EXPERIMENT 4

Alpha Spectroscopy with Surface Barrier Detectors

EQUIPMENT NEEDED FROM EG&G ORTEC

- Source Kit SK-1A (see Appendix)
- Surface Barrier Detector R-017-050-100
- 142A Preamplifier
- Bin and Power Supply
- 575A Amplifier
- 807 Vacuum Chamber
- 428 Detector Bias Supply
- 408A Biased Amplifier
- 480 Pulser
- ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
- Mechanical Vacuum Pump
- Oscilloscope
- ORC-4 Cable Set

Purpose

The purpose of this experiment is to familiarize the student with the use of silicon charged-particle detectors and to study some of the properties of alpha-emitting isotopes.

Applicability

Semiconductor charged-particle detectors have been used extensively in experimental nuclear research for almost 20 years. In this period of time they have revolutionized nuclear particle detection. Recent publications in any of the nuclear journals indicate that semiconductor detectors are now used almost exclusively for the detection of charged particles. Semiconductor gamma- and x-ray detectors have contributed perhaps even more significantly in their own field of photon spectroscopy.

Semiconductor charged-particle detectors can be used through an extensive range of energies. These include 20-keV electrons on one end of the spectrum and 200-MeV heavy ions on the other. The inherent resolution of these surface barrier detectors is surpassed only by magnetic spectrometers. The detector output pulses rise rapidly and hence are well-suited for fast (~1 ns) timing with coincidence circuitry or time-to-amplitude converters (TACs).

The efficiency of these detectors for their active volume is essentially 100%, and their energy vs pulse-height curves are linear over a rather impressive range. It is fortunate that they also have good long-term pulse-height stability. This is particularly noticed when they are contrasted with scintillation counters, gas proportional counters, or ionization chambers. Finally, their small size and compactness make them easily adaptable to almost any type of counting geometry. The remaining fact of particular interest in the educational market is that they are relatively inexpensive.

It should take about 6 h to complete all parts of Experiment 4. The parts are written so that they can be completed in two 3-h laboratory periods, or certain parts can easily be omitted if equipment or time is not available.

Alpha Sources

CAUTION: Alpha sources offer a potential personal contamination problem. Never touch the face of a source with your fingers. Most alpha sources are electrodeposited onto platinum blanks. The actual radioactive source is usually a spot about 1 mm in diameter, and it has been deposited in the geometrical center of the disk. If you look carefully, you may be able to see the deposited spot. The ^{210}Po source in SK-1A has been evaporated onto a silver disk, and the disk covered with a piece of plastic with a hole through the center for transmission of the alpha particles. Always handle an alpha source by the edge of the mounting disk.

Surface Barrier Detectors

There are three main parameters that define a silicon surface barrier detector: resolution, active area, and depletion depth. The EG&G ORTEC model numbers reflect each of these three parameters in that order. The R-017-050-100 detector is a style R (Ruggedized) detector with a resolution of 17-keV FWHM for ^{241}Am alphas, an area of 50 mm^2, and a depletion depth of 100 μm.

The quoted resolution of an EG&G ORTEC detector is a measure of its quality. These resolutions can be measured only with a complete set of electronics, set for standard conditions, and the EG&G ORTEC quaranteed resolutions are measured with standard EG&G ORTEC electronics. A resolution of 20 keV or better is satisfactory for all parts of Experiment 4.

Since the shape of the detector is a circular disk, its active area is determined by the diameter of its face. At any given distance from the source a larger area will subtend a larger angle and thus intercept a greater portion of the total number of alpha particles that emanate from the source. A nominal area of 50 mm^2 is suggested for this experiment, but any area from 25 through 100 mm^2 will provide the information.

