The Geiger Counter

Andrew Mark Allen - 05370299

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Abstract

In this experiment, a Geiger counter, an amplifier and bias unit, and a counting unit were used to measure the half-life of a sample of radioactive Indium, and two C^{14} samples were used to measure the dead-time of the Geiger Counter. We found the half-life of the Indium sample to be 925 ± 5 seconds, and the dead time of the Geiger counter to be $5.4 \pm 0.2 \times 10^{-5}$ seconds.

Aims

- To determine the half-life of an irradiated sample of indium.
- To determine the dead-time of the Geiger counter.

Introduction and Theory

Radioactive Decay

The spontaneous decay of radioactive atoms is given by the equation

$$\frac{dN}{dt} = \lambda N$$

where N is the number of undecayed nuclei and λ is a constant parameter called the decay constant. Solving this equation for N gives us

$$N(t) = N_0 e^{-\lambda t}$$

where N_0 is the number of nuclei present at time $t = 0$. This describes an exponential decay, and since the rate $R \propto N(t)$,

$$\log R \propto -\lambda$$

The half life of a radioactive sample, that is, the time for which it takes a radioactive sample to decay to the point where only half as many of the original radioactive atoms are present, is given by the formula

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

The Geiger Counter

A Geiger counter is a device that measures ionising radiation. It consists of a tube, the Geiger-Müller Tube (GM Tube), filled with an inert gas such as Argon at low pressure. The tube is connected to an electric circuit such that the surface acts as a cathode while a central wire acts as an anode (see diagram). The tube is open on one end but for a thin mica window, which is thin enough to allow alpha particles along with beta and gamma radiation through.

When a photon or particle enters the tube it ionises some of the particles of gas so that the resulting ions and free electrons are accelerated towards the anode and cathode respectively. On the way they will cause collisions with more particles creating further ionisations, with the resulting cascade referred to as an *electron avalanche*. The resulting pulse of electricity can be amplified by the electric circuit to create an audible pulse, or can be counted with an electronic circuit.

However, there is not a one to one correspondence between the interactions in the tube and the resulting pulses. There is a period of time between a gas particle being hit by radiation and the count being registered during which any additional interactions will not be recorded as additional counts. This time period is called the *dead time*. The effect of this dead time becomes more pronounced as the count rate increases.

Calculating Dead Time

The dead time for the GM Tube can be calculated if one has two samples of radioactive sources, by recording the individual count rates and the combined count rate, as described here. To avoid confusion, n will always refer to the *true count rate*, i.e. what would be recorded if the dead time of the tube was zero, while m variables refer to the *measured count rate*, a number in all instances read off the machine. A combined rate refers to the rate corresponding to the situation where the Geiger counter is exposed to the two sources at the same time.

Let n_1 and n_2 stand for the true count rates of each of the two radioactive sources, and let $n = n_1 + n_2$ be the combined count rate. Let τ be the dead time, and let m_1 and m_2 be the measured count rates, with the combined measured count rate $m \neq m_1 + m_2$.

It should be seen that during a measurement $m\tau$ is the total dead time, and thus $nm\tau$ are the number of readings lost during this time. Then,

$$n_1 = m_1 + n_1 m_1 \tau$$

or rearranging,

$$n_1 = \frac{m_1}{1 - m_1\tau}$$

Since $n = n_1 + n_2$,

$$\frac{m_1}{1 - m_1\tau} + \frac{m_2}{1 - m_2\tau} = \frac{m}{1 - m\tau}$$

Cross-multiplying and cancelling terms gives us

$$mm_1m_2\tau^2 - 2m_1m_2\tau + (m_1 + m_2 + m)$$

and solving this quadratic gives us the equation for the dead time:

$$\tau = \frac{\frac{2}{m} \pm \sqrt{\frac{4}{m^2} - \frac{4(m_1+m+2-m)}{m_1 m_2 m}}}{2}$$

Experimental Method

Background Radiation

To measure the background radiation the counter was set to record for two minutes, and the Geiger counter was allowed to run with no radioactive source.

Half-Life

To measure the half life of a radioactive source, the radioactive source (Indium) was placed in the Geiger counter, and the counter was set to record for a minute. Then, the count was recorded at five minute intervals over the course of two hours. The value for the half-life could then be computed from a graph of the Log of the rate versus time.

0.1 Dead time

To find the dead time, readings were taken with a component containing two sources of radioactive C^{14}. Three readings of two minutes each were recorded, in the first case with one of the sources covered, in the second with the other covered and the first uncovered, and finally with both uncovered. The dead time could then be computed as outlined in the Theory section.

