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LETTER TO THE EDITOR

Total absolute cross sections for electron scattering on H_2O at intermediate energies

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Abstract. Absolute measurements of the total cross section for electron scattering on H_2O molecules are presented. The energy range extends from 81 to 3000 eV. A comparison with previous experimental data is given.

Collisions of electrons with water molecules play an important role in atmospheric and interstellar space processes. In spite of this there are relatively few theoretical and experimental data for electron-H_2O scattering. Total cross sections have been measured in the low-energy region by Brüche (1929) using the beam technique and by Sokolov and Sokolova (1981) in a microwave experiment. Sueoka *et al* (1986) have performed measurements of the total cross sections for electron- and positron-H_2O scattering at energies up to 400 eV with a time of flight spectrometer. However, there is a substantial disagreement among the published experimental data.

In the intermediate (>100 eV) energy range relatively more results have been published for elastic scattering. Differential cross sections for elastic scattering have been measured at 500 eV by Lassettre and White (1973), up to 200 eV by Danjo and Nishimura (1985) and recently up to 1000 eV by Katase *et al* (1986). The data of Katase *et al* are systematically higher than those of Danjo and Nishimura for angles up to 90°, but are in good agreement with the data of Lassettre and White. The integral cross section derived from the measurements of Katase *et al* are higher by 25% at 100 eV and by 50% at 200 eV than those of Danjo and Nishimura. The calculations of Fujita *et al* (1983) lend support to the experimental results of Danjo and Nishimura.

The present measurements have been performed on a Ramsauer-type apparatus designed for intermediate-energy electron scattering (Dalba *et al* 1981). The radius of the electron trajectory is 200 mm. The scattering chamber is divided in two parts with the use of an additional aperture, in order to improve the angular resolution. The first part contains gas; the length of the electron path in this region is 140.2 mm. The three apertures of the scattering chamber have dimensions (height × width): 2.3×2.5, 3.3×3.6 and $4.4 \times 3.4\ mm^2$. The resulting angular acceptance of the apparatus is 3.4×10^{-4} sr. Non-scattered electrons were collected by a Faraday cup. In the course of the experiment the currents I_c to the collector and I_s to the scattering chamber were measured at various pressures. The ratio of the currents I_c/I_s without gas in the scattering chamber varied from about 12 below 100 eV to about 20 above 150 eV. In

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principle, a low I_c/I_s ratio should not affect the measured value of the cross section. However, it is evidence of improper aperture dimensioning and/or misalignment, and/or beam instability. For this reason we did not perform measurements at energies lower than 80 eV, where the ratio I_c/I_s drops below 10. The energy resolution of the apparatus is constant and equal to 0.5 eV. The pressure in the scattering chamber was measured by an MKS Baratron capacitance meter (type 94A-H1); the head temperature was stabilised at 19 °C. The zero of the pressure was read twice—before and after a measurement run. The gas pressure readings were corrected assuming a linear zero drift in the time between the two zero readings. The gas chamber temperature varied from a minimum of 19 to a maximum of 24 °C. No correction for thermal transpiration was applied to the data. The ultimate pressure in the vacuum chamber was 2×10^{-6} Pa and the background pressure during measurements was about 5×10^{-4} Pa. The experiment was completely controlled by a microcomputer.

The total cross section σ was evaluated from the formula

$$I_{ci}/(I_{ci}+I_{si}) = I_{cj}/(I_{cj}+I_{sj})\exp[-\sigma l(N_i-N_j)]$$

where l is the gas chamber length, N is the gas density and the indices i and j label the values corresponding to two different pressures. The pairs of currents (I_c, I_s) were measured for several (usually seven) pressures. The value of the cross section in a run was computed from the slope of the beam attenuation against pressure. The highest pressures used were chosen to reach an attenuation of the I_c current of about 3, to keep the probability of multiple scattering low. Thus, the maximum pressure was different for different energies and dependent on the cross section. At 80 eV the pressure in the scattering chamber did not exceed 5 Pa and 50 Pa at 3000 eV. For a given energy this procedure has been repeated several (from four to ten) times. The final values given in table 1 and in figure 1 are the arithmetic averages of the measurements done at the same energy.

Table 1. Total absolute cross sections for electron-H_2O scattering (10^{-20} m^2). In parentheses are given standard deviations of the mean values (%).

Energy (eV)	Cross section	Energy (eV)	Cross section
81.3	8.08 (1.9)	676	1.91 (0.7)
90.5	7.55 (1.4)	782	1.75 (0.3)
100.3	7.18 (2.1)	900	1.55 (0.6)
110.5	6.67 (3.0)	1000	1.42 (0.3)
121.0	6.19 (3.0)	1024	1.38 (0.4)
132.0	6.11 (1.3)	1156	1.23 (0.6)
144.0	5.92 (0.8)	1296	1.18 (0.5)
169.3	5.36 (0.7)	1444	1.06 (0.7)
196.0	4.86 (0.8)	1500	0.999 (0.9)
225	4.44 (0.7)	1600	0.948 (0.3)
256	4.42 (0.8)	1760	0.865 (0.8)
289	3.78 (0.5)	2000	0.746 (0.8)
361	3.19 (0.2)	2116	0.721 (1.1)
400	2.97 (1.1)	2304	0.669 (1.3)
484	2.53 (0.6)	2500	0.599 (1.2)
500	2.48 (0.5)	2706	0.550 (1.3)
576	2.20 (0.9)	3000	0.490 (1.5)