The depletion depth is synonymous with the sensitive depth of the detector. For any experiment the depth must be suf-

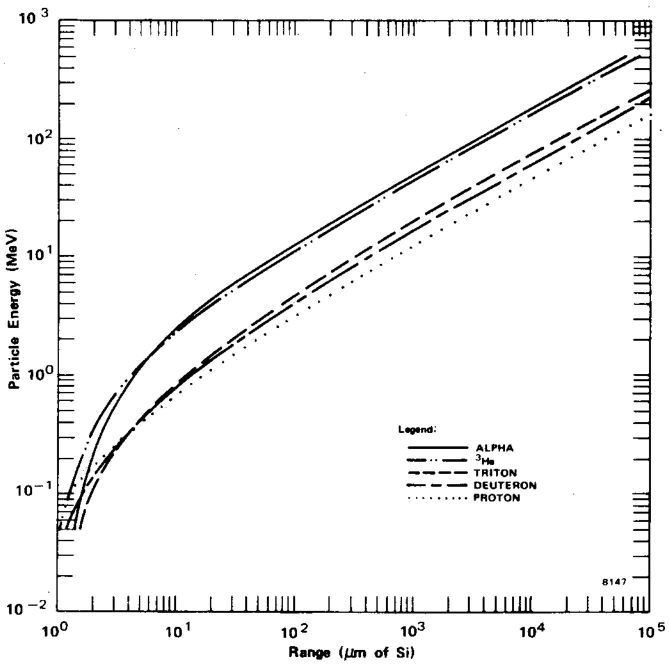

Fig. 4.1. Energy-Range Curves for Charged Particles in Silicon. [Data taken from C. F. Williamson, J. P. Boujot, and J. Picard, *Tables of Range and Stopping Power of Chemical Elements for Charged Particles of Energy 0.5 to 500 MeV*, CEA-R-3042 (July 1966).]

ficient to completely stop all the charged particles that are to be measured, and its ability to do this is dependent upon both the energy and the particle type. Figure 4.1 is a range-energy curve for five of the more common charged particles. From it, the minimum depth can be determined for the maximum energy of a particle type. From Fig. 4.1 note that a 5.5-MeV alpha is completely stopped with ~27 μm of silicon. Since natural alphas are usually <8 MeV in energy, a 50-μm detector is adequate to stop all natural alphas.

EXPERIMENT 4.1

Simple Alpha Spectrum and Energy Calibration with a Pulser

Procedure

1. Connect the equipment as shown in Fig. 4.2. For the examples shown below, the ^{210}Po source from Source Kit SK-1A has been selected.

2. Make the following settings: Adjust the distance from the alpha source to the detector to about 1 cm (inside the 807 Vacuum Chamber). Pump the vacuum in the chamber down to 500 μm or less. (If a vacuum gauge is not available, a pumping time of 2 min is usually adequate.) Set the 575A Amplifier for a negative input and unipolar output. Set the 480 for a positive pulse polarity and use the attenuated output. Set the 428 for a negative bias output and raise the voltage slowly to the value recommended on the detector data sheet. Voltage must be increased to compensate for voltage dropped across the high-value resistor in the Model 142A Preamplifier. Refer to Section 4.7 of the Model 428 Detector Bias Supply Manual.

3. Adjust the gain of the 575A Amplifier until the pulse amplitude observed by the oscilloscope is ~5 V. The ^{210}Po alpha source used for this example has an alpha energy of 5.31 MeV. The source activity (~1 μCi) and the counting geometry are such that the pulse rate should be adequate for oscilloscope observation.

4. Accumulate a spectrum with the MCA long enough to have about 400 counts in the peak channel. The spectrum should resemble that of Fig. 4.3. Determine the centroid channel number for the alpha peak. Call this channel C_0. In the example of Fig. 4.3, C_0 is channel 520, and this represents the location in the spectrum for the ^{210}Po 5.305-MeV alpha events. The FWHM, measured in number of channels, is $\delta = 16$.

