Brief Reports

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Measurement of the $2p\,3s\ ^1P^\circ$ lifetime in O III with the beam-foil–laser method

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We have applied the beam-foil–laser (BFL) method to determine the lifetime of the $2p3s\ ^1P^\circ$ level in O III. The result ($\tau=0.17\pm0.01$ ns) is in good agreement with most of the theoretical predictions but significantly shorter than the two beam-foil lifetime values reported previously. The oscillator strengths of the $2p^2\,^1D-2p3s\ ^1P^\circ$ transition deduced from the present lifetime result in O III and from the very recently reported BFL lifetime in N II confirm the f-value trend along the carbon sequence calculated by Fawcett [At. Data Nucl. Data Tables **37**, 411 (1987)].

I. INTRODUCTION

Several calculations of the oscillator strengths for the $2p^2\,^1D-2p3s\ ^1P^\circ$ transition in ions belonging to the carbon sequence have been reported.[1–10] Recently, Fawcett[10] computed weighted oscillator strengths of this transition for the ions C I to Ni XXIII using a Hartree-Fock relativistic program package.

"Experimental" oscillator strengths of the $2p^2\,^1D-2p3s\ ^1P^\circ$ transition can be deduced from $2p3s\ ^1P^\circ$ lifetime measurements. Several lifetimes have been measured for the $2p3s\ ^1P^\circ$ level in the first ions of the sequence by the phase-shift[11] or beam-foil (BF) methods;[12–19] one lifetime value has been obtained in N II by the accurate beam-foil–laser (BFL) method.[20] As the $2p3s\ ^1P^\circ$ level is strongly repopulated by cascading, only the BFL result in N II is expected to be reliable. The f value deduced from this result is in very good agreement with the most recent calculations.[7–10] However, to confirm the validity of the f-value trend established by Fawcett[10] accurate oscillator strengths must be measured for ions other than N II.

In the present work, we determine an accurate lifetime for the $2p3s\ ^1P^\circ$ level in O III using the beam-foil–laser method and we discuss the f-value trend for the $2p^2\,^1D-2p3s\ ^1P^\circ$ transition along the carbon sequence.

II. EXPERIMENT

The beam-foil–laser method and the experimental setup have been described in detail in Refs. 21 and 22. An O_2^+ beam of 1.5 MeV—supplied by a 2-MV Van de Graaff accelerator—crosses at right angles successively a thin carbon foil ($\approx 5\ \mu g/cm^2$) and the intracavity beam of a cw dye laser (pumped by a 20-W argon laser). The wavelength of the dye laser is tuned to resonance with the $2p3s\ ^1P^\circ-2p3p\ ^1P$ transition in O III at 559.24 nm and the laser-on and laser-off intensities of the $2p^2\,^1D-2p3s\ ^1P^\circ$ transition at 39.56 nm were recorded (see inset of Fig. 1). The distance between the foil and the dye laser beam axis has been chosen equal to ≈ 8 mm so that the population of the short-lived $2p3s\ ^1P^\circ$ level, at the laser field entrance, is much smaller than the population of the long-

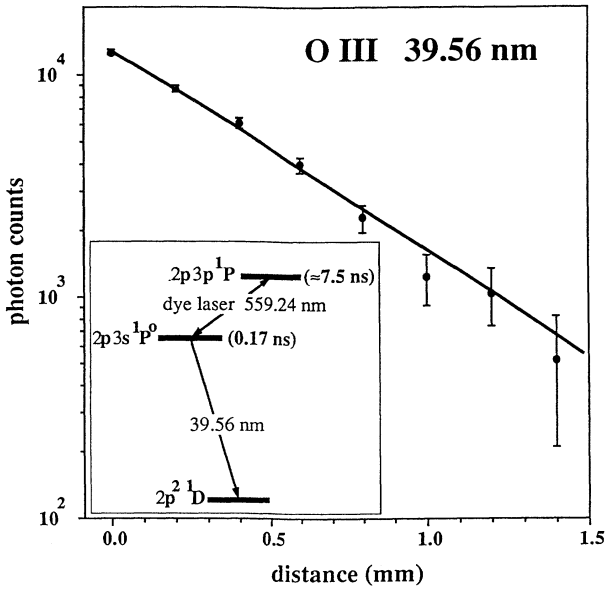

FIG. 1. BFL (laser-on–laser-off) decay curve for the O III 39.56-nm line recorded using 1.5-MeV O_2^+ ions. The error bars represent the statistical errors (one standard deviation). The solid line is a least-squares fit of the data to a difference of two exponentials (see text). In the inset the transitions involved in the O III $2p3s\ ^1P^\circ$ lifetime measurement are shown together with the level lifetimes.

