Lab2: Nuclear Electronics

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1 Statement of Purpose

The purpose of this lab is to apply some the skills and understanding acquired in Lab 1 to explore the basic properties of scintillation counters, detect two back-to-back gamma rays emitted by a Na-22 source by setting up discriminator pulses to establish a coincidence between two scintillator detectors. In doing so, we require an understanding of a few important physics concepts, including the photoelectric effect as well as gamma ray emission from the decay of Na-22 to Ne-22. We are further able to analyze some results and observe the interaction of a positron with an electron through the detection of coincidence signals.

2 Theory

2.1 Scintillators

A scintillator is a material that exhibits scintillation, the property of luminescence, when undergoing an interaction with ionizing radiation. We used such a material coupled with a photomultiplier tube (PMT) to create a scintillation counter. The PMTs absorb the light emitted by scintillator and produce electrons via the photoelectric effect:

$$K_{max} = hf - \phi \tag{1}$$

where K_{max} is the maximum kinetic energy of an ejected electron, h is the Planck constant, f is the frequency of the incident photon, and ϕ is the work function, the minimum required energy to eject an electron. ϕ can be determined by solving for $K_{max} = 0$, giving:

$$\phi = hf_0. \tag{2}$$

where f_0 is a threshold frequency for the photoelectric effect to occur. We can then make the above substitution, giving:

$$K_{max} = h(f - f_0). \tag{3}$$

Since kinetic energy is always positive, we can there require the condition that $f > f_0$ in order for the photoelectric effect to occur.

2.2 Beta Decay

The radioactive isotope used in this lab is Na-22, which decays to Ne-22 through the below process.

$$^{22}_{11}Na \rightarrow^{22}_{10} Ne^* + e^+ + \nu_e \tag{4}$$

$$^{22}_{10}Ne^* \rightarrow^{22}_{10} Ne + \gamma \tag{5}$$

$$e^- + e^+ \rightarrow \gamma + \gamma \tag{6}$$

The above process is an example of β^+ decay. In this specific process, the $^{22}_{11}Na$ isotope decays to an excited state of Ne, $^{22}_{10}Ne^*$, emitting a positron, e^+ and an electron neutrino ν_e. The excited Ne then emits a photon, changing to a stable state and emitting a photon γ in the process. Finally, we see a positron-electron annihilation, resulting in coincidence emission of two more photons of equal energy. This process emits photons of two different energies of $1.275 MeV$ and $0.511 MeV$ from the initial β^+ decay and the subsequent electron-positron annihilation, respectively. Both of these photons can be detected from the theory mentioned prior in §2.1.

3 Apparatus

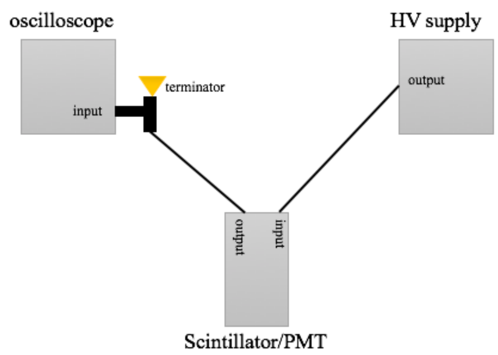

Figure 1: Apparatus sketch used to display signal noise from PMT.

This apparatus configuration was used to determine the magnitude of dark noise inherently in the PMT, as well asl to determine the presence of light leakage after constructing the scintillator counter.

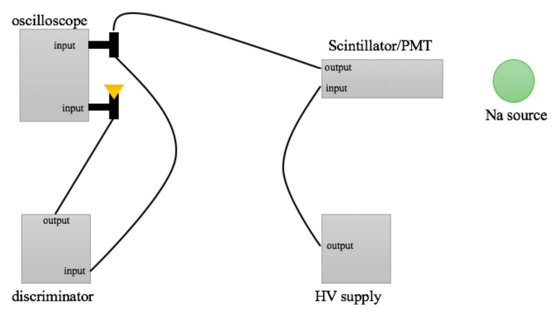

Figure 2: Apparatus sketch used to display signal from PMT with the source.

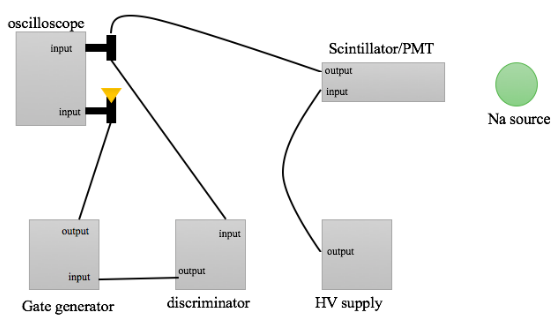

Figure 3: Apparatus sketch used to display signal from PMT with the source, discriminator, and gate generator.

Figure 2 above displays the apparatus used to create a signal from the discriminator based on the input signal from the photomultiplier tube (PMT). Unfortunately, this was the only sketch made for the different combinations of units for each apparatus. However, they were all very similar. The most complicated combination differed only in the inclusion of a logic unit, in order to detect coincident signals.