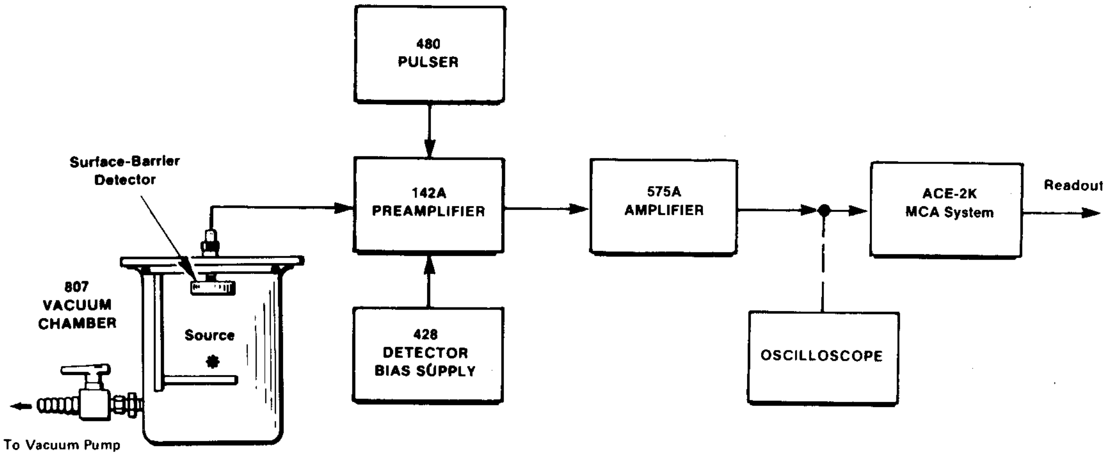

Fig. 4.2. System for Alpha Spectroscopy.

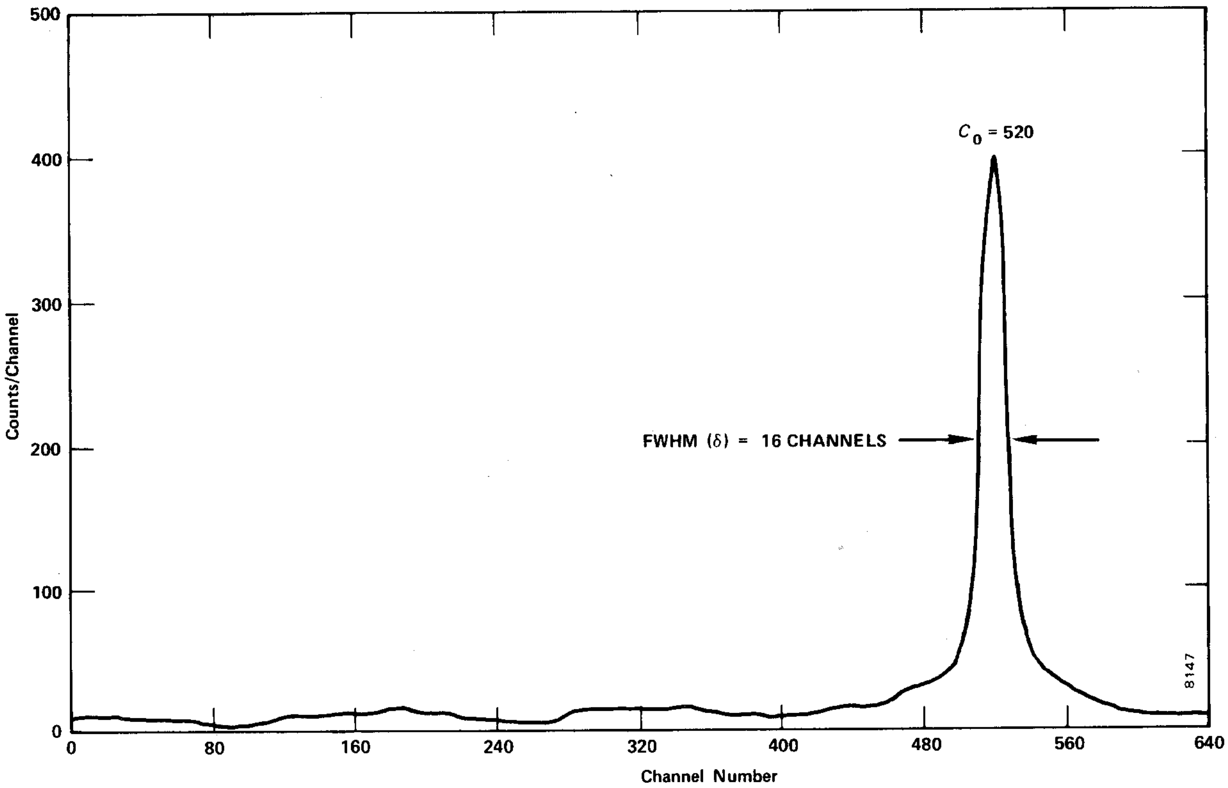

Fig. 4.3. Plot of a Typical ^{210}Po Alpha Spectrum.

