Lab 1: Alpha Spectroscopy

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Abstract

Alpha-particle spectra of Americium-241 (^{241}Am) are collected across an open path through an evacuated chamber and across 25, 50, and 100 microinch absorption depths of nickel foil. A totally depleted silicon surface barrier detector model (ORTEC Model B) provides a voltage response proportional to the kinetic energy of the particle it absorbs, and this response is used to produce an energy-count spectrum for each setup. The mean kinetic energy of the particles incident on the detector for each case are compiled to create a curve describing the attenuation as a function of absorption depth. The alpha-particle spectrum of a radium sample is also analyzed, and four alpha-particle peaks associated with the decay chain beginning with radium are identified.

1 Introduction

Spectroscopy of alpha radiation is a method for testing and measuring the properties of any alpha emitter, which is a class of radioactive particles that emit alpha particles, a bound collection of two protons and two neutrons. This is one of the primary classes of radiation, along with beta and gamma radiation, and of these the only hadronic form of radiation. An alpha particle is emitted during alpha decay of a nucleus, when the nucleus gives off 2 protons and 2 neutrons. The isotope loses 2 from its atomic number, decaying into an isotope of a new element. Radium decays by emitting an alpha particle into the daughter element Radon, then Polonium, and then Lead. This isotope of Lead decays through beta decay – the emission of an electron and a neutrino – into Bismuth, which then decays through alpha emission into Thallium. Alpha particles created in this process often have kinetic energy near 5 MeV and are highly ionizing, but with a small penetration depth. They are therefore not considered a dangerous form of radiation unless ingested.

This exercise explores the kinetic energy spectrum of alpha particles emitted by an Americium-241 sample and a Radium sample. The physics student gains greater confidence in physical theory by confirming the alpha particle activity from the Americium sample, and quantifying the loss as a function of absorption depth through an impeding medium. The alpha decay chain beginning with Radium, consisting of four distinct alpha emission processes, is also confirmed.

2 Alpha Detector and Energy Profile

A totally depleted silicon surface barrier (ORTEC model B) is used to count alpha particles emitted by samples used in this study. This detector absorbs alpha particles, transducing their kinetic energy into electronic activity. The detector provides a signal in the form of a potential difference, proportional to the kinetic energy of the absorbed alpha particle. Signals were collected in this way to generate each spectrum of alpha particle kinetic energy. The active detection area of the device was not measured, and this is a major oversight. Quantifications made in this work are fundamentally a flux through this single surface with constant area, so this oversight should not be consequential. As a rough estimate, the detection area is round with radius of approximately half of one centimeter.

Maestro software is used to operate a sensor on which 8191 channels monitor a linear domain of voltage inputs. This device monitors the alpha detector's output signal, and because this signal is proportional to the kinetic energy of the absorbed alpha particle, this setup provides a profile of the kinetic energy of particles absorbed by the detector. These data are saved to a plaintext file for analysis.

3 Energy-Domain Analysis

The primary mode of study here will be to compare energy values determined by fitting Gaussian Distributions whose means μ are associated with an average kinetic energy of an alpha particle from the incident emitter. To serve as a strong confirmation of undergraduate concepts, results need not be terribly precise. If the correct patterns are seen in the data, the processes will be confirmed, and if all values of energy agreed with published experimental values to within 30%, a generous tolerance, this would be very satisfactory. The Gaussian Distribution is not a very good fit for these data, but this rough determination may be sufficient under these tolerant criteria.

3.1 Calibration of Energy Scale

An unimpeded alpha particle spectrum is collected to calibrate the energy scale. Measurements of the vacuum were not taken at this stage, another glaring omission, but from vacuum measurements taken during other trials, it appears safe to assume a pressure of less than 40 millitorr. Processing by the gas molecules still in the chamber does reduce the observed kinetic energy, but this effect is likely to be insignificant. The Americium emission peak is fitted to a Gaussian distribution with parameters ($\mu = 7813.84, \sigma = 68.82$) in channel units, drawn with a blue line in figure 1. This fit leaves a residual sum-of-squares of 183325; this poor quality measure is not surprising given the extreme length of the tail. The distribution is negatively skewed and so would likely better fit to a Mirror Gumbel Distribution. The energy scale is calibrated by setting the mean of the Gaussian peak μ to the experimentally-determined value $5.486 MeV$(85% likelihood) [2], and $0V = 0MeV$.

