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The 2s2p $^4P^o_{5/2}$ - $2p^2$ $^4P^e_{5/2}$ transition in O VI

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Abstract

The Li-like doubly excited transitions 2s2p $^4P^o_{5/2}$ - $2p^2$ $^4P^e_{5/2}$ in O VI has been studied with the beam-foil technique. Oxygen ion beams with energies between 4.5 to 9 MeV were used. The wavelength of the transition was measured to 944.0±0.5 Å and the lifetime for the upper level $2p^2$ $^4P^e$ was measured to be 0.51±0.04 ns.

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Introduction

In this paper the lifetime of the doubly excited $2p^2\ {}^4P^e{}_{5/2}$ level in O VI is reported. The measurements have been performed on the resonans transition $2s2p\ {}^4P^o{}_{5/2} - 2p^2\ {}^4P^e{}_{5/2}$ for which also the wavelength has been determined experimentally.

Observations of photons originating from the doubly excited $2p^2\ {}^4P^e$ levels in the Li-like isoelectronic sequence have been reported for Li I, Be II, B III, C IV and N V (Ref. 1). Due to autoionization photon de-excitation is less probable for higher values of Z. Electrons originating from different doubly excited states have previously been observed and analysed for N V, O VI, F VII, Ne VIII, Al XI, Si XII, S XIV, Cl XV and Ar XVI (Ref.2-3). Generally the process of electron emission is much more likely than that of photon emission. However, some of the levels involved are metastable against autoionization. The beam-foil method has proved to be an efficient technique to study energies and lifetimes for such states. This is due to the fact that the beam-foil source is a light source in which multiple-excited states are heavily populated. Lifetime measurements by means of the beam-foil technique have been performed in the Li-like isoelectronic sequence for a number of states in Li I, Be II, B III, C IV, N V, O VI and F VII by observing photons (Ref. 1). The lifetime for the levels $2s2p\ {}^4P^o$ and $2p3p\ {}^4P^e$ in O VI, F VII, Cl XV and Ar XVI and the $2s2p\ {}^4P^o$ levels in N V, Al XI and Si XII have also been measured by observing electrons (Ref. 1-3)

Method

Using an oxygen ion beam from the Uppsala Tandem Van der Graaff accelerator spectra were recorded at beam energies of 4.5, 6, 7.5 and 9 MeV. After passage through a self-supporting carbon foil with a typical thickness of 10 $\mu g/cm^2$ the beam was stopped in a Faraday cup guarded by an electrostatic supressor ring. Photons emitted at an angle of 90^o to the excited beam were analysed with a 1 m Seya-Namioka type grating monochromator equipped with a channeltron electron multiplier. Spectra and lifetime measurements were recorded by using an automatic control system. (Ref. 4). Spectra as well as lifetime data were directly fed into the memory of a PDP-15 computer. A least square fitting program LSQFIT (Ref. 5), was used to resolve the different peaks by fitting Gaussian profiles of a given halfwidth to the collected data. The same routine was also used to fit exponential functions to the lifetime data. Examples of the result can be seen in Fig. 1 and Fig. 3.

The energy of the 2s2p $^4P^o$ - $2p^2$ $^4P^e$ transition in O VI.

According to variational calculations made by Holøien and Geltman (Ref. 6) the transition 2s2p $^4P^o$ - $2p^2$ $^4P^e$ could be expected at 954 Å. However, experience from lower values of Z show that the theoretical energy values for the $^4P^o$ terms are not so accurate. Therefore the transition looked for might be found at a slightly shorter wavelength than that calculated. An example of a recorded spectrum over the region of interest can be seen in Fig. 1. The energy calibration for the different peaks in the spectra was done from three well determined transitions, which could be readily found in every recorded spectrum. The first peak used for calibration originates from the 2s2p $^1P^o$-$2p^2$ ^1S transition in O V(Ref. 7) and the second peak is the 2s ^2S - 2p ^2P transition in O VI (Ref. 7). The third peak from the transition 4f ^2F - 5g ^2G in O VI was calculated to 1125.05 Å by using the polarization formula given by

Edlen (Ref. 8). Thereby hydrogenic term values are used, and corrected by the formula $\Delta p = A(Z)\cdot P(n,\ell)\ [1+k(Z)\ q(n,\ell)]$ which takes into account the dipole polarizability and the quadrupole polarizability. In Fig. 1 a number of lines can be found just below 950 Å. Excitation functions were studied, in order to identify the proper transition.

