Calibration of EJ-301, a Liquid Scintillator

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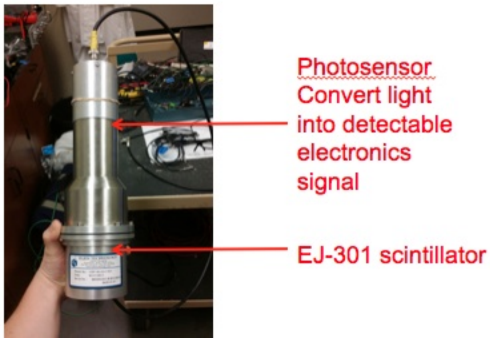
Abstract: A calibrated scintillator is helpful in many nuclear physics experiments. It can be used to identify the source of an unknown gamma ray through the analysis of its energy or to determine the amount of neutrons produced in an experiment through pulse shape characterization. We have done an energy calibration on the liquid scintillator EJ 301 by testing the Compton edge of known gamma ray sources and a pulse shape characterization with an Am/Be source. Once the response of the scintillator was carefully analyzed, we use it to discriminate between neutrons and gamma rays in an experiment at Crocker Lab.

1 Introduction

EJ 301 is a liquid organic scintillator. The wide spread use of scintillators in experimental physics began in the mid nineteen hundreds and continues to be used today due to the many advantages they have over other types of equipment. There are several different types including organic and inorganic scintillators that can be plastic, liquid or gaseous. The type of scintillator used in an experiment is chosen based on qualities such as high density, fast operation speed, or cost. The use of liquid scintillators is advantageous because they are small, portable, and require no use of cryogens to operate. EJ 301 couples a scintillator with a photomultiplier tube shown in figure 1. A scintillator is a material that emits light when excited by ionizing radiation, and the photomultiplier tube is a device that absorbs light and reemits it in the form of an electron. When these two devices work together, an electrical pulse is generated that can be used to determine the energy of the ionizing radiation that enters the detector. The response of the liquid scintillator will vary depending on the type of radiation that enters the detector and the energy of such radiation. The integrated amplitude of the peak produced by the scintillating process depends linearly on the energy deposited by the radiation. However, the shape of the peak depends on the type of radiation. For example, gamma rays produce more fluorescent energy than neutrons resulting in larger detector output amplitudes for gamma rays than neutrons [1]. The reason is that gamma rays deposit energy in the detector through Compton scattering interactions with electrons in the detector while neutrons deposit energy primarily through elastic scattering with the nuclei of hydrogen atoms in the detector. [1] Gamma rays, therefore, deposit energy in the detector through electrons while neutrons deposit energy through protons. Due to the difference between protons and electrons, the protons will deposit energy more densely than electrons causing a difference in the output signal. It is this difference that allows us to characterize the pulse shapes of both neutrons and gammas. [2]



Photosensor
Convert light
into detectable
electronics
signal

EJ-301 scintillator

Figure 1: A diagram of EJ-301.

2 Experiment

2.1 Energy Calibration

The energy calibration of EJ 301 is done using standard gamma ray sources Na-22 and Cs-137. While there are a few different techniques to find the correlation between the measured pulse area and energies, we choose to use relate the peak area with the Compton edge of the gamma sources. The Compton effect will dominate in the detector because EJ 301 is comprised of low Z elements and the energies are less than that required for pair production. If the EJ 301 were made of higher Z elements, we would expect to see photoelectric effects and would need to account for those in our calculations.[3] The diagram below displays the three effects as a function of both energy and Z of the absorber.

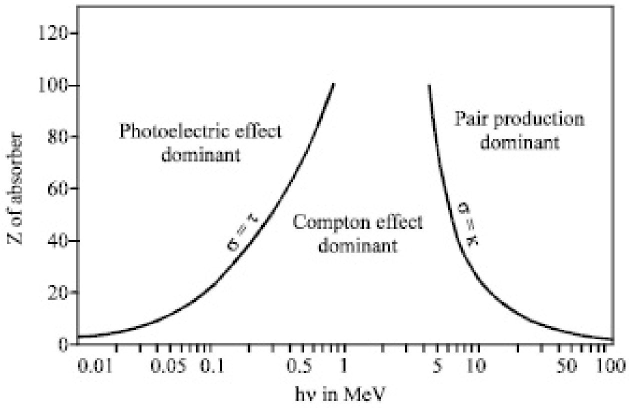


Figure 2: The diagram shows the ranges of energies for the Photoelectric Effect, Compton Scattering, and Pair Production.

