Chapter 5

Lifetime of 1s2s2p 4P 5/2 Level in Ti 19+

5.1 Introduction

In previous studies [1,2], the beam single-foil [3] and beam two-foil technique [4] are coupled to an iterative multi-component exponential growth and decay analysis [1] to address blending in lifetime measurements in He– and Li–like vanadium [1] and nickel [2]. These measurements in our laboratory have confirmed the satellite blending problem of He–like M2 line. The transition 1s 1S 0–1s2p 3P 2 led to the mean lifetime measurements of partially autoionizing satellite level of 1s2s2p 2P 5/2 in the Li–like ions. It was subsequently shown in our laboratory that blending from the H–like M1 (1s 2S 1/2– 2s 2S 1/2) line may also be accounted for the beam–two–foil approach in the study of the level 1s2p 3P 2 lifetime in He–like nickel [2]. In the present study, a similar approach have been employed to determine the lifetime of 1s2s2p 4P 5/2 level in Ti 19+ through its x-ray decay channel to the Li–like ground state 1s2s 3S 1/2. The lifetime for this level has been determined by Dohmann et al [5] through a different method, based on the Auger electron emission process 1s2s2p 4P 5/2 →(1s 2 1S 0 + e −), in which an electrostatic cylindrical mirror analyser was used. It is noted [5] that the reason for the two standard deviations difference between their experimental result (236 ± 12 ps) and the theoretical estimates (205 ps [6] and 212 ps [7] is not known. We have therefore decided to re-investigate the 1s2s2p 4P 5/2 lifetime
using a different experimental set-up and analysis, this time focusing on x-ray, rather than Auger electron emission, in order to determine whether this difference between theoretical and experimental results still persists.

5.2. Theoretical Background

Fig. 5.1 shows the partial level scheme of He-like and Li-like $^{48}$Ti with lifetime and the decay modes of the various levels. Our investigation focuses on the determination of the lifetime for 1s2s2p $^{4}P_{5/2}$ Li-like level using its M2 decay channel to the Li-like ground state (transition energy 4.69 kev [8]). We note that for this level, a substantial decay through an autoionization channel (66%, [6]) is also possible. A theoretical investigation with the code GRASP [8] has revealed the presence of 16 Li-like titanium levels whose excitation energies lie in the energy range 4.673–4.782 keV with respect to Li-like ground state. These levels originate from the electronic configurations 1s2s2 $^2S_{1/2}$, 1s2p2 $^2P_{1/2, 3/2}$, $^2P_{1/2, 3/2, 5/2}$, $^2D_{5/2, 7/2}$, $^2S_{1/2}$, 1s2s2p $^2P_{1/2, 3/2, 5/2}$ and $^2P_{1/2, 3/2}$. However, the even parity levels in the list mentioned above are linked however to the Li-like ground state with low radiative transition probabilities [8] and do not contribute to the 4.7 keV line. For the odd parity levels, with the exception of 1s2s2p $^4P_{5/2}$, we note that the E1 transitions linking them to the Li-like ground state are significant [6,8]. These levels have short half-lifetimes and do not therefore to be considered. As a result, the only Li-like level that will be considered in the analysis of the 4.7 keV line is the 1s2s2p $^4P_{5/2}$ level (1s2s2 $^2S_{1/2}$–1s2s2p $^4P_{5/2}$ M2 emission rate $1.6 \times 10^8 s^{-1}$ [6]).

We note further that a number of He-like levels (Fig. 5.1) may also in principle contribute to the 4.78 keV line (Fig. 5.2). The He-like 1s2p $^3P_2$ level decays through (M2) to ground state 1s2 $^1S_0$ by emission of 4.734 keV x-ray photon. The 1s2s $^1S_0$ level on the other hand decays through a two-photon process [9], whereas the 1s2p $^1P_0$ level decays to the 1s2s $^3S_1$ level through an E1 transition in the vuv region. These two levels do not, therefore, directly contribute to the 4.78 keV line. The 1s2p $^1P_1$ and 1s2p $^3P_1$ levels, that have lifetimes are of
Fig. 5.1: Energy level diagram of He–like and Li–like titanium including their lifetimes and decay modes
the order of femtoseconds [10] do not contribute to the decay curves shown in (Fig. 5.4, 5.5). The only other He–like level that needs to be considered is 1s2s 3S1 (26.6 ns. [11]). The Li–like 1s2s2p 4P3/2 and the He–like 1s2p 3P2 and 1s2s 3S1 levels all lie within 50 eV. Since contributions from these levels to the 4.78 keV line could not resolved by the x–ray detector used in our experiment, all three levels were taken into consideration in the analysis of the 4.78 keV data. The H–like 2s 2S1/2 level (lifetime 1.014 ns [12], which decay through M1 channel by emission of 4.99 keV photon [11] is possible, should in principle be resolved by the x–ray detector used. This line however, has not been observed in the spectrum, implying that the H–like 2s 2S1/2 level is not populated in our experiment (Fig. 5.2).

