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Revised and extended analysis of the fourth spectrum of indium: In IV



Swapnil, A. Tauheed*

Physics Department, Aligarh Muslim University, Aligarh 202002, India

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ABSTRACT

The spectrum of triply ionized indium (In IV) has been investigated in the wavelength region 245-4443 Å. The In³⁺ is a Pd-like ion with the ground configuration 4p⁶4d¹⁰. All levels of the low lying excited configurations $4d^95p$, $4d^9ns$ (n=5-7), $4d^95d$ and $4d^85s^2$ have been reported earlier, while for the higher configurations $4d^9np$ (n=6.7) and $4d^9nf$ (n=4-11), only the I=1 levels radiatively decaying to the ground level have been reported. The present work extends the analysis to include the 4d⁹6p, 4d⁹6d, 4d⁹4f and 4d⁹5f configurations. A total 116 levels have been established, 56 of them being new. All the previously reported levels have been confirmed except 4d⁹7s ³D₁, 4d⁹7p ³P₁, 4d⁹6f $^{3}P_{1}$ and $4d^{8}5s^{2}$ $^{3}P_{1}$. The experimental data for the present work was recorded on a 3-m normal incidence spectrograph of St. Francis Xavier University, Antigonish (Canada), as well as on the 10.7 m normal and grazing incidence spectrographs of the National institute of Standards and Technology, Gaithersburg (USA). In both laboratories, a triggered spark source was used. The wavelengths above 2000 Å were supplemented from Bhatia's thesis where an electrodeless discharge source was used. Theoretical predictions were made using Cowan's Hartree-Fock-relativstic atomic codes with superposition of configurations. Least squares fitted (LSF) parametric calculations were used to interpret the energy levels. For vacuum ultraviolet wavelength region our wavelength accuracy is +0.005 Å. We estimate the ionization potential of In IV to be 450,921.7 + $86.0 \text{ cm}^{-1} \text{ (55.9072} \pm 0.0106 \text{ eV}).$

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1. Introduction

Atomic structure of Indium and its ions attracted much interest from spectroscopists, partly because indium-based compounds have numerous industrial applications. The spectrum of triply ionized indium (In IV) has been investigated here which is a member of the Palladium isoelectronic sequence. It has the ground configuration $4d^{10}$ 10 10 and excited configurations are $4d^{9}$ np $(n \ge 5)$, $4d^{9}$ ns $(n \ge 5)$, $4d^{9}$ nd $(n \ge 5)$, $4d^{9}$ nf $(n \ge 4)$ and further excited configurations are $4d^{8}$ 5s², $4d^{8}$ 5s5p, $4d^{8}$ 5p² etc. The first work on In

IV was carried out by Gibbs and White [1], followed by Kruger and Shoupp [2] and Nodwell [3]. Their work is already compiled in Atomic Energy Levels [4] and at NIST atomic spectra database [5]. Bhatia et al. [6] revised and extended the earlier work by including 4d⁹5p. 4d⁹ns (n=5-7), $4d^9$ nd (n=5, 6) and $4d^85s^2$. Recently, van Kleef and Joshi [7] confirmed 4d⁹5s and 4d⁹5p levels of Bhatia and revised all the levels of 4d96s, 4d95d and 4d85s2 configurations. They did not study 4d96d and 4d97s configurations; therefore, these levels remained yet to be verified. Secondly, a few more J=1 levels of $4d^9$ nf (n=4-9)and $4d^9$ np (n=6,7) were reported by Churilov et al. [8] using triggered spark source while Kilbane et al. [9] extended J=1levels up to 4d⁹11f using dual laser plasma technique. The present study has been undertaken considering the importance of indium ions for astrophysical interest [10] and to

^{*} Corresponding author. Tel.: +91 9997737268.

E-mail addresses: swapnilamu@gmail.com (Swapnil),
ahmadtauheed@rediffmail.com (A. Tauheed).

confirm the $4d^97s$ levels of Bhatia et al. [6] as well as to complete the remaining levels of $4d^96p$, $4d^96d$, $4d^94f$ and $4d^95f$ configurations.

2. Experimental details

The spectrum of indium for the present work was mainly recorded on the 3-m normal-incidence vacuum spectrograph at St. Francis Xavier University, Antigonish (Canada) using a triggered spark light source. The spectrograph was equipped with a holographic concave grating with surface ruling 2400 lines per mm giving first order inverse dispersion 1.385 Å per mm. The cavities of the Aluminum electrodes were packed with the Indium metal and these electrodes were connected to a fast charging low inductance 14.5 µF capacitor, chargeable up to 20 kV. The capacitor was charged to different voltages from 2 to 7 kV for different tracks. Several exposures were taken on each plate in varying conditions to have a reliable ionization separation. The conditions can be varied by either varying charging potential or by introducing an inductance coil in the discharge circuit. The high inductance quenches the higher ionizations. The higher ionization ions concentrated towards the anode whereas the lower ions are uniformly distributed in the gap between two electrodes. The In IV lines were separated from In III on higher inductance track by their variation in intensity and appearance. In III lines stayed much stronger and with fuller length while In IV declined their intensity and size. The In V lines were separated from In IV on the medium inductance track where In IV and In V had the similar feature as explained for In III and In IV lines. For the wavelength region 245 Å-2080 Å, Kodak short wave radiation (SWR) plates were used. The spectra were measured on Semiautomatic grant's comparator in Canada and on Abbe comparator at Aligarh. The known carbon, oxygen and aluminum lines [11] appeared as impurities on our plates, were used as internal standard to calibrate the wavelengths. The measured data were calibrated into the wavelength using a polynomial fit program (MOSFIT). For the NIST plates, triggered as well as sliding spark sources were used whose experimental detail can be found elsewhere [8,12]. Our wavelength accuracy for sharp and unblended lines is expected within ± 0.005 Å. The wavelengths above 2000 Å were taken from Bhatia's thesis [13]. He recorded the spectrum on a Littrow-type quartz-glass spectrograph with electrodeless discharge source and estimated the wavelength uncertainties up to ± 0.05 Å. The further experimental detail can be found in Ref [6].

3. Results and discussion

3.1. Ab initio calculations

The *ab initio* calculations were performed using Cowan's Hartree–Fock relativistic atomic codes with superposition of configurations [14] including 4d⁹(5s+6s+7s+8s+5d+6d+7d), 4d⁸5s², 4d⁸5p² for even parity configurations and 4d⁹(5p+6p

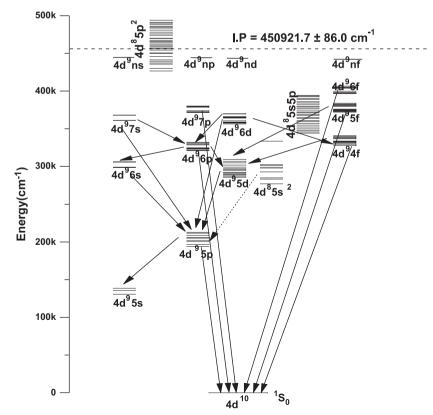


Fig. 1. Energy-level diagram of In IV.

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