Calibration of Alpha Decay Apparatus and Determination of Effect of Pressure on Energies of Alpha Particles

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Abstract

The apparatus to measure the energy of alpha particles is calibrated. This is done using an Americium alpha source of known energy and a pulser that gives voltage pulses of known amplitude that mimic those caused by incident alpha particles. Peak channel number of a multi chanel analyzer is determined for each spectra by fitting a Gaussian around the peak, and a linear fit is performed on the peak channel number against voltage data. An Amerisium source is used to determine the relationship between amplifier voltage and energy of alpha particles, as the energy of alpha particles from the Ameresium source is known. A linear relationship is thereby obtained between peak channel number c and energies of incoming alpha particles E, with the slope given by $k = 0.2030 \pm 0.0013(stat)^{+0.0013}_{-0.0014}(sys)$ $(keV)^{-1}$ and the intercept by $k_0 = 8.0 \pm 8.5(stat)^{+1.6}_{-1.0}(sys)$ (Here $(stat)$ and (sys) refer to statistical and systematic uncertainties respectively.) The pressure in the vacuum chamber is also varied and the energies of the alpha particles measured. It is observed that the energies decrease linearly with increasing pressure, with the slope of this graph being given by $-85.5 \pm 2.1\frac{keV}{KPa}$ and the intercept is $5734 \pm 44keV$.

Contents

1 Experimental Setup

The experiment consists of an alpha source in a vacuum chamber connected to a bais voltage, and a detection circuit to measure energies of incoming alphas (See Figure 1). The vacuum

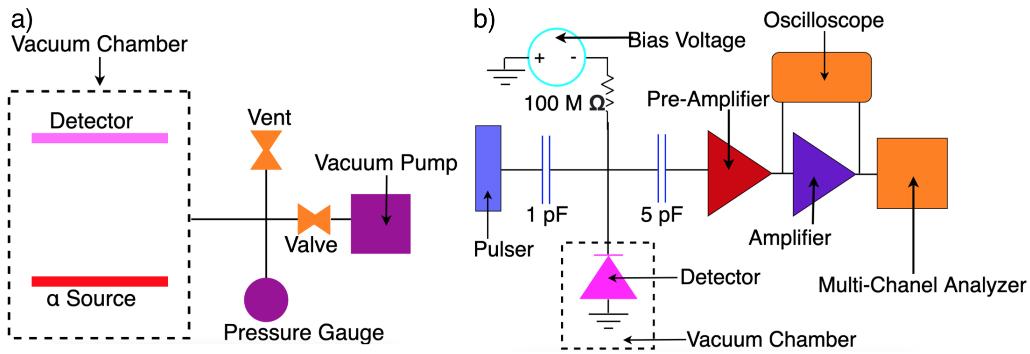

Figure 1: Experimental Setup for detecting alpha particles. a) Schematic of the experimental apparatus. Alpha particles travel from the source to the detector through air at variable pressure. b) Schematic of the detection circuit. The circuit can either be connected to receive pulses from the detector, caused by incident alpha particles, or from the pulser for calibration.

chamber is coupled to a pressure pump, and contains valves to let air in and change the pressure in the chamber. A transducer and Piriani gauge are also connected to measure pressure in the vacuum chamber. An arduino is used to open or close the valves and change the pressure in the chamber. The pressure readings can be read off the McPhysics Alpha Decay software.The detection circuit comprises of an alpha detector connected to a Pre-Amplifier, an Amplifier and a Multi-Channel Analyzer(MCA). An oscilloscope can also be connected across the devices to measure the voltage output from each. The detector contains a P-N junction diode, and hence when an alpha particle enters the detector some of the nominally bound charges are freed in proportion to the energy of the alpha. There are capacitors inside the detector which then release charges to fill up the holes produced in the diode, and the current produced flows through the circuit. The bias voltage is there to charge the capacitors, and thereby make sure the detector can detect another alpha particle. The current is converted to a voltage pulse with amplitude proportional to the incoming current via the pre-amplifier. This pulse is then amplified and filtered by the amplifier. Using a fast analogue-to-digital converter, the MCA processes each analogue signal pulse by measuring its amplitude. Based on the amplitude, it registers a count in one of the 2048 channels corresponding to the energy of the voltage pulse. The MCA only provides channel numbers, and therefore must be calibrated to relate channel number to incident alpha energy.

