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Mean lifetime measurements of F II and F III levels using beam-foil technique

B N RAJA SEKHAR, S PADMANABHAN, APARNA SHASTRI, P MEENAKSHI RAJA RAO†, M B KURUP* and K G PRASAD*
Spectroscopy Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India
*Tata Institute of Fundamental Research, Colaba, Mumbai 400 005, India
†Address for correspondence
Email: spectr@magnum.barct1.ernet.in

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Abstract. Beam-foil spectrum of fluorine was recorded in the wavelength region of 2000–4500 Å using F^+ ion beams of energies ranging from 216 to 296 KeV. Some of the spectral lines of fluorine observed during the present investigation are hitherto unknown. Mean lifetimes of a few of the excited levels of F II and F III are reported for the first time.

Keywords. Beam-foil spectroscopy; fluorine; lifetimes.

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1. Introduction

The earliest published results on the lifetimes of the energy levels of fluorine were by Kaselevskii and Trukhan [1]. They reported f-values for lines from F II–F V in the wavelength region 2450–3450 Å. The results were based on experiments carried out in emission using a pulsed capillary discharge source and photographic detection. Due to the uncertainty in measuring line intensities, particle densities and temperature, their estimated f-values were in error by 35–40%. Kurucz and Peytremann [2] have evaluated semiempirical gf-values for a few fluorine transitions. Smith and Wiese [3] have studied the transitions that are isoelectronic with fluorine but they could not establish any trend for f-values. Pinnington *et al* [4, 5] have carried out beam-foil measurements of lifetimes of several transitions belonging to F II–F IV in the wavelength region of 2100–4500 Å. The authors evaluated the lifetimes by correcting the effects of cascade repopulation using ANDC method and theoretically calculated the corresponding lifetimes under the Coulomb approximation. However the theoretical and the experimental data available till date differ very much from each other. In the present studies the beam-foil spectrum of singly and doubly ionized fluorine was reinvestigated in the wavelength region 2200–4500 Å and the mean lifetime measurements of quite a number of energy levels were carried out for the first time. The details of the results are discussed.

2. Experimental

The experiments were carried out with singly ionized fluorine beams from 400 KeV accelerator at TIFR. The experimental arrangement for recording the beam-foil spectrum has been described in detail elsewhere [6]. SF_6 gas was used in the ion source for extracting mass analysed F^+ ion beams. The F^+ beam was collimated and passed through carbon foils of thickness 6 to 8 $\mu g/cm^2$. The emitted spectra were recorded on a 0.45 M monochromator in Czerny–Turner mount and a Peltier cooled photomultiplier was used as a detector. The photomultiplier was used in the single photon counting mode and spectra were recorded using a PC based multiscaling system. For lifetime studies the beam-foil light was focussed onto the entrance slit of the monochromator by means of a quartz lens in 1 : 1 magnification. Taking into account the energy loss suffered by the ions while passing in the foil and using the computer code TRIM [7], the post foil velocities of the ions were calculated. These calculated velocities were used to extract level lifetimes. During all these lifetime measurements a constant beam current ~ 40 nA was maintained. The photon counts at each measured distance downstream the foil were normalized to the incident ion beam intensity measured by a current integrator and a deep Faraday cup located behind the foil. The target chamber containing the carbon foils was evacuated using a cryo pump up to a pressure of 10^{-6} torr. The holder on which the foil was mounted has a provision for linear movement along the beam axis to facilitate mean lifetime measurement and also facility to change the foil in vacuum. The experimental data was analysed using a multi exponential fitting program and the lifetimes were derived from the fitted data after background correction.

