Lab 4: Gamma, Beta, and Alpha Particle Attenuation

J.R. Powers - Luhn
09 February 2017
Thursday
Lab Partner: Dory Miller

Pre-Laboratory Questions:

1. How long does it take for Y-90 to become in secular equilibrium with Sr-90? What is the ratio of their activities?

In[233]:= `(* half life of Y-90 64.1h *)`

`Y90HalfLife = 64.1;`

`(* half life of Sr-90 28.79y *)`

`Sr90HalfLife = 28.79 * 365.241 * 24; (*convert to hours*)`

`8 * Y90HalfLife`

Out[235]= 512.8

The two isotopes reach secular equilibrium in 8 half-lives of the daughter nuclide, $t_{(1/2)} = 512.8\ h$. At this point their activities are equal, $A_{Sr-90} = A_{Y-90}$

2. Using the NIST ESTAR database, determine the range of the most probable and maximum emission energy for the beta particles from Sr-90 and Y-90 in Aluminum and plastic. Provide the answer in units of mass thickness (mg/cm^2).

In[236]:= `(* From https://www.nndc.bnl.gov/chart/decaysearchdirect.jsp?nuc=90SR&unc=nds *)`

`Sr90BetaEnergy = {195.88} (* keV *);`

`(* From https://www.nndc.bnl.gov/chart/decaysearchdirect.jsp?nuc=90Y&unc=nds *)`

`Y90BetaEnergy = {25.07, 185.61, 933.7} (* keV *);`

In[238]:= `(* Ranges in Aluminum *)`

Beta Energy (keV)	Stopping Power (cm^2/g)	Range (mg/cm^2)
195.8	2.204	88.84
25.07	8.328	3.010
185.61	2.261	82.09
933.7	1.489	627.1

;

In[239]:= `(* Ranges in Plastic (Polyethylene) *)`

Beta Energy (keV)	Stopping Power (cm^2/g)	Range (mg/cm^2)
195.8	3.001	29.60
25.07	11.89	0.2532
185.61	3.081	26.64
933.7	1.950	321.6

;

The 933.7keV beta is the most probable decay for Y-90; The 195.8keV beta is the most probable decay for Sr-90.

3. Where are gamma rays on the electromagnetic spectrum? What are the characteristics of their wavelength, frequency, and energy?

Gamma rays are the most energetic photons on the electromagnetic spectrum. Their wavelength is on the order of tenths of angstroms (10^{-11} *m*), making their frequency on order of 10^{19} Hz. Their energies are normally in the range of tens to hundreds of keV, but can reach the MeV range.

4. Using the NIST X-ray Mass Attenuation Coefficient Database (http://www.nist.gov/pml/data/xraycoef/), use linear interpolation to find the mass attenuation coefficient of 88keV gamma-rays in Aluminum. Provide the answer in units of cm^2/mg.

In[240]:= `e0 = 80 (* keV *);`
`e1 = 100 (* keV *);`
`mu0 = 0.2018 * 10`$^{-3}$` (* cm`^{2}`/mg *);`
`mu1 = 0.1704 * 10`$^{-3}$` (* cm`^{2}`/mg *);`
$$mu = mu0 + \frac{mu1 - mu0}{e1 - e0} * (88 - e0)$$

Out[244]= `0.00018924`

Mass attenuation coefficient for 88keV gammas in Aluminum is $1.892 * 10^{-4} \frac{cm^2}{mg}$.

5. Using the value found in question 4, calculate the thickness of Aluminum required to absorb between 10-80% of the 88keV gamma-rays in steps of 10%.

In[245]:= `density = 2700 (* mg/cm`^{3}` *);`
`ap = Table[i, {i, 0.1, 0.8, 0.1}] (* Attenuation Percentages *);`
$$at = Table\left[\frac{-1}{mu * density} * Log[1 - ap[[i]]], \{i, Length[ap]\}\right] // N;$$
`Multicolumn[Join[ap, at], 2]`

Out[248]=
```
0.1  0.206206
0.2  0.436725
0.3  0.698065
0.4  0.99976
0.5  1.35659
0.6  1.79332
0.7  2.35635
0.8  3.14991
```

See above for the thickness (in cm, second column) to attenuate the gamma-rays to the fractions in the first column.

6. Calculate the mass thickness of an aluminum shim 0.080±0.005 inches thick. Report your answer in cm^2/mg.

In[249]:=
$$\frac{\frac{1}{density} * \frac{1}{0.080 * 2.54}}{\frac{1}{density} * \frac{1}{(0.080 * 2.54)^2} * 0.005 * 2.54}$$

Out[249]= 0.00182269

Out[250]= 0.000113918

The mass thickness of an aluminum shim is 0.0018±0.00011 $\frac{cm^2}{mg}$

In-Lab

Beta particle attenuation

1. With no radiation sources around your station, take a background measurement. Use the count time of 60 seconds and 10 runs.

