Measurement of Metastable Lifetimes of Highly-Charged Ions

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The present work is part of a series of measurements of metastable lifetimes of highly-charged ions (HCIs) which contribute to optical absorption, emission and energy balance in the ISM, stellar atmospheres, *etc.* [1]. Measurements were carried out using the 14-GHz electron cyclotron resonance ion source (ECRIS) at the JPL HCI facility. The ECR provides useful currents of charge states such as $C^{(1-6)+}$, $Mg^{(1-6)+}$ and $Fe^{(1-17)+}$. In this work the HCI beam is focused into a Kingdon electrostatic ion trap [2] for measuring lifetimes *via* optical decays. A schematic diagram of the beamline is given in Fig. 1. After extraction the ions are directed into one of three beam lines for excitation, charge-exchange/X-ray emission, and lifetime measurements. A description of data acquisition procedures has been given in Refs. [1,3].

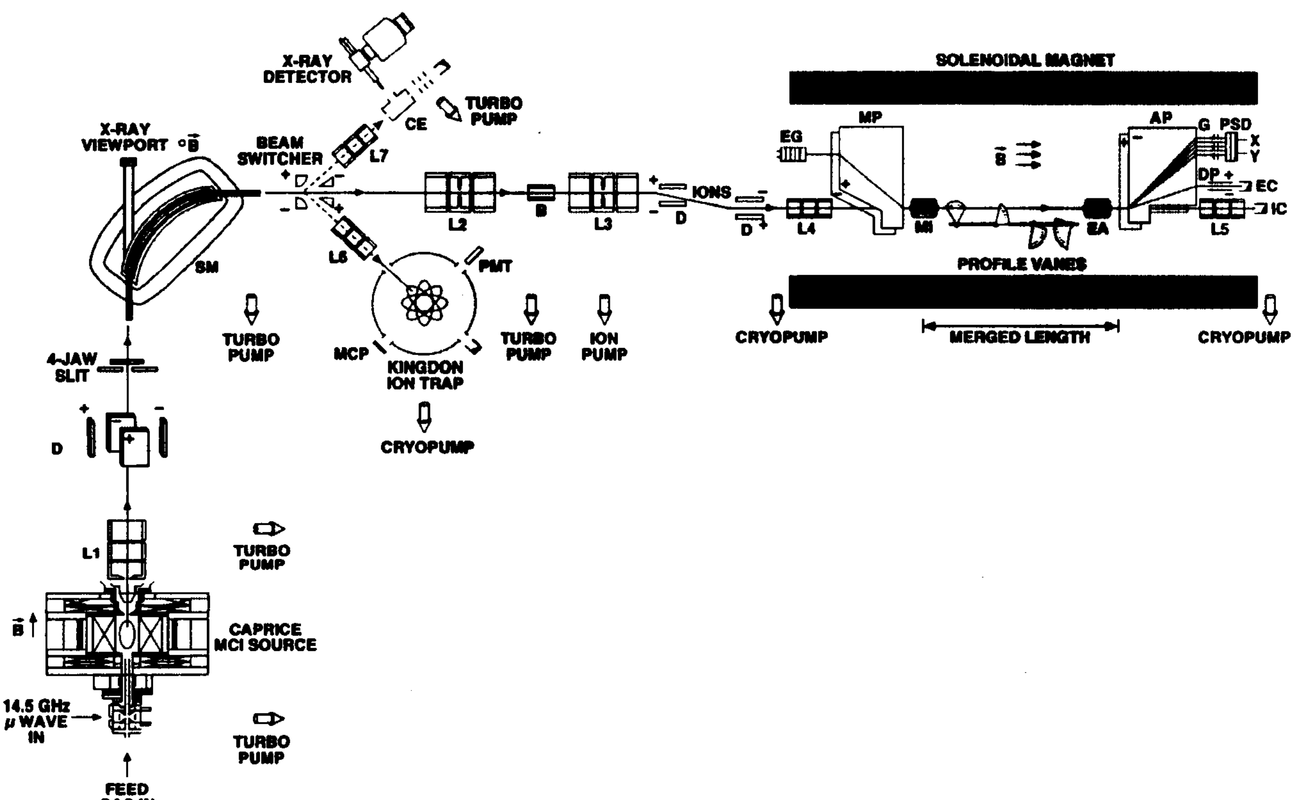

Fig. 1. Experimental set-up of JPLs Highly-Charged Ion Facility (HCIF). (L1-L7) three-element focusing lenses, (SM) mass/charge selection magnet, (B) differential pumping baffle, (D) deflector plates, (MP) electron-merging trochoidal plates, (AP) electron-analyzing trochoidal plates, (MI) electron mirror to reflect backward-scattered electrons, (EA) electronic aperture to discriminate against elastically-scattered electrons, (DP) trochoidal plates to deflect parent electron beam out of the scattering plane, (PSD) position- sensitive detector, (G) electron-retarding grids for discrimination against elastically-scattered electrons, (EC) electron Faraday cup, (IC) ion Faraday cup, (CE) charge-exchange cell, (MCP) microchannel plate, (PMT) multiplier phototube. The three beam lines after the switcher are for excitation, meta- stable lifetimes, and charge-exchange/X-ray measurements.

