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Laser Induced Ionization of Diatomic Molecular Ions

Author:
Sam Roland
Cornell University
sbr68@cornell.edu

Supervisor:
Itzik Ben-Itzhak
Kansas State University
ibi@phys.ksu.edu

Project Goals

The aim of my project was to understand how a short laser pulse ionizes particular diatomic ions. The primary analysis was of CO^+. First I was interested in the effect of the laser intensity on the occurrence of the two ionization cases:

- Non-Dissociative Ionization: $CO^+ + n\hbar\nu \Longrightarrow CO^{++} + e^-$
- Dissociative Ionization: $CO^+ + n\hbar\nu \Longrightarrow C^+ + O^+ + e^-$

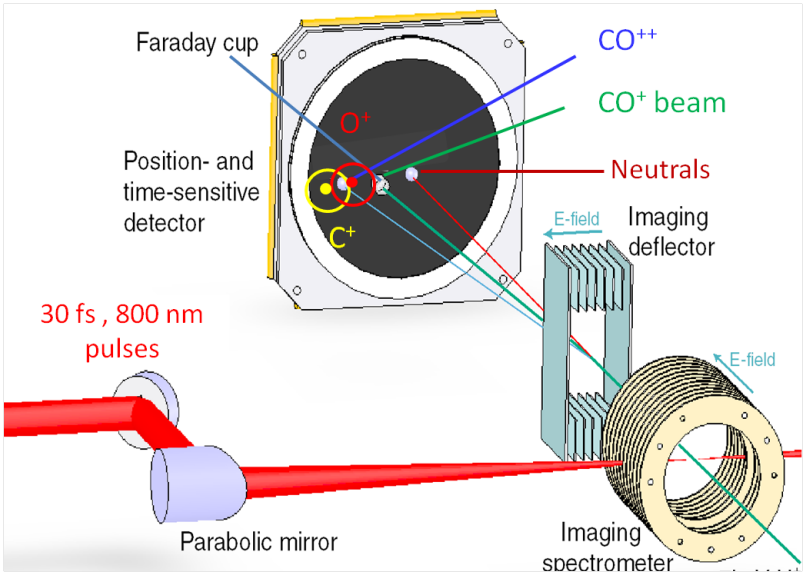
Second I hoped to study NO^+ interactions with the laser in an analogous fashion; however, due to laser failures I obtained a smaller data set that yielded a more limited analysis. Third I planed to observe and understand the differences between the ionization of NO^+ and CO^+. Finally my project was a demonstration of our ability to detect both dissociative and non-dissociative ionization.

Experimental Setup

The experimental apparatus is designed to cross a beam of ions (CO^+ or NO^+) with a laser beam and detect the resulting fragments. The primary components are:

- Electron Cyclotron Resonance (ECR) Ion Source (not shown in Figure 1)
- Time-of-flight Spectrometer
- Deflector
- Faraday Cup
- Chevron Micro-channel Plate (MCP)

Figure 1: Schematic of the experimental setup



- Hex-anode Delay-line Detector (DLD)

The ECR generates molecular ions via electron impact ionization. A particular ion species is selected and tuned using ion optics including electrostatic and magnetic fields and a series of mechanical slits.

The intersection of the ion beam and laser occurs inside the time-of-flight spectrometer. This spectrometer consists of a series of coaxial rings. Each ring is held at a particular voltage to generate an electric field inside the spectrometer. This field accelerates ions towards the particle detector. The acceleration of an ion through the spectrometer is proportional to its charge-to-mass ratio. Therefore the spectrometer temporally separates fragments of different charge-to-mass ratios from a single event[1].

The laser beam was focused by a parabolic mirror to the interaction region within the spectrometer. The axis of the laser beam is perpendicular to the ion beam axis. An 800 nanometer laser beam was used. The pulse duration of the laser beam was 30 femtoseconds and the repetition rate of the pulses was 2 kilohertz.

