EXPERIMENTS ON ELECTRON IMPACT EXCITATION AND DIELECTRONIC RECOMBINATION AT HARVARD-SMITHSONIAN

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Abstract
    Measurements of absolute cross sections are being carried out for electron impact excitation and dielectronic recombination in singly and multiply charged ions of relevance to astrophysical and laboratory plasmas. New measurements of electron impact excitation in C^{3+} and in C^+ and of dielectronic recombination in C^{3+} are reported.

1.   Introduction

Ultraviolet light production from high temperature, low density, plasmas, such as those found in the Sun's corona and in tokomaks, is often dominated by line radiation from the decay of ions excited by electron impact.[1,2] The determination of plasma parameters such as electron temperature and density and the determination of the ion charge-state balance rely on measurements of the intensity of the emitted light. In order to understand and model the behavior of such plasmas, it is necessary to determine atomic parameters such as excitation and recombination cross sections for the ions of interest.

Experiments are being carried out at Harvard-Smithsonian to measure absolute cross sections for electron impact excitation (EIE) and dielectronic recombination (DR) in systems of relevance to astrophysical and laboratory plasmas.[3-6] These measurements include determinations of EIE in C^{3+} and in C^+ and measurements of DR in C^{3+}. It is well recognized that DR cross sections are sensitive to the presence of fields.[7,8,9] Therefore the latter measurement is being carried out as a function of the strength of an externally applied electric field.

2.   Experimental Method

An inclined electron/ion beams arrangement is used. Ions produced in a Penning Oscillatory Discharge Source with an externally heated cathode[10] are accelerated, formed into a beam, charge-to-mass analyzed, and transported to a collision chamber (Figure 1). The incident beam is charge-state analyzed in the collision chamber to minimize the lower charge state content caused by charge transfer collisions with background gas (at about 2×10^{-10} torr). Ions in the incident beam collide with electrons from an electron gun oriented at 45 degrees to the ion beam. The photons produced by collisions of the ions and electrons are collected by a concave mirror, which images the beams' intersection region through a MgF_2 vacuum window and a synthetic quartz filter onto a solar-blind photomultiplier.

The wavelength bandpass of the photon collection system extends from 149 nm
to 165 nm, as determined by the short-wavelength cutoff of the quartz
filter and the long-wavelength cutoff of the CsI coating of the
photomultiplier. Beam current densities are scanned using computer
controlled Faraday cups. Form factors are calculated with programs
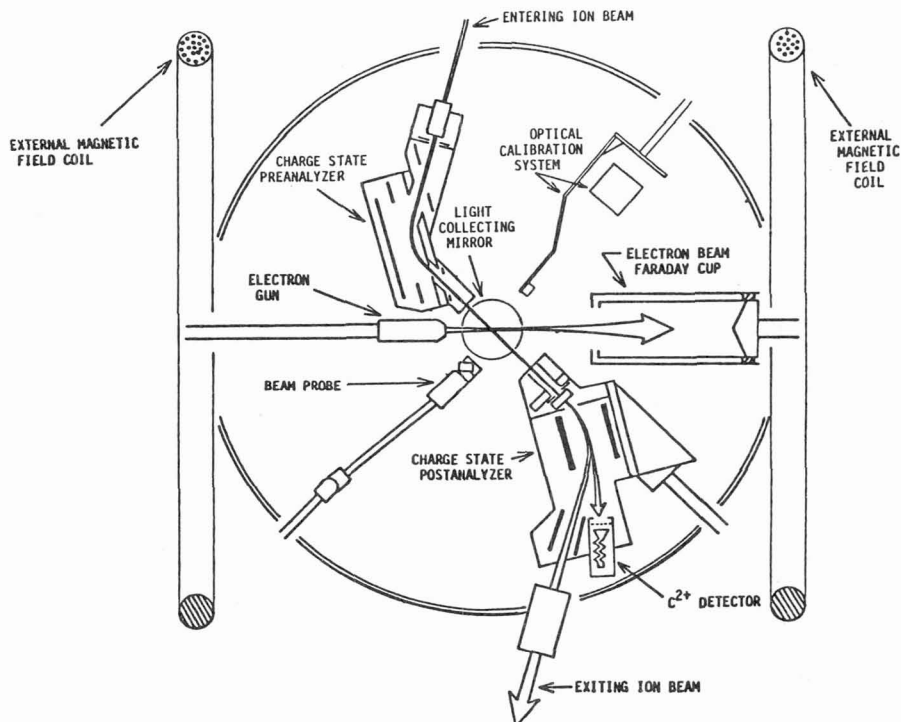operating on a remote VAX computer. Ions leaving the beams intersection