Ions are focused into the trap, after which the central wire is rapidly pulsed to a low voltage. Trapped ions orbit the center wire where they emit radiation at the wavelength corresponding to the energy of the transition, and (in the absence of cascading into the upper level) at a decay rate given by the inverse lifetime of the upper level. Observed decay channels include intercombination, E2, M1 and 2E transitions. Ion population is also lost *via* collisional-quenching, charge-exchange collisions of the HCI with the background gas, and by collisions with the trap and walls. The UV emissions are detected by an interference filter and phototube using a UV grade optical system. For wavelengths less than 180 nm, a cesium-iodide coated microchannel plate, enhanced for UV performance, is used. The output of the photomultiplier (pulse-counting mode) is coupled to a multichannel scaler having a variable time resolution of 0.1-10 ms/channel. The range of lifetimes that can be measured is determined, at the short end, by the time it takes for ions to settle into stable orbits (1-2 ms); and at the long end by the various trap loss mechanisms (1.5 s). The stored ion cloud is estimated to extend over a diameter of 5-10 mm. This is much smaller than the diameter of the trap (100 mm), hence wall collisions are minimized.

We have published measurements of the lifetimes of the $^2P^o{}_{1/2,3/2} \rightarrow {}^4P_{1/2,3/2,5/2}$ intersystem transitions of C^+ at 232.5 nm [1]. Results are in good agreement with other experiments and theoretical calculations [4,5]. Reported herein is the measurement of the lifetime of the $2s^2 2p^2$ $^1S_0$ level in O^{2+} at 232.17 nm [6]. These transitions are detected in diffuse nebulae- H II regions, planetary nebulae, in our own Sun, and in the Io plasma torus. The data, when combined with absolute excitation cross sections for O^{2+} [7] provide benchmark values for assessing results of astrophysical line-intensity ratio calculations. The interference filter was centered at 232 nm, with a 12 nm (FWHM) bandwidth. The filter rejected emissions lines for the transition $^1S_o \rightarrow$ $^1D_2$ at 436.4 nm, and the transition $^5S^o{}_2 \rightarrow {}^3P_{1,2}$ at 166 nm. The latter rejection was aided by the fact that the light path to the UV phototube and interference filter is exterior to the (fused quartz) window of the vacuum chamber. Hence the path was partly through the absorbing atmosphere. The photon-decay is shown in Fig. 2. As in the C^+ work, because of the low pressure in the trap during operation (3×10^{-10} torr), there is negligible loss of population of the emitting state by ion-gas collisions. The trap decay rate is measured by using the microchannel plates exterior to the trap. The ion population is monitored as the trap is emptied after different elapsed trapping times, up to a maximum trapping time of 1.5 s. In addition, the photomultiplier signal is monitored over a longer (1.5-2.0 s) time interval. This longer-term signal arises from ion-central wire, ion-trap wall, and ion-lens surface collisions. Results of both techniques give a minimum trap lifetime of 1.1 s. The trapped O^{2+} ions may also decay by collisions with the background gas. The JPL measured lifetime of the $^1S_0$ level was found to be 541 $\pm$ 40 ms at the 1σ limit of error. Theoretical values range from 392 ms to 1333 ms [8-12], factors of 0.7 to 2.5 times the experimental values. The present compares well with an ion-storage ring experimental measurement of 530 $\pm$ 25 ms [13]. The spread in theoretical results points out the difficulty of using theoretical data. Additional lifetime measurements have been made for $Fe^{9,10,13+}$ and Mg^{6+} and are in the preparation/submission stage.

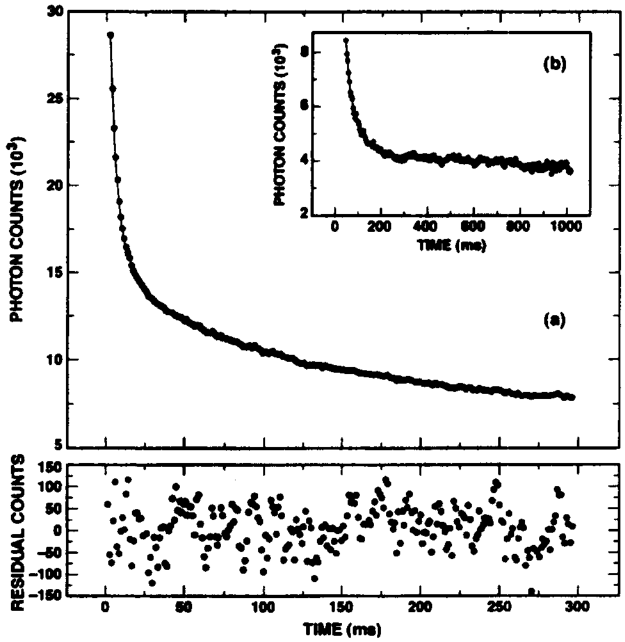

Fig. 2.— Comparison of experimental absolute excitation cross sections for the 2s2 2p2 3P0,1,2 (2s2 2p2 1D2 transitions in O2+ (solid circles) [4], with theoretical results in the 26-state R-matrix calculation [10]. (Photon-decay signal for the M1 232 nm decay branch in the 2s2 2p2 1S0 3P1 transition of O2+. Shown are the decay in the range 0-300 ms (a) and the 0-1000 ms range (b). The data fit is shown by the thin solid line through the points. The lower figure shows the residuals of the data fit throughout the 0-300 ms portion of the decay.)

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