# Stark broadening of Sn III spectral lines of astrophysical interest: predictions and regularities

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**ABSTRACT**

The determination of the Stark broadening parameters of Sn ions is useful for astrophysicists interested in the determination of the density of electrons in stellar atmospheres. In this paper, we report on the calculated values of the Stark broadening parameters for 171 lines of Sn III arising from $4d^{10}5sns$ ($n$ = 6–9), $4d^{10}5snp$ ($n$ = 5, 6), $4d^{10}5p^2$, $4d^{10}5snd$ ($n$ = 5–7), $4d^{10}5s4f$ and $4d^{10}5s5g$. Stark linewidths and line shifts are presented for an electron density of $10^{23}$ m$^{-3}$ and temperatures $T$ = 11 000–75 000 K. These have been calculated using a semi-empirical approach, with a set of wavefunctions obtained from Hartree–Fock relativistic calculations, including core polarization effects. The results obtained have been compared with available experimental data. These can be used to consider the influence of Stark broadening effects in A-type stellar atmospheres.

**Key words:** atomic data – atomic processes.

## 1 INTRODUCTION

The Stark broadening parameters of Sn III spectral lines are of interest not only for astrophysical purposes but also for plasma diagnosis, research into regularities and systematic trends and theoretical considerations. In astrophysics, the presence of elements beyond the iron group has been discovered in the atmospheres of the cold DO white dwarfs, HD 149499 B and HZ 21. Photospheric lines of tin are observed in the ultraviolet spectra of HD 149499 B, obtained using the *Far Ultraviolet Spectroscopic Explorer*, the Goddard High Resolution Spectrograph and the *International Ultraviolet Explorer*. The spectral lines of neutral tin are present in the spectra of A-type stars (Adelman, Bidelman & Bidelman 1979), and interstellar singly ionized tin has been detected in several stars: 15 Mon, 23 Ori, $\pi$ Sco, 1 Sco and $\varsigma$ Oph (Hobbs et al. 1993; Savage & Sembach 1996; Sofía, Meyer & Cardelli 1999). These measurements have demonstrated that tin is exchanged between the gas and dust phases of the diffuse interstellar medium. In this way, Proffitt, Sansonetti & Reader (2001) determined the tin abundance of the early B main-sequence star, AV 304, in the Small Magellanic Cloud using the 1313.5-Å resonance line of Sn IV. Simić et al. (2008) and Simi (2009) investigated theoretically the influence of collisions with charged particles on heavy metal spectral-line profiles for Sn III in the spectra of A stars and white dwarfs. Also, Sn plasmas are being intensively studied as a candidate for the extreme ultraviolet light source for next-generation microlithography (Harilal, O'Shay & Tillack 2005; Sasaki et al. 2009).

In a pulse tin discharge, Kieft et al. (2004) determined Stark broadening parameters for the 5371.1-, 5292.7-, 5351.0- and 5226.2-Å lines of Sn III. In 2007, Djeniže (2007) measured the Stark broadening parameters for seven spectral lines of Sn III ranging between 2000 and 7000 Å.

Previously published theoretical studies of the Stark parameters of Sn III are scarce (Kieft et al. 2004; Simić et al. 2008; Simi 2009). Kieft et al. (2004) present the theoretical parameters of the Stark broadening of the experimentally investigated spectral lines mentioned above. They use the Griem (1968) approach, but they do not indicate the method used to calculate the $r^2$ matrix elements that are required. Simić et al. (2008) have carried out calculations for the 5226.2-Å line of Sn III by using both the full semi-classical perturbation approach (Sahal-Bréchot 1969a,b) and the semi-empirical approach – the so-called modified semi-empirical method (Dimitrijević & Konjević 1980). In both cases, the matrix elements used were obtained using the method of Bates & Damgaard (1949).

In this paper, we present the Stark broadening of 171 lines of Sn III arising from $4d^{10}5sns$ ($n$ = 6–9), $4d^{10}5snp$ ($n$ = 5, 6), $4d^{10}5p^2$, $4d^{10}5snd$ ($n$ = 5–7), $4d^{10}5s4f$ and $4d^{10}5s5g$. Stark widths and shifts are presented for an electron density of $10^{23}$ m$^{-3}$ and temperatures $T$ = 11 000–75 000 K. These have been calculated using a semi-empirical approach with a set of wavefunctions obtained from Hartree–Fock relativistic calculations, including core polarization effects. The values presented are compared with the experimental and calculated values that can be found in the references. We have studied the regularity of the Stark broadening parameter versus temperature. The regularity of the Stark broadening of the 5226.2-Å

Sn III spectral line versus temperature has been compared with the theoretical trends deduced by other authors.

## 2 THEORETICAL CALCULATIONS

Based on the original formulation of Baranger (1958) and the use of an effective Gaunt factor, proposed by Seaton (1962) and Van Regemorter (1962), Griem (1968) suggested a simple semi-empirical impact approximation. The Stark linewidth and Stark line shifts can be calculated from the following semi-empirical formulae:

$$\omega_{\mathrm{se}} \approx 8\left(\frac{\pi}{3}\right)^{3/2}\frac{\hbar}{m a_0}N_{\mathrm{e}}\left(\frac{E_{\mathrm{H}}}{kT}\right)^{1/2} \times\left[\sum_{i'}|\langle i'|\boldsymbol{r}|i\rangle|^2 g_{\mathrm{se}}\left(\frac{E}{\Delta E_{i'i}}\right) +\sum_{f'}|\langle f'|\boldsymbol{r}|f\rangle|^2 g_{\mathrm{se}}\left(\frac{E}{\Delta E_{f'f}}\right)\right] \quad (1)$$

$$d \approx -8\left(\frac{\pi}{3}\right)^{3/2}\frac{\hbar}{m a_0}N_{\mathrm{e}}\left(\frac{E_{\mathrm{H}}}{kT}\right)^{1/2} \times\left[\sum_{i'}\left(\frac{\Delta E_{i'i}}{|\Delta E_{i'i}|}\right)|\langle i'|\boldsymbol{r}\ |i\rangle|^2 g_{\mathrm{sh}}\left(\frac{E}{\Delta E_{i'i}}\right) -\sum_{f'}\left(\frac{\Delta E_{f'f}}{|\Delta E_{f'f}|}\right)|\langle f'|\boldsymbol{r}\ |f\rangle|^2 g_{\mathrm{sh}}\left(\frac{E}{\Delta E_{f'f}}\right)\right]. \quad (2)$$

Here, $\omega_{\mathrm{se}}$ and $d$ are the Stark linewidth and shift, respectively, in angular frequency units, $E_{\mathrm{H}}$ is the hydrogen ionization energy, $N_{\mathrm{e}}$ is the free electron perturber density, $T$ is the electron temperature, $E=(3/2)kT$ is the mean energy of the perturbing electron and $g_{\mathrm{se}}$ and $g_{\mathrm{sh}}$ are the effective Gaunt factors suggested by Niemann et al. (2003). These factors are slowly varying functions of $x_{i'i}=E/\Delta E_{i'i}$, where $\Delta E_{i'i}$ is the energy difference between a perturbing level $i'$ and the initial level $i$. The indices $i$ and $f$ denote the initial (upper) and final (lower) levels of the transition, respectively. $\omega_{\mathrm{se}}$ is the half width at half-maximum (HWHM) of the Lorentz profile in angular frequency. $\omega_{\mathrm{se}}$ is proportional to the full width at half-maximum

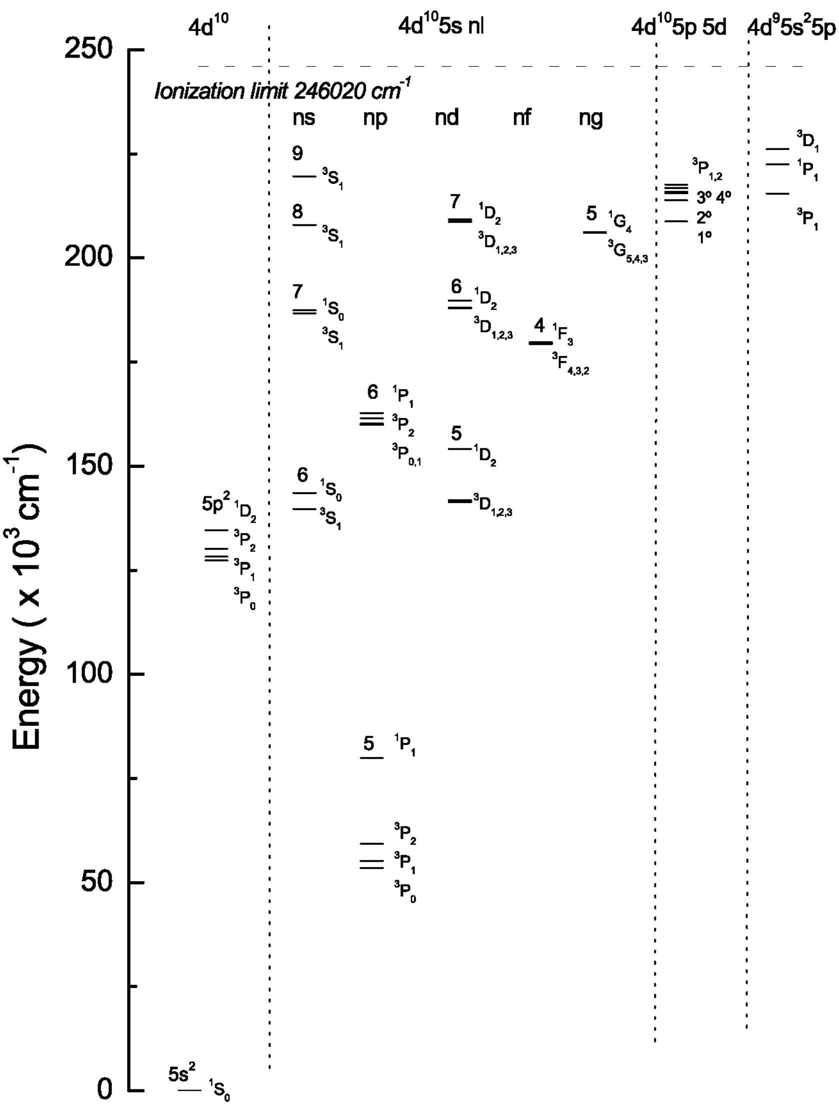


**Figure 1.** Energy level diagram of Sn III (Moore 1958).

(FWHM) line $\omega$ in wavelength units, through the expression $\omega = \omega_{se}\lambda^2/(\pi c)$.

The atomic matrix elements were obtained using relativistic Hartree–Fock calculations and configuration interaction in an intermediate coupling (IC) scheme. The code of Cowan (1981) was selected for this calculation. The experimental levels used for the calculations have been taken from the tables of Moore (1958). We have included the three levels of $4d^5 5s^2 5p$ reported by Dunne et al. (1999). Fig. 1 displays a Gotrian scheme of the Sn III energy levels used in this work.

The system considered is complex, with high $Z$ (atomic number) where both relativistic and correlation effects are expected to be important. Following the suggestions of Migdalek & Baylis (1978), we have included in our calculations the core polarization effects.

The basis set used in this work consists of 10 configurations of even parity, namely, $4d^{10}5s^2$, $4d^{10}5p^2$, $4d^{10}5sns$ ($n = 6$–9), $4d^{10}5snd$ (5–7) and $4d^{10}5s5g$, and five configurations of odd parity, namely, $4d^{10}5snp$ (5–6), $4d^{10}5s4f$, $4d^{10}5p5d$ and $4d^9 5s^2 6p$. The wavefunctions obtained in this description have been used in this work to obtain the matrix elements. A more detailed description of these calculations is presented in Colón & Alonso-Medina (2010).

## 3 RESULTS AND DISCUSSION

Our results for the Stark linewidth (FWHM) and line shift at an electron density of $10^{17}$ cm$^{-3}$ and several temperatures $T = 11\,600$–$75\,000$ K are displayed in Tables 1–4. Columns (2) and (3) give the corresponding transition array and the multiplet. The wavelengths (in Å) and the temperatures (in K) are shown in columns (4) and (5). Stark broadening linewidths (in pm) are displayed in column (6). The last column displays the theoretical Stark line shift.

In Tables 2 and 4, we compare our values with those measured and calculated in the references. We have found experimental values for 11 Sn III lines (measured by Kieft et al. 2004 and Djeniže 2007). When comparing these with our results, we have found good agreement in five of the transitions studied, as can be observed in the above-mentioned tables: 5371.1 and 5226.2 Å (both have been measured by Kieft et al. 2004), 2896.8, 2632.6 and 2070.7 Å (these last three lines have been measured by Djeniže). Fig. 2 displays the calculated Stark widths FWHM [$\omega$(Å)] and Stark line shifts [$d$(Å)] versus temperature for the 1570.4- and 2896.8-Å Sn III lines.

