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Angular distribution of electrons elastically scattered from water vapor

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The angular distributions of electrons elastically scattered from H_2O have been measured by electron impact using a modulated crossed-beam method. The energy and angular range measured were from 30 to 200 eV and 12° to 156°, respectively. The present results show a high backward scattering for low incident energies, but this falls off for high incident energies. The present results are in qualitative agreement with the measurements of Danjo and Nishimura [J. Phys. Soc. Jpn. **54**, 1224 (1985)] and in quantitative agreement with the measurements of Katase *et al.* [J. Phys. B **19**, 2715 (1986)]. Agreement between the present results and the calculation of Jain, Tripathi, and Jain [Phys. Rev. A **37**, 2893 (1988)] is good except at 200-eV impact.

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I. INTRODUCTION

Water vapor is now known to be the major constituent of cometary atmospheres. Ice has been observed on the surfaces of the Galilean satellites of Jupiter. Water is also a significant contaminant in the space-shuttle environment. The elastic differential cross sections (DCS's) of water are one of the essential parameters to understand the cometary atmosphere and atmospheres of other planets including our planet Earth.

Brüche [1] measured total cross sections over the energy range of 3–100 eV and Danjo and Nishimura [2] reported elastic DCS's for water at electron impact energies ranging from 4 to 200 eV and angles ranging from 10° to 120°. Katase *et al.* [3] also measured elastic DCS's for impact energies ranging from 100 to 1000 eV and angles from 5° to 130°. Shyn and Cho [4] have measured elastic DCS's for impact energies from 2.2 to 20 eV and angles from 15° to 150°.

On the theoretical side, Fujita, Ogura, and Watanabe [5] calculated the elastic DCS's for impact energies greater than 50 eV, using the Glauber eikonal approximation. Jain, Tripathi, and Jain [6] computed elastic differential, integral, and momentum-transfer cross sections for impact energies of 100–1000 eV using a near-Hartree-Fock one-center expansion method.

In general, agreement between the measurements and theoretical predictions is unsatisfactory. It is therefore desirable to measure DCS's for an extended energy range to higher energy than the previous measurement [4].

This paper presents experimental results from which the DCS's of electrons vibrationally elastically scattered from H_2O have been measured. A modulated crossed-beam method was used. The energy range was from 30 to 200 eV and the angular range was from 12° to 156°. The present results have been normalized among themselves and placed on an absolute scale using the experimental values of He cross sections determined by Shyn [7] and by Register, Trajmar, and Srivastava [8].

II. APPARATUS AND PROCEDURE

Detailed descriptions of the apparatus can be found elsewhere [4,7]. Briefly, differentially pumped upper and lower chambers contain the apparatus. A neutral water-vapor beam source is in the upper chamber. The vertically collimated water vapor beam is modulated by a chopper at audio frequency (≈ 100 Hz). Since the time constant of the present vacuum system for water vapor is estimated to be longer than 0.2 s, the background pressure is believed to be a negligible contribution to the beam signal. The modulated beam enters the lower chamber through a double skimmer. A monoenergetic electron beam source and an electron detector system (in a horizontal plane) are located in the lower chamber.

The electron beam source consists of an electron gun, a 127° electrostatic energy selector, two electron lenses, and horizontal and vertical deflectors. The source is continuously rotatable from −90° to +160°. The detector system consists of double analyzer in series (127° electrostatic energy analyzer and hemispherical electrostatic energy analyzer), a Channeltron electron multiplier, and two electron lenses. The position of the analyzer is fixed on the vacuum wall. The energy resolution of the detector system is better than 80 meV. With this energy resolution, the vibrational excitations can be resolved, however, the rotational excitations cannot be resolved. The divergence angle of the electron beam is ±3°. Three sets of Helmholtz coils reduce stray magnetic fields to less than 20 mG in all directions near the interaction region.

In the interaction region, electrons of a given incident energy in the horizontal plane are scattered off the vertical, modulated neutral water-vapor beam. The scattered electrons at a given angle and at the incident energy are detected after energy analysis.

For the normalization procedure, absolute pressure measurements in a volume experiment were made using an MKS Baratron pressure gauge to determine the density of neutral water vapor in the interaction region. This was also done for He so that the relative water cross sections could be normalized to the known absolute He cross sections.

III. EXPERIMENTAL RESULTS

Differential elastic cross-section measurements were made at energies of 30, 40, 60, 100, and 200 eV at angles ranging from 12° to 156° in 12° increments. The results of DCS, integrated elastic cross section, and momentum-transfer cross-section measurements are shown in Table I.