3. Results and discussion

3.1 *Wavelength spectrum*

Beam-foil spectrum of fluorine was recorded at three energies i.e. 216, 256 and 296 KeV in the wavelength range of 2000–4500 Å. Typical spectrum in the region of 2950–3250 Å is shown in figure 1. The spectrum consisted mainly of lines due to F II and F III. Most of the lines observed for the first time in the present studies fall in the region of 4900 to 5000 Å and are shown in figure 2. A core-excited transition at 2656.2 Å belonging to F III was also observed. The spectral features were carefully examined for possible blending and spectral lines which were free from blending were chosen for lifetime determinations. The observed wavelengths were compared and identified with the data reported by Palenius for F II and F III [8, 9]. The notations and terminology followed are the ones used in the references [8] and [9].

3.2 *Mean lifetimes*

The mean lifetime measurements were carried out using the procedure of measuring the intensity decay of a line for constant beam charge as a function of distance from the foil. The lifetime measurements for most of the lines in the present studies were carried out at two energies viz. 216 and 256 KeV several times. Such a procedure is useful in sorting

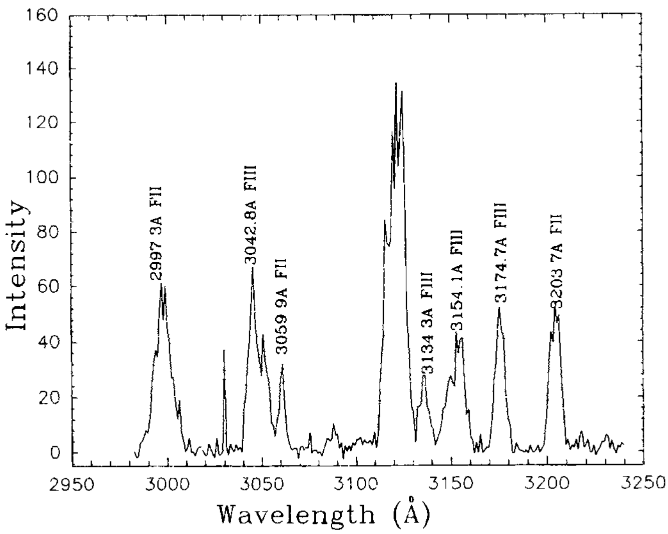

Figure 1. Beam-foil spectrum of fluorine in 2950–3250 Å region.

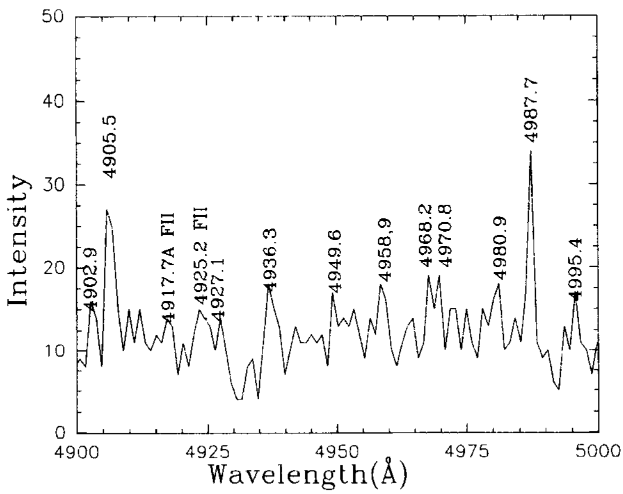

Figure 2. New lines observed in fluorine in 4900–5000 Å region.

out spectral line blending and cascading problems and serves as a cross check. In the present investigations, different measurements agreed within 10%. The values included in table 1 refer to an average value of all the measurements considered.

3.2.1 *FII*: Mean lifetimes of components of six energy levels of singly ionized fluorine were evaluated and they are listed in table 1. Lifetimes for two lines 3972.1 and 4024.7 Å involving the $2s^2 2p^3(^2P)3\bar{\bar{p}}\ ^3D$ and $2s^2 2p^3(^4S)3p\ ^3P$ lines respectively were reported by Pinnington *et al* [4] and our values agree well with their values. Figure 3 shows the decay curve for 4024.7 Å. The mean lifetimes measured for the lines at 3202.7, 3473.3 and

Table 1. Radiative lifetimes (ns) for F II and F III.

