**Journal of Atomic, Molecular, Condensate & Nano Physics**
Vol. 2, No. 2, pp. 127–132, 2015
ISSN 2349-2716 (online); 2349-6088 (print)
Published by RGN Publications
http://www.rgnpublications.com

# Lifetime Measurement of Highly Charged Ions Relevant to Astrophysics

Research Article

Ranjeet K. Karn[1]*, C. N. Mishra[2], Nissar Ahmad[3], C. P. Safvan[4] and T. Nandi[4]

[1] *Department of Physics, Jam. Co-operative College, Jamshedpur 831036, India*
[2] *Department of Physics, Kolhan University, Chaibasa 833201, India*
[3] *Department of Physics, University of Kashmir, Sri Nagar 190006, India*
[4] *Inter University Accelerator Centre, New Delhi 110067, India*
***Corresponding author:** rkkarn@gmail.com

**Abstract.** We have measured the 1s2s2p $^4P^0_{5/2}$-1s$^2$2s $^2S_{1/2}$ magnetic quadrupole X-ray transition energy in Li-like Fe along with the 1s2s $^3S_1$-1s$^2$ $^1S_0$ transition energy in He-like Fe using multi channel doppler tuned spectrometer. These states have been produced through the interaction of 165 MeV $Fe^{12+}$ ion beam with 100 $\mu$g/cm$^2$ thin carbon foil. Further we have measured the lifetime of 1s2s2p $^4P^0_{5/2}$ level in Li-like Fe. The measured transition energy of 1s2s $^3S_1$-1s$^2$ $^1S_0$ is in good agreement with the available theoretical predictions and experimental measurements, whereas the measurement of 1s2s2p $^4P^0_{5/2}$-1s$^2$2s $^2S_{1/2}$ energy is little lower than the theoretical estimations. However, the measured lifetime of 1s2s2p $^4P^0_{5/2}$ level compares well with the theoretical predictions.

**Keywords.** X-rays, atomic data; Atomic processes; Line: formation

**PACS.** 34.90.+q; 0.7.85Nc; 34.60.z; 34.50.Fa

**Received:** June 8, 2015 **Accepted:** October 14, 2015



## 1. Introduction

Iron is the most aboundant and, therefore, the most important intermediate-Z element for the diagnostics of hot astrophysical plasma. Wealth of x-ray spectra from such sources have been observed by various x-ray missions. The K-lines of H-, He- and Li-like Fe has been observed in spectra of nearly all classes of cosmic X-ray sources and have a well-known plasma diagnostics potential for the physical conditions and chemical compositions of such objects. They have been observed in the supernova remnant [1], in compact X-ray binaries [2], solar flares [3], active stellar coronae [4], in clusters of galaxies [5] and active galactic nuclei [6]. The dielectric satellites of the resonance line of He-, Li-like Fe has been extensively studied through EBIT, Tokamak and beam-foil plasma sources [7–10]. The 1s2s2p $^4P^o_{5/2}$-1s$^2$2s $^2S_{1/2}$ magnetic dipole transition (M2) of Li-like ions have been studied for long for different ion species, using beam-foil and EBIT-Tokamak plasma [11–15]. In the present work, we have studied the astrophysicaly significant 1s2s2p $^4P^0_{5/2}$ state of Li-like Fe using a multi channel Doppler tuned spectrometer (MCDTS) [16]. In the first step we test the accuracy of our energy measurement through 1s2s $^3S_1$-1s$^2$ $^1S_0$ M1 transition of He-like Fe, labelled as z in astrophysical notation [17], by comparing it with previous experimental and theoretical findings. Then we extend the measurement for the transition energy of 1s2s2p $^4P^o_{5/2}$-1s$^2$2s $^2S_{1/2}$ M2 line of Li-like Fe as well as for the lifetime of the corresponding upper level using beam-foil spectroscopy (BFS) [18].

## 2. Experiment

The detailed description of the experimental setup can be seen in [16]. A beam of 165 MeV $^{56}_{26}Fe^{+12}$ ions from the 15 UD Pelletron accelerator [19] at IUAC, New Delhi has been used in this experiment. When a well focused beam interacts with the 100 $\mu$g/cm$^2$ thin carbon foil, various electron stripping, capture and excitation processes take place, which produce the excited states of H-, He- and Li-like Fe ions. The production probability of H-, He-, Li-, Be-like Fe for our experimental conditions has been estimated, using ETACHA code [20] to be 0.7%, 16%, 33% and 30% respectively. Both Si-PIN detector and MCDTS are focused at the center of chamber, whereas the target has been kept 3 mm away from the center, which corresponds to 127 ps delay, at this beam energy. This allows detection of x-rays from the metastable states only. The x-ray spectra obtained by Si-PIN detector are calibrated with a standard $^{241}$Am source. Spectra taken from both the detectors are normalized to the beam current.

