EXPERIMENT 31

GAMMA RAY ABSORPTION IN MATTER

PRELAB PROBLEMS:

Do Exercises 1 and 2. page 31-5.

Suggested Reading:

Primer on Data Analysis, pp 1-11 to 1-15.

W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments* (2^{nd} revised ed., Springer-Verlag: 1987, 1994): Section 2.7.5, 4.5.3

INTRODUCTION

This experiment is a continuation of the ideas developed in Experiment 30a; you may want to review that experiment, especially the section on the mass attenuation coefficient.

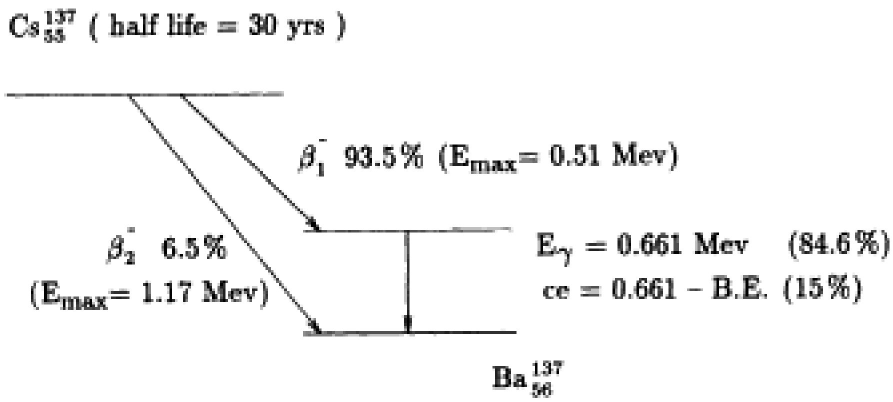
In this experiment you will measure the attenuation of ^{137}Cs gamma rays as a function of type and thickness of material, determining the mass attenuation coefficient. The results are then used to show that Compton scattering is the dominant interaction of gamma rays within the materials, but photoelectric absorption makes a noticeable contribution to absorption by heavy elements such as lead.

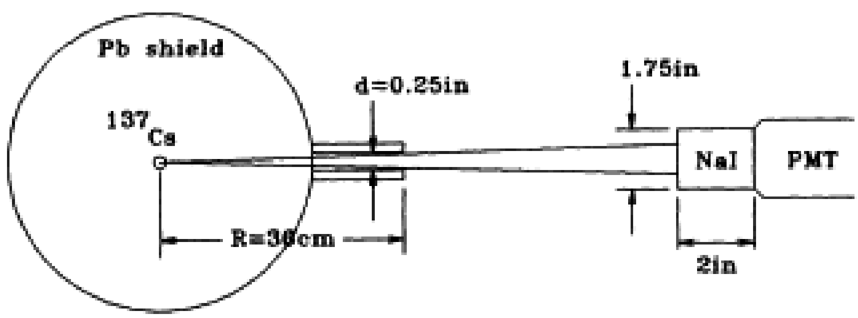
Finally, an absolute measurement of the ^{137}Cs source strength is made.

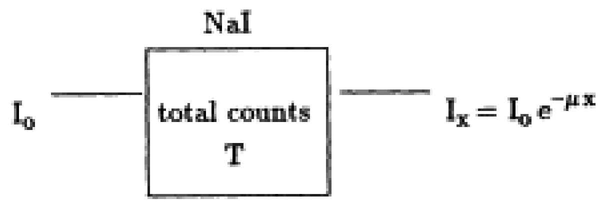
PROCEDURE

For this experiment you will use a NaI scintillation detector and the highly collimated ^{137}Cs source (See Figure 2, page 31-3).