2 Calibration

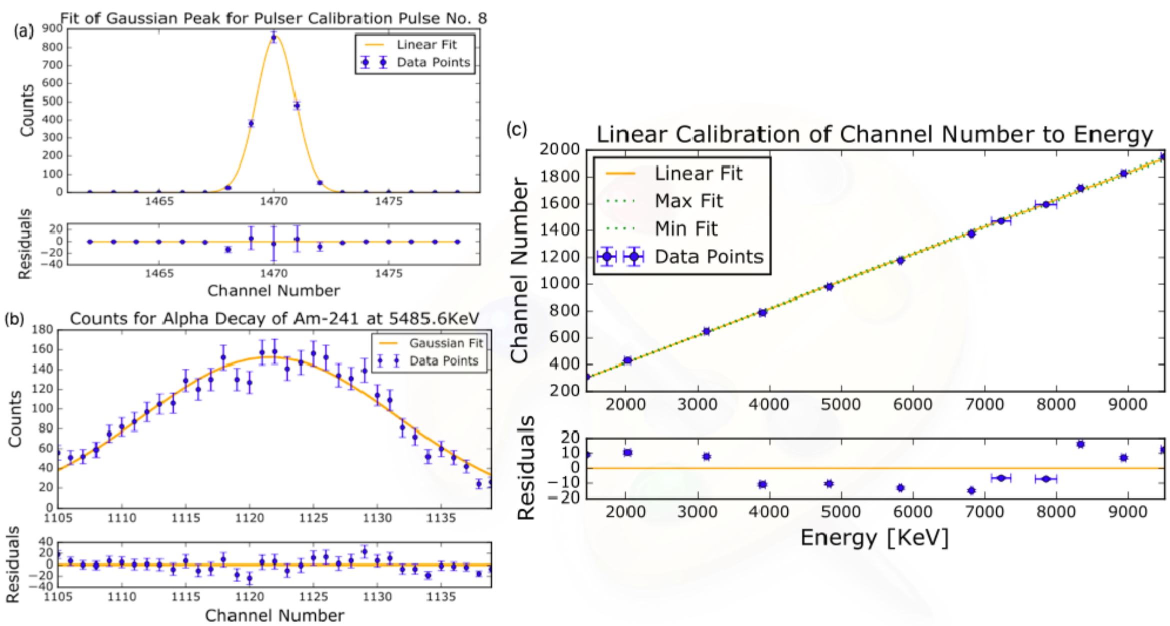

Figure 2: (b) Gaussian fit of sample pulsar signal, according to $y = A * e^{\frac{-(x-m)^2}{\sigma^2}}$ with parameters $m = 1470.084 \pm 0.005$, σ =0.839 $\pm$0.005, and A = 865 ± 4. The calculated reduced $\chi^2 = 2.82$ with an expected $\chi^2 = 2.60$ and DOF = 3. (a) Gaussian fit of $Am - 241$ sample with known alpha energies and parameters m = 1121.6 ± 0.2, σ =10.0 $\pm$0.3, and A = 153 ± 3. The calculated reduced $\chi^2 = 1.45$ with an expected $\chi^2 = 1.44$ and DOF = 34. (c) Resulting linear calibration fit of channel number vs. energies, for parameters $k = 0.2030 \pm 0.0013^{+0.0013}_{-0.0014}$ and $k_0 = 8.0 \pm 8.5^{+1.6}_{-1.0}$.

The pulser is used to produce pulses of different voltages. Corresponding voltage outputs from the amplifier and the channel spectra from the MCA are collected. The voltage output from the amplifier is measured using the oscilloscope. The peak voltage was observed to oscillate by 0.04mV for every pulse, which is a source of systematic uncertainty in the experiment. The spectra obtained from the MCA is fitted using a Gaussian function to determine the peak channel number. This is required as channel number measured in the MCA is not always exactly the channel number corresponding to the energy of the incoming alpha particle. An Amerisium source used, as it produces alpha particles of known energies [1]. The corresponding peak channel number is determined, and the amplifier voltage is calculated using the linear fit. It is assumed the amplifier voltage is proportional to the energy of incoming alphas, and thereby an equation relating alpha energy and peak channel number is obtained. The equation is given by $c = kV + k_0$, with $k = 0.2030 \pm 0.0013(stat)^{+0.0013}_{-0.0014}(sys)$ $(keV)^{-1}$ and $k_0 = 8.0 \pm 8.5(stat)^{+1.6}_{-1.0}(sys)$.

