

# EXPERIMENT 6

## Beta Spectroscopy

### EQUIPMENT NEEDED FROM EG&G ORTEC

Source Kit SK-1B  
 Surface Barrier Detector (A-015-025-1500)  
 142A Preamplifier  
 Bin and Power Supply  
 575A Amplifier  
 807 Vacuum Chamber  
 428 Detector Bias Supply

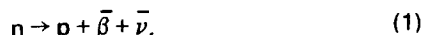
480 Pulser  
 ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)  
 Mechanical Vacuum Pump  
 Oscilloscope  
 ORC-6 Cable Set

### Purpose

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

### Theory

The measurement of beta-particle energies can be made with surface barrier 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,  $^{204}\text{Tl}$  decays to  $^{204}\text{Pb}$  and emits a beta particle. In order to achieve stability, one of the neutrons in the nucleus of the  $^{204}\text{Tl}$  will be converted into a proton. The process is



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 ( $\beta_{\max}$ ), but the probability for any event to have this amount of energy accompany its  $\bar{\beta}$  is very low.

A typical beta spectrum, shown in Fig. 6.1, indicates the distribution of relative probabilities for the portions of  $\beta_{\max}$  that accompany a quantity of events measured for  $^{204}\text{Tl}$ . This is a typical continuum of  $\bar{\beta}$  energies. The energy that is represented at the extrapolated baseline crossover of the curve (around channel 350 in Fig. 6.1) is  $\beta_{\max}$ . From ref. 7, this endpoint energy for  $^{204}\text{Tl}$  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 ( $E_c$ ). This energy is given by

$$E_c = E_x - E_B, \quad (2)$$

where

- $E_c$  = 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.

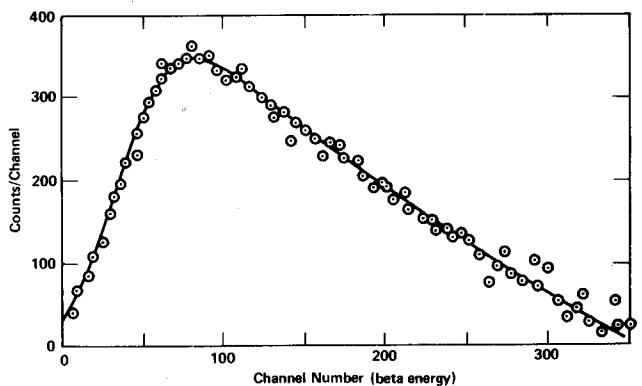


Fig. 6.1. Beta Spectrum for  $^{204}\text{Tl}$ .

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

### Application of Surface Barrier Detectors

The list of equipment specifies an appropriate EG&G ORTEC surface barrier detector for this work. The A-015-025-1500 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 that will be irreparably damaged by skin oils or any abrasive. Always handle the detector by its edges and/or its protective case.

Figure 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  $^{207}\text{Bi}$ , as shown in Fig. 6.2. According to Fig. 6.5, a 1.048-MeV beta would have a range of  $\sim 1700 \mu\text{m}$ . 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- $\mu\text{m}$  detector.

