Measuring Half Life and Stopping Power Through the Alpha Decay of ^{212}Pb

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Abstract

This experiment aims to measure the energies of alpha particles released during the various steps of the decay of ^{212}Pb into ^{208}Pb. This is done by placing a ^{212}Pb sample in a vacuum chamber, and using the known decay energy of ^{241}Am to calibrate an energy scale. Using the calibrated energy scale, the ^{212}Pb decay energies were found to be 6.1 ± 0.1 and 8.8 ± 0.1 MeV, which agree with literature values. Statistical uncertainties highlight the need for higher precision in the calibration process. By measuring counts associated to the different energies of the lead decay, the half life of the different stages of Pb decay can be investigated. By varying the pressure of the detection chamber, the stopping power of air can be probed as well.

Contents

1 Components completed thus far

- We varied the pulser voltage and measured the location of peaks to get a channel-voltage dependence.
- An americium source was used to convert the channel/voltage scale into energy.
- We charged a disk in the gas for 22 minutes and measured counts for 1.5 days.

2 Planned Measurements

- We currently have a disk charging, which will allow us to observe a sample which charge for 5 days. Running the counts for longer on this source will also allow us to look into half-life behaviour.
- Re-do the calibration run to place better constraints on the voltage-channel dependence.
- Repeat the lead observations at various pressures to probe the dependence on pressure and the stopping power of air on alpha particles.

3 Hypothesis and theory

Alpha decays are observed when the nucleus of an element decays to another element, emitting alpha particles in the process. Similarly to photons, these particles are emitted in discrete amounts of allowed energies, and are essentially ^{4}He nuclei without any electrons (i.e. two protons and two neutrons). As these particles are emitted, they can be detected when they encounter and go through a material, which allows them to excite the electrons of the material and consequently lose energy according the Bethe Formula [1]

$$\left\langle \frac{dE}{dx} \right\rangle = -\left(\frac{4\pi}{m_e c^2}\right)\left(\frac{nz^2}{\beta^2}\right)\left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \left[\ln\left(\frac{2m_e c^2\beta^2}{(1-\beta^2)I}\right) - \beta^2\right], \tag{1}$$

where I is the mean excitation potential (the average energy required to excite an electron), β is the velocity of the alpha particle scaled by c, n is the electron density in the material, z is the charge number of the incident alpha particle, m_e is the electron mass, e is the fundamental charge, c is the speed of light, and ϵ_0 is the permittivity of free space.

The energy loss per distance traveled given by Equation 1 (also know as the stopping power) is dependent on the density of the material, and therefore on temperature, pressure, structure, etc.

Another quantity to look at is the range, which is the mean total distance traveled before an alpha particle loses all its kinetic energy [1]

$$T = \int_0^{\Delta x} \left\langle \frac{dE}{dx} \right\rangle dx, \tag{2}$$

where Δx is the mean total distance traveled and T is the alpha particle's initial kinetic energy.

In this experiment, samples of ^{241}Am and ^{212}Pb are charged by putting 1000 V through them for varying amounts of time, allowing radon gas in the chamber to 'stick' to the polarized sample. One at a time, the samples are placed in a vacuum chamber which contains a silicon P-N junction used as a detector. When an alpha particle goes through the depletion region of the detector, bound charges are released in an amount proportional to the particle's energy, allowing the current to flow from the capacitor in the circuit. A voltage supply is used to recharge the capacitor, and the current pulse is converted to a voltage pulse. The peak voltages are measured as a counts and binned into a histogram, where the axis can be converted from voltage to particle energy due to the linear relationship between the two. The decay of the ^{212}Pb nucleus to ^{208}Pb happens on the scale of hours and can therefore be easily measured.

The energy scale was calibrated by varying the pulser voltage and using an Americium source (see Figure 1). The location of the peak for the americium source was assumed to be affected by statistical noise and therefore fitted to a Gaussian to get a constraint on the peak location. The result of this fitting placed the peak for the Americium at channel 469.85 with a standard deviation of 0.01, which was used for the. Using the voltage-channel relationship established with the pulser, and knowing that the primary energy emitted via alpha decay for Americium is 5.4612 MeV [2], the error on the energy scale was taken to be 0.1 MeV. Further work with the calibration process should be done to better constrain this uncertainty, especially by improving precision on the voltage readings from the oscilloscope.