In[251]:= `PartABackgroundFilename = "beta_bkg.dat";`

`PartABackgroundCounts =`
`  Import[NotebookDirectory[] <> PartABackgroundFilename][[12 ;;]][[ ;; , 3]]`

Out[252]= {36, 39, 36, 37, 43, 32, 43, 51, 40, 30}

2. Use a hollow source holder to hold the Sr-90 source up on the second to top shelf. Take a 60 second count. Record actual setup parameters.

3. On the top shelf, place an absorber between the source and the detector. Choose an absorber that is approximately 10% of the range for the maximum emission energy of Sr-90.

4. Repeat step 3 for five more absorbers with mass thicknesses between 30% and 300% the range of the most probable beta energy for Sr-90. Use any material absorbers for these measurements that meet the mass thickness requirements. Record the absorber material, mass thickness and count data for all experiments in your laboratory notebook.

In[253]:= `PartASr90DataFilename = "beta_exp.dat";`

`PartASr90Counts =`
`  Import[NotebookDirectory[] <> PartASr90DataFilename][[12 ;;]][[ ;; , 3]]`
`PartAAbsorberThicknesses = {0., 0., 19.2, 102, 141, 216, 522, 655} (* mg/cm`^{2}` *)`

Out[254]= {10 570, 10 294, 8385, 4859, 4408, 3542, 729, 295}

Out[255]= {0., 0., 19.2, 102, 141, 216, 522, 655}

5. Return the beta source to the GTA.

Alpha particle attenuation

1. Measure the distance between the source holder shelves and note it in the laboratory notebook.

In[256]:= `ShelfSeparationDistance = 0.8 (* cm *);`

2. Check out a Po-210 source from the GTA. **Note the source born date to estimate the source strength.**

Po-210 source dated October 2014, 0.1 μCi. $t_{1/2}$ = 138.4

3. Place a series of 0.08±0.005 inch aluminum shims on the source holder so that, when the Po-210

alpha source is placed on top, the distance between the alpha source and GM window is minimized but **not touching the GM window.**

4. Estimate the separation distance between the source and the window of the GM tube.

Separation distance approximately 0.3 cm

5. Conduct one 60 second counting experiment. Record your results in your laboratory notebook.

6. Remove one of the aluminum shims from the source holder and repeat step 5.

7. Repeat step 6 until all but one aluminum shim has been removed. Then move the source holder down one shelf, add shims to get the next separation distance approximately equal to one aluminum shim thickness, and continue taking 60 second counts at each separation distance.

8. When the count rate observed is approximately equal to the background, take a couple more measurements to enhance the fidelity of the collected data for post-lab analysis.

```
In[257]:=  (* All data recorded in single file *)
           PartBPo210DataFilename = "alpha_exp.dat";
           PartBPo210Counts =
            Import[NotebookDirectory[] <> PartBPo210DataFilename][[12 ;;]][[ ;; , 3]]
```

Out[258]= {165, 101, 72, 54, 30, 30, 30}

```
In[259]:=  PartBPo210SourceDistance = {0.3, 0.5, 0.7, 0.9, 1.1, 1.3, 1.5} (* cm *)
           AluminumDensity = 2700 (* mg/cm^3 *);
```

Out[259]= {0.3, 0.5, 0.7, 0.9, 1.1, 1.3, 1.5}

9. Return the Po-210 source to the GTA.

Gamma-ray attenuation

NOTE: Data were not collected in lab. Instead, Prof. Lukosi collected data for extended time periods. Error propagation will be conducted assuming that there is no error in the counting time.

1. Check out a 1μCi Cd-109 button source (or other low energy gamma-ray source) from the GTA.

2. Place the source on the source holder on the second shelf of the GM test stand. Place another source holder on the top shelf with one aluminum shim on it and conduct a 60 second count.

3. Now start adding aluminum shims to the top source holder to attenuate some of the 88 keV gamma-rays. Use the answer from the pre-laboratory exercise to attenuate between 10% and 80% of the incident 88 keV gamma-rays. Conduct a total of four experiments between this range at 60 second count times each.

```
In[261]:=  PartCBackground = {166, 182}
           PartCCounts = {724, 366, 493, 871, 1105, 986}
           PartCPlates = {1, 2, 4, 6, 7, 8}
           PartCTimes = {300, 300, 600, 1241.5, 1582, 1421.5}/60 (* convert to minutes *)
           PartCBackgroundTimes = {300, 300}/60 (* convert to minutes *)
```

Out[261]= {166, 182}

Out[262]= {724, 366, 493, 871, 1105, 986}

Out[263]= {1, 2, 4, 6, 7, 8}

Out[264]= $\left\{5, 5, 10, 20.6917, \frac{791}{30}, 23.6917\right\}$

Out[265]= $\{5, 5\}$

4. Record results in the laboratory notebook (i.e., how many shims used and counts observed for each).

5. Return the Cd-109 button source to the GTA.

Post-Lab

In[266]:= ## Beta particle attenuation

1. From the data collected in steps 1-4, determine the background and dead time corrected count rate for all data collected and the associated uncertainty.

