Radioactivity II: Absorption of Radiation

Introduction

In this experiment you will use the equipment of the previous experiment to learn how radiation intensity is influenced by its passage through matter. This subject is described in the "Introduction to Radiation" handout in the section titled "Interactions with matter". We will use two sources during this lab (^{137}Cs and ^{60}Co) which both emit **β**'s and photons, although in different ratios and with different energies. It will be possible to see the **β**'s from one of the source, but not from the other. Their decay schemes are described in the Appendix A of this handout.

Experiment 8.1. Background

Recheck the operating point of your Geiger tube and adjacent points, by measuring the plateau using the ^{60}Co source. Remember that the maximum counting rate should not exceed 1000 counts/sec. After establishing the operating point, measure the background rate keeping all sources of radiation at least *5* or 6 feet away. Count for a time period sufficiently long to determine the background to *5%* accuracy.

QI. How would you try to reduce the background?

Experiment 8.2: "Absorption"

Start with the Cs source on a shelf under the counter where the counting rate for the bare source does not exceed 1000 counts/sec. Point the thin β window of the source towards the counter and count the bare source for 1 minute. All counting measurements with both the bare source and with the absorbers in place should have at least 2% statistical precision.

Q2: What is the minimum count necessary to get 2% statistical precision?

Your box with absorbers contains a variety of lead and polyethylene absorbers of varying thickness. Even though some thicknesses are given in inches and in [mg/cm^2], you should not trust those numbers because the absorbers may be placed in the wrong slots. Instead, you should measure the absorber thickness with the micrometer and calculate the thicknesses in mg/cm^2. For this, you will need the density of lead (11.3 g/cm^3) and of polyethylene (0.96 g/cm^3).

For the ^{137}Cs source with its thin β window pointing towards the counter, measure the count rate for 1 layer, 2 layers, 4 layers and 8 layers of the thin plastic foil absorber (9.6 mg/cm^2). Then measure the count rate for plastic absorbers of about .84 mm, 1,6 mm, 3.2 mm, 6 mm and 12 mm in thickness. (These are approximate values for thicknesses. You should measure them yourself and use your measured values.) Next measure the count rate for lead absorbers of about .84 mm, 1,6 mm, 3.2 mm, 6 mm and 12 mm in thickness. Repeat the latter measurements for the lead absorbers using the ^{60}Co source. You will not need to measure the absorption of ^{60}Co radiation with the ^{137}Cs source. Subtract the background from each count for both polyethylene and Pb absorbers. Make sure you express all your results in the same units e.g. counts/sec and that your measurements have at least 2% statistical precision.

Using the program Kaleidagraph, plot the counting rate against ρx in [mg cm-^{2}] of absorber using a logarithmic “y” axis. Make separate graphs for lead and polyethylene containing data from both sources. From the graph determine μ, the mass attenuation coefficient, for lead for the two sources.

Q3. Can you tell from your curve or otherwise whether you have appreciable alpha particles?
Q4. Do you have substantial beta rays? How do you know?
Q5. Does Cs/Co emit gamma rays? Justify your answer.
Q6. Is there evidence of more than one energy of gamma ray present in Cs? Justify your answer.

If the gamma ray part of your polyethylene curve is approximately a straight line (exponential absorption), draw a straight line through the points and extend it back to zero [mg·cm^{-2}]. Subtract the values for gamma ray counting rate, determined by this line, from your total curve to get a curve for beta rays only. Plot beta rays only on a 10 or more times expanded [mg·cm^{-2}] scale.

Q7. Are beta rays absorbed exponentially?
Q8. If the source emits approximately equal numbers of beta and gamma rays, what is the approximate efficiency of the counter for gamma rays if you assume every beta ray is counted?

THE USE OF SEMI-LOG GRAPHS

In the “Introduction to Radiation” handout under “Interactions with matter”, we have predicted a behavior for the radiation intensity as a function of distance into an absorber:

$$N = N_0 \exp(-(\mu/\rho)\cdot(\rho x)) \quad (1)$$

where

- N = no. of counts after passing through material of thickness x
- N_0 = no. of counts before passing through material
- (μ/ρ)= mass attenuation coefficient.

