ORTEC®

Experiment 6
Beta Spectroscopy

Equipment Required

• **BA-016-025-1500** Partially-Depleted Silicon Surface-Barrier Detector model • **142A** Preamplifier • **4001A/4002D** NIM Bin and Power Supply • **575A** Spectroscopy Amplifier • **807** Vacuum Chamber • **710** Quad 1 kV Bias Supply • **480** Pulser • **EASY-MCA-8K** System including a USB cable, and MAESTRO software (other ORTEC MCAs may be substituted) • **C-36-12** RG-59A/U 75-Ω Coaxial Cable with SHV Plugs, 12-ft (3.7-m) length • **C-24-1/2** RG-62A/U 93-Ω Coaxial Cable with BNC Plugs, 0.5-ft. (15-cm) length • Two **C-24-4** RG-62A/U 93-Ω Coaxial Cables with BNC Plugs, 4-ft. (1.2-m) length	• Two **C-24-12** RG-62A/U 93-Ω Coaxial Cables with BNC Plugs, 12-ft (3.7-m) length • **C-29** BNC Tee Connector • **ALPHA-PPS-115** (or 230) Portable Vacuum Pump Station • **TDS3032C** Oscilloscope with bandwidth ≥150 MHz • **BF-113-A-1*** 1 μCi ^{113}Sn Beta Source. A license is required for this source. • **BF-137-A-0.1*** 0.1 μCi ^{137}Cs Beta Source. A license is required for this source. • **BF-204-A-0.1*** 0.1 μCi ^{204}Tl Beta Source. A license is required for this source. • Small, flat-blade screwdriver for tuning screwdriver-adjustable controls • Personal Computer with USB port and Windows operating system • Access to a suitable printer for printing/plotting spectra acquired with MAESTRO
*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 of obtaining the energy spectrum from beta decay, and outlines a method for determining the endpoint energy. The internal conversion decay mechanism is also covered, because it offers well defined energy peaks from conversion electrons that can be used to calibrate the energy scale. Instrumentation and set-up is similar to that employed in Experiment 4. Consequently, Experiment 4 is a prerequisite for implementing this experiment.

Relevant Information

Beta Decay

The measurement of beta-particle energies can be made with charged-particle detectors, using the same techniques that were outlined in Experiment 4. Beta decay occurs when a nucleus has an excess number of neutrons compared to its more stable isobar. For example, ^{204}Tl decays to ^{204}Pb and emits a beta particle. In order to achieve stability, one of the neutrons in the nucleus of the ^{204}Tl is converted to a proton. The process is

$$n \rightarrow p + \beta^- + \bar{\nu} \qquad (1)$$

Where $\bar{\nu}$ is an antineutrino.

From equation (1) you can see that there are three particles in the final state, the beta particle, the antineutrino and the daughter nucleus, (in which the final proton is bound). The decay energy will be distributed among those three objects. The electron (β^-) has a miniscule mass compared to the daughter nucleus, and the antineutrino has essentially zero rest mass. Therefore, virtually all of the available decay energy is shared between the β^- and $\bar{\nu}$ particles. Theoretically, the β^- particle could have any energy up to the maximum (E_{max}). But, the probability that any decay event will have this amount of energy accompanying its β^- particle is very low. Consequently, the beta-particle energy will vary randomly from 0 to E_{max}. Curiously, the antineutrino is very difficult to detect, because it has no charge and essentially zero rest mass. Consequently, the antineutrino is not easily stopped in a detector having a bench-top size. Therefore, most of the observations of beta decay are based on measuring the energy of the beta particle. The spectrum of energies carried off by the antineutrino can be inferred from the beta-particle energy spectrum. See reference 9 to find out why postulating the existence of the antineutrino was necessary to explain what was observed in beta decay.

Fig. 6.1 shows a beta-decay spectrum for ^{204}Tl. It illustrates the relative probability that the beta particle will carry off a specific fraction of E_{max} for a large number of random decay events. This continuum of energies is typical for β^{-} decays. The energy that corresponds to the extrapolated baseline crossover of the curve (around channel 350 in Fig. 6.1) is the endpoint energy, E_{max}. From reference 7, this endpoint energy for ^{204}Tl is 0.766 MeV.