## 3. Results and Discussion

It is clear that except 1s2s $^3S_1$-1s$^2$ $^1S_0$ M1 and 1s2p $^3P^o_2$-1s$^2$ $^1S_0$ M2 transitions in He-like and 1s2s2p $^4P^o_{5/2}$-1s$^2$2s $^2S_{1/2}$ M2 transition of Li-like Fe, all other transitions, mentioned in [10, 14, 17] are fast decayed and hence, will not be observed by detector at delay times of ≥ 127 ps. Therefore, as expected, the spectra obtained by PIN detector, contains only one composite peak at 6.65 keV corresponding to three unresolved metastable lines viz., 1s2p $^3P^0_2$-1s$^2$ $^1S_0$ (M2), 1s2s $^3S_1$-1s$^2$ $^1S_0$ (M1) lines in He-like at 6.682 and 6.636 keV, respectively and its satellite 1s2s2p $^4P^o{}_{5/2}$-1s$^2$2s $^2S_{1/2}$ (M2) line at 6.619 keV of Li-like Fe [21, 22].

In next step we have made use of MCDTS to resolve the satellite 1s2s2p $^4P^0_{5/2}$-1s$^2$2s $^2S_{1/2}$ M2 transition in Li-like Fe from its parent transition in He-like Fe and to measure the lifetime of corresponding upper level. The MCDTS scan has been carried out by tuning the angle at which x-ray absorption occurs. The x-rays, after passing through the absorber foil and a sollar slit, were detected by a PSPC, kept at a distance of 600 mm from the source. An 8 mg/cm$^2$ thick iron absorber having K-absorption edge at 7112 eV [23] was used to obtain approximately 62% and 3% absorption, below and above the K-absorption edge, respectively. The observed

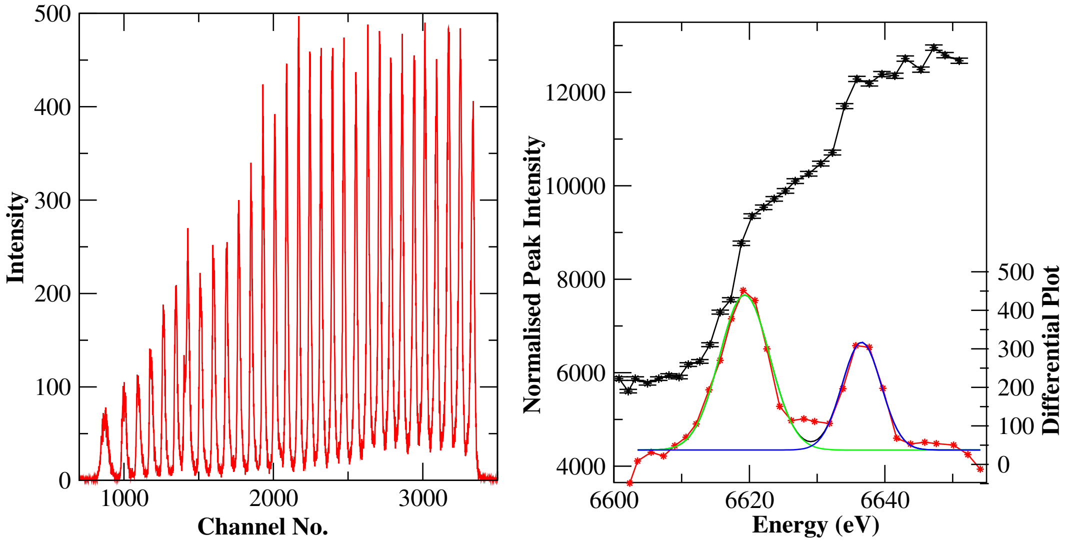


**Figure 1.** MCDTS Spectra: Left-The one shot spectrum obtained from 31 slots of the soller slit. Right-The integrated intensity is plotted with energy. The differential plot is shown below the intensity plot.

one shot of spectra has been shown in Figure 1 (left). This shows the peaks at an interval of 0.4°. The beam velocity, $\beta$ and $\gamma$ have been calculated, considering the energy loss in the target using the code SRIM [24]. Next, the spectra are transformed into energy scale. We note that the 1s2p $^3P^0_2$-1s$^2$ $^1S_0$ (M2) line at 6.682 keV is not appearing in this shot of spectra (6.600-6.650 keV); it ought to appear at a different angle of 36°. The integrated intensity after smoothening, as discussed by Cocke *et al.* [25], and its differential plot as a function of x-ray energy is shown in Figure 1 (right).

