PHYS 2150
#5: Photoelectric Effect
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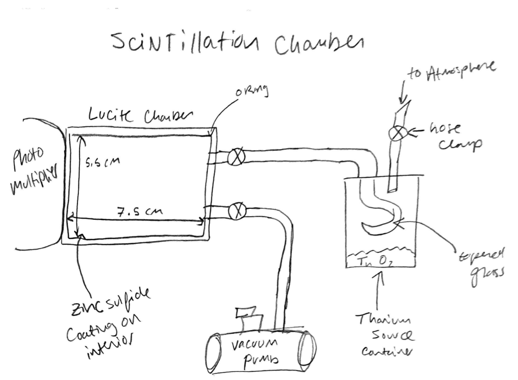
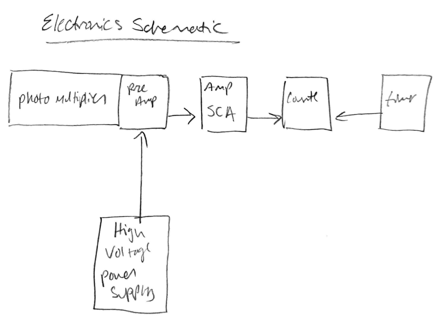
Abstract/Introduction

In this lab, we determine the half life of the radioactive gas ^{220}Rn collected in a bottle over a sample of powdered thorium oxide in order to also estimate the half life of the ^{232}Th parent activity. We are able to do this by using the apparatus as described below, to trap the decay process within a chamber of controlled pressure with zinc sulfide coating. This coating provides a photon emission when an ionizing particle comes into contact, and this photon is transferred through a series of steps leading to a count output. Our goal was accomplished of experimentally deriving a value for the half life of both Rn_{220} and Th_{232}. The average background radiation measured before taking the radioactive count sets was 81.3. The average background radiation was found to be 81.3 counts. The Total volume of the system containing radioactive isotopes was found to be around 0.16 meters^3. The half life of Rn 220 for sets 1, 2 and 3 respectively were found to be: -62.9634 seconds, -63.6982 seconds, and -60.9736 seconds. The uncertainty for the half life of Rn 220 of sets 1, 2 and 3 respectively were found to be: 4.04686, 4.36202, and 3.98282 (in seconds). Neither of our experimental values for the half lives of Thorium 232 or Radon 220 agreed with the accepted values, however, the Rn_{220} was nearly within the uncertainty. Possible sources of error are discussed in detail in the discussion section.

Apparatus:





This apparatus in contained in a thick plexiglass chamber, with a lid to access parts of it to set up the experiment. The main source of Thorium oxide is contained in a glass cylinder, which has a tube coming up through the top, giving it access to atmosphere if the hose clamp attached is open. Another tube comes from this container and connects to a Lucite Chamber, which is connected to a vacuum pump via another hose. The Lucite Chamber contains a coating on the interior of zinc sulfide and a photomultiplier. When an ionized particle comes into contact with the coating, a photon is emitted, and then absorbed by a photocathode, which is sent through a photo multiplier, a pre-Amp, an amplifier and then a single channel analyzer. Through this technique, the single photons emitted within the chamber can be converted into measurable currents at output. A counter is placed at the end of this “output” where, within a set min and max, will count the pulses coming through. A diagram of this apparatus/ experimental set-up and electrical schematic are provided above.

Description of Experimental Procedure

First, we turned on the AC power to the high-voltage power supply. We also turned the power on the the NIM modules, which contain the counter and timer, Amp and SCA. Then, we set the high-voltage power to 1300 volts DC to the photomultiplier. There were recommended settings for the modules in the NIM bin, which we checked and made sure each was where they needed to be. We set up our timer to count for an exposure time of 1 second, every 10 seconds. We practiced doing this a few times to get the hang of it.

The first actual counts we got were of the background radiation. We took 10 trials of this, to take into account later in our data. We then turned on the vacuum pump, and opened the valve to the chamber, which evacuated the Lucite chamber. We then opened the hose clamp to the thorium source container and let the vacuum pump continue for a few minutes. This caused a pressure difference between the thorium source and the chamber. Then we closed the pump valve and hose clamp and opened the valve between the thorium source and the Lucite chamber. This allowed a small amount of the radioactive source to travel to the chamber. Only leaving the valve open, for about 5 seconds, as soon as we closed it, we began counting and recording counts.

