Measurement of the Compton-electron Response in Liquid Scintillator

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1. Introduction

Liquid scintillator has very fast timing characteristics in addition to the pulse shape discrimination for neutron and γ-rays and therefore widely used detector for neutron spectroscopy. The information of absolute efficiency for incident neutron energy and threshold is necessary for unfolding of the neutron spectra. However, the deposited energy in the liquid scintillator should be estimated in an appropriate manner based on the Compton edges of light output for various γ-rays sources, because there is no photopeak.

Converting from the light output to deposited energy requires an energy calibration curve and the non-proportionality of the light output should be considered. A more precise position of Compton-electron peak for liquid scintillator can be obtained using a Compton coincidence method between Compton scattered γ-rays and the recoil electrons in the scale of electron energy equivalent [1,2]. If the scattering angle is determined, the deposited electron-energy in liquid scintillator and the energy of scattered γ-ray can be determined by using Compton scattering formula.

We have used the Compton coincidence method to study the response of Compton electrons in liquid scintillator with Cs-137 and Eu-152 γ-ray sources.

2. Methods and Results

2.1 Experimental setup

Fig.1 shows the schematic of the experimental setup used in the present study. The Φ 2.0 in. × 2.0 in. EJ-301 liquid scintillator (ELJEN Technology) and the Φ 51.0 mm × 51.0 mm $CeBr_3$(Ce) detector (SCIONIX) as reference detector were aligned to face-to-face each other at a distance of 40 cm. Because of the reference detector, the fixed high-voltage was applied for the $CeBr_3$(Ce) detector set to be +720 V. And the high voltage was applied for EJ-301 detector set to be -1200 V or -1300 V. Two detectors were installed inside a copper box which have a thickness of 3.0 mm in a underground shield-chamber. The shield chamber consists, from inside out, 3.0 mm of copper, 200.0 mm of lead and 3.0 mm of copper.

The detector signals were directly reading by a digitizer CAEN DT5730S (500 MHz sampling-rate, 14-bits resolution). The data were accumulated on a digitizer and sent to a PC via USB for event-by-event recording. And the maximum digitized in a single pulse is 2 V. And a long integrated gate (250 ns) are used to determine the total light output or charge [4]. The energy calibration of the $CeBr_3$(Ce) detectors were done with Cs-137 and Eu-152 radioactive isotopes. The energy resolution at 661 keV is 5.23%, full width at half maximum (FWHM), at room temperature for $CeBr_3$(Ce) detector.

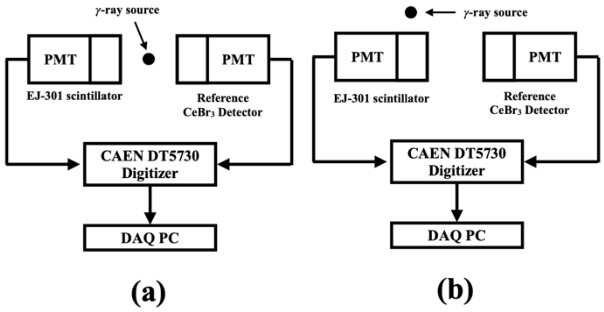

Fig.1. Schematic diagram of the experimental setup for Compton coincidence; (a) scattering angle $\theta = \pi$, (b) scattering angle $\theta = \pi/2$.

2.2 Calibration of liquid scintillator

In the present study, the Compton-coincidence method was used for precise calibration of light output from EJ-301 liquid scintillator. A scattered γ-rays from liquid scintillator were deposited in reference $CeBr_3$(Ce) detector at a scattering angle of 180° or 90° because of the face-to-face detector geometry and position of γ-ray source. The trigger time difference for Compton coincidence events in both detectors is within ±15 ns.

For evaluation of the Compton electron event in liquid scintillator, the Gaussian functions were fitted to coincidence spectrum of EJ-301 liquid scintillator with energy gate of signal selected between ±3σ around the corresponding scattered γ-rays in $CeBr_3$(Ce) detector. And Compton electron events were selected ±3σ around correlated peak of the integrated-charge channels in EJ-301 liquid scintillator. The ratio of selected Compton-electron and total events are 0.123 and 0.209 for scattering angle of 180° and 90°, respectively, with Cs-137 gamma-ray source and applied high-voltage -1300 V for EJ-301 liquid scintillator. Fig.2. shows the relationship between energy of Compton electron and centroid channels of integrated charge for EJ-301 liquid scintillator. The relation function between deposited electron-energy and centroid channels was obtained by linear fitting : f(E) = 0.932 x E – 6.226 and f(E) = 1.504

x E – 8.871 for applied high-voltage -1200 V and -1300 V, respectively. The slope of the function seems to be relation with the characteristics of scintillator photomultiplier-tube.

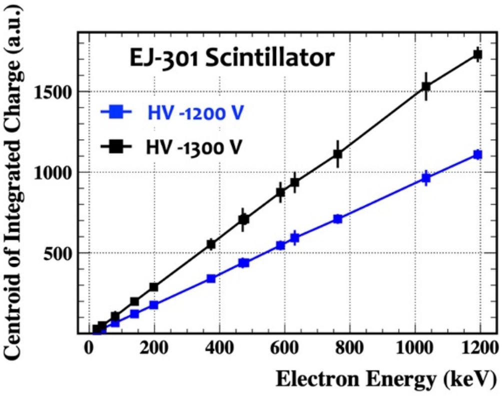

Fig.2. The relationship between the deposited electron energy and centroid channels of integrated-charge on EJ-301 liquid scintillator.

The centroid channel of integrated charge can be used to determine the energy resolution and calibration. The energy resolution at 477.57 keV which is Compton edge of 661 keV is about 12.27% (FWHM) at room temperature and applied high-voltage -1300 V for EJ-301 liquid scintillator.

2.3 Measurement of Electron response

According to the theoretical approach proposed by Birks, the light output from ionizing particles in the scintillator materials depends on its stopping power (*dE/dx*) [3]. The total light output is determined by equation (1) over the energy interval 0 to E:

$$L(E) = \int_0^E \frac{A}{1+kB\frac{dE}{dx}} \quad (1)$$

where E is the initial electron energy and A is the scintillation efficiency. The data of total stopping power for EJ-301 liquid scintillator were taken from ESTAR database [5].

The value of the Birks parameter was obtained fitting with the relative total light-output equation (2) and a scintillation efficiency are normalized with Compton edge of 661 keV.

$$L'(E) = \left(\frac{L(E)}{E}\right) \times \left(\frac{477.56\,keV}{L(477.56\,keV)}\right) \quad (2)$$

The scintillation efficiency A was assumed to be 1 and the experimental data were fitted with equation (2). The Birks parameter (*kB*) is estimated the 0.019 ± 0.001 g cm^{-2} MeV^{-1} from resulting of fitting with equation (2) and applied high-voltage -1300 V for EJ-301 liquid scintillator.

3. Conclusions

The presented work describes the measurement of Compton electron response in the ELJIN Φ 2.0 in. × 2.0 in. EJ-301 liquid scintillator by using the Compton coincidence method. The energy resolution at 477.57 keV which is Compton edge of 661 keV is 12.27% (FWHM) at room temperature and applied high-voltage -1300 V for EJ-301 liquid scintillator. The Birks' formula fitted to the measured electron-response data for EJ-301 scintillator with total stopping power from ESTAR database. The Birks parameter (*kB*) was determined as 0.019 ± 0.001 g cm^{-2} MeV^{-1} from fitting of relative total light-output equation.

Acknowledgments

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