The differential plot given in Figure 1 (right) has got only two line structures. Peak at lower energy corresponds to 1s2s2p $^4P^o{}_{5/2}$-1s$^2$2s $^2S_{1/2}$ (M2) line of Li-like whereas the peak at higher energy represents 1s2s $^3S_1$-1s$^2$ $^1S_0$ (M1) line of He-like Fe. The lines have been fitted with Gaussian function to get the energy resolution as well as centroid of each line. The full width at half maxima (fwhm) of these two peaks are 5.4 and 4.3 eV, respectively, which represents the energy resolution of the spectrometer. The measured transition energy of 1s2s2p $^4P^o{}_{5/2}$-1s$^2$2s $^2S_{1/2}$ (M2) line comes out to be $6619.9 \pm 1.2$ eV whereas that of the 1s2s $^3S_1$-1s$^2$ $^1S_0$ (M1) line is $6636.1 \pm 1.4$ eV. The uncertainty in transition energy is just one standard deviation in the fitting. The comparison of our present measurement with earlier theoretical and experimental results have been shown in Table 1. For lifetime measurement, the target foil has been moved at steps of 1 mm to accurately measure the lifetime for shorter lived 1s2s2p $^4P^0_{5/2}$ state. The spectrum has been recorded at every step and analysis was repeated as discussed above. The decay profile for 1s2s2p $^4P^0_{5/2}$ level of Li-like Fe is plotted in Figure 2. Single exponential fit to the data leads to the lifetime of the upper state 1s2s2p $^4P^o{}_{5/2}$ in Li-like Fe turns out to be $76 \pm 1.7$ ps. In this spectra, the decay curve is truly single exponential. The comparison of results for lifetime with previous theoretical predictions has been shown in Table 1.

**Table 1.** Transition energies of $1s2s^3S_1$-$1s^{2\,1}S_0$ M1 transition of He-like and 1s2s2p $^4P^0_{5/2}$-$1s^22s^2S_{1/2}$ M2 transition of Li-like Fe (the transitions are represented as He-like M1 and Li-like M2, respectively) and the lifetime of 1s2s2p $^4P^0_{5/2}$ level of Li-like Fe.

| Transition | | | Experiment / Theory | Reference |
|---|---|---|---|---|
| He-like M1 | Energy eV | $6636.1 \pm 1.4$ | Experiment | Present |
| | | $6636.846 \pm 3.9$ | Experiment | [10] |
| | | $6634.70 \pm 0.628$ | Experiment | [3] |
| | | $6636.97 \pm 6.4$ | Experiment | [26] |
| | | 6636.587 | Theory | [21] |
| | | 6636.34 | Theory | Present |
| Li-like M2 | Energy eV | $6619.9 \pm 1.2$ | Experiment | Present |
| | | 6626.4 | Theory | [27] |
| | | 6628.3 | Theory | [28] |
| | | 6626.5 | Theory | [29] |
| | | 6626.68 | Theory | Present |
| | Lifetime ps | 75 | Theory | [30] |
| | | 76.3 | Theory | [27] |
| | | $76 \pm 1.7$ | Experiment | Present |

