Electron Impact Ionization of Atomic Hydrogen and Atomic Oxygen

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The total cross sections for the ionization of atomic oxygen and atomic hydrogen have been measured by a modulated molecular beam technique. The impact energies were 100 to 500 ev for oxygen and 100 to 750 ev for hydrogen. The number of ions formed in a region defined by the intersection of an electron beam and a modulated molecular beam was compared with the number formed when the neutral beam was partially dissociated. All ions were collected, including those energetic ions formed in dissociative ionization. The degree of dissociation was measured with a mass spectrometer. From the data, the ratios of the atomic to the molecular ionization cross sections were obtained. The absolute atomic values were calculated by multiplying these ratios by the molecular ionization cross sections of Tate and Smith. The results are compared with theoretical estimates and previous experimental determinations.

IONIZATION cross sections of atomic oxygen and atomic hydrogen have been measured, the former from 100 to 500 ev, the latter from 100 to 750 ev. The apparatus has been described in papers on electron scattering.[1,2] The only change was the replacement of the low-energy scattering gun by an electron impact ionizer.

The procedure was very similar to that previously described.[1] Total ion signals were measured (at a given energy) when the neutral beam was molecular and again when the beam was partially dissociated. The degree of dissociation was measured with a mass spectrometer. From the ratio of ion signals and the degree of dissociation, one may compute the ratio of the total atomic to the total molecular ionization cross sections. Since the latter have been measured by Tate and Smith,[3] we may calculate the atomic cross sections.

Both cross sections have been previously measured.[4,5] Although in those experiments a modulated molecular beam was also used, the measurement technique was different. The present method is somewhat more direct.

The ionizer, shown in Fig. 1, was constructed of cylindrical stainless steel electron gun parts. The filament was thoriated tungsten. Electrons passed through four circular apertures (all at the ionization chamber potential) before intersecting the neutral beam. The ions formed were extracted into the collector. The gun was designed to collect all ions, including energetic ions formed in dissociative ionization. To collect these energetic ions an extraction field must be produced in the interaction region. This field caused some changes in the electron energy. At the lowest electron energies, where a given field would produce the greatest percentage change, fields were used that were very close to the minimum necessary for total ion collection. At higher energies larger extraction fields were used. Since the maximum energy for dissociatively ionized oxygen[6] ions is 2.5 ev and for hydrogen[6] ions it is 1.5 ev, the potentials applied to the ionizer at a given electron energy were different for these two species.

An equipotential diagram (obtained by means of an electrolytic plotting tank) was made of the ionization chamber, the secondary electron suppressor, and the ion collector. The collector was always kept at ground potential. The filament was positive with respect to ground. Scattered electrons were not collected and secondary electrons were suppressed.

Figure 1 shows the ionizer voltages used for oxygen between 100 and 200 ev. In this energy range the equipotential plot indicates that all ions formed with 3 ev or less will be collected. At impact energies of 200 ev and above, larger extraction fields were also tried so that ions with initial kinetic energies of 5 ev or less would be collected. At energies of 200, 400, and 500 ev, the cross sections obtained for the two conditions of extraction were compared and found to be the same within the experimental error.

The gun potentials that were used for hydrogen were somewhat different. The ratio of ionization chamber to electron suppressor potential was kept the same as that shown in Fig. 1. The filament was always kept 50 v above ground. At 150 ev, for example, the ionization chamber and electron suppressor would be at 200 and

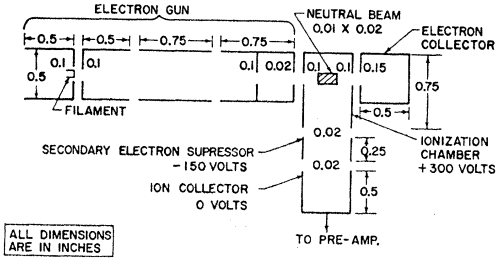

FIG. 1. Ionizer. The molecular beam goes into the paper. All ions formed in the interaction region are collected, including those energetic ones formed in dissociative ionization. Cylindrical components and circular electron beam apertures are used.

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[2] R. H. Neynaber, L. L. Marino, E. W. Rothe, and S. M. Trujillo, Phys. Rev. **124**, 135 (1961).

[3] J. T. Tate and P. T. Smith, Phys. Rev. **39**, 270 (1932).

[4] W. L. Fite and R. T. Brackmann, Phys. Rev. **112**, 1141 (1958).

[5] W. L. Fite and R. T. Brackmann, Phys. Rev. **113**, 815 (1959).