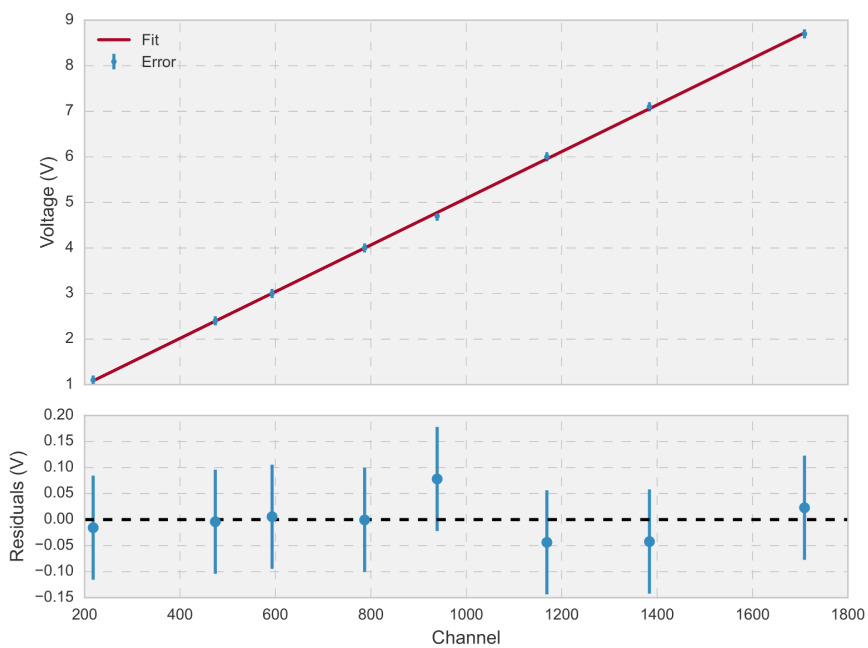

Figure 1: Calibration process for assigning energy levels to each MCA channel. The voltage height of the pulser was adjusted and the corresponding bin location of the peak was recorded 8 times, allowing a relationship between voltage and channel to be established. The relationship was taken to be linear, with residuals shown in the bottom panel. This voltage-channel relationship was used to convert the channels to energy later using the Americium source.

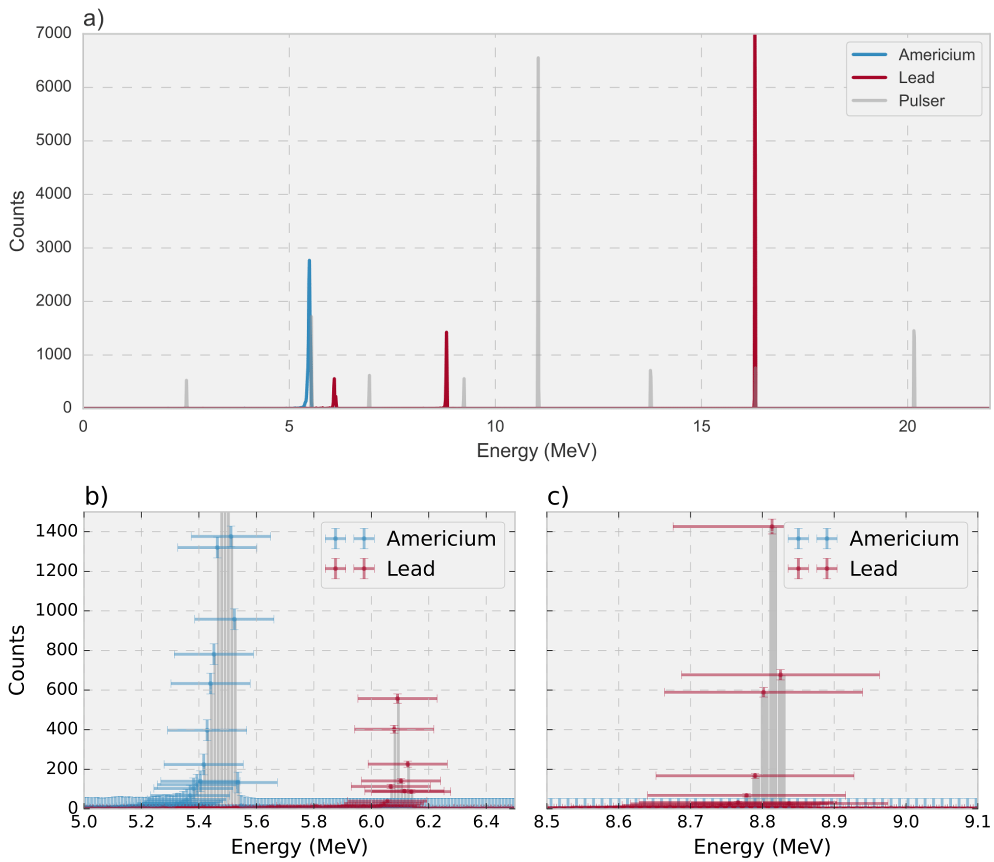

Figure 2: Histograms of counts detected for different runs of the experiment. a) shows the full energy scale probed with the pulser (grey), the americium source (blue) and the lead source (red). Note that the rightmost peak for the lead run is from the pulser being left on, and does not correspond to counts from the source. Panels b) and c) show the counts with error bars, where errors in the counts themselves come from Poissonian statistics of $\sqrt{\text{counts}}$ and the energy errors come from the calibrations.

With this energy scale constructed, the energy of the lead peaks was found to be 6.1 and 8.8 $\pm$ 0.1 MeV, which is in agreement with accepted values 6.05078 MeV of and 8.78486 MeV [3]. It can be seen in panel b) of Figure 2 that a smaller secondary peak was observed for the lower-energy lead peak, which requires further investigation. The lead sample used in this data was charged for only 22 minutes. Repeating the above process with a more charged sample and with more precise voltage measurements should vastly improve the constraints on these measurements.

References

[1] *Alpha Decay Lab Manual*. McGill Department of Physics. 2

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