Total cross section measurement for e-CO_2 scattering down to 0.07 eV

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LETTER TO THE EDITOR

Total cross section measurement for e–CO_2 scattering down to 0.07 eV

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Abstract. We report transmission measurements made with an electron time-of-flight spectrometer. The gas pressure in the target cell was determined by means of a capacitance manometer. From 2 eV down to 0.07 eV the results agree extremely well with the predictions of Morrison *et al* obtained from a coupled-channel theory.

Carbon dioxide is a molecule of great interest because of its importance in planetary atmospheres as well as in gas lasers and fusion plasmas. With the coupled-channel computations of Morrison *et al* (1977) and Morrison and Lane (1977) it became the one polyatomic molecule for which the most accurate low-energy electron-scattering cross section calculations are available.

The e–CO_2 scattering has a prominent resonance at 3.8 eV; at lower energies the cross section increases rapidly with decreasing energy. The latter behaviour was first detected in swarm experiments (Pack *et al* 1962) and is believed to be caused by a nearly bound $l = 0$ state in the e–CO_2 potential (Morrison *et al* 1977). It is this range of very low energies which was emphasised in the theoretical work of Morrison *et al* (1977). At higher energies, in the vicinity of the resonance, the theoretical results are not suited for a critical comparison with experimental data because these authors employed a semi-empirical polarisation potential whose cut-off parameter was chosen such that the resonance peak occurs at the correct energy of 3.8 eV. The authors also state that the neglect of vibrational channels affects the form of the calculated resonance curve. If included, vibrational effects would broaden the resonance and reduce the peak value of the cross section.

Thus the crucial test of this theory must take place at electron energies well below the resonance. At very low energies only swarm experiments have provided data for comparison thus far. Lowke *et al* (1973) published momentum transfer cross sections extracted from swarm experiment data. These swarm results agree with the calculated momentum transfer cross sections at energies below 0.3 eV; around 1 to 2 eV, however, the swarm cross sections are distinctly smaller than the theoretical values. Total cross section measurements in previous electron–beam experiments were not extended to very low energies: the measurements of Brüche (1927) and Szmytkowski and Zubek (1978) end at 1.3 and 1.5 eV respectively.

With our time-of-flight (TOF) spectrometer we determined the total electron cross section in the energy range of 0.07–4.5 eV. The lower bound is the lowest energy for which Morrison *et al* made a theoretical prediction; the upper bound was chosen such that the range includes the resonance. The experimental arrangement is shown in

figure 1. A 200 eV DC beam is chopped by RF sweeping into 7 ns wide bursts at a rate of 250 kHz. The electrons are decelerated abruptly when entering the target cell, which also serves as a time-dispersing drift tube, and reaccelerated to 200 eV when leaving. The detector is a channel electron multiplier. The rate of detection events is much less than the burst rate, only a few thousand per second. For each detected electron the time between detection and the next zero crossing of the RF sweep is measured and recorded. From this the actual flight time through the drift tube and the corresponding kinetic energy can easily be computed. The distribution spectrum of about 10^6 electrons is accumulated once with and once without gas in the target cell. A comparison of the two spectra shows the scattering out of the beam by electron interaction with the target gas. This leads to the total cross section as a function of electron energy over the energy range covered by the energy distribution of the primary electrons. That distribution can be shaped and shifted in energy by variation of the electron optical parameters. Measurements with different energy distributions are then spliced together. A detailed description of apparatus and technique was previously published (Ferch *et al* 1980).

In TOF systems the energy resolution increases with decreasing energy. At $E =$ 0.09 eV our energy resolution ΔE is better than 0.01 eV but at $E = 3.8$ eV (where the resonance lies) ΔE is much larger, about 0.25 eV. With decreasing energy the technical difficulties increase. The primary intensity drops sharply and, therefore, tuning of the electron optical system becomes a tedious procedure. The danger of systematic errors increases because the slow electrons are much more sensitive to electric and magnetic stray fields. In order to get systematic errors under control we performed measurements with different target gas pressures under a great variety of electron optical conditions. The results presented are the average results of many (typically ten)

