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Differential elastic electron scattering cross sections for SO_2

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Abstract. Differential cross sections for elastic electron scattering by SO_2 were measured by utilising a modulated, crossed-beam method and calibration against He. The energy and angular ranges were from 5 to 50 eV and from 12 to 156°, respectively. The present results are compared with earlier data of Orient *et al* and it is suggested that their cross section values should be increased by about a factor of two.

1. Introduction

Observations made by the Voyager spacecraft indicated the importance of electron–SO_2 collision processes in the Jupiter–Io environment (Pearl *et al* 1979, Kumar 1979). Elastic cross sections are needed to normalise the cross sections for inelastic processes as well as to obtain momentum transfer cross sections.

Orient *et al* (1982) measured elastic differential scattering cross sections (DCS) for SO_2 at impact energies (E_0) of 12, 20, 50, 100 and 200 eV at scattering angles (Θ) ranging from 15 to 150°. They also obtained integral elastic and momentum transfer cross sections by extrapolation and integration of the measured DCS data. These cross sections include rotational excitation and should be called vibrationally elastic cross sections. The fundamental vibrational mode excitations (at 0.064, 0.143 and 0.169 eV) were not fully resolved either but their contribution to the measured elastic signal is negligible at impact energies above about 5 eV. Hayashi (1987) recommended momentum transfer cross sections in the 0.3 to 1000 eV region using available swarm and beam data and performing a consistency check on transport coefficients based on the Boltzmann equation in a Monte Carlo simulation method. Total electron scattering cross sections have been reported by Sokolov and Sokoleva (1981), Zubek *et al* (1981) and Szmitkowski and Maciag (1986). These cross sections can serve as upper limits for integral elastic scattering cross sections.

In the present article, we report vibrationally elastic DCS measured at 5, 10, 12, 15, 20, 30 and 50 eV impact energies in the 12 to 156° angular region and the corresponding integral and momentum transfer cross sections obtained by extrapolation and integration of the DCS data.

2. Apparatus and procedure

The schematic diagram of the apparatus used for the measurements is shown in figure 1. A detailed description of the apparatus can be found elsewhere (Shyn and Sharp 1986). Briefly, the apparatus consists of an upper and a lower chamber. The two

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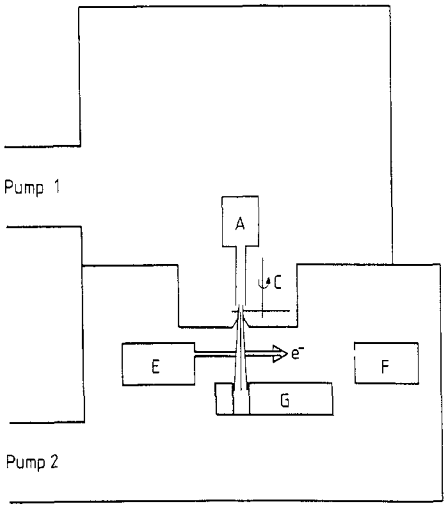

Figure 1. Schematic diagram of the apparatus. A: SO_2 beam source; C: chopper wheel; E: electron beam source; F: electron detector; G: mass spectrometer.

chambers are pumped differentially to maintain a low background pressure (10^{-6} Torr) for the measurements in the lower chamber. Three sets of Helmholtz coils reduce stray magnetic fields down to less than 20 mG in all directions near the interaction region. The apparatus consists of three subsystems: the SO_2 beam source, a rotatable electron beam source and a fixed electron detector system.

The target gas source is located in the upper chamber. SO_2 gas effuses from a 0.3 cm diameter hole and is collimated by two 0.2 cm diameter skimmers which are placed between the two chambers. The beam is modulated with a chopper wheel (located between the effusive hole and the skimmers) at an audio frequency ($\simeq 150$ Hz).

The electron beam source can be continuously rotated from $-90°$ to $+160°$. It 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 a full width of half maximum (FWHM) of about 60 meV. The electron beam diameter in the interaction region is about 0.1 cm and its divergence is about $\pm 3°$.

The detector system is fixed on the lower vacuum chamber wall. It consists of two electron lens systems, two electrostatic energy analysers in series and a channeltron electron multiplier. The energy resolution of the detector system is adjusted to about 80 meV at FWHM. The solid angle of detection was about 10^{-3} s and it was identical for the two gases.