5.3. Experimental Setup

Fig. 5.3 shows a schematic diagram of the experimental arrangement [13] used for the lifetime measurements of different states produced in highly charged ions. The 48Ti ions used in the measurements were obtained from the 15 MV Pelletron accelerator at Nuclear Science Center, New Delhi. A collimated 3 mm diameter titanium beam was excited by passage through 90 μg/cm2 carbon target. In the two–foil experiment, the thinner foil 4 μg/cm2 carbon foil was placed at 2.5 mm upstream from the detector. The experiment was performed with 95 MeV 48Ti and 143 MeV 48Ti beams. A beam collimator, first carbon foil and a gold foil were installed on the horizontal rail. The horizontal rail arrangement was fixed to the bottom of the chamber such that it was horizontal and parallel to the beam axis and it would remain in the plane of the incident beam. A rod along the target manipulating shaft fixed to the bottom of the foil holder was made to pass through the central hole bored in the horizontal rail. This always ensures the foil holder at the center of the chamber. Optical alignment of the beam collimator, first foil holder, second foil holder and the gold
Fig. 5.2. X-ray spectra obtained using a single foil target. Beam energy 143 MeV, foil-detector distance (a) 6.96 mm and (b) for 14.73 mm
Fig. 5.3. Schematic experimental arrangement
foil holder was done using a theodolite ensuring all components in the beam direction. Vacuum better than $1 \times 10^{-6}$ mbar was maintained throughout the experiment using a 250L/S Turbo molecular pump. X-ray emerging from the foil excited beam was passed through a collimating system consisting of three slits in a direction perpendicular to the beam axis to detect them in a low energy germanium detector. Normalization was achieved with the elastically recoiled ions from the gold foil and detected them in two surface barrier detectors placed at 30° to the incident beam. Two surface barrier detectors were used in order to take care of the minor deflections that may take place in either directions. Normalization procedure will be discussed in the next section. The main components of the chamber are shown in Fig. 5.3.

For making fine horizontal movement, a motorized linear motion feed through (Model MFL–275–4) and a programmable motor logic controller (Model MLC–1, programmable indexer /driver) were procured from Huntington Laboratories Inc., Mountain View, CA 94043. The linear motion feed through has the following features: Linear travel 4 inch, Ext 6.58 inch, Et 2.58 inch, L14.06 inch, backlash 0.002 inch, shaft pitch 0.125 inch motorized accuracy 25,000 microsteps/ revolution. The linear motion feed through was rigidly connected to the base of the first carbon foil holder. The distance traveled in a microstep was 0.127 μm. A computer program written at Nuclear Science Center, New Delhi, was used to control and read out its movement using a PC placed at a distance.

It is very much essential to make the foils flat for the experiment. Stretching the carbon foil mechanically is impossible and therefore a method was found to ensure that the carbon foils remain stretched while lifted on the target holder. The aluminum target holder having (2mm thick and 20mm in diameter) having 8mm hole, tapered in one side was used in the experiment. After fabricating the target holder, it was polished using polish powder of different
grades as explained in the chapter 4.

