ORTEC®

AN34 Experiment 6

Beta Spectroscopy

Equipment Needed from ORTEC

- Charged Particle Detector BA-016-025-1500
- TRUMP-PCI-2K Plug-In MCA Card with MAESTRO-32 Emulation Software (Other ORTEC MCAs may be used)
- 142A Preamplifier
- 4001A/4002D NIM Bin and Power Supply
- ALPHA-PPS-115 Portable Vacuum Pump Station
- 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 Cable
- C-29 BNC Tee Connector

Other Equipment Needed

- Sealed Beta and Conversion Electron Sources (Disk Type) 1–5 µCi, ^{204}Tl, ^{207}Bi, ^{137}Cs, ^{113}Sn
- PC with Microsoft Windows 2000/XP
- Oscilloscope

Purpose

This experiment demonstrates the technique of obtaining a beta-particle spectrum and outlines a method for determining β_{max}.

Theory

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 will be converted to a proton. The process is

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

where $\bar{\nu}$ is a neutrino.

From Eq. 1 you can see that there are three particles in the final state. The excitation energy will be shared by the $\bar{\beta}$ and $\bar{\nu}$ particles. Theoretically, $\bar{\beta}$ could have any energy up to the maximum (β_{max}), but the probability that any event will have this amount of energy accompanying its $\bar{\beta}$ is very low.

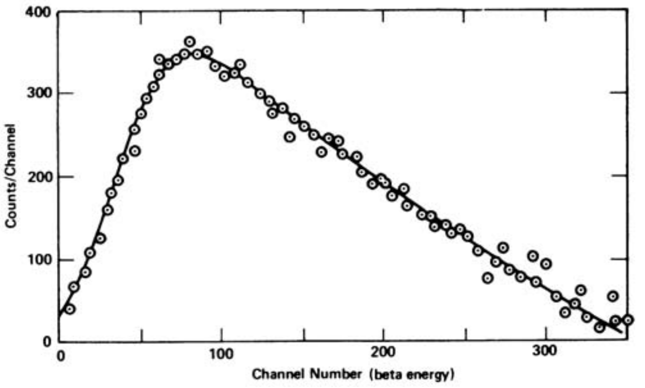

Fig. 6.1. Beta Spectrum for ^{204}Tl.

A typical beta spectrum, shown in Fig. 6.1, indicates the distribution of relative probabilities for the portions of β_{max} that accompany a quantity of events measured for ^{204}Tl. This is a typical continuum of $\bar{\beta}$ energies. The energy that is represented at the extrapolated baseline crossover of the curve (around channel 650 in Fig. 6.1) is β_{max}. From ref. 7, this end-point energy for ^{204}Tl is 0.766 MeV. The system can be calibrated with known conversion electron energies since 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 and the electron will then leave the atom with a discrete energy (E_e). This energy is given by

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

where

E_e = the measured energy of the conversion electron,

E_x = the excitation energy available in the decay,

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

These three quantities can be found in ref. 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

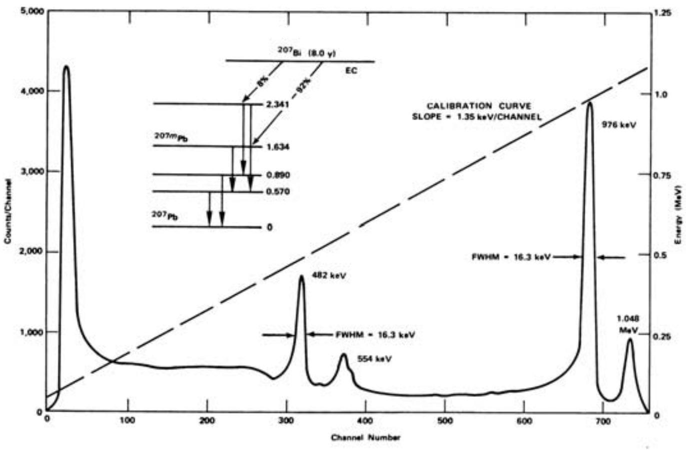

Fig. 6.2. ^{207}Bi Converion Electron Spectrum.