Species	Wavelength	Upper level	Life-time	
			Present	Others
F II	3202.7	$2s^22p^3(^2D)3\bar{p}\ ^1D_2$	4.06 ± 0.1	
	3472.9	$2s^22p^3(^2D)3\bar{d}\ ^3F_{2,3}$	4.81 ± 0.1	
	3473.3	$2s^22p^3(^2D)3\bar{d}\ ^3F_{2,3}$		
	3473.6	$2s^22p^3(^2D)3\bar{d}\ ^3F_{2,3}$		
	3971.6	$2s^22p^3(^2P)3\bar{\bar{p}}\ ^3D_{1,2}$	6.92 ± 0.1	$8.50^{\dagger\#}, 7.80^{\dagger @}$ $6.90 \pm 0.6^{\#}$
	3972.0	$2s^22p^3(^2P)3\bar{\bar{p}}\ ^3D_{1,2}$		
	3972.4	$2s^22p^3(^2P)3\bar{\bar{p}}\ ^3D_{1,2}$		
	3972.7	$2s^22p^3(^2P)3\bar{\bar{p}}\ ^3D_{1,2}$		
	4024.7	$2s^22p^3(^4S)3p\ ^3P_{0,1,2}$	7.35 ± 0.2	$8.20 \pm 0.7^{\#}$ $8.30^{\dagger\$}, 7.80^{\dagger @}$
	4025.0	$2s^22p^3(^4S)3p\ ^3P_{0,1,2}$		
	4025.5	$2s^22p^3(^4S)3p\ ^3P_{0,1,2}$		
	4112.7	$2s^22p^3(^2D)3\bar{p}\ ^3D_{3,2}$	8.31 ± 0.2	
	4112.9	$2s^22p^3(^2D)3\bar{p}\ ^3D_{3,2}$		
	4299.2	$2s^22p^3(^2D)3\bar{p}\ ^1F_3$	11.5 ± 0.4	$10.41 \pm 0.7^{\#\#}$ $11.0 \pm 1.0^{\$\$}$ $10.5^{\dagger\$\$}, 9.7^{\dagger @}$
F III	2592.8	$2s^22p^2(^3P)3d\ ^4F_{3/2,5/2}$	3.82 ± 0.1	
	2593.2	$2s^22p^2(^3P)3d\ ^4F_{3/2,5/2}$		
	2629.7	$2s^22p^2(^1D)3\bar{d}\ ^2G_{9/2}$	4.10 ± 0.1	$2.50^{\dagger\$\$}$, $2.20^{\dagger *}$, $3.70 \pm 0.4^{\$\$}$ $4.10^{\dagger **}$
	2656.0	$2s2p^3(^5S)3d'\ ^6D_{9/2,7/2,5/2}$	3.37 ± 0.1	$3.3 \pm 0.3^{\$\$}$ $2.7^{\dagger\$\$}$
	2656.3	$2s2p^3(^5S)3d'\ ^6D_{9/2,7/2,5/2}$		
	2656.4	$2s2p^3(^5S)3d'\ ^6D_{9/2,7/2,5/2}$		
	2877.3	$2s^22p^2(^3P)4p\ ^2D_{3/2}$	5.95 ± 0.1	
	2916.3	$2s^22p^2(^3P)3p\ ^4P_{5/2}$	3.86 ± 0.2	
	3115.7	$2s^22p^2(^3P)3p\ ^4D_{5/2}$	7.27 ± 0.2	
	3154.4	$2s^22p^2(^1D)3\bar{d}\ ^2D_{5/2}$	4.48 ± 0.1	

** [1], @ [2], * [3], $$ [4], # [5], ## [10], $ [11], † Theory.

4112.8 Å involving $2s^22p^3(^2D)3\bar{p}\ ^1D_2, 2s^22p^3(^2D)3\bar{d}\ ^3F$ and $2s^22p^3(^2D)3\bar{p}\ ^3D$ are being reported for the first time.

