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Lifetimes and oscillator strengths for the 5s5p6s, 5s5p5d and $5p^3$ levels in single-ionized tin*

C. Colón and A. Alonso-Medina

Dpto. de Física Aplicada, EUIT Industrial, Universidad Politécnica de Madrid, Calle Ronda de Valencia 3, 28012 Madrid, Spain
e-mail: ccolonh@fais.upm.es

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Abstract. Radiative oscillator strengths for 103 lines arising from 5s5p6s, 5s5p5d and $5p^3$ configurations of Sn II and lifetimes corresponding to several levels of these configurations have been calculated. These values were obtained in intermediate coupling (IC) and using ab initio relativistic Hartree-Fock (HFR) calculations. We use the standard method of least square fitting of experimental energy levels for the IC calculations by means of computer codes from Cowan.

Key words. atomic data

1. Introduction

The levels of single ionized tin have been the subject of both experimental and theoretical studies. McCormick & Sawyer (1938) published an extension and revision of the earlier work on Sn II. In 1976, Wujec & Musielok measured the transition probabilities of four lines of Sn II in the spectral range of 5400–6850 Å and corresponding to configurations $5s^2nl$. Transition probabilities for nine lines in the spectral range 5400–6850 Å corresponding to $5s^2nl$ were measured by Wujec & Weniger in 1977. In 1979, Miller et al. measured transitions probabilities for 18 Sn II lines in the spectral range 3200–7900 Å including levels corresponding to the $5s5p^2$ configuration. By means of a semi-empirical method, 24 transition probabilities of lines corresponding to the configurations $5s^26p$ and $5s^2ns$ (n = 6–11) were calculated by Kunisz & Migdalez in 1974. Using a semi-empiric calculation that included relativistic effects, Migdalek in 1976 predicted a systematic behavior in oscillator strengths for 39 transitions from the configurations $5s^2ns$ (the n = 6–10), $5s^2np$ (the n = 6–8) and $5s^2nd$ (the n = 5–9). Shock-tube data were used to examine the experimental f-value behavior in visible transitions ($5s^2ns$, $5s^2np$ and $5s^2nd$) of Sn II, by Miller & Bengtson in 1980. An important theoretical study of oscillator strengths of Sn II was presented in 1994 by Marcinek & Migdalek.

Radiative lifetimes of the $5s^24f$ configuration were performed in intersecting atomic and electron beams by the multichannel method of retarded coincidences by Gorskov & Verolainen (1985). Andersen & Lindgard (1977) carried out measurements of $5s^25d$ configurations using beam foil spectroscopy. In 2000 Schectman et al. measuared the lifetimes and oscillator strengh for levels arising from the $5s^25d$ and $5s^24f$ configurations in Sn II using a beam foil method.

Theoretical analysis of Sn II was extended to autoionized levels in a previous work carried out by us (Alonso-Medina et al. 2003). The parametric description of 5s5p5d and 5s5p6s levels was improved by taking into account the far $5p^3$ configuration mixing effects and using relativistic Hartree-Fock calculations and configuration interactions. In this work we confine our study to the identification of the autoionized levels completing all the existent gaps in the charts of Moore (1958). The mixing of configurations achieved also allowed us to explain the experimental value obtained for Schetman et al. (2000) of the lifetime of $5s^2$ 5d ^{2} $D_{3/2}$. However the oscillator strengths corresponding to all these autoionized levels were not calculated.

In this work the transition probabilities and the oscillator strengths corresponding to these levels, not indexed in the bibliography, are calculated. The mentioned above transitions do not correspond to autoinonized levels. Their initial energy levels are therefore lower than those of the transitions analyzed in this work. Almost all the oscillator strengths correspond to lines in the ultraviolet range (UV) of high interest in astrophysics. With these calculations the study of the transition probabilities of Sn II is completed. The analysis of other spectroscopic parameters such as the Stark broadening of Sn II UV lines can be carried out with the semiempiric approach. This requires an exhaustive knowledge of the transition probabilities.

In this work we also include the lifetimes of levels corresponding to the configuration 5s5p5d.