After interacting with the laser beam inside the spectrometer ions are accelerated toward the particle detector. Before reaching the detector ions pass through a deflector. The deflector can be modeled as a parallel plate capacitor oriented so that the laser axis is parallel to the normal of each plate. The plates

[1] An event is defined with respect to the laser pulse. Each laser pulse that results in the detection of a particle is an event

are held at a constant voltage to induce an approximately uniform electric field parallel to the laser axis. As ions travel between the two plates of the deflector the field accelerates the ions proportionally to their charge-to-mass ratio. This provides spatial separation of the various fragments. Figure 1 shows how fragments of different charge-to-mass ratio are spatially separated when they reach the particle detector.

A Faraday Cup is placed in front of the detector to collect the original ion beam (CO^+ or NO^+). This prevents the ion beam from damaging the detector and allows the ion beam current to be measured.

The particle detector consists of a chevron MCP and a hex-anode DLD. The MCP is a plate with a grid of tubes (or channels) with diameter on the order of 10 micrometers. An incoming particle will reach the front MCP and enter a channel. The channels on the front MCP are angled so that the particle will collide with the wall of the channel. This collision releases electrons which also collide with the wall and release more electrons. This process continues until a shower of electrons exits the channel. Typically one particle will yield an electron shower of approximately 10^3 electrons. The chevron MCP consists of two plates with their channels aligned at an angle (shown if Figure 2). Each electron emitted from the first MCP causes an electron shower in the second MCP. Therefore the chevron provides a gain of approximately 10^6. The front MCP is held at -20V and the back MCP at 2000V. When front MCP emits an electron shower its voltage suddenly increases. This voltage increase provides the timing signal for the arrival of a particle. The timing of every particle reaching the detector in a given event is measured from the laser pulse that began that event.

Behind the second MCP is a hex-anode DLD which is held at a higher voltage than the second MCP and attracts all the emitted electrons. The DLD is a grid of three wires (u,v and w wires shown in Figure 3). The electron shower generates an electrical signal on each wire. This signal travels down each wire in both directions. The times that the signals arrives at the ends of each wire are recorded. From the difference in arrival times for a given wire the position of the electron shower can be calculated. This position is interpreted at the position of the incident particle.

The experimental setup allows fragments of different charge-to-mass ratio to be separated in time and space. The particle detector provides timing and position information for every detected particle. Therefore particles hitting the detector can be identified based on their time-of-flight and position.

Data Analysis

Data from the particle detector provided a count for the number of ionization and dissociation events. To obtain an ionization count the number of CO^{++} (or NO^{++}) particles that hit the detector was measured. The time-of-flight and the position of the doubly-charged ion were calculated based on its charge-to-mass ratio. The number of particles that hit the detector in a small window around

Figure 2: Side-view of Chevron MCP: two MCPs stacked so that the channels are angled.

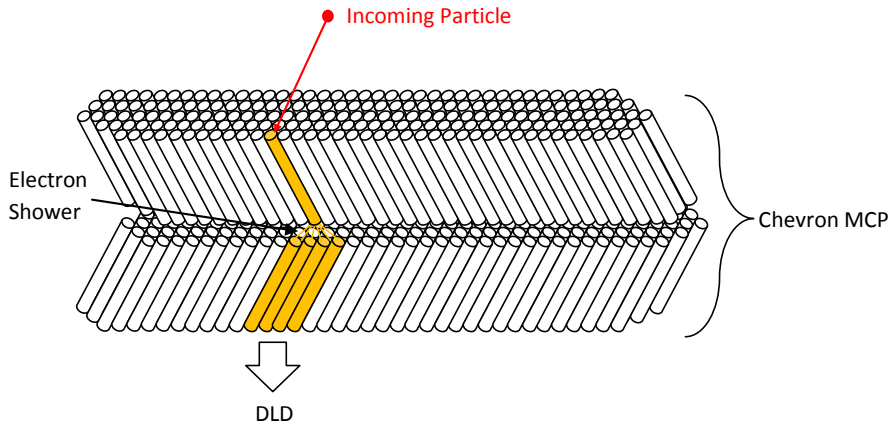
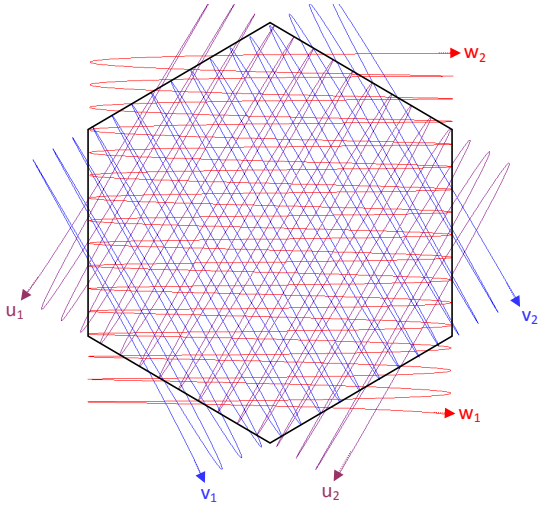