Knowing the dominant effects that will be seen from the gamma ray sources and knowing that the response of an organic liquid scintillator is linear for electrons allows us to do an energy calibration. The energy of the incoming gamma is related to the pulse area by some factor that we will find through analysis. [4]

The gamma ray source is placed near the scintillator and data is collected for several seconds as shown in figure 3. The output on the scope for several gamma rays is displayed in figure 4.

Figure 3: Experimental setup for the energy calibration of EJ-301.

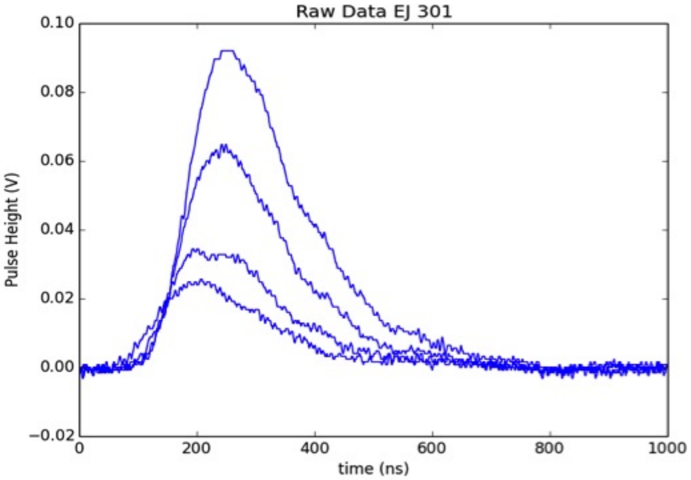


Figure 4: Sample gamma ray pulses from the Na-22 source.

Each pulse area is counted and put into a histogram for both the Na and Cs source. This graph is what we use for our energy calibration. Both Na and Cs have known gamma ray energies. We do not see gamma rays directly with EJ 301 for reasons stated above; however, we do see the Compton continuum for each gamma. When the gamma ray enters the detector and escapes, only some fraction of its energy is registered by the detector. The amount of energy deposited in the detector depends on the scattering angle of the photon which leads to a spectrum of energies that correspond to each scattering angle. The maximum scattering angle is a complete backscatter of 180 degrees and is given by equation 1. [3]

$$E_c = \frac{2E_\gamma}{m_e c^2 + 2E_\gamma} \tag{1}$$

Each gamma ray source has a particular gamma ray energy and therefore a particular maximum backscatter energy. The maximum backscatter energy is called the Compton edge. Theoretical calculations for the Compton edge of the gamma rays for Na and Cs are shown in table 1.

Table 1:

source	$E_\gamma (MeV)$	$E_c (MeV)$
Na-22	0.511	0.341
Na-22	1.27	1.06
Cs-137	0.662	0.477

These theoretical calculations are used to relate the experimentally determined Compton edge to the pulse areas created by the gamma rays. Because the detector efficiency is not perfect, we use the fifty percent mark of the maximum shown in figure 5 to find the area that corresponds to the known Compton edge energy.

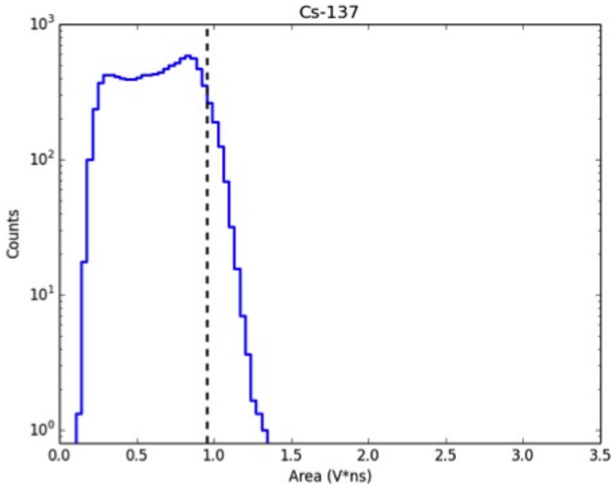


Figure 5: The Compton continuum from the 0.662 MeV Cs-137 gamma ray. Note, this is a log plot.