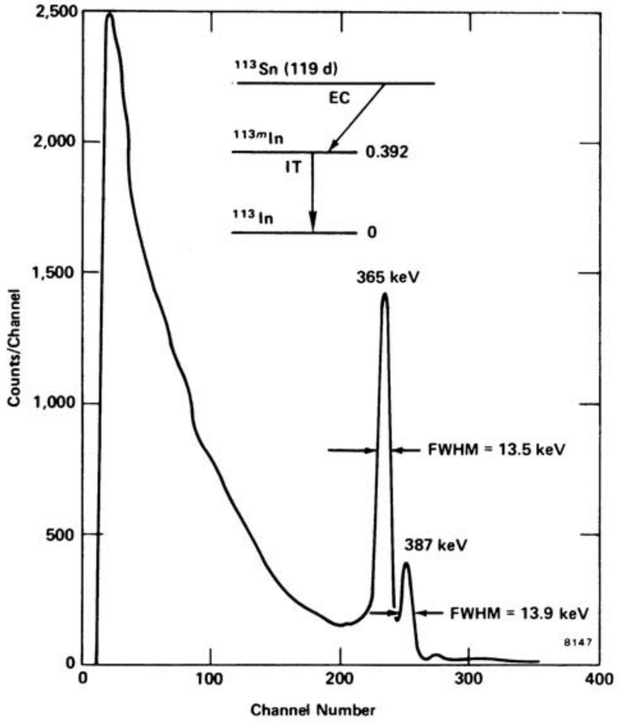

Fig. 6.3. ^{113}Sn Conversion Electron Spectrum.

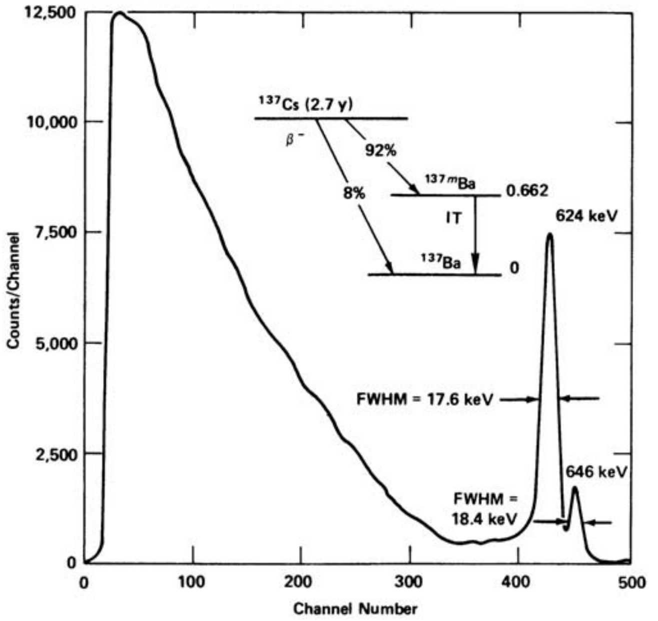

Fig. 6.4. ^{137}Cs Beta and Conversion Electron Spectrum.

Application of Surface Barrier Detectors

The list of equipment specifies an appropriate ORTEC surface barrier detector for this work. The BA-016-025-1500 detector has the combination of parameters that satisfies the requirements.

WARNING

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

Fig. 6.5 shows a range vs. energy curve for betas 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 1.048 MeV conversion electron from ^{207}Bi, as shown in Fig. 6.2. According to Fig. 6.5, a 1.048 MeV beta would have a range of ~1700 µm. Since the path of a beta is not a straight line, it is not absolutely essential that the detector have the indicated thickness. Therefore, for this experiment we are recommending a 1500 µm detector.

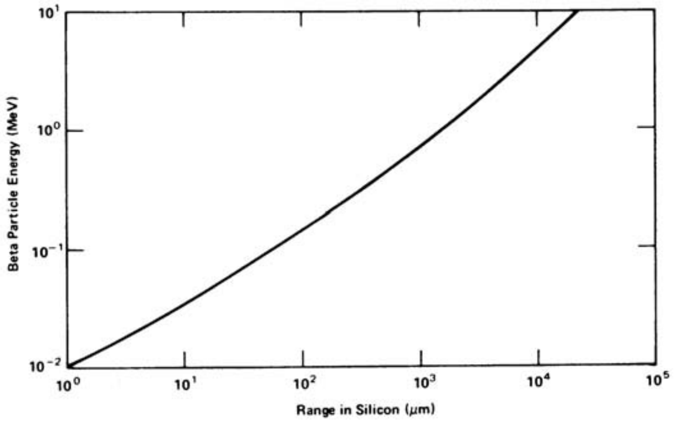

Fig. 6.5. Beta Energy vs. Range in Silicon.

EXPERIMENT 6.1

Calibration with a Pulser

The equipment used in this experiment is 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 precautions in this experiment are much more important because you are working with a more delicate and expensive detector.