1. Adjust the detector voltage and MCA amplifier gains until your obtain a spectrum with the ^{137}Cs full energy peak at approximately channel 700 or so.
2. Set the ***live time*** for the spectrum acquisitions to 100 sec (you may need to lengthen this value for the weaker signals obtained with a thick layer of absorber). To set the live time push the MCA program's *Presets* button or look under the *Settings/Presets* menu.
3. Take a sample spectrum with no absorber.
4. Select menu: *Display/ROIs*. Then select: *Settings/ROIs: Clear All*. Now select *Settings/ROIs: Set ROI*, then drag the cursor across the full energy peak to highlight it. You have now defined a **Region of Interest** (ROI). Note that below the spectrum x-axis you get integrated count numbers and statistics regarding the ROI you've created. The *Gross* count is the important number; this gives the total number of counts in the channels defined by your ROI (to see the gross count for your ROI, you must position the cursor within it).
5. Erase and acquire several 100 sec runs and check the statistical nature of the set of gross counts obtained in the ROI. What sort of statistics should describe the fluctuations in count number?
6. Accumulate ^{137}Cs histograms for various thicknesses of the Al, Cu, and Pb absorbers. Use enough layers of absorber to reduce the beam by at least a factor of 10 for each element. Use the gross counts each time to get the number of events within the ROI. Since gain shifts in the electronics are possible this technique allows you to visually check the position of the peak relative to the ROI. Periodically repeat a measurement at least three times to check your statistics.
7. Block off the beam and measure the background several times in the ROI.
8. Source Strength Measurement: Accumulate a ^{137}Cs spectrum for 100 seconds. Set an ROI to span the entire spectrum and record the total number of events. Block off the beam and accumulate a background spectrum and record the number of background events using the same limits.







$$T = I_o - I_x = I_o (1 - e^{-\mu x})$$

DATA ANALYSIS

In this experiment you are verifying the equation

$$I(x) = I_0 e^{-\mu x}$$

by looking at how the counting rate in the NaI detector depends on the amount of material between the source and the detector. Fit your counting rate v. absorber thickness data for each absorber material and determine its attenuation coefficient, μ. When you attempt to fit your data to the above equation, should you also include a constant term in the expression you actually fit to the data? Why? Calculate μ / ρ for each element and compare with the mass attenuation coefficient graphs provided in experiment 30 (exp 30 figures 6–8). Note that at E_γ = 0.662 MeV, the attenuation of photons in Al and Cu depends almost entirely on Compton scattering, so if you normalize your results to account for the different electron densities in the two elements the results should be approximately the same (μ / ρ_e is constant). Are your results consistent with this theoretical prediction? Electron density is given by:

$$\rho_e = Z\, N_A\, \rho / M$$

Where: N_A = Avogadro's constant M = Atomic Weight

Thus $\mu / \rho_e \propto (\mu / \rho)(M / Z)$.

For Pb, on the other hand, the contribution to the mass attenuation coefficient due to photoelectric absorption is significant. Estimate its contribution to the Pb mass attenuation coefficient by calculating the quantity $(\mu M / \rho Z)_{\text{Pb}} - (\mu M / \rho Z)_{\text{Al}}$. Are your results consistent with the ratio of the photoelectric and Compton contributions shown in Figure 3 (page 31-6)?

Another useful quantity to note is the attenuation length of a particular material at a specified E_γ. The attenuation length is that thickness of material at which the rate, I, is reduced to I_0/e. How is the attenuation length related to μ ? Determine the attenuation length, in cm, for the three absorber elements.

Next estimate the strength of the ^{137}Cs source. Figure 2 points out that the total number of events, T, calculated from the Procedure step 8 results, was some fraction of I_0, namely:

$$I_0 = T/(1 - e^{-\mu_{\mathrm{NaI}} x})$$

where:

μ_{NaI} = total attenuation coefficient for NaI at $E_\gamma = 0.662$ MeV (see Figure 5A in Experiment 30; you must convert the μ/ρ value to μ_{NaI})

x = the thickness of the NaI scintillator = 5.1 cm.

Now I_0 results from looking through a small window (Area = $\pi d^2/4$) on a large sphere (Area = $4\pi R^2$), thus the geometry factor is $16R^2/d^2$, and we can determine the total number of γ-rays per second emitted by the source.

Note that the branching ratios of Figure l imply that there are 0.935×0.846 γ-rays per disintegration, so our result must be multiplied by the reciprocal of this factor to determine the number of disintegrations/sec. With l millicurie = 3.7×10^7 disintegrations/sec, what is the strength of the source in millicuries (mCi)?

EXERCISE 1

Gross rate (source + background) is measured 3 times by counting for 1 minute each time, with a resulting mean = 823/min.

Background rate (measured 3 times for 1 minute each time) has mean = 510/min.