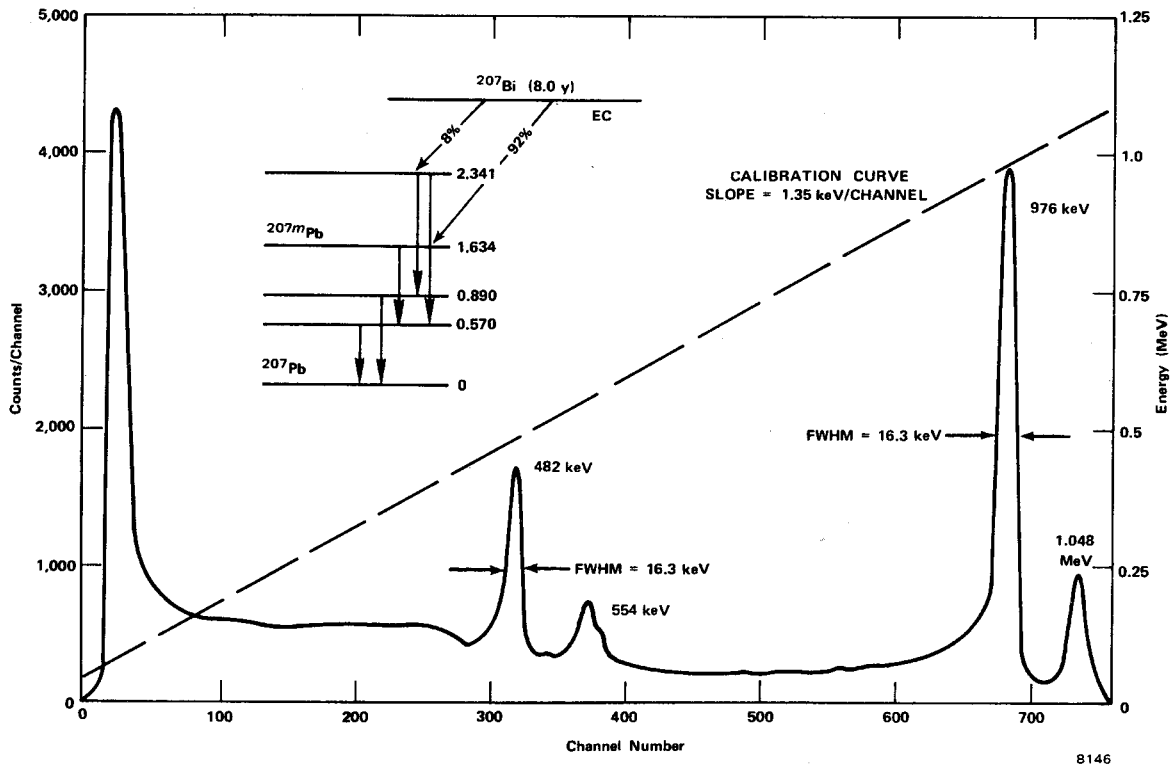


Fig. 6.2. <sup>207</sup>Bi Conversion Electron Spectrum.

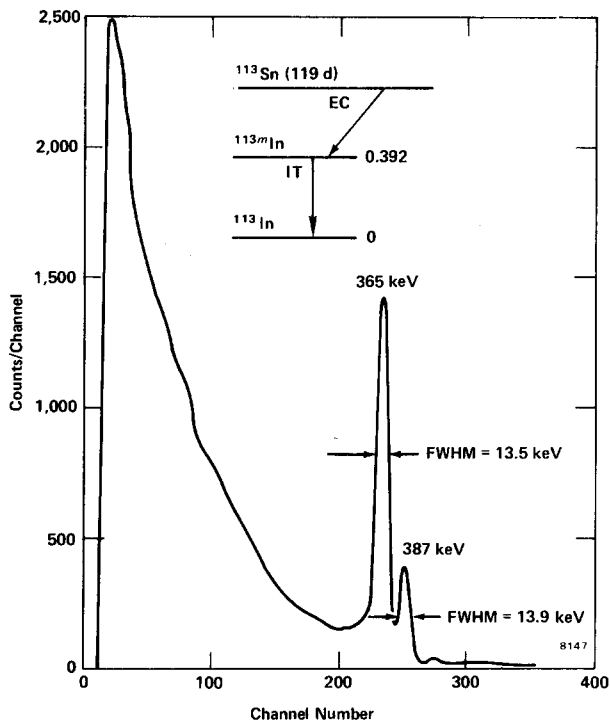


Fig. 6.3. <sup>113</sup>Sn Conversion Electron Spectrum.

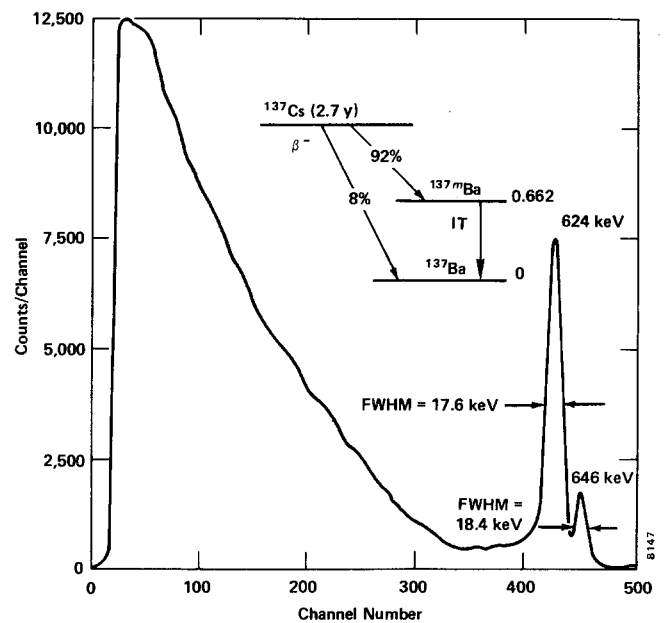


Fig. 6.4. <sup>137</sup>Cs Beta and Conversion Electron Spectrum.