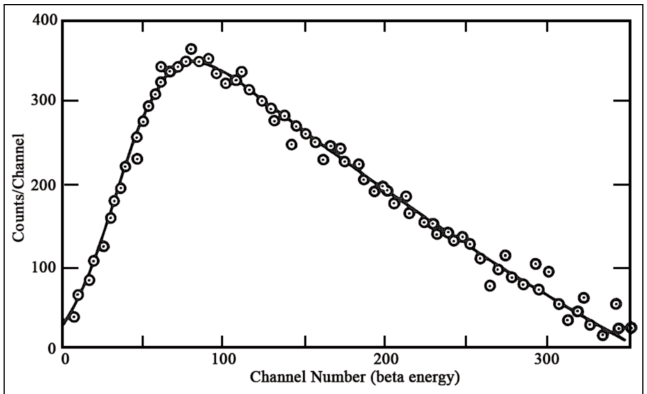

Fig. 6.1. The Beta-Decay Energy Spectrum for ^{204}Tl.

Internal Conversion Electrons

The energy spectrometer can be calibrated by using radioisotopes that emit conversion electrons having a precisely defined energy. In the internal conversion process, it is possible for a nucleus to impart its energy of excitation directly to one of its nearby orbiting electrons. Consequently, the electron is ejected from the atom with a discrete energy, E_e. This energy is given by

$$E_e = E_x - E_B \quad (2)$$

where

E_e = the measured energy of the conversion electron,

E_x = the excess energy available in the decay,

E_B = the binding energy of the orbiting electron in the atom.

These three quantities can be found in reference 7. Figs. 6.2, 6.3, and 6.4 show the conversion electron spectra for ^{207}Bi, ^{113}Sn, and ^{137}Cs. The calibration curve for channel number vs. energy is also shown in Fig. 6.2.

Internal conversion competes with gamma-ray emission for discharging the excess energy created in the daughter nucleus after a radioactive decay by some other process. Internal conversion becomes more likely for nuclei with high atomic numbers, where the inner shell electrons can spend some of their time travelling through the nucleus. When the spin change between the excited state and the ground state inhibits a gamma-ray transition, or if the energy of the excited state is very low, the situation favors internal conversion. However, as Fig. 6.2 demonstrates, conversion electron energies as high as 1 MeV can be found. Reference 1 presents a table listing 5 radioisotopes that produce conversion electron spectra that are useful for energy calibration.

As Figure 6.4 illustrates, the spectrum often incorporates a beta-decay continuum with conversion-electron peaks superimposed on that continuum. The continuum is generated by the beta decay of the parent nucleus, and the conversion electrons come from the daughter nucleus discharging the excess energy.

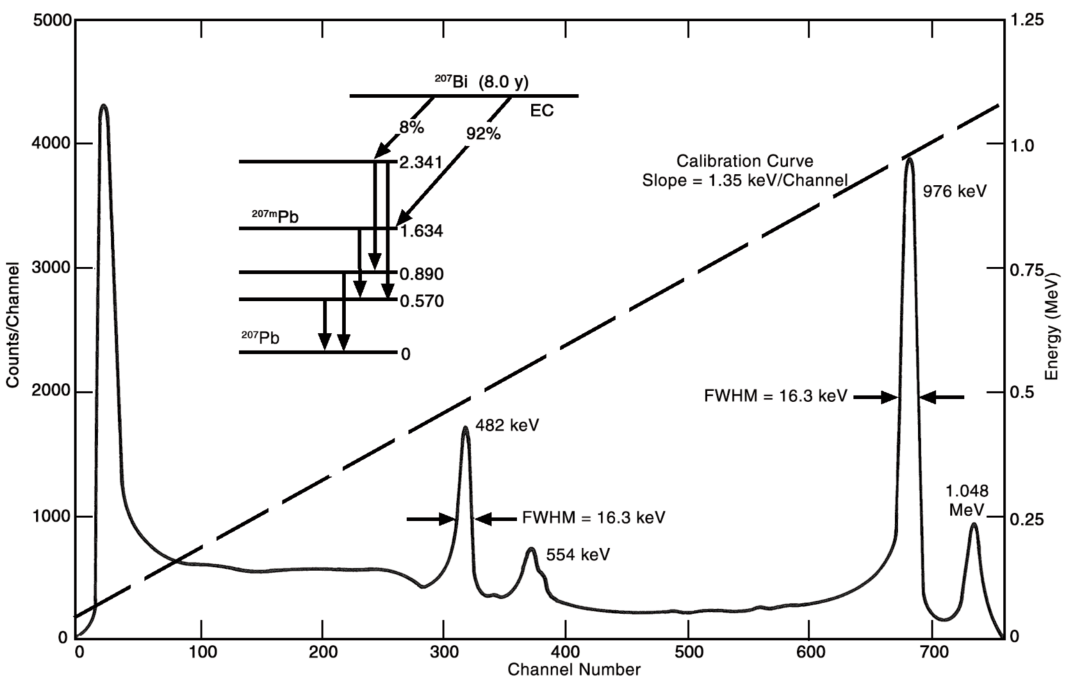

Fig. 6.2. The Conversion Electron Spectrum for ^{207}Bi.

