The Geiger Counter
A Measurement of the Dead Time of a Geiger Counter Using Carbon-14 Decay and the Determination of the Half-Life of Indium-116

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Abstract

In this experiment, the half life of a radioactive source of Indium-116 was measured to be 48.97 minutes. The dead time of the Geiger Counter was also measured under different circumstances. Under normal detection conditions, it was measured to be 205 microseconds. With low gain, it was 160 microseconds, and with low bias and low gain it was 560 microseconds. Despite the experimental results, it seems clear the gain has no effect on the dead time of the Geiger Counter.

1 Introduction and Theory

The Geiger Counter is an instrument which can be used to detect various types of ionising radiation such as alpha, beta, and gamma radiation. It consists of a Geiger-Müller Tube and various electronics for counting instances of radiation. A window is used to filter out different types of radiation. For example, mica is used when detecting alpha, low energy beta, or low energy gamma radiation. As a high energy particle enters the tube, it ionises an atom of Argon. This then causes more atoms to be ionised which causes an "avalanche" effect. These free electrons allow a voltage to pass between the anode and the cathode, which is measured as one count by the Counter.
A limitation of the GM Tube is that for count rates above about 10^4 counts per second, the effects of "dead time" start to become noticable. The dead time refers to the period of time after an avalanche occurs where the Geiger Counter cannot detect another count. This happens because a small amount of time is required for the detector to return to a non-conducting state. During the dead time, when the current can flow, the detector cannot differentiate between multiple simultaneous avalanches.

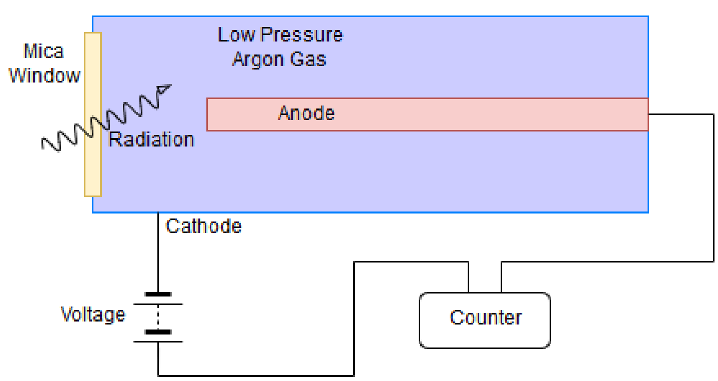

Figure 1: A Geiger Counter

In this experiment, Indium-116 and Carbon-14 are used. ^{116}In and ^{14}C both undergo β^- decay, whereby a neutron in the nucleus decays into a proton, an electron, and an antineutrino. The proton is captured by the nucleus, so the daughter isotope of ^{116}In is ^{116}Sn and the daughter isotope of ^{14}C is ^{14}N.

A sample of radioactive material decays at a rate proportional to the amount of material present. That is,

$$N(t) = N_0 e^{-kt} \tag{1}$$

where $N(t)$ is the amount of material at time t, N_0 is the initial amount of substance, and k is a decay constant for the material. The half life, $T_{\frac{1}{2}}$, refers to the time it takes for half of the current sample to decay. This can be derived as follows:
We know that $N(t) = N_0 e^{-kt}$ and that at time $t = T_{\frac{1}{2}}$, $N(T_{\frac{1}{2}}) = \frac{N_0}{2}$. So,

$$\frac{N_0}{2} = N_0 e^{-kT_{\frac{1}{2}}} \tag{2}$$

$$\frac{1}{2} = e^{-kT_{\frac{1}{2}}} \tag{3}$$

$$2 = e^{kT_{\frac{1}{2}}} \tag{4}$$

$$\ln(2) = kT_{\frac{1}{2}} \tag{5}$$

$$T_{\frac{1}{2}} = \frac{\ln(2)}{k} \tag{6}$$

Thus, we can see that the half life is proportional to the decay constant of the material. We can also see that the decay constant can be measured directly from the exponential decay of the substance.

2 Experimental Method and Results

The first part of the experiment involves measuring the half life of radioactive ^{116}In. This is done using a Geiger Counter, with the operating voltage at 0.6kV and the gain set at 30.
Firstly, the background count rate was measured. The number of background counts over 300s was found to be 244, corresponding to a background count rate of 0.8 counts per second. This offset was accounted for in subsequent measurements of the count rate of ^{116}In.
The number of counts from the Indium sample was measured for 60 seconds every 4 minutes. That is, a measurement began on every 5 minute mark. The measurements were taken over the course of an hour. A representative sample of the results is shown in Table 1. Graphs of Count Rate vs. Time are given in Fig. 2 and Fig. 3.

Table 1: Time since the first count began, Counts, and Count Rate (with background rate offset) from ^{116}In over 60s intervals.

