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DIFFERENTIAL EXCITATION CROSS SECTION MEASUREMENT OF O(^{1}D) AT 20 eV ELECTRON IMPACT

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Abstract. The differential excitation cross section of O(^{1}D) from the ground state has been measured at 20 eV electron impact by a crossed-beam method. The angular range covered was from 30 to 150 degrees. Atomic oxygen was generated by a thermal dissociation method (iridium oven). The measured total excitation cross section is $(1.5\pm0.7)\times10^{-17}$ cm^2 which agrees, within the accuracy of the measurement, with the theoretical value (1.7×10^{-17} cm^2) calculated by Henry et al. (1969).

Introduction

The interaction of electrons with atomic oxygen plays an important role in the energy deposition in the upper atmosphere. Of particular importance is the metastable ^{1}D state which radiates emission at 6300 A in a transition to ground state. Hays et al. (1978) have demonstrated from a large data base that in sunlight above 200 Km, the excitation source for the ^{1}D level is electron impact. The nighttime atmosphere under auroral electron bombardment has been shown by Sharp et al. (1983) to be a case where the ^{1}D level is produced predominantly by mechanisms other than electron impact.

The electron impact cross section has been calculated to have a maximum of 2.6×10^{-17} cm^2 in the 4 to 7 eV region (Henry et al., 1969; Vo Ky Lan et al., 1972; Thomas and Nesbet, 1975). In the context of the Earth's atmosphere, this represents a major sink for electron energy. When measurements of the electron energy distribution are compared with the calculated equilibrium energy distribution of photoelectrons (e.g. Nagy et al. 1977; Richards and Torr, 1981) and auroral secondary electrons (e.g. Sharp et al., 1979), then some disagreements exist. Since accurate cross sections are required for these calculations, a concern is raised about the explicit magnitude and shape of the ^{1}D excitation cross section used.

Only calculated cross sections of this state are available along with some indirect inferences from airglow experiments about their correctness. An experiment has been designed to test the calculations. This report presents the first direct experimental measurement of the excitation cross section of the metastable ^{1}D level of atomic oxygen by electron impact. The energy loss spectra of the scattered electrons were measured in a crossed-beam method at a primary beam energy of 20 eV. The atomic oxygen beam was produced by thermal dissociation of molecular oxygen in an iridium oven which is similar to the one used by Lo et al. (1971). The energy loss spectrum was measured over an angular range of 30 to 150 degrees.

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Apparatus and Procedure

A schematic diagram of the apparatus used for this measurement is shown in Figure 1. A more detailed description can be found elsewhere (Shyn and Sharp, 1979; Shyn and Carignan, 1980; Shyn and Sharp, 1982) with the exception of the iridium oven system. Briefly, the apparatus consists of three parts: an atomic oxygen generator which contains an iridium oven, a rotatable electron beam source, and a fixed detector system on the vacuum chamber wall.

The iridium oven, which is similar to the one used by the Pittsburg group (Lo et al. 1971), is heated resistively by a high current power supply to 2200 K. The fractional dissociation of molecular oxygen into atomic oxygen, FD, was obtained by measuring the atomic and molecular oxygen ion currents (S_1 and S_2, respectively) with a quadrupole mass spectrometer inserted into the interaction region and using the following equation (Lo et al., 1971):

$$FD = (1 + \sqrt{2}\, Q_1/Q_2(S_1/S_2 - a)^{-1})^{-1} \qquad (1)$$

a is a cracking factor (S_1/S_2 for O_2 beam only) and Q_1/Q_2 is the ratio of the ionization cross sections of atomic and molecular oxygen at the ionizing beam energy of 100 eV (0.795).

A typical fractional dissociation at the interaction region where the neutral beam and electron beam intersect is deduced to be 7% when the pressure and temperature inside the oven are 6×10^{-1} torr and 2150 K, respectively. The pressure was measured by a MKS Baratron pressure meter and the temperature inside the oven was measured by an optical pyrometer through the slit on the oven. The cracking factor was 0.12 and the ratio of the ion currents was near 0.21; thus the difference of these numbers in the inner parenthesis is generally in the same order of magnitude as these numbers.

Equation (1) is valid when the gases are in a thermal equilibrium inside the oven and the beam effused through the circular aperture on the oven (0.8 mm in radius) is in free molecular flow. Since the mean free path (Ramsey, 1963) of the particle inside the oven at 0.6 torr and 2170 K (2.6 mm) is larger than the radius of the slit of the oven, the flow through the slit is in a molecular flow regime. The thermal equilibrium inside the oven has been verified by the fact that several measurements of FD using equation (1) agree with the predicted values under conditions of thermal equilibrium as shown in Figure 2. Curves for 2300 and 2170 K were obtained from the measurements of Lo et al. (1971) and curve for 2100 K was obtained from that of Rutherford and Vroom (1974). The crosses (x) and open circles (o) are the present measurements at 2170 and 2100 K, respectively.

