Ionization of Gases by Collisions of Their Own Accelerated Atoms and Molecules

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Apparatus for producing fast neutral atom beams and measuring ionization caused by collisions of these atoms with others is described together with preliminary results on argon and nitrogen. The ionization of argon atoms appears to be similar to ionization by electron collisions in that the efficiency reaches a peak and falls off again with increasing speed. Ionization of nitrogen by neutral nitrogen was observed but the nature of the ionization function was not positively established.

IONIZATION of noble gases by their own fast neutral atoms has been observed by various experimenters.[1–3] In these cases the ionizing atom needed only to have an energy of 30 to 70 electron volts in order to succeed in detaching an electron from another atom during a collision. The onset energies observed were roughly only three times the ionization potentials of the respective atoms. The results indicated the desirability of further experiments for several reasons: First, no trace of ionization of other than noble gases had been observed, although at least one of the workers had looked for it. Second, the experimental velocities used were not high enough either to assure that ionization failed to occur in the low energy range or to connect the observations with the higher range sometimes described as the alpha-particle range. Finally, no theory satisfactorily explains the very low energy ionization, and hence more complete experimental information concerning what actually does occur is essential to the understanding of the process.

The apparatus was accordingly set up to permit forming a beam of neutral atoms with energies up to 8000 electron volts. (See Fig. 1.) An ion gun accelerated singly charged positive ions to the desired speed; an electrostatic velocity selector homogenized the beam; the beam then passed through a chamber containing the same gas so that the neutralization by charge exchange could occur. The beam of now neutralized ions passed through a set of electrodes charged with retarding potentials to remove any remaining ions from the beam. Finally the beam passed through a space charge type of ion detector[4] in which the ionizing collisions could be measured.

The apparatus was first tested with argon whose ionization was already known to occur. Intense ionization was observed in this case.

In order to determine even a qualitative ionization function, it is necessary to know something about the intensity of the neutral atom beam, if only that it is fairly constant at different speeds. The magnitude of the neutral atom intensity was measured by permitting the beam to pass through the detector and liberate secondary electrons from a small nickel plate placed behind the detector. These secondary electrons were repelled by a potential of 10 to 45 volts to the outside of the space charge cylinder, and the current was read on a galvanometer. Previous results indicated that about two neutrals were required per secondary electron liberated when the neutral energy was in the range used in our

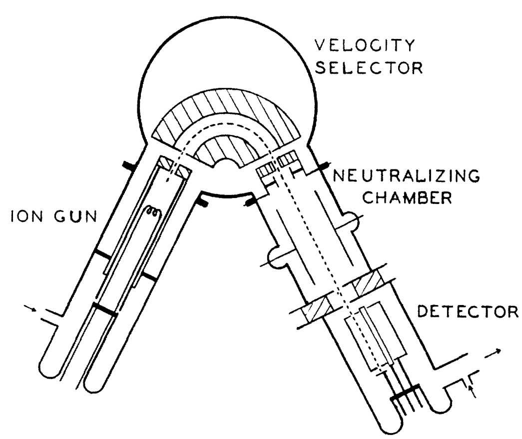

FIG. 1. Diagram of the apparatus.

[1] R. N. Varney, Phys. Rev. **50**, 159 (1936).
[2] A. Rostagni, Nuovo Cimento **11**, 34 (1934).
[3] H. Wayland, Phys. Rev. **52**, 31 (1937).
[4] R. N. Varney, Phys. Rev. **47**, 483 (1935) and **53**, 732 (1938).

experiments. This is qualitatively in agreement with the extrapolated results of Rostagni.[5] Rostagni's results further suggest that there is not a very great change in secondary emission with voltage in the range of our experiments.

A qualitative ionization function for argon neutrals in argon was obtained and is shown in Fig. 2. The ordinates indicate only the relative space charge effect per neutral atom, but they should be fairly accurate as far as neutral atom intensities are concerned. Because of the long and intricate path of the beam, adequate intensities could not be obtained with speeds under 1000 volts. The curve is seen to fall off steeply with increasing energy.

An ionization function was also obtained for nitrogen. The efficiency of ionization, even at best, was far less than in argon. The reader is warned against drawing more than qualitative conclusions concerning the relative efficiency of N_2 and A because of the qualitative nature of the data. This is the first definite evidence of ionization of nitrogen by collisions of heavier particles in the energy range lower than that of alpha-particles. It is interesting to note that it occurs at all, for the previous evidence in the 0–500 volt range indicated that it must be very

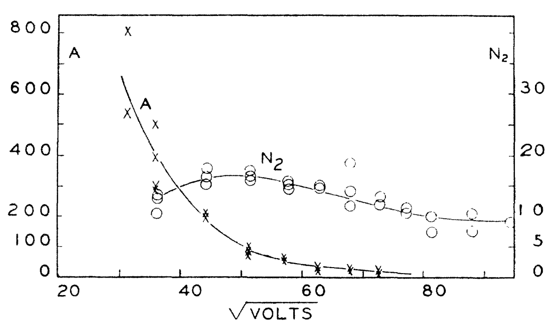

FIG. 2. Ionization functions for A and N_2 by their own neutrals. The ordinates are ratios of galvanometer readings and have no absolute significance. The numerator of the ratio is the space charge effect as shown by the galvanometer in the space charge bridge circuit. The denominator is the secondary electron current produced by the neutral beam in hitting the plate after passing through the space charge cylinder.

[5] A. Rostagni, Zeits. f. Physik **88**, 55 (1934).

feeble if it did occur. It is also of great interest to note that both argon and nitrogen ionization functions have a peak, for this is the first indication that ionization by neutral atom collisions occurs by a mechanism at least outwardly similar to ionization by electron impacts.

It must be noted here that the drop in ionizing efficiency at higher energies can conceivably be only an apparatus defect. The ionization produced by collisions is detected with a space charge type of detector which is notably dependent on the speed of the ions being detected; in fact, an ion speed of only a few volts very greatly decreases the sensitivity of the detector.

It is imaginable that in ionizing collisions between neutral atoms, the newly formed ions acquire more kinetic energy as the energy input of the collision increases. The writers are at present only able to suggest that this is not the true cause of the fall in measured efficiency at higher energies. The reason for this opinion is based on the observation that the efficiency of the detector must still be very high for argon ions produced by 1000-volt neutral atoms, and for that matter even 4000-volt atoms. If the detector efficiency is low, the space charge effect observed would correspond to a collision cross section for ionization large beyond all reason. Hence it must be concluded that in raising the speed of the ionizing argon neutrals from the onset at 48 volts to 1000 or even 4000 volts, relatively little change has occurred in the kinetic energy delivered to the newly formed argon ions. It thus seems to be unlikely that the mechanism of ionization is one involving a transfer of kinetic energy at all for there appears to be relatively little change in the kinetic energy transferred with a very great change of energy of the ionizing particle. If this conclusion in itself can be established, it will be a major addition to the knowledge of ionization mechanisms.

Preliminary results exist in helium similar to those in nitrogen. However, a more intense source is necessary to complete this work and to verify the details of the nitrogen measurements.