Ionization and dissociation fractions of CO$_2$ under 10–30-keV H$^\{-\}$, C$^\{-\}$, and O$^\{-\}$ negative-ion impact

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Ionization and dissociation fractions of CO$_2$ under 10-30 keV H$^-$, C$^-$ and O$^-$ negative ion impact

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The ionization and dissociation fractions of CO$_2$ molecule are studied under impact of 10-30 keV negative ions H$^-$, C$^-$ and O$^-$. The four recoil ions originating from the target molecule CO$_2$ (CO$_2^+$, CO$^+$, O$^+_2$, and C$^+$) are measured and identified in coincidence with projectiles in two final charge states (q = 0 and q = +1) by using time-of flight spectrometer. The ionization and dissociation fractions of CO$_2$ are found to associate with the momentum of the impacting ions. We also analyze the fractions for ionization and dissociation from a physical point. No comparison is given since no other experimental and theoretical data exist in the investigated energy range.

Keywords: TOF, Coincidence Measurement Technique, Ionization and dissociation fraction

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I. INTRODUCTION

Recently, the ionization and dissociation dynamics of molecules and atoms have attracted growing interest [1–9]. The total and partial ionization cross section data are of practical importance in various field, such as, in fusion-edge plasma diagnostics; gas discharge; planetary-, stellar-, and cometary atmospheres; radiation chemistry; and mass spectrometry and in modeling radiation effects on materials including biomolecules [10]. In the above works [1–9], the cross sections for ionization and dissociation of some kinds of molecule and atom targets have been described very well for the impact of electrons, positive ions and negative ions. However, these data for the cross sections of ionization and dissociation of some kinds of molecule and atom targets are still very scarce, in particular for the impact of negative ions which are only given in [3–5] for B, C, O, and F anions.

Negative ions, and especially their collision processes with molecules, play an important role on a number of areas, such as in plasma physics, ionosphere physics, astrophysics and flame chemistry. On the other hand, the ionization and dissociation cross section data for atmospheric molecules, in particular for CO$_2$ are very important for a variety of reasons. Primarily, it is one of the fundamental constituents of planetary atmospheres. In view of this scenario, it is demanding and worthwhile to acquire reliable experimental data for ionization and dissociation cross sections of the CO$_2$ molecule induced by anions and to study the details of collision dynamics of fragmentation of this molecule. The different, and sometimes important, characteristic of anions may be helpful in the research of dissociation dynamics of ionized molecules.

In the present work, we measure the ionization and dissociation fractions for the fragment ions of CO$_2$ induced by the impact of 10-30 keV H$^-$, C$^-$ and O$^-$. The four recoil ions originating from target molecule CO$_2$ (CO$_2^+$, CO$^+$, O$^+_2$, and C$^+$) are measured and identified in coincidence with projectiles in two final charge states (q = 0 and q = +1) by using time-of flight spectrometer. Also we analyze the fractions for ionization and dissociation from a physical point. No comparison is given since no other experimental and theoretical data exist in the investigated energy range.

II. EXPERIMENTAL APPARATUS AND TECHNIQUE

Fig. 1 shows the apparatus used for studying ionization and dissociation processes in negative ions-gas collisions. It has been described in detail in our previous work [11]. Here, we will give the description of the apparatus briefly. Negative ions produced by a cesium-sputtered negative-ion source (CSNIS) are analyzed by a 90° bending magnet according to their mass to charge ratio, and then are focused and collimated to enter the collision chamber. In the chamber, the projectiles are made to cross a gas beam effusing from a grounded hypodermic needle at right angles, with the detection system mutually perpendicular to them. The gas jet target and electric field direction of the TOF spectrometer are orthogonal to each other. After the collision, the neutrals or positive ions from the projectile anions are detected by the position sensitive delay-line detector; the anions that do not lose electron (s) are collected by a Faraday cup (FC); the recoil ions are detected by the anode plate detector after passing through a time of flight (TOF) spectrometer with a homogeneous electronic field of 12 V/cm perpendicular to the detector plane. In our experiment, the ejected electrons are not yet detected. The gas flow is controlled by a reducing valve and a fine needle valve. A turbo molecular pump backed by rotary pump is used to maintain the base pressure of the chamber at 1 × 10$^{-7}$ Torr, typical working pressures are of the order of 1 × 10$^{-6}$ Torr with gas load.

