EXPERIMENT 5

Beta and Conversion Electron Measurements with Solid State Detectors

Scope

In this experiment, calibration of a surface barrier detector with the known energies of the conversion electrons from ^{137}Cs will be done. This calibration will be done with a precision pulse generator that is normalized to the 620 keV line from ^{137}Cs. The next part of the experiment will be to determine the precise energies of the conversion lines from several other isotopes. The beta end point energy of ^{204}Tl will then be determined with this calibration and a Kurie plot.

Discussion

Beta emission is perhaps one of the most important decay mechanisms that will be studied in this manual. It has been through the measurement of Beta end point energies that many of the nuclear levels listed in the Table of the Isotopes have been determined. One of the main reasons for this, is that many of the isotopes that can be studied are produced in a reactor by the so called (n, γ) reaction. These reactions will be studied in detail in a later experiment. In producing these isotopes, the material to be studied is placed in the thermal neutron flux of the reactor. The material that is to be irradiated will produce the following reactions:

$$ {}^{m}_{z}A_1 + n \rightarrow {}^{m+1}_{z}A_1^* + \gamma \qquad (1)$$

The γ is prompt and will leave the sample in a time of the order of 10^{-15} seconds. The remaining nucleus ${}^{m+1}_{z}A_1^*$ is, in general, radioactive and will decay to an energetically more stable nucleus. A typical decay scheme for ${}^{m+1}_{z+1}A_1^*$ is shown in fig. 5.1.

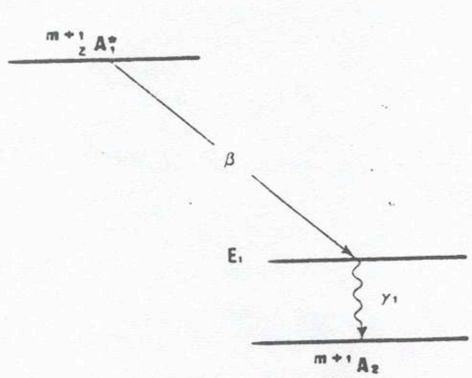

Figure 5.1. Typical Decay Scheme for a Beta Emitting Isotope.

The nucleus ${}^{m+1}_{z}A_1^*$ is neutron rich. In other words, the absorption of the neutron in eq. (1) has produced an excess of neutrons in the nucleus for stability. In order to reach a more stable configuration, one of the neutrons in the nucleus is converted to a proton by the following reaction:

$$ n \rightarrow p + \beta^- + \text{neutrino} \qquad (2)$$

Neither the proton, β^-, or neutrino from (2) can exist in the nucleus prior to the decay. The energy from the decay will be kinematically shared between the three products on the right of eq. (2).

From these Kinematic laws of conservation of energy and momentum, it can be shown that the proton receives very little of the energy that is available. The energy is therefore shared by the β^- and the neutrino. Since the neutrino can't be detected with this laboratory equipment, only the β^-'s can be measured. There are three nuclear particles on the right hand side of eq. (2) and therefore the β's that are measured will not have discrete energy. If the energy available during the decay is E_1, any combination of sharing this energy between the β's and the neutrino is possible. Figure 5.2 shows a picture of what the β spectrum for the decay of ${}^{m+1}_{z}A_1^*$ might show:

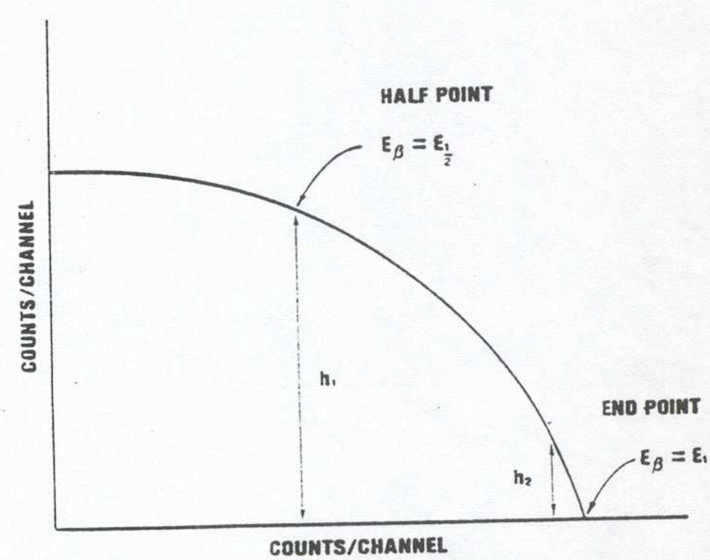

Figure 5.2. Typical Beta Spectrum showing the Continuous Distribution of Beta Energies up to the $E\beta_{max}$ End Point Energy.