Fig. 3 displays the calculated Stark widths FWHM versus temperature for the 5226.2-Å line. In this figure, we compare our calculations with the experimental value and with that calculated by other authors. As can be seen, all the calculations are near to the experimental value measured by Kieft et al. (2004), inside the error margins. As can be expected, the value calculated by Kieft et al. (2004) underestimates the experimental value.

In the six remaining lines, it can be seen that our values are above the experimental values found.

It is well known (Konjević 1999) that for some ionic spectral lines there are large discrepancies between the experimental results obtained for the Stark broadenings and the theoretical results for these broadenings, when they have been calculated using the Griem (1968) approach. This situation can be attributed to the difficulties in using equations (1) and (2). As indicated (Dimitrijević & Konjević 1980), there are two problems that can explain the accuracy of the application of these equations in multiply ionized

**Table 1.** Sn III $4d^{10}5sns$ linewidths (FWHM), $\omega$(pm) and shifts, $d$(pm), normalized to $Ne = 10^{23}$ m$^{-3}$.

| Line no | Transition array | Multiplet | Wavelength (Å)$^a$ | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 1 | 5p–6s | $^3P_0$–$^3S_1$ | 1161.6 | 11.6 | 5.2 | −4.2 |
| | | | | 17.5 | 4.0 | −3.2 |
| | | | | 20 | 3.7 | −3.0 |
| | | | | 25 | 3.2 | −2.6 |
| | | | | 35 | 2.6 | −2.1 |
| | | | | 50 | 2.1 | −1.8 |
| | | | | 75 | 1.7 | −1.4 |
| 2 | 5p–6s | $^3P_1$–$^3S_1$ | 1184.3 | 11.6 | 6.5 | −5.5 |
| | | | | 17.5 | 5.0 | −4.2 |
| | | | | 20 | 4.5 | −3.8 |
| | | | | 25 | 4.0 | −3.4 |
| | | | | 35 | 3.2 | −2.7 |
| | | | | 50 | 2.6 | −2.2 |
| | | | | 75 | 2.1 | −1.8 |
| 3 | 5p–6s | $^3P_2$–$^3S_1$ | 1243.6 | 11.6 | 8.3 | −7.2 |
| | | | | 17.5 | 6.3 | −5.5 |
| | | | | 20 | 5.8 | −5.0 |
| | | | | 25 | 5.0 | −4.4 |
| | | | | 35 | 4.1 | −3.6 |
| | | | | 50 | 3.3 | −2.9 |
| | | | | 75 | 2.6 | −2.3 |
| 4 | 5p–6s | $^1P_1$–$^3S_1$ | 1674.3 | 11.6 | 15.1 | −11.2 |
| | | | | 17.5 | 11.5 | −8.6 |
| | | | | 20 | 10.6 | −7.9 |
| | | | | 25 | 9.2 | −6.9 |
| | | | | 35 | 7.5 | −5.6 |
| | | | | 50 | 6.1 | −4.6 |
| | | | | 75 | 4.8 | −3.7 |
| 5 | 5p–6s | $^3P_1$–$^1S_0$ | 1131.3 | 11.6 | 3.0 | −2.3 |
| | | | | 17.5 | 2.3 | −1.8 |
| | | | | 20 | 2.1 | −1.6 |
| | | | | 25 | 1.8 | −1.4 |
| | | | | 35 | 1.5 | −1.1 |
| | | | | 50 | 1.2 | −1.0 |
| | | | | 75 | 1.0 | −0.8 |
| 6 | 5p–6s | $^1P_1$–$^1S_0$ | 1570.4 | 11.6 | 7.7 | −4.7 |
| | | | | 17.5 | 5.9 | −3.6 |
| | | | | 20 | 5.4 | −3.3 |
| | | | | 25 | 4.6 | −2.9 |
| | | | | 35 | 3.8 | −2.3 |
| | | | | 50 | 3.0 | −1.9 |
| | | | | 75 | 2.4 | −1.5 |
| 7 | 5p–7s | $^3P_0$–$^3S_1$ | 751.1 | 11.6 | 1.2 | 0.74 |
| | | | | 17.5 | 0.90 | 0.57 |
| | | | | 20 | 0.82 | 0.52 |
| | | | | 25 | 0.72 | 0.46 |
| | | | | 35 | 0.58 | 0.38 |
| | | | | 50 | 0.47 | 0.31 |
| | | | | 75 | 0.38 | 0.25 |
| 8 | 5p–7s | $^3P_1$–$^3S_1$ | 760.5 | 11.6 | 1.6 | 0.31 |
| | | | | 17.5 | 1.3 | 0.25 |
| | | | | 20 | 1.1 | 0.23 |
| | | | | 25 | 1.0 | 0.21 |
| | | | | 35 | 0.81 | 0.18 |
| | | | | 50 | 0.65 | 0.15 |
| | | | | 75 | 0.52 | 0.13 |
| 9 | 5p–7s | $^3P_2$–$^3S_1$ | 784.6 | 11.6 | 2.2 | −0.13 |
| | | | | 17.5 | 1.7 | −0.084 |
| | | | | 20 | 1.5 | −0.071 |
| | | | | 25 | 1.3 | −0.052 |
| | | | | 35 | 1.1 | −0.030 |
| | | | | 50 | 0.87 | −0.012 |
| | | | | 75 | 0.69 | 0.001 |
| 10 | 5p–7s | $^1P_1$–$^3S_1$ | 936.5 | 11.6 | 3.2 | 0.38 |
| | | | | 17.5 | 2.4 | 0.31 |
| | | | | 20 | 2.2 | 0.29 |
| | | | | 25 | 1.9 | 0.26 |
| | | | | 35 | 1.5 | 0.22 |

**Table 1** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 50 | 1.2 | 0.19 |
| | | | | 75 | 0.99 | 0.16 |
| 11 | 6p–7s | $^3P_0$–$^3S_1$ | 3738.5 | 11.6 | 46.5 | 18.5 |
| | | | | 17.5 | 35.7 | 14.3 |
| | | | | 20 | 32.9 | 13.2 |
| | | | | 25 | 28.7 | 11.6 |
| | | | | 35 | 23.5 | 9.5 |
| | | | | 50 | 19.2 | 7.8 |
| | | | | 75 | 15.4 | 6.2 |
| 12 | 6p–7s | $^3P_1$–$^3S_1$ | 3777.5 | 11.6 | 93.8 | 9.1 |
| | | | | 17.5 | 72.2 | 7.2 |
| | | | | 20 | 66.4 | 6.7 |
| | | | | 25 | 58.0 | 5.9 |
| | | | | 35 | 47.5 | 5.0 |
| | | | | 50 | 38.9 | 4.2 |
| | | | | 75 | 31.2 | 3.5 |
| 13 | 6p–7s | $^3P_2$–$^3S_1$ | 3959.6 | 11.6 | 154.3 | −1.5 |
| | | | | 17.5 | 118.7 | −0.88 |
| | | | | 20 | 109.2 | −0.72 |
| | | | | 25 | 95.3 | −0.49 |
| | | | | 35 | 78.1 | −0.23 |
| | | | | 50 | 63.9 | −0.044 |
| | | | | 75 | 51.3 | 0.085 |
| 14 | 6p–7s | $^1P_1$–$^3S_1$ | 4173.1 | 11.6 | 111.8 | 21.2 |
| | | | | 17.5 | 86.3 | 16.7 |
| | | | | 20 | 79.5 | 15.5 |
| | | | | 25 | 69.4 | 13.7 |
| | | | | 35 | 57.0 | 11.5 |
| | | | | 50 | 46.7 | 9.6 |
| | | | | 75 | 37.6 | 7.8 |
| 15 | 5p–7s | $^3P_1$–$^1S_0$ | 756.4 | 11.6 | 0.92 | −0.41 |
| | | | | 17.5 | 0.69 | −0.30 |
| | | | | 20 | 0.64 | −0.28 |
| | | | | 25 | 0.55 | −0.23 |
| | | | | 35 | 0.44 | −0.18 |
| | | | | 50 | 0.35 | −0.14 |
| | | | | 75 | 0.28 | −0.11 |
| 16 | 5p–7s | $^1P_1$–$^1S_0$ | 930.3 | 11.6 | 2.1 | −0.71 |
| | | | | 17.5 | 1.5 | −0.53 |
| | | | | 20 | 1.4 | −0.48 |
| | | | | 25 | 1.2 | −0.41 |
| | | | | 35 | 0.99 | −0.32 |
| | | | | 50 | 0.79 | −0.25 |
| | | | | 75 | 0.62 | −0.19 |
| 17 | 6p–7s | $^3P_1$–$^1S_0$ | 3678.6 | 11.6 | 72.0 | −8.3 |
| | | | | 17.5 | 55.4 | −6.2 |
| | | | | 20 | 51.0 | −5.6 |
| | | | | 25 | 44.6 | −4.8 |
| | | | | 35 | 36.6 | −3.8 |
| | | | | 50 | 29.9 | −3.0 |
| | | | | 75 | 24.0 | −2.3 |
| 18 | 6p–7s | $^1P_1$–$^1S_0$ | 4052.8 | 11.6 | 84.9 | −0.58 |
| | | | | 17.5 | 65.6 | −0.030 |
| | | | | 20 | 60.4 | 0.10 |
| | | | | 25 | 52.8 | 0.28 |
| | | | | 35 | 43.4 | 0.47 |
| | | | | 50 | 35.6 | 0.58 |
| | | | | 75 | 28.7 | 0.62 |
| 19 | 5p–8s | $^3P_0$–$^3S_1$ | 647.6 | 11.6 | 0.16 | −0.15 |
| | | | | 17.5 | 0.12 | −0.11 |
| | | | | 20 | 0.11 | −0.10 |
| | | | | 25 | 0.096 | −0.095 |
| | | | | 35 | 0.077 | −0.076 |
| | | | | 50 | 0.061 | −0.060 |
| | | | | 75 | 0.047 | −0.046 |
| 20 | 5p–8s | $^3P_1$–$^3S_1$ | 654.6 | 11.6 | 0.56 | −0.44 |
| | | | | 17.5 | 0.42 | −0.33 |
| | | | | 20 | 0.38 | −0.30 |
| | | | | 25 | 0.33 | −0.26 |

**Table 1** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 35 | 0.26 | −0.21 |
| | | | | 50 | 0.21 | −0.16 |
| | | | | 75 | 0.16 | −0.13 |
| 21 | 5p–8s | $^3P_2$–$^3S_1$ | 672.4 | 11.6 | 0.92 | −0.80 |
| | | | | 17.5 | 0.70 | −0.60 |
| | | | | 20 | 0.64 | −0.55 |
| | | | | 25 | 0.55 | −0.47 |
| | | | | 35 | 0.44 | −0.38 |
| | | | | 50 | 0.35 | −0.30 |
| | | | | 75 | 0.27 | −0.23 |
| 22 | 5p–8s | $^1P_1$–$^3S_1$ | 781.0 | 11.6 | 1.26 | −0.68 |
| | | | | 17.5 | 0.95 | −0.52 |
| | | | | 20 | 0.87 | −0.47 |
| | | | | 25 | 0.75 | −0.40 |
| | | | | 35 | 0.60 | −0.32 |
| | | | | 50 | 0.48 | −0.26 |
| | | | | 75 | 0.37 | −0.20 |
| 23 | 6p–8s | $^3P_0$–$^3S_1$ | 2082.6 | 11.6 | 7.8 | −1.0 |
| | | | | 17.5 | 5.9 | −0.76 |
| | | | | 20 | 5.4 | −0.70 |
| | | | | 25 | 4.7 | −0.60 |
| | | | | 35 | 3.9 | −0.48 |
| | | | | 50 | 3.2 | −0.38 |
| | | | | 75 | 2.5 | −0.30 |
| 24 | 6p–8s | $^3P_1$–$^3S_1$ | 2094.6 | 11.6 | 22.0 | −4.0 |
| | | | | 17.5 | 16.9 | −3.0 |
| | | | | 20 | 15.6 | −2.8 |
| | | | | 25 | 13.6 | −2.4 |
| | | | | 35 | 11.1 | −1.9 |
| | | | | 50 | 9.1 | −1.5 |
| | | | | 75 | 7.3 | −1.2 |
| 25 | 6p–8s | $^3P_2$–$^3S_1$ | 2149.7 | 11.6 | 38.3 | −7.6 |
| | | | | 17.5 | 29.4 | −5.8 |
| | | | | 20 | 27.1 | −5.3 |
| | | | | 25 | 23.6 | −4.6 |
| | | | | 35 | 19.4 | −3.7 |
| | | | | 50 | 15.8 | −3.0 |
| | | | | 75 | 12.7 | −2.4 |
| 26 | 6p–8s | $^1P_1$–$^3S_1$ | 2210.8 | 11.6 | 23.8 | −1.7 |
| | | | | 17.5 | 18.3 | −1.2 |
| | | | | 20 | 16.9 | −1.0 |
| | | | | 25 | 14.8 | −0.85 |
| | | | | 35 | 12.1 | −0.63 |
| | | | | 50 | 10.0 | −0.46 |
| | | | | 75 | 8.0 | −0.33 |
| 27 | 5p–9s | $^3P_0$–$^3S_1$ | 602.6 | 11.6 | 0.16 | −0.13 |
| | | | | 17.5 | 0.12 | −0.094 |
| | | | | 20 | 0.11 | −0.086 |
| | | | | 25 | 0.092 | −0.074 |
| | | | | 35 | 0.073 | −0.059 |
| | | | | 50 | 0.058 | −0.047 |
| | | | | 75 | 0.045 | −0.036 |
| 28 | 5p–9s | $^3P_1$–$^3S_1$ | 608.6 | 11.6 | 0.015 | 0.014 |
| | | | | 17.5 | 0.012 | 0.011 |
| | | | | 20 | 0.011 | 0.010 |
| | | | | 25 | 0.009 | 0.009 |
| | | | | 35 | 0.007 | 0.007 |
| | | | | 50 | 0.006 | 0.006 |
| | | | | 75 | 0.005 | −0.004 |
| 29 | 5p–9s | $^3P_2$–$^3S_1$ | 623.9 | 11.6 | 0.76 | −0.73 |
| | | | | 17.5 | 0.57 | −0.55 |
| | | | | 20 | 0.52 | −0.50 |
| | | | | 25 | 0.45 | −0.43 |
| | | | | 35 | 0.36 | −0.34 |
| | | | | 50 | 0.28 | −0.27 |
| | | | | 75 | 0.22 | −0.21 |
| 30 | 5p–9s | $^1P_1$–$^3S_1$ | 716.4 | 11.6 | 1.0 | −0.62 |
| | | | | 17.5 | 0.76 | −0.47 |
| | | | | 20 | 0.70 | −0.43 |