- ρx = "thickness" in [mg/cm²]; ρ= density of the material [mg/cm³].

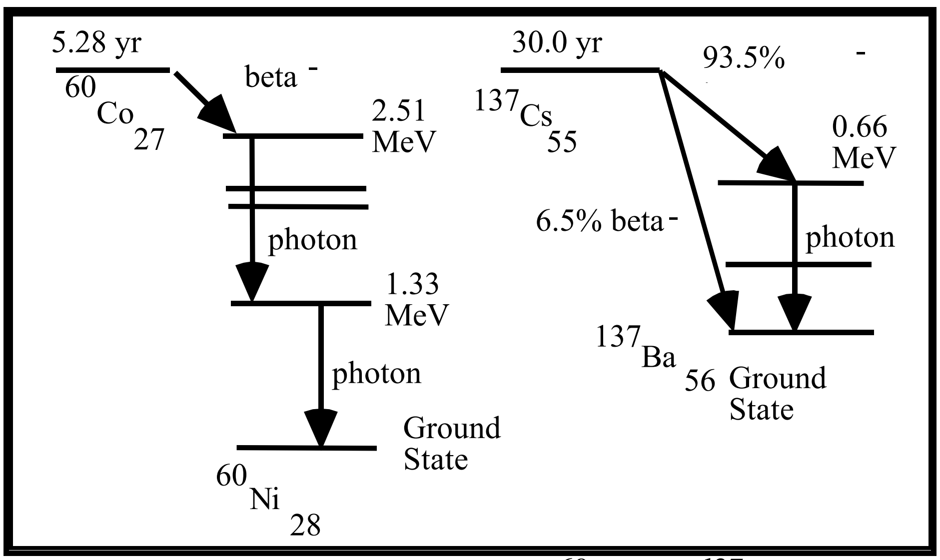
We want to determine absorption of nuclear radiation, especially, β's and γ's, obeys this law, and to determine (μ/ρ), if it does. To do this, we make a graph of N vs. (ρx) using a logarithmic y-axis. Taking natural logarithms of both sides of Eq. (1):

$$\ln(N) = \ln(N_0) - (\mu/\rho)\cdot(\rho x)$$

which is the equation for a straight line, y = b + mx, with b, the y-intercept, equal to log N_O (N_O can be read from the non-linear logarithmic scale at that point) and $-(\mu/\rho)/2.3$ as the slope. Thus you should expect to observe a straight line if you plot with a logarithmic y-axis.

APPENDIX A

Decay schemes for ^{60}Co and ^{137}Cs



The above figure shows the decay schemes for ^{60}Co and ^{137}Cs. Vertical arrows pointing down represent simple transitions from one nuclear energy level to another, which results in emission of a photon whose energy is equal to the difference in energy levels. Sloped arrows represent a beta decay which results in an electron and a neutrino being emitted. The electron in this case does not have a fixed energy but rather a spectrum which has a maximum value. Some more details of the decays are given below:

^{60}Co: This isotope has a half life of 5.28 years and beta decays to the excited states of the stable nucleus of **^{60}**Ni, which results in an electron and neutrino being emitted. In 99.9% of the cases the ^{60}Ni 2.51 MeV 4th excited state is formed, with a maximum beta decay energy of 0.31 MeV. The excited state subsequently decays in less than 10^{-12} sec to the ground state via the emission of 2 photons, one with energy 1.17 MeV and one with 1.33 MeV.

^{137}Cs: This isotope beta decays with a half-life of 30.0 years, with 93.5% of the decays creating ^{137}Ba in its 2nd excited state at 0.66 MeV and 6.5% creating ^{137}Ba in the ground state. The maximum beta energy is 0.52 MeV for the decay to the excited state and 1.18 MeV for the decay directly to the ground state. The excited state has a half-life of 2.55 min. and decays 90% of the time through the emission of a 0.66 MeV photon and 10% of the time with the emission of an atomic conversion electron. So 84% (= 0.935 * 0.90) of all beta decays of this isotope produce a photon in the final state.