* Tables 1 and 2 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/422/1109

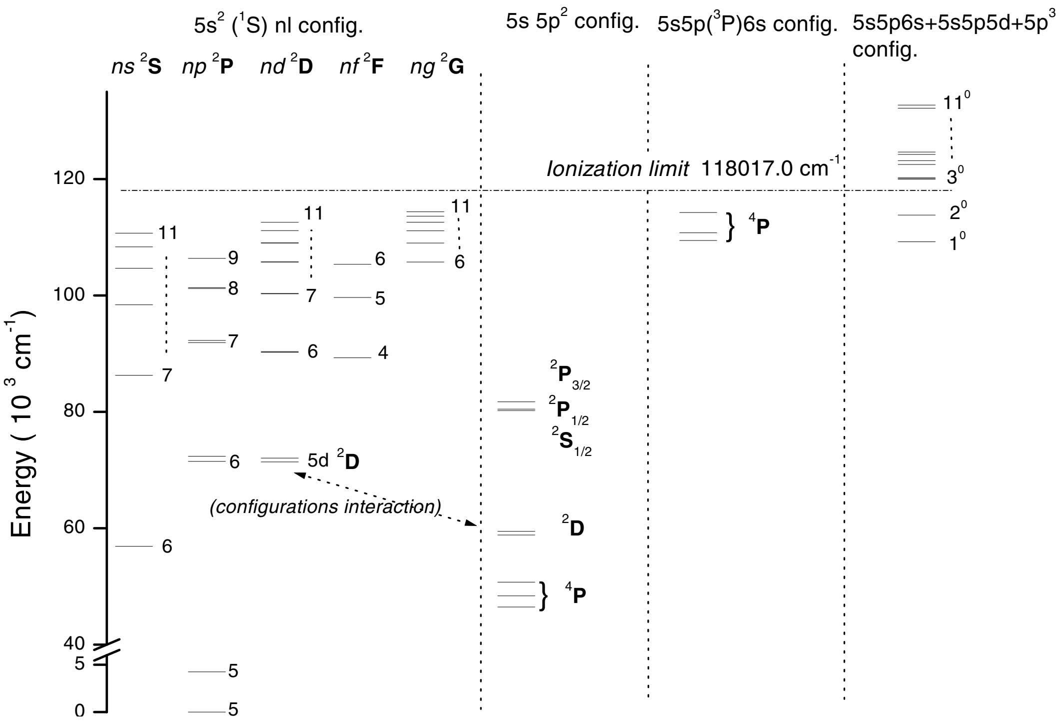

Fig. 1. Effects of $5p^3$–5s5p5d–5s5p6s configuration interaction.

2. Theoretical calculations

An energy levels diagram of Sn II is presented in Fig. 1. Most of the known experimental levels of singly ionized tin involves a single optical electron whose energy levels are well separated. This structure allows us to obtain a suitable comparison between experimental and theoretical results with relativistic central field calculations using the LS coupling scheme. In the left part of Fig. 1 a number of experimental configurations ($5s^2$ (^{1}S) *nl*) that can be described in this way can be observed. Nevertheless this model is not adequate to describe the remaining configurations of this figure ($5s5p^2$, 5s5p6s and 5s5p5d configurations). Likewise neither the position of the levels $5s^25d^2D$ nor the inversion in the $5s^2nf$ multiplets couls be explained. A more detailed description is necessary to take into account these discrepancies.

In our previous work (Alonso-Medina et al 2003), we have considered the interaction of three configurations of even parity namely, $5s5p^2$–$5s^25d$–$5s^26d$ and six configurations of odd parity namely, $5s^25p$–$5p^3$–5s5p5d–5s5p6s–$5s^24f$–$5s^25f$. For the interaction of configurations (IC), ab initio quasirelativistic Hartree-Fock (HFR) calculations were performed. We used the standard method of least-square fitting of experimental energy levels (Moore 1958) by means of computer codes from Cowan (1981). For the HFR calculations the Cowan computer code provides the radial parts for determination of transition probabilities and initial estimation of the parameters for the IC fittings. The system considered is complex, with high *Z* where both relativistic and correlation effects are expected to be important. Least-square fitting of experimental energy levels partially accounts for the correlation effects not explicitly calculated in our work.

In this way we obtained the LS composition of each level and the degree of configuration mixing, when we consider their interaction. These levels were not clearly identified in the existing literature.

In this work we used the wave functions previously obtained by this method in order to calculate the matrix elements of transitions probabilities and the oscillator strengths

3. Results

Oscillator strengths calculated for 103 lines of Sn II arising from autoinized levels are displayed in column three of Table 1, while columns one and two give the transitions and corresponding wavelengths, respectively.

In the second column of Table 2, we present the radiative lifetimes calculted for 13 levels of Sn II. Two levels correspond to $5s^24f\ ^2F_{5/2,7/2}$ for both theoretical and experimental values obtained by other authors. In Cols. 3 and 4 of Table 2 we present these values. A good agreement exists between our work and the experimental values.

The eleven remaining values correspond to the levels labeled by Moore as 1^0 at 11^0 and whose identification is based on the IC $5p^3$–5s5p5d–5s5p6s.

4. Conclusions

In this work we present theoretical oscillator strengths and lifetimes of Sn II levels in a range of wavelengths (UV) of high astrophysical interest. An analisis of the Sn II has been carried out. However some smaller discrepancies persist: the energy of the levels $5s5p^2\ ^2S_{1/2}$ and $5s5p^2\ ^2P_{1/2}$ is not determined. The mentioned above discrepancies between experimental and theoretical energy levels suggested the presence of other configurations in the interaction. In order to eliminate we have considered the 20 even configurations suggested by Marcinek & Migdalek (1994). Consideration of some of these configurations and a HFR calculation show that the complete set was not successful. Attempts to carry out a least-square fitting, including these configurations, resulted in no improvement while presenting difficulties due to the increase in the number of parameters above the number of experimentally observed energy levels. The discrepancies pointed out should not influence in future calculations of Stark line broadening. Given the large quantity of levels involved in these calculations the contribution of the levels mentioned will be small.

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