Time (s)	Counts	Count Rate (s^{-1})
0	4310	71.033
300	3921	64.550
900	3403	55.917
2100	2472	40.400
4500	1494	24.100

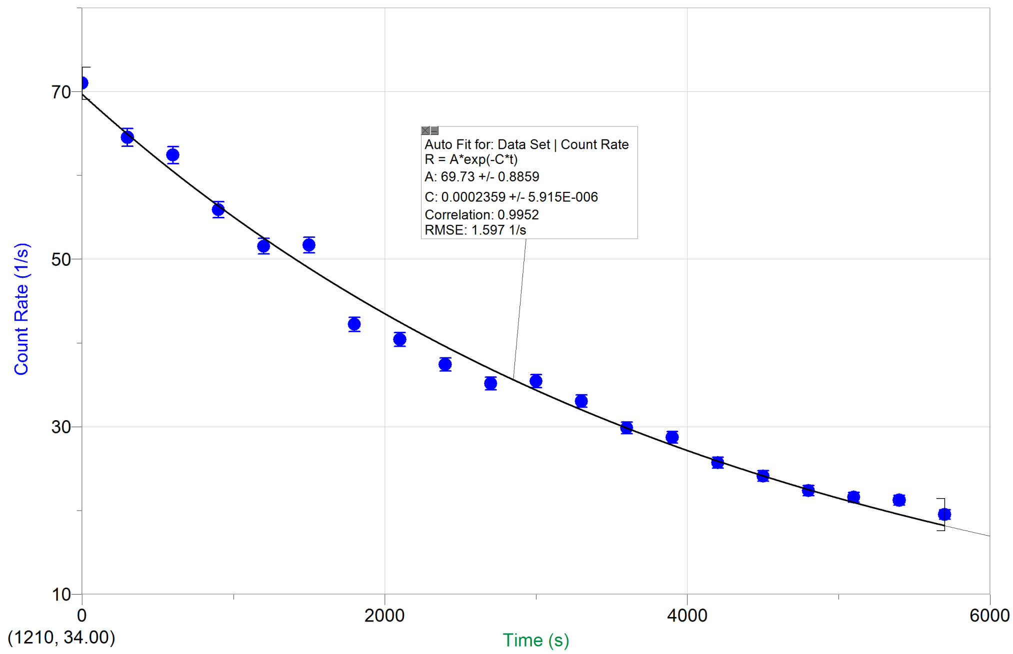

Figure 2: A plot of the Count Rate vs. Time of the Indium-116 source. The decay is exponential, as shown in the theory, and the exponential curve fit yields a decay constant value of $2.359 \times 10^{-4} \pm 5.91 \times 10^{-6}$, corresponding to a half life of 48.97 ± 1.22 minutes, using equation (6).

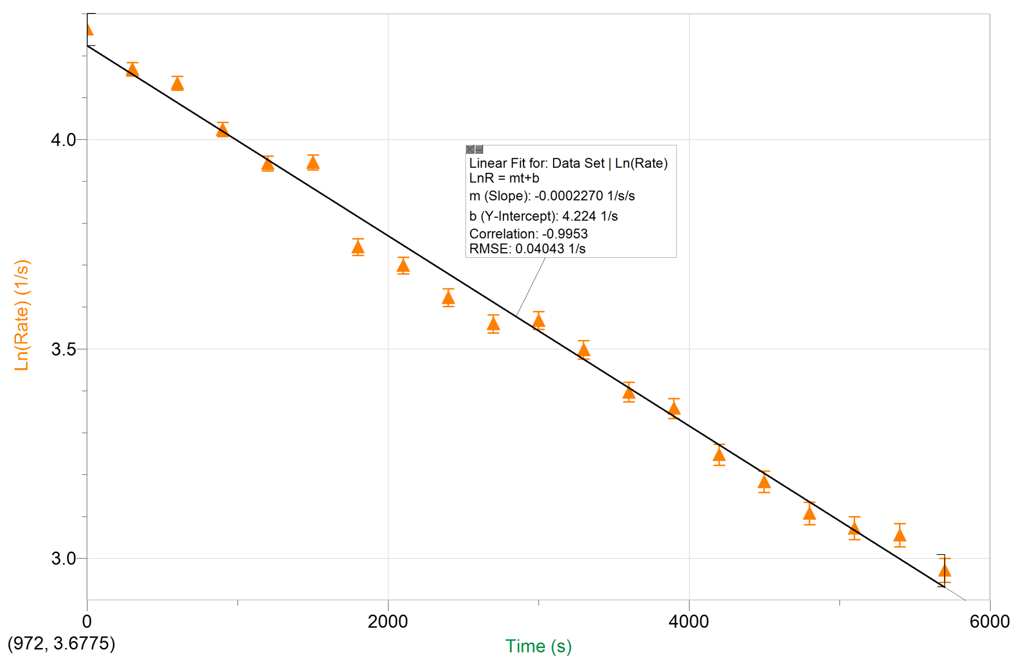

Figure 3: The graph of the natural log of the Count Rate vs. Time proves the exponential relationship between the two variables. We can also directly measure the decay constant from the slope of the graph.

The next part of the experiment involves measuring the dead time of a Geiger Counter. This is accomplished in two ways; observing the recovery envelope on an oscilloscope and by the two-source method. The recovery envelope gave a rough estimate of the real value, on the order of 100 microseconds, as seen in Fig. 4.

