

## Lifetime measurement of excited atomic and ionic states of some noble gases using the high-frequency deflection technique

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MS received 20 September 2004; revised 30 May 2005; accepted 2 July 2005

**Abstract.** High-frequency deflection (HFD) technique with a delayed coincidence single photon counting arrangement is an efficient technique for radiative lifetime measurement. An apparatus for measurement of the radiative lifetime of atoms and molecules has been developed in our laboratory and measurements have been performed with great success in a large number of atoms and ions. The present version of the apparatus is described in this paper together with a brief description of the basic features and performance.

**Keywords.** Radiative decay; beam sweeping system; single photon detection.

**PACS Nos** 32.70.Cs; 34.50.Fa

### 1. Introduction

Measurement of lifetimes of atomic and ionic states has been of constant interest. Measurements of lifetime together with branching ratio can be used to deduce transition probability and oscillator strength which have important application in different branches of physics, viz., astrophysics, laser physics, plasma physics, meteorology etc [1]. An apparatus for the measurement of lifetime has been designed and developed in our laboratory based on the principle of high-frequency deflection (HFD) technique [2]. The present arrangement is a refinement of the single photon delayed coincidence technique with electron excitation. The basic principle of our measuring technique is shown schematically in figure 1. Here a high-energy ( $\sim 4$  keV) pulsed electron beam of current adjustable up to 2 mA collides periodically with the gas molecules (repetition rate 0.25–2 MHz) and is finally collected by a metallic electron collector cup. The excitation volume is viewed by a scanning monochromator to select the particular transition of interest.

Delayed coincidence technique is used to record the decay. Single photons are detected with a photomultiplier tube (PMT) coupled to the exit port of the

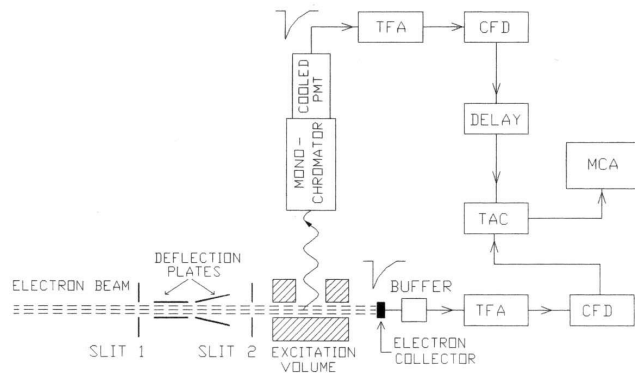


Figure 1. Basic principle of HFD technique.

monochromator. 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 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 decay photon. The output pulses from the TAC are fed to a multichannel analyzer (MCA) to generate the decay curve from which the life of the level concerned is evaluated. In this paper a detailed technical description of the associated apparatus will be given after a brief discussion of the different techniques used for lifetime measurement and the inherent properties of HFD method adopted by us.

## 2. Brief discussion of various techniques and basic features of the measuring technique adopted by us

Nowadays radiative lifetimes are measured mostly by beam-foil, beam-laser, laser-induced fluorescence and delayed coincidence techniques with pulsed electron excitation. In addition, measurement using stored ion beam and ion trap is also being done particularly for long-lived transitions.

In the beam-foil method [3], a beam of ions of various degrees of ionization emerges from the thin carbon foil in different states of excitation. The excited states decay as the beam travel downstream from the foil. The rate of fall of intensity of any particular line with distance from the foil gives the lifetime of the relevant excited state.

The main advantages of this technique are very high states of ionization of a large number of elements as well as multiply excited levels in atom can be studied. The density of the beam is very low such that pressure dependent effects like resonance absorption (trapping) and collisional de-excitation [4] are not expected to occur in the measurement. However, as a general method for lifetime measurement, this technique has certain limitations.

It is restricted to studies on atoms only since molecular beam will dissociate during the passage through the carbon foil. A large number of levels are excited simultaneously which give rise to serious distortions from cascade feeding and line blending in lifetime measurements. For longer lifetimes the decay curves are to be extended so long that the cross-section of the ion beam will be too big to be viewed by any normal-sized detector. One way to resolve it is to bend the ion beam around and to let it circulate in an ion trap while watching the decay as reported by Träbert [5] for the lifetime measurement of inter-combinational and forbidden transitions.

