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Experiment 20
A Study of the Decay Scheme of ^{244}Cm by an Alpha and X-Ray Coincidence Experiment

Equipment Required

- **5T1200B2/2** (Alpha Spectra) 1.2-inch x 0.2-inch NaI(Tl) detector with PMT and thin Be window for X-ray detection.
- **BU-021-450-100** ULTRA™ Ion-Implanted-Silicon Charged-Particle Detector
- **266** Photomultiplier Tube Base
- **113** Scintillation Preamplifier
- **142C** Preamplifier
- **428** Detector Bias Supply
- **556** High-Voltage Power Supply
- Two **575A** Amplifiers
- **480** Pulser
- **551** Timing Single-Channel Analyzer
- **427A** Delay Amplifier
- **416A** Gate and Delay Generator
- **4001A/4002D** NIM Bin and Power Supply
- **EASY-MCA-8K** System including a USB cable, a suitable PC and MAESTRO software.
- Two **C-24-1/2** RG-62A/U 93-Ω coaxial cables with BNC plugs, 15-cm (1/2-ft) length.
- Three **C-24-2** RG-62A/U 93-Ω coaxial cables with BNC plugs, 0.61-m (2-ft) length
- Four **C-24-8** RG-62A/U 93-Ω coaxial cables with BNC plugs, 2.4-m (8-ft) length
- Four **C-24-12** RG-62A/U 93-Ω coaxial cables with BNC plugs, 3.7-m (12-ft) length.
- Two **C-36-12** RG-59A/U 75-Ω coaxial cables with SHV female plugs, 3.7-m (12-ft) length.
- **ALPHA-PPS-115** (or -230) Portable Vacuum Pump Station
- **305-AX** Vacuum Chamber (with C-13 Microdot Vacuum Feedthrough for ULTRA detector mounting, adjustable source holder, and 0.9-mm thick carbon-fiber window for X-ray transmission)
- **TDS3032C** 300 MHz, 2-Channel Digital Oscilloscope
- **AF-244-PM-0.1*** (Eckert & Ziegler) 0.1-μCi ^{244}Cm radioactive source (with a thin front window for alpha-particle emission and a thin rear window for X ray emission)
- One **CS-137S*** 1-μCi ^{137}Cs radioactive source
- One **GF-057-M-5*** (Eckert & Ziegler) 5-μCi ^{57}Co radioactive source with a thin window for 6.4-keV X-ray and 14.4-keV gamma-ray emission.
- Small, flat-blade screwdriver for tuning screwdriver-adjustable controls, or an equivalent potentiometer adjustment tool.

*Sources are available direct from supplier. See the ORTEC website at www.ortec-online.com/Service-Support/Library/Experiments-Radioactive-Source-Suppliers.aspx

Purpose

This experiment demonstrates the technique for measuring the coincidence between alpha particles and x rays, and verifies the alpha-particle branching as indicated in ref.4 for ^{244}Cm.

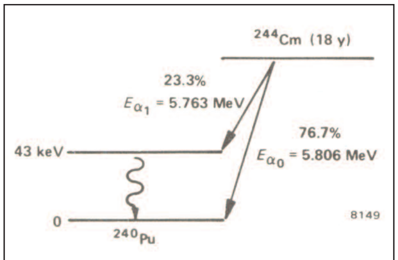

Fig. 20.1. Decay Scheme of ^{244}Cm.

Introduction

Coincidence events such as (γ,γ) have been studied in previous experiments. The decay scheme of ^{244}Cm, given in Fig. 20.1, shows that two alpha particle energies are present in the charged-particle spectrum. The energies are 5.806 MeV and 5.763 MeV. Figure 20.2 is a typical alpha spectrum of ^{244}Cm obtained with a silicon charged-particle detector.

