Angular distribution of electrons elastically scattered from ozone

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We have measured differential elastic-scattering cross sections of ozone by electron impact. A crossed-beam method was used. The energy and angular range measured were from 3.0 to 20 eV and from 12° to 156°, respectively. Strong forward and backward scattering was observed as the incident energy increased. Integrated and momentum-transfer cross sections have been obtained from the differential cross sections. The integrated cross sections over this energy range were found to be almost constant in magnitude.

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I. INTRODUCTION

Ozone is one of the most important gases in the earth's atmosphere and is probably the substance most commonly associated with atmospheric chemistry. Ozone's presence in the upper atmosphere is essential to all life, as it screens out deadly ultraviolet radiation. In the troposphere, however, ozone is a pollutant; it is not only toxic to both plants and animals, but is also corrosive to most materials. To understand how ozone interacts chemically and physically in these systems we must first have a sound understanding of the properties of the ozone molecule itself.

Information on the scattering of electrons by ozone is particularly important to those who study the upper atmosphere. Electronic quenching and energy transfer involving ozone electronic states in the upper atmosphere can increase the excited-state populations of ozone itself and other atmospheric species and thereby perturb local thermodynamic equilibrium. These effects appear as increased emission from infrared-active gases, affecting radiative cooling and the temperature structure of the atmosphere. While substantial research has been done on the chemical reactions, energy-transfer processes, and spectroscopy of ozone [1–3], no experimental work has yet been done on the elastic scattering of electrons by ozone molecules.

This paper presents the results of measurements of the absolute differential elastic cross sections of ozone by electron impact. A crossed-beam method was used. The energy and angular range measured were from 3 to 20 eV and from 12° to 156°, respectively. We have also obtained integrated and momentum-transfer cross sections. Interestingly, the integrated cross sections are relatively large, with an essentially constant magnitude of about 10^{-15} cm^2 over the energy range we investigated.

II. APPARATUS AND PROCEDURE

The apparatus used for the present measurements is the same as for the measurements of CH_4 [4], H_2O [5], and O_2 [6]. Briefly, the apparatus consists of an upper and a lower chamber. The two chambers are pumped differentially to maintain a low background pressure for the measurements in the lower chamber. The apparatus consists of three subsystems: the ozone source, a rotatable electron-beam source, and a fixed electron detector system on the vacuum chamber wall.

A. Ozone source

The ozone source is located in the upper chamber. Ozone is produced by an ozonizer (a discharge tube) overnight (15 h) and collected in silica gel maintained at dry-ice temperature. Teflon tubing was used for transporting ozone to the interaction region from the silica-gel bottle in order to minimize recombination and dissociation on the wall of tubing. The concentration of ozone at the interaction region is estimated to be nearly 100%. The collimated ozone beam from the silica-gel bottle enters the lower chamber through a double skimmer located between the two chambers.

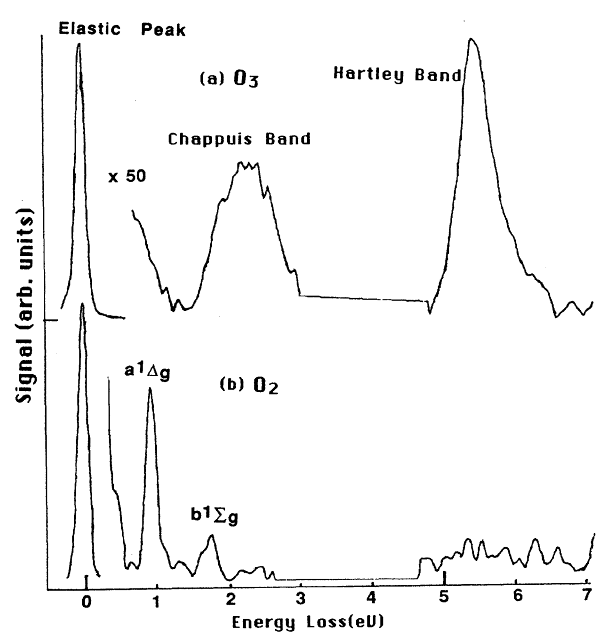

FIG. 1. (a) Energy-loss spectrum of ozone at 10 eV and scattering angle 72°. (b) Energy-loss spectrum of O_2 at 10 eV and scattering angle 72°.

TABLE I. Absolute differential elastic cross sections of ozone by electron impact. Also listed are the integrated and momentum-transfer cross sections. Numbers in parentheses are extrapolated data points.

E (eV) \ ϕ (°)	$d\sigma/d\Omega$ (10^{-17} cm^2/sr) 12	24	36	48	60	72	84	96	108	120	132	144	156	168	σ_i (10^{-16} cm^2)	σ_{MT} (10^{-16} cm^2)
3.0	(21)	14.8	13	12	13	13.5	13.8	11.5	10.2	9.3	8.7	9.5	10	(11)	14.8	13.4
5.0	29	21	18	18.2	15.5	13.4	10	8.4	7.7	7.0	7.7	8.5	9.2	(10.5)	14.9	11.8
7.0	36	25.6	21.9	18.4	14.7	10.9	7.5	6.1	5.6	6.1	6.7	7.5	(9.0)	(11)	14.1	10.2
10	39	29	24	17	12.6	9.2	7.2	6.3	6.3	6.4	7.3	8.9	(11)	(13)	14.4	10.7
15	56	36	21.3	14.4	9.9	6.9	5.8	5.0	4.7	5.9	7.9	10.7	14	(20)	14.1	10.6
20	62	34	13.6	7.9	6.3	5.1	4.6	4.1	4.3	5.6	8.8	15.4	21	(30)	13.0	11.6

B. Electron beam

The electron-beam source, which is rotatable from −90° to 160° continuously, consists of an electron gun, a 127° electrostatic energy selector, two electron-lens systems, and two beam deflectors. The electron-beam source can produce a current exceeding 10^{-8} A at energies above 10 eV with 80 meV full width at half maximum (FWHM). The half angle spread of the electron beam is less than ±3°.