**Table 1** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 25 | 0.60 | −0.37 |
| | | | | 35 | 0.48 | −0.30 |
| | | | | 50 | 0.38 | −0.24 |
| | | | | 75 | 0.30 | −0.18 |
| 31 | 6p–9s | $^3P_0$–$^3S_1$ | 1678.9 | 11.6 | 4.7 | −0.93 |
| | | | | 17.5 | 3.6 | −0.70 |
| | | | | 20 | 3.3 | −0.64 |
| | | | | 25 | 2.9 | −0.55 |
| | | | | 35 | 2.4 | −0.44 |
| | | | | 50 | 1.9 | −0.35 |
| | | | | 75 | 1.6 | −0.28 |
| 32 | 6p–9s | $^3P_1$–$^3S_1$ | 1686.7 | 11.6 | 11.0 | −2.9 |
| | | | | 17.5 | 10.8 | −2.2 |
| | | | | 20 | 9.9 | −2.0 |
| | | | | 25 | 8.7 | −1.7 |
| | | | | 35 | 7.1 | −1.4 |
| | | | | 50 | 5.8 | −1.1 |
| | | | | 75 | 4.7 | −0.86 |
| 33 | 6p–9s | $^3P_2$–$^3S_1$ | 1722.2 | 11.6 | 24.3 | −5.2 |
| | | | | 17.5 | 18.7 | −3.9 |
| | | | | 20 | 17.2 | −3.6 |
| | | | | 25 | 15.0 | −3.1 |
| | | | | 35 | 12.3 | −2.5 |
| | | | | 50 | 10.0 | −2.0 |
| | | | | 75 | 8.1 | −1.6 |
| 34 | 6p–9s | $^1P_1$–$^3S_1$ | 1761.2 | 11.6 | 15.0 | −1.3 |
| | | | | 17.5 | 11.4 | −0.96 |
| | | | | 20 | 10.5 | −0.86 |
| | | | | 25 | 9.2 | −0.72 |
| | | | | 35 | 7.6 | −0.54 |
| | | | | 50 | 6.2 | −0.41 |
| | | | | 75 | 5.0 | −0.30 |

[a]Moore (1958).

**Table 2.** Sn III $4d^{10}5snp$ and $4d^{10}5p^2$ linewidths (FWHM), $\omega$(pm) and shifts, $d$(pm), normalized to $Ne = 10^{23}$ m$^{-3}$. Linewidths compared with other experimental and theoretical values.

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 1 | $5s^2$–5p | $^1S_0$–$^3P_1$ | 1811.7 | 11.6 | 4.95 | −4.93 |
| | | | | 17.5 | 3.72 | −3.71 |
| | | | | 20 | 3.40 | −3.38 |
| | | | | 25 | 2.92 | −2.91 |
| | | | | 35 | 2.33 | −2.33 |
| | | | | 50 | 1.85 | −1.85 |
| | | | | 75 | 1.44 | −1.43 |
| 2 | $5s^2$–5p | $^1S_0$–$^1P_1$ | 1251.4 | 11.6 | 3.57 | −2.51 |
| | | | | 17.5 | 2.69 | −1.89 |
| | | | | 20 | 2.45 | −1.73 |
| | | | | 25 | 2.11 | −1.49 |
| | | | | 35 | 1.69 | −1.19 |
| | | | | 50 | 1.34 | −0.95 |
| | | | | 75 | 1.05 | −0.74 |
| 3 | 6s–6p | $^3S_1$–$^3P_0$ | 4925.7 | 11.6 | 123.4 | −75.4 |
| | | | | 17.5 | 95.0 | −58.1 |
| | | | | 20 | 87.4 | −53.6 |
| | | | | 25 | 76.4 | −46.9 |
| | | | | 35 | 62.6 | −38.6 |
| | | | | 50 | 51.2 | −31.7 |
| | | | | 75 | 41.1 | −25.6 |
| 4 | $5p^2$–6p | $^3P_1$–$^3P_0$ | 3353.4 | 11.6 | 22.3 | −0.21 |
| | | | | 17.5 | 17.1 | −0.16 |
| | | | | 20 | 15.7 | −0.15 |
| | | | | 25 | 13.7 | −0.13 |
| | | | | 35 | 11.2 | −0.11 |

**Table 2** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 50 | 9.1 | −0.10 |
| | | | | 75 | 7.3 | −0.09 |
| 5 | 5d–6p | $^3D_1$–$^3P_0$ | 5371.1 | 11.6 | 88.7 | −41.2 |
| | | | | | 64.0 ± 30 per cent[b] | |
| | | | | | 60.0[b] | |
| | | | | 17.5 | 72.2 | −33.6 |
| | | | | 20 | 67.6 | −3.4 |
| | | | | 25 | 60.4 | −28.1 |
| | | | | 35 | 51.1 | −23.7 |
| | | | | 50 | 42.7 | −19.8 |
| | | | | 75 | 34.9 | −16.2 |
| 6 | $5s^2$–6p | $^1S_0$–$^1P_1$ | 624.2 | 11.6 | 2.0 | −0.32 |
| | | | | 17.5 | 1.5 | −0.23 |
| | | | | 20 | 1.4 | −0.21 |
| | | | | 25 | 1.2 | −0.18 |
| | | | | 35 | 1.0 | −0.14 |
| | | | | 50 | 0.82 | −0.11 |
| | | | | 75 | 0.66 | −0.08 |
| 7 | 6s–6p | $^3S_1$–$^3P_1$ | 4859.7 | 11.6 | 196.8 | −89.5 |
| | | | | 17.5 | 151.5 | −68.8 |
| | | | | 20 | 139.5 | −63.3 |
| | | | | 25 | 121.8 | −55.3 |
| | | | | 35 | 99.9 | −45.3 |
| | | | | 50 | 81.7 | −37.0 |
| | | | | 75 | 65.7 | −29.7 |
| 8 | 6s–6p | $^1S_0$–$^3P_1$ | 6015.2 | 11.6 | 219.8 | −62.3 |
| | | | | 17.5 | 169.2 | −47.6 |
| | | | | 20 | 155.8 | −43.8 |
| | | | | 25 | 136.0 | −38.0 |
| | | | | 35 | 111.6 | −31.0 |
| | | | | 50 | 91.2 | −52.2 |
| | | | | 75 | 73.3 | −20.1 |
| 9 | $5p^2$–6p | $^3P_0$–$^3P_1$ | 3038.9 | 11.6 | 46.2 | −8.7 |
| | | | | 17.5 | 35.5 | −6.5 |
| | | | | 20 | 32.7 | −6.0 |
| | | | | 25 | 28.5 | −5.1 |
| | | | | 35 | 23.4 | −4.1 |
| | | | | 50 | 19.1 | −3.3 |
| | | | | 75 | 15.3 | −2.6 |
| 10 | $5p^2$–6p | $^3P_2$–$^3P_1$ | 3898.9 | 11.6 | 85.2 | −10.9 |
| | | | | 17.5 | 65.4 | −8.2 |
| | | | | 20 | 60.1 | −7.5 |
| | | | | 25 | 52.4 | −6.5 |
| | | | | 35 | 42.9 | −5.2 |
| | | | | 50 | 35.0 | −4.2 |
| | | | | 75 | 28.0 | −3.3 |
| 11 | $5p^2$–6p | $^1D_2$–$^3P_1$ | 3123.9 | 11.6 | 60.0 | −21.3 |
| | | | | 17.5 | 46.0 | −16.1 |
| | | | | 20 | 42.3 | −15.7 |
| | | | | 25 | 36.8 | −12.7 |
| | | | | 35 | 30.1 | −10.2 |
| | | | | 50 | 24.5 | −8.2 |
| | | | | 75 | 19.6 | −6.5 |
| 12 | 5d–6p | $^3D_1$–$^3P_1$ | 5292.7 | 11.6 | 164.9 | −54.5 |
| | | | | | 86.0 ± 30 per cent[b] | |
| | | | | | 60.0[b] | |
| | | | | 17.5 | 134.4 | −44.4 |
| | | | | 20 | 125.7 | −41.6 |
| | | | | 25 | 112.5 | −37.2 |
| | | | | 35 | 95.0 | −31.4 |
| | | | | 50 | 79.5 | −26.3 |
| | | | | 75 | 64.9 | −21.5 |
| 13 | 5d–6p | $^3D_2$–$^3P_1$ | 5350.7 | 11.6 | 199.2 | −77.9 |
| | | | | | 68.0 ± 30 per cent[b] | |
| | | | | | 60.0[b] | |
| | | | | 17.5 | 163.4 | −63.2 |
| | | | | 20 | 152.3 | −59.4 |
| | | | | 25 | 136.2 | −53.8 |

**Table 2** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 35 | 115.5 | −44.3 |
| | | | | 50 | 96.3 | −37.6 |
| | | | | 75 | 79.1 | −31.0 |
| 14 | 5d–6p | $^{1}D_{2}$–$^{3}P_{1}$ | 16393.7 | 11.6 | 2114.1 | −432.3 |
| | | | | 17.5 | 1626.3 | −337.9 |
| | | | | 20 | 1496.6 | −312.7 |
| | | | | 25 | 1306.0 | −275.5 |
| | | | | 35 | 1070.0 | −229.2 |
| | | | | 50 | 873.4 | −190.2 |
| | | | | 75 | 700.2 | −155.3 |
| 15 | 6s–6p | $^{3}S_{1}$–$^{3}P_{2}$ | 4587.1 | 11.6 | 244.0 | −95.1 |
| | | | | 17.5 | 187.8 | −73.1 |
| | | | | 20 | 172.9 | −67.2 |
| | | | | 25 | 151.0 | −58.7 |
| | | | | 35 | 123.8 | −48.0 |
| | | | | 50 | 101.2 | −39.2 |
| | | | | 75 | 81.3 | −31.5 |
| 16 | 5p$^2$–6p | $^{3}P_{1}$–$^{3}P_{2}$ | 3193.0 | 11.6 | 86.6 | −14.7 |
| | | | | 17.5 | 66.6 | −11.1 |
| | | | | 20 | 61.3 | −10.2 |
| | | | | 25 | 53.5 | −8.8 |
| | | | | 35 | 43.8 | −7.2 |
| | | | | 50 | 35.8 | −5.8 |
| | | | | 75 | 28.7 | −4.6 |
| 17 | 5p$^2$–6p | $^{3}P_{2}$–$^{3}P_{2}$ | 3721.5 | 11.6 | 122.8 | −20.1 |
| | | | | 17.5 | 94.3 | −15.3 |
| | | | | 20 | 86.8 | −14.0 |
| | | | | 25 | 75.7 | −12.1 |
| | | | | 35 | 62.0 | −9.8 |
| | | | | 50 | 50.6 | −8.0 |
| | | | | 75 | 40.5 | −6.3 |
| 18 | 5d–6p | $^{3}D_{1}$–$^{3}P_{2}$ | 4970.9 | 11.6 | 252.0 | −76.5 |
| | | | | 17.5 | 193.6 | −58.4 |
| | | | | 20 | 178.1 | −53.6 |
| | | | | 25 | 155.3 | −46.5 |
| | | | | 35 | 127.2 | −37.9 |
| | | | | 50 | 103.7 | −30.7 |
| | | | | 75 | 83.2 | −34.5 |
| 19 | 5d–6p | $^{3}D_{2}$–$^{3}P_{2}$ | 5022.1 | 11.6 | 292.0 | −100.5 |
| | | | | 17.5 | 224.2 | −76.8 |
| | | | | 20 | 206.1 | −70.6 |
| | | | | 25 | 179.7 | −61.4 |
| | | | | 35 | 147.0 | −50.0 |
| | | | | 50 | 119.8 | −40.6 |
| | | | | 75 | 96.0 | −32.4 |
| 20 | 5d–6p | $^{3}D_{3}$–$^{3}P_{2}$ | 5102.8 | 11.6 | 337.8 | −127.6 |
| | | | | 17.5 | 259.1 | −97.6 |
| | | | | 20 | 238.3 | −89.7 |
| | | | | 25 | 207.6 | −78.0 |
| | | | | 35 | 169.7 | −63.7 |
| | | | | 50 | 138.2 | −51.8 |
| | | | | 75 | 110.6 | −41.4 |
| 21 | 5s$^2$–6p | $^{1}S_{2}$–$^{1}P_{1}$ | 614.5 | 11.6 | 1.9 | −0.31 |
| | | | | 17.5 | 1.5 | −0.23 |
| | | | | 20 | 1.4 | −0.20 |
| | | | | 25 | 1.2 | −0.17 |
| | | | | 35 | 0.98 | −0.13 |
| | | | | 50 | 0.80 | −0.10 |
| | | | | 75 | 0.64 | −0.08 |
| 22 | 6s–6p | $^{3}S_{1}$–$^{1}P_{1}$ | 4331.4 | 11.6 | 153.5 | −60.2 |
| | | | | 17.5 | 118.4 | −46.1 |
| | | | | 20 | 109.1 | −42.4 |
| | | | | 25 | 95.3 | −36.9 |
| | | | | 35 | 78.4 | −30.2 |
| | | | | 50 | 64.2 | −24.6 |
| | | | | 75 | 51.6 | −19.7 |
| 23 | 6s–6p | $^{1}S_{0}$–$^{1}P_{1}$ | 5226.2 | 11.6 | 141.6 | −24.8 |
| | | | | | 122 ± 50 per cent[b] | |
| | | | | | 72.0[b] | |
| | | | | 17.5 | 115.3 | −20.2 |