In[267]:= `τ = 267 * 10⁻⁶; (* s, from lab 3 data at station 1. Assume error=0 *)`
`PartACountTime = 60; (* s, Assume error=0 *)`

In[269]:= `PartABackgroundCountRate = Total[PartABackgroundCounts] / 600 // N`

Out[269]= `0.645`

In[270]:= `PartABackgroundCountRateError = 1 / 600 * √(Total[PartABackgroundCounts]) // N`

Out[270]= `0.0327872`

In[271]:= `DeadTimeCorrectedCounts[uncorrected_] := uncorrected / (1 - uncorrected * τ)`

In[272]:= `MyDumbError[u_] = D[DeadTimeCorrectedCounts[u], u]`

Out[272]= $\dfrac{1}{1 - \frac{267\,u}{1\,000\,000}} + \dfrac{267\,u}{1\,000\,000\left(1 - \frac{267\,u}{1\,000\,000}\right)^2}$

In[273]:= `PartADeadTimeCorrectedBackgroundRate =`
`  DeadTimeCorrectedCounts[PartABackgroundCountRate]`
`PartADeadTimeCorrectedBackgrounRateError =`
`  √(MyDumbError[PartABackgroundCountRate]² * PartABackgroundCountRateError²) // N`

Out[273]= `0.645111`

Out[274]= `0.0327985`

In[275]:= `PartASr90CountRate = PartASr90Counts / PartACountTime;`
`PartASr90CountRateErrors = √(PartASr90Counts / PartACountTime²) ;`

In[277]:= `PartADeadTimeCorrectedCountRates = DeadTimeCorrectedCounts[PartASr90CountRate] // N`

Out[277]= `{184.862, 179.803, 145.167, 82.7731, 74.9366, 59.9787, 12.1895, 4.92313}`

In[278]:= `PartADeadTimeCorrectedCountRatesError =`
`  √(MyDumbError[PartASr90CountRate]² * PartASr90CountRateErrors²) // N`

Out[278]= `{1.88683, 1.85725, 1.64676, 1.21369, 1.15127, 1.02394, 0.452934, 0.287012}`

```
In[279]:= PartADeadTimeAndBackgroundCorrectedCountRates =
        PartADeadTimeCorrectedCountRates - PartADeadTimeCorrectedBackgroundRate
      PartADeadTimeAndBackgroundCorrectedCountRatesError =
        √(PartADeadTimeCorrectedCountRatesError² +
          PartADeadTimeCorrectedBackgrounRateError²)
```

Out[279]= {184.217, 179.158, 144.522, 82.128, 74.2915, 59.3336, 11.5444, 4.27802}

Out[280]= {1.88712, 1.85754, 1.64709, 1.21414, 1.15174, 1.02446, 0.45412, 0.28888}

```
In[281]:= PartAPlotData = Multicolumn[
        Join[PartAAbsorberThicknesses, PartADeadTimeAndBackgroundCorrectedCountRates,
          PartADeadTimeAndBackgroundCorrectedCountRatesError], 3] // First
```

Out[281]= {{0., 184.217, 1.88712}, {0., 179.158, 1.85754},
    {19.2, 144.522, 1.64709}, {102, 82.128, 1.21414}, {141, 74.2915, 1.15174},
    {216, 59.3336, 1.02446}, {522, 11.5444, 0.45412}, {655, 4.27802, 0.28888}}

2. Plot the data from part 1 on a semi-log scale with error bars (i.e., transmitted beta fraction vs. absorber thickness). The slope of this line will be the mass attenuation coefficient.

```
In[282]:= Needs["ErrorBarLogPlots`"];
```

```
In[373]:= PartAData =
        ErrorListLogLinearPlot[PartAPlotData, ErrorBarFunction → ErrorBarScale[1]]
```

Out[373]=
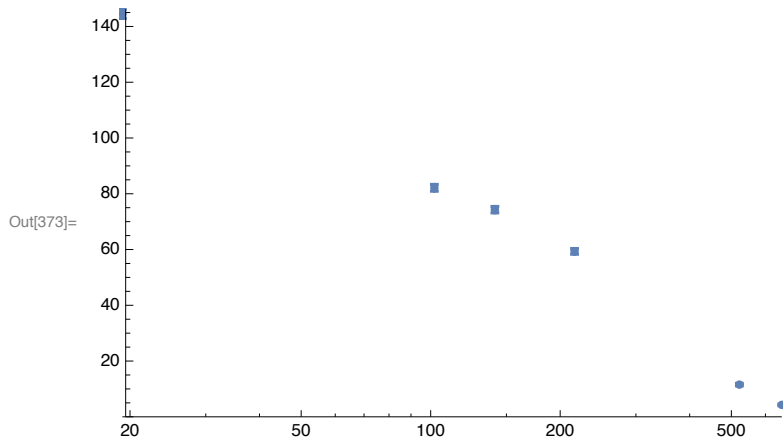
3. Using linear regression, find the slope and its uncertainty. Report the value in units of cm^2/mg in a new, text-formatted cell.

```
In[324]:= PartAFitData = Multicolumn[
        Join[PartAPlotData[[ ;; , 1]], Log[PartAPlotData[[ ;; , 2]]]], 2] // First
      Fit[PartAFitData[[ ;; , 1 ;; 2]], {1, x}, x]
```