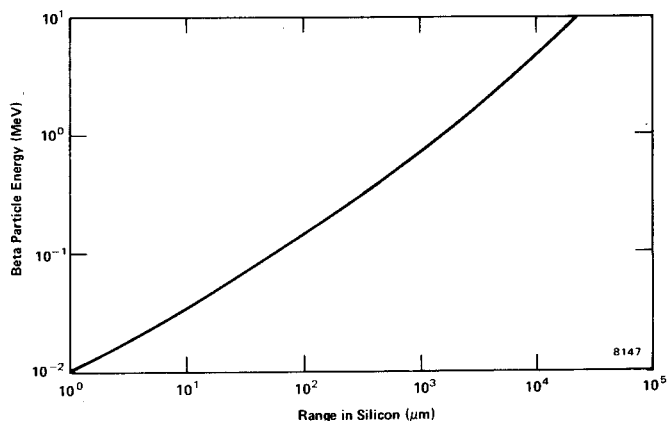


Fig. 6.5. Beta Energy vs Range in Silicon.

### EXPERIMENT 6.1 Calibration with a Pulser

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

### Procedure

1. Connect the equipment as shown in Fig. 6.6. Use the following settings for the module controls: set the 575A Amplifier for a positive input and a unipolar output; set the 480 Pulser for a negative output and use the attenuated output; set the 428 Bias Supply for a positive polarity and increase the voltage gradually to the recommended level.
2. Position the <sup>137</sup>Cs source about 1/4 in. from the detector. Pump down the vacuum chamber and apply the proper operating bias (+) to the detector.
3. Adjust the gain of the 575A Amplifier 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 long enough 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 adjusted properly, accumulate the spectrum long enough to have ~600 counts in the 624-keV peak. Record the channel number for the 624-keV peak and call this channel C<sub>0</sub>.
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<sub>0</sub>. 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.

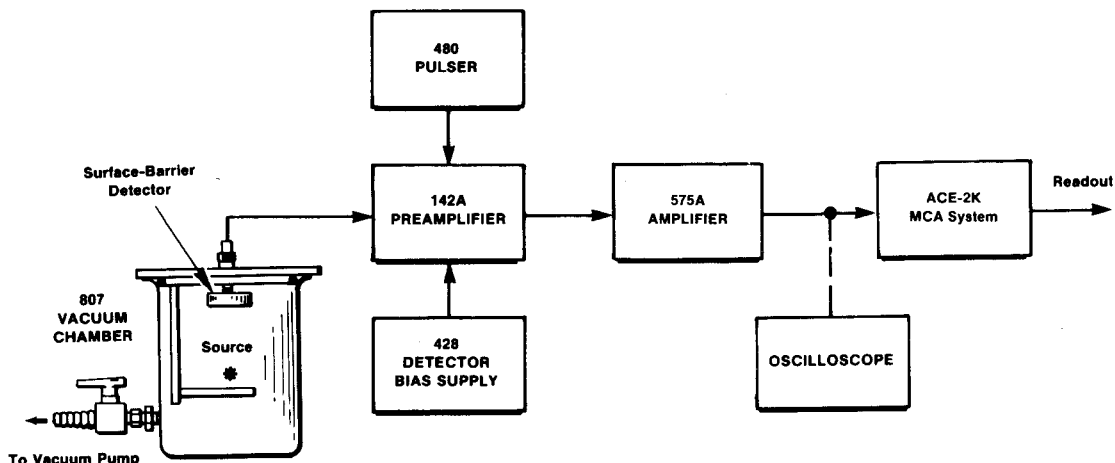


Fig. 6.6. Electronics for Calibration with a Pulser.

Table 6.1

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	

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

c. As in Experiment 4.5, define the following:

- $\delta_T$ , the measured width of the 624-keV line.
- $\delta_E$ , the measured width of the pulser peak.
- $\delta_s$ , the source thickness (assume that this is zero).

Solve for  $\delta_D$ , the resolution of the detector;  $\delta_D = \sqrt{\delta_T^2 - \delta_E^2}$ . How does your calculated  $\delta_D$  compare with the value that the instructor has for the detector?

6. Replace the <sup>137</sup>Cs source with the <sup>207</sup>Bi source. Accumulate its spectrum for a period of time long enough to clearly determine the locations of the pronounced peaks in the spectrum (Fig. 6.2). Read out the analyzer and erase the spectrum.

7. Replace the <sup>207</sup>Bi source with the <sup>113</sup>Sn source. Accumulate its spectrum for a period of time long enough to have ~1000 counts for the 365-keV conversion electron line (Fig. 6.3). Read out the analyzer 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.

Table 6.2

Source	Energy	
	Theoretical (keV)	Calculated
<sup>137</sup> Cs	624	
<sup>137</sup> Cs	626	
<sup>137</sup> Cs	266	
<sup>137</sup> Cs	238	
<sup>207</sup> Bi	1040	
<sup>207</sup> Bi	972	
<sup>113</sup> Sn	365	

8 (optional). If you have a <sup>133</sup>Ba source, obtain its spectrum and add your calculated energies for its lines to Table 6.2. Figure 6.7 shows the details of a typical spectrum for <sup>133</sup>Ba.

