Dissociation and Charge Transfer of CO_2^{1+} and CO_2^{2+} Ions in Collisions with Neutral Atoms and Molecules *

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Cross sections $\sigma_{2,1}$ for single electron capture by CO_2^{2+} ions as well as total collision cross sections $\sigma_{i,\mathrm{tot}}$ $(i=1, 2)$ for CO_2^{1+} and CO_2^{2+} ions in He, Ne, Ar, Kr, Xe, H_2, O_2, N_2, CH_4 and CO_2 gases have been measured at 10 keV impact energy. $\sigma_{2,1}$ varies between $4.5 \cdot 10^{-17}\,\mathrm{cm}^2$ for the He and $1.8 \cdot 10^{-15}\,\mathrm{cm}^2$ for the CO_2 target. On the average, $\sigma_{2,\mathrm{tot}}$ is 1.6 times larger than $\sigma_{1,\mathrm{tot}}$ and shows a nearly linear dependence on the gaskinetic hard sphere cross section of the target particle. The largest observed value of $\sigma_{2,\mathrm{tot}}$ is $9.4 \cdot 10^{-15}\,\mathrm{cm}^2$ for the CO_2 target.

1. Introduction

Dissociation and charge exchange of singly charged molecular ions colliding with neutral atoms and molecules have been extensively studied during the past two decades. Expecially for the simplest molecule, H_2^+, a large quantity of data is available now [1]. However, information about collision processes of multiply charged molecular ions with neutral particles is still scarce [1, 2].

In this paper we systematically investigate the influence of the target species in single collisions of CO_2^{1+} and CO_2^{2+} ions with neutral atoms and molecules.

2. Experimental Procedure

The technique used in this experiment has been described in detail [3]. The primary singly and doubly charged carbon dioxide ions are generated from CO_2 gas in an electron beam ion source [4]. The extracted ions are separated by a double focusing 90° magnet into beams of given charge and mass. One component is selected and passed through a thin gas target providing single collision conditions. With a Faraday cup behind a second double focusing 90° magnet the charge/mass-spectrum of the beam emerging from the gas cell is measured. The design of the collision cell and the second analyzing magnet is such that ions deflected in the gas cell less than ±1.5° can be collected.

Two types of collision cross sections for carbon dioxide ions incident on target atoms or molecules have been measured:

a) one electron capture cross sections $\sigma_{2,1}$ for CO_2^{2+} ions and

b) total collision cross sections $\sigma_{i,\mathrm{tot}}$ $(i=1,2)$ for CO_2^{1+} and CO_2^{2+} ions.

The cross section $\sigma_{2,1}$ is evaluated by using the growth rate method:

For a target thickness $\pi \to 0$ the particle current I_1 of CO_2^{1+} ions generated by electron capture from CO_2^{2+} is given by

$$I_1(\pi) = I_2(0)\,\sigma_{2,1}\,\pi \qquad (1)$$

where $I_2(0)$ denotes the particle current of the incident CO_2^{2+} beam. For the evaluation of $\sigma_{2,1}$ the pressure in the gas cell (effective target length $l_{\mathrm{eff}} = 11.5$ cm) was varied between 10^{-7} Torr and 10^{-5} Torr. The linearity of $I_1(\pi)$ with increasing target thickness π was carefully checked in order to maintain single collision conditions.

For the determination of $\sigma_{i,\mathrm{tot}}$ the attenuation method is applied: At a target thickness π the incident current $I_i(0)$ of CO_2^{i+} ions $(i=1,2)$ is reduced to

$$I_i(\pi) = I_i(0)\exp\{-\sigma_{i,\mathrm{tot}}\,\pi\}; \quad i=1,2. \qquad (2)$$

The dominant inelastic processes responsible for the attenuation are dissociative and electron capture reactions so that the initial ion charge state is nearly not repopulated in additional collisions. In consequence, Eq. (2) holds over a wide pressure range beyond the single collision condition. The target pressure was raised up to 10^{-2} Torr without changing the exponential dependence (2) of $I_i(\pi)$.

Regarding the uncertainties in the measurement of the ion currents, in the determination of the target thickness π and in the realization of pure beams and

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targets, total errors in the absolute values of the measured cross sections are estimated to be less than $\pm 25\%$.