By exchanging the excitation foil in the beam-foil technique for a focused laser beam, selective excitation can be obtained and the problem of cascades can be eliminated. In this way the 4554 Å  $D_2$ -resonance transition in BaII excited by 4545 Å argon ion laser line tuned to resonance has been studied using the Doppler effect [6]. Since the transition wavelength for ions of different charge states rapidly shift into the UV and VUV regions due to the electronic shell contraction and as CW lasers are scarce at such wavelengths the applicability of this high-precision technique is limited.

Since very short laser pulses with a power density sufficient to well saturate optical transitions can be obtained, a large fraction of the irradiated ground-state atoms can be transferred to the excited state. Using step-wise excitations with synchronized laser a large number of atoms can be excited into very highly excited states [7]. The fluorescence photons are imaged by a lens system on to the photomultiplier. The transient signals are applied to a transit digitizer and the digitized data are further processed by a computer to get the decay curve. The method is very accurate due to the selective nature of excitation but the low-duty cycle restricts the application to intense transitions only.

In the delayed coincidence technique [8] the gas is excited by a pulsed electron beam which also triggers off the time-to-amplitude converter (TAC). The stop signal for this is provided by the excited radiations via a monochromator and photomultiplier. A multichannel analyzer (MCA) connected to the converter then readily displays the decay curve of the studied transitions.

Methods using low-energy electron excitation can conveniently be applied to a wide variety of measurements in atoms, molecules and ions over a broad time range ( $10^{-9}$ – $10^{-6}$  s). But the intensity of the emitted photons is not always sufficient to work with the very high spectral resolutions that are necessary to resolve blended lines. It suffers from two potential sources of errors, cascading and pressure dependent effects. Blending can be reduced using high spectral resolution which requires a high intensity and it has been achieved in the HFD technique [2] where high energy (several keV) electrons are used for exciting the atomic, ionic, and molecular states and the periodic excitation is accomplished by sweeping the beam across an aperture at a high frequency.

From the foregoing discussion it follows that there is no single method for lifetime determination that can be applied to all kinds of states in atoms, ions and molecules over a wide range of wavelength and lifetime. A technique that possesses some features generally lacks some other important ones. For highly ionized atoms and multiply excited levels, beam-foil technique is superior and the only approach. For lowered charged atoms various techniques based upon narrow width tuned laser

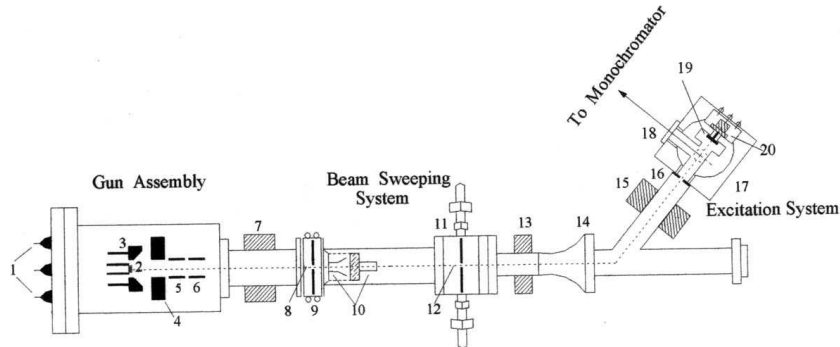
excitation should give highly accurate results for levels which can be excited intensively enough without introducing, for instance, a gas target at high pressure or other systematic sources of error. For most remaining levels in lower charged atoms and molecules, high-power electron excitation at optimum duty cycle as in the HFD technique seems to be a versatile method and is indeed applicable in a large number of cases. Keeping this in mind we have developed in our laboratory an apparatus, based on HFD technique for lifetime measurements in atoms and molecules.

