# Ionisation of $CO_2^+$ ions by electron impact



1980 J. Phys. B: At. Mol. Phys. 13 L221

(http://iopscience.iop.org/0022-3700/13/6/010)

## LETTER TO THE EDITOR

# Ionisation of $CO_2^+$ ions by electron impact†

A Müller‡, E Salzborn‡, R Frodl§, R Becker§ and H Klein§

‡ Institut für Kernphysik, Universität Giessen, D-6300 Giessen, West Germany
§ Institut für Angewandte Physik, Universität Frankfurt, D-6000 Frankfurt, West Germany

Received 3 December 1979

**Abstract.** Absolute ionisation cross sections for electrons incident on $CO_2^+$ ions have been measured at electron energies from threshold up to 830 eV. The measurements have been performed with crossed electron and ion beams. By extrapolation of the cross section a threshold energy of $(23{\cdot}8 \pm 0{\cdot}5)$eV is determined. The cross section maximum is nearly $4 \times 10^{-17}$ cm$^2$ at an electron energy of about 150 eV.

The importance of carbon dioxide for the global atmospheric environment and also astrophysical objects as well as its application as an active medium in high-power lasers has attracted scientific interest to fundamental collision processes of the $CO_2$ molecule. Whereas the single and double electron impact ionisation of neutral $CO_2$ molecules has been extensively studied (see e.g. Märk and Hille 1978), no data are available for the ionisation of $CO_2^+$ ions:

$$CO_2^+ + e \rightarrow CO_2^{2+} + 2e \tag{1}$$

although the latter process can be expected to be more relevant for the charge balance of a dense $CO_2$ plasma than the double ionisation of neutral $CO_2$.

In this paper we present the first direct measurement of cross sections for process (1). For the experiment a crossed-beam technique recently described in detail (Müller *et al* 1980) has been used. In short, beams of ions are extracted from an electron beam ion source and accelerated by a voltage of order 10 kV. With a 90° double focusing magnet the ions are separated with respect to mass, charge and energy and a collimated beam (diameter < 1 mm) of $CO_2^+$ ions then passes perpendicularly through a dense flat electron beam (perveance: $P = 9{\cdot}5\ \mu A\ V^{-3/2}$, interaction length: 6 cm). The electrostatic potential in the region of the traversing ion beam is uniform and hence the electron energy is well defined (within 0·5%) although high electron current densities of about $j_e = 180$ mA cm$^{-2}$ at 1 kV are used. With such a dense electron beam signal rates can be obtained which are much higher than in earlier crossed-beam experiments and signal to background ratios up to 50 were observed. For a sensitive detection of the product $CO_2^{2+}$ ions a single particle detector with a counting efficiency of $93 \pm 5\%$ was used.

The background due to ion stripping in collisions with residual gas particles has been carefully investigated and subtracted. Several separate experiments gave indications of the absence of metastables in parent atomic ion beams extracted from the electron

† Work supported by the Gesellschaft für Schwerionenforschung (GSI), D-6100 Darmstadt.

  

beam ion source (Müller *et al* 1976). We therefore suppose that also the present molecular ion beam does not contain $CO_2^+$ ions in long-lived highly excited electronic or vibrational states. This assumption is confirmed by the observed threshold behaviour of the ionisation cross section (see below).

For the present measurement, beams of about 300 pA $CO_2^+$ ions were used and data were taken at two different ion energies (5 keV and 10 keV) for the following reasons. First, this provided a check for accurate subtraction of the background signal due to stripping which strongly depends on the impact energy in the present ion energy range. If there is no influence of the ion energy on the measured cross sections one can rely on the experimental procedure to extract the true signal rate of ionised ions. The second reason is concerned with the ion flight time and will be discussed below. The obtained cross section data are compiled in table 1 and also shown in figure 1.