The excitation function

The shape of the excitation functions for the Li-like doubly excited levels are not easily predictable. The complexity of the process that leads to the formation and the disintegration of ions with K-vacancies is rewieved in Ref.9. This paper also suggests that the dominating mechanism probably is an electron capture process in the 1s2s or 1s2p triplet heliumlike ion. According to arguments given in Ref.9 and 10the excitation function should have its maximum of intensity at a lower ion velocity than that of the ground-state ions with the same charge.

The excitation function obtained for the transition at 944.0 Å, interpreted as the 2s2p $^4P^o_{5/2}$ $-2p^2$ $^4P^e_{5/2}$ transition in O VI, can be seen in Fig. 2. The same result is obtained wether the normalisation is made on the totaly collected amount of charge in the Faraday cup or on a strong peak in the spectrum. Unfortunately it was impossible to record spectra at a lower beam energy than 4.5 MeV at the prevailing accelerator conditions. As revealed from Fig. 2 the shape of the excitation function for the $2p^2$ $^4P^e$ level follows that of the 2s2p $^4P^o$ level measured by Smith et al. (Ref. 10). The charge state distribution functions (Ref. 11) measured behind the foil are plotted for comparison.

However, there are also two more lines which have to be considered. Their measured wavelengths (946.3 Å and 948.1 Å respectively) agree better with calculated wavelength. Both lines are weak but their excitation functions can be measured. The first line seems to follow a 5+ function and the second one a 6+ function. None of these lines can be definitely excluded as a candidate for the 2s2p $^4P^o$-$2p^2$ $^4P_{5/2}$ transition. The last transition can also be the 4f ^2F - 6h ^2H transition in O VII.

Lifetime measurement

If pure LS-coupling is valid there would be no other possibility for the depopulation of the $2p^2\ ^4P^e$ levels through photon channels than the $2s2p\ ^4P^o - 2p^2\ ^4P^e$ transitions. But decay of the $2s2p\ ^4P^o$ levels in O VI and F VII through the M2 transitions $1s^22s\ ^2S_{1/2} - 1s2s2p\ ^4P^o_{1/2,3/2}$ have been observed (Ref. 12-13). A decay channel for the $2p^2\ ^4P^e$ levels through the transitions $1s^22p\ ^2P^o_{1/2,3/2} - 2p^2\ ^4P^e_{1/2,3/2}$ is therefore probable. The energy available in a doubly excited state is more than sufficient to permit de-excitation through autoionization. Normally there is also a very strong coupling to the continum by the Coulomb repulsion between the electrons. It is therefore likely that the $2p^2\ ^4P^e_{1/2,3/2}$ levels are depopulated predominately through electron emission or through the $1s^22p\ ^2P - 1s2p^2\ ^4P$ intercombination transition. The situation for the $2p^2\ ^4P^e_{5/2}$ level is different. This level is metastabel for decay through autoionization. The f-values as a function of 1/Z for the $2s2p\ ^4P^o_{5/2} - 2p^2\ ^4P^e_{5/2}$ transition in the Li-I isoelectronic sequence has earlier been published (Ref. 14). Comparisons with theoretical calculations are made. It can be seen that for increasing values of Z the measured f-values tend to increase thus increasing also the difference to theoretical values. In order to extend the region of comparison the lifetime of the $2p^2\ ^4P^e_{5/2}$ level was measured through the transition $2s2p\ ^4P^o_{5/2} - 2p^2\ ^4P^e_{5/2}$. The decay curve can be seen in Fig. 3. A single exponential curve corresponding to a lifetime of 0.51±0.04 ns is revealed. No evidence of a shorter lifetime or any trace of a cascade effect could be found. From the lifetime and wavelength measurement in this work an experimental f-value of 0.28±0.04 was calculated. The figure from Ref. 14 with an additional new value for O VI can be seen in Fig. 4.