5. Turn on the 480 Pulser and set its pulse-height dial at 531/1000. Adjust the attenuators and the calibration control until the pulse generator output is ~5 V in amplitude. The output pulses from the 575A Amplifier for the pulse generator input should now be approximately the same amplitude as the pulses from the ^{210}Po alphas. The pulses from both sources can be observed simultaneously on the oscilloscope.

6. Accumulate the pulser pulses in the MCA for ~20 s. Do they fall above or below channel C_0? Adjust the calibrate control on the pulse generator as necessary to locate the pulser peak exactly in channel C_0. Your pulser is now calibrated to the system so that 5.31 MeV corresponds to 531/1000 on the pulse-height dial, and therefore, any setting of the pulse-height dial represents an identified energy level. For example, 600/1000 = 6 MeV, etc.

7. Erase the MCA and accumulate the pulser pulses for ~20 s at each of the pulse-height values in Table 4.1. Determine their position with the cursor of the MCA.

EXERCISES

a. Fill in the column of data that is missing in Table 4.1. Make a plot on linear graph paper of energy (MeV) vs channel number. Compare this plot with that in Fig. 4.4. For identification purposes the 5-MeV point is accumulated for 40 s.

b. The slope of the curve in Fig. 4.4, $\Delta E/\Delta C$, is the energy per channel. For convenience this is usually expressed in keV/channel, and in Fig. 4.4 it is ~10 keV/channel. Determine the keV/channel for the plot you made in Exercise **a**.

c. The resolution in a spectrum is calculated as follows:

$$\text{resolution} = \frac{\Delta E}{\Delta C} \times \delta \text{ (ch)}, \qquad (1)$$

where δ (ch) = channels FWHM. For example, in Fig. 4.3 the δ (ch) for FWHM is 16 channels for the energy range from channel 512 through 528. It is measured at the points in the spectrum where the number of counts per channel is half the number of counts at the peak. In the example the FWHM resolution is, then, 160 keV. Calculate the δ (ch) and the resolution of your alpha peak.

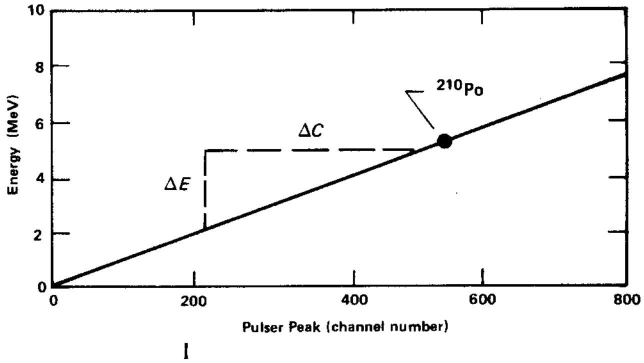

Fig. 4.4. Calibration Curve for Alpha Spectroscopy.

Table 4.1. Channel Numbers for Equivalent Energies

Accumulation Time (approx. s)	Pulse-Height Dial Setting	Equivalent Energy (MeV)	Channel Number of MCA Peak
20	100/1000	1.0	
20	200/1000	2.0	
20	300/1000	3.0	
20	400/1000	4.0	
40	500/1000	5.0	
20	600/1000	6.0	
20	700/1000	7.0	

EXPERIMENT 4.2

Energy Determination of an Unknown Alpha Source

Purpose

The purpose of this experiment is to identify the peak energy of an unknown alpha source. Its energy or energies can be determined with the system of Experiment 4.1 since the system has already been calibrated.

Procedure

1. Reduce the detector bias voltage to zero. Turn off the vacuum pump and allow the chamber pressure to come up to atmospheric pressure. Open the chamber and replace the ^{210}Po standard source with the unknown alpha source. Pump the vacuum back down until the pump is quiet. Increase the detector bias slowly to its proper operating level again. Turn off the 480 Pulser.

