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# Experimental lifetime of some level belonging to the $5p^4 6d$ configuration of XeII

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**Abstract.** Lifetimes of eight levels belonging to the $5p^4 6d$ configuration of singly ionized xenon have been measured by high frequency deflection technique with a delayed coincidence single photon counting arrangement. The results have been compared with other experimental and theoretical values. The lifetimes of the $6d\ ^2\mathrm{F}_{3/2}$ and $6d\ ^4\mathrm{F}_{3/2}$ levels have been measured for the first time.

**PACS.** 32.70.Cs Oscillator strengths, lifetimes, transition moments

## 1 Introduction

The knowledge of the radiative lifetime of excited atomic and ionic states is useful for a better understanding of the atomic structure. The lifetime together with branching ratios provides information about transition probability and oscillator strength which have important application in the fields of spectroscopy, astrophysics, plasma physics and gas and metal-vapor laser. Lifetimes of some $5p^4 6d$ levels of singly ionized xenon (XeII) were measured earlier by us [1,2]. The present work is the direct measurement of lifetime of some other $6d$ states. Lifetimes of some of the $6d$ levels were measured previously by Fink et al. [3], Coetzer and vander Westhuizen [4] and Andersen et al. [5] by beam foil technique. In addition, results of the measurement on some of the levels using the electron excitation delayed coincidence technique were reported by Blagoev and Zimenez et al. [7]. The theoretical works on the $6d$ levels are also very few. However, discrepancies exist among the reported lifetime values. For the $6d\ ^2\mathrm{F}_{3/2}$ and $6d\ ^4\mathrm{F}_{3/2}$ levels no results have been published to our knowledge until now. Therefore, we undertook an experimental investigation on some of the $6d$ levels of XeII. The results obtained in the present work have been compared with the values obtained by the previous investigators. Lifetimes were measured through transitions having wavelengths ranging from 3845 to 4525 Å.

## 2 Experimental method

In the present work, we used the high frequency deflection (HFD) technique in which excitation of the levels was produced by high-energy pulsed electron impact. The corresponding decay had been followed by a delayed coincidence method using the single photon counting arrangement. A focused 2 mA electron beam of energy of 4 keV was produced by an electron gun. To obtain a pulsed beam of very short duration (1.8 ns) the dc beam was deflected by applying a fast rising voltage pulse across a narrow slit at a high frequency (2 MHz). The pulsed electron beam interacted with the xenon molecules and was finally collected by a metal plate as a collector cup. The voltage pulse developed by the charge stored on the collector cup at each electron excitation acts as the start pulse of a time-to-amplitude converter (TAC) whereas the corresponding stop pulse is provided by a photomultiplier tube (PMT) receiving the photon emitted due to de-excitation of the gas atom. Thus the amplitude of the output pulse of the TAC is proportional to the time elapsed between the beginning of the electron burst (i.e. the time of excitation) and the emission of the corresponding decay photon. The output pulses from the TAC are fed to a multi-channel analyzer (MCA) to generate the decay curve from which the life of the level concerned is evaluated. To select the spectral lines of interest, a Minuteman 0.5 meter monochromator (Model 305) with gratings having 1200 grooves/mm blazed at 3000 Å and 5000 Å have been used at a resolution of 0.7 Å. A condensing lens system (Oriel 77260 lens-filter-shutter) has been used for focusing the emitted radiation exactly onto the monochromator entrance slit. Photons were detected with a Hamamatsu R943-02 photomultiplier tube (PMT) cooled down to $-20$ °C to reduce the dark current. Although the excitation cross-sections of atomic and ionic states have their maximum values at low energies, the product of cross-section and available excitation current peaks at much higher energies because of

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**Table 1.** Lifetime of some 6*d* levels of XeII (data in ns).

| Level | Wavelength | Present | Experimental results | | | | | Theoretical results | |
|---|---|---|---|---|---|---|---|---|---|
| | Å | value | Ref. [3] | Ref. [4] | Ref. [5] | Ref. [6] | Ref. [7] | Ref. [4] | Ref. [7] |
| $6d\ ^2P_{1/2}$ | 4158.0 | $3.53 \pm 0.18$ | | | | $4.5 \pm 0.4$ | | 2.12 | |
| $6d\ ^4F_{3/2}$ | 4373.8 | $4.24 \pm 0.20$ | | | | | | | |
| $6d\ ^4F_{7/2}$ | 4330.5 | $4.91 \pm 0.23$ | 16 | $4.69 \pm 0.41$ | $4.3 \pm 0.4$ | $6.3 \pm 0.5$ | $7 \pm 3$ | 4.73 | 4.8 |
| $6d\ ^2F_{3/2}$ | 3849.9 | $3.62 \pm 0.18$ | | | | | | | |
| $6d'\ ^2F_{5/2}$ | 4521.8 | $3.34 \pm 0.17$ | | | | $3.4 \pm 0.4$ | | | |
| $6d\ ^4F_{5/2}$ | 4480.9 | $3.39 \pm 0.17$ | | $4.78 \pm 0.22$ | | $< 3$ | | 5.34 | |
| $6d'\ ^2D_{3/2}$ | 4251.6 | $3.22 \pm 0.15$ | | $4.12 \pm 0.15$ | | $< 3$ | | 3.61 | |
| $6d\ ^4P_{3/2}$ | 4213.7 | $4.30 \pm 0.21$ | 18 | | | $5.3 \pm 0.5$ | $10 \pm 1$ | | 14.1 |

