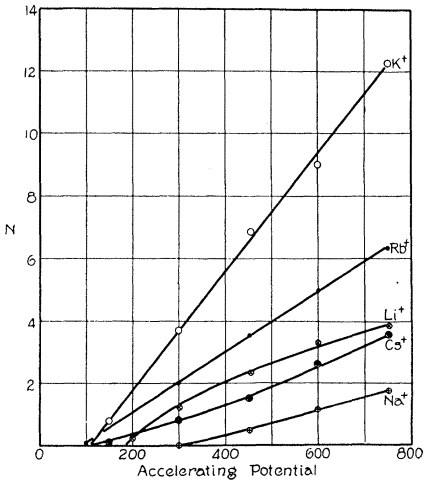

Fig. 3. N for argon.

trons due to secondary emission or photoelectric effect. These potentials were in no case high enough to produce ionization of the gas by electron collision. The distance $S-G$ (2.5 cm) is made large in comparison with the distance $G-P$ (0.2 cm) in order to minimize the effect of ionization between grid and plate. To correlate the results obtained at different pressures, the ratios of I_s/I_p were divided by the length of path between S and G and by the gas pressure in mm of mercury, thus giving the number, N, of ions formed per initial positive ion per centimeter path at one millimeter pressure. The pressure range utilized was from 0.005 to 0.05 mm; in a few cases where the ionization was feeble, pressures as high as 0.1 mm were used.

In general the ionization sets in between 100 and 150 volts (except for sodium in argon) and increases practically linearly with increasing accelerating potential to 750 volts, the highest voltage used. After making correction for the stoppage of the initial positive beam by the gas, the ionization for a particular voltage is found to be linear with respect to pressure; only in the

cases of intense ionization is there evidence of more than one ionizing collision per positive ion at the higher pressures and accelerating potentials. Thus N for each positive ion in a particular gas is independent of gas pressure within the range studied and depends only upon the accelerating potential of the positive ions.

Fig. 2 and Fig. 3 show the results of a large number of runs in neon and argon respectively, in each of which several different positive ions were used as the ionizing agents. The calculated values of N are seen to be practically linear with accelerating potential after ionization once begins, in most cases by 150 volts. Sodium does not ionize argon until an accelerating potential of nearly 300 volts is reached; this behavior, together with a strong reflection of the sodium positive ions to the collector S at accelerating potentials around 150–250 volts, is strangely unaccountable. In all other cases, reflection of the

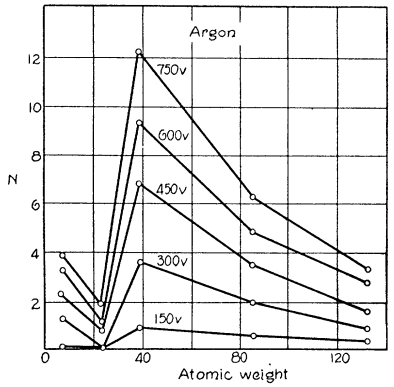

Fig. 4. N as function of atomic weight of positive ions and their energies.

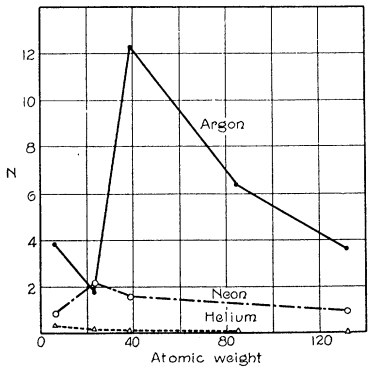

Fig. 5. Comparative values of ionization at 750 volts accelerating potential for different gases as function of atomic weight of ionizing agent.

positives played a negligible part in the currents observed. This method is not sensitive enough to determine the onset of ionization closer than 25 volts, but the slopes of all the ionization curves indicate a fairly sharp origin of ionization which was scarcely to be expected; the "ionization potential" due to positive ions bears no evident relationship to ionization potentials determined by electron impact methods, nor does it seem to be critically dependent upon the mass of the bombarding ions in any regular fashion.

The most striking results of this investigation appear when the values of N in Fig. 3 are plotted against atomic weight of the ionizing agent, as shown in Fig. 4. It appears that the maximum ionization in argon is produced by potassium positive ions, which is scarcely what would be expected from any ballistic transfer of energy considerations. Similarly, as may be seen in Fig. 5, neon is most strongly ionized by sodium positives; helium is most strongly ionized by lithium. The conclusion presents itself that *ionization of a noble gas is best effected by that alkali ion closest to it in mass or number of electrons.* Evidence is not yet available to discern whether the controlling factor is one

of mass or electron configuration of the two constituents of an impact, nor can a comparison yet be made with the ionization of a gas by its own atoms or ions. The experimental difficulties in the path of this latter aspect of the problem have not been solved.

Similar results have been published recently by Dr. Otto Beeck[2] who secured homogeneous beams of positive ions by means of a magnetic analyzer. His method is evidently better designed for the purpose than the one here reported, and he is now in a position to complete the study of the two remaining noble gases at this Institute. The qualitative agreement between the two methods is excellent, and the quantitative agreement is as good as might be expected considering the difference in methods. The only marked departure from regularity of our results appears in the relative interchange of intensities of ionization by lithium and sodium in argon. This may be accounted for by either or both of two causes: first, an impurity of higher atomic weight in the lithium source derived from powdered spodumene (all other sources were Kunsman catalysts); second, the unaccountably large reflection of sodium ions by argon. This inversion of position was carefully checked, and as far as the accuracy of this method is concerned, the effect is real.

Not only is there maximum ionization produced by the alkali positive lying closest to the atomic weight of the gas bombarded, but the intensity of these maxima increases greatly in the heavier gases. The ionization of helium is very feeble, whereas in argon it is quite pronounced. It is rather to be expected that even greater ionization will be found in xenon and krypton. In all of the foregoing work, correction has been made for the secondary emission of electrons from the metal parts of the tube. Inasmuch as there was gas admitted into the tube, no particular precautions were taken to outgas the electrodes. Comparing the secondary emission of the metal surfaces under bombardment of the various alkali ions, the intensity of emission was found to vary in the same way as the intensity of ionization; i.e., greatest for potassium when argon had been present, etc. It would appear that the secondary emission might be due largely to a layer of gas upon the electrodes, and hence this surface effect would bear a close relationship to the volume ionization produced in the gas by different positive ions.

It is felt that more experimental evidence is necessary before an adequate explanation of ionization by two such complicated structures as an alkali ion and a gas atom can be made. This necessitates the development of additional ion sources and improved technique for the study of atom-beams in a gas.

The authors acknowledge their thanks to Dr. Otto Beeck and Dr. Fritz Zwicky for stimulating discussion of the results obtained.

[2] Otto Beeck, Ann. d. Physik **6**, 1001 (1930).