2. Accumulate the spectrum for the unknown until the more pronounced peaks in the spectrum can be identified.

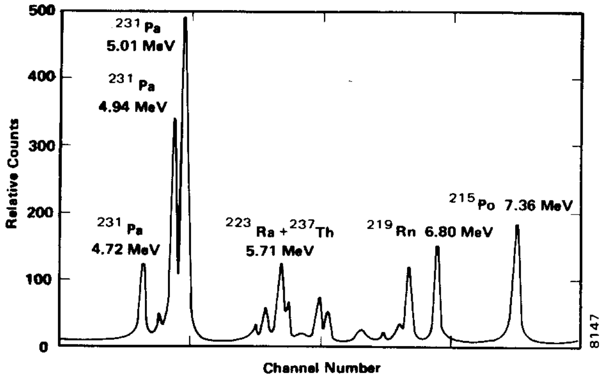

Fig. 4.5. Portion of a Typical ^{231}Pa Alpha Spectrum.

EXERCISE

Determine the energies of the peaks from your calibration curve. The source could contain just one peak, or it might have a number of alpha energies. For example, Fig. 4.5 shows a portion of a spectrum for ^{231}Pa and its daughters. Identify the source by its energy or energies. Figure 4.6 shows a ^{234}U spectrum that was taken with a 25.5-keV resolution.

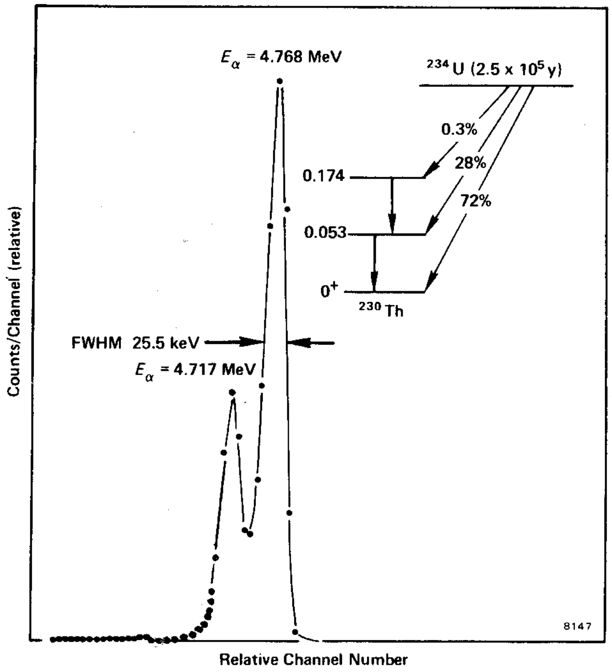

Fig. 4.6. Typical Alpha Spectrum from ^{234}U Showing Alphas from the Two States in ^{230}Th.

EXPERIMENT 4.3

Energy Calibration with Two Alpha Sources

An energy calibration can, of course, be made if two alpha sources are available; for example, ^{241}Am (E_α = 5.48 MeV) and ^{210}Po (E_α = 5.31 MeV).

Procedure

1. Place the ^{241}Am source in the vacuum chamber, pump down, and set the bias voltage. Adjust the gain of the 575A Amplifier until the ^{241}Am (5.48 MeV) is being accumulated in the top half of the analyzer, for example, channel 800. Record the peak channel.

2. Replace the ^{241}Am with the ^{210}Po and accumulate again for a long enough period of time to determine the peak position. If the analyzer zero level has been set so that zero energy is approximately channel zero, three points (0, 5.31, and 5.48 MeV) are now available for the calibration curve. Draw the best straight line through these three points. If the

analyzer zero level has not been set, a line through the source locations will indicate the offset of the analyzer zero.

EXERCISE

From the calibration curve determine the keV/channel and the resolution as in Experiment 4.1. Generally speaking, the pulser method outlined in Experiment 4.1 is the better way to establish the calibration for the system.

EXPERIMENT 4.4

Absolute Activity of an Alpha Source

Purpose

The purpose of this experiment is to determine the absolute activity of an alpha source, which in this case is ^{210}Po.

It was mentioned earlier that surface barrier detectors are essentially 100% efficient for their active area. It is therefore quite easy to determine an unknown source activity.

Procedure

1. Carefully place the ^{210}Po source in the vacuum chamber (exactly 4 cm from the detector's face), adjust the gain so that the 5.31-MeV alpha is in the analyzer (about midscale), and accumulate a spectrum. Store the spectrum long enough for the sum under the peak (Σ_α) to be equal to ~2000 counts. Determine Σ_α.