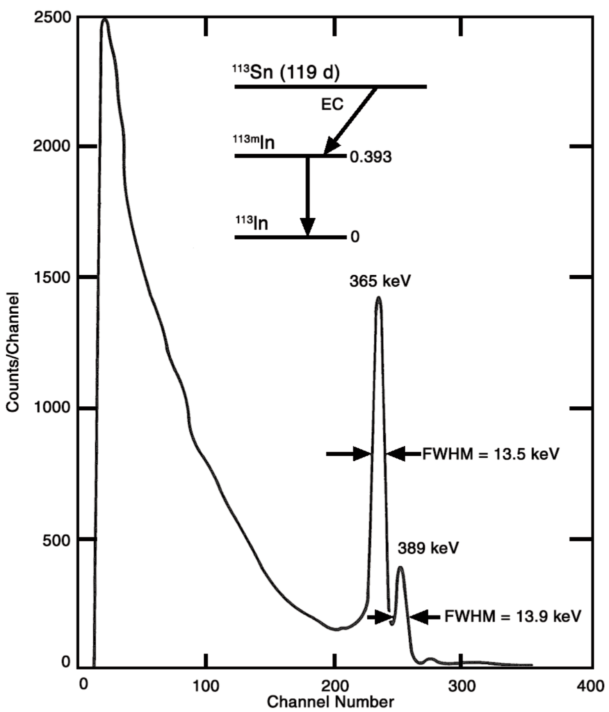

Fig. 6.3. The Conversion-Electron Spectrum for ^{113}Sn.

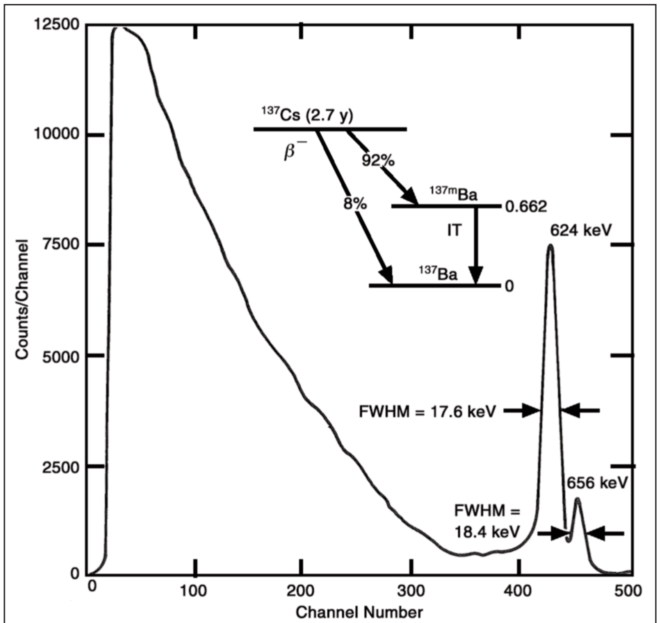

Fig. 6.4. The Beta Continuum and Conversion-Electron Spectrum from ^{137}Cs.

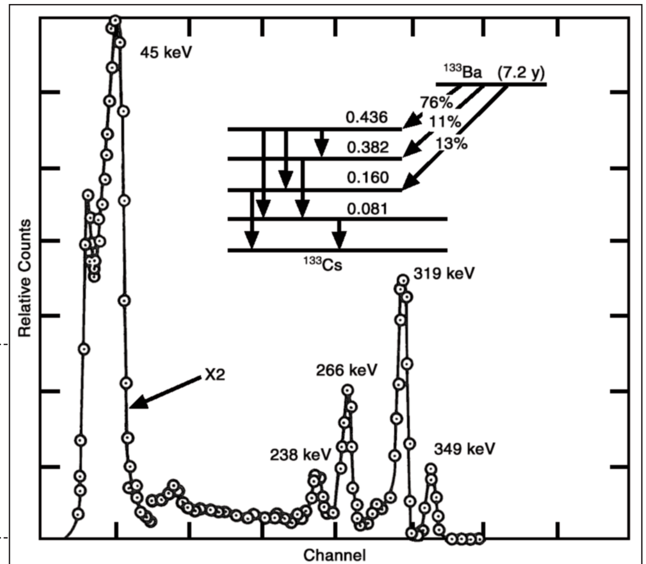

Fig. 6.5. The Conversion-Electron Spectrum from ^{133}Ba.