space charge limitation in electron gun. Thus excitation of a gas sample with high energy (a few keV) electron causes an increase in intensity. A further gain in intensity is accomplished by sweeping the beam very fast across a slit at a high frequency instead of pulsing it at a fairly low repetition rate as is done by conventional delayed coincidence technique. Therefore, enhancement in intensity of the excited radiation increases the spectral resolution thus reducing the problem of line blending. Moreover, the investigation can be done at low gas pressure that reduces the influence of pressure-dependent effect.

The tables of Striganov and Sventitskii [8] have been used to identify the measured transitions. The coincidence resolving time (FWHM) of the whole system was measured by the method described by Erman [9] and was found to be 2.8 ns. The time calibration of the system was accomplished using a time calibrator (Ortec 462). The decay curves were observed in the time range of 200 ns and the time delay in the coincidence setup was 0.3 ns per channel. The measurements were carried out at a few gas pressures ranging from 0.4 to 4 mtorr and a continuous gas flow was maintained during each experiment. No significant change of any of the measured lifetimes with pressure was observed within the experimental error. The lifetime of each level was determined from the corresponding decay curve with the help of a computer programme [10] capable of analyzing the multi-exponential components. The programme also computes the lifetime values after deconvolution of the spectrum convoluted with the known instrumental response function.

## 3 Result and discussion

The results of the present lifetime measurement of some XeII levels are presented in Table 1. It also includes the experimental and theoretical values obtained by other investigators. The lifetime values are the weighted average of three independent measurements for each level. The quoted errors include the statistical and systematic errors. In the present measurement, the statistical error is about 3%. The main sources of systematic error are due to the following factors.

The variation of the width of the instrument response function: it may occur as a result of the variation of the width of the pulsed electron beam mainly due to a change in shape and size of the electron beam profile. Using highly stable voltage and current supplies for the beam focusing and sweeping system, the error has been restricted to 0.2%.

Uncertainty due to non-linearity of the measuring system and uncertainty in the time calibration: there may be some variation in the discriminator threshold of the constant fraction discriminator and the time to amplitude converter and in the gain of the fast amplifier used in the experiment. With our electronic equipments, the uncertainty introduced by the integral and differential nonlinearity of the system including the pulse height analyzer is less than 0.2%, whereas the uncertainty in the time calibration is about 0.1%.

Lifetimes of different XeII levels were measured at gas pressure ranging from 0.4 to 4 mtorr. The pressure-induced change of lifetime is small for a measurement within the pressure range and the maximum error amounts to 1%.

Thus the total error estimation includes the following uncertainties: counting statistics (∼3%), instrumental time resolution (∼0.2%), time calibration (∼0.1%), nonlinearity of the electronic system (∼0.2%), and pressure dependent effect (∼1%).

In order to examine how the different levels are excited in our system, an excitation spectrum (intensity versus wavelength scan) has been recorded between 2000 to 9000 Å, by using the monochromator at a resolution of 0.8 Å, keeping the beam energy and current at values mentioned earlier. All the lines recorded in this spectrum were found in the classified lines of Striganov and Sventitskii [8] for XeII. However, their lists contain many more lines which are not observed in the present experiment. The spectrum was found to contain no line that appears due to repopulation from a higher level to any of the levels under investigation. It was not possible to examine the other cascading levels that decay by emitting photons having wavelength below 2000 Å and higher than 9000 Å in this way because of the limited spectral range of the PMT. But it is seen from the work of Massey [11] that for excitation with electrons having energies well above the threshold, the higher levels are expected to be excited with relatively less probability as compared to the lower ones. As the excitation energy is 4 keV in the present experiment, the probability for cascade interference in the

