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Time profile of the scintillation from liquid and gaseous xenon

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ABSTRACT

The decay time profile of vacuum ultraviolet scintillation induced by electronic recoils has been studied for liquid and gaseous xenon. The scintillation light from xenon excited by a gamma source was measured by using two vacuum ultraviolet sensitive photomultipliers, one for detecting scintillation and the other for counting photons of weak monochromatic light. The analysis results based on the time-correlated single photon counting method show that the time profile in the 176 nm scintillation decay curve for liquid xenon is consistent with a single exponential component and the decay time constant is 31.5 ± 1.3 ns. This constant does not change significantly for pressure ranges between 90 kPa and 130 kPa. There is no emission wavelength dependence of the decay constant. The result corresponds to an average on electronic recoil energies up to 1.3 MeV.

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1. Introduction

Xenon scintillation has been readily observed in gaseous xenon (Gas.Xe) and liquid xenon (Liq.Xe), and has been applied to various modern experiments for radiation detection. The scintillation time profile is a valuable property for understanding the mechanism of scintillation. In liquid xenon, and also in gaseous xenon above a few hundred Torr, the scintillation photon from an excited state is produced by two mechanisms [1] as follows. One is the scintillation process "excitation" that result because of excited atoms directly produced by an ionizing charged particle.

$$Xe^* + Xe \rightarrow Xe_2^* \tag{1}$$

$$Xe_2^* \rightarrow 2Xe + h\nu \quad (VUV) \tag{2}$$

The excited state Xe^* forms the excited metastable excimer Xe_2^* in its lowest singlet or triplet states. The scintillation photons are emitted in a transition from one of the two lowest electronic excited states to the ground state. Their lifetimes are distinct. The other scintillation process known as "recombination" is attributed to electron-ion pairs produced by ionizing charged particles.

$$Xe^+ + Xe \rightarrow Xe_2^+, \tag{3}$$

$$Xe_2^+ + e^- \rightarrow Xe^{**} + Xe, \tag{4}$$

$$Xe^{**} \rightarrow Xe^* + heat, \tag{5}$$

$$Xe^* + Xe \rightarrow Xe_2^*, \tag{6}$$

$$Xe_2^* \rightarrow 2Xe + h\nu \quad (VUV) \tag{7}$$

A xenon atomic ion and a xenon atom form the molecular ion Xe_2^+ which recombines with a thermalized electron and forms Xe_2^*. Subsequently, processes lead to the production of a vacuum ultraviolet (VUV) scintillation photon from an excited state. In the past, these processes have been studied for liquid xenon by excitation with electrons, alpha particles and fission-fragments. Different lifetimes and relative intensities of these processes were reported depending on the type of radiation source. Therefore, the time profile of scintillation from liquid xenon helps to identify incident particles. According to Hitachi et al. [2], two lifetime components were observed under alpha particle (singlet: 4 ns, triplet: 22 ns) and fission-fragment (singlet: 4 ns, triplet: 21 ns) excitation, and only a single component 45 ns was observed under electron excitation. However, different lifetime values were reported for electron excitation depending on the experiment [2,3,4,5,6]. The results are listed in Table 1. Akimov et al. indicated that the decay time values vary for low energy recoils [5]. Dawson et al. studied the dependence with energy [6], and a recent simulation study on liquid xenon scintillation processes suggested that the excitation lifetime varies depending on the energy of gamma rays at zero applied electric field [7].

In the present work, we have excited liquid and gaseous xenon by a ^{60}Co gamma source and measured the scintillation time profile at several wavelengths in the emission spectrum at zero electric field. We then measured the decay constant of liquid xenon and gaseous xenon. We also studied, for liquid xenon, the emission wavelength dependence and the pressure dependence of the decay constant for the peak of the emission spectrum. In this

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Table 1

Decay time for the singlet τ_s and the triplet τ_t components from liquid xenon. The experimental conditions for incident source, energies and electric field are also shown. Energy uses measurement value themselves and "Unknown" for it is not measured.

Source	τ_s (ns)	τ_t (ns)	Energy	Electric field	Reference
Electron					
^{207}Bi, e		34 ± 2	Unknown	Null	Kubota et al. [3]
	2.2 ± 0.3	27 ± 1	Unknown	4 kV/cm	
Electron beam		32 ± 2	200 keV	Null	Keto et al. [4]
^{207}Bi, e		45	Unknown	Null	Hitachi et al. [2]
^{60}Co		29.1 ± 0.6	~13.5 keV	Null	Akimov et al. [5]
^{60}Co		34.0 ± 0.6	~37.5 keV	Null	
^{60}Co, γ		46.1 ± 0.1	Unknown	Null	Dawson et al. [6]
		25.2 ± 0.1		0.5 kV/cm	
		22.6 ± 0.1		3.7 kV/cm	
^{60}Co, γ		31.5 ± 1.3	Unknown	null	This work
α,					
^{252}Cf	4.3 ± 0.6	22 ± 1.5		Null	Hitachi et al. [2]
Fission-fragment					
^{252}Cf	4.3 ± 0.5	21 ± 2		Null	Hitachi et al. [2]

first step, we were not able to study the energy dependence. Consequently, results presented in this paper correspond to an average on electric recoil energies up to 1.3 MeV.