Application of Surface Barrier Detectors

The range of 800-keV beta particles in silicon demands a detector with a 1500-micron depletion depth. Consequently, one has to turn to a very expensive surface barrier detector to achieve that large sensitive depth. The BA-016-025-1500 silicon surface barrier detector specified in the list of equipment requires special care in handling and use to avoid destroying the detector. See the important warning below.

DETECTOR WARNING

Never touch the exposed surface of this non-ruggedized detector with any foreign material — especially your fingers. The front window is a thin layer of deposited gold which will be irreparably damaged by skin oils or any abrasive, thus destroying the function of the detector. Always handle the detector by its edges and/or in its protective case.

Fig. 6.6 shows a range vs. energy curve for beta particles in silicon. If the maximum beta energy for an isotope is known, the required detector thickness can be determined from the curve. The maximum energy for Experiment 6 will be the 766 keV endpoint energy for the β^- particle from ^{204}Tl, as shown in Fig. 6.1. According to Fig. 6.6, a 800-keV beta would have a range of ~1400 μm. Therefore, for this experiment, a 1500 μm depletion depth is recommended.

The parameters for the recommended detector can be derived from the model number, BA-016-025-1500. The “A” specifies the series of partially-depleted silicon surface barrier detectors. The “B” designates a Microdot connector centered on the rear of the detector enclosure. The rest of the numbers fulfill the notation: BA-RESOLUTION-AREA-DEPLETION, where RESOLUTION is the energy resolution for 5.486 MeV alpha particles from a ^{241}Am source, AREA is the sensitive area of the detector in mm^2, and DEPLETION is the depletion depth of the detector in μm.

For further information on silicon semiconductor detectors, review the Silicon Charged-Particle Detectors preamble in Experiment 4, and the information in reference 8.

Detector Leakage Current Requires Bias Voltage Compensation

With a surface-barrier detector, one must almost always compensate for the voltage drop caused by the leakage current when setting the bias voltage. There is a 100 MΩ resistor between the BIAS input and the detector INPUT connector on the 142A Preamplifier. The function of that resistance is to suppress high-frequency noise from the bias supply, and allow virtually all of the charge from the detector to reach the preamplifier input.

Surface-barrier detectors have a typical leakage current of the order of 50 nA. Such a high leakage current would cause a 5 V drop in voltage across the 100 MΩ resistor. Therefore, one would have to raise the voltage of the detector bias supply by 5 V above the desired bias voltage to achieve the specified bias voltage at the detector. This can be a significant adjustment when the bias voltage for the detector is in the range of 50 to 100 V.

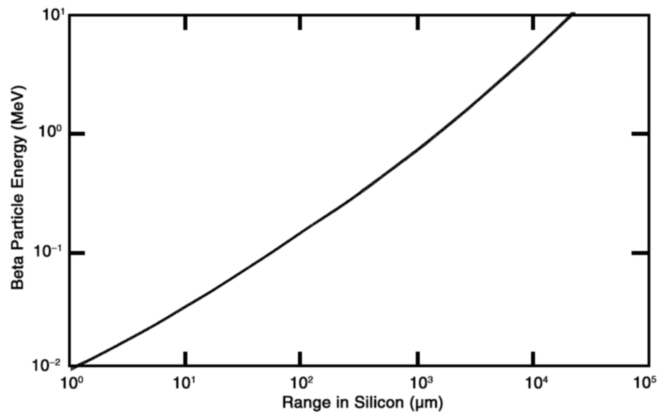

Fig. 6.6. Beta Energy vs. Range in Silicon.

Equation (3) provides a crude guide for the leakage current one can expect from a silicon surface barrier detector (ref. 8).

$$I_L = \left(\frac{D}{100}\right) i_1 A \tag{3}$$

Where:

I_L is the predicted leakage current for the detector,

D is the depletion depth of the detector in microns,

i_1 is the specific leakage current per cm^2, and

A is the active area of the detector in cm^2.

The value of i_1 ranges from 20 to 100 nA/cm^2. This room-temperature prediction is approximate, because of the wide range of i_1, and the fact that the leakage current will increase by about a factor of 2 for every 7°C increase in temperature. The leakage current depends on the resistivity of the depleted silicon, the depletion depth and the applied bias voltage. For small diameter detectors, leakage current at the edges can be a significant addition to the leakage current through the bulk of the detector.

The recommended bias voltage for achieving the specified depletion depth, and the leakage current measured at the factory for that voltage (at 65°F/18°C) are typically listed on the data sheet accompanying the detector. For the BA-016-025-1500 detector, the bias voltage for 1500 microns depletion will likely lie in the range of 200 to 500 V, and the leakage current typically will be in the range of 0.2 to 1 μA at 18°C.