The details of making measurements with silicon charged-particle detectors are covered in Experiment 4. The 43-keV level in Fig. 20.1 de-excites most of the time by internal conversion. The conversion-electron-to-gamma-ray yield ratio for this level is 760, which means there will be 760 conversion electrons for each 43-keV gamma-ray, on the average. This internal conversion process has to involve L- or M-shell electrons, since the binding energy of the K electron is 122 keV for ^{240}Pu. In other words, 43 keV is not enough energy to eject the K electrons from their tightly-bound shell. Therefore, most of the time, α_1 will be in coincidence with the L x rays resulting from the internal conversion process. This

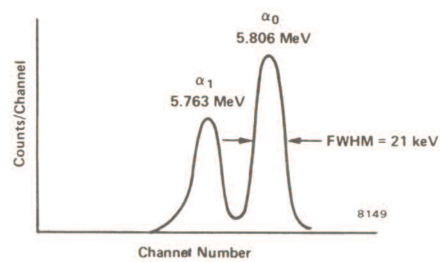

Fig. 20.2. The High-Energy Portion of the Alpha Spectrum from ^{244}Cm.

experiment will show that α_1, and only α_1, is coincident with the conversion electron x rays from the 43-keV state.

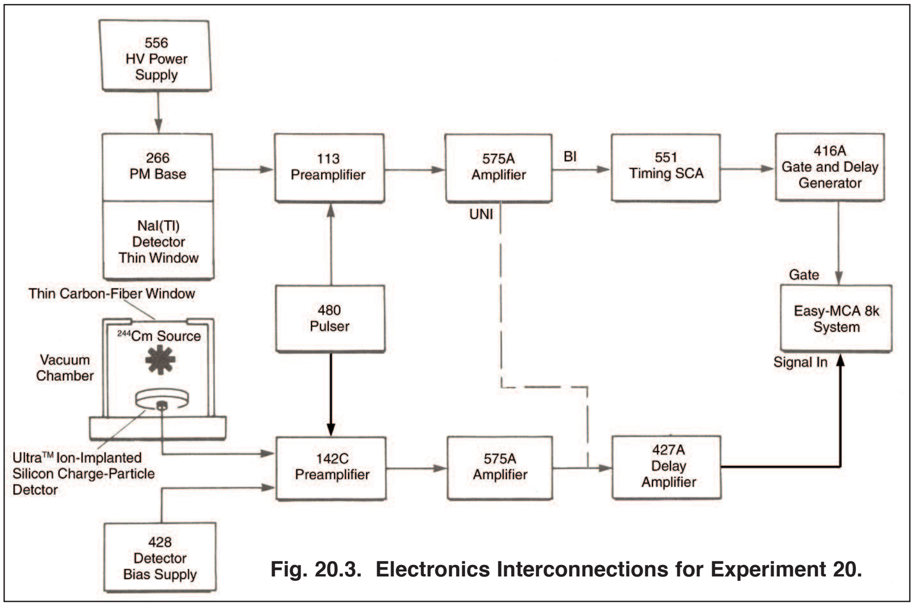

Fig. 20.3. Electronics Interconnections for Experiment 20.