Consider what nuclear information can be determined from the decay scheme in fig. 5.1 and the measured β spectrum in fig. 5.2. From the calibration and measured end point energy in fig. 5.2, the energy difference between $^{m+1}_{z}A_1$ and E_1 the first excited state can be determined. As mentioned in Experiment #2, the energy of level E_1 can be established by simply measuring γ_1. Furthermore, if $^{m+1}_{z}A_1$ also decayed directly to the ground state of $^{m+1}_{z+1}A_2$ that β^- end point energy could be measured and directly establish the energy difference between the ground state of $^{m+1}_{z+1}A_2$ and $^{m+1}_{z}A_1$. In a later experiment, the principle of coincidence measurements will be illustrated. In the example, γ_1 would be in coincidence with the β particle shown in fig. 5.1.

Before leaving this discussion, the topic of Internal Conversion electrons should be discussed since these discrete lines for energy calibration will be used.

Internal electron conversion is a decay process that is in direct competition with gamma emission. In fig. 5.1, $^{m+1}_{z}A_1$ decays by β^- emission to the first excited state E_1 of the nucleus $^{m+1}_{z+1}A_2$. In an earlier example, the state E_1 decayed to the ground state by the emission of γ_1. For some nuclei, it is possible for this energy of excitation to be given directly to an orbiting electron in the daughter nucleus $^{m+1}_{z+1}A_2$. This usually happens to the K, L, or M electrons. If this energy of excitation is large enough to remove the K shell electron, it will be knocked out of its orbit with an energy given by:

$$(E_0) = E_i - K_{ab} \qquad (3)$$

where K_{ab} is the binding energy of the K shell electron of the daughter nucleus. Some smaller fraction of these conversions will occur to the L shell electrons. When this happens, the energy of L conversion electron is given by:

$$(E_0) + E_i - L_{ab} \qquad (4)$$

Since eq. (3) and (4) give discrete energies, they can be used to calibrate the system. Figure 5.3 shows a spectrum of conversion lines from the decay of

Thus, by the use of conversion electron spectra, the system can be accurately calibrated and the β end point energy for an isotope can be measured. As pointed out earlier, β spectroscopy has given much of the valuable nuclear information that is tabulated in the Table of the Isotopes. This is, therefore, one of the most important experiments in this manual.

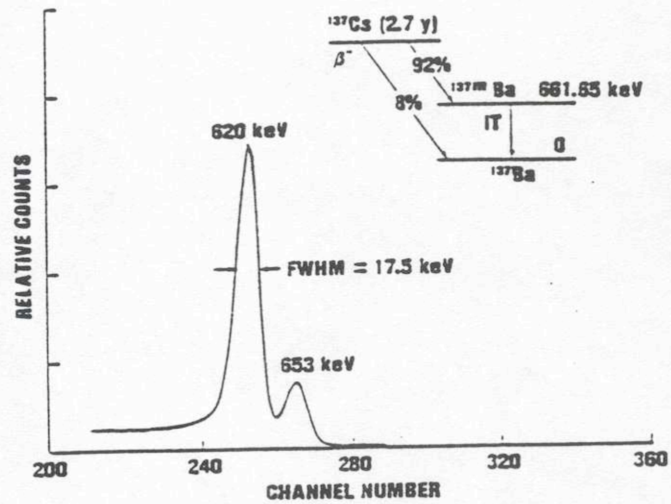

Figure 5.3. Internal Conversion Spectrum for ^{137}Cs.

EXPERIMENT 5.1

Energy Calibration for Beta Spectroscopy

Experimental Procedure

1. Set up the electronics as shown in fig. 5.4. Note this is exactly the same arrangement used for the last two experiments. Please take all of the precautions that were used in these earlier experiments. Place the ^{137}Cs source 2 cm from the face of the detector. Pump the system down and set the bias voltage for the surface barrier detector.

2. Adjust the gain of the amplifier so that the 620 keV conversion line from ^{137}Cs is at approximately channel 250.

3. Record the exact channel of the 620 keV line. Remember, for some analyzers and PCA's, a centroid finding program can be used to determine this value. Turn on the pulser and adjust the pulse height dial to 620/1000. Use the attenuation switches and the calibrate adjustment to set the pulser peak in the same channel as the 620 keV conversion electron line. The pulser is now calibrated so that each division on it corresponds to 1 keV. Set the pulser at 1000/1000 and record the position of the peak. Fill in the rest of the calibration data points in Table 5.1. Plot a calibration curve, and calculate the slope of the curve in keV/ch. From the slope of the calibration curve, calculate the resolution of all of the lines from the pulser and the ^{137}Cs Conversion Spectrum.