The ORTEC Model 710 Quad 1 kV Bias Supply has been selected for this experiment, because it enables the experimenter to easily measure the actual detector leakage current, and compensate for the voltage drop across the 100 MΩ series resistor in the preamplifier.

Handling Radioactive Beta Sources

Compared to alpha particles of the same energy, beta particles have orders of magnitude greater range in materials. For example, a 1-MeV beta particle penetrates about a factor of 570 further in silicon than a 1-MeV alpha particle (~2000 μm vs. ~3.5 μm). Whereas alpha sources must be fabricated with no protective window, beta sources can be sealed behind a 6.4 μm thick aluminized Mylar window. This reduces the risk of migration of the radioactive material. However, it is still wise to avoid touching the active center of the source, by handling it via the outer diameter of the disk. The recommended sources have a thick aluminum backing. Consequently, it is important to orient the aluminized Mylar window towards the detector.

EXPERIMENT 6.1 Set-up and Calibration with a Pulser

The equipment used in this experiment is essentially the same as the system for Experiment 4. Review the rules in Experiment 4 that explain how to properly apply the bias voltage, when the vacuum chamber is to be pumped down, the procedures for changing a source, etc. The methods explained there are basic, but the operating precautions in this experiment are much more important, because you are working with a more delicate and expensive detector.

Procedure

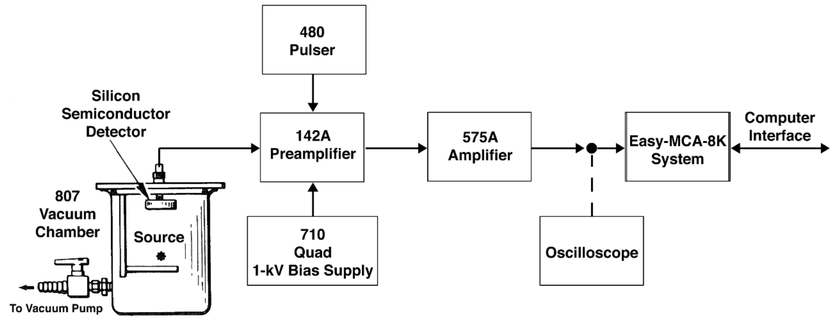

Fig. 6.7. The System for Beta Spectrometry.

1. Connect the equipment as shown in Fig. 6.7. Use the same set-up and settings as established in Experiment 4.1, except the shaping time constant switches on the 575A amplifier must be set to 0.5 μs, and the appropriate bias voltage must be selected to suit the BA-016-025-1500 detector. See the data sheet for the detector to determine the recommended bias voltage. The gain of the 575A amplifier will be selected in a later step.
2. To use the 710 Bias Supply instead of the 428 Bias Supply, connect the Channel 1 HV OUTput on the rear panel of the 710 Bias Supply to the BIAS input on the 142A Preamplifier using the 3.7 m, C-36-12 RG 59A/U 75-Ω Coaxial Cable with SHV Plugs. On the 710 turn the MASTER switch OFF and set all 4 of the 1 kV/100 V/DISABLE switches to DISABLE. Turn all VOLTAGE dials to their minimum value (fully counter-clockwise).
3. Turn on the power to the 4001A/4002D NIM Bin and Power Supply.
4. Install the ^{137}Cs source about 1/4-inch (0.6 cm) from the face of the detector. Pump down the vacuum chamber.
5. On the 710 Bias Supply, confirm that the green POSitive-polarity LED is glowing for the Channel being utilized. (If the NEGative LED is on, the polarity will have to be corrected to POSitive by a printed wiring board jumper.)
6. On the 710, turn the MASTER switch ON. Confirm that the VOLTAGE dial on Channel 1 is at zero. Set the RANGE switch on Channel 1 to 1 kV. Set the VOLTS/CURRENT rotary switch to Channel 1 VOLTS so that the exact voltage applied can be monitored on the display.
7. On the 710 gradually turn the Channel 1 VOLTAGE dial to increase the voltage to the value specified on the detector data sheet.
8. Once the recommended bias voltage is set, turn the rotary VOLTS/CURRENT switch to the Channel 1 CURRENT. Read the current in μA on the display. Multiply the measured current by 100 MΩ to find the incremental voltage that must be added to the bias voltage to compensate for the voltage drop caused by the leakage current on the 100 MΩ series resistor in the preamplifier.
9. Switch the rotary switch to the Channel 1 VOLTS, and adjust the bias voltage to add the increment calculated in the previous step. Record this operating voltage for future reference.
10. Adjust the 575A Amplifier gain until the pulses observed on the oscilloscope are ~5.6 V in amplitude. The most pronounced pulse amplitudes will represent the 624 keV energy of the K-shell conversion electrons.
11. Using the pulses from the ^{137}Cs source, check the pole-zero cancellation adjustment as outlined in Experiment 4, and adjust it if necessary.
12. Accumulate a spectrum with enough counts to identify the channel location in the MCA for the 624 keV line. Adjust the amplifier gain to place the 624 keV peak at about channel 4500 on the 8000-channel MCA. (In Fig. 6.4 the peak is at approximately mid-scale for a 1024-channel analyzer.) When the gain has been properly adjusted, accumulate a spectrum with ~1000 counts in the 624 keV peak. Record the channel number for the 624 keV peak, and call this channel C_0.
13. Save the ^{137}Cs spectrum on the hard disk for future reference.
14. Turn down the bias voltage for the detector, vent the vacuum and remove the ^{137}Cs source from the chamber.
15. Pump down the chamber, and apply the proper bias voltage to the detector.
16. Turn on the 480 Pulser and adjust its PULSE-HEIGHT dial to 624/1000 divisions. Use the ATTENUATOR switches and the CALibration potentiometer to position the pulser peak in channel C_0. The pulser is now calibrated so that 1000 keV = 1000 dial divisions on the PULSE-HEIGHT control.
17. Clear the contents of the MCA memory, and acquire spectra with the Pulser dial set to the values listed in Table 6.1. This is most conveniently accomplished by stopping acquisition, moving the Pulser dial to the new