The incident (horizontal) electron beam of a given energy intersects the collimated and modulated (vertical) neutral beam. The electrons scattered elastically in the interaction region are detected at a given angle. The scattering signals with the chopper open and closed are recorded by two counters and integrated over the elastic peak. The difference of these two signals gives the scattering signal from the pure beam. This procedure is repeated for different angles at each incident energy to obtain the angular distributions. The impact energy scale is calibrated against the 19.3 eV resonance in He and the true scattering angle is determined from the symmetry of the elastic scattering around the nominal zero angle.

The measured angular distributions at each incident energy were put on absolute scale by normalisation to the elastic DCS of He which were reported by Register *et al* (1980). For this purpose the vacuum chamber was filled with SO_2 and then with He and the corresponding elastic scattering signals were measured at 60, 96 and 120° angles to yield an average normalisation factor. The relative density of the two gases was determined by measuring the corresponding pressures with an ion gauge, which was calibrated against an MKS Baratron pressure gauge.

The statistical uncertainty of each data point is 3%, the uncertainty in the normalisation procedure is estimated to be about 10% and the uncertainty in the He DCS were reported to be 5%. The overall uncertainty of the present results is, therefore, about 12%. The integral and momentum transfer cross sections are estimated to be accurate to about 15%.

3. Results and discussion

The normalised DCS are summarised in table 1 and are compared with other available data in figures 2–4. These cross sections show the general behaviour found for other molecular species: forward peaking character with a minimum at around 90° and then a lesser degree of backward peaking. The forward peaking character is enhanced as the impact energy is increased. The DCS data of Orient *et al* (1982) show, in general, the same angular behaviour but are lower in absolute value by about a factor of two (except at 50 eV impact energy in the 30° and 50° range, where the two measurements agree for unknown reasons). This discrepancy is attributable to the normalisation of the relative measurements. Although both works utilised He elastic DCS as standard, Orient *et al* (1982) relied on the relative flow technique (Srivastava *et al* 1975) without consideration of the mean-free-path requirement. The measurement of very small flow rate, required in these investigations, was subject to rather large uncertainties. Further errors could have been introduced into the relative-flow technique if the equal mean-free-path requirement for the two gases was not satisfied. These questions are discussed by Nickel *et al* (1989) and in references in that article. The present method relied on scattering by a static target represented by the gas in the whole chamber and an accurate pressure measurement. We believe that the latter method is more reliable. A renormalisation of the 100 and 200 eV elastic DCS obtained by Orient *et al* (1982) would, therefore, also seem to be appropriate.

The integral (Q) and momentum transfer (Q_M) cross sections were obtained by extrapolation of the DCS to 0° and to 180° and integration with the proper weighing

Table 1. Elastic scattering cross sections for SO_2. Numbers in parentheses are extrapolated data points.

	$d\sigma/d\Omega$ (10^{-18} cm^2 sr^{-1})															
θ (deg) = E (eV)	12	24	36	48	60	72	84	96	108	120	132	144	156	168	Q (10^{-16} cm^2)	Q_M (10^{-16} cm^2)
5.0	792	587	375	270	179	123	92	80	95	110	150	169	180	(191)	23.5	17.2
10.0	1678	927	520	291	104	63	62	72	87	111	137	153	160	(177)	26.7	15.4
12.0	2331	1028	479	219	89	53	51	62	79	100	126	157	194	(223)	27.9	14.9
15	2185	1090	543	188	69	50	61	66	80	94	113	120	120	(123)	26.6	12.8
20	1810	778	328	104	48	34	42	48	58	67	89	116	142	(150)	19.8	10.5
30	1391	433	136	46	27	27	26	29	30	39	48	58	71	(92)	12.2	5.7
50	1002	233	71	35	20	20	19	22	22	25	43	62	70	(85)	8.7	4.7

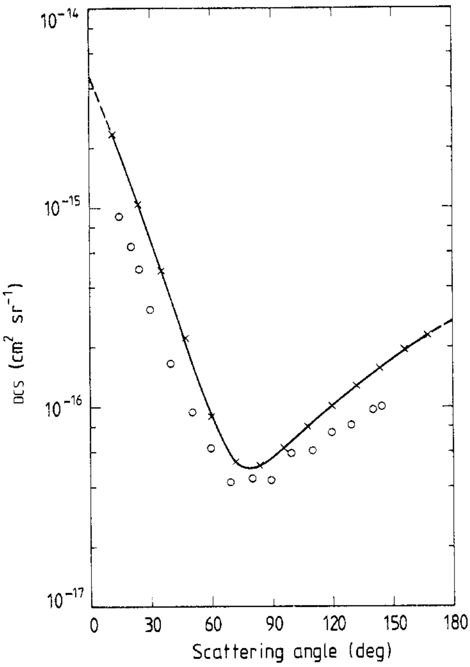

Figure 2. Elastic DCS at $E_0 = 12$ eV: ×, present results; ○, Orient *et al* (1982).