Fine structure

A close look to the spectra reveals a few other transition in the vicinity of the 944.0 Å line. Three of these are found to have excitation functions very similar in shape to that of the $2p^2\ ^4P^e_{5/2}$ level as revealed by the studied transition $2s2p\ ^4P^o_{5/2} - 2p^2\ ^4P^e_{5/2}$. The most probable transition to attribute to one of these lines is the $2s2p\ ^4P^o_{3/2} - 2p^2\ ^4P^e_{5/2}$ transition. The measured wavelength is 941.5±1.5 Å.

Results and conclusion

The above given arguments based on lifetime, excitation functions and energy measurements make probable that the $2s2p\ ^4P^o_{5/2} - 2p^2\ ^4P^e_{5/2}$ transition has been observed at 944.0±0.5 Å. However, two other lines at 946.3 Å and 948.1 Å are still candidates for this assignment. A lifetime of 0.51±0.04 ns is measured for a $2p^2\ ^4P_{5/2}$ level and comparisons with f-values along the Li I isoelectronic sequence are made. Break-down of pure LS coupling is observed. In addition a transition at 941.5 Å is tentatively assigned as the $2s2p\ ^4P^o_{3/2} - 2p^2\ ^4P^e_{5/2}$ transition in O VI.

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Figure captions

Fig. 1. Spectrum (725-1150 Å) from an oxygen beam of 6 MeV recorded with the normal incidence monochromator.

Fig. 2. Excitation function for the $2p^2\ ^4P_{5/2}$ level obtained by using the $2s2p\ ^4P^o_{5/2} - 2p^2\ ^4P_{5/2}$ transition at 944 Å. Charge state distribution curves behind the foil are plotted for comparison.

Fig. 3. Decay curve for the $2p^2\ ^4P_{5/2}$ level obtained by using the 944 Å line.

Fig. 4. f - values for the $2p^2\ ^4P_{5/2}$ level in the Li I isoelectronic sequence (from Ref. 14). A new value for O VI is introduced which clearly shows the break-down of LS-coupling.