A mixture beam of atomic and molecular oxygen effuses from a slit located at the center of the oven and passes through a double skimmer before entering the lower chamber. This vertically col-

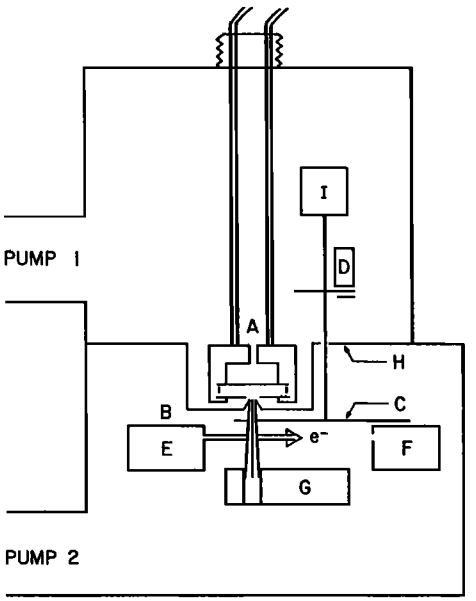

Fig. 1. Schematic diagram of apparatus: A; Iridium oven, B; Skimmer, C; Toothed wheel, D; Light source & sensor, E; Electron beam source, F; Detector system, G; Mass spectrometer, H; magnetic shielding, I; D. C. motor.

limated neutral beam intersects with an electron beam from the electron beam source in a horizontal plane at the interaction region. The scattered electrons from the neutral beam are detected by the channeltron electron multiplier after energy analysis.

The density of the atomic oxygen, d, at the interaction region was deduced from the measured ratio of the beam pressure and background pressure by modulating the beam with a mechanical chopper wheel. The absolute background pressure was measured by MKS Baratron pressure meter. The following equation has been used:

$$d = 2 \times \text{ratio of the beam and background pressure} \times \text{background pressure} \times FD \quad (2)$$

The factor of 2 in the above equation comes from the fact that one oxygen molecule becomes two oxygen atoms. The ratio of the beam and background

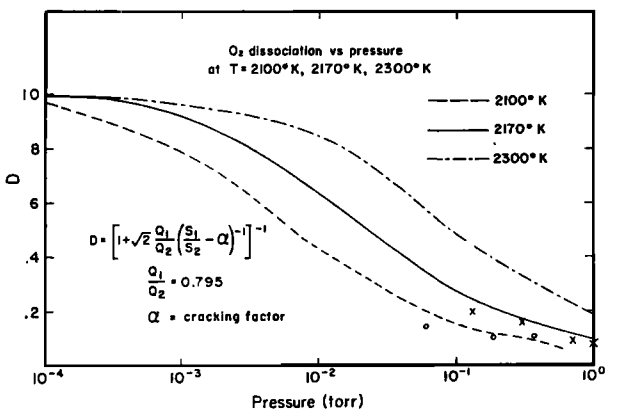

Fig. 2. Fractional dissociation vs pressure at three temperatures.

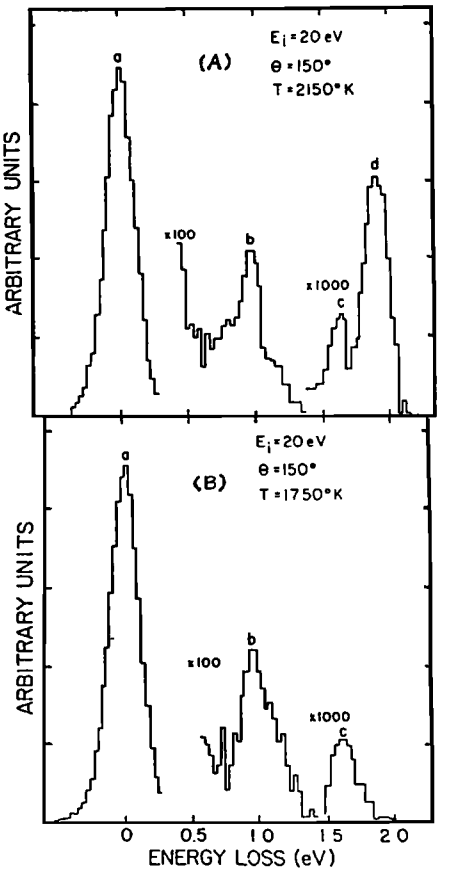

Fig. 3. (a) Energy loss spectrum of atomic and molecular oxygen at $\Delta E_{1/2}$=150 meV when the oven temperature is 2150 K at 20 eV impact and 150 degrees scattering angle (b) when the oven temperature is 1750 K producing no measurable dissociation of molecular oxygen.

pressure was typically 2 when the background pressure was 2 x 10^{-5} torr. The corresponding atomic oxygen density at the interaction region was about 5 x $10^{10}/cm^3$ when FD = 7%.