Figure 1.   Experimental arrangement inside the electron-ion
             interaction chamber.

region are charge-state analyzed, and ions of one lower charge are detected
by a channel electron multiplier. For measurements of EIE, both ion and
electron beams are chopped with synchronous measurement of the photon
production rate in order to account for photons due to ion and electron
collisions with surfaces and with background gas. For measurements of DR,
the stabilizing decay photons are detected in coincidence with the lower
charge state ions. The electron beam is switched on and off at a 0.1 Hz
rate to allow the subtraction of small coincidence rates due to charge
transfer collisions with the background gas. In order to measure the DR
cross section as a function of external field, an electric field in the ion
rest frame is generated by applying an external magnetic field coaxially
with the electron beam.

Measurements of the EIE cross section of $C^{3+}(2s\ ^2S - 2p\ ^2P^o)$ and
$C^+(2s^2 2p\ ^2P^o - 2s 2p^2\ ^2D)$ have been completed,[5,6] the results of a
preliminary measurement of DR in C^{3+} have been published.[4] Since those
measurements were done, substantial improvements to the apparatus aimed at
increasing the signal rates, the signal-to-noise, and the overall system
reliability have been carried out. In order to increase the photon signal,
the light collecting mirror system has been redesigned. Optical ray
tracing was used to define a system that substantially increases the solid

angle. The new system, which includes a set of precisely located baffles, eliminates the need for reimaging with a second mirror. In the new system a 5.1 cm diameter mirror with radius of curvature of 3.6 cm is positioned 2.5 cm from the intersection of the ion and electron beams. It focuses 25% of the light emitted in the beams' intersection volume onto the photomultiplier. This results in a factor of 18 improvement in the EIE and DR signals. The signal-to-background in the DR experiments has been improved by a factor of 2 by the use of a new photomultiplier with a focused dynode structure. The transit time spread of pulses through the new photomultiplier is approximately 5 ns, eliminating it as the primary limiter of the time width of the delayed coincidence peak. The time width is now determined by variations in ion trajectories through the final charge state analyzer and by the transit time of the ions through the electron beam.

3. Results and Discussion

New measurements on the near threshold cross section for EIE in C^{3+} are presented in Figure 2. The error bars shown are for 90% statistical confidence (1.8σ). The data were taken with the electron gun operating parameters adjusted so as to give a relatively wide 2 eV energy distribution. The peak cross section is in very good agreement with both theory[11-14] and earlier experiments.[4,5,15,16]

Shown in Figure 3 are our earlier data[6] for EIE in C^+ together with supporting data recently obtained. Theoretical calculations that include the effects of resonances near threshold are needed for comparison to the results.