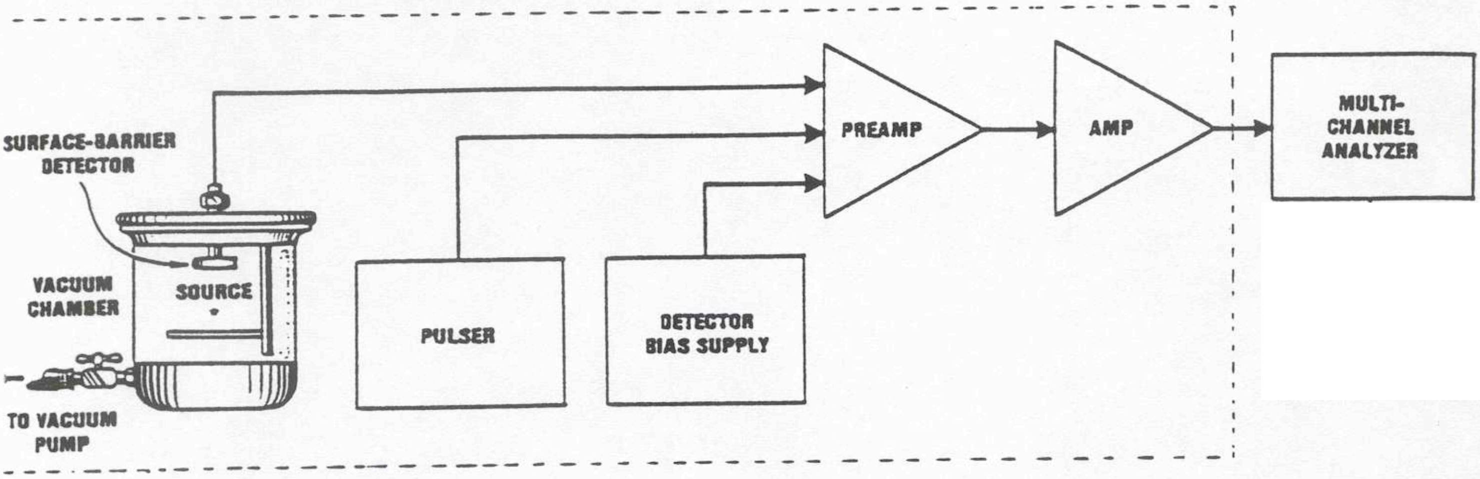

Figure 5.4.

Os componentes inseridos na caixa a tracejado não são fisicamente independentes; são partes de um só módulo electrónico, o TC256 consultar este Manual no Dossier dos Manuais da cadeira.

Table 5.1 Calibration Data from Conversion Electron Lines

Run No.	Pulse Setting	Energy keV	Channel Number	Resolution keV
1	1000/1000	1000		
2	800/1000	800		
3	600/1000	600		
4	400/1000	400		
5	200/100	200		
6	620 keV line	620		

EXPERIMENT 5.2

Beta End Point Energy of ^{204}Tl

Experimental Procedure

1. Remove the source and replace it with the ^{204}Tl source. Accumulate a spectrum for ^{204}Tl for a period of time that is long enough to get reasonable statistics in the spectrum. The ^{204}Tl spectrum will resemble fig. 5.2 which is a pure β emitter. The number of counts/ch at the height h_1 in the spectrum should be approximately 500.

2. From the spectrum select ten points that are evenly spaced between h_1 and h_2 in your ^{204}Tl spectrum (see fig. 5.2). Record in Table 5.2, the channel numbers and the number of counts in these channels. From the calibration curve determine the energy of each point that was taken.

Discussion

The shape of the β distribution for ^{204}Tl will be fitted to a Kurie plot and the end point energy can accurately be determined from this plot.

For an allowed β transition, the pulse height distribution for a given β can be written:

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

where

N(E) = the number of counts at energy E
W = E + 1; E is the energy of the point in MeV divided by 0.511
G(Z,W) = The modified Fermi function (see ref. 5).