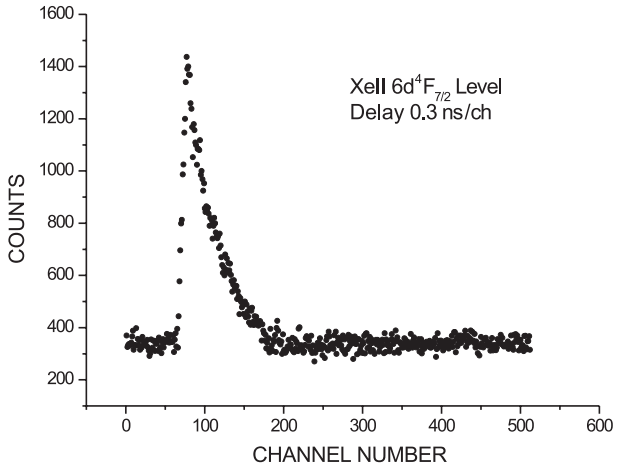


**Fig. 1.** The decay curve of the $6d\ ^4\mathrm{F}_{7/2}$ level of XeII measured at 4330.5 Å (gas pressure $4 \times 10^{-4}$ Torr).

lifetime determination is less severe as compared to the conventionally used electron beam in the low energy region. Furthermore, in the region below 2000 Å and above 9000 Å, the list of Striganov and Sventitskii [8] does not show any level that might be cascading into the levels under study. Thus, in the present case, cascade feedings from higher levels do not seem to contribute any significant error in the lifetime measurement. All the decay curves were analyzed for single as well as multi-exponential components. In the present work each of the decay curves was found to be best fitted to a single exponential. A typical decay curve for the $6d\ ^4\mathrm{F}_{7/2}$ level, measured at 4330.5 Å, is shown in Figure 1.

While comparing the values of lifetime of the levels measured by beam foil technique, it is seen that for the $6d\ ^4\mathrm{F}_{7/2}$ and $6d\ ^4\mathrm{P}_{3/2}$ levels, the experimental values of Fink et al. [3] are considerably larger than the corresponding values obtained in the present work. The reasons for this may be due to the presence of blending, cascading and inaccuracy in the determination of Xe-ion beam velocity in their experiment. The intensity decrease of a line was recorded photographically by Fink et al. [3]. This photographic technique made it impossible to perform corrections for cascading. For the $6d\ ^4\mathrm{F}_{7/2}$ level the present value is in agreement, within the experimental error, with the result reported by Andersen et al. [5]. A low energy ion beam (<500 keV) was used in their measurement. With ions in this energy range one gets mainly neutral and singly ionized species thereby reducing the risk of blending and cascading effect. A proper energy-loss correction was also made through experimental determination of the velocity of the ions after the foil passage. In addition, there is a report on beam foil measurement on some of the $6d$ levels by Coetzer and vander Westhuizen [4] of which the lifetime value of the $6d\ ^4\mathrm{F}_{7/2}$ level is in agreement within the experimental error, with the result obtained by us, but for the $6d\ ^4\mathrm{F}_{5/2}$ and $6d'\ ^2\mathrm{D}_{3/2}$ levels their lifetime values are somewhat larger than the corresponding values obtained in the present measurement. The differences can be attributed to unresolved lines and cascading effects. Moreover, the beam velocity after foil excitation was calculated with only the electronic energy taking into amount neglecting the nuclear energy loss. For the $6d\ ^4\mathrm{F}_{7/2}$ and $6d\ ^4\mathrm{P}_{3/2}$ levels, the experimental results of Jimenez et al. [7] differ widely from the present measurement. In their experimental set-up, the spectral resolution was 7 Å which is quite high in comparison to our and possibility of line blending might have been there affecting the accuracy in the lifetime measurement. Deviations are also noticed for most of the levels with the lifetime values measured by Blagoev et al. [6] through the same technique. In their measurement the pressure was varied in the range of $7 \times 10^{-2}$ to 1.5 Torr. Their lifetime values are extrapolation to zero pressure. So, a considerable pressure dependent effect must be there.

Theoretical works on the lifetimes of $6d$ levels are also very few. For the $6d\ ^2\mathrm{P}_{1/2}$, $6d\ ^4\mathrm{F}_{5/2}$ levels the theoretical values of Coetzer and vander Westhuizen [4] differ from the present value while for the other two levels their calculated values are closer to the present results. For the $6d\ ^4\mathrm{F}_{7/2}$ level the calculated value of Jimenez et al. [7] agrees well with the present result whereas for the $6d\ ^4\mathrm{P}_{3/2}$ level that is much larger than our value. All these calculations are based on $LS$ coupling using coulomb approximation, but the question whether this approach should be considered enough reliable [12] for this heavy atom need to be more critically examined. Relativistic effects are no more negligible for heavier elements. With the help of the effective-operator formalism, LS–coupled wave-functions can be used and relativistic effects are included. It would be interesting to perform a theoretical calculation with relativistic self-consistent field (SCF) wave function. The discrepancies in the lifetime values obtained in the present work and those by the others call for measurement on those states by other technique and further theoretical studies.

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