2. Calculate the activity of the source from the following expression

$$\text{activity (alpha per s)} = \left(\frac{\Sigma_\alpha}{t}\right)\left(\frac{4\pi s^2}{\pi r^2}\right) \qquad (2)$$

where

s = distance from source to detector (4 cm in our example),
r = radius of the detector (cm),
t = time in seconds,
Σ_α = sum under the alpha peak.

Since 1 μCi = 3.7 x 10^4 disintegrations/s, the answer from Eq. (2) can easily be converted to μCi's and compared with the actual source activity. (If it is not written on the source, the laboratory instructor will supply the activity of the source.) Remember, the half-life of ^{210}Po is 138 days. If the instructor gives the activity of the source when it was made, a correction will have to be made for its present activity.

EXPERIMENT 4.5

Spectrum Expansion with a Biased Amplifier

Purpose

The purpose of this experiment is to see how the addition of a biased amplifier to the system will expand a portion of the spectrum. Connect the system as shown in Fig. 4.7.

The EG&G ORTEC 408A Biased Amplifier provides a variable bias level and a subsequent gain to the main amplifier output pulses. Each pulse that has an amplitude less than the bias level setting will be entirely eliminated from the spectrum. Each pulse that has an amplitude greater than the bias level will have the bias level subtracted from it, and the portion above the bias level can then be amplified by a factor of up to 20 using the selectable gain switch on the 408A. The bias level adjustment range is from 0 V (0/1000 on the bias level control) to ~10 V (1000/1000). Thus the minimum energy level of any area of interest in the spectrum can be selected, and the range above this level can be amplified, or expanded, for the desired lower keV/channel analyzer distribution. This experiment, and also Experiment 4.6, shows the advantages of this capability.

Procedure

1. Select a ^{241}Am source with a source thickness of ~15 keV or less. Place the source in the vacuum chamber, evacuate, and raise the detector bias gradually to the amount indicated on the detector data sheet. Adjust the gain of the 575A Amplifier for about 5 V output pulses. Set the bias level of the 408A Biased Amplifier at 0/1000 and its gain at 1; its output

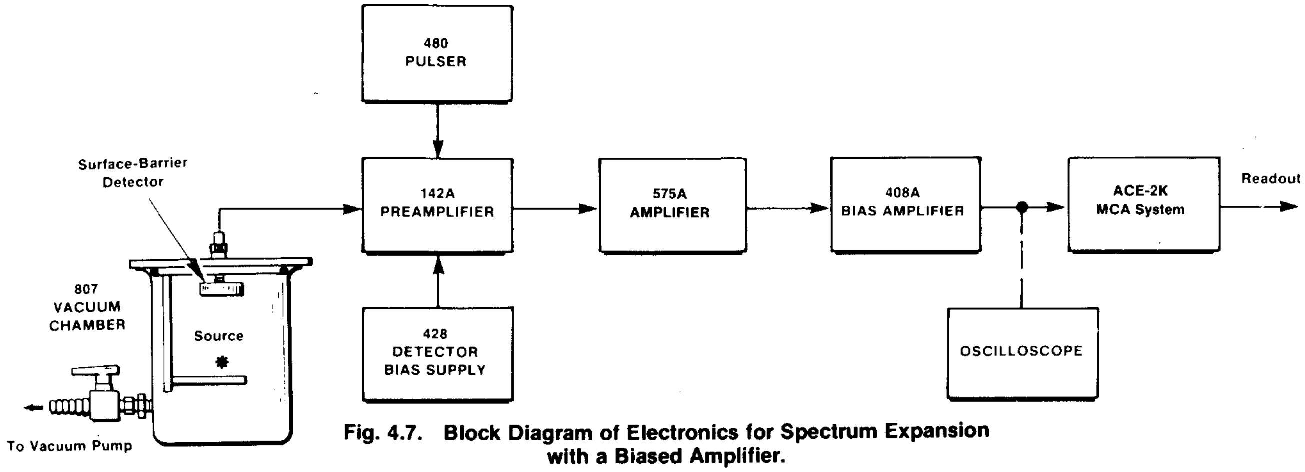

Fig. 4.7. Block Diagram of Electronics for Spectrum Expansion with a Biased Amplifier.

pulses should also be about 5 V. Accumulate a spectrum in the MCA and determine the peak channel location of the 5.48-MeV alpha from ^{241}Am.

