# SPECTROSCOPY OF HIGHLY-IONIZED ATOMS USING POSITION-SENSITIVE DETECTION

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## ABSTRACT

We report new results of atomic structure and atomic lifetime measurements in highly-ionized few electron atoms obtained using position-sensitive detection of extreme ultraviolet emission from excited fast ions. Data is presented from experiments run at the Notre Dame Tandem Accelerator and at the Argonne ATLAS facility using beam-foil spectroscopy with a photon-counting position-sensitive imaging detector. The results include excited state lifetimes in Si XI and Si XII involving both resonance transitions and Rydberg transitions, spectra of highly-ionized He-like, Li-like, and Be-like nickel including comparisons of electron capture and excitation processes for charge selected beams, and spectra and lifetimes in highly-charged bromine ions for both allowed and forbidden transitions.

## INTRODUCTION

Measurements of excited-state lifetimes and transition wavelengths in highly-ionized atoms provide tests of relativistic atomic transition probability calculations and atomic structure calculations. The excitation of a fast-ion beam by a thin-foil target remains the only versatile method for such measurements. We have applied position-sensitive detection of vacuum ultraviolet emission from excited fast ions as a technique for observing these atomic properties. Position-sensitive detectors allow for simultaneous detection of spectroscopic features over wavelength ranges of ~10-100 Å, thereby providing efficient data collection, and the fixed-detector assembly allows for improved monitoring of time dependent source variations for both normal incidence and grazing in-

cidence geometries[1]. Photon detection was accomplished using a photon-counting position-sensitive imaging detector consisting of a one-inch wide windowless channeled electron multiplier array coupled with a resistive anode position sensor. The position decoding of the photon-induced electron pulses was obtained by comparison of the divided pulse charges appearing at the two ends of the anode.

## LIFETIME MEASUREMENTS IN HIGHLY-IONIZED SILICON

Spectra of $Si^{10+}$ and $Si^{11+}$ were produced by ionization and excitation of a beam of 42 MeV $Si^{6+}$ ions from the Notre Dame Tandem Accelerator, by directing the ions through a thin-carbon-foil target of areal density 30μg/cm$^2$. An example of the measured spectrum of highly-ionized silicon near 1000 Å is shown in Fig. 1. Transitions in lithium-like Si XII and beryllium-like Si XI are observed. The two strongest lines are the $1s^22s_{1/2}$-$1s^22p_{3/2,1/2}$ fine structure resonance transitions in Si XII at 499.4 Å and 520.7 Å, appearing in the second order of dispersion. The other two features are highly excited Rydberg transition complexes, which include the unresolved n=5-6 transition in Si XII at 517.7 Å (appearing in second order), and the partially resolved n=6-7 transition in Si XI appearing at ~1020 Å. The second-order linewidth of about 1.2 Å is a convolution of the chosen resolutions of the spectrometer and the detector.

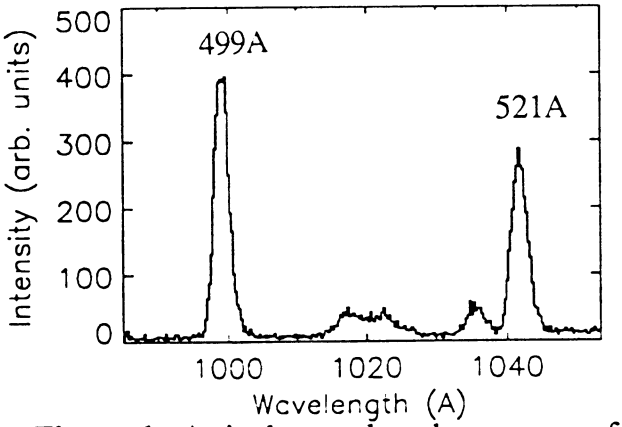


**Figure 1.** A single wavelength spectrum of highly-ionized silicon near 1000 Å.

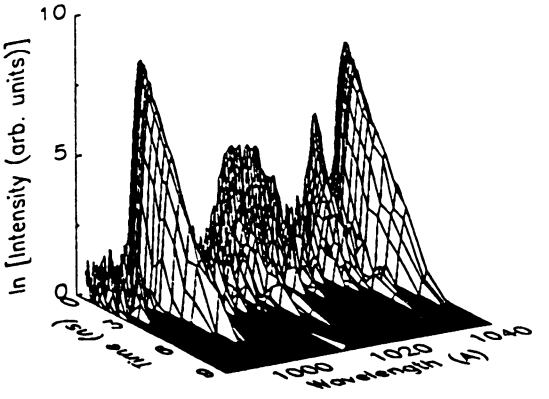


**Figure 2.** A superposition of spectra for a sequence of times after excitation.

Simultaneous decay data for these transitions were obtained by measuring the spectrum at several different distances along the beam from the target foil, normalizing to the ion charge collected in a Faraday cup beam stop. The intensity decay data typically consisted of multiplexed spectra at each of about 20 spatial positions over a total distance of 10 cm. A superposition of these spectra taken for a sequence of times after excitation is shown in Fig. 2. We find the $2p_{3/2}$ lifetime to be 1.07±0.04 ns and the $2p_{1/2}$ lifetime to be 1.20±0.04 ns. The uncertainties account for statistical contributions, variations in small background corrections, and re-

producibility among data sets. These lifetime results are consistent with new relativistic many-body perturbation theory calculations as discussed in Ref. 1.