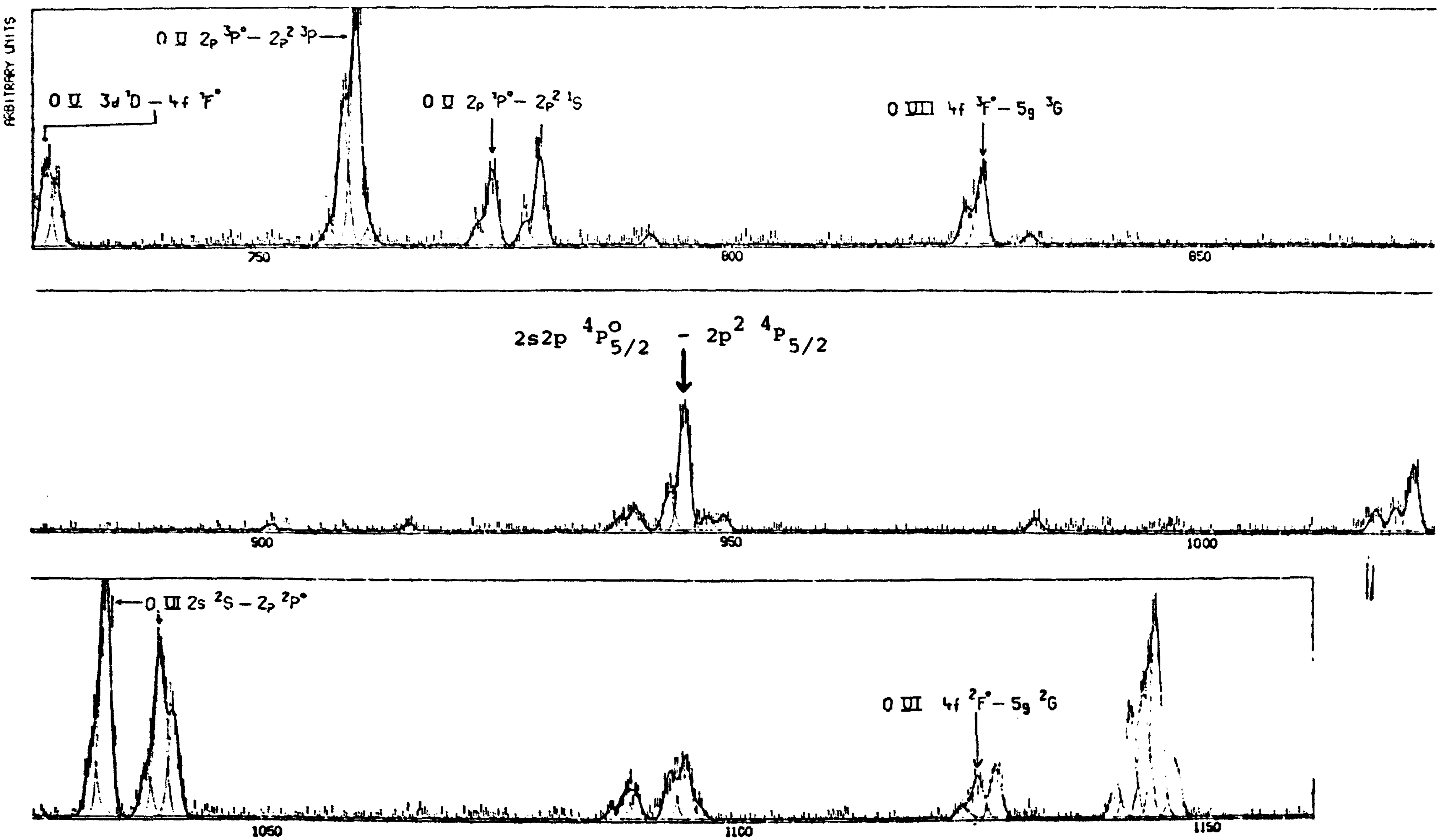
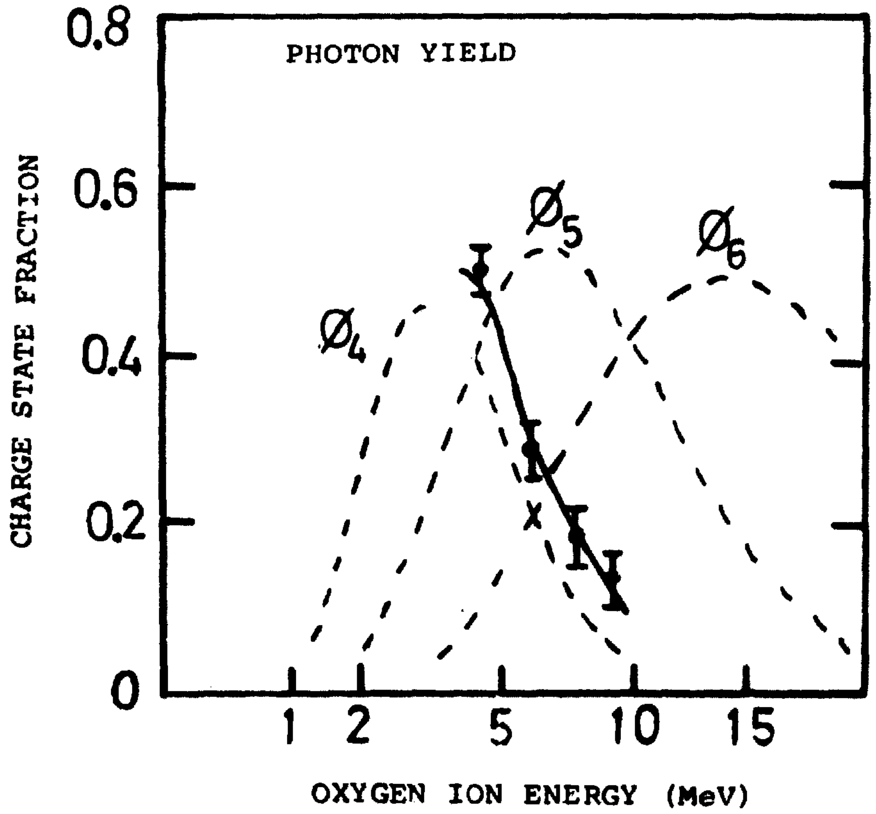