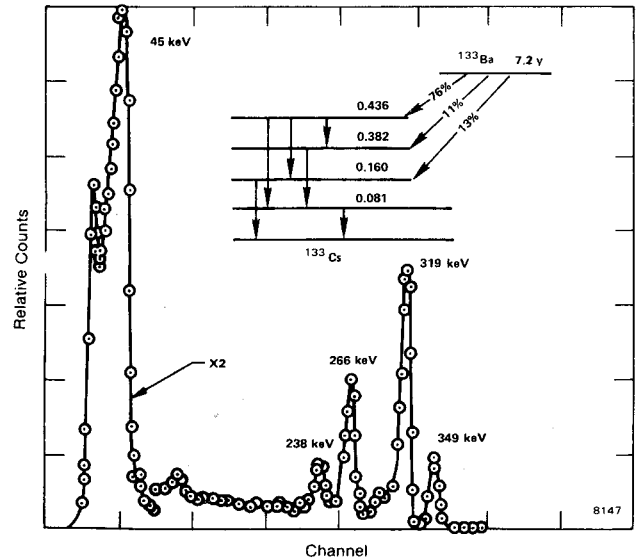


Fig. 6.7. Conversion Lines from <sup>133</sup>Ba.

**EXPERIMENT 6.2**

**Beta End-Point Determination for <sup>204</sup>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

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

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<sub>0</sub> = 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<sub>0</sub>. 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

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

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<sub>0</sub>c<sup>2</sup> units (m<sub>0</sub>c<sup>2</sup> = 0.511 MeV).

Replacing W of Eq. (4) by E gives

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

where

N(E) = the actual number of counts at a particular energy in the spectrum; for example, one of the points for <sup>204</sup>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<sub>0</sub>c<sup>2</sup> (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<sup>2</sup> - 1)<sup>1/2</sup>.

The modified Fermi functions, G(Z,W), for the decay of <sup>204</sup>Tl to <sup>204</sup>Pb are listed in Table 6.3 (from ref. 2).

### Procedure

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

Table 6.3

P	G	P	G
0.0	28.26	2.2	19.10
0.1	28.19	2.4	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		

2. Place the <sup>204</sup>Tl source in the vacuum chamber. Pump down the vacuum, apply the detector bias, 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 <sup>204</sup>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)]<sup>1/2</sup> vs energy (MeV). The intersection at the energy axis gives the end-point energy.

c. Plot √N(E) vs energy (MeV). This is another method to approximate the β<sub>max</sub> end-point energy. Figure 6.8 shows a comparison of the √N(E) plot and the Kurie plot for <sup>204</sup>Tl.

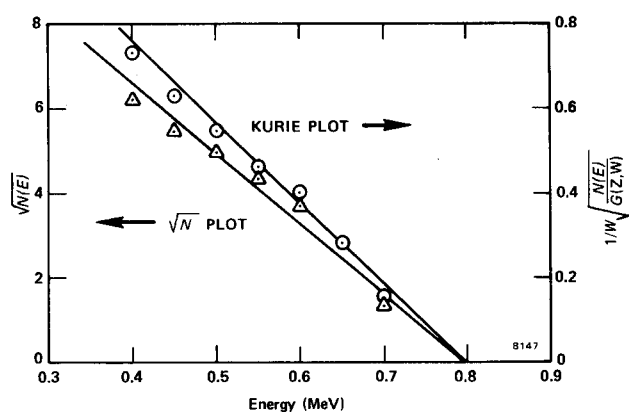


Fig. 6.8. Comparison of √N(E) Plot and Kurie Plot for <sup>204</sup>Tl.

### 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 in the K, L, and M shells that are closest to the nucleus. The energy of the conversion electron is given by

$$E_e = E_x - E_B, \quad (6)$$

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  $^{207}\text{Bi}$  is shown in Fig. 6.2. It shows lines at 1.048 and 0.976 MeV. These are the lines that come from the K and L conversion processes, respectively.

The decay scheme of  $^{207}\text{Bi}$ , 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  $^{207}\text{Pb}$  is 88 keV. For this conversion  $E_e = 1.064 - 0.88 = 0.976$  MeV or 976 keV. The L binding energy for  $^{207}\text{Pb}$  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. The binding energies for all elements are listed in ref. 7, pp. 556–569. 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 spectrum for  $^{207}\text{Bi}$  for a period of time long enough to obtain  $\sim 1000$  counts in the 1.048-MeV peak. Print the data from the MCA.

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### EXERCISES

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- 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 your spectrum. How do your values compare to those in ref. 7?
  - b. Repeat the measurements and calculations for  $^{113}\text{Sn}$  and  $^{137}\text{Cs}$ . 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?
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### References

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