Procedure

1. Connect the equipment as shown in Fig. 6.6. Use the following settings for the instrument controls:

575A Ampifier: Positive input, unipolar output;

480 Pulser: Negative output; use attenuated output;

428 Bias Supply: Positive polarity; increase bias voltage gradually to level recommended on detector QA data sheet.

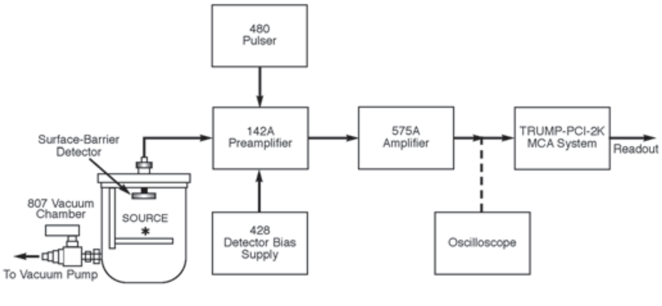

Fig. 6.6. Electronics for Calibration with a Pulser.

2. Position the ^{137}Cs source about 1/4-inch from the face of the detector. Pump down the vacuum chamber and apply the proper positive (+) operating bias to the detector.

3. Adjust the 575A Amplifier gain until the pulses observed on the oscilloscope are ~4 V in amplitude. The most pronounced pulse amplitudes will represent the 624 keV energy of the conversion electrons.

4. 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 mid-scale on the MCA. In Fig. 6.4 the peak is at about mid-scale for a 1024-channel analyzer. When the gain has been properly adjusted, accumulate a spectrum with ~600 counts in the 624 keV peak. Record the channel number for the 624 keV peak and call this channel C_0.

5. 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.

EXERCISES

a. Fill in the information for Table 6.1

b. Plot the calibration points and determine the keV/channel for the curve. From your printed data for the ^{137}Cs spectrum, determine the resolution of the detector system at the 624 keV line. Determine the resolution of one of your pulser peaks.

c. Determine the following:

δ_T, the measured width of the 624 keV line.

δ_E, the measured width of the pulser peak.

δ_s, the source thickness (assume that this is zero).

Solve for δ_D, the resolution of the detector:

$\delta_D = \sqrt{\delta_T^2 - \delta_E^2}$

How does your calculated δ_D compare with the value that the instructor has for the detector?

6. Replace the ^{137}Cs source with the ^{207}Bi 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. 6.2). Read out the MCA and erase the spectrum.

7. Replace the ^{207}Bi source with the ^{113}Sn source and accumulate ~1000 counts in the 365 keV conversion electron peak (Fig. 6.3). Read out the MCA and erase the spectrum.

EXERCISE

d. From your analyzer readouts and the calibration curve, calculate the energy levels for Table 6.2 and fill them in.

8 (optional). If you have a ^{133}Ba source, obtain its spectrum and add your calculated energies for its lines to Table 6.2. Fig. 6.7 shows the details of a typical spectrum for ^{133}Ba.

EXPERIMENT 6.2

Beta End-Point Determination for ^{204}Tl

Theory

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 ref. 2. A description of a beta curve is given by

$$\left[\frac{N(W)}{F(Z,W)\ PW}\right]^{1/2} = K(W_0 - W) \qquad (3)$$

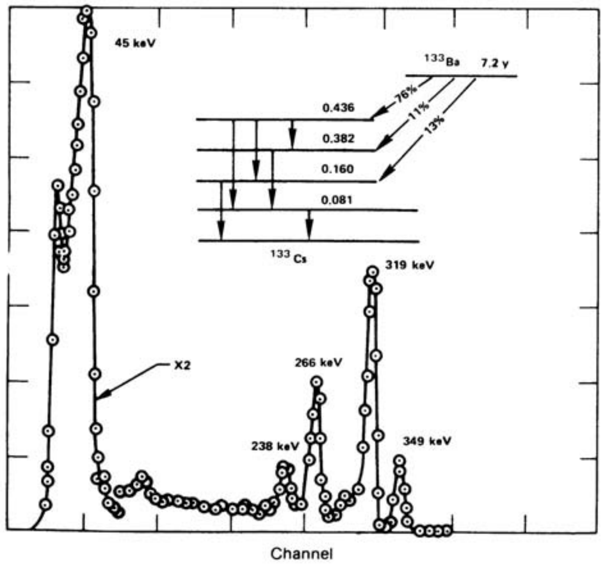

Fig. 6.7. Conversion Lines from ^{133}Ba.

where

N(W) = counts in each channel being considered,

F(Z,W) = Fermi function,

P = momentum of beta particle,

W = total energy of beta particle,

W_0 = maximum end-point energy of beta spectrum,

K = a constant that is independent of energy.

If the left side of Eq. 3 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.