This is done for the 3 gamma rays and the area is plotted as a function of the known energy in figure 6. A line of best fit is calculated because the response of EJ is approximately linear. The slope of the line gives the energy calibration for the detector.

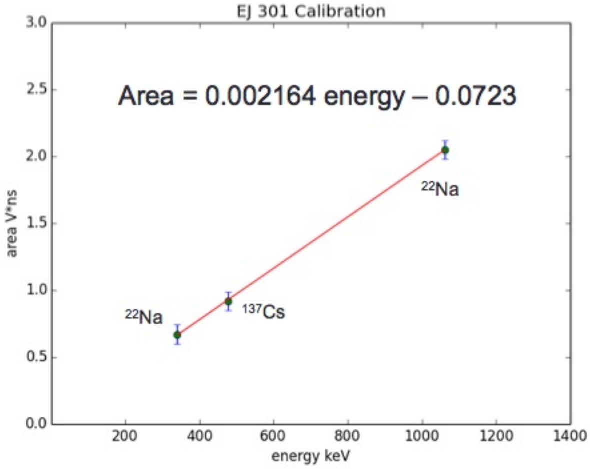


Figure 6: The calibration curve for EJ-301. The three points correspond to the three gamma rays used in the experiments.

2.2 Pulse Shape Characterization

The pulse shape characterization of EJ 301 is done using an AmBe source. Pulses of neutrons and gammas will differ in their tail area as shown below where tail area is the integral of the pulse starting at the maximum or some other predefined point.

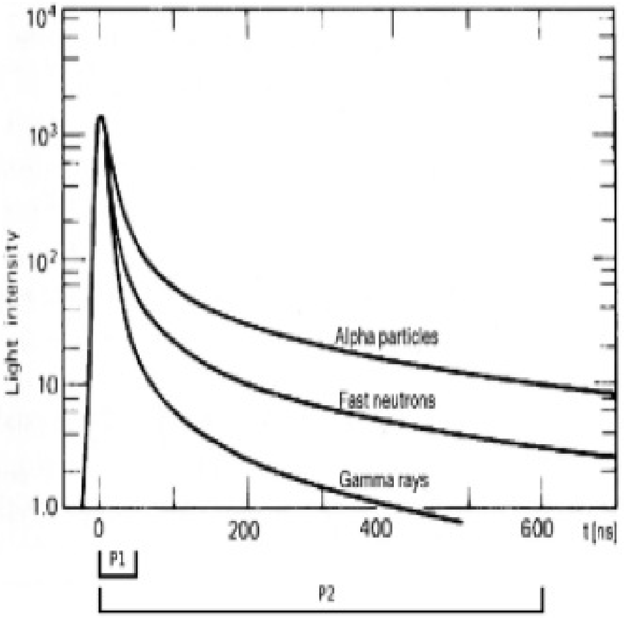


Figure 7: The response of EJ-301 to different particles and electromagnetic radiation.

AmBe sources emit both neutrons and gammas by equation 2, which makes them excellent for pulse shape characterization because we can compare the pulse shapes of the emitted signals to that of the purely gamma ray sources we used in the energy calibration experiments.

$$^{4}_{2}\alpha + ^{9}_{4}\mathbf{Be} \rightarrow ^{12}_{6}\mathbf{C} + ^{1}_{0}\mathbf{n} + \gamma \tag{2}$$

The pulse shapes of a purely gamma ray source are found by counting the area of the tail of the pulse and plotting it as a function of the tail area/the total area of the pulse shown in figure 8.