3. Results and Discussion

For a He target the energy dependence of the cross sections $\sigma_{2,1}$ and $\sigma_{i,\text{tot}}$ $(i=1, 2)$ has been measured for laboratory impact energies from 0.3 keV to 20 keV. While $\sigma_{i,\text{tot}}$ does not show any significant dependence on the impact energy both for CO_2^{1+} and CO_2^{2+} ions, $\sigma_{2,1}$ increases between $1.4 \cdot 10^{-17}$ cm^2 at 0.3 keV and $5.8 \cdot 10^{-17}$ cm^2 at 20 keV. Additional measurements for Xe, H_2, O_2 and CH_4 targets, however, show flat cross section functions $\sigma_{2,1}$ in the same energy range.

The reason for this behaviour is assumed to be the same as in the case of highly charged projectile ions [3, 5]: there is a great variety of possible excited states of projectile and target after the charge transfer collision. The measured cross section is a sum over the partial cross sections for all these different reaction channels and therefore energy dependences are largely smeared out. In the case of He, however, there might be a reduced number of possible, i. e. exothermal, exit channels due to the relatively high ionization potential of the He target atom.

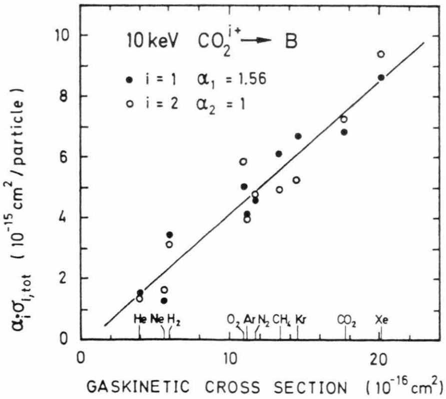

Fig. 1. Scaled total collision cross sections $\alpha_i \cdot \sigma_{i,\text{tot}}$ for 10 keV CO_2^{i+} ions $(i=1, 2)$ versus the gaskinetic cross sections of the target particles B = He, Ne, H_2, O_2, Ar, N_2, CH_4, Kr, CO_2, and Xe $(\alpha_1=1.56, \alpha_2=1)$.

For collisions of CH_n^+ ions $(n=1, \ldots, 4)$ in gases Kupryanov has shown [6] that the total dissociation cross sections increase with increasing size of the ions. In our experiments we have found a corresponding increase of the total collision cross sections $\sigma_{i,\text{tot}}$ for CO_2^{i+} ions $(i=1, 2)$ with the size of the target particles. For a laboratory impact energy of 10 keV these cross sections are plotted in Fig. 1 versus the gaskinetic cross sections [7, 8] of the target atoms and molecules He, Ne, H_2, O_2, Ar, N_2, CH_4, Kr, CO_2 and Xe. Both $\sigma_{2,\text{tot}}$ and $\sigma_{1,\text{tot}}$ grow linearly with increasing geometrical size of the target particles. The ratio $\varkappa = \sigma_{2,\text{tot}}/\sigma_{1,\text{tot}}$ is nearly constant for all targets with $\varkappa = 1.56 \pm 0.2$.

For comparison, in Fig. 2 the electron capture cross sections $\sigma_{2,1}$ for 10 keV CO_2^{2+} ions incident on the same gases are shown also versus the gaskinetic cross sections of the target particles. Obviously there is no simple correlation between electron capture and geometrical size of the target atoms or molecules. On the other hand it has been shown by several authors [5, 9] that electron capture depends on the ionization potential of the target particle. This is qualitatively confirmed by the present experiment as well.

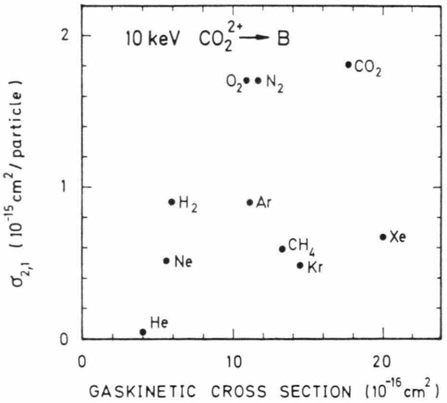

Fig. 2. One electron capture cross sections $\sigma_{2,1}$ for 10 keV CO_2^{2+} ions versus the gaskinetic cross section of the target particles B = He, Ne, N_2, O_2, Ar, N_2, CH_4, Kr, CO_2 and Xe.

In conclusion the experiments show that dissociative collisions of molecular ions can be understood in terms of a simple hard sphere model. This is not at all true for electron capture collisions. On the contrary, charge transfer processes are determined by transitions between electronic energy levels in the quasimolecule formed during the collision and therefore it is understandable that the related cross sections do not depend on the size but on the ionization potential of the target particle.

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