AN34 Experiment 4

Alpha Spectroscopy with Surface Barrier Detectors

Equipment Needed from ORTEC

- Charged Particle Detector BU-014-050-100
- 142A Preamplifier
- 4001A/4002D NIM Bin and Power Supply
- 575A Spectroscopy Amplifier
- 807 Vacuum Chamber
- 428 Detector Bias Supply
- 480 Pulser
- C-36-12 Cable
- C-24-12 Cables (4 ea.)
- C-24-1 Cables (2 ea.)
- C-29 BNC Tee Connector
- TRUMP-2K-32 Plug-In MCA with MAESTRO-32 Software (other ORTEC MCA may be used)
- ALPHA-PPS-115 Portable Vacuum Pump Station

Other Equipment Needed

- Unsealed Alpha Sources (Disk Type) 0.01–0.1 µCi, ^{241}Am, ^{210}Po, ^{244}Cm (substitute alternate sources with similar energies)
- PC with Windows 98/2000/XP
- Oscilloscope

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 over 30 years, and have revolutionized nuclear particle detection. Publications in 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 even more significantly in their own field of photon spectroscopy.

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

The efficiency of silicon charged-particle detectors for their active volume is essentially 100%, and their energy vs. pulse-height curves are linear over a rather impressive range. 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 compact size make them easily adaptable to almost any counting geometry. The remaining fact of particular interest in the educational market is that they are relatively inexpensive.

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

Alpha Sources

CAUTION: Alpha sources offer a potential contamination problem. Never touch the face of a source with your fingers. Most alpha sources are electrodeposited onto platinum disks. The actual radioactive source is usually a spot ~1 mm diameter 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 the alpha source kit 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.

Ion-Implanted and Surface Barrier Detectors

There are three main parameters that define silicon charged-particle detectors: resolution, active area, and depletion depth. ORTEC model numbers reflect each of these three parameters in that order. The BU-014-050-100 is an ULTRA (ion-implanted) detector with a resolution of 14 keV FWHM for ^{241}Am alphas, an active area of 50 mm^2, and a minimum depletion depth of 100 µm. The quoted resolution of an ORTEC detector is a measure of its quality. These resolutions can be measured only with a complete set of electronics, calibrated for standard conditions. The ORTEC guaranteed resolutions are measured with standard 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.

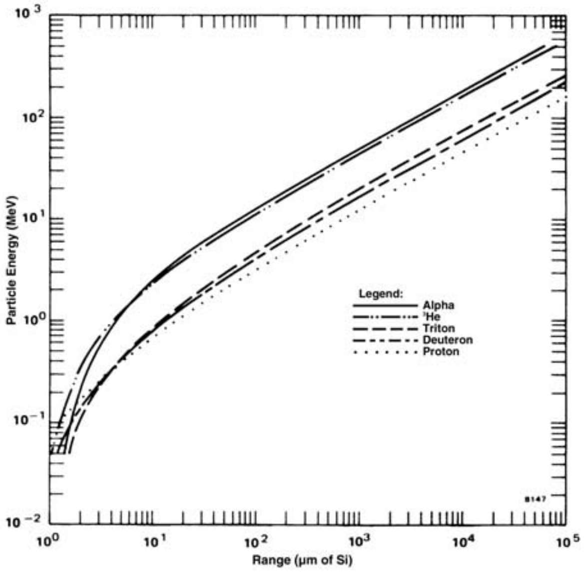

Fig. 4.1. Energy-Range Curves for Charged Particles in Silicon.[8]

The depletion depth is synonymous with the sensitive depth of the detector. For any experiment, the depth must be sufficient 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. Fig. 4.1 is a range-energy curve for five of the more common charged particles. From it, the minimum depth for the maximum energy of a particle type can be determined. From Fig. 4.1, note that a 5.5 MeV alpha is completey stopped by ~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 the Alpha Source Kit 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 gage is not available, a pumping time of 2 minutes is usually adequate. Set the 575A Amplifier for a positive input and unipolar output. Set the 480 for a negative pulse polarity and use the attenuated output. Set the 428 Bias Supply for a positive bias output and raise the voltage slowly to the value recommended on the detector data sheet. Voltage must be increased to compensate for the voltage dropped across the high-value resistor in the 142A Preamplifier. Refer to Section 4.7 of the Model 428 detector Bias Supply Manual.

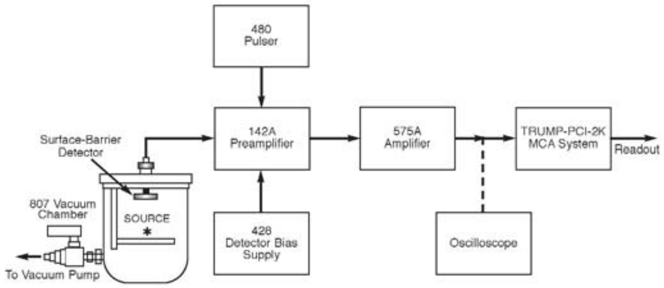

Fig. 4.2. System for Alpha Spectroscopy.

