BETA DECAY ENERGY

OBJECTIVE: To find the beta decay energy of two different radioisotopes by determining the maximum energy of the emitted beta ray for each.

THEORY:
When a “radioisotope” (short for radioactive isotope) undergoes beta decay, two particles emerge: a beta particle ($\beta$) and an antineutrino ($\bar{\nu}$). The decay process provides a certain amount of energy, $E_M$, which depends on the particular radioisotope. This energy is split between the particles according to probability: sometimes the $\beta$ receives almost all the energy, sometimes the $\bar{\nu}$ receives almost all the energy, other times the energy is split more evenly between the two. This means that the $\beta$ particles come out of the decays with a range of kinetic energies between zero and $E_M$.

The experimental method to find $E_M$ for each of the two radioisotopes studied here is a simplified version of a more complex method called Feather’s Analysis. This simplified version will not give highly accurate results. The method involves determining the maximum distance (the range, $R$) that a $\beta$ particle with energy $E_M$ can travel in aluminum. Then an empirical formula relating $E_M$ to the range $R$ will be used to find $E_M$.

How does one find the range, $R$, for the $\beta$ particles? We will assume that aluminum absorbs $\beta$ particles according to an exponential model. We let the $\beta$ particles with energy $E_M$ travel along the $x$ axis. They encounter the aluminum at $x=0$. The number of $\beta$ particles incident at $x=0$ is $N_0$. If $N(x)$ is the number of $\beta$’s that make it to position $x$ in the aluminum, then we assume that

$$N(x) = N_0 e^{bx/E_M}.$$ (1)

The parameter $b$ depends on the absorbing material (aluminum in this case). Notice that if the energy of the $\beta$ particles increases, then they will penetrate farther into the aluminum since $N$ does not decrease as quickly. (Note: This exponential absorption model is commonly used for any type of absorption process. For example, the absorption of light by a material is modeled with a decaying exponential. Keep in mind that this model is an approximation to the actual absorption process. It predicts that an infinite amount of material is necessary to absorb all of the $\beta$’s, but we know that this is not the case.)

We can adapt Eq. (1) to relate count rates by letting $n_o$ be the count rate with no aluminum between the radioisotope and the detector, and $n(x)$ be the count rate with a thickness $x$ of aluminum between the radioisotope and the detector. Then Eq. (1) becomes

$$n(x) = n_o e^{bx/E_M}.$$ (2)

If we take the base 10 logarithm of both sides of Eq. (2), we obtain

$$\log n = \log n_o - \frac{bx}{E_M} \log e = \log n_o - \frac{0.434b}{E_M} x.$$ (3)

Thus, a semilog plot of count rate $n$ versus aluminum thickness $x$ (or number of aluminum foil sheets) should yield a straight line with a negative slope. The range $R$ can be found from the plot by finding the thickness necessary to reduce the count rate to the background count rate $K$ (the count rate obtained with no radioisotope present).
We will be using increasing numbers of aluminum foil sheets to increase the distance \( x \). Thus, you will plot count rate versus number of sheets. Each sheet is \( 1.68 \times 10^{-3} \) cm thick. You will find the number of sheets necessary to reduce the count rate to the background level on your plot. The range \( R \) is then this number of sheets plus three times the thickness of a sheet. We add three to the number of sheets to account for the absorption of \( \beta \)'s by the air and the window of the G-M tube. This value of \( R \) is then used in the following empirical relation to find \( E_M \):

\[
E_M = (4.98 \text{ MeV/cm})R + 0.244 \text{ MeV} \quad (4)
\]

This equation is specific to using aluminum as the absorber. You can see from Eqs. (1)-(3) that \( E_M \) will depend on the material parameter \( b \). \((\text{Note}: \text{You may be tempted to plug } x=R \text{ and } n=K \text{ into Eq. (3) to solve for } E_M. \text{ The resulting equation is not the same as Eq. (4). The problem is that Eq. (3) is an approximation as noted earlier.)\)

**Part 1: Beta Rays from Tl-204 \( (E_M = 0.764 \text{ MeV}) \)**

**PROCEDURE:**

1. Set-up the tube and counter.
   1.1. Connect the G-M tube to the counter with the coaxial cable. Plug the counter's transformer into the socket and turn the counter ON via the toggle switch on the back of the counter.
   1.2. Turn the selector knob on the front of the counter to "REMOTE".
   1.3. Turn on the computer. Double click on the "LABLINK" icon on the desk top.
   1.4. Click on "OK" on the first screen. Select COM1 on the next screen.
   1.5. Under **File**, select "New".
   1.6. Under **Presets**, select "High Voltage". Enter the operating voltage of your tube.

2. Place the Tl-204 beta source in the sample holder with the small hole and slide it in the fourth level from the top in the G-M tube holder. A prepared set of five aluminum foil absorbers has been supplied with thicknesses of 3, 6, 9, 12, and 21 sheets. Slide the sample holder with the large hole in the second level. The foil absorbers will be placed on this holder and will cover the large hole.

