Ionization of Atomic Oxygen on Electron Impact*

WADE L. FITE AND R. T. BRACKMANN
John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California

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The cross section for ionization of atomic oxygen has been measured by using modulated atomic beam techniques. First the ratio of the cross sections for production of the molecular oxygen ion and for total ion production in collisions of electrons with oxygen molecules was measured. Then the ratio of the ionization cross section of the free oxygen atom and the cross section for production of the molecular ion in electron-molecule collisions was determined. From the previously known total ionization cross section of the molecule, and the measured ratios, the unknown cross sections were determined. The experimental results are compared with the calculations of Seaton.

A MEASUREMENT of the cross section of atomic oxygen for ionization on electron impact has been made using modulated-atomic-beam techniques. A beam containing oxygen atoms which was mechanically modulated at a frequency of 100 cps was crossed by a dc electron beam, and the ions formed were detected in a sector-magnetic-field mass spectrometer. Modulating the neutral beam allowed the signals arising from interaction of the two crossed beams to be separated from those due to ionization of the residual gas in the vacuum, because the former signal appears at the modulation frequency and in specified phase. The details of this general approach have been described elsewhere.[1]

The principal source of oxygen atoms was a radio-frequency electrodeless gas discharge, the neutral beam from which contained insignificant amounts of all species except atomic and molecular oxygen. The beam ranged from 20% to 30% dissociated, and ionization threshold studies indicated that at least 97% of the atoms and molecules were in the ground state.

The first part of the measurement consisted of determining the ratio Q_1/Q_2, where Q_1 is the cross section for single ionization of the neutral atom and Q_2 is the cross section for the process $e+O_2 \rightarrow O_2^+ + 2e$. This ratio was obtained from the comparision of the heights of the mass peaks 16 and 32 with the discharge power turned off (so that the beam consisted only of O_2) and from the changes of the peak heights upon turning on the discharge power. The neutral beam carried the same mass flow per unit time with the power on and off.

The second part of the measurement determined the ratio Q_2/Q_T, where Q_T is the total ionization cross section for the oxygen molecule. This latter cross section, measured absolutely by Tate and Smith,[2] is that for the formation of all ions, irrespective of mass, charge, or initial kinetic energy. In order to evaluate the ratio Q_2/Q_T, the mass spectrometer alone was inadequate. Because the atomic ions appearing from electron bombardment of molecules are formed in a dissociative process, they possess some initial kinetic energy,[3] and the collection efficiency of the mass spectrometer was therefore less for the atomic ions than for the directly ionized molecular ions, which are formed with no initial kinetic energy.

To determine Q_2/Q_T, simultaneous measurements were made of (1) mass-spectrometer signals and (2) signals arising from the collection of all ions, using the method described by Boyd and Green.[4] Comparison of these two signals using an inert gas beam, in which case the ions are formed with no initial kinetic energy,[3] gave the mass-spectrometer collection efficiency for such ions. Using a molecular-oxygen beam, the required ratio of cross sections at a given electron energy was obtained by dividing the O_2^+ mass-spectrometer signal, after correction for the slow-ion collection efficiency, by the signal obtained when all ions were collected indiscriminately.

Multiplying the measured ratios and the absolute values of Tate and Smith for Q_T gave absolute values

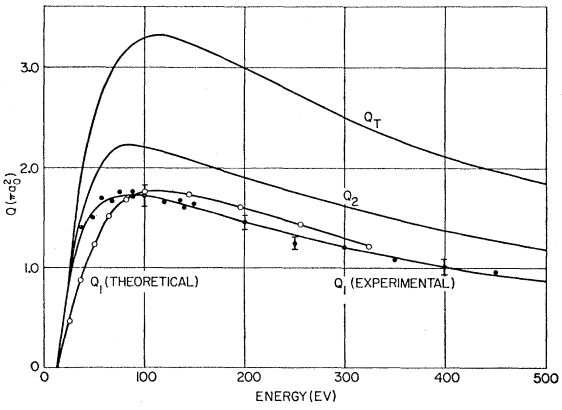

FIG. 1. Cross sections for ionization of oxygen. Q_T is the total cross section for ionization of the molecule, Q_2 is the cross section for the process $e+O_2 \rightarrow O_2^+ + 2e$, and Q_1 is the cross section for $e+O \rightarrow O^+ + 2e$. The theoretical curve was calculated by Seaton.