The statistical uncertainty in this experiment is ±4.5%. The quoted uncertainty in the He elastic DCS's used for normalization is ±10% for 30-, 100-, and 200-eV incident energy and ±6% for 40- and 60-eV incident energy. This gives an overall uncertainty of ±11% for the 30-, 100-, and 200-, eV results and ±7.5% for the 40- and 60-eV results.

Figure 1 shows the DCS at 30-eV impact along with

TABLE I. Differential cross sections of water (in units of 10^{-18} cm^2/sr). Numbers in parentheses are extrapolated data points. Integrated and momentum-transfer (MT) cross sections are in units of 10^{-16} cm^2/sr.

θ (deg) \ E (eV)	30	40	60	100	200
12	1340	1110	1370	664	456
24	449	485	407	277	94.0
36	189	161	122	47.2	22.8
48	78.2	68.3	46.3	18.6	9.52
60	41.6	34.7	21.5	9.89	4.52
72	22.6	20.4	11.6	4.64	2.52
84	17.2	12.8	7.62	2.65	1.82
96	13.3	10.4	5.18	2.43	1.82
108	12.8	9.53	5.54	3.89	2.37
120	18.9	17.2	11.2	6.98	2.50
132	30.9	31.5	20.6	11.0	3.12
144	51.9	56.0	41.7	17.2	3.16
156	50.8	70.1	47.8	17.0	2.92
168	(60.0)	(90.0)	(50.0)	(19.0)	(2.80)
Integ.	1100	1020	899	459	229
MT	425	438	295	134	45.2

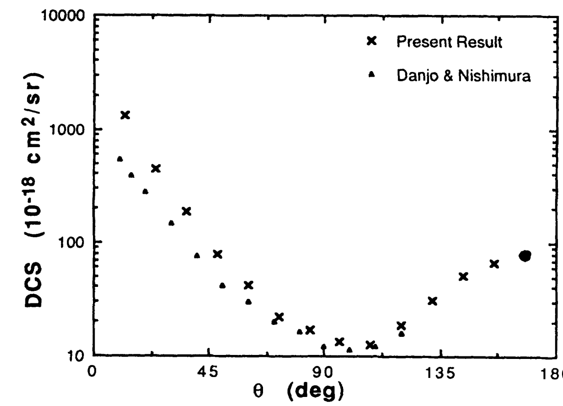

FIG. 1. Angular distribution of elastic cross sections of water vapor at 30-eV impact energy along with the results of Danjo and Nishimura. The dot is an extrapolated data point.

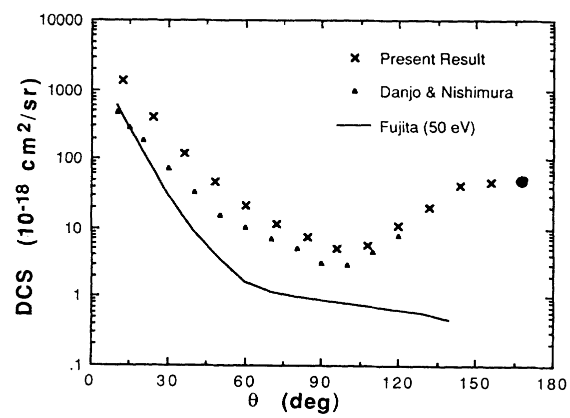

FIG. 2. Same as Fig. 2 except at 60-eV impact energy. Theoretical results of Fujita, Ogura, and Watanabe are also included.

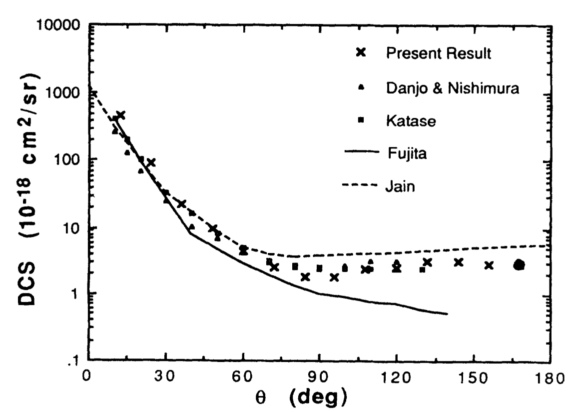

FIG. 3. Same as Fig. 2 except at 200-eV impact energy. Additionally, measurements of Katase *et al.* and theoretical results of Jain, Tripathi, and Jain are included.