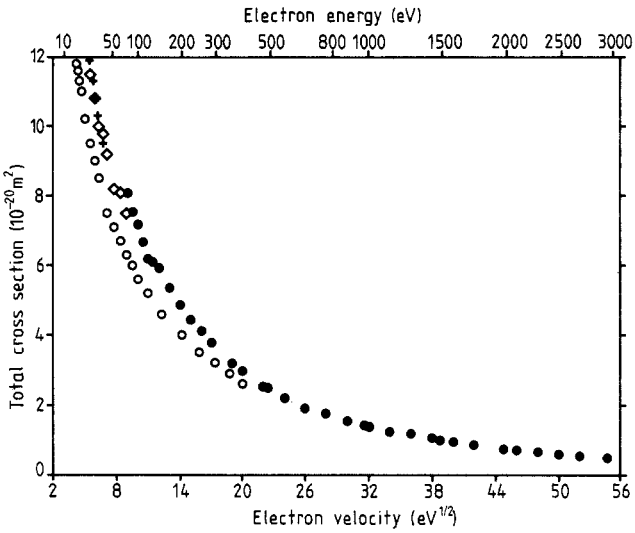

Figure 1. Total e^-–H_2O scattering cross section. Full circles, present measurements; open circles, Sueoka *et al* (1986); open diamonds, Szymytowski (1986); crosses, Brüche (1929).

The systematic error has been estimated to be 2.2% (quadratic sum of the components). 1% of this error is introduced by the non-linearity of the current measurements, 0.2% by the uncertainty of the scattering chamber length and 0.4% by the spread of the electron trajectories. The error in the energy scale was about 1% and this results in less than 1% uncertainty of the cross section. The measurement of the gas temperature, the thermal transpiration and the temperature compensation of the manometer give, respectively a 0.3, 0.6 and 0.3% error in the cross section. The effects deriving from the outflow of the gas from the scattering chamber through orifices (end effect), following Wagenaar and de Heer (1985) are negligible. The finite angular resolution of the apparatus systematically lowers the measured cross sections. In order to estimate this effect it is necessary to know the differential cross section for zero-angle scattering. Using recently published data of Katase *et al* (1986) for elastic scattering we concluded that the correction is about 0.1% at 100 eV and 0.25% at 1000 eV. We are not aware of published differential cross sections up to 3000 eV. The largest error is introduced by the pressure reading. Although the manufacturer states the calibration accuracy to be 0.15%, we assumed, as in the previous measurements (Dalba *et al* 1979), a 1% error.

The values of the total cross sections together with the statistical deviation of the mean value are given in table 1. The total cross section decreases monotonically from the value 8.08×10^{-20} m^2 at 81 eV to the value 0.49×10^{-20} m^2 at 3000 eV. The statistical error, measured as the standard deviation of the mean value, decreases from 2.1% of the cross section at 100 eV to 0.5% at 500 eV and rises again up to 1.5% at 3000 eV. At low energy the beam stability is poorer; the gas pressures are lower, so the manometer zero drift introduces a higher random error. It is difficult to estimate quantitatively the influence of these two effects on the measured cross section but both of them cause a higher statistical spread of the data at low energies. The rise of the statistical error for high energies has been caused by the instability of the emission current.

In figure 1 our data are plotted together with the data of Sueoka *et al* (1986) and the data for low-energy scattering of Brüche (1929) and of Szmytkowski (1986). The data of Sueoka *et al* are lower than ours in the whole range of overlap. The discrepancy varies from 22% of our value at 80 eV to 12% at 400 eV. We note the same type of disagreement for low energies between the data of Sueoka *et al* and the measurements of Brüche and of Szmytkowski. A rough extrapolation of our data toward low energies seems to be in better agreement with the latter authors. If we compare the total cross section measurements performed by Sueoka and Mori (1984) on CO_2 and N_2 with the measurements done in other laboratories, we find that also for these gases the results of the Japanese group are lower than others available. This could be an indication of a systematic error in their apparatus.

In the intermediate-energy range the total cross section for electron scattering is lower for H_2O than for diatomic molecules like O_2 and N_2. The O_2 molecule cross section is 24% higher at 100 eV and 40% at 1000 eV (Dalba *et al* 1980). For low-energy scattering the relation is reversed—up to 35 eV the cross section for H_2O is higher than for O_2 (see Brüche 1929, Szmytkowski 1986, Zecca *et al* 1986). It could be an indication that for high-energy scattering the long-range potentials, like a dipole one (water is a polar molecule), do not contribute much to the total cross section. In the total cross section at 100 eV the contribution from elastic scattering is 41% (Katase *et al* 1986) and 35% from ionisation (Bolorizadeh and Rudd 1986). At 1000 eV the cross section for ionisation amounts to 55% of the total cross section.

Further measurements of the differential and total cross sections for electron-H_2O molecule scattering would serve as a check on theoretical works and as an evaluation of the accuracy of electron and positron scattering experiments.

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