## WAVELENGTH MEASUREMENTS IN HIGHLY-IONIZED NICKEL

We have also made recent measurements of wavelength spectra of highly-ionized nickel using a position-sensitive detector in the grazing incidence geometry. These measurements were performed at the ATLAS facility at Argonne National Laboratory using beam-foil spectroscopy of 600 MeV nickel ions preselected in the helium-like (26+) and hydrogen-like (27+) charge states. The selection of different incident ion charge-states was done in order to compare the relative efficiencies of electron excitation and electron capture in the foil interaction. Under our experimental conditions we found single electron capture to be more efficient, and a section of the spectrum using $Ni^{26+}$ incident ions is shown in Fig. 3, where the $Ni^{25+}$ lines are shown to be more intense then other charge states. The transitions visible in these spectra are the following Rydberg transitions, helium-like $Ni^{26+}$ n=8-9 at 381.1 Å, lithium-like $Ni^{25+}$ n=8-9 at 411.0 Å, and in the second order of dispersion lithium-like $Ni^{25+}$ n=6-7 at 182.8 Å and beryllium-like $Ni^{24+}$ n=6-7 at 197.8 Å. The effective background noise was decreased in these spectra by taking into account the 12.5 MHz pulsed nature of the beam by setting up a narrow window of time in which true photon events were occurring, thereby allowing data collection only when the true signal was present. One motivation for these transition studies is a measurement of the $1s2s\ ^3S_1$-$1s2p\ ^3P_0$ transition wavelength in helium-like $Ni^{26+}$, to complement our earlier measurement of the $^3S_1$-$^3P_2$ fine structure transition[2].

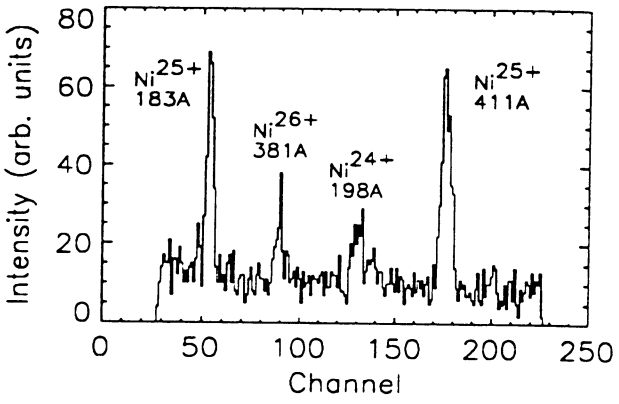


**Figure 3.** A spectrum taken with preselected helium-like $Ni^{26+}$ ion beam.

## LIFETIME AND WAVELENGTH MEASUREMENTS OF INTERCOMBINATION TRANSITIONS IN HIGHLY-IONIZED BROMINE

We have also performed measurements using a position-sensitive detector to determine the lifetimes and wavelengths for fine structure components of spin changing intercombination transitions in multiply ionized bromine. This experiment was done at ATLAS and involved beam-foil spectroscopy of 120 MeV bromine ions. With the violation of conservation of spin, the intercombination transitions are intrinsically weak and have long lifetimes when compared with spin-conserving transitions. By taking data at

several different positions after the target foil, the long lived nature of these states will allow them to be visible in spectra far downstream of the excitation region (Fig. 4)[3]. The prominent transition in the spectrum taken nearest the foil is the sodium-like $3s\ ^2S_{1/2}$-$3p\ ^2P_{1/2}$ transition in $Br^{24+}$ at 229.2 Å, and the transitions that remain downstream of the foil

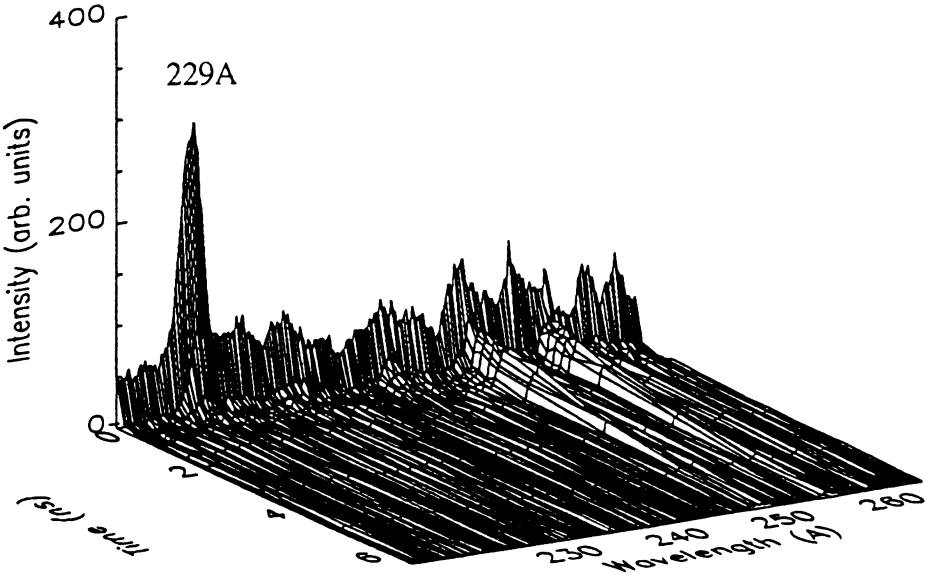


**Figure 4.** A superposition of wavelength spectra for highly-ionized bromine for a sequence of times after excitation.

are the inter-combination transitions $3s^2\ ^1S_0$-$3s3p\ ^3P_1$ in magnesium-like $Br^{23+}$ at 254 Å and $3s^23p\ ^2P_{3/2}$-$3s3p^2\ ^4P_{5/2}$ in aluminum-like $Br^{22+}$ at 260 Å. The lifetimes for these intercombination transitions are ~2 ns.

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