2. Experiment

2.1. Apparatus

A schematic diagram of the experimental apparatus is shown in Fig. 1. A stainless-steel vacuum chamber is connected to a vacuum monochromator (Acton Research Corp.VM-502-S). The wavelength resolution of the monochromator is 0.1 nm. The xenon cell is a cylindrical vessel made by SUS304 (16 mm in diameter, 56.6 mm in length) and installed in the vacuum chamber. This xenon cell is designed to minimize the effect of scattering or absorption of light. Both ends of the cell are equipped with MgF$_2$ windows (10 mm in diameter and 1 mm thick) with one end facing the entrance slit of the monochromator. The other end faces the 18 mm square VUV-sensitive photomultiplier tube (PMT) (R7600-06: HAMAMATSU) in the vacuum chamber, which has a quartz window and a bialkali photocathode. Another VUV-sensitive 28 mm diameter PMT (R6836: HAMAMATSU) is set at the exit slit of the monochromator.

Xenon was excited by a 1.8 MBq ^{60}Co gamma source, which was set besides the chamber.

The cell was filled with research-grade xenon gases (Japan Air Gases Co. with a purity of >99.999%) through a purifier. The purifier contained about 5000 pieces of St707 getters (4 mm in diameter and 2 mm thick) supplied by SAES Getters. The getters were activated at approximately 250 °C for 15 min.

Prior to filling, the chamber and filling systems were evacuated down to 10^{-4} Pa. The purified gas was cooled and liquefied by a pulse-tube refrigerator, which was set at the top of the vacuum chamber.

2.2. Measurements

Fig. 2 shows a block diagram of the electronic system. A charge integrating analog-to-digital converter (ADC) was used to measure the luminosity. The ADC measured the total charge signal from PMT2 (R6836) detecting the monochromatic photon. The gate pulse for the ADC was issued by the constant fraction discriminator (CFD) output from PMT1 (R7600) detecting scintillation occurrence. The width of the gate pulse for the charge integration is 250 ns and it is located 20 ns prior to the PMT2 signal. 500 μs
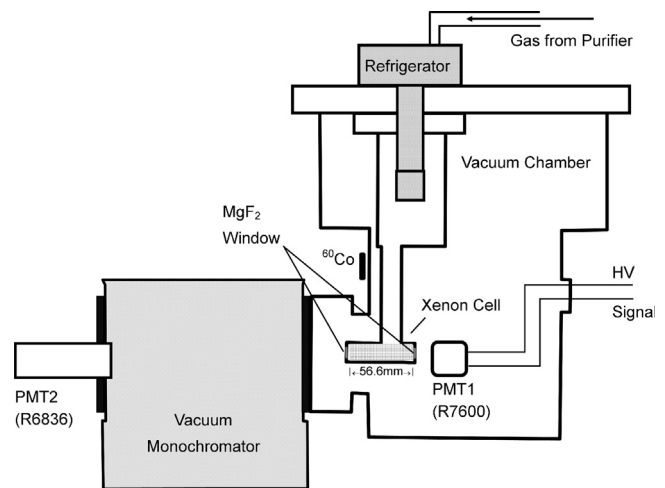
Fig. 1. Schematic view of the experimental apparatus (vacuum chamber and vacuum monochromator).
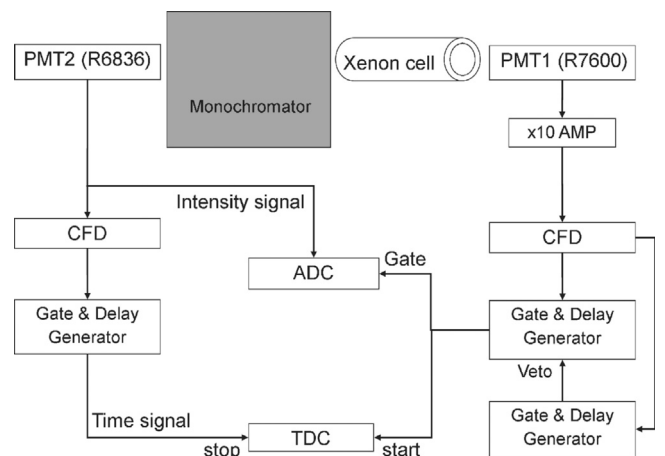
Fig. 2. Block diagram of the electronic system used to measure the time profile of scintillation from liquid and gaseous xenon. The ADC measured the total charge signal of the monochromatic photon. VETO input occurring during the time from the Gate start up to 500 ms.