Low-Energy Electron Scattering from Atomic Nitrogen*

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The total cross section for the scattering of electrons by atomic nitrogen has been measured as a function of electron energy from 1.6 to 10 eV. An electron gun was developed that produced a more intense beam of electrons than was used for similar experiments with atomic hydrogen and atomic oxygen. The number of electrons scattered from a region defined by the intersection of an electron beam and a modulated molecular nitrogen beam was compared with the number scattered when the nitrogen beam was partially dissociated. A pulsed dc discharge dissociated about 20% of the molecules. The degree of dissociation was measured with a mass spectrometer. From the data, the ratios of atomic to molecular scattering cross sections were obtained. The absolute atomic values were calculated by multiplying these ratios by the molecular nitrogen cross sections obtained by Normand. The results are compared with theoretical estimates of the cross section.

I. INTRODUCTION

MODULATED molecular beam techniques have previously been used to study low-energy electron scattering from atomic oxygen[1] and atomic hydrogen[2] (hereafter referred to as I and II). Analogous collision studies of atomic nitrogen with electrons were deferred because it was more difficult to produce a sufficiently dissociated nitrogen beam. A source for such a beam was recently described.[3] Substitution of this source for the source previously used in I and II indicated that a greater signal-to-noise ratio was required for the measurement of the electron-atomic nitrogen scattering cross sections. A gun which produced a more intense beam of electrons was constructed and was used to measure the total scattering cross sections of electrons by atomic nitrogen in the energy range from 1.6 to 10 eV.

II. EXPERIMENTAL

The modulated molecular beam apparatus and its associated phase-sensitive electronics were previously described in I. The atomic nitrogen source was that used in a study of the ionization of atomic nitrogen by electron impact.[3] The nitrogen (Liquid Carbonic, 99.6% pure) was used directly from a cylinder.

In I and II the source exit was larger than that allowed by the Knudsen condition for effusive flow. This was necessary to obtain greater signal-to-noise ratios from the electron gun. In the present experiment studies made with this gun also required the use of a noneffusive source. Even then poor signal-to-noise ratios allowed satisfactory measurements to be made only at the high end of our energy range. Because of this difficulty, a scattering cross section using this electron gun was obtained at only one energy (i.e., 10 eV). As in I and II, a correction (about minus 20%), which was determined by an ionization experiment, had to be applied.

In order to achieve greater electron beam densities a two-dimensional gun was built. It was designed to have better focusing properties than the scattering gun used in I and II. A schematic of the gun is shown in Fig. 1. The gun was similar to types discussed by Pierce.[4] Curved electrodes and an oxide-coated cathode were used. The cathode was made relatively long in order to obtain greater electron currents. A directly heated cathode was not used because it could not have been made an equipotential surface. At equivalent energies, electron currents were six to seven times larger than those from the gun used in I and II. For example, the current in the new gun at 10 eV was about 14μA. The gun was operated with space-charge limited emission. With this gun, sufficiently large signal-to-noise ratios were obtained to operate the source with effusive flow conditions.

The energy and energy spread of the electrons were determined by a retarding potential technique. The full width at half-maximum was about 0.35 eV at all energies in the range of interest.

The angular resolution of the experiment, as calculated by a method outlined by Kusch,[5] was about 16°.

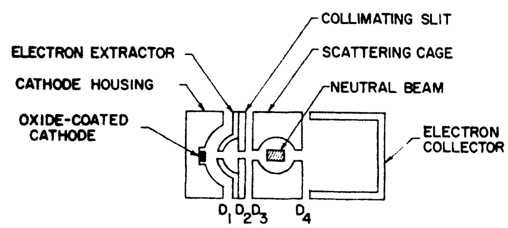

FIG. 1. Diagram of low-energy electron gun. The electrodes are copper. The gun is at ground potential except the cathode housing and the cathode, which are at a negative potential whose magnitude is equal to the desired energy. The electrodes are separated from each other by about 0.020 in. The cathode and electron beam slits D_1, D_2, D_3, and D_4 are 0.10, 0.042, 0.035, 0.048, and 0.051 in. high, respectively. The cathode is 1.25 in. long into the paper and each of the slits is 1.38 in. long. The dimensions of the neutral beam are 0.085 in.×0.114 in. at the interaction region.

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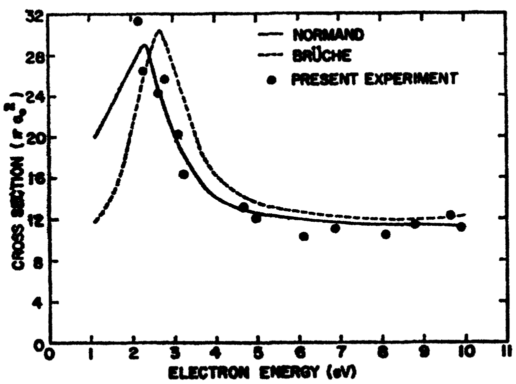

FIG. 2. Total collision cross sections for electrons scattered by molecular nitrogen. A few measurements were made at energies lower than for the data shown but were not included because of the large associated errors. These measurements, however, do establish the existence of a peak in our cross-section curve.

This angle is defined as the scattering angle at which the efficiency of detection of scattering is 50%. This resolution was better than that in I and II. The effect of the nondetectable scattering must await angular distribution measurements. However, the method of obtaining the cross sections by measuring a ratio of cross sections reduces the error.

To eliminate surface charging, the electron gun was surrounded by an oven which allowed it to be degassed at about 525°C. After degassing, it was normally operated at between 150 and 225°C. A collimating slit was attached to the oven, which permitted the neutral beam to pass cleanly through the scattering chamber.