Out[285]= Fit[{{0., 5.21611}, {0., 5.18827}, {19.2, 4.97343}, {102, 4.40828}, {141, 4.308},
    {216, 4.08318}, {522, 2.4462}, {655, 1.45349}}, {1, 0.2032}, 0.2032]

Out[324]= {{0., 5.21611}, {0., 5.18827}, {19.2, 4.97343}, {102, 4.40828},
    {141, 4.308}, {216, 4.08318}, {522, 2.4462}, {655, 1.45349}}

Out[325]= `5.1349 - 0.00543875 x`

In[433]:= `PartAFit = Plot[5.134896351342388` - 0.0054387485165248994` x, {x, 0, 700},`
        `PlotLabel → Style["Log(Counts) vs. Absorber Mass Thickness (mg/cm`^{2}`)", 22],`
        `FrameLabel → {Style["Absorber Mass Thickness", 18], Style["Log(Counts)", 18]},`
        `Frame → True, ImageSize → Full, PlotLegends →`
          `Placed[{"Fit of Log(Counts)"}, {0.85, 0.85}], PlotStyle → {Gray, Dashed}];`
     `PartATest = Multicolumn[Join[PartAFitData[[ ;; , 1]], PartAFitData[[ ;; , 2]],`
          `PartAPlotData[[ ;; , 3]] / PartAFitData[[ ;; , 2]]], 3] // First;`
     `(*PartALogData=ListPlot[PartAFitData[[;;,1;;2]],`
        `PlotLegends→Placed[{"Counts"},{0.85,0.85}]];*)`
     `PartALogData = ErrorListPlot[PartATest,`
        `PlotLegends → Placed[{"Counts"}, {0.85, 0.85}]];`
     `Show[PartAFit, PartALogData]`

Out[436]=
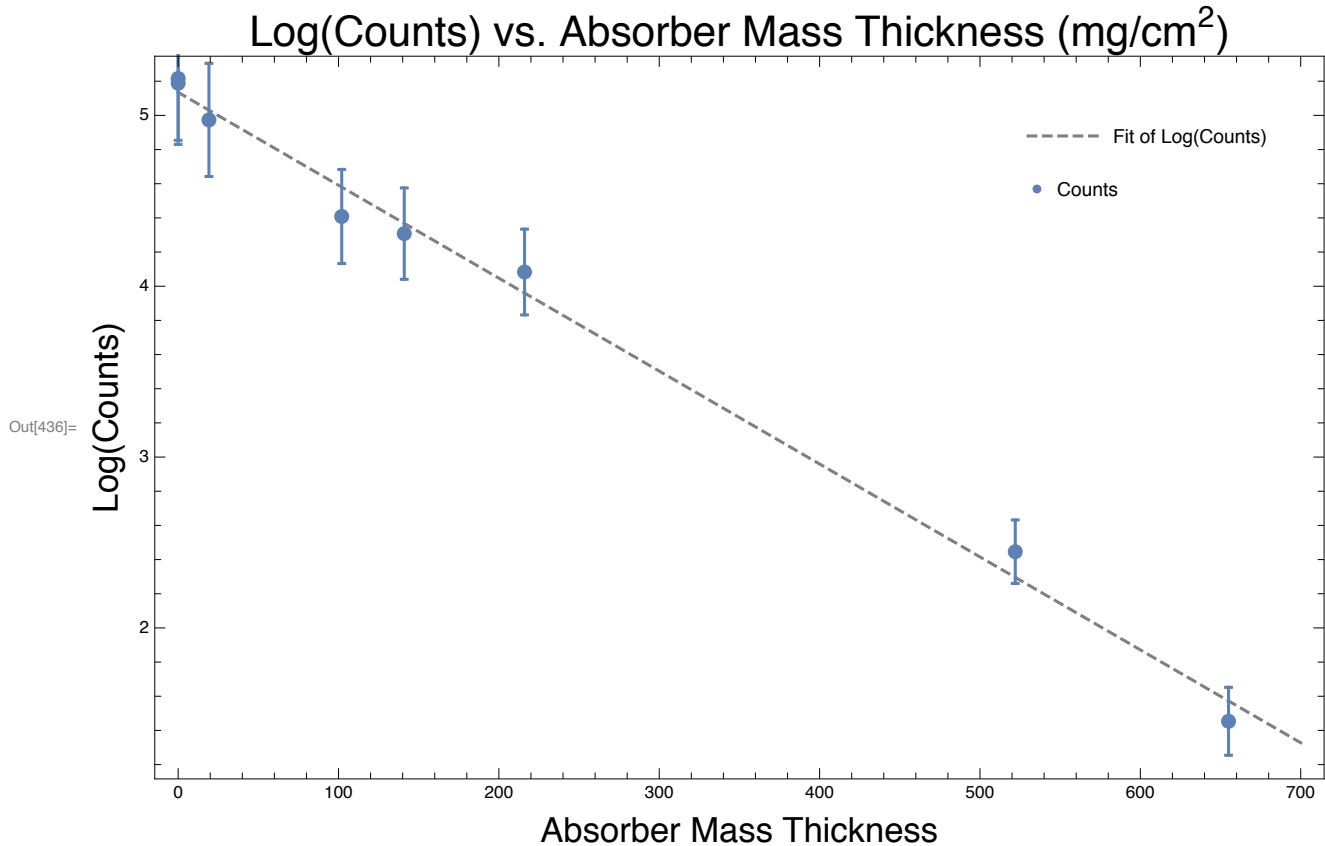
4. Using equation 4, determine the mass attenuation coefficient for Sr-90 and Y-90 in units of cm^2/mg.