3. With a counting period of 1 minute (2 minutes if the count rate is below 1000 cpm), determine the count rate for 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, and 39 sheets of foil between the source and the detector. In order to get the desired thicknesses, you will have to use various combinations of the absorbers.
   To measure the count rate:
   3.1. Under **File**, select "New".
   3.2. Under **Presets**, select "Time". Enter either 1 or 2 minutes.
   3.3. Click "RESET".
   3.4. Click "COUNT".

4. Remove the beta source and place the thick aluminum plate on the absorber holder. Take a 5-minute count. This will yield the background count rate \( K \). Express \( K \) in cpm.

5. Turn-off the tube voltage while you analyze your data. Under **Presets**, select "High Voltage".
Enter 0 or click "Off" to turn the tube voltage off.

REPORT:
1. Using semilog graph paper, plot the logarithm of the count rate $n$ (i.e., plot the count rate on the semilog side) versus absorber thickness (number of sheets). Draw the best straight line through the plotted points and extrapolate the line to get the number of sheets required to reduce the count rate to the background level measured in Step 4. Add three to this number and multiply this sum by the thickness of a sheet ($1.68 \times 10^{-3}$ cm) to find the range $R$. (Recall that adding three sheets corrects for absorption by the air and the window of the G-M tube.)

*NOTE:* You can use Excel to make this plot on your computer. You could get a semilog plot by first plotting $n$ vs. number of sheets. Then click on the $n$ axis and select "Logarithmic" scale. Unfortunately, you cannot get a linear best fit on a semilog plot in Excel. Thus, you must first generate the log of the $n$ values in a separate column and plot these log values vs. number of sheets. Now you can use the trendline tool and obtain the best line through the data.

2. Using Eq. (4), calculate the maximum energy $E_M$ of the $\beta$’s for Tl-204. Compare this value to the given energy of 0.765 MeV by finding the percent difference.

**Part 2: Beta Rays from Co-60 ($E_M = 0.319$ MeV)**

PROCEDURE:
1. Using 1 minute (or 2 minutes for rates below 1000 cpm) periods, determine the count rate for 0 through 16 sheets of foil. Additional foil is supplied for making the needed thicknesses.

2. When the counting is done, be sure to turn off the tube and counter.
   2.1. Under Presets, select "High Voltage". Enter 0 or click "Off" to turn the tube voltage off.
   2.2. Under File, select "Exit".
   2.3. Turn off the counter's toggle switch and unplug it from the outlet.

REPORT:
1. Plot the log of the count rate versus number of sheets on semilog paper. Again, you can use Excel to do this. This time, you can simply plot $n$ vs. number of sheets and make the $n$ axis logarithmic. We do not need to generate a single best line as described below.

2. The determination of the range in this case is complicated by the fact that Co-60 emits gamma rays as well as beta rays, and each contributes to the observed count rate. However, it can be assumed that the counts produced by radiation passing through the thickest absorbers are due to the gamma radiation only. And since the count rate for the thickest absorbers is only a small portion of that for the thin absorbers, it will be assumed that the count rate for low absorber thickness is due to the beta radiation only. Thus, you should see the formation of two line segments in your plot. A steep line should first be seen as the number of sheets increases from zero. Here the $\beta$ particles are being absorbed. Once they are all absorbed, then only $\gamma$ rays get through. Since they are not absorbed as readily by the aluminum, a second line should be seen that is not nearly as steep. Draw the best straight line through the first six or so points on your graph. Draw another straight line...
through the last five or points on your graph. The intersection of these two lines gives the approximate number of sheets necessary to eliminate the counting of the Co-60 $\beta$ particles. (If you are using Excel, you can judge the intersection of the two lines on the screen or you should print the plots if a printer is available and draw the lines by hand.) Adding three to this number and multiplying by the thickness of a sheet gives the range $R$. Calculate $R$.

3. Using Eq. (4), calculate the maximum energy $E_M$ of the $\beta$'s for Co-60. Compare this value to the given energy of 0.319 MeV by finding the percent difference.

### Part 3: Released Energy Comparisons

**REPORT:**

1. Calculate the energies released ($Q$) in the $\beta$ decays in this experiment and compare with the given maximum beta decay energies. Recall that $Q = \Delta m c^2$ where $\Delta m$ is the mass deficit in the decay process. The decay equations and masses of the isotopes appear below.

2. You should find good agreement between the calculated $Q$ and the given $E_M$ for the Ti-204. However, you should find that the $Q$ calculated for Co-60 is significantly greater than the given $E_M$ of the $\beta$ particle. Explain this difference. (Hint: Check the decay scheme of Co-60 on the radioisotope chart on the wall in S114.)

#### DECAY EQUATIONS

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<thead>
<tr>
<th>Isotopic Masses ($1 \text{ u} = 931.5 \text{ MeV}/c^2$)</th>
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<tbody>
<tr>
<td>$^{204}\text{TI} \rightarrow ^{204}\text{Pb} + ^0\text{\beta} + \bar{\nu}$</td>
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<tr>
<td>$^{60}\text{Co} \rightarrow ^{60}\text{Ni}^+ + ^0\text{\beta} + \bar{\nu}$</td>
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