This process was repeated for each of the 3 sets of data taken, but the background radiation was only required to be collected one time.

Results

<u>Analysis Part 1 &2:</u>

Background Radiation Data and Time interval/exposure data

Here, the values for background radiation count, average background radiation, and time interval/exposure time data are all stored. Also known values and measurements of pieces of the apparatus are included. Volume of the system where the isotopes travel are quickly calculated prior to the set analysis. Then the counts are put into a list and a separate list of the natural log of all the counts are created and stored. Uncertainty for each count is calculated using Poisson Distribution Standard Deviation as such : $\sigma = \frac{\text{Sqrt[count]}}{\text{count}}$. Using this uncertainty for each point, stored in its own list, we then can use a weighted linear least-squares fit to plot the natural log of the corrected counts and the time in increments of 10 seconds (As measured). This fitting method assumes that not all counts are weighted equally, as defined by the uncertainty in each measured count. This program also provides a calculated slope, uncertainty in the slope, the y intercept, and the uncertainty in the intercept. Each of the described calculations above are done for each of the 3 sets of data. Half life of Rn220 is also calculated for each set using the formula: $T_{1/2} = \frac{\ln(2)}{\lambda}$, where λ is the slope obtained from the weighted linear fit function. Uncertainty in the half life for Rn220 are then calculated for each of the three sets using uncertainty in Any function of One Variable formula : $\delta q = | \frac{dq}{dx} | \delta x$. The decay rate of Thorium 232 is then calculated within set1, and will not be repeated in the sets following. The formula used to calculate decay rate is: $\text{DecayRate} = R_0 \; x \; \frac{\text{total volume of system}}{\text{volume of chamber}} \; x \; \frac{1}{\text{probability of escape}}$, where R_0 is *a* representative decay constant λ from set 3. Then the decay constant for Th232 can be calculated using the formula:

λTh232= $\frac{\text{decay rate}}{\text{# nuclei present}}$. Finally, the half life for Thorium 232 can be calculated using the same formula as before but with the decay constant for Thorium instead.

The results were as follows. The average background radiation was found to be 81.3 counts. The Total volume of the system containing radioactive isotopes was found to be around 0.16 meters^3. The half life of Rn 220 for sets 1, 2 and 3 respectively were found to be: -62.9634 seconds, -63.6982 seconds, and -60.9736 seconds. The uncertainty for the half life of Rn 220 of sets 1, 2 and 3 respectively were found to be: 4.04686, 4.36202, and 3.98282 (in seconds). The experimental half life calculated for Thorium 232 was found to be 4.2021×10^{11} in years.

In[866]:=
```
(*Background Radiation in counts*)
BGRtrial1 = 84;
BGRtrial2 = 84;
BGRtrial3 = 78;
BGRtrial4 = 88;
BGRtrial5 = 90;
BGRtrial6 = 79;
BGRtrial7 = 84;
BGRtrial8 = 76;
BGRtrial9 = 78;
BGRtrial10 = 72;
(*Average Background Radiation in counts*)
avgBGR = N[(BGRtrial1 + BGRtrial2 + BGRtrial3 + BGRtrial4 +
     BGRtrial5 + BGRtrial6 + BGRtrial7 + BGRtrial8 + BGRtrial9 + BGRtrial10) / 10]
```
Out[876]= 81.3

```
(*count data*)
exposurePeriod = 1.0; (*second*)
interval = 10.0; (*seconds*)

(*Actual Rn 220 half life*)
Rn220HalfLifeAccepted = 55.61; (*seconds*)
Rn220UncertaintyHalfLife = 0.4 ;(*seconds*)
```

In[1259]:=
```
(*Actual Th232 half life*)
Th232HalfLifeAccepted = 1.14 * 10^10; (*years*)
```

In[1296]:=
```
(*Volume of bottle + hose + chamber in cubic meters*)
vbottle = π * (0.066 / 2)^2 * 0.11;
vhose = π * (0.05 / 2)^2 * 0.5;
vchamber = 0.055 * 0.075 * 0.05;

totalVolume = vbottle + vhose + vchamber (*in cubic meters*)
```
Out[1299]= 0.00156433

```
(*Uncertainty in Volume*)
δV = 0.01; (*in cubic meters*)

In[1228]:= (*Escape probability*)
escape = 0.025;

In[1229]:=
(*Thorium data : Atomic mass/ num nuclei / mass *)
Th232Mass = 0.04; (*Kilograms*)
Th232AtMass = 232.0377;
Th232NumNuclei = Th232Mass * (1 / Th232AtMass) * 6.0221409 * 10^23

Out[1231]= 1.03813 × 10^20

In[1232]:= (*R0*)
R = 0.011367987534455573;
```