Results and Analysis

The experimental results for the Indium half-life portion of the experiment are shown in Figure 1 and Figure 2. The half-life for the indium sample is computed from 2. The decay constant, 7.59×10^-4 can be read off directly from the graph, and from the formula in the Theory section, the half-life was calculated to be 925 seconds.

The values of m_1, m_2 and m were found to be 9783, 9071 and 12522, and inserting these values into the equation in the Theory section gave use the value of 5.4×10^-5 seconds for the dead time of the Geiger counter.

Discussion and Conclusion

The results for half-life experiment were not particularly satisfactory due to the lower than expected counts from the sample, the suspected cause of which were incorrect bias and gain settings on the Geiger counter.

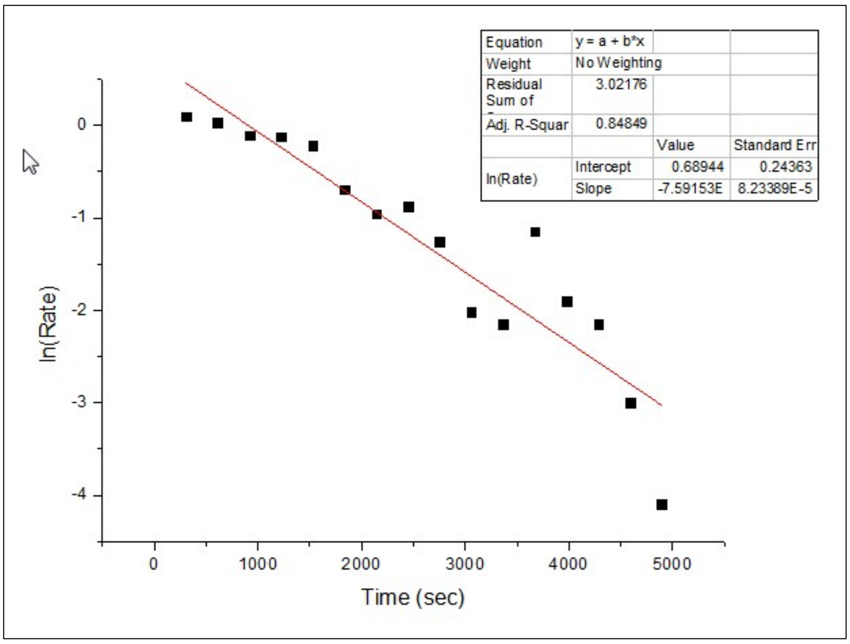

Figure 1: Plot of rate against time for Indium sample

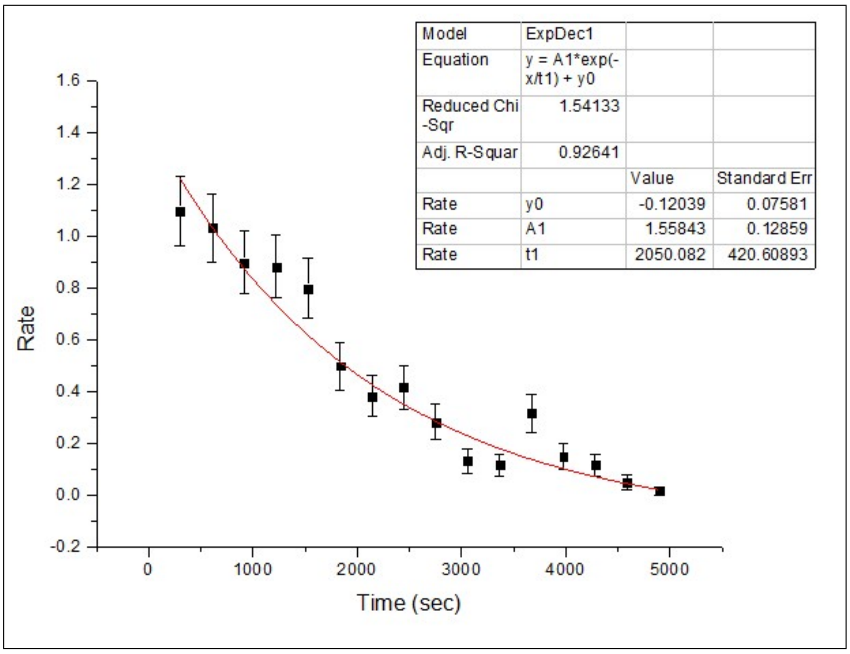

Figure 2: Plot of $\log rate$ against time for Indium sample