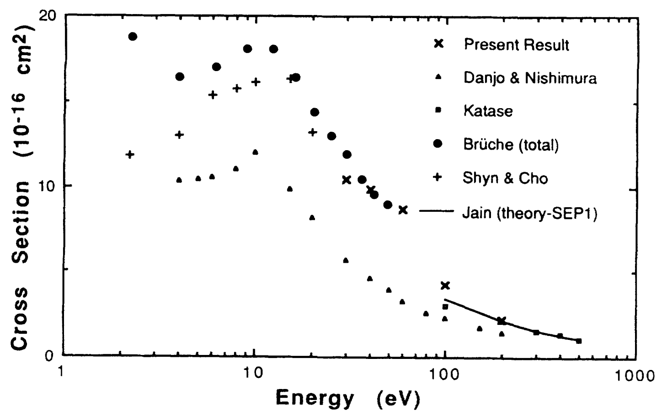

FIG. 4. Integrated cross sections of water vapor along with those of Danjo and Nishimura, Katase *et al.*, total cross sections of Brüche, and theoretical results of Jain, Tripathi, and Jain. Also the previous results of Shyn and Cho are included for comparison.

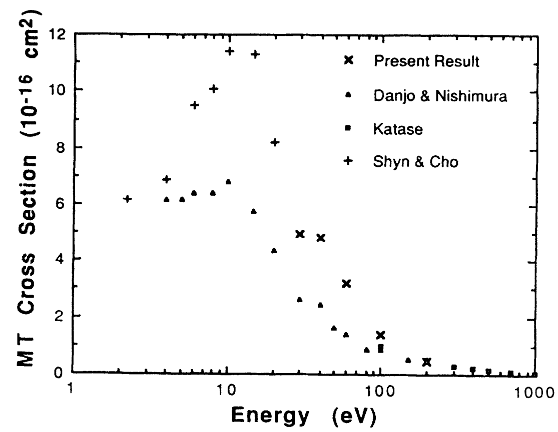

FIG. 5. Momentum-transfer cross sections of water vapor along with those of Danjo and Nishimura and those of Katase *et al.*

the results of Danjo and Nishimura (DN). The present results indicate larger cross sections in the forward angles than those of DN. Relatively good agreement exists between the measurements near 90°.

Figure 2 is the same as Fig. 1 except for the 60-eV impact. Theoretical results by Fujita, Ogura, and Watanbe at 50-eV impact are also included. It should be noted that the present results lie consistently above those of DN. They normalized relative cross sections against He gas by a relative flow method and there may be some difficulty in the normalization process. The theoretical results of the eikonal Glauber calculation by Fujita, Ogura, and Watanabe do not agree with the present results at all angles. This theory may not be suitable for the intermediate energy range.

Figure 3 shows the DCS at 200 eV along with those of DN and of Katase *et al.* The theoretical results of Fujita, Ogura, and Watanabe and Jain, Tripathi, and Jain are also included. Agreement among the measurements and the results of the near-Hartree-Fock one-center calculation by Jain, Tripathi, and Jain is relatively good. It should be noted, however, that above 60° their result flattens out in a manner similar to the measured values but lies consistently above them. The theoretical results of Fujita, Ogura, and Watanabe are in agreement with the present results at angles below 30°. Above 30°, the results of Fujita, Ogura, and Watanabe consistently lie below the present results. As Fujita, Ogura, and Watanabe pointed out, this is because the Glauber approximation is good for small angles and their calculation neglected exchange effects, which influence the results at high angles. Good agreement with the results of Katase *et al.* exists at all energies and angles.

The total cross section for a given incident energy was determined by integrating over solid angle after an exponential extrapolation to 168°. The present results, including the previous measurement [4] by Shyn and Cho for 2.2–20-eV impact, are shown in Fig. 4 with a comparison to the results of DN, Katase *et al.*, the total cross-section measurements of Brüche, and the SEP1 calculation of Jain, Tripathi, and Jain, where the SEP1 potential is the static potential plus the modified semiclassical exchange potential plus the correlation-polarization potentials. The measurements of Katase *et al.*, those of DN, and theoretical results of Jain, Tripathi, and Jain agree with the present results above 100-eV impact. However, agreement does not exist between the present results and the measurements of DN below 100 eV. This probably reflects the disagreement in DCS at low angles and underestimated cross sections at large angles in their extrapolation process for obtaining the integrated cross sections. The present results lie lower than the total cross-section measurements of Brüche, since Brüche's measurements include vibrational excitation cross sections.

Finally, the momentum-transfer cross sections are also determined from the present results and are shown in Fig. 5 along with those of the previous results of Shyn and Cho, and those of DN. The present results lie consistently above those of DN. Since momentum cross sections are sensitive to backward scattering, this discrepancy may reflect an inaccurate extrapolation to 180° by DN.

ACKNOWLEDGMENT

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