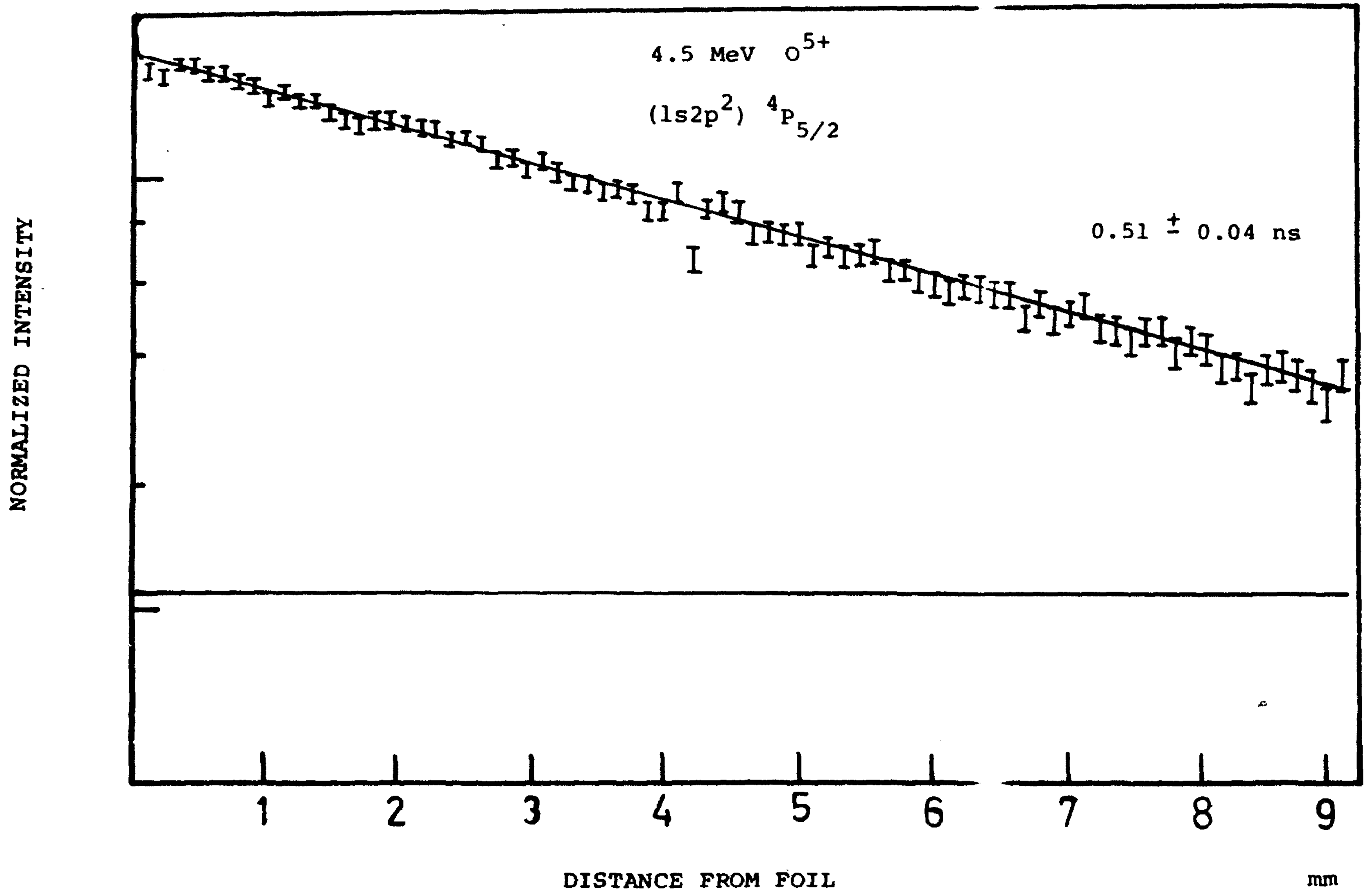