3 Determination of the effect of pressure in the chamber on the energies of the alpha particles

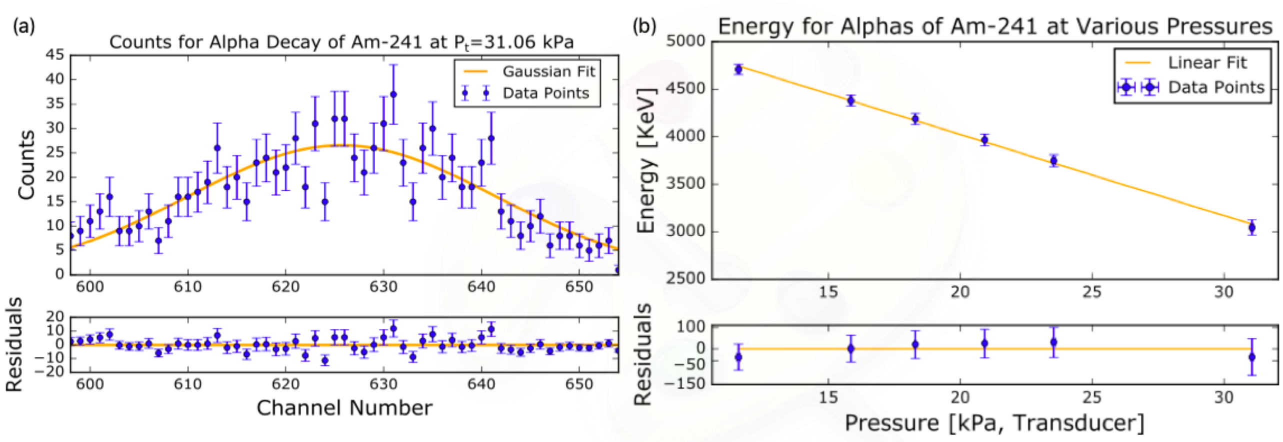

Figure 3: (a) Gaussian fit of Am-241 sample, at a decreased internal pressure of $p_{transducer} =$ 31.06 kPa, and fit parameters m = 626 ± 1, o = 16 ± 1, and A = 27 ± 1. The calculated reduced $\chi^2 = 1.33$ with an expected $\chi^2 = 1.33$ and DOF = 34. (c) Resulting plot of shifted alpha energies as a function of pressure (read at transducer), and associated linear fit for slope $= -85.5 \pm 2.1 \frac{KeV}{kPa}$ and intercept $= 5734 \pm 44$ KeV. For this linear fit, the calculated reduced $\chi^2 = 0.26$ with an expected $\chi^2 = 2.37$ and DOF = 4. This small calculated χ^2 is likely due to over-estimations of the systematic error in Energy.

Since alpha particles are charged, they ionise the air they pass through, losing energy in the process. This is can be studied by varying the pressure in the vacuum chamber and determining the peak energies of alphas at each pressure from the MCA for an Am source. The pressure is varied via an arduino, and the Pressure Transducer value is recorded. Fluctuations in the value of the pressure displayed which is a source of systematic uncertainty.

4 Progress

- We changed the gain in the Pre-amplfiier to the right values so that energies of all the alpha particles for the decay experiments can be measured.

5 Plan

- We plan to measure the half-life of the ^{212}Pb and ^{212}Bi in the lab.
  - This is to be done by placing the radioactive ^{212}Pb source, and collecting MCA spectra every 5 minute for 60 second intervals.
  - Since the energies of alpha particles produced by the radioactive ^{212}Pb and ^{212}Bi are at significantly different energies, the peaks can be determined separately, and thereby the activity of each material can be determined.
  - We can then plot a graph of activity against time, and the activity should decay exponentially for both sources.
  - The half-life can be determined by fitting the correct equation for radioactive decay.
- We plan to measure the stopping power and range of alphas in air.

References

[1] M. S. Basunia, *Nuclear Data Sheets 107, Vol 3323*, 2006. 3