Figure 3: Hex-anode delay-line detector. The electrical signal from the MCP propagates along each wire in both directions and gives the position of the particle.



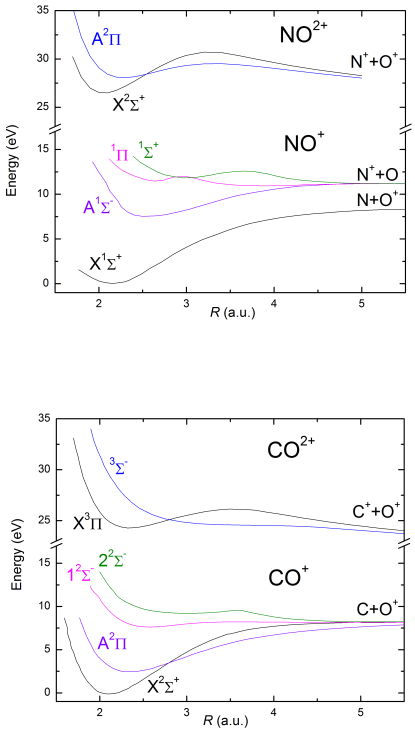


Figure 4: Potential Energy Curves

this time and position was measured. Subtracting the noise from this number yields the number of ionization events.

The dissociation count is obtained differently. This count corresponds to the number of C^+ (or N^+) ions arriving in coincidence with an O^+ particle. Therefore the number of particles that arrive near the expected time and position of C^+ and are *in the same event* as a particle arriving near the expected time and position of O^+ is measured. This provides a dissociation count.

To compare the counts from different experiments the data must be normalized. The number of counts is normalized to the total number of ion that pass through the laser-ion interaction region during a laser pulse.

Results and Interpretation

Analysis of data collected from seven different laser intensities yielded the number of non-dissociative ionization events [CO^{++}], the number of dissociative

ionization events [C^++O^+] and the ratio of the two events [CO^{++}]/[C^++O^+] for each laser intensity. Preliminary results show a higher rate of total ionization in CO^+ than NO^+. Furthermore I observed less dissociative ionization of NO^+ than CO^+ but approximately the same rate of non-dissociative ionization.

These result maybe be accounted for by appealing to the potential energy curves of these various ions (Figure 4). The lower total ionization rate in NO^+ may be due to the fact that the difference in potential energy between the ground states of CO^+ and CO^{++} is smaller than the difference between NO^+ and NO^{++}. The smaller rate of dissociative ionization of NO^+ may be explained by the deep potential well in the NO^{++} potential curves compared to the CO^{++} potential curves.

Furthermore I observed that the kinetic energy release distribution of the breakup $CO^+ \Longrightarrow C^+$+O^+ was qualitatively similar the kinetic energy release distribution of the breakup $CO^{++} \Longrightarrow C^+$+$O^+$. The same observation was made for the breakup $NO^+ \Longrightarrow N^+$+O^+ and $NO^{++} \Longrightarrow N^+$+$O^+$. These results suggest that the primary ionization mechanism was direct ionization from CO^+ (or NO^+) states to CO^{++} (or NO^{++}) states.

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