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A MEASUREMENT OF THE 1s2p3P1 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 1s2p3P1 lifetime of the helium like system. Standard beam foil decay curve techniques were used and the 3P1 decay to the ground state was observed with a curved crystal X-ray spectrometer. A preliminary result of 6.68 ± 0.40 ps was obtained which compares with theoretical estimates of 6.33 ps and 6.62 ps.


INTRODUCTION

In helium like ions the 1s2p3P1 state is mixed with the 1s2p1P1 and other 1P1 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.

The principal allowed decay mode for the 1s2p3P states is electric dipole to the 1s2s3S1 state (A ~ 2 x 10^8 s⁻¹ in silicon [1]). The 1s2p3P1 level however can decay directly to the ground state by electric dipole radiation, and has a very short lifetime (A ~ 4 x 10^13 s⁻¹ in silicon [1]). Due to singlet triplet mixing, the 3P1 state can also decay directly to the ground state; the decay rate scaling approximately as Z^4. The 3P2,0 levels do not mix with the singlet system and they have lifetimes 10^3 times as long as 3P1 [1,2]. See also Drake [3] for details of magnetic quadrupole decay of the 3P2 state.

A study of the 3P1 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 [4,2]. The 3P1 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 µg cm\(^{-2}\) carbon foil which
was moved in 2.5 µm steps by a stepping motor.
The position of the target holder was measured to
within ±1 µm 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 µm) 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
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To allow for beam fluctuations our signal
was normalised to integrated beam current. A
Faraday cup which moved at a constant distance
of 3 cms from the foil was used, thus minimising
possible errors due to change in the geometry of
the charge collection system. The change in
yield of photons per unit charge due to foil
ageing was less than 1% over one lifetime of the
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 \(^3\!P_1\) 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 \(^3\!P_1\) decay at 57 MeV](image)

**Fig.5**

To remove the effects of small uncertainties in the window function, we cut off the first part of the decay curves. The loss in statistical precision introduced by this procedure was more than balanced by the elimination of systematic errors due to an imperfect description of the window function in the analysis programme.

To help show up possible systematic errors in our measurements, we worked at two different beam energies, and with different masks on the crystal, to give different time windows. The results of fitting the decay with 2 cascades are shown in table 1.

<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 (~80 μm)</td>
<td>6.70, 1.0, 48</td>
<td>6.68, 0.8, 30</td>
</tr>
<tr>
<td>long (~110 μm)</td>
<td>6.69, 1.1, 57</td>
<td>6.64, 4.2, 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 \(^3\!P_1\) 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 ls2p\(^3\!P_1\) 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>
</tr>
</thead>
<tbody>
<tr>
<td>Our Result</td>
<td>Johnson and Lin [8] 6.33 ps</td>
</tr>
<tr>
<td></td>
<td>Vainstein and Safranova [1] 6.62 ps</td>
</tr>
<tr>
<td>Varghese et al [5]</td>
<td>6.35±0.33 ps</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENTS

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REFERENCES