**Table 2** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 20 | 107.7 | −18.9 |
| | | | | | 105.0[c] | |
| | | | | | 78.4[d] | |
| | | | | 30 | 88.1 | −15.4 |
| | | | | | 90.7[c] | |
| | | | | | 64.0[d] | |
| | | | | 35 | 81.5 | −14.3 |
| | | | | 50 | 68.2 | −12.0 |
| | | | | | 78.8[c] | |
| | | | | | 51.4[d] | |
| | | | | 75 | 55.7 | −9.8 |
| 24 | 5p$^2$–6p | $^{1}D_{2}$–$^{1}P_{1}$ | 2896.8 | 11.6 | 43.0 | −9.6 |
| | | | | 17.5 | 35.0 | −7.8 |
| | | | | | 32.0 ± 5.1[e] | |
| | | | | 20 | 32.8 | −7.3 |
| | | | | 25 | 29.3 | −6.5 |
| | | | | 30 | 26.8 | −6.0 |
| | | | | 50 | 20.7 | −4.6 |
| | | | | 75 | 16.9 | −3.8 |
| 25 | 5p$^2$–6p | $^{3}P_{2}$–$^{1}P_{1}$ | 3551.4 | 11.6 | 68.7 | −1.7 |
| | | | | 17.5 | 52.9 | −1.1 |
| | | | | 20 | 48.7 | −0.93 |
| | | | | 25 | 42.5 | −0.71 |
| | | | | 35 | 34.9 | −0.46 |
| | | | | 50 | 28.5 | −0.28 |
| | | | | 75 | 22.9 | −0.16 |
| 26 | 5d–6p | $^{3}D_{1}$–$^{1}P_{1}$ | 4672.1 | 11.6 | 148.0 | −38.9 |
| | | | | 17.5 | 113.9 | −29.4 |
| | | | | 20 | 104.9 | −26.9 |
| | | | | 25 | 91.5 | −23.2 |
| | | | | 35 | 75.0 | −18.7 |
| | | | | 50 | 61.3 | −15.1 |
| | | | | 75 | 49.2 | −12.0 |
| 27 | 5d–6p | $^{3}D_{2}$–$^{1}P_{1}$ | 4717.3 | 11.6 | 181.6 | −59.5 |
| | | | | 17.5 | 139.6 | −45.2 |
| | | | | 20 | 128.4 | −41.4 |
| | | | | 25 | 112.0 | −35.8 |
| | | | | 35 | 91.7 | −29.1 |
| | | | | 50 | 74.8 | −23.6 |
| | | | | 75 | 59.9 | −18.7 |
| 28 | 5d–6p | $^{1}D_{2}$–$^{1}P_{1}$ | 11614.9 | 11.6 | 1040.5 | −138.5 |
| | | | | 17.5 | 802.1 | −108.1 |
| | | | | 20 | 738.6 | −100.0 |
| | | | | 25 | 645.3 | −88.2 |
| | | | | 35 | 529.6 | −73.4 |
| | | | | 50 | 433.0 | −61.1 |
| | | | | 75 | 347.6 | −50.0 |
| 29 | 5p–5p$^2$ | $^{3}P_{1}$–$^{3}P_{0}$ | 1386.7 | 11.6 | 2.47 | −2.0 |
| | | | | 17.5 | 1.85 | −1.51 |
| | | | | 20 | 1.69 | −1.37 |
| | | | | 25 | 1.45 | −1.18 |
| | | | | 35 | 1.16 | −0.94 |
| | | | | 50 | 0.92 | −0.75 |
| | | | | 75 | 0.72 | −0.58 |
| 30 | 5p–5p$^2$ | $^{1}P_{1}$–$^{3}P_{0}$ | 2109.1 | 11.6 | 9.13 | −5.1 |
| | | | | 17.5 | 6.9 | −3.8 |
| | | | | 20 | 6.3 | −3.5 |
| | | | | 25 | 5.4 | −3.0 |
| | | | | 35 | 4.3 | −2.4 |
| | | | | 50 | 3.4 | −1.9 |
| | | | | 75 | 2.7 | −1.5 |
| 31 | 5p–5p$^2$ | $^{3}P_{0}$–$^{3}P_{1}$ | 1289.1 | 11.6 | 1.2 | −0.060 |
| | | | | 17.5 | 0.92 | −0.044 |
| | | | | 20 | 0.84 | −0.040 |
| | | | | 25 | 0.73 | −0.034 |
| | | | | 35 | 0.58 | −0.026 |
| | | | | 50 | 0.46 | −0.020 |
| | | | | 75 | 0.36 | −0.015 |
| 32 | 5p–5p$^2$ | $^{3}P_{1}$–$^{3}P_{1}$ | 1334.7 | 11.6 | 2.70 | −1.44 |
| | | | | 17.5 | 2.03 | −1.08 |

**Table 2** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 20 | 1.85 | −0.99 |
| | | | | 25 | 0.59 | −0.85 |
| | | | | 35 | 1.27 | −0.68 |
| | | | | 50 | 1.01 | −0.54 |
| | | | | 75 | 0.79 | −0.42 |
| 33 | 5p–5p$^2$ | $^3P_2$–$^3P_1$ | 1410.6 | 11.6 | 4.50 | −3.10 |
| | | | | 17.5 | 3.39 | −2.33 |
| | | | | 20 | 3.09 | −2.13 |
| | | | | 25 | 2.66 | −1.83 |
| | | | | 35 | 2.13 | −1.46 |
| | | | | 50 | 1.69 | −1.16 |
| | | | | 75 | 1.31 | −0.90 |
| 34 | 5p–5p$^2$ | $^1P_1$–$^3P_1$ | 1991.7 | 11.6 | 9.07 | −3.60 |
| | | | | 17.5 | 6.83 | −2.71 |
| | | | | 20 | 6.24 | −2.48 |
| | | | | 25 | 5.37 | −2.13 |
| | | | | 35 | 4.30 | −1.71 |
| | | | | 50 | 3.42 | −1.36 |
| | | | | 75 | 2.67 | −1.06 |
| 35 | 5p–5p$^2$ | $^3P_1$–$^3P_2$ | 1259.9 | 11.6 | 2.99 | −1.30 |
| | | | | 17.5 | 2.25 | −0.98 |
| | | | | 20 | 2.06 | −0.89 |
| | | | | 25 | 1.77 | −0.77 |
| | | | | 35 | 1.42 | −0.62 |
| | | | | 50 | 1.13 | −0.49 |
| | | | | 75 | 0.88 | −0.38 |
| 36 | 5p–5p$^2$ | $^3P_2$–$^3P_2$ | 1327.3 | 11.6 | 3.37 | −3.30 |
| | | | | 17.5 | 2.53 | −2.48 |
| | | | | 20 | 2.31 | −2.20 |
| | | | | 25 | 1.99 | −1.80 |
| | | | | 35 | 1.59 | −1.47 |
| | | | | 50 | 1.26 | −1.10 |
| | | | | 75 | 0.98 | −0.80 |
| 37 | 5p–5p$^2$ | $^1P_1$–$^3P_2$ | 1829.6 | 11.6 | 8.89 | −3.07 |
| | | | | 17.5 | 6.70 | −2.32 |
| | | | | 20 | 6.12 | −2.12 |
| | | | | 25 | 5.27 | −1.83 |
| | | | | 35 | 4.22 | −1.47 |
| | | | | 50 | 3.36 | −1.18 |
| | | | | 75 | 2.62 | −0.92 |
| 38 | 5p–5p$^2$ | $^3P_1$–$^1D_2$ | 1369.7 | 11.6 | 4.54 | 4.28 |
| | | | | 17.5 | 3.43 | −3.23 |
| | | | | 20 | 3.13 | −2.96 |
| | | | | 25 | 2.70 | −2.55 |
| | | | | 35 | 2.17 | −2.05 |
| | | | | 50 | 1.74 | −1.64 |
| | | | | 75 | 1.36 | −1.28 |
| 39 | 5p–5p$^2$ | $^3P_2$–$^1D_2$ | 1449.8 | 11.6 | 6.66 | −6.38 |
| | | | | 17.5 | 5.02 | −4.81 |
| | | | | 20 | 4.59 | −4.40 |
| | | | | 25 | 3.96 | −3.79 |
| | | | | 35 | 3.18 | −3.04 |
| | | | | 50 | 2.54 | −2.43 |
| | | | | 75 | 1.98 | −1.90 |
| 40 | 5p–5p$^2$ | $^1P_1$–$^1D_2$ | 2070.7 | 11.6 | 16.68 | −9.21 |
| | | | | 17.5 | 12.33 | −8.72 |
| | | | | 20 | 11.94 | −7.56 |
| | | | | | 17.2 ± 2.8[e] | |
| | | | | 25 | 9.14 | −6.09 |
| | | | | 35 | 7.55 | −4.90 |
| | | | | 50 | 5.23 | −3.93 |
| | | | | 75 | 4.10 | −3.08 |

[a]Moore (1958).
[b]Kieft et al. (2004).
[c]Simić et al. (2008) – the Sahal–Bréchot approach.
[d]Simić et al. (2008) – the Griem modified approach.
[e]Djeniže (2007).

**Table 3.** Sn III $4d^{10}5snd$ linewidths (FWHM), $\omega$(pm) and shifts, $d$(pm), normalized to $Ne = 10^{23}$ m$^{-3}$.

