This sheet is the lab document your TA will use to score your lab. It is to be turned in at the end of lab. To receive full credit you must use complete sentences and explain your reasoning clearly.

What’s this lab about?
This is the second lab about quantum mechanics. Your goal is to learn about particles emitted in radioactive decay, and about the decay process. You do this by measuring the penetrating power of these particles through various materials: Lead, Aluminum, and Plastic. You investigate two different radioactive sources $^{60}$Co (cobalt-60) and $^{204}$Tl (thallium-204) - here are their properties:

<table>
<thead>
<tr>
<th></th>
<th>Particle emitted</th>
<th>Particle energy</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>photon</td>
<td>1.3 MeV</td>
<td>5.3 years</td>
</tr>
<tr>
<td>$^{204}$Tl</td>
<td>electron</td>
<td>Max 0.75 MeV</td>
<td>3.8 years</td>
</tr>
</tbody>
</table>

Why are we doing this?
Radioactive materials are all around us. Many occur naturally in small abundances, and many are artificially enriched for technological applications, primarily for applications in medicine.

What should I be thinking about before I start this lab?
You should think about radioactive decay as being a random process, where there is a certain probability for the nucleus to emit a particle. Also think about what this particle is, where it came from, and how it might interact with the matter that it passes through.
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 of source and absorber, then you record other group's data at the end, so that you will have data for all different source/absorber combinations. You will find multiple absorbers of the same type and thickness on your lab table.

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

**Group 1**: Two $^{60}\text{Co}$ source on top of each other in slot #5 (from top).
- Use 0, 1, 2, and 3 lead absorbers (each 0.25” thick). [two lab tables]

**Group 2**: Four $^{60}\text{Co}$ sources on top of each other in very bottom slot. Use 0, 2, 4, and 6 “triple” aluminum absorbers (each “triple” absorber has three 1/8” sheets, so 3/8” thick) [one table]

**Group 3**: Two $^{204}\text{Tl}$ sources on top of each other in slot #5 with writing side down.
- Use 0, 1, 2 and 3 ‘D’ poly absorbers (each 0.010” thick). (Remove plastic Geiger counter protective cap) [rest of lab tables]

1) Go to the course web page and click on the Lab11Settings file on the “Laboratories” page to start up the PASCO software.

2) First you need to measure the background radiation level. 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 for 300 seconds (it will stop automatically). What is the background count rate (average counts / second)? Remember there are 10 sec in each “data sample”

3) Put the appropriate number of sources on the clear tray, and slide the tray in the appropriate slot (see above). Make sure the side without writing faces the detector, and for $^{204}\text{Tl}$ make sure that the plastic cap is removed from the Geiger counter. Click start and let it run for until it stops (300 sec). Determine the mean number of counts / second from the radioactive source by subtracting the background signal. There are 10 sec in each “data sample”.

**While the data is accumulating, complete part 4 on the next page.**
4) Radioactive decay is a random process, so that the decay of any individual nucleus cannot be predicted. As your data shows, the number of decays in each ten-second interval varies quite a bit. In each short time interval \( dt \) an individual nucleus has the same fixed probability \( r dt \) of decaying. \( r \) is the decay rate of an individual nucleus.

Think of this as rolling a die once per second trying to get a six, which here means ‘decayed’. Each roll tells you whether the nucleus decayed in that \( dt \) of 1 second. Each time you roll, you have the same 16.7% chance to get a six, so the decay rate \( r \) is 0.167/s. For radioactive nuclei, the decay rate is much smaller, which you can think of as rolling a cup of many dice once per second, trying to get all sixes (how often have you gotten all sixes in Yahtzee?).

The measured decays per second in your experiment 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 \( N_{\text{decay}} = N_r dt \) where \( N \) is the total number of radioactive nuclei. Once they decay, the number of radioactive nuclei has decreased. The number remaining after time \( t \) works out to be \( N = N_0 e^{-rt} \) where \( N_0 \) is the number at \( t=0 \).

But usually the half-life \( t_{1/2} \), not the decay rate, is specified for a radioactive material. The relation between them is \( t_{1/2} = \ln(2)/r = 0.69/r \).

a. Use the listed 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 once per second to make the rate of getting all sixes the same as your radioactive source decay rate?

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 \( \pi r_{\text{window}}^2 / 4 \pi r_{\text{sample}}^2 \), \( r_{\text{window}} = 4.6 \text{mm} \) is the detector window radius, \( r_{\text{sample}} \) is the distance of the source(s) from the detector window.
Second, the detector is only 10% efficient (counts only 10% of the entering particles).
Use your result from part 3 to find 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).

**Group 2:** Four $^{60}$Co sources on top of each other in very bottom slot.
- Use 0, 2, 4, and 6 aluminum absorbers

**Group 3:** Two $^{204}$Tl sources on top of each other in slot #5 with writing side down.
- Use 0, 1, 2 and 3 ‘D’ poly absorbers (each 0.010” thick).

(Remove plastic Geiger counter protective cap)

a) Put your results in the table. Answer b) and c) below while data accumulates.

<table>
<thead>
<tr>
<th>Source</th>
<th>Absorber</th>
<th>Thickness in cm (T)</th>
<th>Counts / sec</th>
<th>Counts / sec - background</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td></td>
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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 radiation hitting it. For 0, 1, 2, and 3 total absorbers, make a bar chart of what you would expect for the transmitted radiation (you aren’t plotting your data here, but basically doing a little calculation). Answer this while your data is accumulating.

\[
\text{Fraction getting through} = 1 - e^{-\alpha T}
\]

\[
\text{Counts / sec} = C_0 \cdot e^{-\alpha T}
\]

\[
\alpha = \frac{\ln(2)}{T}
\]

As you saw in b) your counts / second $C$ go down exponentially with absorber thickness as $C(T) = C_0 \cdot e^{-\alpha T}$ (here $T$ is the thickness again).

What is the meaning of the constant $\alpha$? Will $\alpha$ depend on the material? The source? Answer this while your data is accumulating.
d) In this section you will analyze the data that you accumulated in part a. You want to
find $\alpha$ in units of cm$^{-1}$ for your absorber/source by plotting
(counts/sec – background) vs thickness. You can easily do this in Excel (“Add
Trendline” in the “chart” menu, and also “display equation” in the “options” tab).
Then either fit an exponential function to it, or plot
ln(counts/sec – background) vs thickness and find the slope. Tape your plot below, and
write down your value of $\alpha$ in units of cm$^{-1}$ for your source/absorber combination.

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?