What are the uncertainties in the mean rates? What is the corrected source rate (Gross rate – Background rate) and its uncertainty?

EXERCISE 2

Calculate the electron densities for Al and Cu.

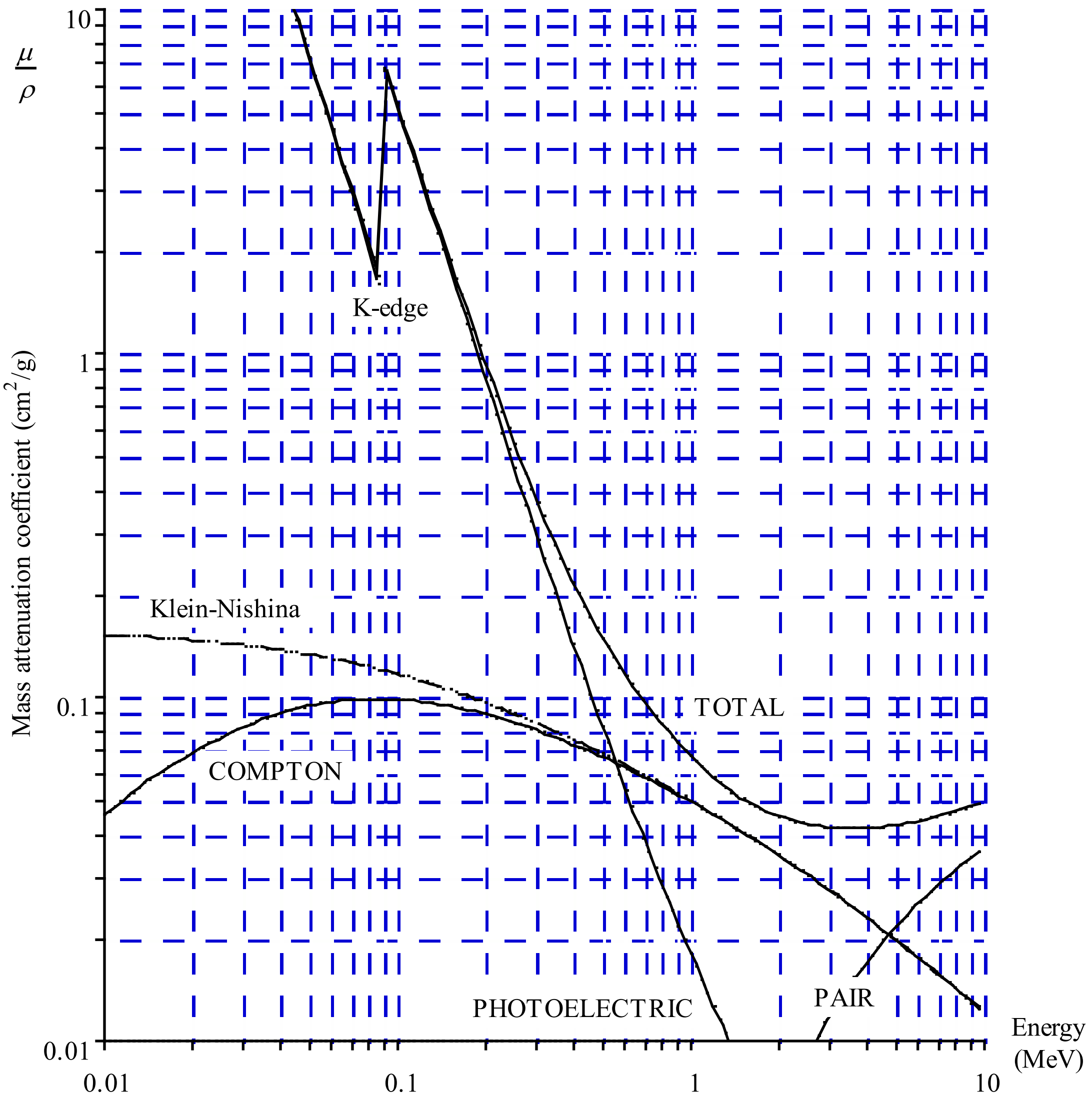


Figure 3

Mass attenuation coefficients for photons in lead.

$\rho = 11.35$ g/cm^3, $Z = 82$, $M = 207.19$