Charge transfer of 0.5-, 1.5-, and 5-keV protons with H_2O: Absolute differential and integral cross sections

B. G. Lindsay, D. R. Sieglaff, K. A. Smith, and R. F. Stebbings
Department of Space Physics and Astronomy, Department of Physics, and Rice Quantum Institute, Rice University, 6100 Main Street, Houston, Texas 77005-1892
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We report measurements of the absolute differential cross sections for charge-transfer scattering of 0.5-, 1.5-, and 5-keV protons by H_2O at laboratory scattering angles between 0.01° and 2.6°. Absolute integral cross sections are also reported and compared to the published total cross sections. [S1050-2947(97)06305-1]

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Charge-transfer collisions between protons and H_2O take place in many environments. As well as being important in the study of planetary atmospheres, including our own, this process can also be the cause of potential artifacts in laboratory experiments where water vapor is often the most significant background constituent. The present measurements were undertaken in order to account for such an effect in an earlier study in this laboratory [1], because the available literature values for the total cross section differed from one another by more than an order of magnitude and there were no data available on the differential cross sections.

The apparatus and experimental procedure used for this study have been described in detail in a previous publication [1], and will only be discussed briefly here. Ions are extracted from a low-pressure plasma-type ion source containing hydrogen, accelerated to the desired energy, and focused by an electrostatic lens. The proton beam is then mass selected by a pair of 60° sector magnets and passes through a collimating aperture before traversing the target cell. A position-sensitive detector (PSD) on the beam axis 26 cm beyond the target cell is used to monitor both the primary ion beam and the fast neutral collision products. The pressure in the target cell is chosen to ensure single-collision conditions. The relatively short target cell length, approximately 1 mm, ensures that the collisions occur within a very well-defined location, and as the PSD records the position of each incident neutral particle the scattering angle is easily obtained. The number density of the target gas is obtained from a measurement of the target gas pressure (approximately 10 mtorr) using a capacitance diaphragm gauge. The purity of the water vapor target was checked using a mass spectrometer that directly sampled gas effusing from the target cell.

The differential H^+-H_2O charge-transfer cross sections for 0.5, 1.5, and 5 keV are shown in Fig. 1 and tabulated in Table I. The vertical error bars in the figure represent the statistical uncertainty only. The horizontal error bars are primarily an indication of the angular resolution of the measurement [1]. As has been observed for other near-resonant processes, the differential cross sections are strongly forward peaked. As the impact energy is increased the cross section becomes even more forward peaked, as would be expected from simple momentum-transfer considerations.

From inspection of the differential cross sections shown in Fig. 1 it is apparent that only a small fraction of the scat-

TABLE I. Laboratory frame differential charge-transfer cross sections for H^+-H_2O collisions, where E is the projectile energy and the numbers in square brackets represent powers of ten.

Laboratory angle θ (deg)	$\frac{d\sigma(\theta)}{d\Omega}$ (Å^2 sr^{-1}) $E=500$ eV	$E=1.5$ keV	$E=5$ keV
0.012	5.26 [5]	1.37 [6]	3.14 [6]
0.036	5.42 [5]	1.34 [6]	2.25 [6]
0.059	5.07 [5]	1.01 [6]	1.02 [6]
0.083	4.16 [5]	5.63 [5]	3.29 [5]
0.107	2.98 [5]	2.92 [5]	1.40 [5]
0.130	1.92 [5]	1.99 [5]	7.60 [4]
0.154	1.33 [5]	1.53 [5]	4.24 [4]
0.178	1.07 [5]	1.04 [5]	2.61 [4]
0.202	9.54 [4]	6.36 [4]	1.71 [4]
0.225	7.95 [4]	3.97 [4]	1.24 [4]
0.249	6.40 [4]	2.93 [4]	9.18 [3]
0.273	5.02 [4]	2.36 [4]	6.20 [3]
0.297	4.08 [4]	1.90 [4]	4.61 [3]
0.320	3.54 [4]	1.44 [4]	3.48 [3]
0.344	3.16 [4]	1.10 [4]	3.16 [3]
0.368	2.79 [4]	8.47 [3]	2.65 [3]
0.415	2.11 [4]	5.97 [3]	1.95 [3]
0.486	1.36 [4]	3.74 [3]	1.23 [3]
0.557	1.01 [4]	2.47 [3]	8.53 [2]
0.629	7.04 [3]	1.57 [3]	5.54 [2]
0.700	4.69 [3]	1.10 [3]	4.98 [2]
0.771	3.27 [3]	8.01 [2]	3.57 [2]
0.842	2.50 [3]	6.51 [2]	2.86 [2]
0.913	1.96 [3]	5.08 [2]	2.44 [2]
0.984	1.38 [3]	3.92 [2]	1.84 [2]
1.06	1.12 [3]	3.56 [2]	1.29 [2]
1.13	8.33 [2]	3.01 [2]	1.21 [2]
1.20	7.06 [2]	2.51 [2]	1.05 [2]
1.27	5.96 [2]	2.02 [2]	1.05 [2]
1.34	4.69 [2]	1.87 [2]	7.84 [1]
1.41	4.31 [2]	1.60 [2]	7.28 [1]
1.51	3.60 [2]	1.44 [2]	6.27 [1]
1.63	2.72 [2]	1.05 [2]	5.24 [1]
1.74	1.85 [2]	1.05 [2]	4.65 [1]
1.86	1.79 [2]	9.02 [1]	3.13 [1]
1.98	1.32 [2]	7.49 [1]	3.30 [1]
2.10	1.14 [2]	7.58 [1]	2.12 [1]
2.22	1.02 [2]	5.43 [1]	2.62 [1]
2.34	7.24 [1]	3.84 [1]	1.34 [1]
2.46	6.19 [1]	4.15 [1]	2.05 [1]
2.57	4.83 [1]	4.64 [1]	1.33 [1]