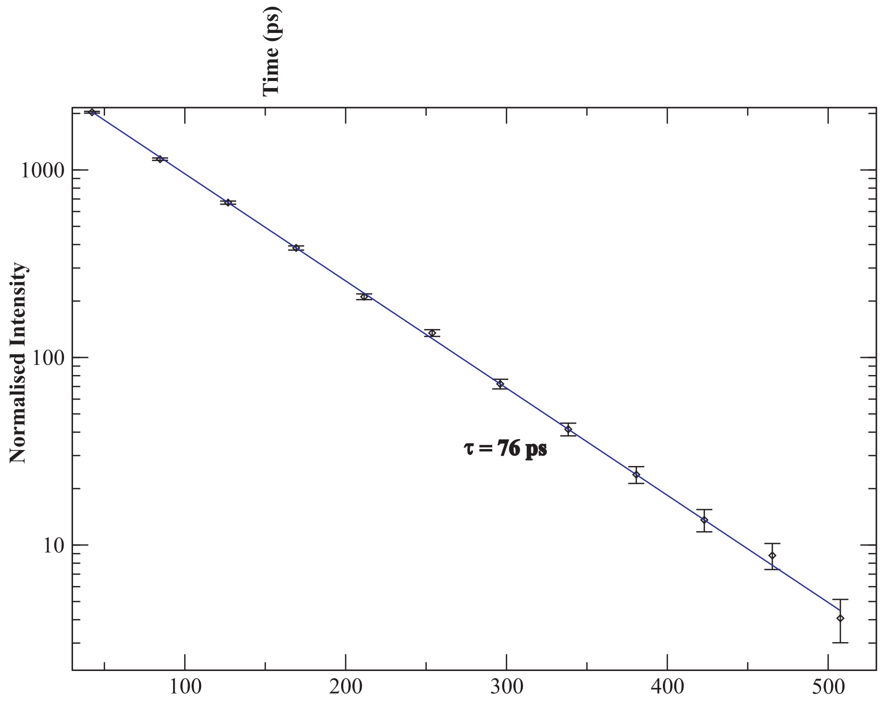


**Figure 2.** Decay curve obtained for 1s2s2p $^4P^0_{5/2}$-$1s^22s^2S_{1/2}$ (M2) transition of Li-like Fe.

## 4. Conclusion

We have accurately measured the transition energy of astrophysically significant 1s2s2p $^4P^0_{5/2}$-$1s^22s$ $^2S_{1/2}$ (M2) transition of Li-like Fe and determined precisely the lifetime of the upper level. Hope this work will help to identify the spectra obtained from various astrophysical x-ray missions as we have tentatively assigned this line in a solar flare spectrum [3].

## Competing Interests

The authors declare that they have no competing interests.

## Authors' Contributions

All the authors contributed equally and significantly in writing this article. All the authors read and approved the final manuscript.

## References

[1] P. J. Serlemitsos et al., *ApJ* **184** (1973), L1.

[2] N. E. White, A. Peacock and B. G. Taylor, *ApJ* **296** (1985), 475.

[3] F. J. Seely, U. Feldman and I. U. Safronova, *ApJ* **304** (1986), 838.

[4] N. E. White et al., *ApJ* **301** (1986), 362.

[5] M. P. Ulmar, *ApJ* **319** (1987), 118.

[6] A. C. Fabian and I. M. George (1991), in *Iron Line Diagnostics in X-ray sources* (Lecture Notes in Physics), eds: A. Treves, G. C. Perola and L. Stella (Berlin: Springer-Verlag), 169.

[7] H. Gould, R. Marrus and P. J. Mohr, *Phys. Rev. Lett.* **33** (1974), 676.

[8] M. Bitter et al., *Phys. Rev. Lett.* **42** (1979), 304.

[9] M. Bitter et al., *Phys. Rev. Lett.* **47** (1981), 921.

[10] P. Beiersdorfer et al., *ApJ* **409** (1993) 846.

[11] J. I. Pietenpol, *Phys. Rev. Lett.* **07** (1961), 64.

[12] I. A. Sellin, D. J. Pegg and P. M. Griffin, *Phys Rev Lett.* **28** (1972), 1229.

[13] T. Nandi et al., *Phys. Rev. A* **66** (2002), 1052510.

[14] P. Beiersdorfer et al., *Phys. Rev. A* **66** (2002), 032504.

[15] T. Nandi, N. Ahmad and A. Wani, *Phys. Rev. A* **7** (2005), 022711.

[16] R. K. Karn et al., *Rev. of Sci. Instrum.* **85** (2014), 066108.

[17] A. H. Gabriel, *Mon. Not. R. Astron. Soc.* **160** (1972), 99.

[18] H. G. Berry, *Rep. Prog. Phys.* **40** (1977), 155–217.

[19] D. Kanjilal et al., *Nucl. Instru. Methods A* **328** (1993), 97.

[20] J. P. Rozet et al., *Nucl. Instr. Meth. B* **107** (1996), 67.

[21] http://physics.nist.gov/cgi-bin/ASD/lines.ph

[22] T. Nandi, *Astrophys. J. Lett.* **673** (2008), L103.

[23] http://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html

[24] F. Ziegler and J. P. Bierssek, http://www.srim.org

[25] C. L. Cocke et al., *Phys. Rev. A* **9** (1974), 57.

[26] M. Bitter et al., *Phys. Rev. Lett.* **43** (1979), 129.

[27] M. H. Chen, B. Crasemann and H. Mark, Phys. Rev. A **24** (1981), 1852.

[28] T. Kato et al., *At. Data Nucl. Data Tables* **67** (1997), 225.

[29] M. A. Bautista et al., *Astronomy & Astrophysics* **403** (2003), 339.

[30] K. Cheng, C. Lin and W. R. Johnson, *Phys. Lett. A* **48** (1974), 437.