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Scintillation yield of liquid xenon at room temperature

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ABSTRACT

The intensity of scintillation light emission from liquid xenon at room temperature was measured. The scintillation light yield at 1 °C was measured to be 0.64 ± 0.02 (stat.) ± 0.06 (sys.) of that at −100 °C. Using the reported light yield at −100 °C (46 photons/keV), the measured light yield at 1 °C corresponds to 29 photons/keV. This result shows that liquid xenon scintillator provides high light yield even at room temperature.

1. Introduction

Scintillation detectors based on liquid xenon have been constructed for various experiments, such as including dark matter searches [1–3], double beta decay [4], $\mu \to e\gamma$ search [5]. One of the great advantage of liquid xenon is its large scintillation yield, which enables us to measure low energy phenomena and perform experiments which require good energy resolution. The light yield of liquid xenon at −100 °C has been measured in many experiments [6–11]. The scintillation light of liquid xenon is vacuum ultraviolet (VUV). The mechanism of light emission was reported in Ref. [12]. Because of low boiling point of xenon around standard pressure (−100 °C at 0.18 MPa absolute pressure), a cooling is necessary to make detectors using liquid xenon. If it is possible to use liquid xenon at room temperature, it would make detector construction easier and enable various new possibilities for detectors. The density of liquid xenon at room temperature is 65% of that at −100 °C (1.88 g/cm^3 at 1 °C) [13], but it is still a high density scintillator. Xenon can be in liquid phase below the critical point of 17 °C.

As an example of new applications by using liquid xenon at room temperature, a detector for double beta decay which requires a low background technique is discussed here. The conceptual design of the detector is shown in Fig. 1. The detector consists of an elliptic tank filled with water, an acrylic vessel filled with enriched ^{136}Xe and a few photosensors. The acrylic vessel is

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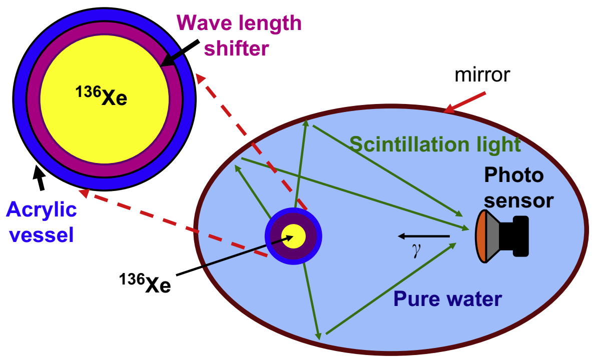

Fig. 1. Conceptual design of a double beta decay experiment. The elliptic tank detector consists of photosensors and enriched liquid xenon. Since the inner surface of the elliptic tank is mirrored, the scintillation light from ^{136}Xe is detected with high efficiency. Furthermore, the photosensors which are the main BG source are kept away from ^{136}Xe.

put at one focus and photosensors are put at the other focus. Since the scintillation light of liquid xenon is VUV, it is not possible to transmit through the acrylic vessel and water, therefore wave-length shifter is necessary on the inner surface of the acrylic vessel. The inner surface of the elliptic tank is a reflector for the wavelength-shifted photons with high efficiency in order to guide them to the photosensors. Because of the convergence of photons to a relatively small focus point, we can dramatically reduce the number of photosensors. Usually, one of the most serious sources of background in low background experiments is radioactivity in the photosensors. The large reduction of the number of photo-sensors helps a lot in reducing the background. Furthermore, because the gamma rays from the photosensors are attenuated by pure water in the elliptic tank, it is possible to reduce the backgrounds further.

The scintillation yield of liquid xenon at $-100\,^{\circ}$C has been reported in several papers [14], but the yield at room temperature has not been reported so far. In this paper, we present the measurement of scintillation light yield at room temperature and compare to that at $-100\,^{\circ}$C.