Table 6.1. Energy Calibration Data

Approximate Accumulation Time (s)	Pulse-Height Dial Setting	Equivalent Energy (keV)	Analyzer Channel No.
20	200/1000	200	
20	400/1000	400	
40	600/1000	600	
20	800/1000	800	
20	1000/1000	1000	

setting and resuming the acquisition. The process is repeated until the spectrum contains pulser peaks of approximately equal heights for all the Pulser dial settings.

18. Set individual Regions of Interest (ROI) across each pulser peak. Using MAESTRO features, find the centroid of each pulser peak. Enter those positions into the last column of Table 6.1. Using the energy calibration feature of MAESTRO, calibrate the horizontal scale so that the cursor reads directly in energy. Save the calibration spectrum on the hard disk for possible future reference.

EXERCISES

a. From the saved spectrum for ^{137}Cs, measure the FWHM energy resolution in keV for the 624 keV peak. Call this value δ_{ET}, i.e., the total resolution at energy E.

b. Determine the FWHM energy resolution of one of your pulser peaks. Call this pulser resolution δ_{noise}. This is the contribution of the detector leakage current noise and preamplifier noise to the energy resolution.

c. Calculate the contribution of detector ionization statistics at energy E, δ_{DE}, to the total resolution at energy E from equation (4).

$$\delta_{ET} = \sqrt{\delta_{DE}^2 + \delta_{noise}^2} \qquad (4)$$

How do the three different values δ_{ET}, δ_{DE}, and δ_{noise} relate to the detector specifications?

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19. Replace the ^{137}Cs source with the ^{113}Sn source and accumulate its spectrum for a period of time long enough to clearly determine the location of the pronounced peaks in the spectrum (Fig. 6.3). Save the spectrum on the hard disk for possible future reference.

20. Print the ^{137}Cs, pulser calibration and ^{113}Sn spectra for inclusion in your report. The easiest way to accomplish this task to use MAESTRO to export the spectra as ASCII text files. Save those files on a transportable storage medium such as a CD, memory stick, or external hard drive. Import the ASCII file into Excel on your laptop computer using tab and space delimiters. Subsequently, the spectra can be graphed and printed at your convenience from the Excel spreadsheet.

EXERCISE

d. From your analyzer readouts, enter the measured energy levels in Table 6.2.

e. Optional: The spectrum in Fig. 6.3 includes a continuum at energies less than the conversion-electron peak energies. But, the ^{113}Sn radioisotope decays only by electron capture, with no competing β^+ decay. So there should be no β^+ decay contribution. Using the information in references 1, 7 and 9, discuss why the first six candidates below cannot explain the continuum. Is issue (vii) a viable explanation?

    i. Backscattered electrons from the source backing,
    ii. Electrons backscattered from the detector,
    iii. Inadequate detector depletion depth,
    iv. External Bremsstrahlung from the source backing,
    v. Internal Bremsstrahlung from the electron-capture decay of ^{113}Sn,
    vi. 255-keV gamma rays (from ^{113}Sn decay) Compton scattering in the detector, or
    vii. Contamination from ^{113}Cd residing in the 0.27 MeV state.

f. If item (vii) is the cause of the continuum, how should the ratio of the counts in the continuum to the counts in the conversion electron peaks change with time?

