Lab 10: MPC Interaction of radiation with matter.

In this lab you use a Geiger counter to investigate the radiation from two radioactive sources, $^{60}\text{Co}$ (cobalt-60) and $^{204}\text{Tl}$ (thallium-204). Here are their properties:

<table>
<thead>
<tr>
<th></th>
<th>Particle emitted</th>
<th>Particle energy</th>
<th>Half-life</th>
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<tbody>
<tr>
<td>$^{60}\text{Co}$</td>
<td>photon</td>
<td>1.3 MeV</td>
<td>5.3 years</td>
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<tr>
<td>$^{204}\text{Tl}$</td>
<td>electron</td>
<td>Max 0.75 MeV</td>
<td>3.8 years</td>
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Using the Geiger counter, you will measure the penetrating power of this radiation through different thicknesses of aluminum and lead for $^{60}\text{Co}$, and through plastic for $^{204}\text{Tl}$. Since the measurement procedures are all the same, your lab group investigates only one combination, then you summarize other group’s data at the end, so that you will have data for all different source/absorber combinations. You will need multiple absorbers of the same type and thickness.

We will be doing only section MPC-1b of the MPC-1 lab. Should take somewhat over an hour.

Your TA will distribute radioactive source(s) to your group. If you work with a $^{204}\text{Tl}$ beta emitter (plastic (poly) absorber), your TA will remove the plastic cap from your Geiger counter (the electrons can’t penetrate through much at all). Groups using the $^{60}\text{Co}$ source (Al or Pb absorber) should leave the caps on to protect the (very thin and fragile) detector window.

1) Go to the web version of the lab manual and click on the Launch NC-1B icon to start up the PASCO software.

2) Turn on your Geiger counter by plugging it into input 1 of the PASCO interface. Make sure any radioactive sources are at least 1 m away. The Geiger counter should click periodically, as it detects cosmic rays and other background radiation. Take data with the PASCO interface. What is the background count rate (average counts / second)?

3) Follow the lab manual instructions to put your source(s) in the Geiger counter platform without any absorbers. Make sure the side without writing faces the detector. Determine the mean number of decays / second (don’t forget to subtract the background signal!).
4) As discussed in class, radioactive decay is a random process, so that the decay of any individual nucleus cannot be predicted. We summarize our ignorance by saying that in every time interval $dt$ an individual nucleus has the same fixed probability $\lambda dt$ of decaying. $\lambda$ is the decay rate of an individual nucleus. Think of this as rolling a die once per second trying to get a six, which means ‘decayed’. Each time you role, you have the same 16.7% chance to get a six, so the decay rate $\lambda$ is 0.167/s. For radioactive nuclei, the decay rate is much smaller, which you could think of as rolling lots of dice once per second, trying to get all sixes (how often have you gotten all sixes in Yahtzee?).

When observing a very large number of nuclei, the measured decays per second is proportional to the number of radioactive nuclei in the sample. The average number $N_{\text{decay}}$ that decay in a time interval $dt$ is then $N_{\text{decay}} = N\lambda dt$ where $N$ is the total number of radioactive nuclei. Once they decay, the number of radioactive nuclei has decreased.

The number remaining after time $t$ is $N = N_0 e^{-\lambda t}$ where $N_0$ is the number at $t=0$.

But usually the half-life $\tau_{1/2}$, not the decay rate, is specified for a radioactive material.

The relation between them is $\tau_{1/2} = \ln(2)/\lambda = 0.69/\lambda$.

a. Use the known half-life to calculate the decay rate (in sec$^{-1}$) of a single nucleus in your radioactive source.

b. When you roll $N$ dice, there are $6^N$ possible ways for them to come up, but only one of these is all sixes. About how many dice would you have to roll per second to make the rate of getting all sixes to be the same as the decay rate for your radioactive source?

c. The number of decays per second you measured in part 3) are only a fraction of the total number of decays. First, the radiation goes in all directions, but the detector intercepts only a fraction $\pi r_{\text{window}}^2/4\pi r^2$, where $r_{\text{window}}=4.6\text{mm}$ is the radius of the detector window and $r$ the distance of the source(s) from the detector window. Second, the detector is only 10% efficient. Using these factors and your result from part 3, estimate the number of radioactive nuclei in your source.
5) In this section you determine how well different materials can stop radiation. Your group will do only one source/absorber combination, then combine data with other groups.

Group 1: Two $^{60}$Co source on top of each other in slot #5 (from top).
   Use 0, 1, 2, and 3 lead absorbers (each 0.25” thick). [two-three lab tables]
Group 2: Four $^{60}$Co sources on top of each other in very bottom slot. Use 0, 2, 4, and 6 double aluminum absorbers (each 0.25” thick) [one lab table]
Group 3: One $^{204}$Tl source in slot #5 with writing side down. Use 0, 1, 2 and 3 ‘D’ poly absorbers (each 0.010” thick). [rest of lab tables]

a) Put your results in the table below. You can answer b) and c) below while data accumulates!

<table>
<thead>
<tr>
<th>Absorber name</th>
<th>Thickness in cm (T)</th>
<th>Counts / sec</th>
<th>Counts / sec - background</th>
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b) Your counts/sec will go down as you add more absorbers. As an example, suppose that each absorber absorbs 50% of the incident radiation. For 0, 1, 2, and 3 total absorbers, plot the transmitted radiation:

\[
\text{Fraction getting through} = 1 \\
\text{Number absorbers}
\]

\[
C(T) = C_0 e^{-\alpha T}
\]

Here $T$ is the thickness again.

What is the meaning of the constant $\alpha$? Will $\alpha$ depend on the material? The source?

c) As you saw in b) your counts / second $C$ go down exponentially with absorber thickness as $C(T) = C_0 e^{-\alpha T}$ (here $T$ is the thickness again).
d) Take ln of both sides of $C(T) = C_0 e^{-\alpha T}$ to show that ln(count rate) is linear in thickness $T$. Determine $\alpha$ in units of cm\(^{-1}\) for your absorber/source by plotting ln(count rate) vs $T$.

e) Using all groups' data, summarize $\alpha$ for different source/absorber combinations.

<table>
<thead>
<tr>
<th>Source</th>
<th>Particle emitted</th>
<th>Absorber</th>
<th>$\alpha$ (cm(^{-1}))</th>
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What general conclusions can you draw about the penetrating power of photons vs electrons? About the stopping power of aluminum vs lead? What is the explanation?