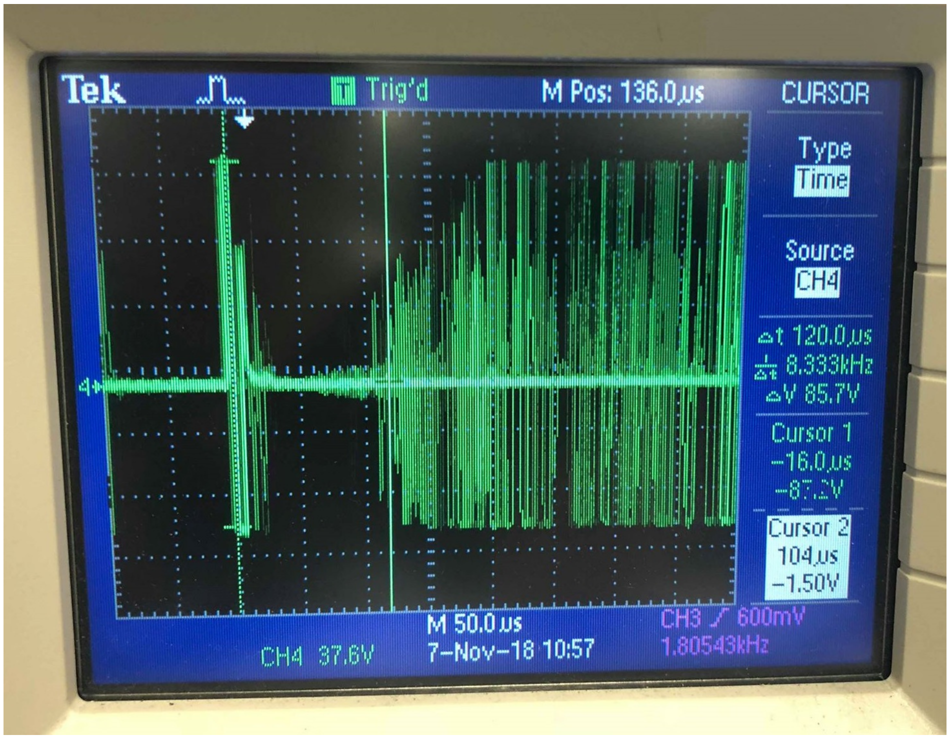

Figure 4: The recovery envelope of the Geiger Counter with a source of Carbon-14. The interval between the first detection and the second detection is approximately 120μs.

The two source method is more accurate. This involved measuring the count rates, m_1 and m_2 of each of two sources 1 and 2 of ^{14}C and of the two sources combined, m. The true counts are not measurable due to the dead time of the detector. The dead time can be found from

$$\tau^2 - \frac{2}{m}\tau + \frac{m_1 + m_2 - m}{m m_1 m_2}$$

The solutions are solutions for the quadratic in τ. The smaller value is taken.

$$\tau = \frac{1}{m} \pm \sqrt{\frac{1}{m^2} - \frac{m_1 + m_2 - m}{m m_1 m_2}}$$

Several tests were run, one with bias at 0.6kV and gain at 30, one with bias at 0.6kV and gain at 10, and one with bias at 0.36kV and gain at 10. The count rates m_1, m_2, and m and the corresponding value for τ were measured twice each. The results are in Tables 2, 3, and 4.

Table 2: Bias: 0.6kV, Gain: 30

m_1	m_2	m	τ	$\Delta\tau$
1102	1244	1890	207μs	4μs
1023	1173	1800	202μs	4μs

Table 3: Bias: 0.6kV, Gain: 10

m_1	m_2	m	τ	$\Delta\tau$s
909	1018	1662	166μs	5μs
902	1019	1668	159μs	5μs

Table 4: Bias: 0.36kV, Gain: 10

m_1	m_2	m	τ	$\Delta\tau$
724	807	1092	528μs	12μs
757	831	1082	591μs	8μs

We can see from the tables that with a normal setup, the average dead time was measured to be approximately 205μs, for reduced gain 163μs, and for reduced gain and bias 560μs. The gain and bias readings both deviate from the reading at normal detector settings.

3 Error Analysis

The error in the count, ΔN is given by $\Delta N = \sqrt{N}$

The error in the rate, ΔR is given by $\Delta R = R\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta N}{N}\right)^2} = R\sqrt{\frac{1}{t^2} + \frac{1}{N}}$ $(\Delta t \approx 1s)$

The error in the natural log of the rate, used for Fig. 3 is $\Delta \ln(R) = \frac{\Delta R}{R}$

4 Conclusions and Closing Remarks

The half life of Indium-116 was measured and found to be 48.97 ± 1.22 minutes.
The experiment was, overall, successful, with some minor comments. The reduction in gain on the amplifier should not affect the dead time, yet reduced gain seems to result in a reduction on the dead time of about 40μs. This change is, however, far smaller than the change due to reduction in bias, which gives an average dead time of 560μs. There is, very likely, also some dead time as a result of the counting system itself, which becomes more evident as the bias is changed. This increase in count dead time is due to the lower voltage across the GM Tube, so it takes longer to recover back to an equilibrium state.