C. Detector system

The detector system consists of two electron-lens systems, two electrostatic energy analyzers in series, and a channeltron electron multiplier. The energy resolution of the detector system is better than 80 meV FWHM.

Figure 1(a) shows an energy-loss spectrum of ozone at 7-eV impact energy and scattering angle of 60°. The elastic peak is located on the left-hand side. There are two energy-loss regions near 1.7 and 5 eV (the Chappuis and Hartley bands). Figure 1(b) is the same as Fig. 1(a) except for a pure molecular oxygen beam. Clearly, it is demonstrated that the beam was nearly pure O_3 because there is no trace of the $a\,^1\Delta_g$ state of molecular oxygen in Fig. 1(a). The concentration of O_2 in the O_3 beam is estimated to be less than a few percent.

The incident electron beam of given energy in the horizontal plane intersects with the vertically collimated ozone beam in the interaction region. The elastically scattered electrons from the beam at a given angle are detected by the channeltron electron multiplier after energy analysis. This procedure is repeated for different angles and incident energies. It should be noted that before the final data were taken, the angular distributions of electrons elastically scattered from helium and molecular oxygen for each incident energy were measured carefully and confirmed with previous measurements in order to eliminate all systematic errors, including stray magnetic-field effects and interaction volume effects.

The relative angular distributions measured at each energy were put on an absolute scale by normalization with the elastic differential cross section of He reported by Shyn [7] utilizing a volume experiment (static gas background). The relative densities of the two gases (He and O_3) were determined by measuring the corresponding pressures with an ion gauge, which was calibrated against an mks Baratron pressure gauge.

Three sets of helmholtz coils reduce stray magnetic fields down to less than 20 mG in all directions near the interaction region. The absolute energy scale has been established by an He resonance dip at 19.3 eV.

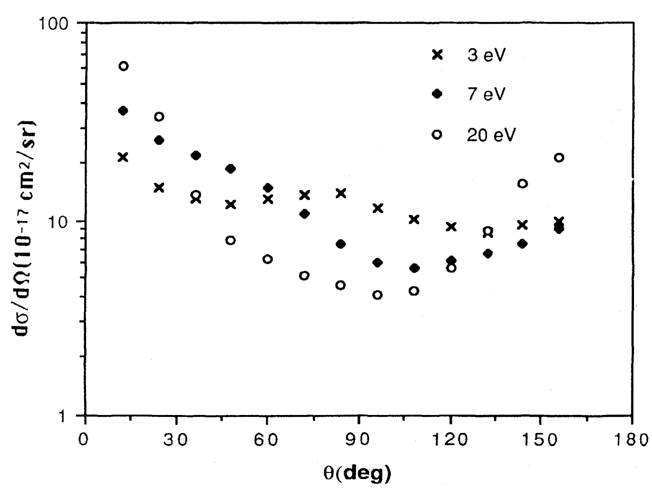

FIG. 2. Angular distributions of elastic cross sections at 3-, 7- and 20-eV impact.

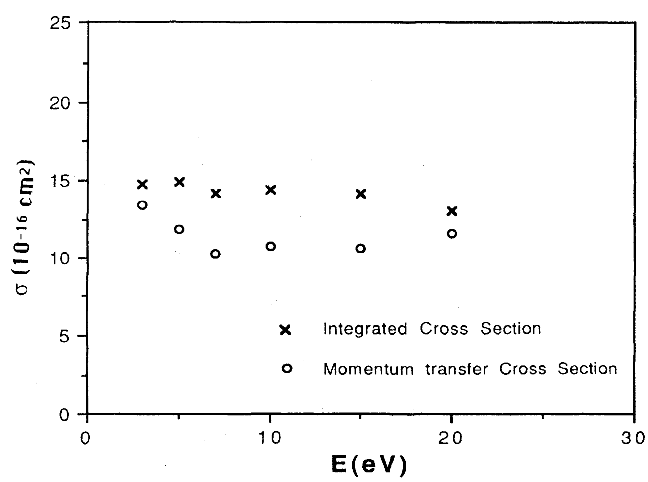

FIG. 3. Integrated and momentum-transfer cross sections of ozone.

III. EXPERIMENTAL RESULTS

We have measured the absolute elastic differential cross section of ozone by electron impact. The incident energies used were 3.0, 5.0, 7.0, 10, 15, and 20 eV and angular range was from 12° to 156°. The final results are shown in Table I.

The statistical uncertainty of the measurements was 3% and the uncertainty of normalization to He cross sections was 10%. Overall uncertainty of the present results is 15% including the uncertainty of the He cross sections (10%).

Figure 2 shows the angular distributions at 3-, 7- and 20-eV impact. There are two local minima near 40° and 120° for 3-eV impact and a slight bump near 40° for 7-eV impact energy. The forward- and backward-scattering cross sections become larger and the cross sections near 90° become smaller as the incident energy increases.

Figure 3 shows the integrated and momentum-transfer cross sections. It is found that the integrated cross sections have almost the same values over the measured energy range and are on the order of 10^{-15} cm^2, which is very large compared to those of other atoms and molecules. Momentum-transfer cross sections have a minimum near 7 eV and the same order of magnitude as the integrated cross sections.

ACKNOWLEDGMENT

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