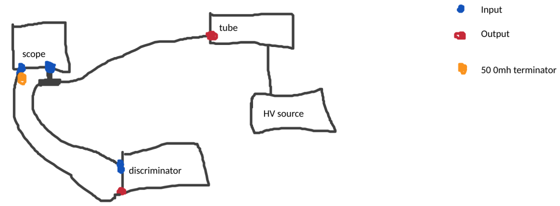

Figure 4: Apparatus sketch for discriminator signal

4 Procedures

The lab began with the construction of the scintillator counter. This was constructed using a scintillator attached to a photomultiplier tube, using black paper and electrical tape to guard against any external light leakage entering the scintillator. The scintillator was first covered in black construction paper, which was made flush with the ”cookie.” Then the electrical tape was wrapped around the entire outer surface of the scintillator, excluding the ”cookie,” in order to secure the construction paper to the surface, as well as prevent any further light leakage. With both the construction paper and electrical tape flush with the edge of the ”cookie”, we applied a small dab of optical grease to the ”cookie” to act as a transition medium between the scintillator and photomultipleir tube. Once attached, another layer of electrical tape was added to secure the connection between the scintillator and PMT.

Figure 5: Finished scintillator counter.

In order to confirm there was no light leakage, we covered the scintillator counter with a black cloth, and while looking at the signal on the oscilloscope, removed the cloth to see if there was any change in signal. There was not, so we concluded there was no light leakage. Below (Figure 6) shows the signal used to determine if there was any leakage, as well as the inherent noise from the PMT. At this point, we vary the high voltage power supply to the PMT and observe its effects on the signal. (Table 2)

Next, we added the discriminator to the circuit, giving us the apparatus shown in figure 1. We then attempted to reduce the noise in our signal by lowering the threshold on the discriminator. However, the minimum threshold on our discriminator was 300mV, while the amplitude of the inherent noise in the PMT was about 3mV, so noise could not entirely be eliminated. Yet, since the noise was so low, it was not of major concern.

With this setup, we were finally able to introduce a radioactive source, the Na-22 isotope. The distance between source and detector was varied to show how a smaller distance coincided with a increase in signal brightness on the oscilloscope.

The next step was to introduce the gate generator to create an output signal based on the input from the discriminator, shown in figure 5.

The gate generator was necessary in order for the computer to process the short, fast, negative NIM pulses generated by the source. Instead, the gate generator is used to convert these pulses into a longer, positive pulse, able to be counted by the data acquisition side. Data was then taken for 1s and 10s interval times.

Finally, we modified the apparatus to be able to detect coincident pulses. We added in the second scintillator counter (NaI) by connecting it to the second input channel on the discriminator, and then to the second input on a logic unit, with the original discriminator output placed into the first input of the logic unit. The coincidence level was set to level 2 to create an AND gate, essentially only creating an output signal if both scintillator counters produce a signal simultaneously. The output signal from this logic unit was then fed into the NIM-counter, which provided a LED readout of the number of counts generated by the logic unit. Using this readout, we were able to observe the differences in count depending on the kind of logic gate used (AND vs OR).

Unfortunately, we were running very late and were only able to set up the equipment to view coincident pulses within the last 15 minutes of lab, and unable to actually collect data from coincident pulses. We were also therefore unable to follow the procedures to create a delay curve.

5 Data

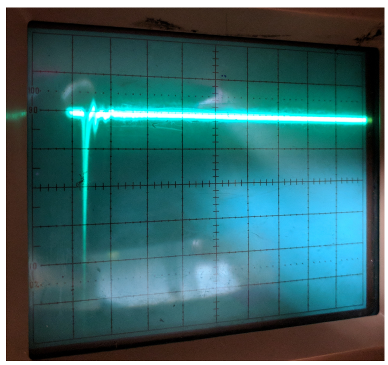

Figure 6: The noise from the PMT, used to determine presence of light leakage(none), with x-axis scaled to 100ns/div, and y-axis scaled to 2mV/div

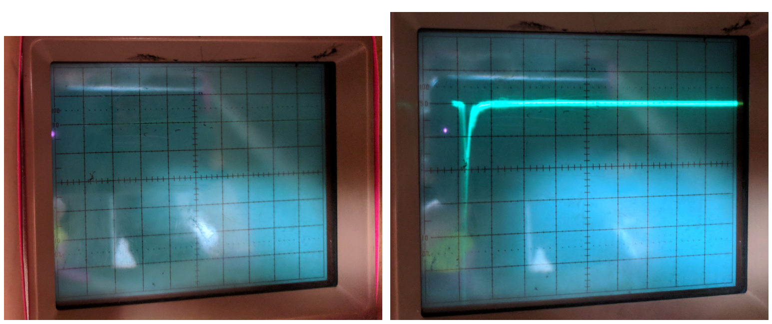

Figure 7: Left: No signal with the Na-22. Right: Signal with the Na-22 in detector range.