The present experimental arrangement is a refinement of the single photon delayed coincidence technique with pulsed electron excitation. Although the excitation cross-sections of atomic and molecular states have their maximum values at low energies, the product of cross-section and available excitation current peaks at much higher energies because of space-charge limitations in electron guns. Thus excitation of a gas sample with high-energy (a few keV) electron causes an increase in intensity by some order of magnitude. An intensity gain is further accomplished by sweeping the beam very fast across a narrow slit at a high frequency instead of pulsing it at fairly low repetition rate as is done by conventional delayed coincidence technique. Thus an enhancement of intensity of the emitted radiation increases the spectral resolution because measurements can be done with a narrow slit-width of the spectrometer. Another advantage of this technique is that the investigation can be done at low gas pressure that reduces the influence of pressure-dependent effect. Cascading is still present because of the non-selective nature of excitation. It has been found, however, that cascading is not as important in many cases provided the decay is followed for many lifetimes of the transition of interest using the variable sweep frequency (the problem of cascading is discussed in §4). In the present set-up repetition period can also be varied from 500 ns to 4000 ns so that the decay curve can be followed for many lifetimes which permits extraction of cascade components.

### **3. General technical description of the apparatus**

The basic components are the gun assembly, the beam sweeping system and the excitation system. These are housed in vacuum enclosures that are connected to each other by brass and glass pipes, flexible hose and proper flange and O-ring arrangements. The general view of the apparatus is shown in figure 2. A DC electron beam of energy 4 keV and current up to 2 mA beyond the slits S1 is produced by the electron gun. To keep the beam focused throughout its path up to the excitation chamber, there are three magnetic lenses L1, L2 and L3 which are formed by current carrying solenoids enclosed by soft iron cases. Suitable DC voltage is applied across the pair of plates placed in the glass tube containing the beam sweeping system for quiescent positioning of the beam along the axis of the tube.

The DC beam emerges through the slit S1 and enters into the beam sweeping system where it is swept across the slit S2 to produce a pulsed electron beam of very short duration in the region beyond S2. After passing through the slit S2 the pulsed electron is bent by the deflection coil which is an ordinary yoke coil used in television receiver to an angle of  $40^\circ$ . To make the beam lie along the



**Figure 2.** General view of the apparatus: 1 – Electrical feedthrus, 2 – filamentary cathode, 3 – control electrode, 4 – accelerating electrode, 5 – central electrode, 6 – final electrode, 7 – electromagnetic lens L1, 8 – slit S1, 9 – cooling coils, 10 – deflection plates, 11 – vacuum feedthrough manifold, 12 – slit S2, 13 – lens L2, 14 – yoke coil, 15 – lens L3, 16 – slit S3, 17 – excitation chamber, 18 – quartz window, 19 – electron beam collector and 20 – emitter follower.

axis of the beam transport tube, the DC current through the yoke coil is adjusted. Final focusing is done by a magnetic lens L3 before it is allowed to enter into the excitation chamber through slit S3. The reason for bending the beam is to hinder any light from the gun filament from reaching the excitation volume. In this way a narrow parallel beam (diameter of cross-section = 3 mm) is steered through the deflection and bending systems up to the excitation chamber [9].

The vacuum inside the system is  $10^{-5}$  Torr or better except in the excitation chamber where a pressure of  $10^{-3}$  Torr or higher is often wanted when the sample gas is introduced. To maintain this condition of differential pressure across the slit S3, differential pumping is resorted to. To achieve the desired vacuum, two independent diffusion pump sets, each of capacity 300 l/s are employed with one below the gun housing and the other below the excitation chamber.

### 3.1 *The gun system*

A brass cylinder of diameter 11.5 cm and length 22 cm is used for housing the electron gun. In this pre-accelerator type of gun the cathode is a directly heated tungsten spiral (3 mm long) made by cutting from the filament of a 500 W, 230 V incandescent lamp. The cathode is kept at a negative potential of 4 kV. The cylindrical control electrode that surrounds the cathode is adjusted between 0 V and 100 V, negative with respect to the cathode and it controls the beam current as well as the beam diameter. Beyond this electrode there is an electrostatic lens system consisting of one circular metal plate with a central circular opening (accelerating electrode) and two cylindrical electrodes placed coaxially with the accelerating electrode. The accelerating and the outermost electrodes are kept at ground potential while the potential of the middle one is adjusted lower than the other two so as

to achieve best focusing. The materials of the electrodes are stainless steel. The beam finally focused by the magnetic lens L1 emerges through the slit S1. The accelerating voltage is supplied from a  $-4$  kV, 100 mA stabilized voltage supply. The filament power is  $\sim 12$  W and is obtained from a step-down transformer (1:20) where the primary is controlled by a variable transformer (0–220 V). The secondary of this transformer is insulated for 10 kV and is designated for 5 A load current. The electrical connections for supplying current to the filament and high voltage to the electrodes are provided via vacuum feedthroughs fitted on the rear flange of the gun housing.