Table 6.2 Measured vs. Reference Energies for Conversion Electrons.

Source	Reference Energy (keV)	Measured Energy (keV)
^{137}Cs	624	
^{137}Cs	656	
^{113}Sn	365	
^{113}Sn	389	

EXPERIMENT 6.2 Beta End-Point Determination for ^{204}Tl

Relevant Information

The most precise method for determining maximum beta energy requires that a Kurie plot be made. This method is derived from the theory of beta decay discussed in references 2 and 9. A description of a beta curve is given by

$$\left[\frac{N(\eta)}{\eta^2 F(Z,\eta)}\right]^{1/2} = K(W_0 - W) \qquad (5)$$

where

$N(\eta)$ is the number of beta particles with normalized momentum between η and $\eta + d\eta$,

$\eta = p/m_0c$ is the normalized (dimensionless) momentum of the beta particle,

p is the momentum of the beta particle,

m_0 is the rest mass of the electron,

c is the speed of light,

$m_0c^2 = 0.511$ MeV, if E is expressed in MeV,

$F(Z,\eta)$ is the Fermi function,

$W = (E + m_0c^2)/m_0c^2$ is the normalized (dimensionless) total energy of the beta particle,

E is the kinetic energy of the beta particle,

$W_0 = (E_0 + m_0c^2)/m_0c^2$ is the normalized (dimensionless) total energy corresponding to the maximum end-point energy, E_0, in the beta spectrum, and

K is a constant that is independent of energy.

If the left side of equation (5) is plotted against W, an *allowed* spectrum will yield a straight line that may be extrapolated to the energy axis to give W_0. *Forbidden* β transition spectra will show an upward curvature in the low-energy region. See reference 9 for an explanation of *allowed* and *forbidden* beta-decay.

Equation (5) was developed when the available beta-spectrometers measured the momentum of the particle by passing the charged particles through a magnetic field. Consequently, $N(\eta)$ is expressed in terms of momentum. Silicon surface-barrier detectors measure the energy spectrum of the beta particle. Therefore, a more appropriate expression uses a modified Fermi function G(Z,W) which may be calculated from the precise Fermi value. With this modification, $N(\eta)$ is replaced by N(E), i.e., the probability of observing a beta particle with energy between E and E + dE. Tabulations of G(Z,W) are available in reference 2. Substitution of this function casts equation (5) in the more convenient form:

$$\frac{1}{W}\left[\frac{N(E)}{G(Z,W)}\right]^{1/2} = K(W_0 - W) = \frac{K}{m_0c^2}(E_0 - E) \qquad (6)$$

Because there is a proportionality constant, K, on the right side of the equation, one can use the actual number of counts at a particular energy in the spectrum for the value N(E). For example, one of the points for ^{204}Tl (Fig. 6.1) could be channel 200, where N(E) ≅ 190. In reference 2, G(Z,W) is tabulated for the daughter nucleus as a function of the normalized momentum, η, of the beta particle. Note that the normalized momentum is related to the normalized energy by

$$\eta^2 = W^2 - 1 = \left(\frac{E}{m_0c^2} + 1\right)^2 - 1 \qquad (7)$$

Values for the modified Fermi function, G(Z,W), for the decay of $^{204}_{81}$Tl to $^{204}_{82}$Pb are listed in Table 6.3 (from ref. 2).

Table 6.3. Tabulated Values for G(Z,W) vs. η for the ^{204}Tl Beta Decay.

η	G	η	G
0.0	28.26	2.2	19.10
0.1	28.19	24	18.54
0.2	27.99	2.6	18.03
0.3	27.67	2.8	17.55
0.4	27.25	3.0	17.12
0.5	26.76	3.5	16.18
0.6	26.23	4.0	15.39
0.7	25.66	4.5	14.71
0.8	25.09	5.0	14.13
0.9	24.53	6.0	13.17
1.0	23.98	7.0	12.40
1.2	22.95	8.0	11.77
1.4	22.01	9.0	11.24
1.6	21.17	13.0	9.718
1.8	20.41	15.0	9.182
2.0	19.72		

Procedure

1. Use the system of Experiment 6.1, including the calibration.
2. Remove the ^{113}Sn source from the chamber.
3. Place the ^{204}Tl source in the vacuum chamber, pump down the vacuum, apply appropriate bias to the detector, and obtain a spectrum similar to Fig. 6.1.
4. Save the spectrum to hard disk for future reference.
5. Export the spectrum as an ASCII text file and import it into an Excel spreadsheet on your laptop PC, as previously described.
6. Plot the spectrum against linear vertical and horizontal scales, so that the trend near the endpoint energy is well defined.

