PHSC 2105 **Absorption of Gamma Rays** **Name:**____________________

Object: To determine how aluminum absorbs gamma rays.

Introduction: The radioactive source used to provide gamma radiation for this experiment is a $5.0\,\mu$Ci cesium-137 sample. This isotope has a half-life of 30.2 years and emits gamma (γ) radiation at an energy of 0.6616 MeV. It also emits a some beta minus (β^-) radiation which we don't want.

It has been found that gamma radiation interacts with matter in a manner quite different from alpha or beta rays (particles). This is due to the fact that gamma rays consist of high energy electromagnetic waves, while alpha and beta rays are made up of high-speed charged particles. As alpha and beta particles travel through matter they scatter off the atoms and thus follow a rather zig-zag path through the material, slowing down as they go. A gamma ray, being an EM wave or photon, can travel at only one speed—the speed of light. High energy photons can travel through significant amounts of material without interacting with the matter, but the greater the distance of travel through a substance, the greater probability that the photon will be absorbed. When they do interact they can lose their energy all at once, rather than in bits and pieces.

Radioactive processes are random and probabalistic; however, with large numbers of data the absorption can be aproximately described mathematically as "exponential decrease as a function of distance." This means that the number of photons (counts) per minute N that survive a distance x in a substance is modeled by the formula

$$N = N_0 e^{-\mu x} \tag{1}$$

where μ is the linear absorption coefficient of the material (this μ is not related to the μ above in the 5.0 microcurie reference), and N_0 is the initial count rate (without a barrier). Linearizing Equation 1 (in $y = mx + b$ form) gives

$$-\ln\left(\frac{N}{N_0}\right) = \mu x \tag{2}$$

where ln is the natural (base e) logarithm (you should have a ln button on your calculator).

A useful number related to this absorption process is the half-value layer (HVL), also known as the half distance, or $x_{1/2}$ of a substance. This is defined to be the distance through the material for which one half of the original photons will be absorbed ($N/N_0 = 1/2$). It can be calculated from Equation 2.

$$x_{1/2} = \frac{-\ln\frac{1}{2}}{\mu} = \frac{\ln 2}{\mu} \approx \frac{0.6931}{\mu} \tag{3}$$

So, once we have determined the absorption constant μ, we can calculate the half-value layer $x_{1/2}$.

Because the decay process is totally random and predictions can be made only statistically, it is important to get as many counts as you have time for—this reduces the uncertainties. The effect of the air is negligible in this experiment.

Safety: The radioactive sources are of extremely low activity and are not hazardous when used as directed. However, it is a good idea to treat all radioactive materials safely. For example, do not put the source in your pocket or bring it too near your body; handle it only when necessary, and return it when the experiment is over. Also, please do not touch the end window of the Geiger tube or you will break it and destroy the tube; it cannot be repaired and it is expensive to replace.

Procedure: It would be convenient to make all time measurements in minutes for this lab.

1. With the Geiger tube mounted in its stand and with all radioactive sources placed well away, measure the background radiation. Place one aluminum plate in the stand in the top slot and leave it there for the rest of the experiment. This is done to block out the alpha and beta radiation that may be part of the background (and also emitted by the source). These alpha and beta particles are easily blocked by a single plate of aluminum, whereas most of the gamma radiation (which is what you want to count) passes through. Simultaneously press the reset button on the counter and start your stop watch. Allow the counts to go to at least 200 and record the time (an integer number of minutes is convenient).

2. Place the ^{137}Cs source, printed side up, in the depression at the bottom of the plastic stand.

   Simultaneously press the reset button on the counter and the start button on the stopwatch. Stop the stopwatch when the counter reads at least 2500 counts (more is better). Then correct the count rate for the background radiation by subtracting the background count rate. This corrected count rate is N_0. It will be the first entry in the corrected count rate column of your table (corresponding to $x = 0.00\,\text{cm}$).

   Then insert additional aluminum plates two at a time noting the cumulative plate thickness (do not count the beta-shield in your plate thickness measurements) and the corresponding counts each time; let the counts go to at least 2500 (more is better) for each thickness. Then correct each count rate for the background radiation by subtracting the background count rate to obtain successive values of N.

3. Make a graph of $-\ln(N/N_0)$ vs. x. From Equation 2, we see that the slope of the best-fit straight line graph should be μ_{Al}.

4. Record your slope as the experimental value of μ_{Al} and use Equation 3 to compute your experimental value of the half-value layer $x_{1/2}$.

5. Interpolate the accepted value of $x_{1/2}$ from the chart(s) in the Canvas module and compare your value to it.

Apparatus: Draw a diagram of the apparatus.

Results:

1. Counts = ____________ Time = ____________ Background count rate = ____________

2.

total plate thickness x (cm)	counts	time t (min)	count rate (counts/min)	corrected count rate N (counts/min)	$-\ln(N/N_0)$
0.00				$N_0 =$	0.00

3.

4. Experimental $\mu_{\mathrm{Al}} =$ ______________ Experimental HVL $(x_{1/2}) =$ ______________

5. Accepted value of HVL $(x_{1/2}) =$ ______________ % diff = ______________

Questions:

1. Explain why if your data points do not lie well on a straight line.

2. Average your value of $x_{1/2}$ with those of the other groups in the class. How much closer is the average to the accepted value? Discuss systematic vs. random errors.

3. In elementary physics we have gone to great lengths to make our graphs linear (you linearized some graphs in the Simple Harmonic Motion lab by squaring the periods). This is because the math of straight lines is straightforward. You linearized your graph today by taking logarithms. Qualitatively sketch a graph of your data *without* linearizing it, *i.e.,* a graph of N/N_0 vs. x. No numbers are necessary.

4. By what factor would you expect the count rate to fall off if you put four times the half-value layer of some material between the source and the Geiger tube?

5. If you start with 8×10^{20} atoms of ^{137}Cs, about how many would your grandchildren have left (undecayed) 90.60 years later? (Hint: how many half-lives is 90.60 years?)

6. By what factor would you expect the (corrected for background) count rate to fall off if you move the Geiger tube twice as far away from the source (without any shielding plates)?

Conclusions: