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Absolute total cross section measurements of the collision-induced dissociation of CO^+

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Abstract

Absolute total cross sections for the dissociation of the CO^+ beam to C^+ and O^+ [$CO^+ + H_2$ (or N_2, SF_6) → C^+ (or C) + O (or O^+)] in the energy range from 1.0 to 9.0 keV were measured. We found values of the order from 10^{-19} to 10^{-17} cm^2 for the dissociation to channel $C^+ + O$ with all targets used herein. While for the dissociation through channel $C + O^+$ the absolute total cross section show overall decreases of at least one order of magnitude. The measurements reported here are not found in the literature and the increasing availability of the data on these systems may stimulate work in this direction.

Keywords: CO^+; Absolute total cross section; Collision-induced dissociation

1. Introduction

In any collisional interaction between ions and neutral molecules, the perturbation of the projectile ion with the neutral target molecule leads to the collisional excitation of the former. If the vertical excitation energy is much larger than the dissociation energy of projectile ions, then projectile ion could result in its fragmentation. Collision-induced dissociation (CID) can be used to study different fundamentals aspects. CID has been a widely used ion-molecule collision technique for structure determination and fragment pathway analysis, has also been useful in identifying the electronic states of the dissociation products, as well as to measure cross section of dissociation process [1–8].

Collision of fast molecular ions with target atoms or molecules is a subject of fundamental interest as well as of importance for fields such as astronomy, chemical reactions, and most importantly plasma injection heating. In collisions of molecular ions with target atoms, several competing reactions are involved such as dissociation, ionization, and electron capture. The importance of each of these reactions is dependent upon the initial state of the molecular ions as well as on the collisional energy.

Carbon monoxide is the second most abundant molecule in the universe after molecular hydrogen, and is present in wide variety of astrophysical environments. Therefore, it is important the investigations about CO^+ ion for the knowledge of physical and chemical processes taking place in the atmospheres of planets. However, singly charged carbon monoxide has been less observed in those environments [2]. Studies about collision-induced dissociation of CO^+ ion are scarce; however, the studies about photoionization as well as dissociative recombination and excitation of CO^+ ion are very abundant [9–15].

Studies about ion-molecule and ion-atom with CO^+ are scarce, however several experiments related with the interaction between CO^+ ion with atoms and simples molecules have been reported [16–23]. These investigations have allowed obtaining fundamental information about its electronic structure. The first work about the collision of CO^+ with molecules appeared in 1957 [16]. In this work, Melton and Wells studied the induced-collision dissociation of CO^+ with H_2, D_2, N_2 and CO. They measured the relative cross section for dissociation of CO^+ with respect to dissociation with He from 1 to 5 keV projectile energy.

Dowek et al. [6] studied the He^+–CO and He–CO collision to know different electronic states of CO and CO^+. Their results

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show a Rydberg series from 11 to 14 eV in the CO. They also could identify the excited states $A^2\Pi$, $B^2\Sigma^+$, $C^2\Sigma^+$, $D^2\Pi$ y $F^2\Sigma^+$ of CO^+. Krishnamurthi et al. [23] used the CO^+–H_2 collision to study the excitation to states $B^2\Sigma^+$, $C^2\Sigma^+$ and $D^2\Pi$, with energies of projectile of 1.8 keV. Dentamaro and Katayama [24] studied the transition between $A^2\Pi(v=0)$ and $B^2\Sigma^+(v=0)$ states of CO^+ using CID. Moran et al. [24] measured the threshold of dissociation of CO to C^+ and O using CID form 0.65 to 3.2 keV, their results show a threshold of dissociation at 19.5 ± 1.0 eV. Lu et al. [5] studied $CO^+ + CO$ reaction and found the appearance potential of C^+ at 2.5 ± 0.1 eV. The fragmentation of CO^+ has been also studied using multicharged heavy impact ion [25–27].

In this work, we have measured the absolute total cross section of the dissociation of CO^+ to $C^+ + O$ and $C + O^+$ in collision with H_2, N_2 and SF_6, in the range from 1 to 9 keV and 5 to 9 keV, respectively.

2. Experimental

The present apparatus is practically the same used previously [28–30]. A schematic diagram of the experimental apparatus is shown in Fig. 1. The CO^+ beam was electrostatically accelerated, momentum analyzed by means of a magnetic mass spectrometer, and passed through a series of collimators before entering the gas cell. The dissociation cross sections were measured by passing the CO^+ beam through the gas cell. The beam interacted with the gas in the cell and is dissociated to C^+ and O or C and O^+. The dissociation products entered the detection chamber and were mass/charge separated by an electric field produced by the appropriate voltage applied to a pair of plates. This field diverted the charged fragments 12° from the path of the undeflected beam direction. On one side, a parallel-plate electrostatic analyzer was located 20 cm away from the edge of the plates and oriented at 45° between the charged fragment direction and the field. A channel electron multiplier (CEM) was positioned at the exit of the analyzer. A rectangular slit of 0.3 mm width and 10 mm long was placed in front of the CEM, and a collimator of 2.8 mm diameter at the entrance of the energy analyzer provided the energy analysis of the charged fragments by sweeping the applied voltage between the plates of the analyzer. These conditions result in an energy resolution ($\Delta E/E$) of 0.04. In this work, the parallel-plate analyzer was not used. On the opposite side from the undeflected beam direction, a CEM with a 0.9-cm-diameter active area was located to register the total fragment count rate. A retractable Faraday cup was placed at the exit of the target cell to measure the total current of the ions beam. The detectors and the analyzer were shielded to prevent unwanted events. This setup allows the measurement of the laboratory energy distribution of the charged fragments, the current intensity of the initial ion beam, and the total intensity of the fragments, all necessary for the measurement of the absolute total cross sections. Due to the energy liberated in the dissociation process, and to ensure the detection of all particles, the cross sections were measured under different conditions. The diameter of the entrance aperture of the collision cell was reduced from 1 to 0.45 mm, and the distance from the exit aperture to the detectors was decreased by 10 cm; no significant change in the measurements for the total cross sections was found. The data from which the cross sections were calculated were obtained under "single collision condition" by the well known expression:

$$F_j = \alpha \sigma_{ij} P \tag{1}$$

where F_j is the ratio of the intensity of the fragment j to the intensity of the initial beam with single charge i, σ_{ij} the cross section for the dissociation to the fragment j, where i is the charge state of the beam particle before interaction, j the fragment after the interaction, P the gas cell pressure, and α is given by the expression:

$$\alpha = \frac{N_L l}{RT} \tag{2}$$

where N_L is the Loschmidt's number, R the gas constant, T the absolute temperature, and l is the effective length of the gas cell.

The interaction cell contained the molecular gas targets (H_2, N_2 or SF_6) at a constant pressure of less than 0.2 mTorr, thereby guaranteeing single collision conditions.

3. Results and discussion

When CO is ionized, CO^+ is formed, and in collisions with target, the CO^+ may undergo the following processes:

$$CO^+ + X_2 \rightarrow C^+ + O^0 + X_2 \tag{3}$$

$$CO^+ + X_2 \rightarrow C^0 + O^+ + X_2 \tag{4}$$

$$CO^+ + X_2 \rightarrow C^0 + O^0 + X_2{}^+ \tag{5}$$

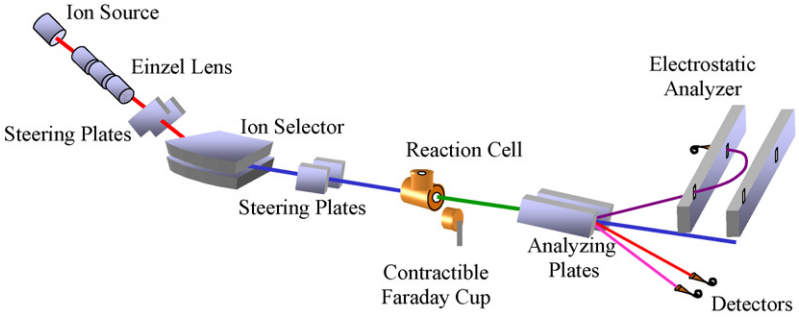

Fig. 1. Experimental apparatus.