3.2.2 *FIII*: Mean lifetime measurements for 7 levels of doubly ionized fluorine are experimentally determined and they are included in table 1. Two of the levels investigated by us viz. levels involved in the transitions at 2629.7 and 2656.2 Å were reported earlier by Pinnington *et al* [5]. The measured values during the present studies are in close agreement with the reported results. The decay curves for the energy levels involved in

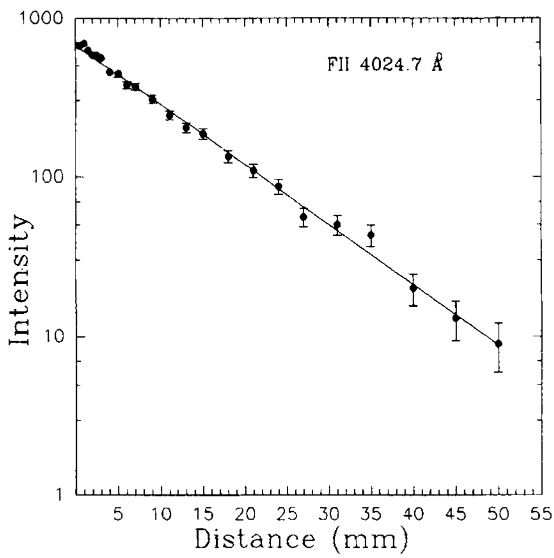

Figure 3. Decay curve of 4024.7 Å (F II) line.

lines at 2877.3 and 2916.3 Å, studied for the first time during present investigations exhibit cascading. The secondary lifetimes corresponding to cascading transitions are of the order of 15 ns. The 2877.3 Å line with the upper state $2s^22p^2(^3P)4p\ ^2D_{3/2}$ has its main cascading contribution from $2s^22p^2(^3P)5s\ ^2P_{1/2}$. Even though the transition at 4221.1 Å involving $4p\ ^2D_{3/2}$–$5s\ ^2P_{1/2}$ was observed in our spectrum, it was blended with an F II line at 4221.5 Å ($3\bar{d}\ ^3F_2 - 4\bar{f}(5/2)[5/2]_3$) thus making the lifetime determination of the level $2s^22p^2(^3P)5s\ ^2S_{1/2}$ impossible. For the 2916.3 Å line the upper state is $2s^22p^2(^3P)3p\ ^4P_{5/2}$, and the cascading is from the $2s^22p^2(^3P)3d\ ^4D, 2s^22p^2(^3P)3d\ ^4P$ and $2s^22p^2(^3P)3\bar{d}\ ^2F$ levels. Lifetime determination of the cascading levels was not possible in our present experiment as most of these transitions fall in the vacuum ultraviolet region. The mean lifetimes of transitions involving the $2s^22p^2(^3P)3p^4D$, $2s^22p^2(^3P)3d\ ^4F$ and $2s^22p^2(^1D)3\bar{d}\ ^2D$ levels are reported for the first time.

3.3 *Excitation function studies*

Beam-foil excitation copiously populates highly excited levels of several charge states. The source is of low intensity thereby necessitating the use of medium resolution monochromators. Therefore, line blending problems are very severe in beam-foil spectra. Blending of lines within the same as well as different charge states is very common. In order to sort out such problems during the present studies excitation function studies were carried out. For the excitation function studies the signal was collected very close to the foil so as to minimize the influence due to cascade repopulations and the intensity variation as a function of excitation energy was studied. The details of the procedure followed are discussed elsewhere [12]. The line at 3042.8 Å was reported by Pinnington *et al* [4] as belonging to doubly ionized fluorine based upon beam-foil spectrum using 1.3 MeV F^+ beam. However, as pointed out by Bashkin [13], the line appeared to belong