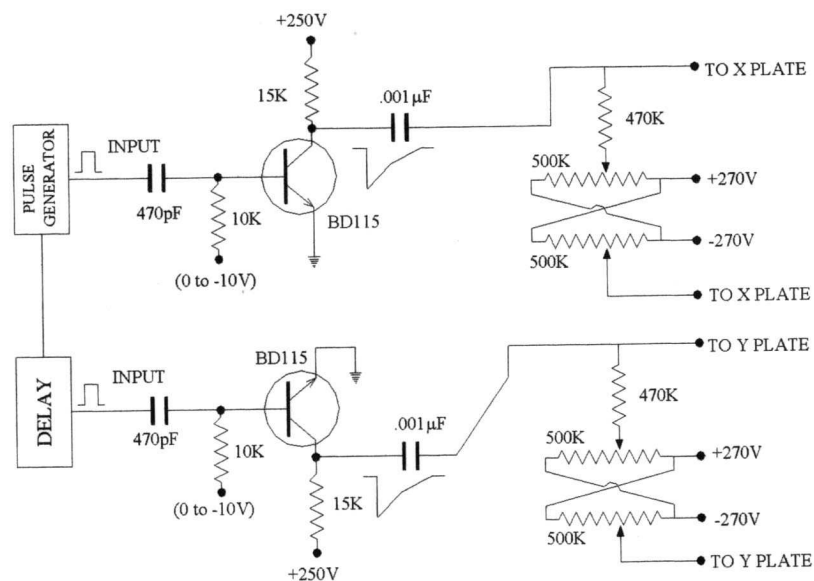
### 3.2 *Beam sweeping system*

The system is contained in a glass cylinder (diameter 4.2 cm, length 24 cm) as shown in figure 2. An electrostatic deflection system consisting of two pairs of X–X and Y–Y plates for horizontal and vertical deflections respectively are constructed and used to sweep the beam. The slit S1 collimates the beam so as to allow it to pass freely through the deflection system without touching the plates. The X and Y deflection plates are made from 0.5 mm thick molybdenum sheets and are  $5 \times 2$  cm<sup>2</sup> and  $4 \times 2$  cm<sup>2</sup> respectively in size. These are mounted within the glass chamber with the help of ceramic blocks. The DC voltages on the X and Y plates for quiescent positioning of the beam can be adjusted to any value in the range from  $-270$  to  $+270$  V.

The glass cylinder containing the deflection system has two brass flanges, one at each end with Wilson seals so as to render it demountable. The circular slit S1 of diameter 3 mm is made on a 4 cm diameter and 2 mm thick molybdenum plate screwed to the ceramic block facing the gun side. The flange on the other side is specially constructed having arrangements for moving two insulated probes inside the vacuum chamber without disturbing the vacuum. The first one is used for beam current measurement. The rectangular slit S2 cut on a molybdenum sheet with an opening (width 3 mm, length 8 mm) is mounted on the second probe held at ground potential. However, wider slit may be used for getting electron beam having longer pulse width. The electron beam (cross-sectional diameter  $\sim 3$  mm) is swept across the width of the slit S2 at a high speed to obtain a pulsed beam of very short duration.

The deflection sensitivity of the system is 80 V/cm for a 4 keV electron beam. Therefore, the pulse meant to deflect the beam very quickly across the slit S2 (width 3 mm) has to be impressed on the deflection plates and should ideally have a width of several microseconds, short and equal rise and fall times and a flat top. In addition these pulses should have amplitude of about 200 V and rise-time of about 7 ns for our deflection system to have a beam pulse width of about 2 ns.