3. Adjust the gain of the 575A Amplifier until the pulse amplitude observed on 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. Acquire a spectrum in the MCA long enough to have about 400 counts in the peak channel. The spectrum should resemble that in 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; this represents the location in the spectrum for the ^{210}Po 5.305 MeV alpha events. The FWHM, measured in number of channels, is $\delta = 16$.

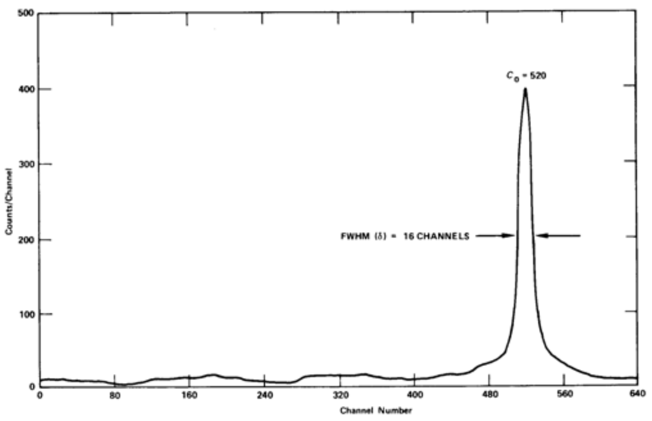

Fig. 4.3. Plot of a Typical ^{210}Po Alpha Spectrum.

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 seconds. Do they fall above or below channel C_0? Adjust the Calibrate control on the pulser as necessary to locate the peak exactly in channel C_0. The 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. Clear the MCA and accumulate the pulser pulses for ~20 seconds at each of the pulse-height values in Table 4.1. Determine their position with the cursor of the MCA.

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	

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 seconds.

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.

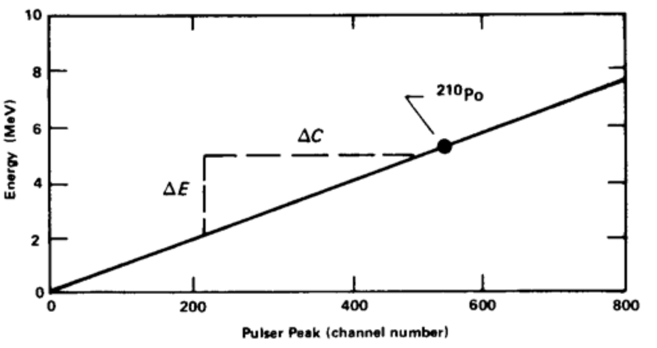

Fig. 4.4. Calibration Curve for Alpha Spectrometry.

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. Open the vent valve on the 807 Vacuum Chamber and allow the chamber to come up to atmospheric pressure. Open the chamber and replace the ^{210}Po source with the unknown source. Pump the vacuum back down to ~500 µm (approximately 2 minutes pumping time). Again, slowly increase the detector bias to its proper operating value. Turn off the 480 Pulser.

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

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.

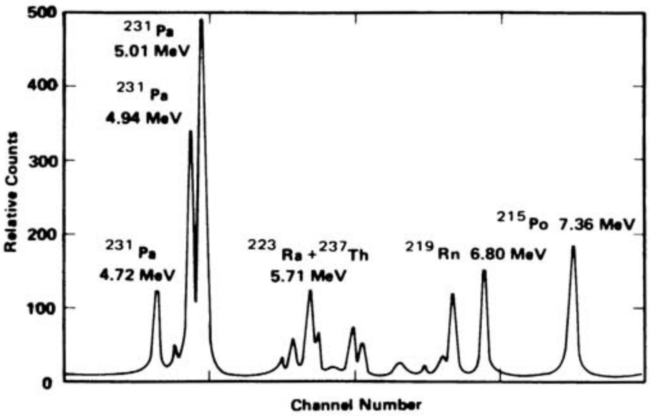

Fig. 4.5. Portion of a Typical ^{231}Pa Alpha Spectrum.

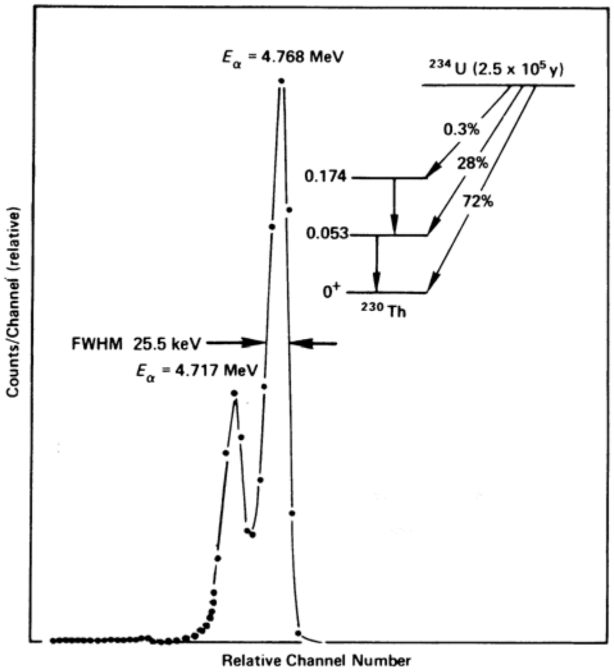

Fig. 4.6. Typical Alpha Spectrum from ^{234}U Showing Alphas from the Two States in ^{230}Th.