Set 1 Data and Analysis:

In[1166]:=
```
(*Set 1 counts upon Thorium Decay in each exposure period
 (minus average background radiation taken from the same 1 second exposure time)*)
set1t0 = 962 - avgBGR;
set1t1 = 872 - avgBGR;
set1t2 = 685 - avgBGR;
set1t3 = 666 - avgBGR;
set1t4 = 599 - avgBGR;
set1t5 = 515 - avgBGR;
set1t6 = 465 - avgBGR;
set1t7 = 424 - avgBGR;
set1t8 = 371 - avgBGR;
set1t9 = 401 - avgBGR;
set1t10 = 346 - avgBGR;
set1t11 = 301 - avgBGR;
set1t12 = 287 - avgBGR;
set1t13 = 273 - avgBGR;
set1t14 = 243 - avgBGR;
set1t15 = 192 - avgBGR;
set1t16 = 211 - avgBGR;
set1t17 = 181 - avgBGR;
set1t18 = 195 - avgBGR;
set1t19 = 169 - avgBGR;
set1t20 = 167 - avgBGR;
set1t21 = 152 - avgBGR;
set1t22 = 147 - avgBGR;
set1t23 = 160 - avgBGR;
set1t24 = 117 - avgBGR;
set1t25 = 121 - avgBGR;
set1t26 = 119 - avgBGR;
set1t27 = 116 - avgBGR;
set1t28 = 135 - avgBGR;
set1t29 = 114 - avgBGR;
set1t30 = 113 - avgBGR;
set1t31 = 97 - avgBGR;
set1t32 = 110 - avgBGR;
set1t33 = 123 - avgBGR;
set1t34 = 96 - avgBGR;
set1t35 = 92 - avgBGR;

(*set 1 of corrected counts as list*)
set1Counts = {set1t0, set1t1, set1t2, set1t3, set1t4, set1t5, set1t6, set1t7, set1t8,
   set1t9, set1t10, set1t11, set1t12, set1t13, set1t14, set1t15, set1t16, set1t17,
   set1t18, set1t19, set1t20, set1t21, set1t22, set1t23, set1t24, set1t25, set1t26,
   set1t27, set1t28, set1t29, set1t30, set1t31, set1t32, set1t33, set1t34, set1t35};

(*natural log of set 1 of corrected counts as list*)
set1LnCounts = Log[set1Counts];

(*set1 ln of uncertainty for each count as list*)
σSet1 = Sqrt[set1LnCounts] / set1LnCounts;
```

In[1205]:=
```
(*Time intervals to corresponding data points*)
x = {0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190,
   200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 340, 350, 355};
y = set1LnCounts;
σ = σSet1;
L = Length[σSet1];
yerr = Around[VectorAround[y, σ]];
xydata = {};
For[i = 1, i < L + 1, i++, AppendTo[xydata, {x[[i]], yerr[[i]]}];]
```

In[1212]:=
```
xydata
```

Out[1212]=
```
{{0, 6.8 ±0.4}, {10, 6.7 ±0.4}, {20, 6.4 ±0.4}, {30, 6.4 ±0.4}, {40, 6.2 ±0.4}, {50, 6.1 ±0.4},
 {60, 5.9 ±0.4}, {70, 5.8 ±0.4}, {80, 5.7 ±0.4}, {90, 5.8 ±0.4}, {100, 5.6 ±0.4},
 {110, 5.4 ±0.4}, {120, 5.3 ±0.4}, {130, 5.3 ±0.4}, {140, 5.1 ±0.4}, {150, 4.7 ±0.5},
 {160, 4.9 ±0.5}, {170, 4.6 ±0.5}, {180, 4.7 ±0.5}, {190, 4.5 ±0.5}, {200, 4.5 ±0.5},
 {210, 4.3 ±0.5}, {220, 4.2 ±0.5}, {230, 4.4 ±0.5}, {240, 3.6 ±0.5}, {250, 3.7 ±0.5},
 {260, 3.6 ±0.5}, {270, 3.5 ±0.5}, {280, 4.0 ±0.5}, {290, 3.5 ±0.5}, {300, 3.5 ±0.5},
 {310, 2.8 ±0.6}, {320, 3.4 ±0.5}, {340, 3.7 ±0.5}, {350, 2.7 ±0.6}, {355, 2.4 ±0.6}}
```