For this experiment G(Z,W) can be obtained from Table 5.3. In these dimensionless units, $P = (W^2 - 1)^{1/2}$. This is the momentum of the electron. For example, assume that the energy of one of the points N(E) is 0.50 MeV. Therefore W = .5/.511 + 1 or 1.978. This would give the momentum a value $p = [(1.978)^2 - 1]^{1/2} = 1.71$. The corresponding value of G(Z,W) from Table 5.3 would be 20.8.

Table 5.3 Modified Fermi Function G(Z,W) for the β Decay of ^{204}Tl (See Reference 5)

P	G(Z,W)	P	G(Z,W)
0.0	28.26	0.9	24.53
0.1	28.19	1.0	23.98
0.2	27.99	1.2	22.95
0.3	27.67	1.4	22.01
0.4	27.25	1.6	21.17
0.5	26.76	1.8	20.41
0.6	26.23	2.0	19.72
0.7	25.66	2.2	19.10
0.8	25.09	2.4	18.54

Exercise On linear graph paper, make a plot of P vs G(Z,W). Calculate the dimensionless momentum P for each Energy in Table 5.2. Record these (P) values in the table. From the curve of P vs G(Z,W) read off G(Z,W) for each of the momentum values and record them in Table 5.2. Calculate $1/W\,[N(E)/G(Z,W)]^{1/2}$ for each point and record in the table. Make a plot of $1/W\,[N(E)/G(Z,W)]^{1/2}$ versus the energy of the point in MeV. Figure 5.6 shows this typical Kurie plot for ^{204}Tl. Look up the accepted value in ref. 1 or ask the instructor.

Table 5.2 Data Table for the Kurie Plot of ^{204}Tl

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

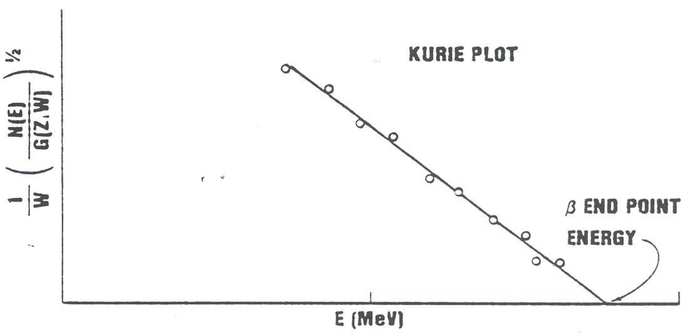

Figure 5.6. Typical Kurie Plot for the Allowed Beta Transitions from ^{204}Tl.

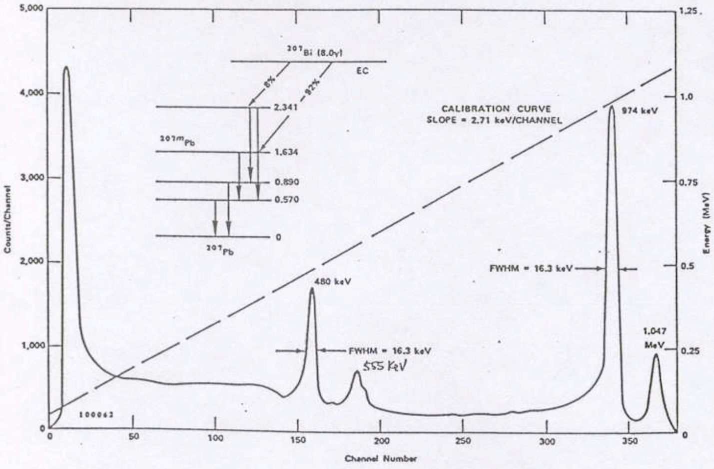

Fig. 6.2. ^{207}Bi Conversion Electron Spectrum.

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

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

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 1.047 and 0.974 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}Bi is 90 keV. For this conversion, E_e = 1.064 - 0.090 MeV = 0.974 MeV, or 974 keV. The L_I binding energy for ^{207}Bi is 16 keV. For this conversion, E_e = 1.064 - 0.016 MeV = 1.047 MeV.

In a similar manner the conversion electron energies for the 570-keV excitation can be calculated. These are 480 and 554 keV. The binding energies for all elements are listed in ref. 6, 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}Bi for a period of time long enough to obtain about 1000 counts in the 1.047-MeV peak. Print the data from the multichannel analyzer.

Exercise a. Find the sum under the 1.047-MeV peak. Define this quantity to be $\Sigma L_{1.064}$. Find the sum under the 974-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 480-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 to those in ref. 6, p. 398?

Exercise 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. 6 for these isotopes?