The procedure for obtaining the atomic cross section was that described in I. The number of electrons scattered was measured 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 data the ratios of the total atomic to the total molecular scattering cross sections were computed. The atomic cross sections were calculated from these ratios and the molecular values measured by Normand.[6] As in I and II, a null system was used for the measurements.

To test the apparatus, relative cross sections for molecular nitrogen were measured. These cross sections as well as the experimental results of Normand[6] and Brüche[7] are shown in Fig. 2. Our data seemed slightly more consistent with Normand's results and so were normalized to give what was considered the best fit to his curve.

Some data were taken at energies lower than for the points shown in Fig. 2. These are not included because the errors associated with them are quite large. The uncertainties are due to the small dc electron beam obtainable at such low energies. These data do indicate, however, that the cross section decreases at energies less than the lowest energy point shown in the figure.

III. DISCUSSION OF RESULTS

The results are presented in Fig. 3 together with two theoretical estimates. The points shown are averages of cross sections obtained at a given energy. Relative weighting factors have been assigned to the points and these are indicated by different symbols. The weighting factor for a given point was determined by the number of measurements made at that energy and an assessment of the reliability of each measurement. Root-mean-square deviations from the averages were calculated at energies where sufficient data were obtained to give them significance. These rms deviations are shown by brackets and represent reasonable estimates of the experimental uncertainty. It is noted that the three brackets indicate roughly the same deviation of $\pm 1\pi a_0^2$.

The points shown in Fig. 3 below 5 eV suggest that the cross section decreases with energy. Although rms deviations were not calculated in this energy range, an estimate showed that the experimental precision was not significantly different from that above 5 eV.

Four measurements were made in the energy range from 1.6 to 2.2 eV. The cross sections are not shown because the uncertainties are unusually large. By estimating limits on the experimental errors associated with the measurements, an upper bound to the cross section for this energy range was established. The value of this limiting cross section is 4.5 πa_0^2. Since this is an upper limit, the cross sections are probably below those for the range above 5 eV. These facts further indicate that the cross section decreases below 5 eV.

The large errors in the very low energy (1.6 to 2.2 eV) atomic cross sections can be explained by examining the expression from which the cross sections were cal-

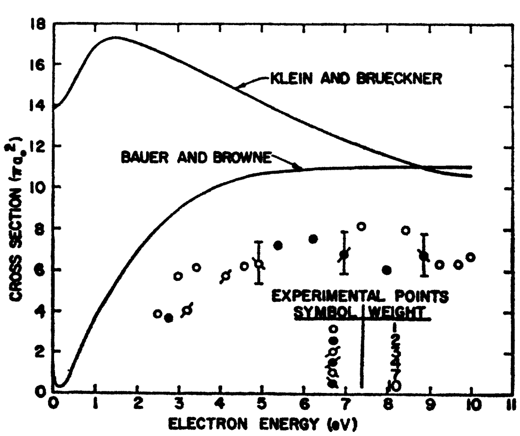

FIG. 3. Total collision cross sections for electrons scattered by atomic nitrogen. The symbols indicate averages of experimental cross sections for a given energy. Different symbols denote different weighting factors for the points as denoted in the legend. A weighting factor of 1 was assigned to the least reliable data.

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[7] E. Brüche, Ann. Physik 82, 912 (1927).

culated. This is

$$\frac{Q_A}{Q_M}=\frac{(S'/S)-1+D}{D\sqrt{2}},$$

where Q_A and Q_M are the atomic and molecular cross sections, respectively; S' and S are the scattered alternating current per unit dc electron beam current with the discharge on and off, respectively; and D is the fraction of molecules dissociated. For the very low energy region the numerator turns out to be relatively small, being equal to the difference of two quantities (i.e., $S'/S+D$ and 1) whose magnitudes are almost the same. Errors in the measured values of S'/S and D are then magnified in the determination of Q_A/Q_M and, hence, Q_A.

Brüche's values of the molecular cross sections[7] lead to results that are almost the same as those in Fig. 3. Because Brüche's curve peaks at a slightly higher energy than Normand's, however, the decrease in atomic cross section begins at an energy somewhat less than 5 eV and is more abrupt.

As previously discussed, one atomic cross section was measured using the electron gun of I and II. This is the point shown at 10 eV in Fig. 3. This value is consistent with data taken with the new gun.

Included in Fig. 3 are the theoretical predictions of Klein and Brueckner (KB)[8] and preliminary calculations of Bauer and Browne (BB).[9] To obtain the scattering cross section of atomic nitrogen, Klein and Brueckner utilized their work for atomic oxygen.[8] In this latter calculation they determined a polarization (and, implicitly, exchange) potential by using experimental results on the binding energy of O^-. The corresponding polarization potential for atomic nitrogen was obtained from the oxygen results by an extrapolation based on the theory of polarization. The KB curve includes *s*- and *p*-wave contributions.

Bauer and Browne used an approximation of the Hartree-Fock equations for a free electron-atom system as in their atomic oxygen calculations.[10] In this approximation the polarization, exchange and exchange-polarization terms were represented by potentials. Their curve includes *s*-, *p*-, and *d*-wave contributions.

Robinson[11] also made predictions of electron-atomic nitrogen scattering cross sections. His results are above the KB curve but are not shown in Fig. 3. These calculations did not include exchange or polarization.

The KB curve does not agree well with the experimental results, differing in both magnitude and shape. For example, the theoretical cross section decreases with increasing energy between 2 and 5 eV, whereas the experimental results increase over the same energy interval.

The BB calculations are in better agreement with the experiment than those of Klein and Brueckner. The BB cross sections are, nevertheless, considerably greater than the experimental values. The shape of the BB curve is consistent with the data. In particular, over the energy range investigated in the experiment, a reasonable fit to the points would be obtained if the BB curve were uniformly lowered by about $4\pi a_0^2$.

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