Equation Four: $\mu(E_{Max}) = 1.7 * E_{Max}^{-1.14}$

In[286]:= `MassAttenuationCoefficientSr90 = 1.7 * 546`$^{-1.14}$
     `MassAttenuationCoefficientY90 = 1.7 * 2280.1`$^{-1.14}$

Out[286]= `0.0012884`

Out[287]= `0.00025257`

5. Comment on how well the collected data agrees with that calculated in equation 4. Include a discussion on the fact that Y-90 is present in the Sr-90 source, and whether this may have affected the experimental result and its comparison with the calculated mass attenuation coefficient.

While the calculated value for Sr-90 is lower (less attenuating) than that determined in the lab, the sample had partially decayed to Y-90, which emits three additional betas at varying energy. The resultant number of counts, therefore, includes all four of these betas. To account for this, a more accurate equation would have been $R_T = R_1 e^{-\mu_1 t} + R_2 e^{-\mu_2 t} + R_3 e^{-\mu_3 t} + R_4 e^{-\mu_4 t}$.

In[288]:= # Alpha particle attenuation

1. From the data collected, determine the average count rate (background corrected and dead time corrected) with uncertainty, for all shims used.

In[289]:= `PartBPo210Counts`

Out[289]= {165, 101, 72, 54, 30, 30, 30}

In[290]:= `PartBPo210CountsError =` $\sqrt{\text{PartBPo210Counts}}$ `// N`

Out[290]= {12.8452, 10.0499, 8.48528, 7.34847, 5.47723, 5.47723, 5.47723}

In[291]:= `PartBCountTime = 60; (* s, Assume error=0 *)`

In[292]:= `PartBCountRates = PartBPo210Counts / PartBCountTime // N`

Out[292]= {2.75, 1.68333, 1.2, 0.9, 0.5, 0.5, 0.5}

In[293]:= `PartBCountRateErrors =` $\sqrt{\dfrac{\text{PartBPo210Counts}}{\text{PartBCountTime}^2}}$ `// N`

Out[293]= {0.214087, 0.167498, 0.141421, 0.122474, 0.0912871, 0.0912871, 0.0912871}

In[294]:= `PartBDeadTimeCorrectedCountRates = DeadTimeCorrectedCounts[PartBCountRates]`

Out[294]= {2.75202, 1.68409, 1.20038, 0.900216, 0.500067, 0.500067, 0.500067}

In[295]:= `PartBDeadTimeCorrectedCountRateErrors =`
$\sqrt{\left(\text{MyDumbError[PartBDeadTimeCorrectedCountRates]}^2 * \text{PartBCountRateErrors}^2\right)}$ `// N`

Out[295]= {0.214402, 0.167649, 0.141512, 0.122533, 0.0913115, 0.0913115, 0.0913115}

In[296]:= `(* Using the background count rate from part A *)`
`PartBDeadTimeAndBackgroundCorrectedCountRates =`
`PartBDeadTimeCorrectedCountRates – PartADeadTimeCorrectedBackgroundRate`

Out[296]= {2.10691, 1.03898, 0.555274, 0.255105, −0.145044, −0.145044, −0.145044}

In[297]:= `PartBDeadTimeAndBackgroundCorrectedCountRateErrors =`
$\sqrt{\left(\text{PartBDeadTimeCorrectedCountRateErrors}^2 + \text{PartABackgroundCountRateError}^2\right)}$ `// N`

Out[297]= {0.216895, 0.170825, 0.145261, 0.126844, 0.0970195, 0.0970195, 0.0970195}

2. Properly plot the collected data (observed counts vs. distance) with error bars. In a new, text-style cell, estimate the range of alpha particles in air. Also comment on whether you would argue that the count rate vs. distance is flat or not. If not, theorize why this is the case. Hint: see chapter 8 and assume the alpha source is a point source.