**Table 1.** Cross section $\sigma_{1,2}$ for the ionisation of $CO_2^+$ ions by electron impact. The error limits are calculated from the quadrature sum of all experimental uncertainties including 95% confidence level counting statistics.

| Electron energy (eV) | Cross section $\sigma_{1,2}$ ($10^{-17}$ cm$^2$) |
|---|---|
| 24·9 | 0·126 ± 0·11 |
| 26·5 | 0·326 ± 0·08 |
| 27·4 | 0·450 ± 0·08 |
| 29·0 | 0·626 ± 0·18 |
| | 0·662 ± 0·16 |
| 33·2 | 1·24 ± 0·13 |
| 41·5 | 2·13 ± 0·23 |
| 49·8 | 2·64 ± 0·25 |
| 58·1 | 3·08 ± 0·30 |
| 83·0 | 3·72 ± 0·35 |
| 124·5 | 3·95 ± 0·38 |
| 166·0 | 3·96 ± 0·40 |
| 232·4 | 3·47 ± 0·37 |
| | 3·58 ± 0·38 |
| 332·0 | 2·91 ± 0·35 |
| 456·5 | 2·37 ± 0·29 |
| 622·5 | 2·18 ± 0·29 |
| 830·0 | 1·66 ± 0·25 |

By extrapolating the low-energy data to zero cross section the ionisation threshold of $CO_2^+$ ions is determined to be $23{\cdot}8 \pm 0{\cdot}5$ eV. For neutral $CO_2$ molecules Märk and Hille (1978) have determined the threshold energies for the production of $CO_2^+$ and $CO_2^{2+}$ ions with $13{\cdot}79 \pm 0{\cdot}05$ eV and $37{\cdot}2 \pm 0{\cdot}5$ eV, respectively. The resulting estimation of the threshold energy for process (1) yields $23{\cdot}4 \pm 0{\cdot}6$ eV which compares well with the present results.

The shape of the measured cross section curve does not give evidence for additional ionisation channels or molecular effects (like dissociative ionisation) besides the process (1). In principle, however, it is possible to populate a metastable state of the $CO_2^{2+}$ ion which dissociates with a half life of $2{\cdot}3 \pm 0{\cdot}2$ μs (Newton and Sciamanna 1964) according to

$$CO_2^+ + e \rightarrow (CO_2^{2+})^* + 2e \rightarrow CO^+ + O^+ + 2e. \qquad (2)$$

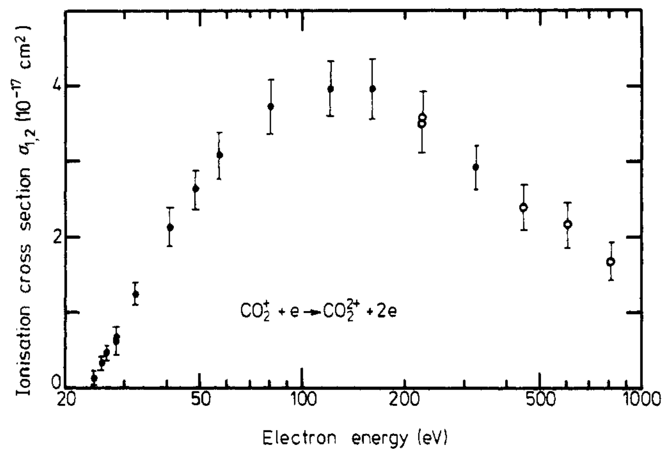


**Figure 1.** Cross section for the ionisation of $CO_2^+$ ions plotted against electron impact energy. The error limits are calculated from the quadrature sum of all experimental uncertainties including 95% confidence level counting statistics. ●, 5 keV ion energy; ○, 10 keV ion energy.

Since the magnetic field of the product ion analyser is set for the detection of the $CO_2^{2+}$ ions, the dissociation products $CO^+$ and $O^+$ of equation (2) are not transmitted to the detector if the decay occurs ahead of or inside the analyser field. As a consequence of choosing different ion energies, different ion flight times and hence also different rates of surviving $(CO_2^{2+})^*$ ions result. At energies of 5 keV and 10 keV the transit times between interaction region and magnet exit are about 5·4 μs and 3·8 μs respectively, which corresponds to a fraction of surviving $(CO_2^{2+})^*$ ions of 20% and 32%. Although these fractions differ considerably, the cross sections measured at different ion energies do not show any definite dependence on the ion energy and hence it may be concluded that the population of metastable $(CO_2^{2+})^*$ states is too small to influence the measured cross sections via incomplete ion collection considerably.

In the case of double ionisation of the neutral $CO_2$ molecule Newton and Sciamanna observed the production of up to 30% of metastable $(CO_2^{2+})^*$ ions. Even if such a high fraction would also be produced by process (1), the percentages of surviving metastables were only 8% and 12% of the total $CO_2^{2+}$ beam, respectively, which is within the experimental error. Hence, the measured ionisation cross section can be regarded as a partial cross section for the production of chemically stable $CO_2^{2+}$ ions.

The authors would like to thank Dr H Winter for fruitful discussions.

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