We set up a new data acquisition system which is different from the previous work [11]. The present data acquisition system is similar to the one as described in [12]. Here, we will give a detailed description. Fig. 2 shows the present data acquisition system. As in our previous work, two microchannel plate(MCP) detectors are used in the experiments. One is a position sensitive delay-line detector used as the projectile ion detector, the other is a MCP detector with a plate anode.
which is used as the recoil ion detector. After amplification and time discrimination, the signals $x_1$, $x_2$, $y_1$, $y_2$ from the position sensitive delay-line detector are sent into one input channel of a multi-hit time-to-digital converter (TDC). The signal of recoil ions from the anode plate detector is also sent into one input channel of the TDC. In addition, it is used as the trigger signal of the TDC after delay of some microseconds. Finally, the time information of these five signals is stored and analyzed by a self-developed data acquisition and process software. After analysis, TOF spectra of the recoil ions and position spectra of the projectile ions can be obtained. In current experiments, the TOF spectrum of recoil ions are obtained in coincidence with projectiles in two final charge states ($q = 0$ and $q = +1$).

### III. RESULTS AND DISCUSSION

By analysis of the TOF spectrum of recoil ions, the fractions for ionization and dissociation of CO$_2$ targets under the impact of H$^-$, C$^-$, and O$^-$ are obtained for two different final charge states of projectiles. It means that the fractions for ionization and dissociation of CO$_2$ will be analyzed from the point of the final charge state of the projectiles. The process in which the projectiles are neutral is called the single electron loss (SL) channel. The process where the projectiles are singly charged positive ions is called the double electron loss (DL) channel. The scattered ions are electrostatically analyzed and detected by the position sensitive delay-line detector. Fig 3 gives the typical one-dimensional position spectrum of projectiles for 20 keV H$^-$ impact. Fig 4 shows the TOF spectrum of recoil ions of SL channel for CO$_2$ targets under the impact of 30 keV H$^-$. As seen in Fig 4, the most dominant peak corresponds to the CO$_2^{2+}$ ions produced due to the direct ionization of CO$_2$ molecules. The peak CO$_2^{2+}$ is also from the direct ionization of CO$_2$ molecules. The fragment ions C$^+$, O$^+$ and CO$^+$ originate from the dissociative ionization of CO$_2$ molecules. In the present study, since it is difficult to completely resolve the fragment ions C$^+$ and O$^+$, as well as CO$^+$ and O$_2^+$, the computer fitting procedures are used to separate the peaks of C$^+$ and O$^+$ from H$_2$O$^+$, and CO$^+$ from O$_2^+$ (see Fig 4).

![FIG. 3: A scattered ions position spectrum.](image3.png)

![FIG. 4: Time of flight spectrum of recoil ions formed by 30keV H- impact on CO$_2$.](image4.png)
The possible dissociation channels after the multiple ionization of CO$_2$ are list in the following [1]:

\[
\begin{align*}
\text{CO}_2 & \rightarrow \text{CO}_2^+ + e^+ \quad (1) \\
& \quad \text{CO}_2^+ + \text{O} \quad (1a) \\
& \quad (C, O) \quad (1b) \\
& \quad (O, O) \quad (1c) \\
\text{CO}_2 & \rightarrow \text{CO}_2^{2+} + 2e^+ \quad (2) \\
& \quad (C + O^+) \quad (2a) \\
& \quad 2O^+ + C \quad (2b) \\
& \quad O^+ + \text{CO}^+ \quad (2c) \\
& \quad \text{CO}^{2+} + (O, O) \quad (2d) \\
& \quad O^2+ + (C, O) \quad (2e)
\end{align*}
\]

Multi-hit measurements were performed to look for the double and triple ionization channels and their fragmentation channels. It is found that there are not two or more charged ions produced in one event. Thus we rule out the channels (2a-2e) and the fragmentation channels of CO$_2^{2+}$. In addition, although there is a well-defined CO$_2^{2+}$ peak in the spectrum, the count of CO$_2^{2+}$ ions is so few that it cannot be analyzed well. No triply charged ions CO$_2^{3+}$ have been observed experimentally. Here, we only analyze the ionization and dissociation fraction of channels (1a-1c).