[6] H. D. Hagstrum, Revs. Modern Phys. **23**, 185 (1951).

-100 v, respectively. At the lowest electron energy of 100 ev, the extraction field was just sufficient to ensure the collection of 1.5-ev ions.

The equipotential diagram indicates that in the hydrogen experiment the electron energy varied by 4% in different parts of the beam intersection volume. However, the present method of obtaining ratios of atomic-to-molecular cross sections made this an almost negligible source of error. The measured quantity (the ion signal ratio with discharge on and off at a given degree of dissociation) changed only slightly in the entire energy range. A variation in this measured quantity would not be detectable in a 4% energy increment. For oxygen at lower impact energies, the electron energy

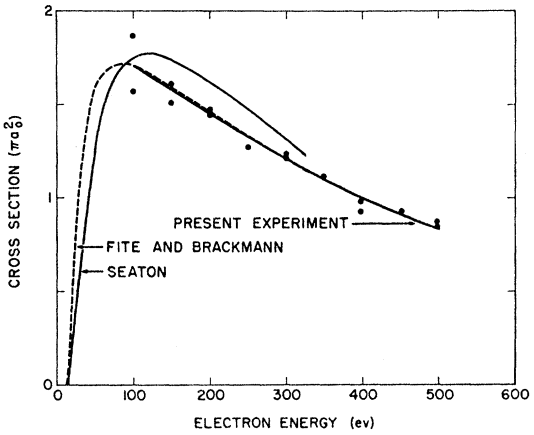

FIG. 2. Cross sections for ionization of atomic oxygen by electron impact.

change was greater than that for hydrogen, and in the worst case, at 100 ev, was 10%. As for hydrogen, the effect of this energy change was small because of the slow change of the ratio of ion signals with electron energy. Between 100 and 500 ev the change in the ratios was less than 5%.

The oxygen results are shown in Fig. 2. Each point represents an average of about three readings. The curve shown was considered the best fit to these points. The largest error in the experiment was caused by nonreproducibility. At 100 ev this error was about $\pm 8\%$ and decreased with increasing energy. For example, at 300 ev it was about 4%. It is noted that agreement with the results of Fite and Brackmann[5] is

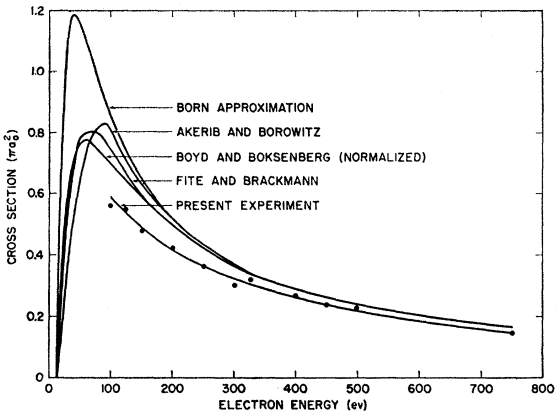

FIG. 3. Cross sections for ionization of atomic hydrogen by electron impact.

good, although we are in disagreement with a recent unpublished experiment. The curve is also in fair agreement with a calculation made by Seaton.[7] Although our measurements also include multiple ionization of atomic oxygen, its contribution is expected to be small. Fite and Brackmann measure only single ionization.

The hydrogen results are shown in Fig. 3. In general, the points represent an average of several readings. The curve was considered the best fit to these points when they were properly weighted. The errors associated with this experiment are the same as those for the oxygen data. Our results are in fair agreement with, although lower than, the Born approximation,[8] the impulse approximation of Akerib and Borowitz,[9] and the experimental curve of Fite and Brackmann.[4] The discrepancy is somewhat greater than our experimental error. Also shown is an experimental curve of Boyd and Boksenberg,[10] which is a relative measurement and is normalized to the Born approximation.

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[8] A formula for the cross sections was derived by H. S. W. Massey and C. B. O. Mohr, Proc. Roy. Soc. (London) **A140**, 613 (1933). Calculations were made by A. Dalgarno (1953, unpublished), quoted by R. McCarrol, Proc. Phys. Soc. (London) **A70**, 460 (1957). Some values also given by H. S. W. Massey, *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1956), Vol. XXXVI, p. 354.

[9] R. Akerib and S. Borowitz, Phys. Rev. **122**, 1177 (1961).

[10] R. L. F. Boyd and A. Boksenberg, *Proceedings of the Fourth International Conference on Ionization Phenomena in Gases, Upsala, 1959* (North-Holland Publishing Company, Amsterdam, 1960), Vol. I, p. 529.