Procedure

1. Connect the system as shown in Fig. 20.3. Details are as follows:
2. For the NaI(Tl) detector:
   a. Turn off power to the NIM bin and the 556 HV Power Supply.
   b. Ensure that the rear-panel polarity switch on the 556 is set to POSitive. Turn the HV controls to their minimum value.
   c. Using a 3-7-m C-36-12 RG-59B/U 75-Ω cable, connect one of the 556 HV OUTPUTS to the POS HV input of the 266 PMT base on the thin-window NaI(Tl) detector.
   d. Using a 15-cm C-24-1/2 RG-62A/U 93-Ω cable, connect the ANODE output of the 266 PMT Base to the INPUT of the 113 Preamplifier. Set the preamplifier INPUT CAPacitance to 0 pF.
   e. Check that the switches on the side panel of the 575A Amplifier supporting the NaI(Tl) detector are all set to 0.5 μs.
   f. Connect the power cable for the 113 Preamplifier to the rear-panel PREAMP POWER connector on this 575A Amplifier. Using a 3.7-m C-24-12 RG-62A/U 93-Ω coaxial cable, connect the 113 Preamplifier OUTPUT to the INPUT on the 575A Amplifier. Set the input polarity to NEGative on the 575A Amplifier.
   g. Connect the BIpolar OUTput of this 575A Amplifier to the DC INPUT of the 551 Timing SCA, using a 0.61-m C-24-2 RG-62A/U 93-Ω coaxial cable.
   h. Check that the LL REF and STROBE switches on the rear panel of the 551 are both in the INTernal position. On the front panel set the mode switch to NORmal, and the delay range switch to 0.1 – 1.1 μsec. Set the DELAY dial to its minimum value, and the UPPER LEVEL to its maximum value. Set the LOWER LEVEL dial to approximately 0.1 Volts.
   i. With a 0.61-m C-24-2 RG-62A/U 93-Ω coaxial cable connect the POSitive OUTput of the 551 SCA to the POSitive INPUT of the 416A Gate and Delay Generator. Connect the POSitive DELAYED OUTPUT of the 416A to the GATE input of the EASY-MCA with a 2.4-m C-24-8 RG-62A/U 93-Ω coaxial cable. Ensure that the EASY-MCA is connected to the supporting computer with a USB cable.
3. For the silicon charged-particle detector:
   a. Ensure that the dials on the 428 Detector Bias Supply are both set to their minimum values, and the bias voltage is turned OFF. Connect the A OUTPUT of the 428 to the BIAS input of the 142C Preamplifier with a 3.7-m C-36-12 RG-59B/U 75-Ω cable.
   b. Confirm that the silicon charged-particle detector is mounted in the vacuum chamber with its output connected to the vacuum feedthrough connector. To avoid damage to the detector, do not touch the sensitive area that accepts the alpha particles.
   c. Connect the BNC feedthrough on the outside of the vacuum chamber to the INPUT of the 142C Preamplifier using a 15-cm C-24-1/2 RG-62A/U 93-Ω cable.

d. Connect the power cable for the 142C Preamplifier to the rear-panel PREAMP POWER connector on the supporting 575A Amplifier. Ensure that the slide switches accessible though the side panel of the amplifier are all set to 1.5 μs. Using a 3.7-m C-24-12 RG-62A/U 93-Ω coaxial cable, connect the 142C Preamplifier E output to the INPUT of this same 575A Amplifier. Set the 575A INPUT polarity to POSitive.

e. With a 0.61-m C-24-2 RG-62A/U 93-Ω coaxial cable, connect the UNIpolar OUTput of the 575A Amplifier to the INPUT of the 427A Delay Amplifier.

f. Connect the OUTPUT of the 427A to the analog signal INPUT of the EASY-MCA with a 2.4-m C-24-8 RG-62A/U 93-Ω coaxial cable.

4. Source and vacuum chamber:

a. **CAUTION:** The ^{244}Cm is a thin window alpha source. The source material is a deposit that is located on one side of a thin metal foil. This minimum absorption side of the source should face the Ultra detector in the vacuum chamber to minimize the energy loss for the alpha particles. DO NOT TOUCH THE ACTIVE REGION OF THE ^{244}Cm SOURCE.

b. Place the ^{244}Cm source approximately 2.5 cm in front of the ULTRA detector in the vacuum chamber. Pump the vacuum in the chamber to lower than 200 μm using the fore pump.

c. Place the NaI(Tl) detector close to the chamber, and in a position to efficiently detect the x rays coming from the alpha source through the thin window of the vacuum chamber. The NaI(Tl) detector should be located about 2.5 cm from the source.