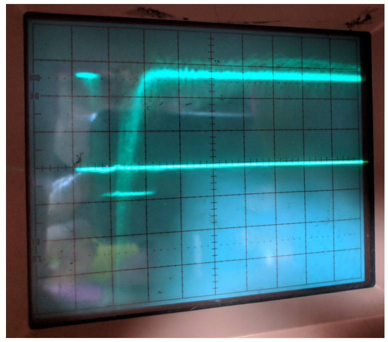

Figure 8: Signal shown from Na-22 source, as well as the output of the discriminator that fed into the gate generator.

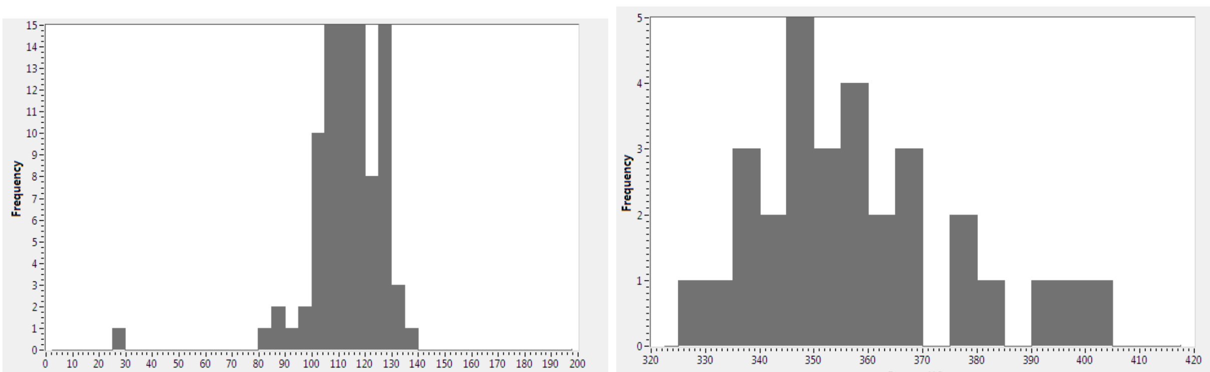

Figure 9: Left: Count Histogram for 1 second intervals. Right: Count Histogram for 10 second intervals

The data above is taken using two separate variations on the same condition, interval size. The scintillator counters fed a signal into the computer, which then divided the constant stream of signals into 1 or 10 second intervals. This is what is shown in both the histograms above.

6 Analysis

Table 1: Statistics for the above histograms.

Interval(s)	Mean	Variance	Standard Deviation	Bins	Counts
1s	113.78	116.78	10.806	40	10039
10s	357.43	352.17	18.766	20	10914

Table 1: Statistics for the above histograms.

Voltage(V)	Amplitude(mV)	Uncertainty
700	22.5	0.2
800	7.5	0.5
900	7.5	0.5

The above histograms (Figure 6) look approximately Gaussian. However, after further inspection by looking at the mean and variance of each distribution, we can conclude that they are in fact Poisson distributions, as expected. This is because for large N, where N is the number of events, a Poisson distribution begins to look Gaussian. Since the above distributions shown N $\sim$ 10,000, we can conclude that N is in fact large, confirming that they are Poisson distributions.

We can further confirm the above distributions are Poisson distributions by comparing the variance and the mean. For a Poisson distribution the mean $\approx$ variance, which is in fact true, displayed in Table 1.

Finally, with increasing N, we can expect the standard deviation, and hence the variance to decrease, since the standard deviation is proportional to the square root of N: $\sigma \propto \frac{1}{\sqrt{N}}$

- calculation examples
- graphs, fits
- uncertainty
- explain how determined statistical and systematic uncertainties
- all data analyzed, and correct
- calculations performed
- computer code
- formulas written and variables obvious

7 Results

Our results from this lab can be viewed in Figure 6 and Table 1, which display both the distributions and statistics for 1s and 10s time intervals. These two distributions were the only sets of data collected during the lab, since we were unable to complete all the procedures for this lab.

Also, since we were unable to complete the lab, specifically unable to complete the delay curve section, there were no calculations to be made. Therefore, there were provided parameters to confine the number of significant figures to use in the above table, allowing us choose a limit of five significant figures to impose.

For the data that we were able to collect, we can attribute our uncertainty to the number of counts received, and therefore the length of time in which the counting software was counting. If we had run the software for longer to receive higher counts, our uncertainty would decrease. For the data provided and their respective uncertainties, this is the dominant source of uncertainty.

- precision in sig figs
- results are correct and complete
- sig figs, and uncertainty

8 Discussion

Since we were unable to collect data for the coincident pulses section of the lab, we cannot provide an in-depth analysis of results. However, we can still predict the kinds of results we would expect. For instance, this section made use of a logic gate to determine if signals from two separate scintillator counters were coincident. We could therefore change the settings on the logic unit to compare statistics when counter every received pulse (using an OR gate) with those of coincident pulses (using an AND gate). The only prediction we are able to make is that the counts when using an AND gate will be significantly lower than those of the OR gate.

- why results disagree or agree with theory (within uncertainty)
- results assessed
- correct discussion (physical reasoning)
- when possible, results compared to literature
- results compared and interpreted
- trends/patterns are noted and interpreted
- dominant source of uncertainty addressed

9 References

- citations ot journals or books