2. Turn on the 480 Pulser and set its Pulse-Height control at 548/1000. Use the attenuation switches and the calibrate control to place the pulse generator pulses in the same channel location as the 5.48-MeV peak for the ^{241}Am source. This is the same procedure that was followed in Experiment 4.1. The pulse generator's Pulse-Height dial is now calibrated for 0 to 10 MeV.

3. Set the pulse generator at 4 MeV (400/1000). Switch the analyzer back to accumulate. Raise the bias level on the 408A while periodically observing where the pulses are being stored in the analyzer. Continue raising the bias level until the 4-MeV pulse just disappears at the low end of the MCA. The bias level is now set at 4 MeV. All pulses below 4 MeV are being blocked by the biased amplifier.

4. Set the pulse generator at 6 MeV (600/1000). Increase the gain of the 408A Biased Amplifier until the 6-MeV pulses are being stored in the top portion of the MCA. The analyzer is now roughly calibrated from 4 to 6 MeV. Clear the MCA.

Table 4.2

Time (approx. s)	Pulse Height Setting (Pulse Generator)	E (MeV)	Channel No.
20	420/1000	4.20	
20	460/1000	4.60	
20	480/1000	4.80	
40	500/1000	5.00	
20	520/1000	5.20	
20	560/1000	5.60	
20	580/1000	5.80	

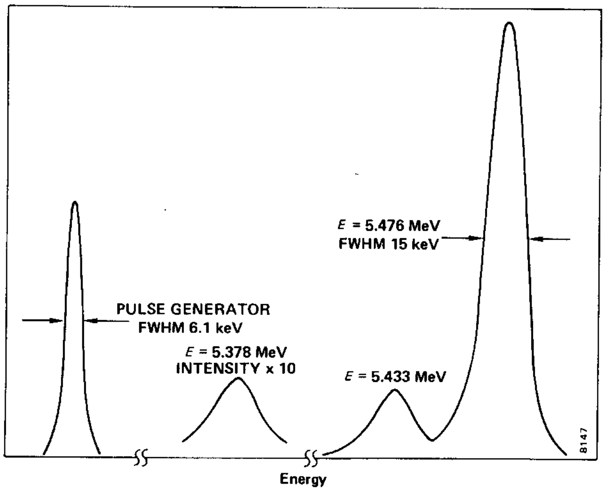

Fig. 4.8. ^{241}**Am Alpha Spectrum.**

5. Return the pulse generator to 4.20 MeV (420/1000) and accumulate in the MCA for ~20 s. Continue for the rest of the values in Table 4.2.

EXERCISE

From Table 4.2 plot E vs channel number and determine the keV/channel. This value can be used in Experiment 4.6. Compare this calibration curve with the one taken in Experiment 4.1 as shown in Fig. 4.4.

EXPERIMENT 4.6

Decay Ratios for ^{241}Am

This experiment is a continuation of Experiment 4.5.

Procedure

1. Clear the MCA and accumulate the ^{241}Am spectrum long enough to see a spectrum similar to that in Fig. 4.8.

2. From the MCA, determine the sum under the 5.476-MeV group. Call this sum Σ_2 since it comes from alpha decay to the second excited state of ^{237}Np (Fig. 4.9). In the same manner determine Σ_4 (5.433-MeV group) and Σ_5 (5.378 MeV).

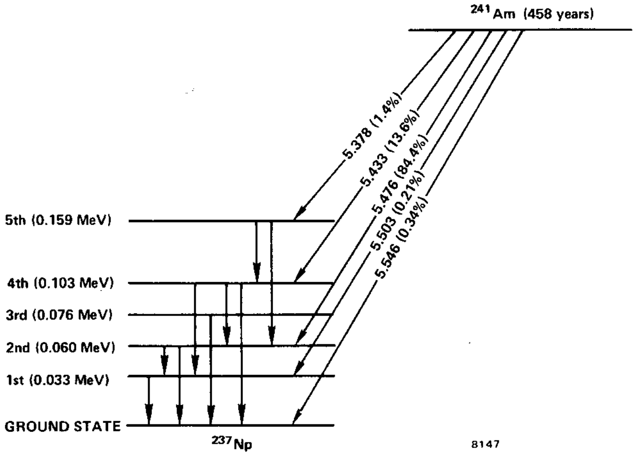

Fig. 4.9. Decay of ^{241}**Am.**

EXERCISES

a. With $\Sigma_T = \Sigma_2 + \Sigma_4 + \Sigma_5$, the decay ratio for α_2 (5.476 MeV) = Σ_2/Σ_T.