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 1 | 5p–5d | $^3P_0$–$^3D_1$ | 1139.3 | 11.6 | 3.17 | −2.20 |
| | | | | 17.5 | 2.41 | −1.68 |
| | | | | 20 | 2.21 | −1.55 |
| | | | | 25 | 1.92 | −1.35 |
| | | | | 35 | 1.55 | −1.10 |
| | | | | 50 | 1.25 | −0.89 |
| | | | | 75 | 0.99 | −0.71 |
| 2 | 5p–5d | $^3P_1$–$^3D_1$ | 1161.1 | 11.6 | 4.34 | −3.32 |
| | | | | 17.5 | 3.29 | −2.53 |
| | | | | 20 | 3.02 | −2.32 |
| | | | | 25 | 2.61 | −2.01 |
| | | | | 35 | 2.11 | −1.63 |
| | | | | 50 | 1.70 | −1.32 |
| | | | | 75 | 1.34 | −1.04 |
| 3 | 5p–5d | $^3P_2$–$^3D_1$ | 1218.1 | 11.6 | 5.88 | −4.77 |
| | | | | 17.5 | 4.46 | −3.62 |
| | | | | 20 | 4.08 | −3.32 |
| | | | | 25 | 3.53 | −2.87 |
| | | | | 35 | 2.84 | −2.32 |
| | | | | 50 | 2.28 | −1.87 |
| | | | | 75 | 1.80 | −1.47 |
| 4 | 5p–5d | $^1P_1$–$^3D_1$ | 1628.4 | 11.6 | 10.58 | −6.80 |
| | | | | 17.5 | 8.02 | −5.18 |
| | | | | 20 | 7.34 | −4.75 |
| | | | | 25 | 6.35 | −4.12 |
| | | | | 35 | 5.12 | −3.35 |
| | | | | 50 | 4.12 | −2.70 |
| | | | | 75 | 3.24 | −2.12 |
| 5 | 5p–5d | $^3P_1$–$^3D_2$ | 1158.3 | 11.6 | 6.17 | −4.50 |
| | | | | 17.5 | 4.69 | −3.44 |
| | | | | 20 | 4.30 | −3.15 |
| | | | | 25 | 3.72 | −2.74 |
| | | | | 35 | 3.01 | −2.23 |
| | | | | 50 | 2.43 | −1.80 |
| | | | | 75 | 1.92 | −1.44 |
| 6 | 5p–5d | $^3P_2$–$^3D_2$ | 1215.1 | 11.6 | 7.89 | −6.06 |
| | | | | 17.5 | 5.99 | −4.62 |
| | | | | 20 | 5.49 | −4.23 |
| | | | | 25 | 4.75 | −3.67 |
| | | | | 35 | 3.84 | −3.00 |
| | | | | 50 | 3.09 | −2.40 |
| | | | | 75 | 2.43 | −1.90 |
| 7 | 5p–5d | $^1P_1$–$^3D_2$ | 1623.0 | 11.6 | 14.14 | −9,10 |
| | | | | 17.5 | 10.74 | −6.95 |
| | | | | 20 | 9.84 | −6.38 |
| | | | | 25 | 8.52 | −5.54 |
| | | | | 35 | 6.89 | −4.51 |
| | | | | 50 | 5.54 | −3.66 |
| | | | | 75 | 4.38 | −2.91 |
| 8 | 5p–5d | $^3P_2$–$^3D_3$ | 1210.5 | 11.6 | 9.87 | −7.35 |
| | | | | 17.5 | 7.50 | −5.61 |
| | | | | 20 | 6.88 | −5.15 |
| | | | | 25 | 5.95 | −4.47 |
| | | | | 35 | 4.82 | −3.63 |
| | | | | 50 | 3.88 | −2.94 |
| | | | | 75 | 3.07 | −2.33 |
| 9 | 5p–5d | $^3P_1$–$^1D_2$ | 1010.9 | 11.6 | 4.24 | −1.75 |
| | | | | 17.5 | 3.24 | −1.36 |
| | | | | 20 | 2.97 | −1.26 |
| | | | | 25 | 2.58 | −1.10 |
| | | | | 35 | 2.10 | −0.92 |
| | | | | 50 | 1.70 | −0.76 |
| | | | | 75 | 1.34 | −0.61 |
| 10 | 5p–5d | $^3P_2$–$^1D_2$ | 1053.9 | 11.6 | 5.44 | −2.73 |
| | | | | 17.5 | 4.14 | −2.11 |
| | | | | 20 | 3.80 | −1.94 |

**Table 3** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 25 | 3.29 | −1.69 |
| | | | | 35 | 2.67 | −1.39 |
| | | | | 50 | 2.16 | −1.13 |
| | | | | 75 | 1.70 | −0.91 |
| 11 | 5p–5d | $^1P_1$–$^1D_2$ | 1347.6 | 11.6 | 9.93 | −3.28 |
| | | | | 17.5 | 6.81 | −2.56 |
| | | | | 20 | 6.25 | −2-36 |
| | | | | 25 | 5.42 | −2.08 |
| | | | | 35 | 4.40 | −1.72 |
| | | | | 50 | 3.55 | −1.42 |
| | | | | 75 | 2.81 | −1.15 |
| 12 | 5p–6d | $^3P_0$–$^3D_1$ | 744.2 | 11.6 | 1.61 | 1.18 |
| | | | | 17.5 | 1.25 | 0.93 |
| | | | | 20 | 1.15 | 0.86 |
| | | | | 25 | 1.01 | 0.76 |
| | | | | 35 | 0.83 | 0.63 |
| | | | | 50 | 0.68 | 0.52 |
| | | | | 75 | 0.55 | 0.43 |
| 13 | 5p–6d | $^3P_1$–$^3D_1$ | 753.5 | 11.6 | 2.09 | 0.77 |
| | | | | 17.5 | 1.61 | 0.62 |
| | | | | 20 | 1.48 | 0.58 |
| | | | | 25 | 1.29 | 0.52 |
| | | | | 35 | 1.06 | 0.44 |
| | | | | 50 | 0.86 | 0.37 |
| | | | | 75 | 0.69 | 0.31 |
| 14 | 5p–6d | $^3P_2$–$^3D_1$ | 777.1 | 11.6 | 2.68 | 0.37 |
| | | | | 17.5 | 2.05 | 0.32 |
| | | | | 20 | 1.89 | 0.30 |
| | | | | 25 | 1.64 | 0.28 |
| | | | | 35 | 1.34 | 0.25 |
| | | | | 50 | 1.09 | 0.22 |
| | | | | 75 | 0.87 | 0.20 |
| 15 | 5p–6d | $^1P_1$–$^3D_1$ | 925.9 | 11.6 | 3.82 | 1.08 |
| | | | | 17.5 | 2.93 | 0.87 |
| | | | | 20 | 2.70 | 0.81 |
| | | | | 25 | 2.35 | 0.73 |
| | | | | 35 | 1.92 | 0.62 |
| | | | | 50 | 1.56 | 0.52 |
| | | | | 75 | 1.24 | 0.44 |
| 16 | 6p–6d | $^3P_0$–$^3D_1$ | 3574.5 | 11.6 | 53.11 | 27.53 |
| | | | | 17.5 | 41.15 | 21.53 |
| | | | | 20 | 37.96 | 19.93 |
| | | | | 25 | 33.27 | 17.56 |
| | | | | 35 | 27.43 | 14.60 |
| | | | | 50 | 22.54 | 12.09 |
| | | | | 75 | 18.20 | 9.83 |
| 17 | 6p–6d | $^3P_1$–$^3D_1$ | 3610.1 | 11.6 | 101.95 | 20.17 |
| | | | | 17.5 | 78.77 | 16.07 |
| | | | | 20 | 72.60 | 14.96 |
| | | | | 25 | 63.52 | 13.31 |
| | | | | 35 | 52.26 | 11.23 |
| | | | | 50 | 42.86 | 9.43 |
| | | | | 75 | 34.52 | 7.78 |
| 18 | 6p–6d | $^3P_2$–$^3D_1$ | 3776.8 | 11.6 | 152.19 | 10.47 |
| | | | | 17.5 | 117.42 | 8.66 |
| | | | | 20 | 108.18 | 8.16 |
| | | | | 25 | 94.58 | 7.41 |
| | | | | 35 | 77.74 | 6.43 |
| | | | | 50 | 63.68 | 5.54 |
| | | | | 75 | 51.25 | 4.68 |
| 19 | 6p–6d | $^1P_1$–$^3D_1$ | 3969.7 | 11.6 | 114.29 | 32.26 |
| | | | | 17.5 | 88.51 | 25.57 |
| | | | | 20 | 81.64 | 23.77 |
| | | | | 25 | 71.52 | 21.10 |
| | | | | 35 | 58.96 | 17.72 |
| | | | | 50 | 48.43 | 14.82 |
| | | | | 75 | 39.08 | 12.17 |
| 20 | 4f–6d | $^3F_2$–$^3D_1$ | 12175.1 | 11.6 | 780.00 | 376.19 |
| | | | | 17.5 | 606.40 | 286.66 |
| | | | | 20 | 560.05 | 262.94 |

**Table 3** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 25 | 491.64 | 228.16 |
| | | | | 35 | 406.41 | 185.37 |
| | | | | 50 | 334.68 | 150.04 |
| | | | | 75 | 270.66 | 119.29 |
| 21 | 5p–6d | $^3P_1$–$^3D_2$ | 753.0 | 11.6 | 3.05 | 1.73 |
| | | | | 17.5 | 2.35 | 1.36 |
| | | | | 20 | 2.17 | 1.26 |
| | | | | 25 | 1.90 | 1.12 |
| | | | | 35 | 1.56 | 0.94 |
| | | | | 50 | 1.28 | 0.78 |
| | | | | 75 | 1.02 | 0.64 |
| 22 | 5p–6d | $^3P_2$–$^3D_2$ | 776.6 | 11.6 | 3.69 | 1.38 |
| | | | | 17.5 | 2.84 | 1.11 |
| | | | | 20 | 2.62 | 1.03 |
| | | | | 25 | 2.28 | 0.92 |
| | | | | 35 | 1.87 | 0.78 |
| | | | | 50 | 1.53 | 0.66 |
| | | | | 75 | 1.22 | 0.55 |
| 23 | 5p–6d | $^1P_1$–$^3D_2$ | 925.2 | 11.6 | 5.26 | 2.52 |
| | | | | 17.5 | 4.05 | 1.99 |
| | | | | 20 | 3.73 | 1.85 |
| | | | | 25 | 3.25 | 1.64 |
| | | | | 35 | 2.67 | 1.37 |
| | | | | 50 | 2.18 | 1.14 |
| | | | | 75 | 1.74 | 0.94 |
| 24 | 6p–6d | $^3P_1$–$^3D_2$ | 3599.6 | 11.6 | 117.76 | 40.78 |
| | | | | 17.5 | 91.12 | 32.09 |
| | | | | 20 | 84.02 | 29.76 |
| | | | | 25 | 73.57 | 26.31 |
| | | | | 35 | 60.60 | 21.98 |
| | | | | 50 | 49.75 | 18.29 |
| | | | | 75 | 40.12 | 14.95 |
| 25 | 6p–6d | $^3P_2$–$^3D_2$ | 3765.4 | 11.6 | 175.12 | 34.26 |
| | | | | 17.5 | 135.28 | 27.18 |
| | | | | 20 | 124.69 | 25.27 |
| | | | | 25 | 109.09 | 22.44 |
| | | | | 35 | 89.75 | 18.87 |
| | | | | 50 | 73.59 | 15.80 |
| | | | | 75 | 59.29 | 12.99 |
| 26 | 6p–6d | $^1P_1$–$^3D_2$ | 3957.1 | 11.6 | 139.91 | 58.40 |
| | | | | 17.5 | 108.46 | 45.92 |
| | | | | 20 | 100.07 | 42.57 |
| | | | | 25 | 87.72 | 37.61 |
| | | | | 35 | 72.37 | 31.39 |
| | | | | 50 | 59.49 | 26.10 |
| | | | | 75 | 48.04 | 21.30 |
| 27 | 4f–6d | $^3F_2$–$^3D_2$ | 11508.1 | 11.6 | 919.66 | 558.89 |
| | | | | 17.5 | 715.23 | 429.56 |
| | | | | 20 | 660.65 | 395.20 |
| | | | | 25 | 550.08 | 344.68 |
| | | | | 35 | 479.69 | 282.21 |
| | | | | 50 | 395.18 | 230.22 |
| | | | | 75 | 319.72 | 184.48 |
| 28 | 4f–6d | $^3F_3$–$^3D_2$ | 11556.3 | 11.6 | 1073.68 | 567.80 |
| | | | | 17.5 | 834.77 | 439.38 |
| | | | | 20 | 770.99 | 399.00 |
| | | | | 25 | 676.84 | 347.02 |
| | | | | 35 | 559.55 | 282.94 |
| | | | | 50 | 460.84 | 229.84 |
| | | | | 75 | 372.74 | 183.40 |
| 29 | 4f–6d | $^1F_3$–$^3D_2$ | 12056.0 | 11.6 | 1149.42 | 677.68 |
| | | | | 17.5 | 892.37 | 520.34 |
| | | | | 20 | 823.80 | 478.54 |
| | | | | 25 | 722.65 | 417.09 |
| | | | | 35 | 596.75 | 341.11 |
| | | | | 50 | 490.94 | 277.92 |
| | | | | 75 | 396.68 | 222.39 |
| 30 | 5p–6d | $^3P_2$–$^3D_3$ | 775.8 | 11.6 | 4.69 | 2.39 |
| | | | | 17.5 | 3.62 | 1.89 |
| | | | | 20 | 3.34 | 1.76 |

