STRUCTURE AND SPECTRA OF IONIZED TIN ATOMS: SnII - V

ABSTRACT OF THE THESIS SUBMITTED FOR THE AWARD OF THE DEGREE OF Doctor of Philosophy IN PHYSICS
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A comprehensive spectroscopic study of the tin ions has special interest from astrophysical, technological and fundamental physics point of views. The updating processes of new version of atomic databases require the highly precise data on energy levels, radiative transitions with intensities and transition rates etc. This enhanced spectral information is always a requisite for astrophysical object studies, for instance cosmic presence of tin is confirmed in various stellar objects [1-6]. The technological application is that tin plasma source is considered to be as source of future/new generation extreme ultraviolet lithography (EUVL) designed for its unresolved transition arrays (UTA) at 13.5 nm [7-11]. Many other application based researches are continuing for the development of micro-plasma which might be applicable to lithography and some metrology [12,13]. The experimental observations are always important to improve and/or include the lacking parameters or interactions in theoretical models of present atomic structure calculations.

The thesis entitled “Structure and spectra of ionized tin atoms: Sn II–V” contains extensive interpretations of the spectra of singly to quadruply ionized tin ions (Sn II–V) on the basis of spectrum of tin taken by us on a 3m normal incidence vacuum spectrograph (300–2080Å) of the Antigonish laboratory (Canada), Wu’s [14] measurements (350–9000Å) and Troitsk’s measurements in 200–650Å wavelength region [15]. The thesis comprised of an introduction, separate chapters for the theory and experimental details involved, and from chapters 3–6, the studies on Sn II–V were discussed in detail. The conclusion of the present work is given at the end.

The chapter 1 contains the theoretical method of atomic structure calculations based on Hartree-Fock formulism with relativistic effects and superposition of configurations which incorporated in the Cowan’s code [16].

Chapter 2 covers the details of the experiments involved and the strategy employed to the critical evaluation of the analyses was also given. The recording of
tin spectrum in 300–2080Å wavelength range, the tin ions/atoms were excited by ns of a vacuum triggered spark source, which consists of a 14.5 μF fast-charging -inductance capacitor, chargeable up to 20 kV, and a trigger module to initiate the harge in vacuum. A holographic osmium-coated grating with 2400 lines/mm was i to obtain the spectrum with reciprocal linear dispersion of about 1.385 Å/mm in first order of diffraction. At least four or five different tracks of spectra were toographed on Kodak SWR (short-wave radiation) plates with varied experimental ditions, such as electric current and charging voltage. Relative positions of xtral lines on the plates were measured using a Zeiss Abbe comparator. For their elength reductions, we used as internal standards the known impurity lines of -IV, N II, O II–IV, Al II–III and Si II–IV. The data were reduced with polynomial of second or third degrees to obtain corrections to the dispersion curve. The entainties of the measurements were found to be varying from 0.003 Å to 0.008 Å sharp and unperturbed lines on different spectral regions and different plates. The 's original wavelengths are corrected with Ritz-type of internal standards derived n highly accurate lines of Sn I and Sn II. The shifts were varying smoothly with elength between +0.019 Å near 900 Å and -0.25 Å near 8300 Å. Thereafter the entainties of lines have been estimated.

The observed energy levels, in each spectrum, were optimized with a least ares level optimization method (LOPT)[17] within a level of one standard iation and consequently, the corresponding Ritz wavelengths with uncertainties e generated. The relative intensities of lines are determined within the local modynamical equilibrium states of optically thin plasmas. The analyses areported by the quasi-relativistic Hartree-Fock method with superposition of furations to take interaction effect due to inter-configuration interactions (CI) lemented in Cowan's code. The extensive calculations with least squares fitted ametric variation was done to reduce the disagreement between observed and critical values. Finally, the observed spectroscopic data were used for deriving the ization potentials.