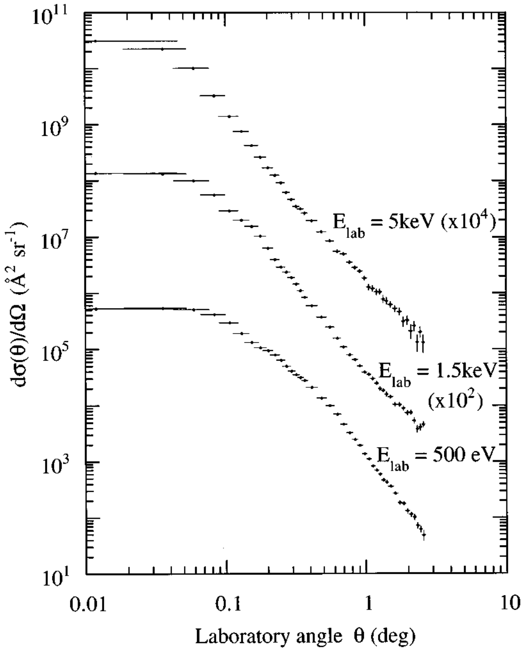

FIG. 1. Differential cross sections for charge-transfer scattering of H^+ by H_2O at projectile energies of 0.5, 1.5, and 5 keV. Note that, for clarity, the 1.5- and 5-keV data are shown on different scales.

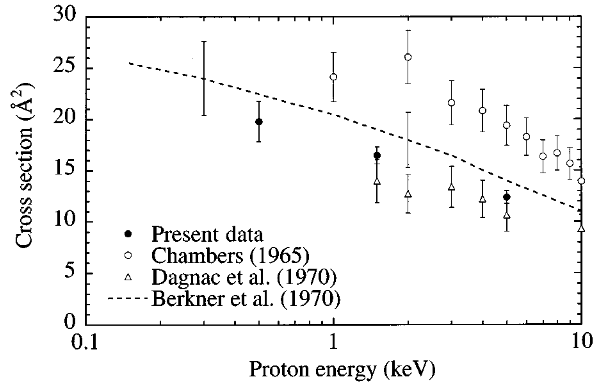

FIG. 2. Absolute H^+-H_2O integral charge-transfer cross sections.

tered ions, estimated to be less than 5%, fail to impact the PSD. In Fig. 2 we therefore compare our integral cross sections with previously measured total cross sections. While there have been several previous studies [2–6], the data are all relatively old, having been obtained in the late 1960s and early 1970s, and the equipment used for measuring the target pressure was generally much less accurate than is commonly available today. This effect may well account for much of the scatter in these measurements. The data of Coplan and Ogilvie [4], which are a factor of 3 higher than the data shown, but are in agreement with the present results to within their large uncertainty, have been omitted from the graph, as has the data of Koopman [3] which lies about an order of magnitude lower than those shown in the figure. Berkner, Pyle, and Stearns [6] actually measured the cross section for D^+, and their data are plotted at the equivalent proton energy, i.e., one half the deuteron energy. Both Dagnac, Blanc, and Molina [5] and Berkner, Pyle, and Stearns [6] are in good agreement with the results presented here, the data of Chambers [2] are somewhat higher, and again the most probable cause of this disagreement is the difficulty in accurately determining the target pressure.

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