5.4. Normalization Procedure

It is essential particularly for lifetime measurements that any fluctuations in the beam intensity should be not interpreted as being associated with "real" intensity changes of a foil-excited transition. Thus the signal corresponding to the intensity of a foil-excited spectral line must be normalized to some quantity that is proportional to the number of ions per second traversing the foil. This is most conveniently done by normalizing the line intensity signal to the amount of the beam charge collected in a shielded Faraday cup placed downstream from the foil. This cup must not receive or lose any electrons in the measurement and so it is desirable to use a shielded metal ring biased negatively by few hundred volts to suppress secondary electrons. Care must be taken to demonstrate that the collected charge does not depend on foil-cup distance which is necessary in lifetime measurements. This geometrical effect is more likely to pose a problem when studying low energy heavy ions, since increased multiple-scattering effects in the foil under these conditions can cause considerable divergence in the postfoil beam.

Another potential problem associated with this beam charge integration method of normalization might be due to changes in the charge state and excitation distributions brought about by the time-dependent foil thickening effects. This method of normalization does, however, appear to be reliable in high-energy beam-foil measurements. A more consistent method of normalization (somewhat more difficult to apply in some experimental arrangements) is to use a second photon detector set at fixed distance downstream from the foil. Either a specific foil-excited line or the total integrated radiation can be monitored by this normalization detector,
5.5. Observations

The spectrum calibrated using $^{242}$Am radiation source, exhibits a prominent peak at 4.78 keV as shown in the (Fig 5.2). This peak consists of a blend of transitions from the He–like $1s2s^2{^1P}_2$ and $1s2s^2{^3S}_1$ levels and the Li–like $1s2s2p^4{^4P}_{3/2}$ level (Table 5.1). This blending is not expected to be resolved by the detector that has been used in this work. The normalized intensity variations of the 4.78 keV peak in the single–foil and two–foil measurements at 95 and 143 MeV are shown in (Figure 5.4 and 5.5) respectively. In the two–foil measurements at we note that, both at 95 MeV as well as at 143 MeV, the intensity of the line under investigation initially decay with distance before saturation is reaching.

5.6. Data Analysis, Results And Discussion

The charge states fractions for the $^{48}$Ti beam used in this work, obtained with the code ETACHA [14] are shown in (Table 5.2). Energy losses in the foil were taken into account in the charge state fraction calculation using code SRIM [15]. The charge state fractions are useful as they provide an indication as of the type of ions that are present in post foil beam. Results of experiments performed at GANIL with 10 MeV / u ions [14] agree with equilibrium as well as non equilibrium predictions of theoretical charge state fractions obtained with the code ETACHA. It has been further noted (Table 1b in [2]) that ETACHA predictions are consistent with the use of low energy (1.6 to 2.5 MeV/A) Cl beam in the investigation of He–like $1s2s^2{^3S}_1$–$1s2p^2{^3P}_2$ and $1s2s^2{^3S}_1$–$1s2p^2{^3P}_0$ transitions [16]. Whereas no charge state fraction data are available for Ti beams in the range 2–5 MeV/A, we note that Dohmann et al [5] used rather low–energy beams (3.6 and 5.0 MeV/A) in their investigation of He– and Li–like Ti lifetime. This is consistent with our ETACHA findings (Table 5.2) that, at these beam energies and for the carbon foil (90 $\mu$g/cm$^2$) of similar thickness to those used.
Fig. 5.4 Normalised intensities for the 4.78 kev line (beam energy 95 MeV) as a function of (a) the distance between foil and the detector in single-foil experiment and (b) the separation between two-foils in two-foil experiment, (the distance between the second foil and detector was fixed to 2.5 mm). Single-foil data curves (a) dashed line obtained from a two-exponents fit, solid line from a three-exponent fit using Eq. 5.2.
Fig. 5.5 Same as Fig. 5.4 but with beam energy was 143 MeV.
in [5] (100–160 $\mu$g/cm$^2$), He–like and Li–like levels are indeed significantly populated in the post–foil beam. We further note that use of 216 MeV Ti$^{19+}$ beams [17] in the measurement of the 1s2s $^3S_1$–1s2p $^3P_2$ transition wavelength in He–like Ti$^{20+}$ is also consistent with the charge state fractions reported in Table 5.2.