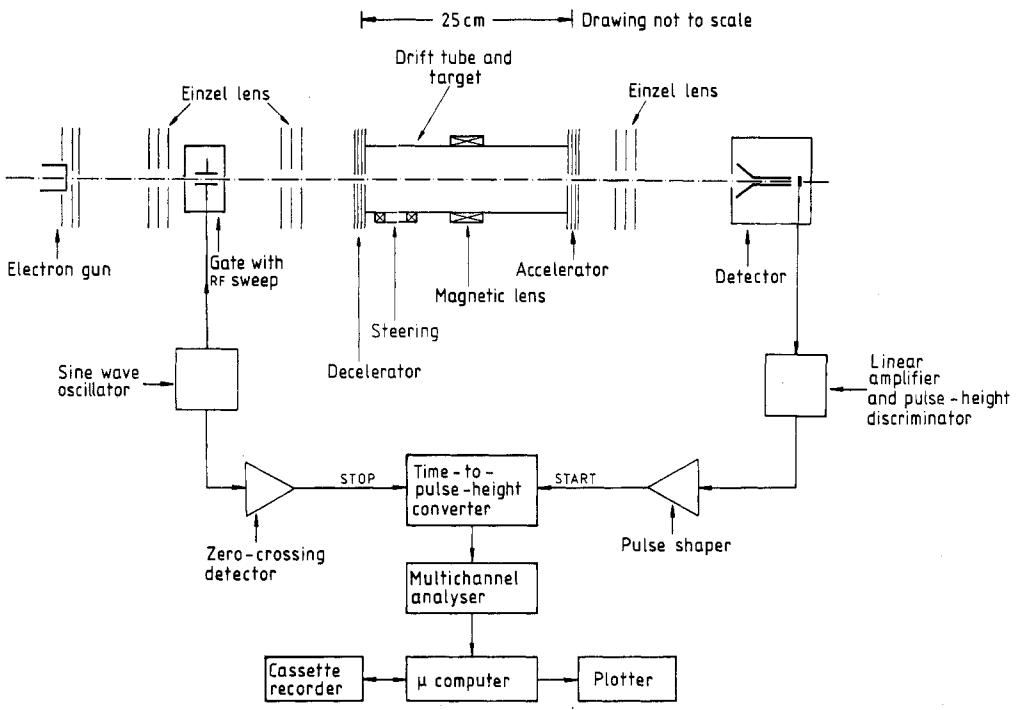

Figure 1. Schematic diagram of the experimental arrangement and electronics.

different measurements and the errors quoted correspond to two standard deviations of this averaging. Compared with the errors thus determined the statistical counting errors are negligible. Systematic errors which are common to all measurements, e.g. the errors in effective target length and in Baratron calibration, were estimated and taken into account by adding 0.5% to the errors described above. This results in an error of about 2.5% at energies around 1 eV. With decreasing energy the error increases to 3.6% because of the steep rise of $\sigma(E)$ in this region. Around the resonance the error is about 6% because fewer measurements were taken there.

The results of our measurements are displayed in figure 2 together with the total cross section measurements of Brüche (1927) and of Szmytkowski and Zubek (1978). The crosses are the theoretical points calculated by Morrison *et al* (1977), supplemented by Morrison and Lane (1977, cf their footnote No 39). From 2 eV down to 0.07 eV the agreement is excellent. Thus the coupled-channel theory serves well for the e–CO_2 interaction at very low energies when employed with an interaction potential which consists of an *ab initio* electrostatic Hartree potential, an approximate local exchange potential and a semi-empirical polarisation potential.

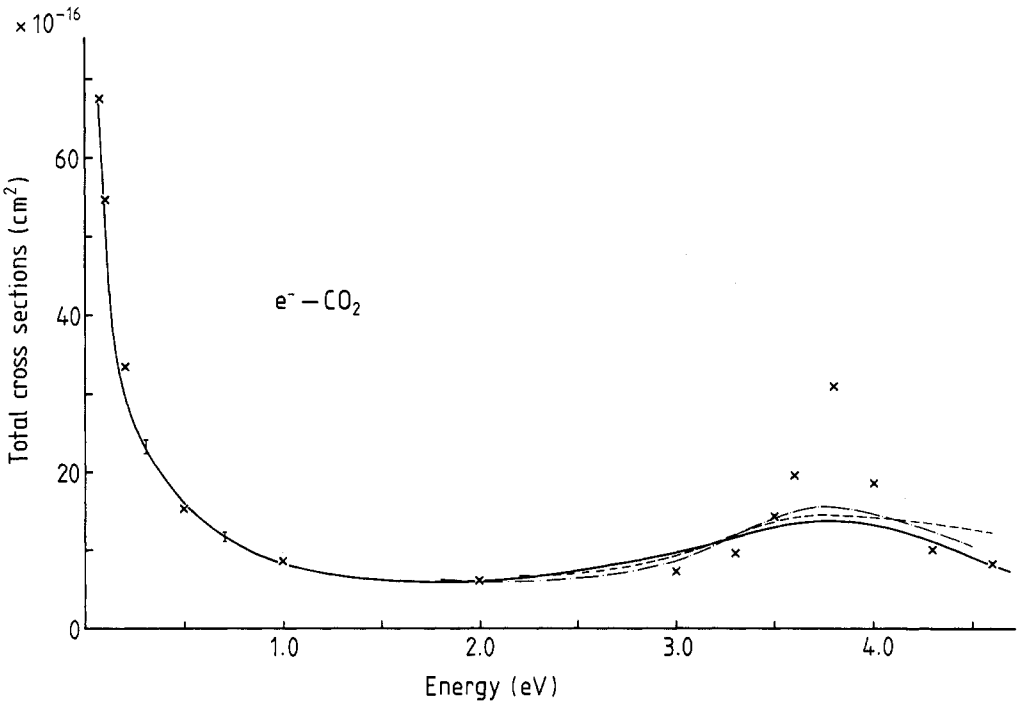

Figure 2. Total e–CO_2 scattering cross sections. Experimental: – – –, Brüche (1927); –·–·–, Szmytkowski and Zubek (1978); ——, this work. Theoretical: ×, Morrison *et al* (1977). The error bars on the full curve correspond approximately to 95% confidence values and were determined as described in the text.

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