Although it is difficult to generate such a pulse by conventional methods, it is relatively easier to generate fast rising pulses of amplitude 200 V having 7 ns rise-time followed by slower RC fall-time. Transistors having high  $V_{ce}$  and  $V_{cb}$  operated in the avalanche mode open up some possibility. The types 2N 3501 and BD 115 have been found to serve the purpose well. The transistor is operated at a collector–emitter voltage a little below its breakdown value with the base reverse biased in the



**Figure 3.** Circuit diagram of the sweep pulse generator.

quiescent condition. Under such an operating condition, if a positive trigger pulse of about 5 V amplitude is injected into the base, avalanche breakdown occurs in the transistors and a large current is switched into the collector-emitter circuit for a very short time giving rise to a pulse of short rise-time at the collector point. The circuit diagram is shown in figure 3. The fast pulse from the circuit when applied onto the X-deflection plates sweeps the beam very fast across the slit during its fast rising part but crosses back the slit quite slowly during the slower fall-time. Consequently the beam pulse width becomes very small during the forward excursion but undesirably large during fly-back. To avoid such a situation it is necessary to shift the beam away from the slit opening during fly-back. This is accomplished by applying to the Y-plates a second similar pulse suitably delayed with respect to the first one. Thus each electrical pulse impressed on the X-deflection plates produces only one electron beam pulse of very short duration beyond S2. The measured beam pulse duration is a little less than 2 ns in the apparatus with the present dimensions of slit S2 and X-Y deflection plates. The 5 V pulse generator generates two trigger pulses having variable repetition rate from 250 KHz to 2 MHz and a delay of 60 ns between the pulses.

### 3.3 The excitation and detection systems

This system is contained in a cubical box of size  $15 \times 15 \times 15 \text{ cm}^3$  made of brass (figure 2). Here the electron beam collides with free molecules and is subsequently stopped and collected. A cylindrical block of machinable ceramic is used to construct the collision volume in which vertical channels are cut along the direction of electron

beam and towards the monochromator which observes the excitation volume. The collision volume should be made of a substance such that it is not degassed nor damaged by the heat produced by electron beam bombardment. The white coloured machinable glass ceramic (Macor) we use has zero porosity and high maximum use temperature. It's high reflectance over a wavelength range of 2000–9000 Å has also been used to facilitate reflection of emitted light towards the monochromator. Zero porosity prevents degassing. A gas flow system and a vacuum gauge are connected to this chamber. A continuous flow of the target gas at a given low pressure is maintained in the excitation chamber by pumping it through a needle valve connected at the top of the chamber. A diffusion pump placed below the excitation chamber finally pumps out the gas.

The electron beam enters the chamber through the slit S3 (a circular opening of diameter 6 mm), passes through one channel and is finally collected by the collector cup which is a circular molybdenum plate and is connected to the input of a fast emitter follower of bandwidth 200 MHz which, constructed on a  $4 \times 2.5$  cm<sup>2</sup> printed circuit board, is placed at the rear of the excitation chamber with all of its electrical connections made via vacuum feedthrus. A voltage pulse is developed when the pulsed electron beam is collected by the collector cup having a stray capacity of about 10 pF to ground paralleled by a resistance of 0.5 kΩ which is the input resistance of the emitter follower. The rise-time of the voltage pulse is the time for which the pulsed beam charges the stray capacity, i.e. the duration of the beam burst. As we are interested only in developing a voltage pulse and not in the total beam current but to develop a voltage pulse, therefore, we have used a thin metal plate as collector cup instead of a Faraday cup so that pulse height may not be attenuated.

The photons emitted perpendicularly to the direction of the beam during de-excitation of atoms of the gas sample come out through a quartz window. A condensing lens system (Oriel 77260 lens-filter-shutter assembly) has been used for focusing the emitted radiation exactly onto the monochromator entrance slit. It is coupled light-tight to the excitation chamber and the monochromator. The emitted light is observed with a 0.5 m grating monochromator (Minuteman, Model 305 MV) having a spectral range of 100–1000 nm at a resolution of 0.5–1.0 Å. Single photons are detected with a Hamamatsu R943-02 photomultiplier tube (PMT) cooled down to  $-20^{\circ}\text{C}$  to reduce the dark current to as low as 40 counts per second.

### *3.4 The electronic equipments and the time resolution of the system*

The electronics used in the present equipment are standard components used in delayed coincidence work (figure 1). The voltage pulses developed by the charge stored on the collector cup are fed via an ORTEC 474 timing filter amplifier (TFA) to an ORTEC 584 constant fraction discriminator (CFD). The pulses at the output of the CFD are then fed to start input of an ORTEC 566 time-to-amplitude converter (TAC). Similarly the pulses from the photomultiplier tube detecting the photons are also amplified by a TFA before they are fed to a CFD. The pulses from this CFD are applied to the stop input of the TAC via a variable delay. The output of the TAC is connected to a MCA that generates the decay curve from which the

life of the level concerned is evaluated. An ORTEC 462 time calibrator was used to determine the time calibration of the system.