2. Experimental setup

2.1. Liquid xenon vessel

Fig. 2 shows the cross-section of the stainless-steel liquid xenon vessel (SUS304). The vertical cylindrical hole (16 mm diameter, 45 mm length) and the horizontal cylindrical hole (10 mm diameter, 70 mm length) are completely filled with liquid xenon and the volume is 15 cm^3. The pressure of liquid xenon at room temperature is 5 MPa. Therefore, the body of the vessel is made from stainless steel with a thickness of 27 mm and the window where scintillation light passes is made from MgF_2 with a thickness of 10 mm. In order to transmit scintillation light to a photomultiplier (PMT), a light guide made from MgF_2 is placed between the MgF_2 window and the PMT. The light guide is needed because oxygen in air easily absorbs the VUV scintillation light. The diameter of the light guide is 16 mm and the length is 10 mm. A 2-in. PMT (R8778 Hamamatsu), which is sensitive to VUV light, is used in this measurement. The gain of the PMT is set to 6.0×10^6 with an applied high voltage of $+1544$ V. The quantum efficiency (Q.E.) of the PMT is 28% at room temperature for 175 nm VUV light. In order to compare measurements at different temperature, the temperature dependence of the Q.E. $\times$ gain were measured independently for 175 nm VUV light. It was measured using scintillation of xenon gas excited by alpha rays. The light

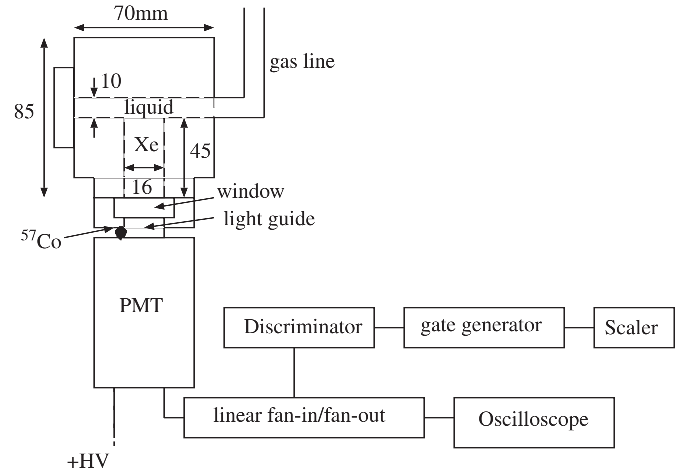

Fig. 2. Cross-section of the liquid xenon vessel and measurement diagram; the inner volume of the high pressure vessel is 15 cm^3. The ^{57}Co source is located at the edge of light guide.

source was kept at room temperature but the PMT was cooled down using liquid nitrogen and heater. As a results, it was revealed that their product, Q.E. $\times$ gain, increased by 15 ± 5% from 1 to $-100\,^{\circ}$C. The temperature dependence of the Q.E. $\times$ gain is taken into account in the following measurements. In order to collect scintillation light efficiently, Dupont™ Krytox® 16350 is used as an optical grease on both side of the light guide. We confirmed that the transmittance of the Krytox at 175 nm was more than 90% with the thickness of 25 μm. The refractive index of Krytox is estimated to be 1.35 at 175 nm. Temperature dependence of optical properties of Krytox, MgF_2 and PMT window material gives negligible effect on our result.

2.2. Filling procedure

Fig. 3 shows a handling system of high pressure gas to fill liquid xenon at room temperature into the liquid xenon vessel. First, xenon gas was collected in a 4200 cm^3 bottle. The pressure of xenon gas in the 4200 cm^3 bottle was 0.5 MPa, which corresponds to 110 g of xenon in the bottle. Second, the collected xenon gas was passed through the Oxisorb (MESSER; large cartridge Oxisorb). The Oxisorb filters out oxygen and water from xenon gas to the level of oxygen <5 ppb and H_2O <30 ppb. In order to fill xenon into the vessel using only temperature cycle (i.e., without using a compressor), a 75 cm^3 bottle was placed between the Oxisorb and the vessel. The 75 cm^3 bottle was cooled down in advance using liquid nitrogen. Accordingly, the filtered xenon gas was transferred to the 75 cm^3 bottle. Finally, by raising the temperature of the 75 cm^3 bottle, the liquid xenon is transferred to the vessel. The pressure of liquid xenon was measured using a pressure gauge (KYOWA PHS-200KA). It was kept at 5.8 ± 0.1 MPa. The temperature of the liquid xenon vessel was kept at $1 \pm 2\,^{\circ}$C using a coolant placed on it. The 75 cm^3 bottle was connected to the liquid xenon vessel throughout the measurement in order to keep the vessel always filled with liquified xenon. For safety, a rupture disk which bursts at 13 MPa was connected to the liquid xenon vessel.

2.3. Setup for the reference measurement

We measured relative light yield at room temperature with respect to that at reference temperature ($T = -100\,^{\circ}$C, $P = 0.18$ MPa). Fig. 4 shows the setup for the reference measure-ment. The liquid xenon vessel, together with the 75 cm^3 bottle and