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for both Q_1 and Q_2 at a number of different electron energies. Relative-cross-section measurements, normalized to these absolute values, were used to complete the experimental curves shown in Fig. 1. This figure also presents the theoretical curve for Q_1 as calculated by Seaton.[5]

Several comments in regard to our measurements are appropriate. First, relative-cross-section measurements of Q_T confirm the shape of Tate and Smith's curve and disagree with the more recent measurements of Craggs, Thorburn, and Tozer.[6] Second, the ratio of atomic ions to molecular ions formed in collisions of electrons with oxygen molecules increases rapidly from zero at a threshold energy of 18.5 ev, reaches a maximum at about 150 ev, and decreases slightly to a value which remains constant at higher energies. Third, at energies in excess of about 100 ev, only about two-thirds of the ions formed in electron collisions with oxygen molecules appear to be O_2^+ ions. Fourth, the cross section for ionization of the atom near threshold increases linearly with the excess energy of the incident electron. Fifth, the agreement between the measured and calculated cross sections for ionization of the atom appears quite satisfactory.

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Formation of H^- Ions by Electron Impact on H_2

G. J. SCHULZ
Westinghouse Research Laboratories, Beulah Road, Churchill Borough, Pittsburgh, Pennsylvania
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The cross section for production of H^- ions by electron impact in hydrogen gas is studied. The cross section exhibits a plateau around 10 ev with a value of 1.2×10^{-20} cm^2. A sharp peak with a cross section of 3.5×10^{-20} cm^2 is observed at 14.2 ± 0.1 ev. The first plateau is associated with the reaction $H_2+e\rightarrow H^-+H$ and the sharp peak with the production of hydrogen atoms in the first excited state, $H_2+e\rightarrow H^*+H^-$.

I. INTRODUCTION

THE formation of negative H^- ions by electron impact was first reported by Lozier.[1] He found peaks in the negative-ion current at an electron energy of 6.6 and 8.8 ev with hydrogen in the apparatus. Because the observed peaks were small, Lozier attributed these to an impurity. When water vapor was admitted to the apparatus, the peaks appeared at the same energy and were more pronounced. The conclusion that the 6.6-ev peak observed by Lozier is due to H^- formation from H_2O was recently confirmed in a mass spectrometer experiment by Khvostenko and Dukel'skii.[2] With either hydrogen or water vapor in the system, they observed a peak in H^- current at 7.2 ev.[3] In addition, Khvostenko and Dukel'skii observed H^- currents resulting from electron impact on H_2 up to 38 ev, with a peak at 14.5 ev, but were able to determine the cross section only approximately.

In the present work, the production of H^- is studied using ultrahigh vacuum techniques. The electron energy scale is established by using the retarding potential difference method,[4] and correcting for contact potentials from the onset of the H_2^+ ions. The collection efficiency for negative ions is higher than in either of the two previous experiments so that cross sections can be determined.

II. EXPERIMENT

A diagram of the tube is shown in Fig. 1. Electrons from the tungsten filament F pass through the electron gun (P_1 P_2 P_3) and are collected, after passage through the collision chamber C, by the electron collector E. A magnetic field of about 200 gauss prevents electron spreading. The collision chamber, formed by grid G_1 is surrounded by a cylindrical grid G_2 (90% transparent) and the cylindrical ion collector M. The ion collector is mounted on long glass supports so that electrical leakage currents are minimized. The electron gun, using the retarding potential difference method, and its dimensions have been described previously.[5] Electrons are retarded at P_2 to zero energy and therefore the potential V_A (see Fig. 1) is the true electron energy except for a small correction for the contact potential between P_2 and G_1. To reduce contact potentials, all parts of the tube are gold plated. The ion collector is operated a few volts positive with respect to G_1 to collect most of the

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