In[298]:= `PartBPlotData = Multicolumn[Join[PartBPo210SourceDistance * 10,`
`        PartBDeadTimeAndBackgroundCorrectedCountRates], 2] // First;`

In[439]:= `ErrorListPlot[Table[{PartBPlotData[[i]], ErrorBar[25.4 * 0.005 * √i ,`
`        PartBDeadTimeAndBackgroundCorrectedCountRateErrors[[i]]]},`
`    {i, Length[PartBPo210SourceDistance]}], ImageSize → Full,`
`  FrameLabel → {Style["Distance from detector (mm)", 18],`
`    Style["Corrected count rate (minutes⁻¹)", 18]},`
`  PlotLegends → Placed[{"Corrected count rate"}, {0.85, 0.85}], Frame → True,`
`  PlotLabel → Style["Po-210 Count Rate vs. Distance", 22]]`

Out[439]=
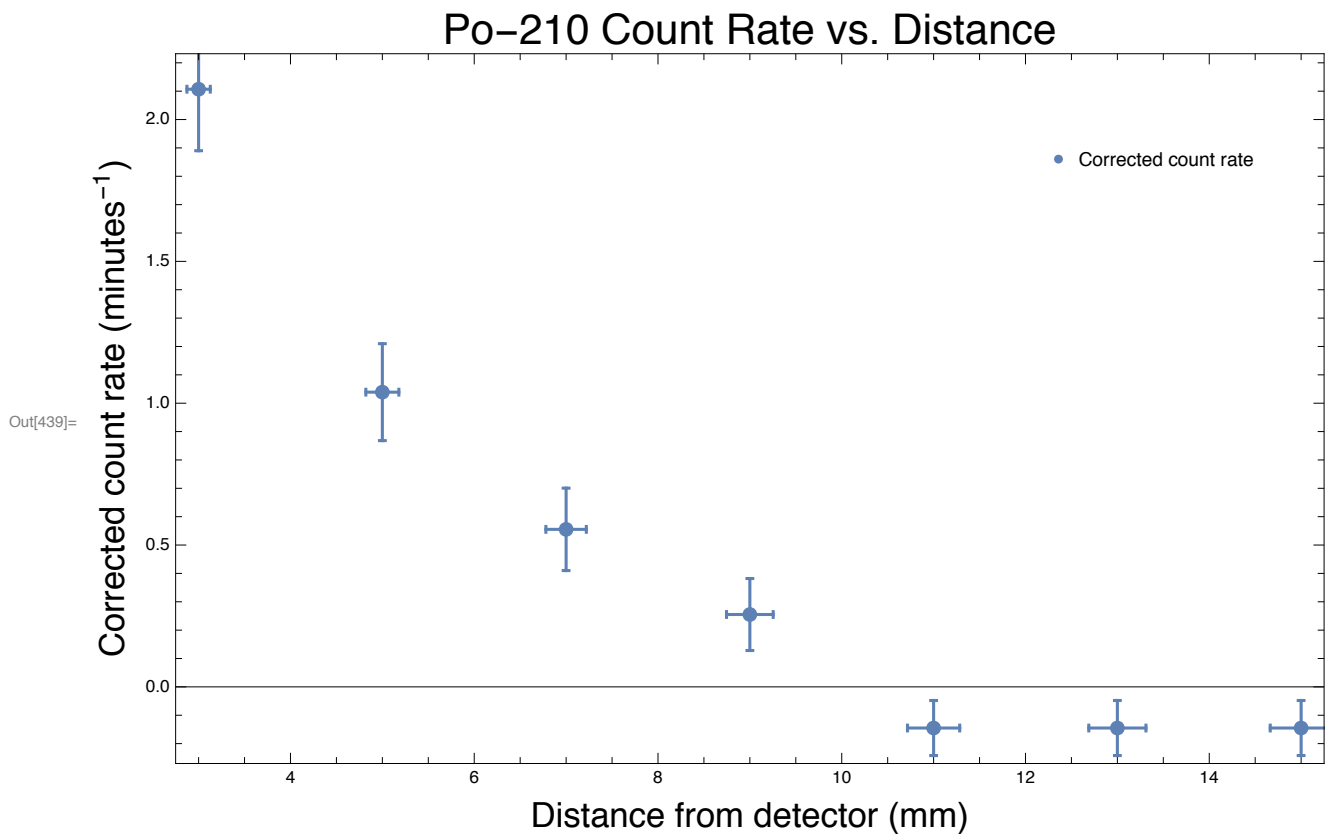
In[300]:= `PartABackgroundCountRate`

Out[300]= `0.645`

The range of alphas in air appears to be in the vicinity of 10 mm. The dependence on distance does not appear to be linear. This is as expected since the incidence of alphas on the detector should depend on several factors. First, there is the

$\sim \frac{1}{d^2}$ dependence that comes out of the solid angle relationship of the face of the cylindrical detector. Secondly there is the attenuation of the alpha particles by the air. As heavy charged particles, this is approximated using the Bethe-Bloch equation which predicts that alpha particles at this energy lose approximately 931 keV per cm in air.

3. Using equation 2, determine the range of alpha particles in air.

Equation 2, from the assignment:
$R(\text{mm}) = (0.05\,T + 2.85)\,T^{3/2}$, $4 < T < 15\,\text{MeV}$

From https://www.nndc.bnl.gov/chart/decaysearchdirect.jsp?nuc=210PO&unc=nds, the energy of the alpha from Po-210 is 5304.33 keV

In[301]:= $(0.05 * 5.30433 + 2.85) * 5.30433^{3/2}$ (* mm *)

Out[301]= 38.057

4. In a text-style cell, compare the calculated and experimentally determined answers. Comment on their level of agreement.