5. NaI(Tl) bias voltage and adjustments:

a. Turn on the power to the bin and to the computer supporting the EASY-MCA.

b. Connect the UNIpolar output of the 575A Amplifier on the NaI (Tl) detector side of the circuit to the 427A Delay Amplifier INPUT, as shown by the broken line in Fig. 20.3.

c. Via the MAESTRO software, turn the MCA Gate Off and set the MCA conversion gain to 1024 channels.

d. Turn on the 556 High Voltage Power Supply, and select the voltage recommended by the detector manufacturer.

e. Adjust the gain of the 575A Amplifier serving the NaI(Tl) to accumulate the spectrum on the MCA as shown in Fig. 20.4. It may be useful to use the 6.4- and 14.4-keV lines from a ^{57}Co source and the 32.2-keV x ray from a ^{137}Cs source to check the energy calibration of this spectrum, as illustrated in Fig. 20.4. The x rays observed in Fig. 20.4 are the L conversion x rays resulting from the internal conversion of the 43-keV level in ^{240}Pu.

f. If the pole-zero screwdriver control on the 575A has not been adjusted to match the specific 113 preamplifier, implement the pole-zero adjustment procedure in the Appendix.

6. Adjusting the 551 SCA:

a. With the 575A UNIpolar output still connected to the 427A Delay Amplifier INPUT, trigger the oscilloscope with the NEGative DELAYED OUTPUT of the 416A.

b. Connect the POSitive DELAYED OUTPUT of the 416A to one input of the oscilloscope. Adjust the logic signal amplitude to be approximately +5 V. Set the coarse and fine DELAY controls to the minimum values.

c. Connect the OUTPUT of the 427A Delay Amplifier to the second input of the oscilloscope.

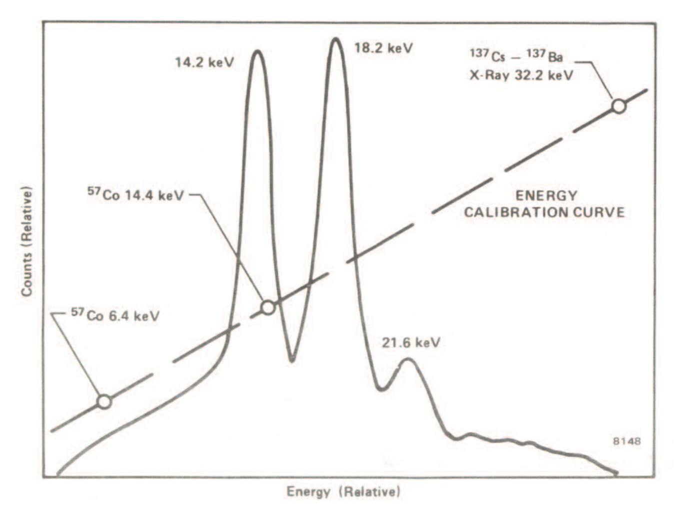

Fig. 20.4. X-ray Spectrum from the ^{244}Cm Source Acquired with the Thin-Window NaI(Tl) Detector.

d. Choose the minimum DELAY on the 427A that causes the positive UNIpolar output of the 575A Amplifier to begin just after the leading edge of the positive logic signal from the 416A.

e. Adjust the WIDTH and DELAY of the 416A OUTPUT so that this gating pulse commences at the beginning of the UNIpolar pulse from the 575A and extends for 4 microseconds. (While a shorter width would span the signal from the scintillation detector, the 4-μs gate pulse duration will be needed with the silicon charged-particle detector.)

f. Reconnect the 416A POSitive DELAYED OUTPUT to the GATE input of the EASY-MCA, and the 427A OUTPUT to the analog signal INPUT of the EASY-MCA.

g. Via the MAESTRO software, turn on the Gate requirement for the EASY-MCA. Adjust the LOWER LEVEL and the UPPER LEVEL of the 551 so that spectral acquisition comfortably spans only the 14.2-keV, 18.2-keV and 21.6-keV x rays. Lock the LOWER and UPPER LEVEL dials at those settings.

h. Disconnect the 427A INPUT from the NaI(Tl) 575A Amplifier, and connect it instead to the UNIpolar output of the 575A Amplifier serving the silicon charge-particle detector.

7. Adjusting the gate for the silicon charged-particle detector.

a. Turn on the 428 Detector Bias Supply with a POSitive voltage. Slowly raise the voltage on the A dial to the setting recommended for the silicon detector.

b. Observe the OUTPUT of the 427A Delay Amplifier on the oscilloscope, with the ‘scope triggered on this analog pulse. Adjust the gain of the 575A Amplifier serving the charged particle detector to achieve a pulse amplitude between +8 V and +9 V for the 5.763-MeV and 5.806-MeV alpha particles.

c. If the pole-zero screwdriver control on the 575A has not been adjusted to match the specific 142C preamplifier, implement the pole-zero adjustment procedure in the Appendix.

d. Using a 3.7-m C-24-12 RG-62A/U 93-Ω coaxial cable, connect the DIRECT OUTPUT of the 480 Pulser to the TEST PULSE input of the 113 Preamplifier. Set the Pulser polarity to NEGative, and turn it on.

e. On the oscilloscope, observe the UNIpolar OUTput of the 575A Amplifier that supports the NaI(Tl) detector. Adjust the CAL and PULSE HEIGHT controls on the 480 Pulser to achieve a +5 V pulse height from the UNIpolar OUTput.

f. Check that the 416A is producing a gate pulse for each Pulser event. If not, then adjust the PULSE HEIGHT dial up or down until the pulse amplitude lies in the window selected by the 551 SCA, thus producing gating pulses. Lock the PULSE HEIGHT dial.

g. Using a 3.7-m C-24-12 RG-62A/U 93-Ω coaxial cable, connect the ATTENuated OUTPUT of the 480 Pulser to the TEST input of the 142C Preamplifier.

h. Observe the OUTPUT of the 427A on the oscilloscope. Adjust the ATTENUATOR switches on the 480 Pulser until the pulse amplitude is in the range of +1 to +9 Volts.

i. Trigger the oscilloscope from the NEGative output of the 416A Gate and DELAY GENERATOR.

j. Observe both the OUTPUT of the 427A and the POSitive DELAYED OUTput of the 416A on the oscilloscope. Make any necessary fine adjustments of the 427A DELAY and the 416A DELAY to ensure the 416A gate pulse starts at the beginning of the 427A pulse and extends past the peak amplitude of the 427A OUTPUT pulse. This adjustment is similar to steps 6d and 6e.

k. Turn off the 480 Pulser and ensure the 416A POSitive DELAYED OUTput is connected to the GATE input and the 427A is connected to the analog signal INPUT on the EASY-MCA.

l. Set the EASY-MCA conversion gain to nominally 8,192 channels full scale, and ensure that the coincidence gating requirement is turned off.

m. Adjust the gain on the 575A Amplifier to accumulate the 5.763-MeV and 5.806-MeV alpha peaks in the top eighth of the EASY-MCA spectrum. The spectrum should look similar to that shown in Fig. 20.2.

8. Check that the 416A gating pulse is connected to the GATE input of the EASY-MCA. Via the MAESTRO software turn on the coincidence gate requirement for data acquisition.
9. Accumulate a spectrum on the MCA long enough to clearly see that the 5.806-MeV alpha is no longer present in the spectrum. A counting period of 1 to 2 hours will be required for a ^{244}Cm source with a 0.1-μCi activity. The resulting spectrum should resemble Fig. 20.5 because the 5.763-MeV alphas are in coincidence with the x-rays and will be present in the spectrum but the 5.806-MeV alphas are not in coincidence with the x-rays and are therefore eliminated from the spectrum.

   This result confirms that the 5.763-MeV alpha decay of ^{244}Cm feeds the 43-keV excited state in ^{240}Pu, and the 5.806-MeV alpha decay corresponds to a direct transition to the ground state of ^{240}Pu.

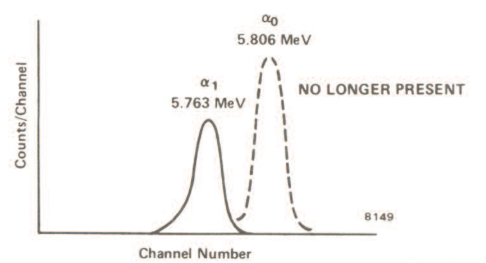

Fig. 20.5. The high-energy Spectrum from the ^{244}Cm source, showing the 5.763-MeV and 5.806-MeV alpha-particle peaks. The dashed peak disappears when a coincidence with the x rays is demanded.