From your data, determine the decay ratios for α_2, α_4, α_5. How do your values compare with those in Fig. 4.9?

b. Determine the resolution of one of the pulser peaks in Table 4.2. Define this quantity to be δ_E. From step **2** find the resolution of the 5.476-MeV alpha group. Define this resolution to be δ_T, which is the combined effect of electronics (δ_E), source thickness (δ_s), and detector resolution (δ_D).

These quantities are said to add in quadrature. That is,

$$\delta_T^2 = \delta_E^2 + \delta_s^2 + \delta_D^2 . \qquad (3)$$

Therefore

$$\delta_D = \sqrt{\delta_T^2 - \delta_E^2 - \delta_s^2} . \qquad (4)$$

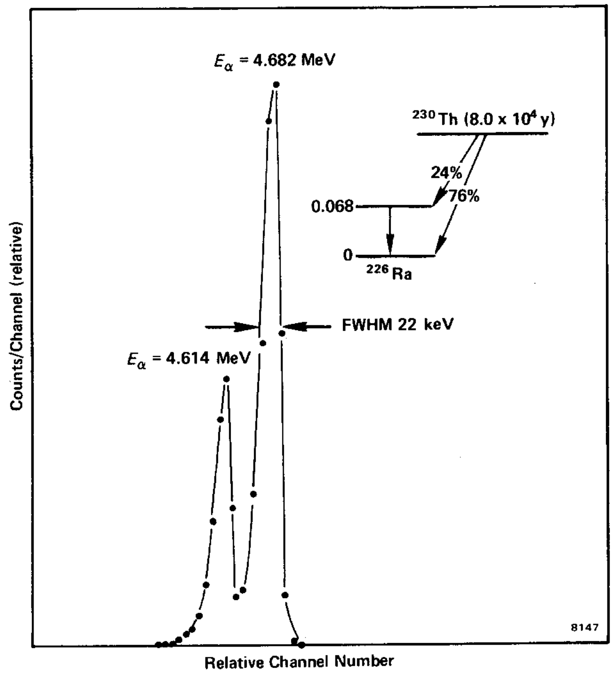

Fig. 4.10. Alpha Spectrum from the Decay of ^{230}Th Showing Alphas to the Ground and First Excited States in ^{226}Ra.

If the alpha source thickness is known, the other quantities can be measured. Find δ_D; how does its value compare with that given on the EG&G ORTEC specification sheet for the detector?

Figure 4.10 is a spectrum for ^{230}Th that has an FWHM of 22 keV.

References

1. G. F. Knoll, *Radiation Detection and Measurement*, John Wiley and Sons, New York (1979).

2. G. Bertolini and A Coche, Eds., *Semiconductor Detectors*, American Elsevier Publishing Co., Inc. (1968).

3. G. Dearnaley, "Nuclear Radiation Detection by Solid State Devices," *J. Sci. Instrum.* **43**, 869 (1966).

4. *Surface-Barrier Radiation Detectors Instruction Manual*, available from EG&G ORTEC.

5. J. L. Duggan, W. D. Adams, R. J. Scroggs, and L. S. Anthony, "Charged-Particle Detector Experiments for the Modern Physics Laboratory," *Am. J. Phys.* **35**(7), 631 (1967).

6. C. M. Lederer and V. S. Shirley, Eds., Table of Isotopes, 7th Edition, John Wiley and Sons, Inc., New York (1978).

7. G. T. Ewan, "Semiconductor Spectrometers" (in progress), *Nucl. Tech. and Instrum.* 3, F. M. Farley, Ed., Elsevier, North Holland, New York (1968).