The experimentally derived value does not agree with the result of the empirically-derived calculation in part 3. Possible sources of error include the need to correct for the stopping power of the detector window, low source strength, and an inadequately-characterized background (the last of these is apparent in the fact that the background-corrected count rate was greater than σ below 0, a non-physical result).

Gamma-ray attenuation

1. From the data collected, determine the background and dead time corrected count rate, with uncertainty, for all absorbers (number them r_{10}, r_{20}, r_{30}, ...). Noting the amount counted with just a single aluminum shim, normalize the results. This represents the relative transmission.

In[302]:= `PartCBackgroundRate =`
    `Total[PartCBackground] / Total[PartCBackgroundTimes] // N` (* counts per minute *)

Out[302]= 34.8

In[303]:= `PartCCountRates = PartCCounts / PartCTimes // N` (* counts per minute *)

Out[303]= {144.8, 73.2, 49.3, 42.0942, 41.909, 41.618}

In[304]:= `PartCBackgroundCorrectedCountRates =`
    `DeadTimeCorrectedCounts[PartCCountRates / 60] * 60 -`
      `DeadTimeCorrectedCounts[PartCBackgroundRate / 60] * 60`

Out[304]= {110.088, 38.4185, 14.5054, 7.29674, 7.1114, 6.82033}

In[305]:= `PartCBackgroundRateError =`
    $\sqrt{\text{Total[PartCBackground]}}$ `/ Total[PartCBackgroundTimes] // N`

Out[305]= 1.86548

In[306]:= `PartCCountRateErrors =` $\sqrt{\text{PartCCounts}}$ `/ (PartCTimes) // N;`
    `PartCDeadTimeCorrectedCountRateErrors =`
      $\sqrt{(\text{MyDumbError[PartCBackgroundCorrectedCountRates]}^2 * \text{PartCCountRateErrors}^2)}$

Out[307]= {5.71232, 3.90595, 2.23766, 1.43188, 1.26554, 1.33023}

In[308]:= `PartCBackgroundDeadTimeCorrectedCountRateErrors =`
    $\sqrt{(\text{PartCDeadTimeCorrectedCountRateErrors}^2 + \text{PartCBackgroundRateError}^2)}$

Out[308]= {6.00921, 4.32856, 2.91327, 2.35166, 2.25424, 2.29118}

2. From the data, estimate the mass attenuation coefficient using linear regression and its uncertainty. Report the value in a text-style cell.

In[309]:= `PartCDataPairs =`
`  Multicolumn[Join[PartCPlates, PartCBackgroundCorrectedCountRates], 2] // First`

Out[309]= {{1, 110.088}, {2, 38.4185}, {4, 14.5054}, {6, 7.29674}, {7, 7.1114}, {8, 6.82033}}

In[310]:= `TwoGammaAttenuation = a1 * e^{-k1*x} + a2 * e^{-k2*x}`

Out[310]= $a1\, e^{-k1\, x} + a2\, e^{-k2\, x}$

In[311]:= `PartCFit = NonlinearModelFit[PartCDataPairs, TwoGammaAttenuation, {a1, k1, a2, k2},`
`  x, Weights → 1 / PartCBackgroundDeadTimeCorrectedCountRateErrors]`

Out[311]= $FittedModel\left[\ \boxed{384.468\, e^{-1.48169\, x} + 27.5165\, e^{-0.192976\, x}}\ \right]$

In[312]:= `PartCFit["RSquared"]`

Out[312]= 0.999428

- **2a. Graduate students: Calculate the mass attenuation coefficient including the weights of each datum.**

In[313]:= `PartCFit["BestFitParameters"]`
`PartCFit["BestFitParameters"][[2, 2]]`
`PartCFit["BestFitParameters"][[4, 2]]`

Out[313]= {a1 → 27.5165, k1 → 0.192976, a2 → 384.468, k2 → 1.48169}

Out[314]= 0.192976

Out[315]= 1.48169

These values are linear attenuation coefficient (in units of "1/plates"). To convert to mass attenuation coefficient we multiply the number of plates by the thickness of each plate and divide by the density of aluminum.