**Table 3** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 25 | 2.92 | 1.56 |
| | | | | 35 | 2.40 | 1.31 |
| | | | | 50 | 1.96 | 1.10 |
| | | | | 75 | 1.57 | 0.90 |
| 31 | 6p–6d | $^3P_2$–$^3D_3$ | 3746.6 | 11.6 | 196.98 | 57.52 |
| | | | | 17.5 | 152.33 | 45.30 |
| | | | | 20 | 140.44 | 42.02 |
| | | | | 25 | 122.95 | 37.16 |
| | | | | 35 | 101.24 | 31.06 |
| | | | | 50 | 83.08 | 25.86 |
| | | | | 75 | 66.98 | 21.15 |
| 32 | 4f–6d | $^3F_2$–$^3D_3$ | 11335.5 | 11.6 | 1108.37 | 758.33 |
| | | | | 17.5 | 862.30 | 585.14 |
| | | | | 20 | 796.60 | 539.06 |
| | | | | 25 | 699.62 | 471.22 |
| | | | | 35 | 578.75 | 387.15 |
| | | | | 50 | 476.98 | 316.93 |
| | | | | 75 | 386.06 | 354.85 |
| 33 | 4f–6d | $^3F_3$–$^3D_3$ | 11381.7 | 11.6 | 1259.33 | 768.62 |
| | | | | 17.5 | 979.47 | 591.09 |
| | | | | 20 | 904.76 | 543.91 |
| | | | | 25 | 794.47 | 474.54 |
| | | | | 35 | 657.04 | 388.72 |
| | | | | 50 | 541.35 | 317.28 |
| | | | | 75 | 438.04 | 254.38 |
| 34 | 4f–6d | $^3F_4$–$^3D_3$ | 11510.3 | 11.6 | 1442.50 | 788.26 |
| | | | | 17.5 | 1121.83 | 603.82 |
| | | | | 20 | 1036.21 | 554.84 |
| | | | | 25 | 909.83 | 483.00 |
| | | | | 35 | 752.36 | 394.29 |
| | | | | 50 | 619.79 | 320.71 |
| | | | | 75 | 501.43 | 256.25 |
| 35 | 4f–6d | $^1F_3$–$^3D_3$ | 11866.9 | 11.6 | 1350.46 | 893.41 |
| | | | | 17.5 | 1049.12 | 688.67 |
| | | | | 20 | 968.72 | 634.20 |
| | | | | 25 | 850.09 | 554.04 |
| | | | | 35 | 702.40 | 454.71 |
| | | | | 50 | 578.20 | 371.81 |
| | | | | 75 | 467.47 | 298.61 |
| 36 | 5p–6d | $^3P_1$–$^1D_2$ | 743.5 | 11.6 | 2.59 | 1.30 |
| | | | | 17.5 | 1.99 | 1.03 |
| | | | | 20 | 1.84 | 0.95 |
| | | | | 25 | 1.60 | 0.85 |
| | | | | 35 | 1.31 | 0.71 |
| | | | | 50 | 1.07 | 0.59 |
| | | | | 75 | 0.86 | 0.49 |
| 37 | 5p–6d | $^1P_1$–$^1D_2$ | 910.9 | 11.6 | 4.52 | 1.87 |
| | | | | 17.5 | 3.48 | 1.48 |
| | | | | 20 | 3.20 | 1.37 |
| | | | | 25 | 2.79 | 1.22 |
| | | | | 35 | 2.28 | 1.02 |
| | | | | 50 | 1.86 | 0.85 |
| | | | | 75 | 1.48 | 0.70 |
| 38 | 6p–6d | $^3P_1$–$^1D_2$ | 3392.8 | 11.6 | 96.70 | 28.31 |
| | | | | 17.5 | 74.72 | 22.28 |
| | | | | 20 | 68.87 | 20.67 |
| | | | | 25 | 60.26 | 18.27 |
| | | | | 35 | 49.59 | 15.27 |
| | | | | 50 | 40.67 | 12.72 |
| | | | | 75 | 32.77 | 10.40 |
| 39 | 6p–6d | $^3P_2$–$^1D_2$ | 3539.6 | 11.6 | 146.134 | 21.65 |
| | | | | 17.5 | 112.76 | 17.23 |
| | | | | 20 | 103.89 | 16.04 |
| | | | | 25 | 90.84 | 14.28 |
| | | | | 35 | 74.68 | 12.04 |
| | | | | 50 | 61.19 | 10.12 |
| | | | | 75 | 49.26 | 8.35 |
| 40 | 6p–6d | $^1P_1$–$^1D_2$ | 3708.5 | 11.6 | 113.42 | 41.82 |
| | | | | 17.5 | 87.81 | 32.89 |
| | | | | 20 | 80.99 | 30.49 |
| | | | | 25 | 70.95 | 26.94 |
| | | | | 35 | 58.48 | 22.49 |
| | | | | 50 | 48.03 | 18.70 |
| | | | | 75 | 38.76 | 15.27 |
| 41 | 4f–6d | $^3F_3$–$^1D_2$ | 9664.7 | 11.6 | 686.67 | 332.84 |
| | | | | 17.5 | 533.29 | 253.25 |
| | | | | 20 | 492.38 | 232.19 |
| | | | | 25 | 432.01 | 201.32 |
| | | | | 35 | 356.86 | 163.39 |
| | | | | 50 | 293.68 | 132.11 |
| | | | | 75 | 237.37 | 104.95 |
| 42 | 4f–6d | $^1F_3$–$^1D_2$ | 10012.3 | 11.6 | 723.76 | 398.40 |
| | | | | 17.5 | 561.21 | 304.62 |
| | | | | 20 | 517.88 | 279.75 |
| | | | | 25 | 453.99 | 243.24 |
| | | | | 35 | 374.55 | 198.23 |
| | | | | 50 | 307.86 | 160.94 |
| | | | | 75 | 248.56 | 128.35 |
| 43 | 5p–7d | $^3P_0$–$^3D_1$ | 644.8 | 11.6 | 0.19 | −0.13 |
| | | | | 17.5 | 0.15 | −0.096 |
| | | | | 20 | 0.13 | −0.088 |
| | | | | 25 | 0.11 | −0.075 |
| | | | | 35 | 0.092 | −0.060 |
| | | | | 50 | 0.073 | −0.048 |
| | | | | 75 | 0.057 | −0.037 |
| 44 | 5p–7d | $^3P_1$–$^3D_1$ | 651.7 | 11.6 | 0.53 | −0.46 |
| | | | | 17.5 | 0.40 | −0.34 |
| | | | | 20 | 0.36 | −0.31 |
| | | | | 25 | 0.31 | −0.27 |
| | | | | 35 | 0.25 | −0.22 |
| | | | | 50 | 0.20 | −0.17 |
| | | | | 75 | 0.15 | −0.13 |
| 45 | 5p–7d | $^3P_2$–$^3D_1$ | 669.3 | 11.6 | 0.89 | −0.82 |
| | | | | 17.5 | 0.67 | −0.62 |
| | | | | 20 | 0.61 | −0.56 |
| | | | | 25 | 0.53 | −0.48 |
| | | | | 35 | 0.42 | −0.39 |
| | | | | 50 | 0.33 | −0.31 |
| | | | | 75 | 0.26 | −0.24 |
| 46 | 5p–7d | $^1P_1$–$^3D_1$ | 776.8 | 11.6 | 1.21 | −0.71 |
| | | | | 17.5 | 0.91 | −0.54 |
| | | | | 20 | 0.83 | −0.49 |
| | | | | 25 | 0.72 | −0.42 |
| | | | | 35 | 0.58 | −0.34 |
| | | | | 50 | 0.46 | −0.27 |
| | | | | 75 | 0.36 | −0.21 |
| 47 | 6p–7d | $^3P_0$–$^3D_1$ | 2053.1 | 11.6 | 7.21 | −1.23 |
| | | | | 17.5 | 5.54 | −0.93 |
| | | | | 20 | 5.10 | −0.85 |
| | | | | 25 | 4.45 | −0.73 |
| | | | | 35 | 3.65 | −0.59 |
| | | | | 50 | 2.98 | −0.47 |
| | | | | 75 | 2.39 | −0.37 |
| 48 | 6p–7d | $^3P_1$–$^3D_1$ | 2064.8 | 11.6 | 21.15 | −4.18 |
| | | | | 17.5 | 16.27 | −3.15 |
| | | | | 20 | 14.98 | −2.87 |
| | | | | 25 | 13.08 | −2.47 |
| | | | | 35 | 10.72 | −1.98 |
| | | | | 50 | 8.77 | −1.58 |
| | | | | 75 | 7.04 | −1.24 |

**Table 3** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 49 | 6p–7d | $^3P_2$–$^3D_1$ | 2118.2 | 11.6 | 36.89 | −7.68 |
| | | | | 17.5 | 28.39 | −5.82 |
| | | | | 20 | 26.13 | −5.33 |
| | | | | 25 | 22.81 | −4.61 |
| | | | | 35 | 18.70 | −3.73 |
| | | | | 50 | 15.29 | −3.00 |
| | | | | 75 | 12.28 | −2.37 |
| 50 | 6p–7d | $^1P_1$–$^3D_1$ | 2177.6 | 11.6 | 22.79 | −1.89 |
| | | | | 17.5 | 17.60 | −1.34 |
| | | | | 20 | 16.22 | −1.20 |
| | | | | 25 | 14.18 | −0.99 |
| | | | | 35 | 11.66 | −0.74 |
| | | | | 50 | 9.56 | −0.55 |
| | | | | 75 | 7.70 | −0.40 |
| 51 | 4f–7d | $^3F_2$–$^3D_1$ | 3408.3 | 11.6 | 32.70 | 1.06 |
| | | | | 17.5 | 25.38 | 0.33 |
| | | | | 20 | 23.43 | 0.15 |
| | | | | 25 | 20.55 | −0.097 |
| | | | | 35 | 16.96 | −0.36 |
| | | | | 50 | 13.94 | −0.52 |
| | | | | 75 | 11.26 | −0.60 |
| 52 | 5p–7d | $^3P_1$–$^3D_2$ | 651.4 | 11.6 | 0.055 | −0.054 |
| | | | | 17.5 | 0.042 | −0.032 |
| | | | | 20 | 0.038 | −0.030 |
| | | | | 25 | 0.033 | −0.026 |
| | | | | 35 | 0.027 | −0.021 |
| | | | | 50 | 0.022 | −0.016 |
| | | | | 75 | 0.017 | −0.013 |
| 53 | 5p–7d | $^3P_2$–$^3D_2$ | 669.1 | 11.6 | 0.91 | −0.80 |
| | | | | 17.5 | 0.69 | −0.60 |
| | | | | 20 | 0.63 | −0.55 |
| | | | | 25 | 0.54 | −0.47 |
| | | | | 35 | 0.43 | −0.38 |
| | | | | 50 | 0.34 | −0.30 |
| | | | | 75 | 0.27 | −0.23 |
| 54 | 5p–7d | $^1P_1$–$^3D_2$ | 776.5 | 11.6 | 1.24 | −0.68 |
| | | | | 17.5 | 0.94 | −0.51 |
| | | | | 20 | 0.86 | −0.47 |
| | | | | 25 | 0.74 | −0.40 |
| | | | | 35 | 0.59 | −0.32 |
| | | | | 50 | 0.47 | −0.26 |
| | | | | 75 | 0.37 | −0.20 |
| 55 | 6p–7d | $^3P_1$–$^3D_2$ | 2062.7 | 11.6 | 20.77 | −4.51 |
| | | | | 17.5 | 15.99 | −3.39 |
| | | | | 20 | 14.72 | −3.10 |
| | | | | 25 | 12.85 | −2.67 |
| | | | | 35 | 10.54 | −2.14 |
| | | | | 50 | 8.62 | −1.71 |
| | | | | 75 | 6.92 | −1.34 |
| 56 | 6p–7d | $^3P_2$–$^3D_2$ | 2116.1 | 11.6 | 37.05 | −7.43 |
| | | | | 17.5 | 28.51 | −5.64 |
| | | | | 20 | 26.24 | −5.16 |
| | | | | 25 | 22.90 | −4.46 |
| | | | | 35 | 18.78 | −3.61 |
| | | | | 50 | 15.35 | −2.90 |
| | | | | 75 | 12.33 | −2.30 |
| 57 | 6p–7d | $^1P_1$–$^3D_2$ | 2175.3 | 11.6 | 22.99 | −1.64 |
| | | | | 17.5 | 17.75 | −1.15 |
| | | | | 20 | 16.35 | −1.02 |
| | | | | 25 | 14.30 | −0.84 |
| | | | | 35 | 11.76 | −0.62 |
| | | | | 50 | 9.63 | −0.46 |
| | | | | 75 | 7.76 | −0.32 |
| 58 | 4f–7d | $^3F_2$–$^3D_2$ | 3402.7 | 11.6 | 33.20 | 1.66 |
| | | | | 17.5 | 25.76 | 0.79 |
| | | | | 20 | 23.78 | 0.57 |
| | | | | 25 | 20.85 | 0.27 |
| | | | | 35 | 17.20 | −0.065 |
| | | | | 50 | 14.13 | −0.29 |
| | | | | 75 | 11.41 | −0.42 |
| 59 | 4f–7d | $^3F_3$–$^3D_2$ | 3406.9 | 11.6 | 46.00 | 2.03 |
| | | | | 17.5 | 35.69 | 0.89 |
| | | | | 20 | 32.94 | 0.61 |
| | | | | 25 | 28.89 | 0.22 |
| | | | | 35 | 23.83 | −0.21 |
| | | | | 50 | 19.59 | −0.49 |
| | | | | 75 | 15.81 | −0.65 |
| 60 | 4f–7d | $^1F_3$–$^3D_2$ | 3449.1 | 11.6 | 45.58 | 6.97 |
| | | | | 17.5 | 35.26 | 4.81 |
| | | | | 20 | 32.51 | 4.25 |
| | | | | 25 | 28.46 | 3.45 |
| | | | | 35 | 23.43 | 2.50 |
| | | | | 50 | 19.21 | 1.77 |
| | | | | 75 | 15.47 | 1.20 |
| 61 | 5p–7d | $^3P_2$–$^3D_3$ | 668.7 | 11.6 | 0.94 | −0.77 |
| | | | | 17.5 | 0.70 | −0.58 |
| | | | | 20 | 0.64 | −0.53 |
| | | | | 25 | 0.55 | −0.46 |
| | | | | 35 | 0.44 | −0.36 |
| | | | | 50 | 0.35 | −0.29 |
| | | | | 75 | 0.27 | −0.22 |
| 62 | 6p–7d | $^3P_2$–$^3D_3$ | 2112.5 | 11.6 | 35.15 | −7.18 |
| | | | | 17.5 | 28.58 | −5.44 |
| | | | | 20 | 26.31 | −4.98 |
| | | | | 25 | 22.96 | −4.31 |
| | | | | 35 | 18.83 | −3.48 |
| | | | | 50 | 15.38 | −2.81 |
| | | | | 75 | 12.35 | −2.22 |
| 63 | 4f–7d | $^3F_3$–$^3D_3$ | 3397.7 | 11.6 | 46.34 | 2.61 |
| | | | | 17.5 | 35.95 | 1.34 |
| | | | | 20 | 33.17 | 1.02 |
| | | | | 25 | 29.08 | 0.57 |
| | | | | 35 | 23.99 | 0.080 |
| | | | | 50 | 19.71 | −0.25 |
| | | | | 75 | 15.91 | −0.46 |
| 64 | 4f–7d | $^3F_4$–$^3D_3$ | 3409.9 | 11.6 | 60.24 | 2.82 |
| | | | | 17.5 | 46.74 | 1.28 |
| | | | | 20 | 43.14 | 0.90 |
| | | | | 25 | 37.83 | 0.37 |
| | | | | 35 | 31.22 | −0.21 |
| | | | | 50 | 25.66 | −0.59 |
| | | | | 75 | 20.71 | −0.81 |
| 65 | 5p–7d | $^3P_1$–$^1D_2$ | 649.1 | 11.6 | 0.58 | −0.39 |
| | | | | 17.5 | 0.44 | −0.30 |
| | | | | 20 | 0.40 | −0.27 |
| | | | | 25 | 0.34 | −0.23 |
| | | | | 35 | 0.28 | −0.18 |
| | | | | 50 | 0.22 | −0.15 |
| | | | | 75 | 0.17 | −0.11 |
| 66 | 5p–7d | $^3P_2$–$^1D_2$ | 666.5 | 11.6 | 0.95 | −0.75 |
| | | | | 17.5 | 0.71 | −0.56 |
| | | | | 20 | 0.65 | −0.51 |
| | | | | 25 | 0.56 | −0.44 |
| | | | | 35 | 0.45 | −0.35 |
| | | | | 50 | 0.36 | −0.28 |
| | | | | 75 | 0.28 | −0.22 |
| 67 | 5p–7d | $^1P_1$–$^1D_2$ | 773.1 | 11.6 | 1.29 | −0.62 |
| | | | | 17.5 | 0.97 | −0.47 |
| | | | | 20 | 0.89 | −0.43 |
| | | | | 25 | 0.76 | −0.37 |