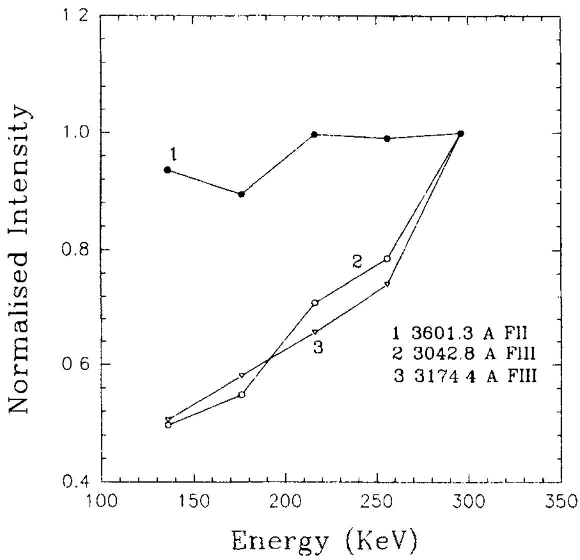

Figure 4. Comparative study of the relative level population of 3042.8 Å with 3601.3 Å (F II) and 3174.4 Å (F III) lines.

to F IV based on the spectra taken at 2 and 3 MeV. Excitation function studies were carried out comparing the relative level populations for F II and F III with that of the transition at this wavelength (3042.8 Å) with all the relative level populations normalized to unity at 296 KeV. In the wavelength spectra recorded by us no lines belonging to F IV were observed. From the comparison of excitation functions as shown in figure 4, it can be concluded that the transition at 3042.8 Å belongs to F III. Thus it appears that at lower excitation energies viz. in the KeV range, F III transition is observed whereas at higher energies in the MeV region F IV transition was predominant.

4. Conclusion

The beam-foil spectra of F II and F III in the region of 2000–4500 Å were recorded. The studies lead to identification of new lines belonging to fluorine. The mean lifetimes of three terms of F II and five terms of F III are reported for the first time.

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References

[1] L I Kiselevski and E P Trukhan, *J. Appl. Spectrosc. (USSR)* **9**, 1299 (1968)
[2] R L Kurucz and E Perthremann, Smith Sonian Astrophysical Observatory Report, 362 (1975)
[3] M W Smith and W L Weise *Astrophys. J. Suppl. Ser.* **23**, 103 (1971)

[4] E H Pinnington, D J G Irwin, A E Livingston, J A Kernahan, R N Gossellin and H G Berry, *Can. J. Phys.* **56**, 517 (1978)
[5] E H Pinnington, R N Gossellin, D J G Irwin, and J A O'Neill, *Can. J. Phys.* **57**, 1047 (1979)
[6] T Nandi, V Nanal, W A Fernandes, C A Desai, M B Kurup, K G Prasad, P M R Rao and S Padmanabhan, *Pramana – J. Phys.* **44**, 67 (1975)
[7] J F Ziegler and J P Bievack, The stopping and range of ions in solids (Pergamon Press, New York, 1990)
[8] H P Palenius, *Arkiv. Fysic. Band* **39**, 3 (1968)
[9] H P Palenius, *Phys. Scr.* **1**, 113 (1970)
[10] S A Chin-Bing and C E Head, *Phys. Rev.* **A10**, 209 (1974)
[11] W L Wiese, M W Smith and B M Glennon, *Natl. Stand. Ref. Data. Ser. Natl. Bur. Stand. 4* (US Government Printing Office, Washington, DC, 1975) vol. I
[12] B N Raja Sekhar, S Padmanabhan, Aparna Shastri, P Meenakshi Raja Rao, M Jagadeesh, M B Kurup and K G Prasad, *Indian J. Phys.* **71B**, 651 (1997)
[13] S Bashkin, *J. Phys.* **C1**, 125 (1979)