10. Turn off the detector bias voltage. Vent the chamber to atmospheric pressure. Remove the radioactive source and return it to its secure, shielded, storage container.

References

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3. G. Dearnaley, “Nuclear Radiation Detection by Solid State Devices,” J. Sci, Instrum., 43, 869 (1966).
4. C. M. Lederer and V. S. Shirley, Eds., Table of Isotopes, 7th Edition, John Wiley and Sons, Inc. New York (1978).
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6. R. D. Evans, The Atomic Nucleus, McGraw-Hill (1955).
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8. Application notes, technical papers, and introductions to each product family at www.ortec-online.com.

Appendix

Apparatus Description

The Model 305 Vacuum Can with Thin Plastic Window, as pictured in Fig. 20.6, was originally manufactured by Metrix, and is no longer available from that source. The Axiom 305-AX Vacuum Chamber is similar in construction. But, it features a carbon-fiber window that allows 80 to 90% transmission of the Pu L x rays.

The radioactive source holder can be adjusted so that it can be moved along the counting axis approximately 2 inches (5.1 cm). This allows the student to maximize the counting geometry between the silicon charged particle detector and the x-ray or gamma-ray detector. The chamber uses a standard ORTEC Ultra Ion-Implanted Silicon Detector with a Microdot-to-BNC vacuum feedthrough.

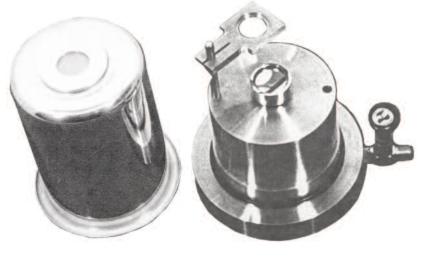
Fig. 20.6 The original Metrix Model 305 Vacuum Chamber.

Pole-Zero Adjustment for the NaI(Tl) Detector, 113 Preamplifier and 575A Amplifier

1. Place a ^{137}Cs or ^{57}Co radioactive source in front of the NaI(Tl) detector.
2. Connect the UNipolar OUTput of the 575A Amplifier to the 1-MΩ input of the oscilloscope.
3. Set the horizontal scale of the oscilloscope to 50 μs/cm and the vertical scale to 100 mV/cm.
4. With a small, flat-blade screwdriver, adjust the PZ ADJ on the 575A Amplifier to make the pulses on the UNIpolar

OUTput return to baseline as quickly as possible without undershooting the baseline between pulses. For further guidance on this Pole-Zero Cancellation adjustment, consult the instruction manual for the amplifier, or the introduction to the amplifier product family on the ORTEC web site at www.ortec-online.com.

5. Remove the radioactive source specified in step 1, and restore the 575A UNIpolar output connection to its normal location in the experiment.

Pole-Zero Adjustment for the Silicon Charged-Particle Detector, 142C Preamplifier and 575A Amplifier

1. Ensure that there is a radioactive source supplying alpha particles to the detector with energies of at least 5 MeV.
2. Connect the 575A UNIpolar OUTput to the 1-MΩ input of the oscilloscope.
3. Set the horizontal scale of the oscilloscope to 1 ms/cm and the vertical scale to 100 mV/cm.
4. With a small, flat-blade screwdriver, adjust the PZ ADJ on the 575A Amplifier to make the pulses on the UNIpolar OUTput return to baseline as quickly as possible without undershooting the baseline between pulses.
5. For further guidance on the Pole-Zero Cancellation adjustment, consult the instruction manual for the amplifier, or the introduction to the amplifier product family on the ORTEC web site at www.ortec-online.com.
6. Return the 575A UNIpolar OUTput to its original connection, and remove any specially inserted alpha source, if necessary for the rest of the experiment.

Specifications subject to change
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