PROCEEDINGS OF SCIENCE

Study of output spectrum and optimization of the composition of toluene-based liquid scintillator

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Liquid scintillator is widely used as a medium for the detection of charged particles for numerous applications in science, medicine, and in other areas. The composition of scintillator affects not only its performance, but also the overall cost. The scintillator light output spectrum also affects a choice of detectors that can be used in conjuncture with a particular scintillator formula. Optimization of this composition provides the ability to design particle detectors with a certain light yield and emission spectra of the detection medium, or to maximize the light yield while optimizing the expenses. This work presents the component optimization for the toluene-based liquid scintillator that uses PPO as a fluor and POPOP as a secondary shifter. The light yield vs concentration and the changes in the output spectra will be discussed. Plans for future work include the light attenuation measurements.

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1. Introduction

Scintillating materials can be inorganic and organic, both solid and liquid. Scintillators are widely used as a medium for the detection of charged particles passage for multiple applications in science, medicine, and other areas [1].

Liquid organic scintillators have both fast rise and decay times of the light emission, and sufficiently high light yield that is suited for detection of charged particles. It is similar to plastic scintillator in properties but is more cost effective per unit mass and is harder to handle due to high flammability. Wavelength shifter additives can increase the overall light detection by a specific photodetector by changing the scintillator output spectrum into the best detection region. New materials, such as novel water-based liquid scintillator material, aim to reduce the cost and provide better control over the light yield while reducing flammability [2]. In addition, scintillator composition affects the output light pulse width that is important for any timing measurements using scintillator-based detectors.

The composition of a scintillator affects not only its performance, but also the overall cost that includes the price of all the components. Optimization of this composition provides the ability to design particle detectors [3] with a certain light yield and emission spectra of the detection medium or maximize the light yield while optimizing the expenses [4]. Figure 1 (left) shows the liquid organic scintillator under UV light: the scintillating liquid is toluene (methylbenzene), with PPO (2,5-diphenyloxazole) as the primary wavelength shifter that is also called a fluor, and with POPOP (1,4-di-(5-phenyl-2-oxazolyl)-benzene) as a secondary shifter that is commonly just called a shifter. Figure 1 (right) shows the polyurethane-based solid organic scintillator with PPO and POPOP as a fluor and a shifter. This article presents the component optimization for the toluene-based liquid scintillator that uses PPO as a fluor and POPOP as a shifter.

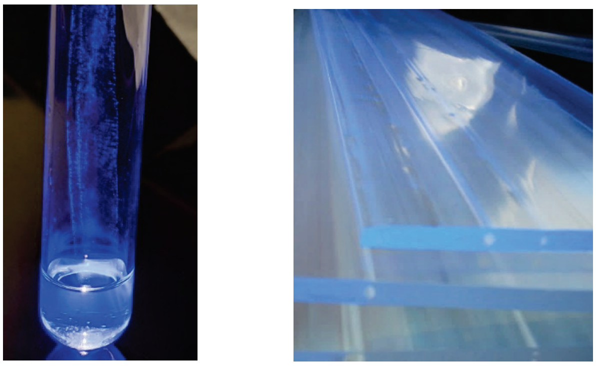


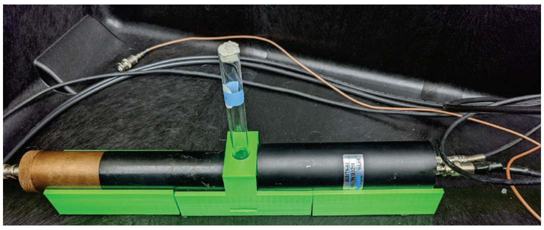
Figure 1: Organic liquid (left) and solid (right) scintillators excitation by UV light.

2. Experimental Setup

The experimental setup was built in the light-tight ‘dark’ box using the two Photo-multiplier tubes (PMT) in a setup shown in Figure 2 (left). The two PMTs used are a Hamamatsu R580 PMT and a MELTZ FEU-115 PMT. These PMTs are used because of their different sensitivity within the general ‘blue sensitivity’ range that is common to PMTs with a bi-alkali cathode.