A somewhat easier calculation can be made by using a modified Fermi function G(Z,W) which may be calculated from the precise Fermi value. Tabulations of these functions are also available in ref. (2).

On substitution of this function in Eq. 3 we have

$$\frac{1}{W}\left[\frac{N(E)}{G(Z,W)}\right]^{1/2} = K(W_0 - W) \qquad (4)$$

In these expressions the measured kinetic energy, E, is given by (W–1) in units of total energy. The kinetic energy, E, is expressed in m_0c^2 units (m_0c^2 = 0.511 MeV).

Replacing W of Eq. 4 by E gives

$$\frac{1}{W}\left[\frac{N(E)}{G(Z,W)}\right]^{1/2} = K(E_0 - E) \qquad (5)$$

where

N(E) = the actual number of counts at a particular energy in the spectrum; for example, one of the points for ^{204}Tl (Fig. 6.1) could be channel 200, where N(E) ≅ 190;

W = E + 1, where E is the kinetic energy in MeV of the point divided by m_0c^2 (0.511 MeV);

G(Z,W) = modified Fermi function from ref. 2; these are listed for the daughter as a function of the momentum, P, of the beta, where $P = (W^2–1)^{1/2}$.

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

Procedure

1. Use the system of Experiment 6.1, including the calibration.

2. 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.

3. Read out the MCA and plot the spectrum on linear graph paper.

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. Select 10 points that are distributed in this range and fill in the data for Table 6.4.

Table 6.4

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

b. Plot 1/W $[N(E)/G(Z,W)]^{1/2}$ vs. Energy (MeV). The interaction at the energy axis gives the end-point energy.

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

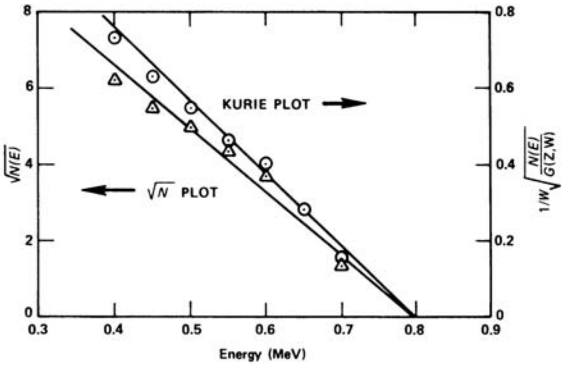

Fig. 6.8. Comparison of $\sqrt{N(E)}$ Plot and Kurie Plot for ^{204}Tl.

EXPERIMENT 6.3

Conversion Electron Ratios

Theory

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

$$E_e = E_x - E_B \qquad (6)$$

where

E_e = the measured energy of the conversion electron,

E_x = the excitation energy available in the decay,

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

The conversion electron spectrum for ^{207}Bi is shown in Fig. 6.2. It shows lines at 1.048 and 0.975 MeV. These are the lines that come from the K and L conversion processes, respectively.

The decay scheme of ^{207}Bi, also shown in Fig. 6.2, shows a gamma transition from the 1.634-MeV level to the 0.570-MeV level. This difference in energy is 1.064 MeV. In Eq. 6 this is the excitation energy, E_x, which is available for the conversion process.

The K binding energy, E_B, for ^{207}Pb is 88 keV. For this conversion, $E_e = 1.064 - 0.88 = 0.976$ MeV or 976 keV. The L binding energy for ^{207}Pb is 15.86 keV for this conversion, $E_e = 1.064 - 0.01586 = 1.048$.

In a similar manner, the conversion electron energies for the 570-keV excitation can be calculated. These are 482 and 554 keV. In this experiment the K/L 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. Accumulate a ^{207}Bi spectrum for a period of time long enough to obtain ~1000 counts in the 1.048 MeV peak. Print the data from the MCA.

EXERCISES

a. Find the sum under the 1.048 MeV peak. Define this quantity to be $\Sigma L_{1.064}$. Find the sum under the 976 keV peak and define this quantity to be $\Sigma K_{1.064}$. Calculate the K/L ratio, which is $(\Sigma K/\Sigma L)_{1.064}$. Repeat these steps for the 482 keV and 554 keV lines and calculate the ratio $[\Sigma K/\Sigma(L + M)]_{0.570}$. Note that the L and M lines are not quite resolved in Fig. 6.2 and probably will not be resolved in your spectrum. How do your values compare with those in ref. 7?

b. Repeat the measurements and calculations for ^{113}Sn and ^{137}Cs. Your spectra should look like Figs. 6.3 and 6.4 respectively. How do your values compare to those in ref. 7 for these isotopes?

References

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