**Table 3** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 35 | 0.61 | −0.29 |
| | | | | 50 | 0.49 | −0.23 |
| | | | | 75 | 0.38 | −0.18 |
| 68 | 6p–7d | $^3P_1$–$^1D_2$ | 2039.1 | 11.6 | 21.22 | −3.48 |
| | | | | 17.5 | 16.32 | −2.62 |
| | | | | 20 | 15.02 | −2.39 |
| | | | | 25 | 13.11 | −2.05 |
| | | | | 35 | 10.75 | −1.65 |
| | | | | 50 | 8.78 | −1.31 |
| | | | | 75 | 7.05 | −1.03 |
| 69 | 6p–7d | $^3P_2$–$^1D_2$ | 2091.3 | 11.6 | 36.59 | −6.86 |
| | | | | 17.5 | 28.14 | −5.20 |
| | | | | 20 | 25.90 | −4.76 |
| | | | | 25 | 22.61 | −4.12 |
| | | | | 35 | 18.53 | −3.33 |
| | | | | 50 | 15.14 | −2.68 |
| | | | | 75 | 12.16 | −2.12 |
| 70 | 6p–7d | $^1P_1$–$^1D_2$ | 2149.1 | 11.6 | 22.86 | −1.18 |
| | | | | 17.5 | 17.64 | −0.80 |
| | | | | 20 | 16.25 | −0.71 |
| | | | | 25 | 14.21 | −0.57 |
| | | | | 35 | 11.68 | −0.40 |
| | | | | 50 | 9.57 | −0.28 |
| | | | | 75 | 7.70 | −0.19 |
| 71 | 4f–7d | $^3F_3$–$^1D_2$ | 3343.1 | 11.6 | 45.31 | 2.97 |
| | | | | 17.5 | 35.14 | 1.63 |
| | | | | 20 | 32.43 | 1.29 |
| | | | | 25 | 28.42 | 0.82 |
| | | | | 35 | 23.44 | 0.29 |
| | | | | 50 | 19.26 | −0.072 |
| | | | | 75 | 1554 | −0.31 |
| 72 | 4f–7d | $^1F_3$–$^1D_2$ | 3383.7 | 11.6 | 44.91 | 7.75 |
| | | | | 17.5 | 34.72 | 5.42 |
| | | | | 20 | 32.01 | 4.82 |
| | | | | 25 | 28.02 | 3.95 |
| | | | | 35 | 23.05 | 2.91 |
| | | | | 50 | 18.89 | 2.11 |
| | | | | 75 | 15.21 | 1.48 |

[a]Moore (1958).

**Table 4.** Sn III $4d^{10}5s4f$ and $4d^{10}5s5g$ linewidths (FWHM), $\omega$(pm) and shifts, $d$(pm), normalized to $Ne = 10^{23}$ m$^{-3}$. Linewidths compared with other experimental values.

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 1 | $5p^2$–4f | $^3P_1$–$^3F_2$ | 2033.0 | 11.6 | 12.8 | 1.51 |
| | | | | 17.5 | 9.88 | 0.97 |
| | | | | 20 | 9.11 | 0.83 |
| | | | | 25 | 7.98 | 0.63 |
| | | | | 35 | 6.57 | 0.40 |
| | | | | 50 | 5.38 | 0.24 |
| | | | | 75 | 4.33 | 0.11 |
| 2 | 5d–4f | $^3D_1$–$^3F_2$ | 2632.6 | 11.6 | 16.93 | −1.53 |
| | | | | 17.5 | 13.79 | −1.25 |
| | | | | | 13.2 ± 2.1[b] | |
| | | | | 20 | 12.90 | −1.17 |
| | | | | 25 | 11.54 | −1.04 |
| | | | | 30 | 10.53 | −0.95 |
| | | | | 50 | 8.16 | −0.74 |
| | | | | 75 | 6.66 | −0.60 |

**Table 4** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 3 | 5d–4f | $^3D_2$–$^3F_2$ | 2646.9 | 11.6 | 36.60 | −15.02 |
| | | | | 17.5 | 29.81 | −12.23 |
| | | | | | 12.0 ± 1.9[b] | |
| | | | | 20 | 27.88 | −11.44 |
| | | | | 25 | 24.94 | −10.23 |
| | | | | 30 | 22.76 | −9.34 |
| | | | | 50 | 17.63 | −7.23 |
| | | | | 75 | 14.40 | −5.91 |
| | | | | 11.6 | 23.1 | −15.2 |
| 4 | 5d–4f | $^3D_3$–$^3F_2$ | 2668.5 | 11.6 | 53.87 | −22.04 |
| | | | | 17.5 | 41.38 | −17.25 |
| | | | | 20 | 38.06 | −15.97 |
| | | | | 25 | 33.17 | −14.08 |
| | | | | 35 | 27.13 | −11.71 |
| | | | | 50 | 22.10 | −9.72 |
| | | | | 75 | 17.67 | −7.92 |
| 5 | $5p^2$–4f | $^1D_2$–$^3F_3$ | 1955.5 | 11.6 | 19.46 | −4.12 |
| | | | | 17.5 | 15.02 | −3.34 |
| | | | | 20 | 13.84 | −3.13 |
| | | | | 25 | 12.10 | 2.81 |
| | | | | 35 | 9.94 | −2.40 |
| | | | | 50 | 8.13 | −2.03 |
| | | | | 75 | 6.53 | −1.69 |
| 6 | $5p^2$–4f | $^3P_2$–$^3F_3$ | 2233.3 | 11.6 | 22.71 | 1.92 |
| | | | | 17.5 | 17.56 | 1.16 |
| | | | | 20 | 16.18 | 0.97 |
| | | | | 25 | 14.16 | 0.70 |
| | | | | 35 | 11.64 | 0.38 |
| | | | | 50 | 9.54 | 0.16 |
| | | | | 75 | 18.6 | 0.11 |
| 7 | 5d–4f | $^3D_2$–$^3F_3$ | 2644.3 | 11.6 | 43.35 | −15.42 |
| | | | | 17.5 | 35.29 | −12.55 |
| | | | | | 14.0 ± 2.2[b] | |
| | | | | 20 | 33.02 | −11.74 |
| | | | | 25 | 29.53 | −10.50 |
| | | | | 30 | 26.96 | −9.59 |
| | | | | 50 | 20.88 | −7.43 |
| | | | | 75 | 17.05 | −6.06 |
| 8 | 5d–4f | $^3D_3$–$^3F_3$ | 2666.3 | 11.6 | 61.57 | −21.78 |
| | | | | 17.5 | 47.35 | 17.16 |
| | | | | 20 | 43.57 | −15.92 |
| | | | | 25 | 38.01 | −14.08 |
| | | | | 35 | 31.12 | −11.78 |
| | | | | 50 | 25.38 | −9.82 |
| | | | | 75 | 20.32 | −8.05 |
| 9 | 5d–4f | $^1D_2$–$^3F_3$ | 3963.9 | 11.6 | 107.11 | −7.93 |
| | | | | 17.5 | 82.80 | −7.57 |
| | | | | 20 | 76.32 | −7.43 |
| | | | | 25 | 66.77 | −7.19 |
| | | | | 35 | 54.90 | −6.76 |
| | | | | 50 | 44.95 | −6.26 |
| | | | | 75 | 36.14 | −5.62 |
| 10 | 5d–4f | $^3D_3$–$^3F_4$ | 2659.4 | 11.6 | 59.20 | −21.80 |
| | | | | 17.5 | 48.20 | −17.75 |
| | | | | | 14.5 ± 2.3[b] | |
| | | | | 20 | 45.10 | −16.60 |
| | | | | 25 | 40.33 | −14.85 |
| | | | | 30 | 36.82 | −13.56 |
| | | | | 50 | 28.52 | −10.50 |
| | | | | 75 | 23.28 | −8.57 |
| 11 | $5p^2$–4f | $^1D_2$–$^1F_3$ | 1941.8 | 11.6 | 15.94 | −2.85 |
| | | | | 17.5 | 12.98 | −2.32 |
| | | | | 20 | 12.14 | −2.17 |
| | | | | 25 | 10.86 | −1.94 |
| | | | | 30 | 9.91 | −1.77 |
| | | | | 50 | 7.68 | −1.38 |
| | | | | 75 | 6.27 | −1.12 |