ARBITRARY UNITS
O V 3d 1D – 4f 1F°
O V 2p 3P° – 2p2 3P
O V 2p 1P° – 2p2 1S
O VII 4f 3F° – 5g 3G
750
800
850
2s2p 4Po5/2 - 2p2 4P5/2
900
950
1000
O III 2s 2S – 2p 2P°
O VI 4f 2F° – 5g 2G
1050
1100
1150

Fig. 1



PHOTON YIELD
CHARGE STATE FRACTION
0.8
0.6
0.4
0.2
0
Ø5
Ø6
Ø4
1
2
5
10
15
OXYGEN ION ENERGY (MeV)

Fig. 2



4.5 MeV O5+
(1s2p2) 4P5/2
0.51 ± 0.04 ns
NORMALIZED INTENSITY
1
2
3
4
5
6
7
8
9
DISTANCE FROM FOIL
mm

Fig. 3

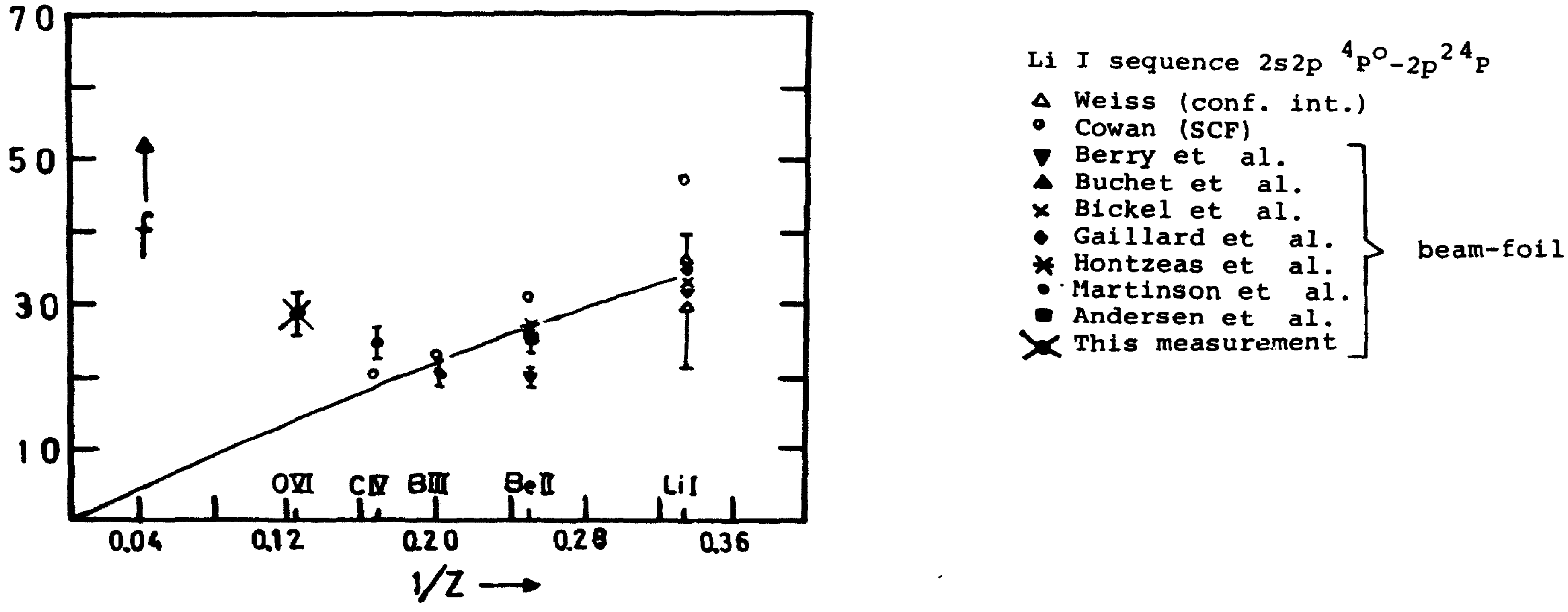

70
50
30
10
f
OVI
CIV
BIII
BeII
LiI
0.04
0.12
0.20
0.28
0.36
1/Z →
Li I sequence 2s2p $^4P^o$-$2p^2$ ^4P
Weiss (conf. int.)
Cowan (SCF)
Berry et al.
Buchet et al.
Bickel et al.
Gaillard et al.
Hontzeas et al.
Martinson et al.
Andersen et al.
This measurement
beam-foil

Fig. 4