Identify the source by its energy or energies. Fig. 4.6 shows a ^{234}U spectrum that was taken with a 25.5 keV resolution.

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 ($E\alpha$ = 5.48 MeV) and ^{210}Po ($E\alpha$ = 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 MCA, for example, channel 800. Record the peak channel.

2. Replace the ^{241}Am with the ^{210}Po source and accumulate again for a long enough period of time to determine the peak position. If the MCA 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 location 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.

As was mentioned earlier, ion-implanted and 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 807 Vacuum Chamber exactly 4 cm from the face of the detector. Adjust the 575A Amplifier gain so that the 5.31 MeV alpha is about midscale in the MCA and accumulate a spectrum. Acquire the spectrum long enough for the sum under the peak ($\sum\alpha$) to be equal to ~2000 counts. Determine $\sum\alpha$.

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

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

where

s = distance from source to detector (4 cm in our example),

r = radius of the detector (cm),

t = time in seconds,

$\sum\alpha$ = sum under the alpha peak.

Since 1 µCi = 3.7 x 10^4 disintegrations/second, 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

Decay Ratios for ^{241}Am

Procedure

1. Clear the MCA and accumulate the ^{241}Am spectrum long enough to see a spectrum similar to that in Fig. 4.7.

2. From the MCA, determine the sum under the 5.476 MeV group. Call this the sum $\sum_2$ since it comes from alpha decay to the second excited state of ^{237}Np (Fig. 4.8). In the same manner, determine $\sum_4$ (5.433 MeV group) and $\sum_5$ (5.378 MeV).

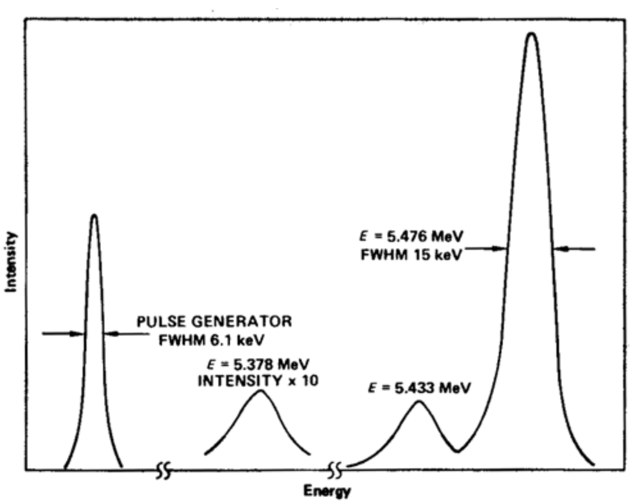

Fig. 4.7. ^{241}Am Alpha Spectrum.

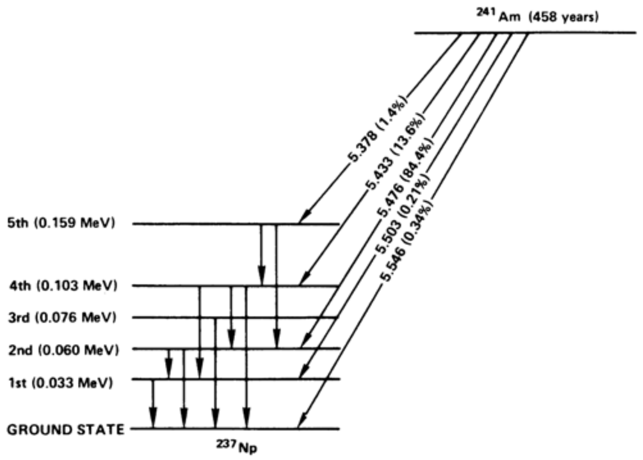

Fig. 4.8. Decay of ^{241}Am.

EXERCISES

a. With $\sum_T = \sum_2 + \sum_4 + \sum_5$, the decay ratio for α_2 (5.476 MeV) = $\sum_2 / \sum_T$.

From your data, determine the decay ratios for α_2, α_4, α_5. How do your values compare with those in Fig. 4.8?

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

$$\sqrt{\vphantom{x}}\;\overline{\delta_D = \delta_T^2 - \delta_E^2 - \delta_s^2} \qquad (4)$$

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 ORTEC detector specification sheet?

References

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8. 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).