MEASUREMENTS OF ABSOLUTE COLLISIONAL CROSS SECTIONS AT HARVARD-SMITHSONIAN CfA

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The major goal of this research program is to determine, experimentally, accurate absolute cross sections for dielectronic recombination (DR) in multiply and singly charged atomic ions. Our initial measurements of DR in C^{3+} are designed to provide a ''bench mark'' cross section for a simple atomic system. The experiment determines energy averaged DR cross sections for a well defined process involving a specific stabilizing transition. The fields in the region where dielectronic recombination occurs can be made small ($\cong$ 0.25 V/cm) in order to minimize the effect of Stark mixing which is expected to enhance the DR process [1]. We are presently adding the capability to apply known mixing fields up to 5 V/cm in the electron-ion interaction region of our apparatus.

Our experiment tests the basic theoretical formulation of the dielectronic recombination process, and it also virtually provides a separate test of the theoretical formulation of the enhancement as a function of the mixing field strength.

The field free dielectronic recombination process in C^{3+} that we are studying is illustrated in Figure 1 and in the following:

$$C^{3+}(2s) + e^- \rightarrow C^{2+}(2p,n\ell) \rightarrow \begin{cases} C^{2+}(2s,n\ell) + h\nu \\ C^{3+}(2s) + e^- \\ C^{2+}(2s^2) + \sum h\nu \end{cases}$$

where the incident electron excites the 2s electron and is captured in a high Rydberg state (HRS). Relaxation of the excited 2p core through emission of a satellite of the C^{3+}(2s - 2p) resonance line completes the dielectronic recombination process into the $C^{2+}(2s,n\ell)$ state. In the absence of external fields, this system would then relax to the $C^{2+}(2s^2)$ ground state through a cascade of radiative decays. However, external fields in the experiment can ionize $C^{2+}(2s,n\ell)$ yielding C^{3+} and a free electron.

The cross section itself exists as a series of narrow resonances which approach the threshold for electron impact excitation (EIE) of C^{3+}(2s - 2p). Our experiment measures the cross section averaged over the spread in the electron energy distribution. Figure 2 illustrates the theoretically predicted energy averaged cross section for C^{3+} of McLaughlin and Hahn [2]. The shaded portion of the histogram identifies an energy averaged cross section appropriate for the present experiment.

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Our experimental approach [3] determines the dielectronic recombination event rate at the intersection of inclined ion and electron beams by measuring delayed coincidences between the stabilizing photons and the recombined C^{2+} ions. The coincidence technique discriminates against other processes such as charge transfer with residual gas molecules or electron impact excitation; they produce only one of these products. In an experiment, recombined ions that survive the applied external electric fields (e.g. charge state analyzer fields) can be detected directly, while recombined ions that undergo field ionization can be detected indirectly by detecting the field ionized electrons.

Recent experiments by Belic et al. [4] and Williams [5] have used the coincidence technique to measure DR in Mg^+ and Ca^+, respectively. Merged beam experiments have been used to measure DR in C^{+} and B^{2+} [6] and in C^+ [7]. All of these experiments have determined DR cross sections that are substantially larger than the predicted values for zero mixing fields. LaGattuta and Hahn [8] have reported calculations for Mg^+ in small applied electric fields that tend to bring the experimental results for Mg^+ into much clearer agreement with theory. Hahn [9] and Griffin [10] have reported ongoing theoretical efforts to account for the other large experimental cross sections in terms of applied field enhancement.

Initial photon-ion coincidence results from this laboratory suggest that for dielectronic recombination (DR) in C^{3+} the energy averaged cross section in a mixing field of about 1.1 V/cm is apparently smaller than that measured in larger mixing fields at the Oak Ridge National Laboratory (ORNL). This result is qualitatively consistent with theoretical predictions of field enhanced DR brought about by the decrease in the autoionization probability of high Rydberg states with increasingly larger ℓ quantum numbers. Comparison of results from the two experiments is complicated by differences in electron energy distributions and because our experiment measures only the DR process which involves stabilization via radiative 2s-2p core relaxation while the ORNL experiment might conceivably include other recombination channels (e.g. radiative recombination). Although our present results only provide evidence for an upper limit on the C^{3+} cross section, additional data accumulation with the present experimental conditions is expected to yield actual values for DR cross sections at several energies near the 2s-2p threshold.