EXERCISES

a. Note that in the ^{204}Tl spectrum there is a linear portion that corresponds to the range from channel 100 to channel 300 in Fig. 6.1. From your spectrum select 10 points that are distributed in this linear range and fill in the data for Table 6.4.

b. Plot $(1/W)[N(E)/G(Z,W)]^{1/2}$ vs. Energy (MeV). Draw a straight line through the linear portion of the curve and find the extrapolated intercept with the energy axis. The intercept gives the endpoint energy.

c. Plot $\sqrt{N(E)}$ vs. Energy (MeV). This is another method to approximate the E_{max} end-point energy. Fig. 6.8 shows a comparison of the $\sqrt{N(E)}$ plot and the Kurie plot for ^{204}Tl.

d. How does your measured endpoint energy compare to the accepted value of 0.766 MeV?

Table 6.4. Calculations for Developing the Kurie Plot.

Channel Number	*N(E)*	*W*	*P*	*G(Z,W)*	$\frac{1}{W}\left[\frac{N(E)}{G(Z,W)}\right]^{1/2}$	Energy (MeV)

EXPERIMENT 6.3. Conversion Electron Ratios

Relevant Information

In the internal conversion process, the energy of excitation can be given to one of the orbiting electrons, as discussed at the beginning of Experiment 6. The electrons that are usually involved are the K, L, and M shells that are closest to the nucleus. The energy of the conversion is given by equation (2).

The conversion electron spectrum for ^{113}Sn is shown in Fig. 6.3. It shows lines at 365 and 389 keV. These are the lines that come from the K and L+M conversion processes, respectively.

The decay scheme of ^{113}Sn, also shown in Fig. 6.3, shows that the internal conversion takes place between the 0.393 MeV and the ground states. Consequently, the available excitation energy, E_x, is 393 keV.

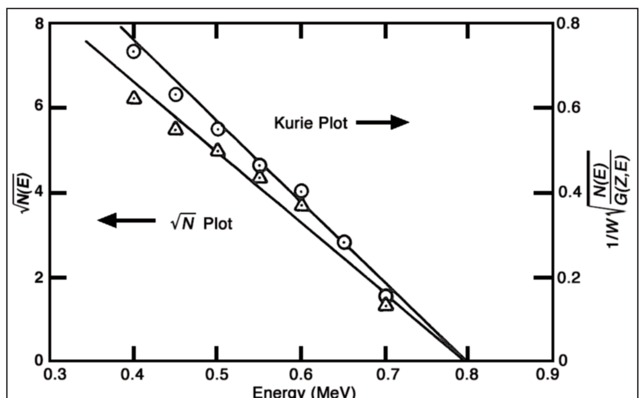

Fig. 6.8. Comparison of the $[N(E)]^{1/2}$ Plot and the Kurie Plot for Determining the Endpoint Energy.

The K shell binding energy, E_B, for ^{113}In is 27.9 keV. For this conversion, E_e = 393–27.9 = 365 keV.

The average L shell binding energy for ^{113}In is 3.9 keV, and for this conversion, E_e = 393–3.9 = 389 keV.

In this experiment the K/(L+M) ratios will be measured.

Procedure

1. Use the system of Experiment 6.1, including the calibration.
2. Be sure to use a detector with 18-keV resolution or better.
3. Recall the ^{113}Sn spectrum that was previously saved on the hard disk. If that spectrum has been lost, or if the counts in the peak are inadequate, acquire it again for a period of time long enough to obtain ~1000 counts in the 389 keV peak.

EXERCISES

a. Find the sum under the 389 keV peak. Because the two adjacent peaks have some overlap, use the net area feature of the MAESTRO program, and set the lower energy limit of the ROI in the valley between the 365 and 389 keV peaks. Set the upper limit of the ROI near the bottom extremity of the 389 keV peak on the high-energy side. The peak from the M-shell conversion electrons is unresolved from the L-shell peak, because it has only 3.4 keV additional energy. The M-shell peak also has a much lower intensity than the L-shell peak. Therefore, define the sum over the 389 keV peak to be Σ_{L+M}.

b. Find the sum under the 365 keV peak and define this quantity to be Σ_K. For the 365 keV peak use the net area feature again, and set the upper limit of the ROI in the valley between the 365 and 389 keV peaks. Set the lower ROI limit in the valley on the low-energy side of the 365 keV peak.

c. Calculate the K/(L+M) ratio, which is (Σ_K/Σ_{L+M}). How do your values compare with those in ref. 7?

d. Repeat the measurements and calculations for ^{137}Cs. Your spectra should look like Fig. 6.4. How do your values compare to those in ref. 7 for ^{137}Cs?

References

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