In[316]:= `thickness = 0.080 * 2.54;`
σ_t `= 0.005 * 2.54;`
`PartCFit["BestFitParameters"][[2, 2]] / (thickness * AluminumDensity)`
`PartCFit["BestFitParameters"][[4, 2]] / (thickness * AluminumDensity)`

Out[318]= 0.000351736

Out[319]= 0.00270065

3. Provide a semi-log plot of the data and the calculated fit as a function of mass thickness of the absorber.

```
In[440]:= PartCPlotData = Multicolumn[Join[PartCPlates, PartCBackgroundCorrectedCountRates,
            PartCBackgroundDeadTimeCorrectedCountRateErrors], 3] // First
        PartCPointPlot = ErrorListLogPlot[PartCPlotData, PlotStyle → "Dark Blue",
            PlotLabel → Style["Attenuation of Cd-109 Source", 22],
            ImageSize -> Full, FrameLabel →
             {Style["Number of Plates", 18], Style["Corrected Counts (Log)", 18]},
            Frame -> True, PlotLegends → Placed[{"Corrected Counts"}, {0.85, 0.85}],
            PlotRange → {{0, 10}, {0, 120}}];
        PartCCurvePlot = LogPlot[PartCFit[t], {t, 0, 10}, AxesOrigin → {0, 0}, PlotStyle →
            {Dashed, Gray}, PlotLegends → Placed[{"a*e^{-μ_1 n}+b*e^{-μ_2 n}"}, {0.85, 0.85}]];
        Show[PartCPointPlot, PartCCurvePlot]
```

Out[440]= {{1, 110.088, 6.00921}, {2, 38.4185, 4.32856}, {4, 14.5054, 2.91327},
   {6, 7.29674, 2.35166}, {7, 7.1114, 2.25424}, {8, 6.82033, 2.29118}}

Out[443]=
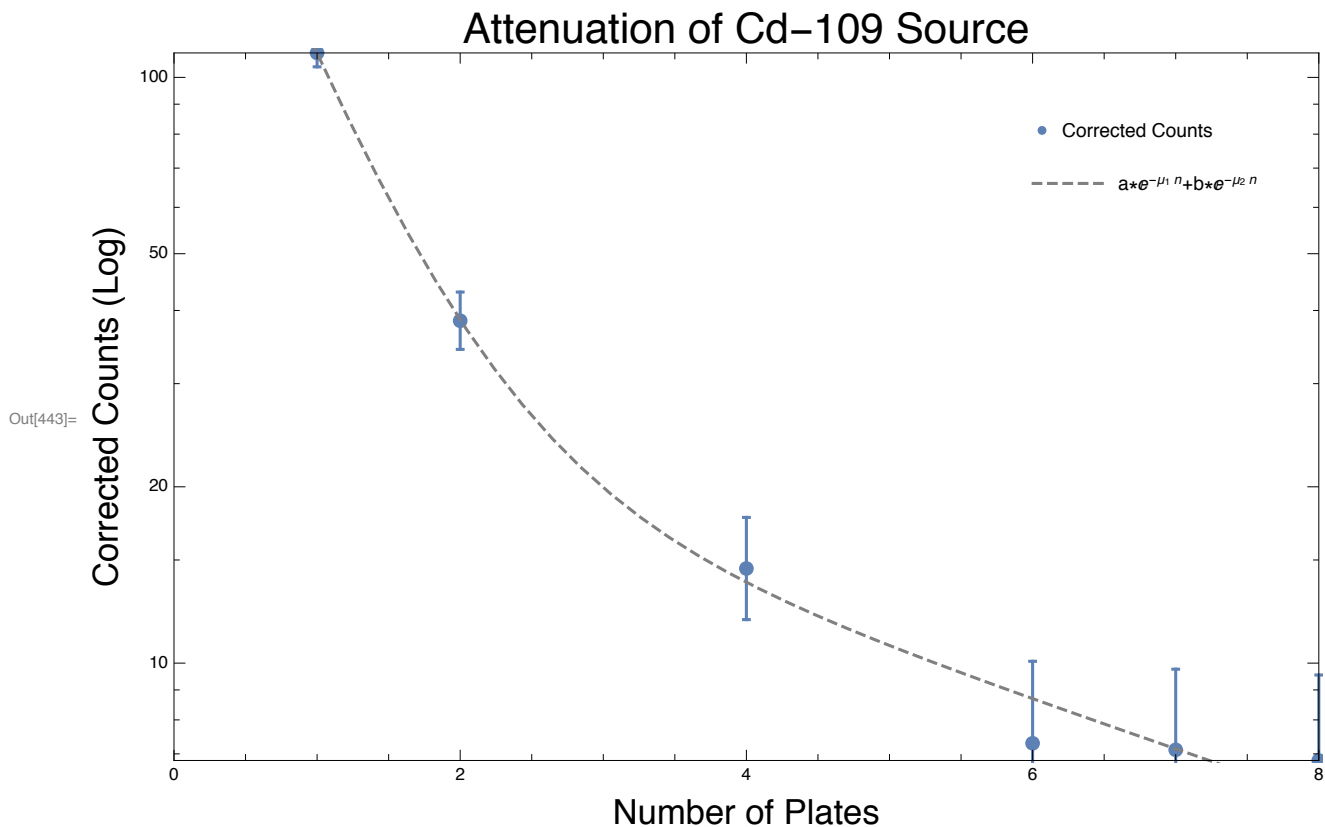
4. Compare the mass attenuation coefficient experimentally calculated to the NIST value (text-style cell). Do the two agree? Is there an unaccounted for buildup factor? Quantify the discrepancy, if any.

These values do not agree well. Measured values were significantly above those reported by NIST. The buildup factor does apply, but it should drive the attenuation factors lower, not higher.

The difference is