Now the lower limit for possible measurements of short lifetimes is set by the time resolution of system. The full-width at half-maximum (FWHM) of the instrument response function is due to a combination of three principal factors, viz., the duration of the electron beam pulse (beam pulse width), the spread in the transit time of photoelectrons in the PMT and timing jitter in the electronic components. The instrumental response function is obtained by placing a Cu target at the site of the gas excitation volume and then measuring the prompt bremsstrahlung photons emitted when the beam pulse falls on it [2]. For a beam pulse width of 1.8 ns, the value of the coincidence resolving time (FWHM) is 2.6 ns as measured with the present set-up. The decay curve can be analyzed for extraction of lifetimes by a least square fit to the exponential decay convoluted with the known instrumental prompt response function [10].

#### **4. Lifetime measurement with the apparatus**

The two major experimental difficulties commonly encountered in the measurement of lifetimes with this apparatus are the pressure-dependent effect and the effect of radiative cascade. The influence of too high a gas pressure on lifetime measurement is mainly two-fold. Photon trapping occurs if the studied excited level in an atom has a strong allowed transition to the ground state (a resonance transition). A number of photons will be absorbed and re-emitted one or more times before they get out of the active volume with the effect that the recorded lifetime of the excited state appears longer. Another source of error that may affect the lifetime measurement is collisional de-excitation. The apparent decay rate is increased by  $nv\sigma$  where  $n$  is the density of the atom in the ground level,  $v$  is the mean relative velocity of the colliding system and  $\sigma$  is the collision cross-section. As a result, the lifetime of the level is shortened. In our system where the high excitation efficiency makes it possible to perform experiments at gas pressures below 1 m Torr, the pressure-dependent effect causes no problem for lifetime measurement except for the resonance levels in neutral rare gas atoms. Very strong trapping effect was observed for some resonance levels (e.g.  $5s'[1/2]_1$ ,  $5s[3/2]_1$ ,  $6s[3/2]_1$  levels of NeI). The decay curves at different pressures for the  $5s[3/2]_1$  level of NeI are shown in figure 4. In this case, lifetime ( $\tau$ ) are measured at different pressures and  $\tau$  are plotted as a function of pressure ( $p$ ). Figure 5 shows such a pressure-dependent curve and extrapolation to zero pressure gives the correct value of the lifetime. For pressure less than 2 mTorr, a contribution of less than 2% is introduced in the lifetime measurement of non-resonance levels by HFD technique. For the non-resonance levels most of our measurements are carried out at gas pressures ranging from 0.2 to 2 mTorr and no variation of lifetime is observed within the experimental error, within this range of pressure.

Before actual lifetime measurement an excitation spectrum (intensity vs. wavelength scan) is recorded between 2000 and 9000 Å using the monochromator at a resolution of about 0.8 Å (FWHM) to examine how well the spectral lines under investigation are separated from the neighbouring lines and to investigate the effect

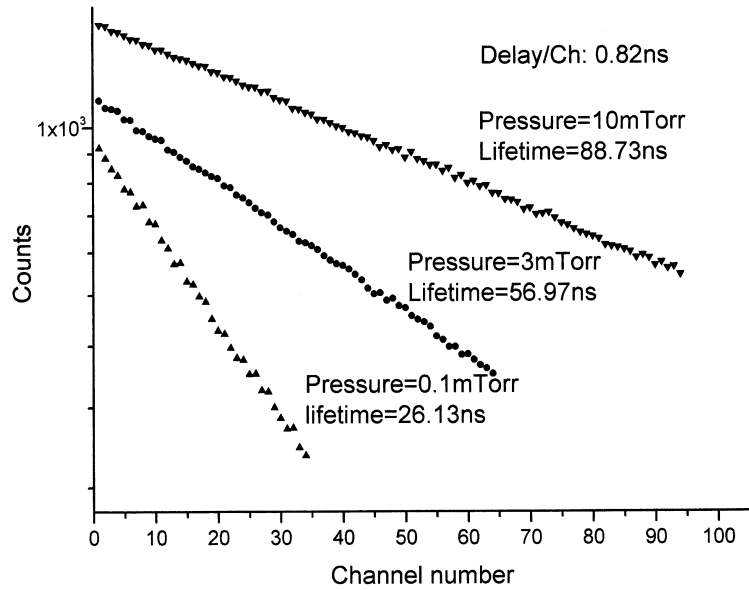


Figure 4. Decay curves at different gas pressures for the  $5s[3/2]_1$  level of NeI.