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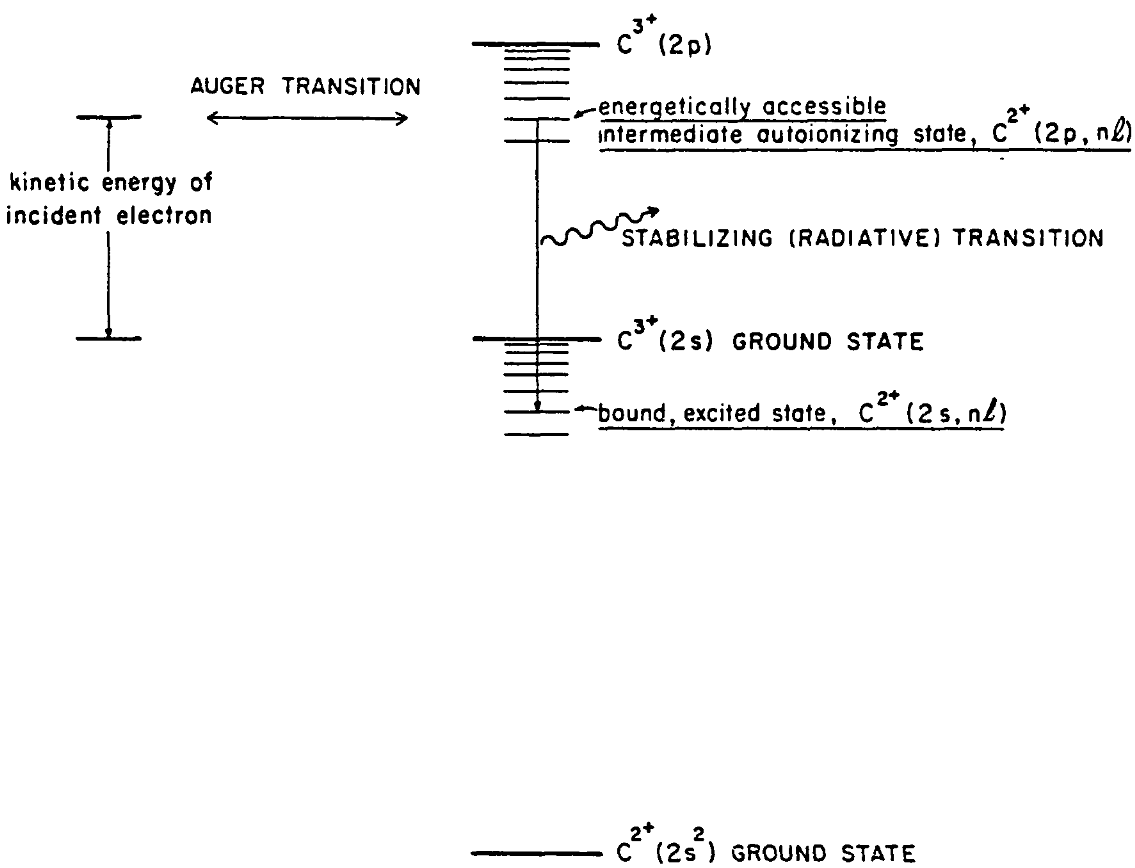

Figure 1. Energy levels for dielectronic recombination in C^{3+}.

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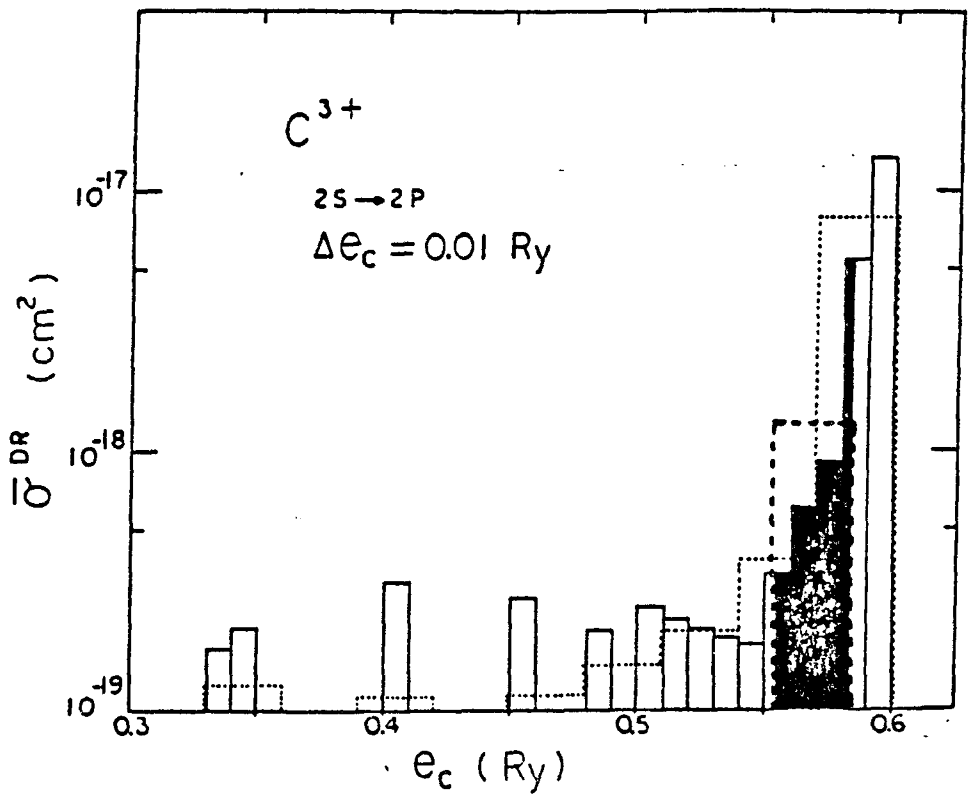

Figure 2. A theoretical dielectronic recombination cross section for C^{3+} averaged over a bin size Δe_c = 0.01 Ry. The shaded section illustrates the energy averaged cross section to be expected in the present experiment (from McLaughlin and Hahn, 1983).