With the above analysis, it can be known that CO$_2^+$, O$^+$ and C$^+$ come from the only channel (1a), (1b), and (1c) respectively. Therefore, the fractions for ionization and dissociation can be expressed by [11]:

\[
F(x) = \frac{N(x)/\varepsilon(x)\eta(x)}{N(\text{CO}_2^+)/\varepsilon(\text{CO}_2^+)\eta(\text{CO}_2^+)}
\]

where \( x \) represents the fragment ions of CO$_2^+$ (C$^+$, O$^+$, and CO$^+$); \( F(x) \) is the ionization and dissociation fractions of channels (1a-1c); \( \varepsilon \) is the detection efficiency of the MCP for recoil ions; \( \eta \) is the collection efficiency of TOF spectrometer for recoil ions; \( N \) is the number of recoil ions. For the detection efficiency of the MCP for ions, \( \varepsilon(\text{CO}_2^+)/\varepsilon(x) \) is considered as 1 within an error of about 5% in the present energy of recoil ions 4 keV [13, 14]. As discussed in our previous work [11], it is considered that all recoil ions are extracted and transported to the detector, and \( \eta(\text{CO}_2^+)/\eta(x) \) is considered as 1 within error about 3.6%. In addition, due to peak fitting procedures, an additional error arises for C$^+$, O$^+$, and CO$^+$ ions with a few percent. Finally, the peaks of CO$^+$ and N$_2$ cannot be resolved by fitting procedures. We measured the TOF spectrum of background. It is found that the count of N$_2^+$ is about 34% of the count of H$_2$O$^+$. Then it can be deduced that the count of N$_2^+$ is about 4.6% of the count of (CO$^+$ + N$_2^+$). Here, we consider the contribution of N$_2^+$ as the error.

The ionization and dissociation fractions of CO$_2$ for channels (1a-1c) and their total errors are presented in Table I for 10-30 keV negative ions H$^-$, C$^-$, and O$^-$ impact. In order to see more clearly, the fractions are also plotted in the Fig.5-7 for H$^-$, C$^-$, and O$^-$ impact, respectively.

![Fig. 5](image1.png)  
**FIG. 5:** (Color online) The ionization and dissociation fractions of CO$_2$ under the impact H$^-$.  

![Fig. 6](image2.png)  
**FIG. 6:** (Color online) The ionization and dissociation fractions of CO$_2$ under the impact C$^-$.  

From Fig 5-7, we can see that the ionization and dissociation fractions for channels (1a-1c) are almost energy dependent both for SL and DL processes for certain negative ions impact. With increasing energy, the ionization and dissociation fractions for channels (1a-1c) increase except for the (1a) channel for both SL and DL processes and (1b) channel for SL process under C$^-$ impact.

From Fig 5-7, we can also see that the ionization and dissociation fractions for DL process are larger than SL process for certain energies and anions impact. As mentioned in our previous work [11], the DL process is preferred for small impact parameters in collision processes. It means that DL requires more energy loss, i.e., more violent collisions where the impact parameters are smaller and the momentum transfer is larger. Under the small impact parameters, more momentum...
is transferred to the target. Thus, larger ionization and dissociation fractions are obtained for DL processes. The data show that this is the general case for these negative ion projectiles.

From Fig 5-7, we can still see that for certain impact energies, the fractions under impact of anions with larger mass is larger than that under impact of anions with smaller mass. Larger mass means more momentum if these anions have the same impact energy. In Fig.8, we give the curve of the fractions as a function of the momentum of the impacting negative ions. It seems the fractions increase with increasing projectile momentum, independent of the projectile type. The ionization and dissociation fractions increase more quickly for DL process than that SL processes. Therefore the dissociation process is associated with the momentum of impacting ions as shown in Fig.8. Further investigations are currently in progress.

### IV. Conclusion

We obtained the ionization and dissociation fractions for the production of the fragment ions of CO$_2$ induced by the impact of 10-30 keV H$^-$, C$^-$, and O$^-$. The four recoil ions originated from target molecule CO$_2$ (CO$_2^+$, CO$^+$, O$^+$, and C$^+$) are detected and identified in coincidence with projectiles in two final charge states (q = 0 for SL process and q = +1 for DL process) by using time-of-flight spectrometer. The ionization and dissociation fractions for channels (1a-1c) are expressed as formula (3). The ionization and dissociation fractions for channels (1a-1c) are almost energy dependent both for SL and DL processes for certain negative ions. It is also found that the ionization and dissociation fractions for DL process occurring for small impact parameters are larger than SL process occurring for large impact parameters. It is still found that the dissociation process may be associated with the momentum.
of impacting ions. We also analyzed the ionization and dissociation fractions from a physical point. No comparison is given since no other experimental and theoretical data about the ionization and dissociation of CO$_2$ exists under the impact of negative ions in the investigated energy range.

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