3.2 Absolute Activity

The absolute activity I_α of the Americium-241 alpha emitter, in alpha particles per second, is computed from counts of alpha particles through the detector over a known amount of time. The number of alpha particles detected Σ_α is related by the solid angle subtended by the detector on the source, and the time the detector was live t_L, to the total number of alpha particles emitted by the sample. The cross-sectional area of the circular detector is πr^2, with r the radius of the detector, s is the distance from the source to the detector, and assuming there are no reflection effects, then

$$I_\alpha = \left(\frac{\Sigma\_\alpha}{t_L}\right)\left(\frac{4\pi s^2}{\pi r^2}\right). \text{ [1]}$$

There are three significant energy modes of the alpha emission from Americium-241, with varying probability of incidence: $5486 keV(85\% probability)$; $5443 keV(13\%)$; and $5388 keV(1\%)$. [2] The sum of each peak must be added to obtain a total count of alpha particles detected. These peaks were impossible to discern from inspection, as the overall magnitude of the activity across that domain out-competed the nuanced distinction. The counts were summed over a bin deemed

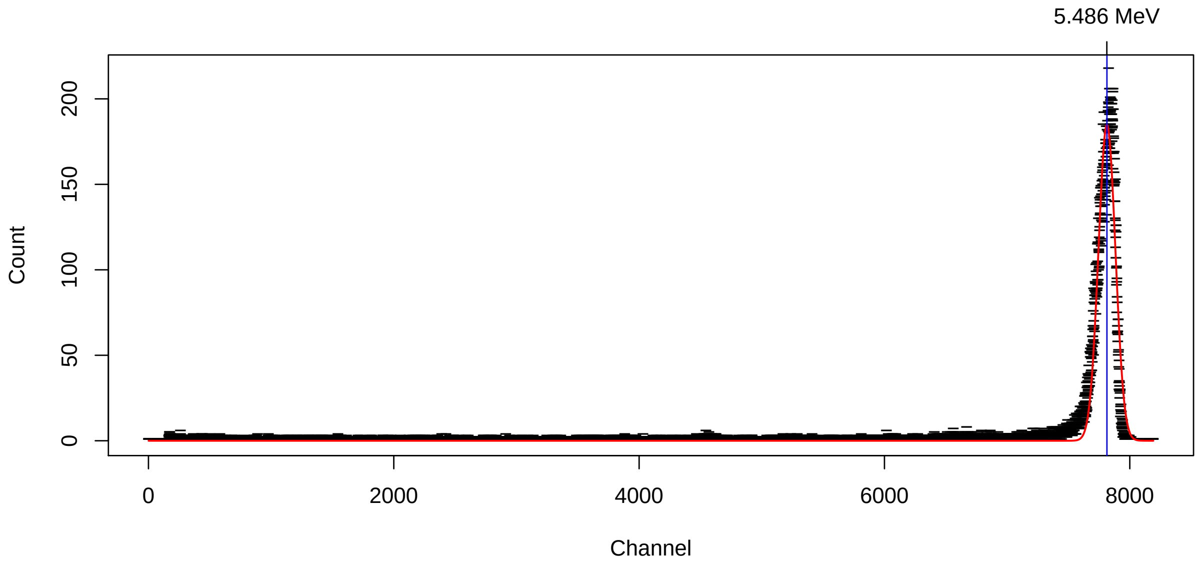

Figure 1: The alpha particle spectrum of an unimpeded Americium-241 source is collected and fitted to a Gaussian Distribution with mean channel 7813.84. The energy scale is calibrated to this value at $5.486 MeV$

sufficient to cover all three modes based on the referenced relative energies. This bin is marked in red on figure 2.

The detector's radius is measured using a flimsy ruler as $5.25 \pm 0.5mm$ The Americium sample is placed $38.5 \pm 0.5mm$ from the detector, and the chamber is evacuated to $30 \pm 2.5 millitorr$. The detector is allowed to run for $3012.56 \pm .005 seconds$ and 11956 detections are registered in that time. The absolute activity computed with this technique is 854 ± 82 alpha particles per second. A standard unit for radioactive activity is the Curie, or microCurie μCi, and $1 \mu Ci = 3.7 \times 10^4$ emitted particles [1], and in this case $I_\alpha = 0.034 \pm 0.0022 \mu Ci$.

4 Energy Loss through an Absorber

When an absorber is present between the alpha radiation source and the detector, alpha particles still reach the detector but with a reduced kinetic energy. This energy is lost mainly to ionization and excitation of atoms in the material [3]. This response is studied as alpha particles travel through a series of thin films and through typical air, which is primarily N_2 gas. In each case, the absorption depth is characterized by a δx in units of mg/cm^2, which is a typical unit used to normalize depths between materials for comparison. This feature is used to compare the loss of energy through a thing film against the loss of energy through a gaseous absorber.