**Table 4** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| 12 | $5p^2$–4f | $^3P_2$–$^1F_3$ | 2215.6 | 11.6 | 18.57 | 1.69 |
| | | | | 17.5 | 15.12 | 1.38 |
| | | | | 20 | 14.14 | 1.29 |
| | | | | 25 | 12.65 | 1.15 |
| | | | | 30 | 11.55 | 1.05 |
| | | | | 50 | 8.94 | 0.81 |
| | | | | 75 | 7.30 | 0.67 |
| 13 | 5d–4f | $^3D_2$–$^1F_3$ | 2619.5 | 11.6 | 38.31 | −11.44 |
| | | | | 17.5 | 31.20 | −9.32 |
| | | | | | 12.4 ± 2.0[b] | |
| | | | | 20 | 29.18 | −8.71 |
| | | | | 25 | 26.10 | −7.79 |
| | | | | 30 | 23.83 | −7.11 |
| | | | | 50 | 18.46 | −5.51 |
| | | | | 75 | 15.07 | −4.50 |
| 14 | 5d–4f | $^3D_3$–$^1F_3$ | 2641.0 | 11.6 | 50.00 | −18.09 |
| | | | | 17.5 | 40.71 | −14.73 |
| | | | | 20 | 38.08 | −13.78 |
| | | | | 25 | 34.06 | −12.33 |
| | | | | 30 | 31.09 | −11.25 |
| | | | | 50 | 24.08 | −8.72 |
| | | | | 75 | 19.66 | −7.12 |
| 15 | 5d–4f | $^1D_2$–$^1F_3$ | 3908.3 | 11.6 | 87.62 | −9.57 |
| | | | | 17.5 | 71.35 | −7.79 |
| | | | | 20 | 66.74 | −7.29 |
| | | | | 25 | 59.70 | −6.52 |
| | | | | 30 | 54.49 | −5.95 |
| | | | | 50 | 42.21 | −4.61 |
| | | | | 75 | 34.47 | −3.76 |
| 16 | 4f–5g | $^3F_2$–$^3G_3$ | 3730.9 | 11.6 | 34.05 | −3.04 |
| | | | | 17.5 | 27.73 | −2.47 |
| | | | | 20 | 25.94 | −2.31 |
| | | | | 25 | 23.20 | −2.07 |
| | | | | 30 | 21.18 | −1.89 |
| | | | | 50 | 16.40 | −1.46 |
| | | | | 75 | 13.39 | −1.19 |
| 17 | 4f–5g | $^3F_3$–$^3G_3$ | 3735.9 | 11.6 | 47.74 | −3.90 |
| | | | | 17.5 | 38.88 | −3.17 |
| | | | | 20 | 36.37 | −2.97 |
| | | | | 25 | 32.53 | −2.65 |
| | | | | 30 | 29.69 | −2.42 |
| | | | | 50 | 23.00 | −1.88 |
| | | | | 75 | 18.78 | −1.53 |
| 18 | 4f–5g | $^3F_4$–$^3G_3$ | 3749.6 | 11.6 | 62.75 | −5.14 |
| | | | | 17.5 | 51.10 | −4.18 |
| | | | | 20 | 47.80 | −3.91 |
| | | | | 25 | 42.75 | −3.50 |
| | | | | 30 | 39.03 | −3.20 |
| | | | | 50 | 30.23 | −2.48 |
| | | | | 75 | 24.68 | −2.02 |
| 19 | 4f–5g | $^1F_3$–$^3G_3$ | 3786.7 | 11.6 | 46.71 | 1.77 |
| | | | | 17.5 | 38.03 | 1.44 |
| | | | | 20 | 35.58 | 1.34 |
| | | | | 25 | 31.82 | 1.20 |
| | | | | 30 | 29.05 | 1.10 |
| | | | | 50 | 22.50 | 0.85 |
| | | | | 75 | 18.37 | 0.69 |
| 20 | 4f–5g | $^3F_3$–$^3G_4$ | 3735.9 | 11.6 | 47.76 | −3.88 |
| | | | | 17.5 | 38.89 | −3.16 |
| | | | | 20 | 36.38 | −2.96 |
| | | | | 25 | 32.54 | −2.65 |
| | | | | 35 | 29.71 | −2.42 |
| | | | | 50 | 23.01 | −1.87 |
| | | | | 75 | 18.78 | −1.53 |
| 21 | 4f–5g | $^3F_4$–$^3G_4$ | 3749.6 | 11.6 | 62.77 | −5.13 |
| | | | | 17.5 | 51.11 | −4.17 |
| | | | | 20 | 47.81 | −3.90 |
| | | | | 25 | 42.76 | −3.49 |

**Table 4** – *continued*

| Line no | Transition array | Multiplet | Wavelength (Å)[a] | $T$ ($10^3$ K) | $\omega$ (pm) | $d$ (pm) |
|---|---|---|---|---|---|---|
| | | | | 35 | 39.04 | −3.19 |
| | | | | 50 | 30.24 | −2.47 |
| | | | | 75 | 24.69 | −2.02 |
| 22 | 4f–5g | $^1F_3$–$^3G_4$ | 3786.7 | 11.6 | 46.72 | 1.78 |
| | | | | 17.5 | 38.04 | 1.45 |
| | | | | 20 | 35.59 | 1.35 |
| | | | | 25 | 31.82 | 1.21 |
| | | | | 35 | 29.06 | 1.11 |
| | | | | 50 | 22.51 | 0.86 |
| | | | | 75 | 18.38 | 0.70 |
| 23 | 4f–5g | $^3F_4$–$^3G_5$ | 3746.4 | 11.6 | 62.67 | −5.10 |
| | | | | 17.5 | 51.03 | −4.16 |
| | | | | 20 | 47.74 | −3.89 |
| | | | | 25 | 42.70 | −3.48 |
| | | | | 35 | 38.98 | −3.17 |
| | | | | 50 | 30.19 | −2.46 |
| | | | | 75 | 24.65 | −2.01 |
| 24 | 4f–5g | $^3F_3$–$^1G_4$ | 3733.8 | 11.6 | 47.70 | −3.88 |
| | | | | 17.5 | 38.84 | −3.16 |
| | | | | 20 | 36.33 | −2.96 |
| | | | | 25 | 32.50 | −2.64 |
| | | | | 35 | 29.67 | −2.41 |
| | | | | 50 | 22.98 | −1.87 |
| | | | | 75 | 18.76 | −1.53 |
| 25 | 4f–5g | $^1F_3$–$^1G_4$ | 3784.5 | 11.6 | 46.67 | 1.77 |
| | | | | 17.5 | 38.00 | 1.44 |
| | | | | 20 | 35.54 | 1.35 |
| | | | | 25 | 31.79 | 1.21 |
| | | | | 35 | 29.02 | 1.10 |
| | | | | 50 | 22.48 | 0.85 |
| | | | | 75 | 18.35 | 0.70 |

[a]Moore (1958).
[b]Djeniže (2007).

atoms. The first problem is that on many occasions we do not have complete information on the set of the matrix elements that are required in the calculation. The second problem comes from the semi-empirical nature of the Gaunt factor. In equation (1), the $r^2$ matrix elements required in the calculations are part of the addends all affected by a positive sign. So, the estimated value of all monomials of the second member is cumulative in the final result. Therefore, the lack of any of the required matrix elements gives lower results than should occur. In our case, the use of a large set of theoretical matrix elements (some of which could not be compared with experimental measurements in the literature) could be an explanation for the overestimation of theoretical values that we present in this paper. Our overestimation does not seem to be the result of an overestimation of the matrix elements used in the calculations; these matrix elements were obtained in a previous work (Colón & Alonso-Medina 2010) and they were used with success in the calculation of transition probabilities and level lifetimes of Sn III. We think that this overestimation is therefore a result of the relative weight of the Gaunt factor considered.

To take this situation into account, other authors have performed calculations with various approaches, in an attempt to avoid these problems: in the semi-classical approach of Sahal-Bréchot (1969a,b), but only for the 5226.2-Å line. In Fig. 3, we can see that our approach is in the same range as the other approaches and that all approaches are compatible with the experimental value.

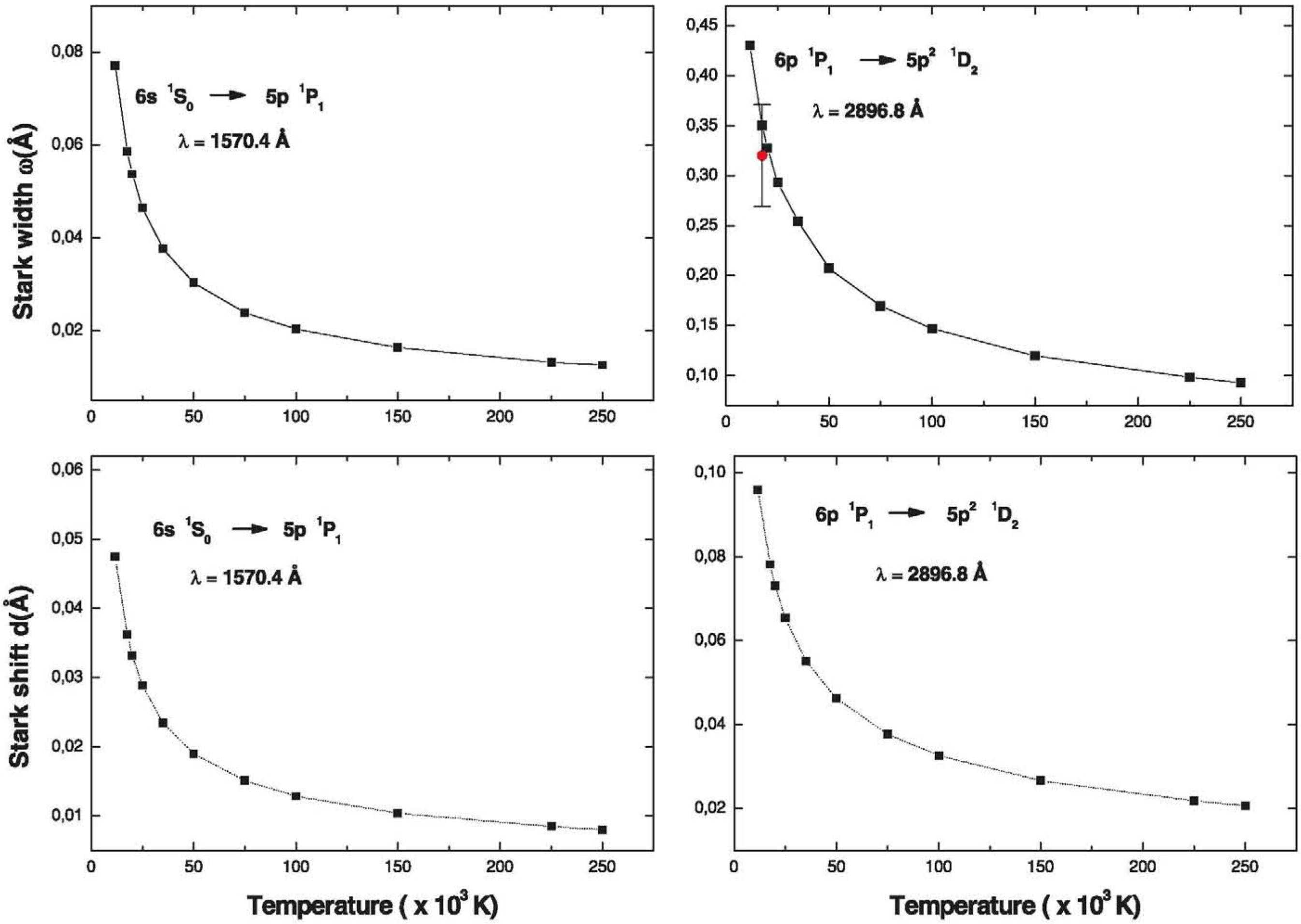


**Figure 2.** Stark width FWHM [$\omega$ (Å)] and Stark line shift [$d$ (Å)] versus temperature for 1570.4- and 2896.8-Å Sn III lines at an electron density of $10^{23}$ cm$^{-3}$. Squares, this paper; circle, Djeniže (2007).

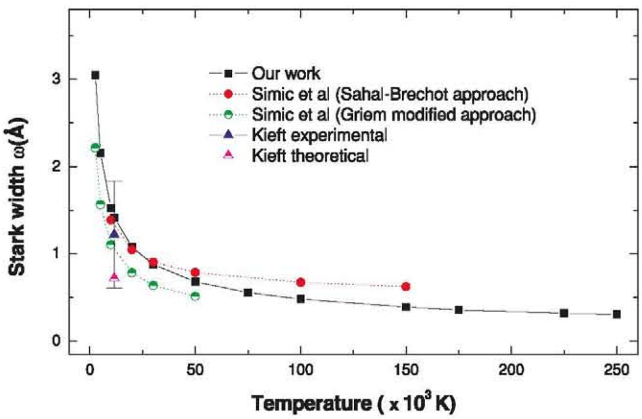


**Figure 3.** Stark width FWHM [$\omega$ (Å)] versus temperature for the 6s $^1S_0$–6p $^1P_1$ line of Sn III (5526.2) Å at an electron density of $10^{23}$ cm$^{-3}$.

In order to obtain new calculations, more precise measurements are necessary and over a larger range of temperatures so that we can carry out adjusted comparisons.

We have not compared the displacements. In equation (2), the monomials are affected by changing signs and these are added or subtracted from the final result. Therefore, we cannot ensure that will be the effect of not including any monomial.

In conclusion, by using the Cowan code and including core polarization effects, we have obtained the matrix elements necessary to calculate the Stark broadening parameter of Sn III spectral lines. Clear trends in the Stark widths are seen in our results.

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