The decay curves from the single–foil experiments at 95 MeV (Fig.5.4(a)) and 143 MeV (Fig.5.5(a)) demonstrates the presence of two components. The first component is linked to an "effective" decay $\tau$, associated with the 1s2p $^3P_2$ and 1s2s3p $^3P_{3/2}$ levels whose theoretical lifetime are within a factor of two. The second component is associated with the (longer–living ) 1s2s $^3S_1$ level, for which reliable theoretical lifetime value (Table 5.1) is available. The lifetime $\tau$, determined in this way for the first component (Table 5.3) is $310 \pm 6$ ps at 143 MeV and $265 \pm 9$ ps at 95 MeV. These values are larger than the theoretical lifetime of the 1s2s3p $^3P_{3/2}$ level (205 ps) and lower than that of the 1s2p $^3P_2$ level (422 ps), an indication that both levels are contributing to this line. This is consistent with ETACHA predictions for the charge state fraction [Table 5.2]. Thus the value $\tau$, represents an "effective" decay time for both levels. The values for this "effective" lifetime are also in good agreement with the ones estimated from a semi–empirical formula [18] (Table 5.3).

The curves from the two–foil measurements at 95 MeV (Fig.5.4 (b)) and 143 MeV (Fig.5.5(b)) exhibit initially a decay, reaching saturation as the distance between the two–foils increases. In order to fit the two–foil data, we proceed along similar lines to those followed in the earlier studies [1,2]. The data are fitted using the following equation

$$I(x) = I_1 e^{-x/\nu \tau_1} + I_2 \left(1 - e^{-x/\nu \tau_1}\right) + I_3 \left(1 - e^{-x/\nu \tau_3}\right)$$

(5.1)
Here \( I(x) \) is the intensity as function of distance \( x \) between the two-foils. The growing components are associated with \( 1s2s2p \, ^3P_{3/2} \) level populated as a result of the presence of \( 1s2p \, ^3P_2 (\tau_2) \) and \( 1s2s \, ^3S_1 (\tau_3) \) levels.

To relate the terms in Eq. 5.1 with processes occurring at the second foil, we put forward a plausible model, summarized in Table 5.4. Intensity \( I_1 \) is associated with levels that give rise to unresolved transitions contributing to the 4.78 keV line. Those levels are generated from \( 1s^2 \) He-like levels. The value (310 ps), used in the above fitting for the decaying component \( \tau_1 \), has been associated to our single-foil discussion with \( 1s2p \, ^3P_2 \) and \( 1s2s2p \, ^3P_{3/2} \) levels. A second decaying component, associated with \( 1s2s \, ^3S_1 \) levels, has also been included in our fitting procedure based on Eq. 5.1. We have found however, that this component enters the fitting procedure with a negligible coefficient. As a result, this term has been dropped and its presence is not manifested explicitly in Eq. 5.1. \( I_2 \) is associated with \( 1s2s2p \, ^4P_{3/2} \) levels, populated as \( 1s2p \, ^3P_2 \) and \( 1s2s \, ^3S_1 \) levels, generated from \( 1s2p \, ^3P_2 \), interact with the second foil, capturing an electron. \( I_3 \) arises as \( 1s2s \, ^3S_1 \) levels, that are present in post-foil, thereby populating the level \( 1s2s2p \, ^4D_{5/2} \). Intrashell transitions may also precede electron capture.

A least square fit of the two-foil data at 143 MeV using Eq. 5.1 was then performed. In the fitting procedure, the "effective" lifetime (\( \tau_1 \)) was fixed to the value (\( \tau_1 \)) (310 ± 6 ps) obtained from the single-foil measurement. This value has been associated with \( 1s2p \, ^3P_2 \) and \( 1s2s2p \, ^4P_{3/2} \). The value of (\( \tau_3 \)) was fixed to 26.6 ns, the theoretical lifetime of the \( 1s2s \, ^3S_1 \) level. The decay time (\( \tau_2 \)) associated with the \( 1s2p \, ^3P_2 \) lifetime, is then determined to be 389 ± 18 ps (Table 5.3) at beam energy 143 MeV. The 95 MeV data were analyzed in a similar manner. The value of \( \tau_2 \) is 419 ± 20 ps (Table 5.3) at beam energy 95 MeV. The Average lifetime (\( \tau_2 \)) (404 ± 16 ps) of the \( 1s2p \, ^3P_2 \) level at the two beam
energies is consistent with an earlier experimental result \((404 \pm 40\text{ps})\) in which a flat spectrometer was used. This result is also consistent with the theoretical value \((422\text{ps}, [10])\) calculated within the relativistic random-phase approximation.

Finally, in order to disentangle the contribution of the \(1s2p \, ^3P_2\), level from the effective decay time \((\tau_s)\) determined from a one-exponent fit of the single-foil data and thus obtained a value for the \(1s2p2s2p \, ^4P_{5/2}\) lifetime, we have repeated the analysis on the single-foil decay curve at \(143\,\text{MeV}\). The decay curve was fitted this time with three, rather than two, exponents as follows

\[
I(x) = I_1 e^{-x/\tau_1} + I_2 e^{-x/\tau_2} + I_3 e^{-x/\tau_3},
\]

where \(\tau_3 = 26.6\,\text{ns}\) and \(I_3\) was fixed to the value obtained from the two exponential fit of the single-foil data and \(\tau_2\) was kept fixed at the average \(1s2p \, ^3P_2\) lifetime value \(404 \pm 16\,\text{ps}\) (Table 5.3). A value of \(238 \pm 14\,\text{ps}\) was thus obtained for \(\tau_1\) associated with the \(1s2s2p \, ^4P_{5/2}\) level. Single-foil data at \(95\,\text{MeV}\) were also fitted in the same manner to yield a value \(1s2s2p \, ^4P_{5/2}\) level lifetime as \(193 \pm 13\,\text{ps}\) (Table 5.3). The average of \(1s2s2p \, ^4P_{5/2}\) lifetime from the measurements at the two beam energies is \(210 \pm 10\,\text{ps}\) (Table 5.3). This value is lower than that determined earlier experimental study \((236 \pm 12\,\text{ps})\) [5] and very close to theoretical value \(212\,\text{ps}\) [7] calculated within a relativistic Hartree–Fock model. A relativistic calculation in the intermediate-coupling scheme [6] using Dirac–Hartree–Slater wave function and the Moeller two electron operator gives a value \((205\,\text{ps})\) that is within the uncertainty range of our present result. The uncertainty in our measurement, however, is not sufficiently low to provide conclusive evidence in favor of either one.

The analysis followed in the current study closely resembles those in our
earlier work [1,2]. We note however that, this time, the $1s2s^3S_1$ level must be considered explicitly in the equations that were used in the fitting procedure. This is due to the fact that our current experimental set-up allows for a considerably longer beam travel than that allowed in our previous studies.

5.7. Conclusion

In this work, we have determined the $1s2s2p\ ^4P_{3/2}$ lifetime for the first time through its M2 x-ray decay channel to the Li–like ground state. Theoretical estimates for the $1s2s2p\ ^4P_{3/2}$ lifetime lie within the uncertainty bounds of our experimental result. A two standard deviations difference between a previous experimental result ($236\pm 12$ps [5]) and theoretical predictions (205 ps [6] and 212 ps [7]) does not therefore arise from our measurements and subsequent analysis. This suggests that previous theoretical values [6,7] provide adequate estimates to the $1s2s2p\ ^4P_{3/2}$ lifetime. The uncertainty in present measurement however does not provide conclusive evidence in favour of either one.

The method followed in the current and earlier studies [1,2] can be used as a tool for the determination of blend–free lifetimes even at low–resolution conditions. It provides a general technique that couples single and two–foil data through the application of an iterative multi–component growth and decay analysis. contributions from blending transitions that are due to other charge states, which cannot be spectrally resolved, are eliminated. The method however may only be applied if the difference in lifetime values of the blending levels in question is not small.
Table 5.1: Theoretical predicted lifetimes and transition energies for the transitions that may contribute to the 4.78 keV line

<table>
<thead>
<tr>
<th>Ion</th>
<th>Transition</th>
<th>Energy (keV)</th>
<th>Lifetime (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti$^{2+}$</td>
<td>$1s^2 , ^1S_0 - 1s2p , ^3P_2$</td>
<td>4.7834 [11]</td>
<td>422 [10]</td>
</tr>
<tr>
<td>Ti$^{3+}$</td>
<td>$1s^2 , ^1S_0 - 1s2p , ^3S_1$</td>
<td>4.702 [11]</td>
<td>26.6 [10]</td>
</tr>
<tr>
<td>Ti$^{19+}$</td>
<td>$1s^22s , ^3S_{1/2} - 1s2s2p , ^3P_{3/2}$</td>
<td>4.690 [8]</td>
<td>205 [6], 212 [7]</td>
</tr>
</tbody>
</table>

Table 5.2: Theoretical (code ETACHA, [14] charge state fractions prediction for Ti beams emerging from a 90 μg/cm² carbon foil. Q_in denotes the charge state fraction of the incident beam. As values for Q_in were not provided in [5].