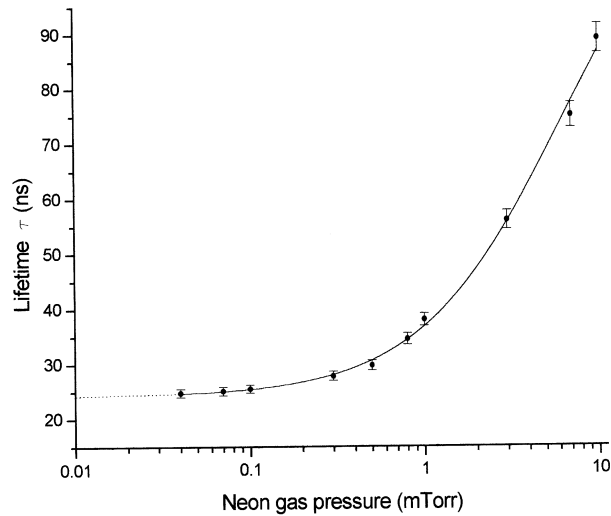
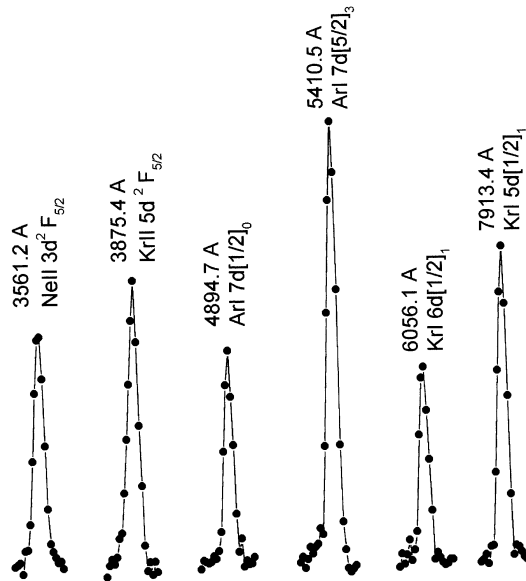


Figure 5. A typical pressure dependence curve for the lifetime  $5s[3/2]_1$  resonance level of NeI.

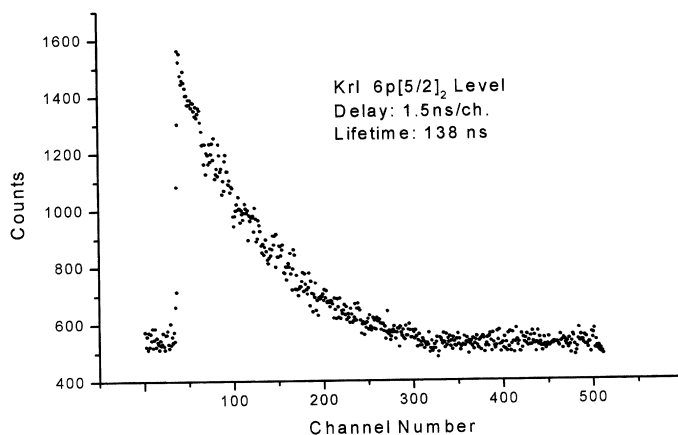
of cascades in our experimental arrangement. Excitation spectrum of some of the measured lines is presented in figure 6. All the lines recorded in these spectra for different gas atoms investigated so far (inert gases) are usually found in the lists of classified lines [11–14] for atoms and ions. However, the lists contain many more