lived $2p3p\ ^1P$ level and then strong repopulation of the $2p3s\ ^1P^\circ$ level occurs in the laser field.[20,23]

The differences of the laser-on and laser-off intensities of the 39.56-nm line plotted as a function of the distance traveled by the ions downstream from the laser interaction region gives a BFL decay curve. At the exit of the laser interaction region, this intensity difference is $\approx 25\%$. In order to avoid thickening or breakage of the foil during the irradiation, it is necessary to record a decay curve in a "sufficiently" short time. We have recorded ≈ 200 BFL decay curves containing each ≈ 300 photon counts at their maximum and 8 data points along a total beam length of 1.4 mm. Moreover, small systematic errors which could be due to changes of the foil during the irradiation are canceled to first order by recording half of the curves along the ion beam direction and the other half along the reverse direction.

III. LIFETIME RESULT

The $2p3s\ ^1P^\circ$ level being the lower level of the laser induced transition, each BFL decay curve is a sum of two exponentials corresponding to the lifetimes of the coupled levels.[21,22] We have estimated the (negative) amplitude of the second exponential to be equal to $1.1\pm 0.4\%$ of that of the primary exponential using relations reported previously.[21–23] In these relations, we have used the theoretical values of Nussbaumer[5] for the $2p3s\ ^1P^\circ - 2p3p\ ^1P$ transition probability and for the lifetimes of the $2p3s\ ^1P^\circ$ and $2p3p\ ^1P$ levels. The ratio of the populations of these levels at the exit of the foil was taken equal to the ratio of the level statistical weights. The quoted error is due to the uncertainty in the population changes of the two levels in the laser field.

With the ≈ 200 individual BFL decay curves, we have formed a sample of 15 BFL decay curves having approximately the same statistical weights by accumulating several individual BFL decay curves. These 15 decay curves have been well fitted to a difference of two exponentials. Due to the large statistical uncertainties of the data, a fit to a sum of two exponentials leads to large uncertainties in the four estimated parameters. For this reason, the 15 decay curves have been adjusted to a sum of two exponentials by fixing the value of the second exponential lifetime to 5 and 10 ns, successively. Indeed, the previously measured value for the $2p3p\ ^1P$ lifetime was equal to 7.5 ns (Ref. 24) and the available theoretical value for this lifetime was equal to 5 ns.[5]

The mean values of the primary lifetime obtained from the analyses of the 15 decay curves are equal to 0.169 ± 0.007 and 0.171 ± 0.007 ns when the lifetime values of the second exponential are fixed to 5 and 10 ns, respectively. The quoted uncertainties represent the statistical errors (one standard deviation) of the mean values estimated from the dispersion of the 15 estimated lifetimes. These results show that the estimated primary lifetime is not changed significantly by the secondary lifetime value (5 or 10 ns). Moreover, the mean (negative) amplitude of the second exponential is estimated from the adjustments to represent only $\approx 1\%$ of that of the primary component. Thus it appears that the amplitude of the second exponential estimated from the fits of the 15 decay curves is in good agreement with the calculated value.

In conclusion, the lifetime value for the $2p3s\ ^1P^\circ$ level obtained form the analysis of the sample of 15 BFL decay curves is

$$\tau = 0.17 \pm 0.01 \text{ ns} .$$

The BFL decay curve resulting from the accumulation of all the BFL decay curves is shown in Fig. 1. These data have been fitted to a sum of two exponentials with the value of the second component lifetime fixed to 7.5 ns and the (negative) amplitude of the second component fixed to 1% of the primary component amplitude. The estimated primary lifetime is also 0.17 ± 0.01 ns where the quoted uncertainty represents the lifetime variation when the second component amplitude varies from 0 to 3% of that of the primary component. We have verified that the lifetime result is again not changed significantly by the value of the long second lifetime (5–10 ns). This decay curve analysis confirms the precedent lifetime result.