In[928]:=

$$J = \sum_{i=1}^{L} \left(\frac{x[[i]]}{\sigma[[i]]}\right)^2;$$

$$M = \sum_{i=1}^{L} \frac{x[[i]]}{\sigma[[i]]^2};$$

$$P = \sum_{i=1}^{L} \frac{x[[i]]\, y[[i]]}{\sigma[[i]]^2};$$

$$G = \sum_{i=1}^{L} \frac{1}{\sigma[[i]]^2};$$

$$H = \sum_{i=1}^{L} \frac{y[[i]]}{\sigma[[i]]^2};$$

In[1213]:=

$$\Delta = J\, G - M^2;$$

$$m = \frac{P\, G - M\, H}{\Delta};$$

$$b = \frac{J\, H - P\, M}{\Delta};$$

$$\delta m = \frac{\sqrt{\sum_{i=1}^{L} \left(\frac{G\, x[[i]] - M}{\sigma[[i]]}\right)^2}}{\Delta};$$

$$\delta b = \frac{\sqrt{\sum_{i=1}^{L} \left(\frac{J - M\, x[[i]]}{\sigma[[i]]}\right)^2}}{\Delta};$$

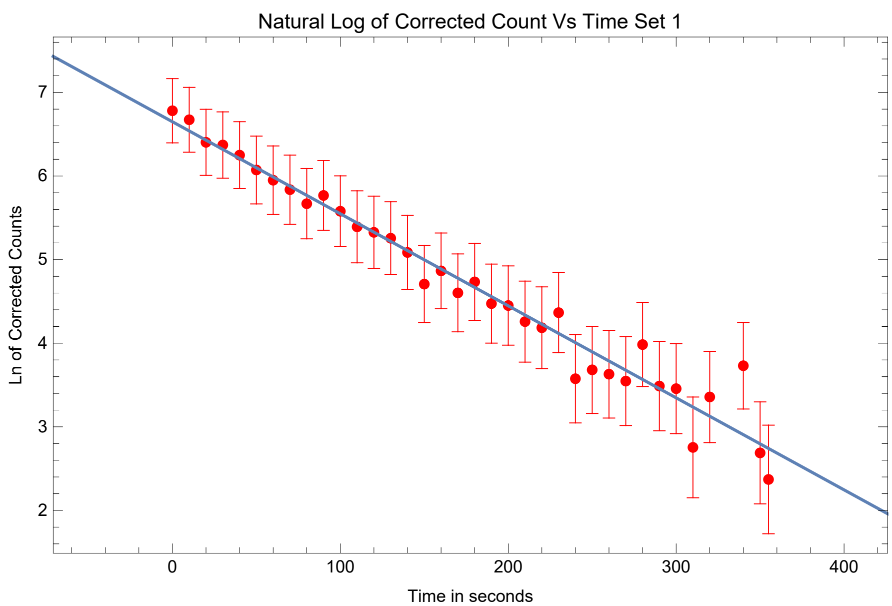
In[939]:=
```
Grid[{{"Slope m", N[m]}, {"Uncertainty δm", N[δm]},
  {"Intercept b", N[b]}, {"Uncertainty δb", N[δb]}}, Frame → All]
```

Out[939]=

Slope m	-0.0110087
Uncertainty δm	0.000754664
Intercept b	6.64916
Uncertainty δb	0.136698

In[940]:=
```
xrng = MinMax[x, Scaled[0.2]];
yrng = MinMax[y, Scaled[0.2]];
P1 = ListPlot[xydata, PlotStyle → Red, PlotRange → {xrng, yrng},
   Frame → True, Axes → False, FrameLabel → {"Time in seconds", "Ln of Corrected Counts"},
   PlotLabel → "Natural Log of Corrected Count Vs Time Set 1"];
P2 = Plot[m x + b, {x, Min[xrng], Max[xrng]}];
Show[P1, P2]
```