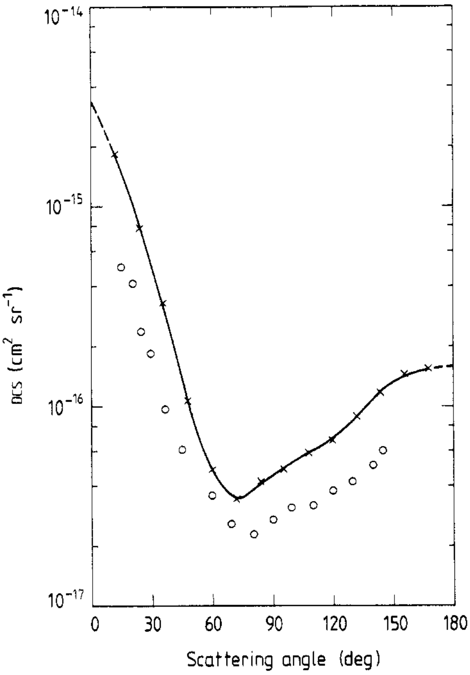

Figure 3. Same as figure 2 except for $E_0 = 20$ eV.

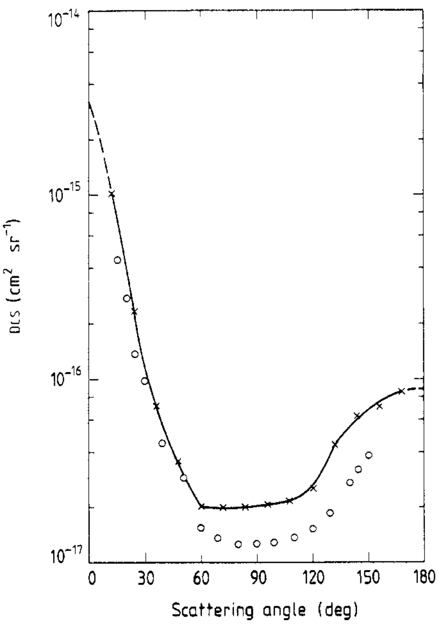

Figure 4. Same as figure 2 except for $E_0 = 50$ eV.

factors. There is some arbitrariness in these extrapolations but their effects are small and have been incorporated in the error estimation. The results are also given in table 1 and are compared with other pertinent data in figure 5. In comparing the present results with those of Orient *et al* (1982), the same remarks apply as to the DCS. The momentum transfer cross sections recommended by Hayashi (1987) are in reasonably good agreement with the present results.

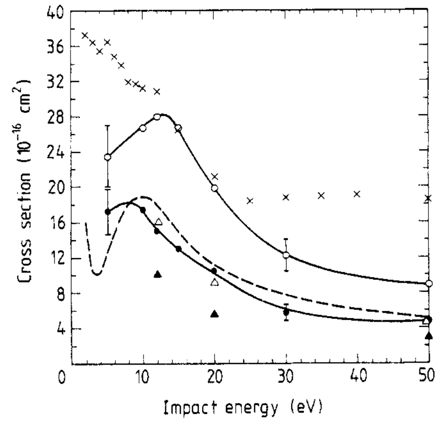

Figure 5. Integral elastic scattering cross sections: ○, present results; △, Orient *et al* (1982). Momentum transfer cross sections: ●, present results; ▲, Orient *et al* (1982), ---, Hayashi (1987). Total electron scattering cross sections: ×, Szmitkowski and Maciag (1986).

In figure 5, the total electron scattering cross sections (Q_T) measured by Szmitkowski and Maciag (1986) are also shown. The corresponding results of Zubek *et al* (1981) (in the 1.5–7.0 eV region) show the same energy dependence shapewise but are about a factor of two higher. The results of Sokolov and Sokoleva (1981) (in the 1.5–10 eV range) show unreasonable magnitudes and energy dependence.

The present integral scattering cross sections and the total electron scattering cross sections measured by Szmitkowski and Maciag (1986), which represent an upper limit to the integral cross sections, show a general consensus. At impact energies below about 10 eV there are significant contributions to Q_T from vibrational (rotational) excitation and from attachment processes. At impact energies above about 20 eV, cross sections for electronic state excitations and ionisation are significant. In the 10–20 eV region, elastic scattering dominates over all other processes and approximately represents the total cross section.

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