The electron beam source consists of an electron gun, 127° energy selector, two electron lens systems and two beam deflectors. A current of 10^{-7} A has been used with an energy resolution of 150 meV in full width at half maximum (FWHM). The divergence angle of the electron beam is ±3 degrees at 10 eV beam energy and smaller for higher energies.

The detector system has two electrostatic energy analyzers in series, two electron lens systems and a channeltron electron multiplier. This double energy analyzer system improves the energy resolution and reduces the background counts by over a factor of 100 compared to the previous single analyzer system.

Figure 3a shows a typical electron energy loss spectrum taken at 150 degrees with 7% dissociation rate in the oxygen beam. The elastic peak is designated by a, b is the $a^1\Delta$ loss peak, c is the $b^1\Sigma$ loss peak and d is ^1D loss peak of atomic oxygen. Figure 3b shows the same measurement as Figure 3a except that the oven is at a lower temperature (1750 K) where no measurable dissociation could be detected. Clearly the ^1D loss of atomic oxygen is absent in Figure 3b.

It is apparent from Figure 3b that the ratio of the excitation cross sections of $a^1\Delta$ and $b^1\Sigma$ at

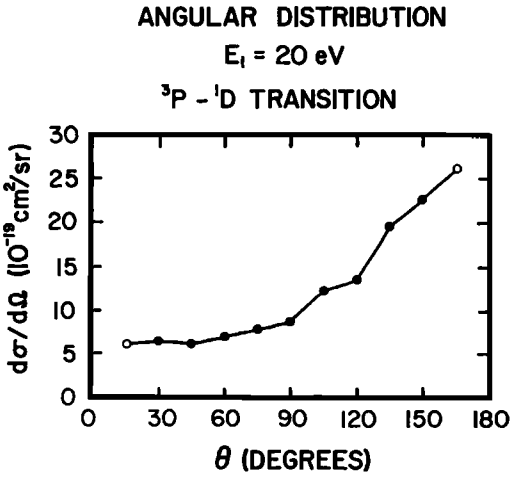

Fig. 4. Angular distribution of ^3P - ^1D transition of atomic oxygen at 20 eV impact. Open circles are extrapolation data points.

150 degrees is about 15. For a pure O_2 beam we found this ratio to be 12 and 2.5 for 150° and 90°, respectively. The 90° ratio compares favorably with the value of 3.0 from Wakiya (1978) and 2.5 from Trajmar et al. (1971) indicating there is no energy loss dependent transmission factor for our detector system. In fact, the angular distributions of $a^1\Delta$, $b^1\Sigma$ and $B^3\Sigma$ of molecular oxygen measured agree with those of Wakiya's measurements up to 110 degrees in shape as well as magnitude but the different states have markedly different angular distributions. This will be the subject of a separate report.

Experimental Result

The final results for the angular distribution have been obtained after averaging five loss spectra for each angle and normalizing the count rate at 90 degrees to the excitation cross section of the $b^1\Sigma$ state of molecular oxygen at 90 degrees (1.2×10^{-19} cm²/sr) measured by Shyn and Sharp (1984). This value is within 10% of that measured by Wakiya (1978) and Trajmar et al. (1971). It is assumed that in this normalization process the cross section of $b^1\Sigma$ at 2150 K is the same as that at room temperature. Figure 4 shows the angular distribution of the excitation cross section for the (^3P - ^1D) transition of atomic oxygen. There is strong backward scattering with a nearly isotropic scattering at angles less than 60 degrees. This is a characteristic of a forbidden transition involving spin exchange. The estimated uncertainty in the present results are 20% in the measurement of dissociation rate, 30% in the counting statistics, and 30% in the cross section of the $b^1\Sigma$ state at 90 degrees. The overall uncertainty of the present results, therefore, is 50%.

The total cross section is obtained by integrating the differential cross section over the solid angle after extrapolation of two extreme angles (a linear extrapolation to 15 and 165 degrees) and using $\int d\sigma/d\Omega\, d\Omega$, where $d\sigma/d\Omega$ is the differential cross section and $d\Omega$ is a solid angle. The total cross section is less sensitive to the extrapolation (few percent) because the sine factor in the solid angle weights the angles between 30 and 150 degrees most strongly. The result for the total excitation cross section for the ^1D level of atomic oxygen at 20 eV impact is $(1.5 \pm 0.7) \times 10^{17}$ cm².

The theoretical calculation of the differential cross section by Thomas and Nesbet (1975) indicates enhanced backward scattering as the incident energy increases. These energies happen to be lower than that used here; however, we would expect the trend to continue. The calculation of the total excitation cross section by Henry et al. (1969) indicates a value of 1.7×10^{-17} cm² at 20 eV. This agrees with our result within the accuracy of the measurement. Thus, direct confirmation of the theoretical total excitation cross section of this state has been made for the first time. Calculations of the angular distribution of this state at several energies including 20 eV would be desirable for purposes of comparison.

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