**Figure 6.** Excitation spectrum of some of the measured lines. Six channels correspond to 1 Å.

lines for every sample which are not observed in the present arrangement. From these spectral lines appearing in the spectra for different gas samples, the higher levels repopulating the levels under investigation can thus be identified. It has not been possible to examine the other cascading levels that decay by emitting photons having wavelengths less than 2000 Å and higher than 9000 Å in this way because of the spectral insensitiveness of the PMT we use (Hamamatsu R943-02) below 2000 Å and above 9000 Å. However, it is seen from the work of Massey [15] that for excitation with electrons having an energy well above the threshold, the higher levels are expected to be excited with relatively less probability when compared to lower ones. Thus if in any measurement the excitation spectrum scanned between 2000–9000 Å is found to contain no line that appears due to repopulation from a higher level to any particular level under investigation, it may be assumed that in the present case where the excitation energy is 4 keV, the high-lying levels have insignificant cascade feedings to that level. A typical delayed coincidence spectrum obtained from a measurement of wavelength 4502.4 Å decaying from the  $6p[5/2]_2$  state in KrI (neutral krypton) is shown in figure 7.

If higher cascading levels are present, then decay curve is followed for many lifetimes of the transition of interest using the variable sweep frequency to generate the multiexponential decay curve that can be analyzed by the computer programme [10] we use to obtain the lifetime values of the level under study as well as the cascading levels. But the contribution due to cascade feedings and the error in the determination of lifetime can be estimated if we can find out  $N(0)^c/N(0)$ , i.e. the initial population of the cascade level relative to the initial population of the level under study. During measurement of lifetime of some  $4p$  levels of ArII [16], we



**Figure 7.** The decay curve of the  $6p[5/2]_2$  level of KrI measured at an instrumental time resolution of 3.4 ns and gas pressure  $5 \times 10^{-4}$  Torr.

observed that the ratio  $N(0)^c/N(0)$  is in no case greater than 0.2 for which the possible maximum error that can be introduced into the lifetime value is only 3%. Thus we find that at normal relative level population cascade feeding seldom create any error of importance in lifetime determination provided that many points on the decay curve can be measured with good counting statistics over long time intervals. In the cases where cascades are not present the sweep frequency is increased to such a value so as to obtain optimum photon yield.

In most of our measurements the statistical error is about 2–3%. The main sources of systematic errors are due to the following factors:

The variation of the width of the instrument response function may occur as a result of 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 within 0.2%.

Uncertainties due to non-linearity of the measuring system and in the time calibration occur due to any variations 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 modern electronic equipments (Ortec modules) the uncertainty introduced by the integral and differential non-linearity of the system including the pulse height analyzer is less than 0.2%, whereas with ORTEC 462 time calibrator, the uncertainty in the time calibration is about 0.1%.

The pressure-induced change of lifetime is small for a measurement within this pressure range and the maximum error amounts to 2%.

Thus the total error estimation includes the following uncertainties: counting statistics (2–3%), instrumental time resolution (0.2%), time calibration (0.1%), non-linearity of the electronic system (0.2%), cascading (3%) and pressure-dependent effects (2%).

The apparatus is in regular use for the measurement of lifetimes of excited atomic and ionic states. It has excellent overall stability, the focusing of the beam, the beam current, the beam pulse width, the sweep frequency and the entire associated

electronics remain stable at their operating values for over hundred hour continuous operation spell. Several measurements have been performed on different levels of neon, argon, krypton and xenon. Lifetimes of five levels of NeI [17], two levels of NeII [18], ten levels of ArI [19,20], eight levels of KrI [21,22], five levels of KrII [23,24], ten levels of XeI [25,26] have been measured for the first time by us.

## 5. Conclusion

An apparatus using the HFD technique was developed indigenously at our laboratory and it is being used successfully for the measurement of lifetimes in atoms and ions. Its inherent properties have been discussed in the various sections above. Very different lifetimes are conveniently studied just by changing the sweep frequency and multi-exponential decay curves can be decomposed in this way. The programme for the near future includes determination of lifetimes of different non-gaseous elements and of molecules and ion molecules which are of fundamental interest to astrophysics.

## Acknowledgements

The authors express their gratitude to R Bhattacharya for his interest in the work. They are thankful to S Bose for his collaboration in developing the electronic circuits. The cooperation of M K Karmakar, A Ghosal and D Das during fabrication of the apparatus is also acknowledged.

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