<table>
<thead>
<tr>
<th>Ion beam</th>
<th>Energy (MeV)</th>
<th>Qin</th>
<th>H-like</th>
<th>He-like</th>
<th>Li-like</th>
<th>Be-like</th>
<th>B-like</th>
<th>C-like</th>
<th>N-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>9</td>
<td>0.43</td>
<td>8.15</td>
<td>23.15</td>
<td>30.00</td>
<td>22.72</td>
<td>11.03</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>143</td>
<td>11</td>
<td>4.32</td>
<td>27.41</td>
<td>36.01</td>
<td>22.01</td>
<td>7.91</td>
<td>1.81</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>172.8 [5]</td>
<td>13</td>
<td>8.62</td>
<td>37.64</td>
<td>34.38</td>
<td>14.55</td>
<td>3.61</td>
<td>0.6</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>240 [5]</td>
<td>17</td>
<td>19</td>
<td>50.41</td>
<td>23.14</td>
<td>4.81</td>
<td>0.579</td>
<td>0.44</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.3: Lifetimes for the $1s2s2p^4P_{5/2}$ Li–like and the $1s2p^3P_2$ He–like $^{49}$Ti levels

<table>
<thead>
<tr>
<th>Upper level</th>
<th>Beam energy (MeV)</th>
<th>Experiment [\text{ps}]</th>
<th>Experiment Other work [\text{ps}]</th>
<th>Theoretical Lifetime [\text{ps}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (unresolved)</td>
<td>95</td>
<td>265±9($\tau_1$)$^a$</td>
<td>–</td>
<td>290±29$^b$</td>
</tr>
<tr>
<td>$1s2p^3P_2$</td>
<td>95</td>
<td>419±20($\tau_1$)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>All (unresolved)</td>
<td>143</td>
<td>310±6($\tau_2$)$^a$</td>
<td>–</td>
<td>328±33$^b$</td>
</tr>
<tr>
<td>$1s2p^3P_2$</td>
<td>143</td>
<td>389±18($\tau_2$)$^b$</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$1s2s2p^4P_{5/2}$</td>
<td>95</td>
<td>193±13($\tau_1$)$^c$</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$1s2s2p^4P_{5/2}$</td>
<td>143</td>
<td>228±14($\tau_1$)$^c$</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$1s2s2p^4P_{5/2}$</td>
<td>Average</td>
<td>210±10</td>
<td>236±12 [5]</td>
<td>212 [7]</td>
</tr>
</tbody>
</table>

$^a$ Single–foil, data fitted with two exponents.

$^b$ Two–foil data fitted with Eq. 5.1

$^c$ Single–foil, data fitted with three exponents

(lifetimes of $1s2s2p^4P_{5/2}$ was varied, lifetimes of $1s2p^3P_2$ and $1s2s^3S_1$ fixed to 404.4 ps and 26.6 ns respectively)
Table 5.4. Correspondence between processes at the second foil that various terms in Eq. 5.1 (see the text).

<table>
<thead>
<tr>
<th>Level before the second foil</th>
<th>Levels after the second foil</th>
<th>Intensity component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1s²</td>
<td>All excited levels giving rise to unresolved transition</td>
<td>I₁</td>
</tr>
<tr>
<td>(a) 1s2s ³S₁ (arising from 1s2p ³P₂) and (b) 1s2p ³P₂</td>
<td>1s2s2p ⁴P½ (Populated by electron capture or intrashell transition followed by electron capture)</td>
<td>I₂</td>
</tr>
<tr>
<td>1s2s ³S₁</td>
<td>1s2s2p ⁴P½ (Populated by electron capture or intrashell transition followed by electron capture)</td>
<td>I₃</td>
</tr>
</tbody>
</table>

References

communication.