The full view of the experimental setup is given in Figure 2 where the dark box, oscilloscope, and the CAEN 12-bit 500 MHz Analog-to-Digital Converter (ADC) are shown. An oscilloscope is used to preview and monitor the signals.

A holder for the back-to-back setup design [4] was 3D printed. This setup design features a coincidence trigger between the two PMTs within a 50 ns window that reduced any external noises



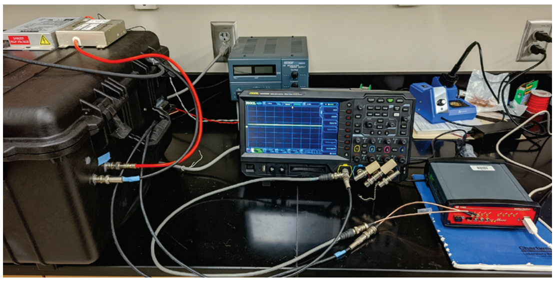


Figure 2: Experimental setup. Two PMTs are shown on the left, the dark box and ADC – on the right.

in the system and allows to obtain two data sets from different detectors. The small sample size and the quick data taking process with the ADC over only a few seconds reduce a contribution from cosmic rays to negligible amount (the cosmic rays' flux is ~ 1 muon per cm^2 per minute per steradian). To excite the scintillator, ^{90}Sr source is used.

3. Experimental Results

The toluene-based liquid scintillator was used with the PPO (fluor) and POPOP (shifter) dopants. The PMT response with different fluor and shifter concentrations was obtained to find optimal concentrations of the dopants. The total light output as seen by the R580 PMT (shown in Figure 3) as well as the PMT pulse width were measured. The FEU-115 is not shown as the shape for the total response for this PMT matches with the R580.

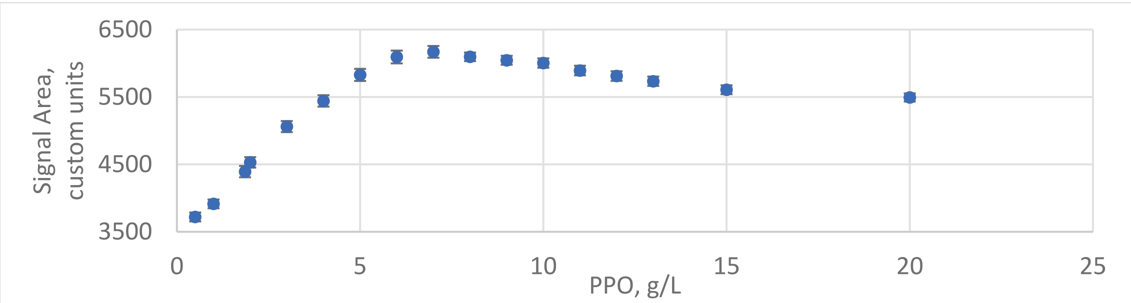


Figure 3: R580 PMT total response to scintillator light as pulse area for different PPO concentrations.

The PMT pulse width measurements are of special interest to anyone who needs fast time resolution between the detections of two consecutive particle and wants to optimize the scintillator composition for that specific parameter. Figure 4 only shows the data for R580 PMT since it has the fastest response of the two detectors used and shows the clear change in the pulse duration. The pulse duration is defined here as the time evaluated at 50% (half of the width) and 80% (full width) of the total area under the pulse, since a median is a statistically solid measure that is also applicable if the pulse shape is distorted by the long transmission line [3].

The addition of the POPOP shifter to 10 g/L PPO solution makes the total response of the R580PMT and FEU115 differ. The pulse width is changing < 0.1 ns and is not shown.