4.1 Interference from a Thin Film

A thin film placed between the source and the detector causes interference such that a loss of energy should be observed, proportional to the penetration depth of the foil. In order to build a rough model of this response function, 3 thicknesses of Nickel foil are placed between the detector and the source, and the average kinetic energy of the alpha particles emitted from the Americium-241

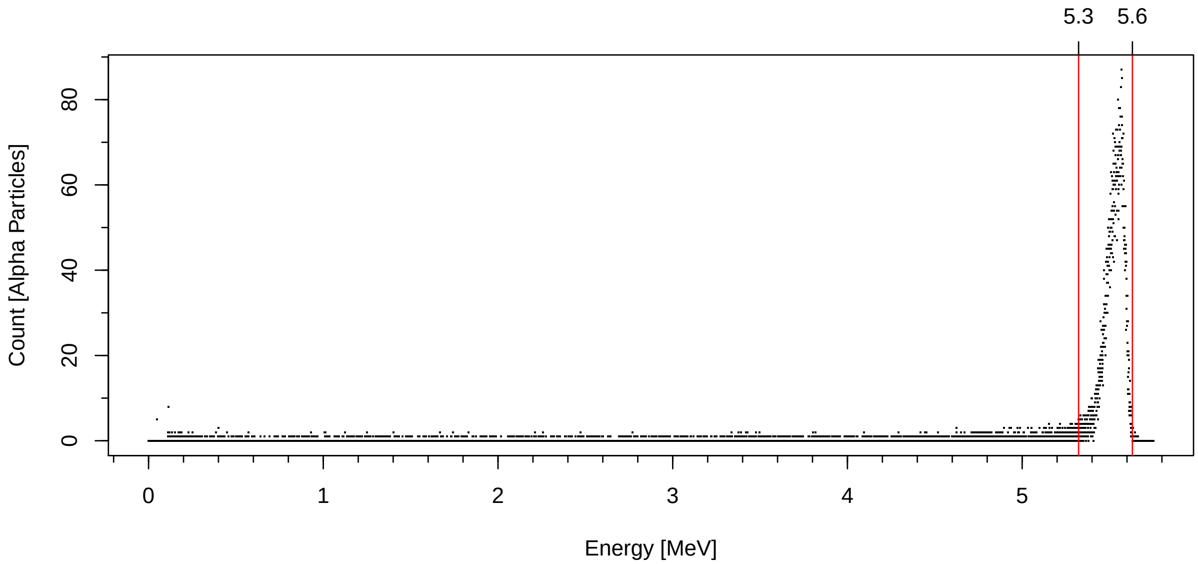

Figure 2: To determine the absolute activity of the Americium-241 alpha emitter, the number of alpha particle detections registered within the range indicated by the two red lines were counted.

Foil Thickness ($\mu inch$)	Kinetic Energy (MeV)
No Absorber	5.55 ± 0.0005
25 ± 5	5.26 ± 0.0006
50 ± 5	4.95 ± 0.0006
100 ± 5	4.38 ± 0.0007

Table 1: Nickel foil thicknesses and the associated loss of kinetic energy by the alpha particles reaching the detector.

sample is computed using the Gaussian fit as outlined above for each condition. The thicknesses and computed average kinetic energies are tabulated below, with the error for the kinetic energy computed as the standard deviation of the mean, i.e., $\frac{\sigma}{\sqrt{n}}$. The density of Nickel near room temperature is extremly well-known to be approximately $\rho_{lead} = 8.908 g/cm^3$. The absorption depth is therefore computed as $\Delta x = \rho_{lead} T$ where T is the thickness of the absorber in centimeters.

4.2 Interference from a Gas

A gas can act as an attenuator similarly to a film. An alpha spectrum is collected under increasing pressure (8 settings total). The gas occupies the entire space between the source and the detecter, so the depth is exactly that distance, but at each step the density changes, dependent on the pressure. Here, air is used as the absorbant gas, and the pressure is reported by a simple spin gauge connected to the vacuum chamber. The density of air at room temperature can be estimated as $\rho_A = 1.28 mg/cm^2$, and while this number is presented without uncertainty, it is an estimate only and can be considered accurate to the precision it is quoted here. Then, assuming any changes to equilibrium between gasses inside the chamber and outside occur quasistatically, the density of the gas at a given pressure can be related to its density at atmospheric pressure as

$$\rho_P = \frac{P}{P_A}\rho_A.$$

5 Radium Alpha Decay Chain

6 Discussion

The known value for radioactivity of Americium-241 is given in terms of per mass ($3.43 Ci/gram$ [2]), but it was not possible to measure the mass of Americium in this sample. The sample is adorned with a screw of comparable length and volume, such that it would be exceedingly difficult to determine the mass of the Americium alone. It is therefore not possible to make a comparison to known values for this quantity.

References

[1] *Alpha Spectroscopy with Silicon Charged-Particle Detectors*. Instruction Manual. ORTEC. 801 South Illinois Ave., Oak Ridge, TN 37831-0895 U.S.A.

[2] *Americium-241*. Tech. rep. University of Cincinnati. URL: `http://www.researchcompliance.uc.edu/Libraries/Isotopes/Am-241.sflb.ashx`.

[3] *Energy Loss with Heavy Charged Particles*. Instruction Manual. ORTEC. 801 South Illinois Ave., Oak Ridge, TN 37831-0895 U.S.A.