Table I gives the experimental[18,19] and theoretical[1,4,5,10] lifetime values available for the $2p3s\ ^1P^\circ$ level in O III. Our BFL result is significantly lower than previous BF values.[18,19] Pinnington *et al.*[18] have measured this lifetime using the $2p^2\ ^1D - 2p3s\ ^1P^\circ$ ($\lambda = 39.56$ nm) and the $2p^2\ ^1S - 2p3s\ ^1P^\circ$ transitions ($\lambda = 43.50$ nm). Their result quoted in Table I represents the mean value of these two lifetime results which are in good agreement. The 39.56 and 43.50-nm lines are weakly blended and repopulated by several cascades as outlined in Ref. 18. Thus the decomposition of the BF decay curve is probably not unique. This situation can explain the discrepancy be-

TABLE I. Lifetime results for the O III $2p3s\ ^1P^\circ$ level.

τ (ns)	τ_{casc} (ns)	Experiment
0.219 ± 0.011	$1.5\pm 0.3, > 500$	Beam-foil (Ref. 18)
0.32 ± 0.08		Beam-foil (Ref. 19)
0.17 ± 0.01		Beam-foil–laser (this work)
τ (ns)	Theory	
0.12	Restricted Hartree-Fock (Ref. 1)	
0.17	Scaled Thomas-Fermi (Ref. 4)	
0.18	Scaled Thomas-Fermi with configuration Interaction (Ref. 5)	
0.14	Hartree-Fock relativistic (Ref. 10)	

tween the BF and BFL results. Our BFL result is in agreement with theoretical values.[4,5,10]

IV. OSCILLATOR STRENGTH OF THE $2p^2\,{}^1D-2p3s\,{}^1P^\circ$ TRANSITION ALONG THE CARBON SEQUENCE

The oscillator strength of the $2p^2\,{}^1D-2p3s\,{}^1P^\circ$ transition along the carbon sequence has been discussed very recently.[20] We have plotted in Fig. 2 theoretical and experimental f values for this transition as a function of $1/Z$. The theoretical values shown in this figure are those reported in the literature after 1970. The "experimental" f values are obtained from experimental lifetimes[11–20] using theoretical branching ratios from Fawcett.[10] In O III, these branching ratios are equal to 0.78 and 0.22 for the $2p^2\,{}^1D-2p3s\,{}^1P^\circ$ and $2p^2\,{}^1S-2p3s\,{}^1P^\circ$ transitions, respectively.

When BF lifetimes have been reported for the $2p3s\,{}^1P^\circ$ level in the same ion by different authors and are in good agreement, only the oscillator strength deduced from the mean value of the lifetime results is plotted in Fig. 2.

It is worth pointing out that the BFL result for N II (Ref. 20) and the present BFL result ($f=0.064\pm0.004$) for O III, deduced from lifetime values not affected by cascading problems, should be reliable. These two f values are in good agreement with the f-value trend calculated by Fawcett using the Hartree-Fock relativistic package program.[10] However, we must note that the BFL results in N II and O III are also in good agreement with the theoretical values of Refs. 7–9 and Refs. 4 and 5, respectively.

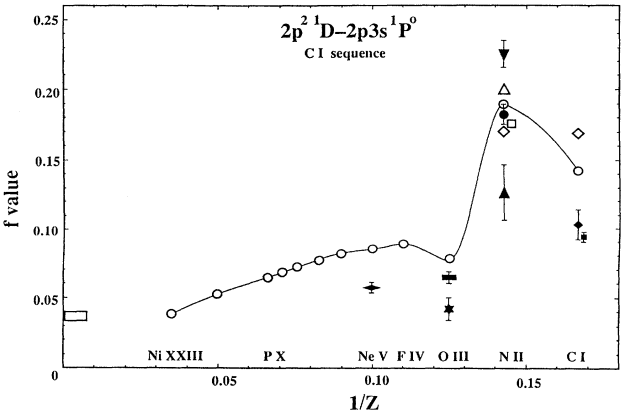

FIG. 2. Oscillator strengths as a function of $1/Z$ for the $2p^2\,{}^1D-2p3s\,{}^1P^\circ$ transition of the carbon sequence. The theoretical data sources (open symbols) are▭, Ref. 6; □, Ref. 7; △, Ref. 8; ◇, Ref. 9; ○, Ref. 10. The experimental data sources (solid symbols) are ◆, Ref. 11 (phase shift); ■, Refs. 12 and 13 (BF mean value); ▲, Refs. 14 and 19 (BF mean value); ▼, Refs. 15 and 17 (BF mean value); ●, Ref. 20 (BFL); ★, Refs. 18 and 19 (BF mean value); ▬, this work (BFL); ◂▸, Ref. 16 (BF). The solid curve is drawn to show the Fawcett's f trend.