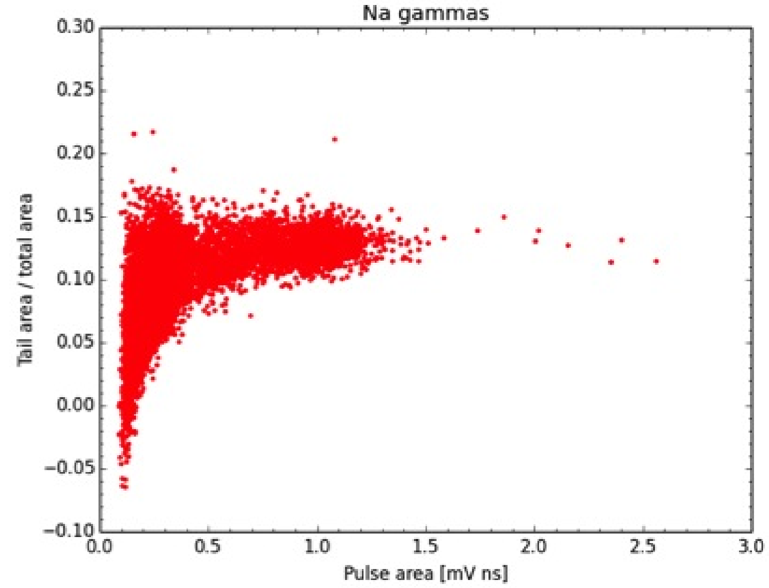


Figure 8: Na-22 gammas.

Next, the same plot is generated for the spectrum created by the AmBe source. The plot shows two distinct populated areas. Neutrons have a wider tail, so there tail/total area is greater than that of gamma rays. [5]

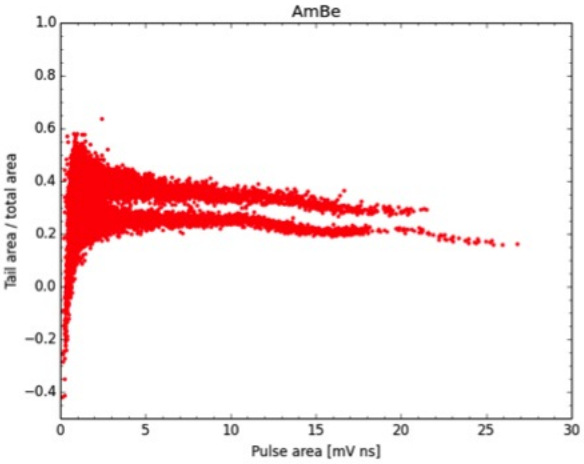


Figure 9: Neutrons and gamma ray from the Am/Be source.

After doing this pulse shape discrimination with the AmBe source, EJ is placed in an experiment at Crocker lab that produces both neutrons and gammas. The goal is to determine the amount of neutrons and gamma rays produced by the cyclotron. When we plot the tail/total area of the pulses for a few different cyclotron energies; however, we do not see the clear distinction that we did for the AmBe source. Plotted below are cyclotron energies 12.5, 14.6, 25, and 55 MeV. The saturated pulses are tagged in blue and are the pulses too large to be fully detected by the settings on the ossiliscope. The smaller energies have more distinction for the neutrons and gamma rays, but as we increased the energy of the Cyclotron, the distinction becomes less clear. More analysis is needed to determine the mark at which to consider the tail of the pulses and to further understand the pulse shape discrimination of EJ 301.

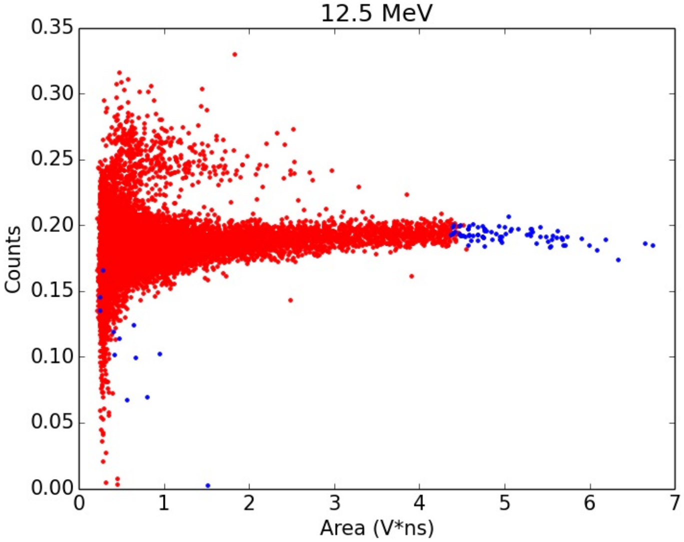


Figure 10: 12.5 MeV Cyclotron Energy.