Recent DR data taken with the current experimental arrangement and at an external electric field of 10 V/cm are shown in Figure 4. The electron beam was chopped on and off at a 0.1 Hz rate with synchronous recording of the coincidence spectra. The total acquisition time required to obtain each is 1500 seconds. Note the presence of a coincidence peak in Figure 4(b). This peak is attributed to charge exchange collisions with background gas leading to excited states of C^{2+} which emit detectable photons. The observed DR signal rate, obtained by subtracting the peak in the reference spectrum (b) from that in (a), is 0.13 ± 0.07 Hz, approximately 25 times larger than in our previous measurement.[4] The coincidence peak time spread is about 23 ns. Further DR measurements in C^{3+} as functions of applied electric field and ion rest frame energy are currently underway.
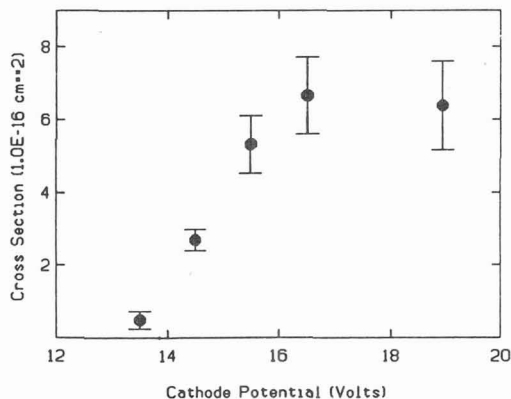

Figure 2. Measured cross section for electron impact excitation of $C^{3+}(2s-2p)$. The error bars are at 90% statistical confidence. The threshold value is in excellent agreement with previous experiments and with theory. See the text.
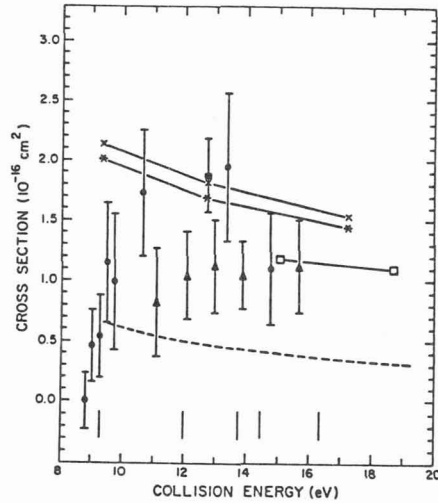
Figure 3.   The electron impact excitation cross sections of
$C^+(2s^22p\ ^2P^o - 2s2p^2\ ^2D)$. The experimental results
of Reference 6 are the solid circles and solid triangles.
The solid square is a recent preliminary measurement
obtained using our new photon collection system. The
close-coupling values of Robb[17] (open squares),
the Coulomb-Born with exchange values of Mann[18]
(asterisk), and the Coulomb-Born without exchange
of Mann (crosses) are also shown. The dashed curve
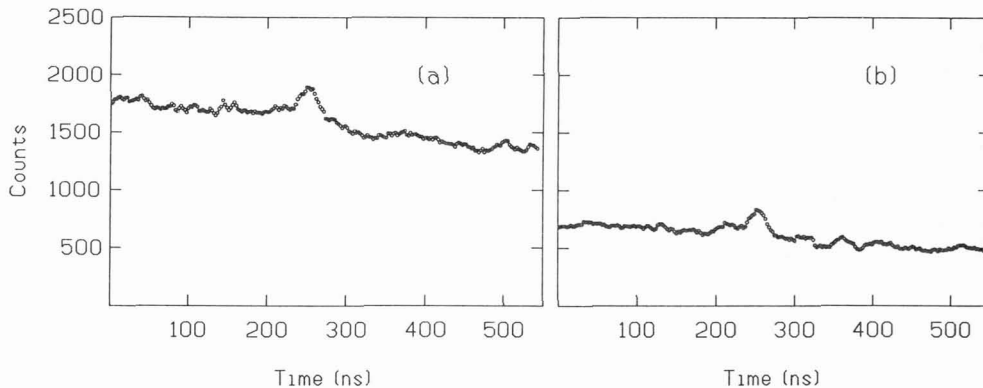is the result of the Gaunt-factor estimator formula.

Figure 4.   Number of photon-ion coincidences vs delay time
for C^{3+} dielectronic recombination using a
23 ns running sum. The center of mass energy is
estimated to be 7.7 eV. Figure (a) is with the
electron beam on and (b) is with it off. The
apparent width of the coincidence peak is exag-
gerated by the running sum.

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