In Chapter 3, the electronic structure of singly ionized tin (Sn II) is described. structure of Sn II is partly a one-electron and partly a three-electron system with und configuration 5s²5p. The excited configurations are of the type 5s²nℓ in the
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one-electron part, and 5s5p², 5p³ and 5s5pₙℓ (ₙℓ=6s, 5d) in the three-electron part
with quartet and doublet levels. The existing interpretation of the one-electron level
system was confirmed, while all the levels of 5s5p² have been confirmed except ⁵S₁/₂
level which is revised. The analysis has been extended to include new configurations
5p³, 5s5p5d and 5s5p6s. The ionization potential obtained from the ng series was
found to be 118023.7(7) cm⁻¹ or 14.63307(8) eV. A complete set of critically
evaluated data on energy levels, observed wavelengths and transition probabilities of
Sn II in the wavelength range 888–10740 Å is presented in this chapter.

The chapter 4, contains the revised and extended analysis of Sn III, which
includes the previous reported level values of 5p², 5sns (ₙ=6-9), 5snd (ₙ=5-7) and
4f5s configurations with improved energy values. The missing ¹S₀ level of 5p² and
5sns (ₙ=7, 9) configurations is established now. All the levels of 5s5g, except ⁵G₂ for
which the value is revised, have been confirmed. In extension of the analysis, the
levels of 5s8d, 5p (5d+6s), 5snf (ₙ=5-10), 5sng (ₙ=6-7), 5p₆p configurations with a
few levels of 5snd (ₙ=10-12) Rydberg members have been established. These
observed series have been used for the improved determination of the ionization
potential to be 246059±9 cm⁻¹. A total of 115 levels (50 being new) based on more
than 350 lines, have been observed.

In chapter 5, the spectroscopic interpretations of the trebly ionized tin (Sn IV)
is given, in which all the levels of previously known single electron configurations
have been confirmed. The 15 levels of 4d⁵5s5p configuration are known now. The
optimization of levels values have been made with the help of 139 observed lines for
this spectrum, out which more than 50 lines are newly identified. The outermost
double electron excitations results to establish the levels of 4d¹⁰np (ₙ=7-8), 4d¹⁰5f,
4d¹⁰ng (8, 9), 4d¹⁰nh (ₙ=6-9) and 4d¹⁰ni (7, 8) configurations. With help of non-
penetrating high-lying series, the ionization limit of the Sn IV has been derived most
accurately to 328909.3±2.5cm⁻¹ or 40.77955(31) eV. This enabled us to determine of
the energy values more precisely for unobserved levels of 4d¹⁰nℓ (ₙ≥5, ℓ=g, h, i, k)
Rydberg members. A total of 66 levels observed for this ion, out of which 25 are
newly observed in this work.

The chapter 6 is devoted to describe the fifth spectrum of tin (Sn V). The
experimental data was mostly used from the measurements of Ryabtsev [15] and
higher wavelength data from our VUV list. It includes, the confirmation of all the
earlier known levels of 4dⁿlᶜ (lᶜ = 5s, 5p, 5d, 6s, 6p, 6d, 7s), 4dᵉ5s² and 4d⁸5s⁵p
configurations, except ¹S⁰ and ¹G⁴ of 4d⁸5d configuration and for them new values
were obtained. More than 450 lines have been used in optimization of the energy
levels, out of which 194 lines are from our VUV measurements and 10 lines from the
Wu's measurements. We have observed fourteen new lines, in 1650-2010Å range,
that are associated to the 4d⁹5d → 4d⁹6p array. With the help of the longer-
 wavelength data observed by us, improved energy values with greater accuracies have
been obtained for the earlier reported levels of 4d⁹5s, 4d⁹5p, 4d⁹5d, 4d⁹6p and 4d⁹6d
configurations. A total of 137 levels are observed in this spectrum. The transition
probabilities (gA) for observed lines were also given. The reported value of ionization
potential of this ion is substantially revised to 617620 cm⁻¹ against the previously
reported value 621300 cm⁻¹ which was derived from the perturbed series.

In the end, conclusion of the present investigation contains the final summary
of the analyses of four different spectra of tin (Sn II–V). At last, an appendix on the
thesis contains some portraits of sample tin spectra used for this work in VUV
wavelength region along with a few marked prominent lines of Sn II–V and
impurities present in them.
References:

[15] Ryabtsev A N 2013 The spectral data of tin ions, private communication