V. CONCLUSION

We have obtained the first accurate lifetime value for the $2p3s\,{}^1P^\circ$ level in O III using the beam-foil–laser method. The lifetimes obtained previously for this level by the BF method are significantly longer than the BFL value. This result can be explained by the complexity of the BF decay curve which in this case is a sum of several exponentials due to the repopulation of the $2p3s\,{}^1P^\circ$ level by several cascades. The lifetime value obtained in the present work is in agreement with most of the theoretical values (see Table I).

The study of the oscillator strength of the $2p^2\,{}^1D-2p3s\,{}^1P^\circ$ transition along the carbon sequence confirms the irregularity expected to occur in the vicinity of N II, O III because of strong configuration mixing among $2s^22p3s\,{}^1P^\circ$ and $2s2p^3\,{}^1P^\circ$ levels[25] and the oscillator strength trend predicted by Fawcett (see Fig. 2).

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[1]P. S. Kelly, Astrophys. J. **140**, 1247 (1964).
[2]W. L. Wiese, M. W. Smith, and B. M. Glennon, *Atomic Transition Probabilities,* Natl. Bur. Stand. Ref. Data Ser., Natl. Bur. Stand. (U.S.) Circ. No. 4 (U.S. GPO, Washington, D.C., 1966), Vol. 1.
[3]A. W. Weiss, Phys. Rev. **162**, 71 (1967).
[4]B. Warner and R. C. Kirkpatrick, Mon. Not. R. Astron. Soc. **142**, 265 (1969).
[5]H. Nussbaumer, Astrophys. Lett. **4**, 183 (1969).
[6]M. W. Smith, G. A. Martin, and W. L Wiese, Nucl. Instrum. Methods **110**, 219 (1973); private communication from A. W. Weiss.
[7]W. L. Luken and O. Sinanoglu, J. Chem. Phys. **64**, 3141 (1976).
[8]D. R. Beck and C. A. Nicolaides, Phys. Lett. **56A**, 265 (1976).
[9]R. P. McEachran and M. Cohen, J. Quant. Spectros. Radiat. Transfer **27**, 119 (1982).
[10]B. C. Fawcett, At. Data Nucl. Data Tables **37**, 367 (1987); **37**, 411 (1987).
[11]G. M. Lawrence and B. D. Savage, Phys. Rev. **141**, 67 (1966).
[12]D. L. Mickey, Nucl. Instrum. Methods **90**, 77 (1970).
[13]J. Bromander, Phys. Scr. **4**, 61 (1971).
[14]E. J. Knystautas, M. Brochu, and R. Drouin, Can. J. Spectrosc. **18**, 153 (1973).
[15]J. A. Kernahan, A. E. Livingston, and E. H. Pinnington, Can. J. Phys. **52**, 1895 (1974).
[16]J. P. Buchet and M. Druetta, J. Opt. Soc. Am. **65**, 991 (1975).
[17]P. D. Dumont, Y. Baudinet-Robinet, and A. E. Livingston, Phys. Scr. **13**, 365 (1976).
[18]E. H. Pinnington, K. E. Donnelly, J. A. Kernahan, and D. J. G. Irwin, Can. J. Phys. **56**, 508 (1978).
[19]G. Sørensen, J. Phys. (Paris), Coll, **40**, C1-157 (1979).
[20]Y. Baudinet-Robinet, H.-P. Garnir, P.-D. Dumont, and J.

Résimont, Phys. Rev. A **42**, 1080 (1990).
[21]P. D. Dumont, H. P. Garnir, Y. Baudinet-Robinet, and A. El Himdy, Nucl. Instrum. Methods B **35**, 191 (1988).
[22]Y. Baudinet-Robinet, P. D. Dumont, H. P. Garnir, and A. El Himdy, Phys. Rev. A **40**, 6321 (1989).
[23]Y. Baudinet-Robinet, H. P. Garnir, P. D. Dumont, and A. El Himdy, Phys. Scr. **39**, 221 (1989).
[24]M. Druetta, M.-C. Poulizac, and M. Dufay, J. Opt. Soc. Am. **61**, 515 (1971).
[25]See, e.g., Ref. 6 or 20.