A MEASUREMENT OF THE 1s2p3P LIFETIME IN HELIUM LIKE SILICON


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A MEASUREMENT OF THE $1s2p^3P_1$ LIFETIME IN HELIUM LIKE SILICON

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Abstract. We have observed the soft X-ray spectrum of highly ionised silicon and made measurements of the $1s2p^3P_1$ lifetime of the helium like system. Standard beam foil decay curve techniques were used and the $3s^1$ decay to the ground state was observed with a curved crystal X-ray spectrometer. A preliminary result of $6.68 \pm 0.40$ ps was obtained which compares with theoretical estimates of 6.33 ps and 6.62 ps.

Résumé. Nous avons observé le spectre des ions de silicium multi ionisé, et nous avons mesuré la durée de vie du niveau $1s2p^3P_1$ de Si$^{12+}$. On a utilisé les techniques de beam foil spectroscopie, et la decroissance du $3s^1$ au niveau fondamental était observé avec un spectromètre de Rayons X à cristal courbe. Notre résultat préliminaire est $6.68 \pm 0.40$ ps, qu'on peut comparer avec les valeurs théoriques de 6.33 et 6.62 ps.

INTRODUCTION

In helium like ions the $1s2p^3P_1$ state is mixed with the $1s2p^1P_1$ and other $1P_1$ states by fine structure interactions. The mixing is very small in helium but increases rapidly as we go to higher Z ions. A term scheme showing states of interest in the present experiment is shown in fig.1.

Fig.1 Term diagram of Si$^{12+}$

The principal allowed decay mode for the $1s2p^3P_1$ states is electric dipole to the $1s2s^3S_1$ state ($A \sim 2 \times 10^8$ s$^{-1}$ in silicon [1]). The $1s2p^1P_1$ level however can decay directly to the ground state by electric dipole radiation, and has a very short lifetime ($A \sim 4 \times 10^{13}$ s$^{-1}$ in silicon [1]). Due to singlet triplet mixing, the $3P_1$ state can also decay directly to the ground state; the decay rate scaling approximately as $Z^{10}$. The $3P_{2,0}$ levels do not mix with the singlet system and they have lifetimes $10^3$ times as long as $3P_1$ [1],[2]. See also Drake [3] for details of magnetic quadrupole decay of the $3P_2$ state.

A study of the $3P_1$ decay rate provides a test of transition probabilities in this simple two electron ion. The rate is also of astrophysical interest, and such transitions may be used in measurements of electron densities in plasmas by the $3P$ to $3S$ intensity ratio method of Gabriel and Jordan [4],[5]. The $3P_1$ lifetime has also been studied by Varghese et al [5] using a Doppler tuned X ray spectrometer.

EXPERIMENTAL ARRANGEMENT

The Si beam was supplied by the 6.7 MV EN Tandem Van de Graaff accelerator at the Oxford Nuclear Physics Laboratory. Beams of about 100 nA, at energies of 40 and 57 MeV, were
excited by passage through carbon foils, and decay curves obtained by varying the foil distance from the entrance slit of the spectrometer. The experimental set up is shown in figure 2.

The target was a 10 \( \mu \text{g cm}^{-2} \) carbon foil which was moved in 2.5 \( \mu \text{m} \) steps by a stepping motor. The position of the target holder was measured to within \( \pm 1 \mu \text{m} \) by a Heidenhain digital length gauge which uses a Moiré fringe measuring grating.

To observe the decay curve of a short lived state we need good time resolution. The time resolution is determined by the beam velocity, the entrance slit width, the angular acceptance of the spectrometer and the distance of the beam from the entrance slits, as shown in figure 4. We used narrow entrance slits (<70 \( \mu \text{m} \)) and masked the crystal to reduce the angular acceptance of the spectrometer. The ion beam had its final collimation to 1 mm x 2 mm on the target itself and passed the entrance slit of the spectrometer at a distance of 1.5 mm. A decay curve showing the fast rise due to good temporal resolution is shown in figure 5.
decay curve and thus had an insignificant effect on the lifetimes deduced from the measured curves. An online data acquisition system controlled by a PDP10 computer via a CAMAC interface was used to control scans and take data. A typical scan would last about 4 hours collecting data at 5 or 10 µm intervals over a distance of 9 or 10 3P1 state lifetimes, i.e. just over 1 mm.

**ANALYSIS**

We analysed our decay curves by making a least squares fit of exponentials. Figure 5 shows a fit obtained by convolving a trapezoidal window function with the exponential decays, using a program developed by Trnbert and Winter [7].

![Si ls2p 3P decay at 57 MeV](image)

**Table 1:** Measurements of the lifetime of the 2P state of Helium-like Silicon under different conditions

<table>
<thead>
<tr>
<th>Observation window</th>
<th>Lifetime and cascades in ps (40 MeV)</th>
<th>Lifetime and cascades in ps (57 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>short (&lt;80 µm)</td>
<td>6.70, 48</td>
<td>6.68, 30</td>
</tr>
<tr>
<td>long (&lt;110 µm)</td>
<td>6.69, 57</td>
<td>6.64, 39</td>
</tr>
</tbody>
</table>

The short cascade was of negative amplitude and the longer cascade of positive amplitude. An unweighted mean gives a lifetime of 6.68 ps. Fitting with only two exponentials (no short lived cascade) causes only a small increase in chi-squared but increases the scatter of results. It is interesting to note that when fitting only two exponentials the measured lifetime increases slightly with increased beam energy and might indicate systematic effects due to fitting too few cascades. This effect also seems to be present in the data of Varghese et al [5].

There are many cascades into the 3P1 state and our approximation of considering only 2 will introduce errors. We are making a more detailed analysis of our data in terms of expected cascades, which should result in a better understanding of the sources of error. The present error quoted is much larger than the statistical error in the extraction of an exponential decay from one typical curve such as fig.5 and corresponds to seven times the total spread in the results given in table 1. This error also corresponds to twice the difference between the final result for the ls2p3P1 lifetime obtained using the three exponential fit, as in table 1, and the final result which is obtained if all the data are analysed using a two exponential fit.

**RESULTS**

Our results may be compared with the theoretical predictions of Johnson and Lin [8], Vainstein and Safranova [1] or with the previous experimental work of Varghese et al [5].
Our present result is consistent with both theoretical values, although much closer to that of Vainstein and Safranova.

<table>
<thead>
<tr>
<th>Experimental</th>
<th>Theoretical</th>
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<tr>
<td>Our Result</td>
<td>Johnson and Lin[8] 6.33 ps</td>
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</table>

REFERENCES


ACKNOWLEDGEMENTS

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