From Figure 5, the R580 response is reducing with POPOP concentration, but the response for FEU115 has a peak (Figure 6). FEU-115 is not UV sensitive so we see the increase in the overall response up to a certain concentration of the shifter. The R580 PMT is partially UV sensitive, so addition of secondary shifter reduces overall light due to conversion efficiency.

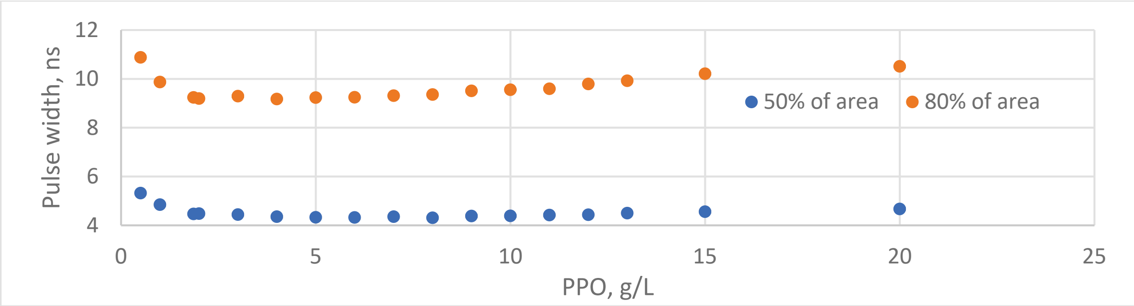


Figure 4: R580 PMT pulse width at 50% and 80% of the total area at different PPO concentrations.

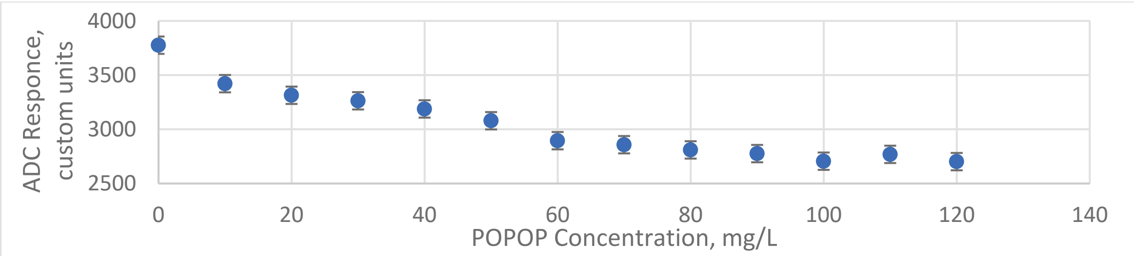


Figure 5: R580 PMT response vs POPOP concentration.

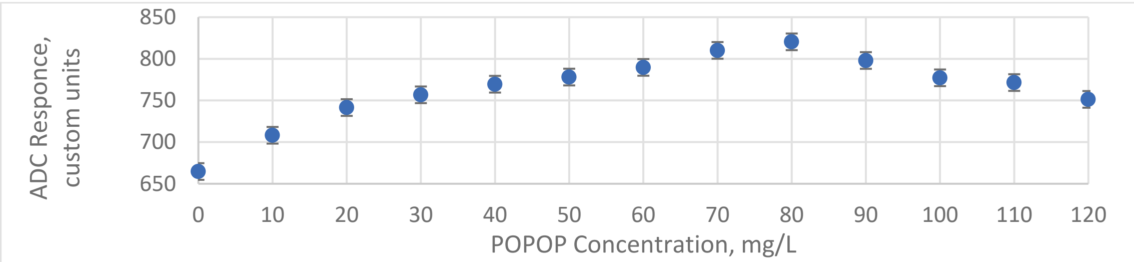


Figure 6: FEU-115 PMT response vs POPOP concentration.

4.Future plans

To further investigate this response difference between the PMTs, we plan to study the changes in the output spectra vs PPO and POPOP concentrations using spectrophotometer and fluorometer. Plans also including measuring the attenuation length of scintillation light in the long tube for different dopant concentrations.

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