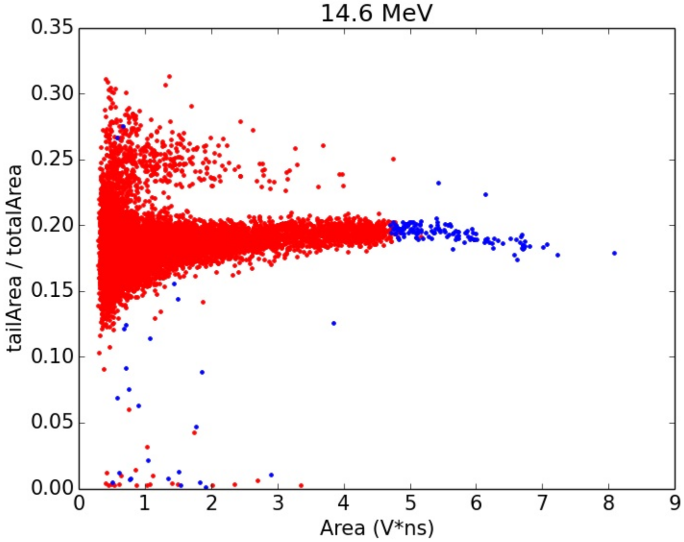


Figure 11: 14.5 Cyclotron Energy

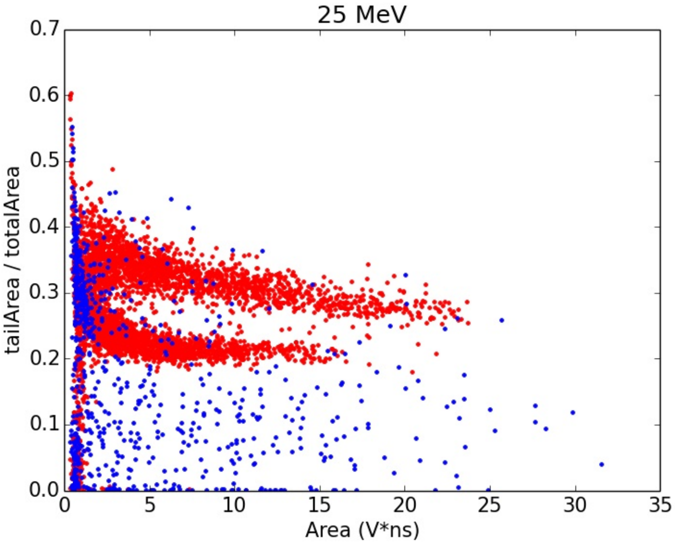


Figure 12: 25MeV Cyclotron Energy.

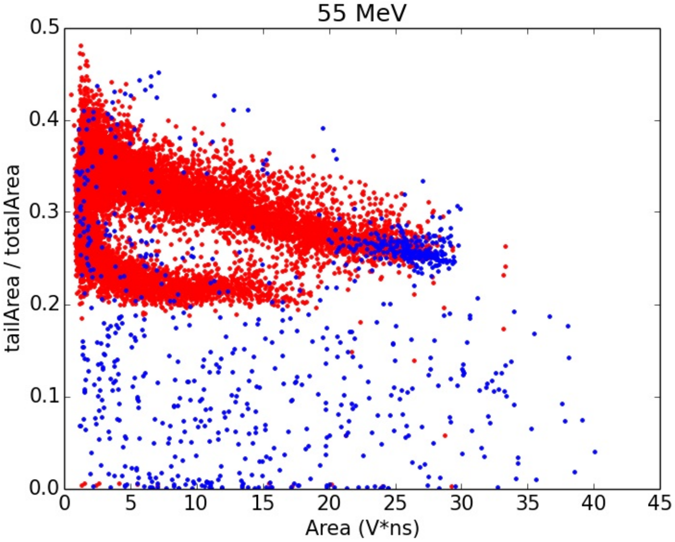


Figure 13: 55 MeV Cyclotron Energy.

3 Conclusion

The Compton edge of standard gamma ray sources Na-22 and Cs-137 are analyzed in order to do an energy calibration of the liquid scintillator EJ-301. We also employ pulse shape characterization techniques to understand the response of EJ-301 to different types of ionizing radiation. More analysis is needed to fully characterize the scintillator's response to incoming neutrons and gamma rays.

References

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