Out[944]=



In[1275]:=
```
(*Uncertainty in R*)
σR = (set1Counts - σSet1)^2
```

Out[1275]= {774956., 624594., 363977., 341411., 267599., 187744., 146911., 117160., 83682.9, 101942., 69842.1, 48079.1, 42134.4, 36581.8, 26003.7, 12152.7, 16704.7, 9847.36, 12823.4, 7608.59, 7263.47, 4930.2, 4252.5, 6118.59, 1237.01, 1534.98, 1381.99, 1167.52, 2830.13, 1034.56, 971.077, 227.931, 792.659, 1695.98, 198.529, 101.012}

In[1276]:= $\sigma R = \sum_{i=1}^{35} \sigma R[[i]]$

Out[1276]= 3.32739×10^6

In[1277]:= $\sigma R = \sqrt{\frac{1}{35} * \sigma R}$

Out[1277]= 308.332

```
(*Standard Deviation of the mean*)
```

In[1278]:= $\sigma_R = \frac{\sigma R}{\sqrt{35}}$

Out[1278]= 52.1175

```
(*Determination of Half life of 220Rn in seconds *)
```

$HalfLifeRn220Set1 = \frac{Log[2]}{N[m]}$

Out[945]= -62.9634

In[948]:=
```
ErrorSet1Rn220HalfLife =
 Abs[HalfLifeRn220Set1 - Rn220HalfLifeAccepted] / Rn220HalfLifeAccepted
```

Out[948]= 2.13223

```
(*uncertainty in halflife of Rn220 in seconds*)
```

$\delta HRn220Set1 = Abs\left[\frac{HalfLifeRn220Set1}{N[m]}\right] * N[\delta m]$

Out[1219]= 4.04686

```
(*Thorium decay rate in decays per second*)
```

$Th232DecayRateSet1 = R * \frac{totalVolume}{vchamber} * \frac{1}{escape}$

Out[1253]= 5.44498

```
(*Thorium decay constant*)
```

In[1254]:= $Th232DecayConstSet1 = \frac{Th232DecayRateSet1}{Th232NumNuclei}$

Out[1254]= 5.24498×10^{-20}

In[1255]:=
```
(*Thorium half life in secons*)
```

$Th232HalfLifeSet1 = \frac{Log[2]}{Th232DecayConstSet1}$

Out[1255]= 1.32154×10^{19}

In[1270]:=
```
(*Thorium half-life in years*)
Th232HalfLifeSet1Years = Th232HalfLifeSet1 / 60 / 60 / 24 / 7 / 52
```

Out[1270]= 4.2021×10^{11}

```
(*Error Propagation/ Uncertainty in Half-Life of Th232*)
```

In[1300]:= $\delta HLTh232 = \sqrt{\left(\frac{Th232HalfLifeSet1Years}{R} * \sigma_R\right)^2}$

Out[1300]= 1.92649×10^{15}

In[1302]:=
```
(*Error value Th232 half life*)
ErrorTh232 = Abs[Th232HalfLifeAccepted - Th232HalfLifeSet1Years]
```

Out[1302]= 4.0881×10^{11}

Set 2 Data and Analysis

In[951]:=
```
(*Set 2 counts upon Thorium Decay in each
 exposure period (minus average background radiation)*)
set2t0 = 947 - avgBGR;
set2t1 = 893 - avgBGR;
set2t2 = 769 - avgBGR;
set2t3 = 729 - avgBGR;
set2t4 = 615 - avgBGR;
set2t5 = 566 - avgBGR;
set2t6 = 494 - avgBGR;
set2t7 = 453 - avgBGR;
set2t8 = 415 - avgBGR;
set2t9 = 358 - avgBGR;
set2t10 = 308 - avgBGR;
set2t11 = 337 - avgBGR;
set2t12 = 289 - avgBGR;
set2t13 = 248 - avgBGR;
set2t14 = 249 - avgBGR;
set2t15 = 230 - avgBGR;
set2t16 = 219 - avgBGR;
set2t17 = 189 - avgBGR;
set2t18 = 199 - avgBGR;
set2t19 = 194 - avgBGR;
set2t20 = 149 - avgBGR;
set2t21 = 156 - avgBGR;
set2t22 = 138 - avgBGR;
set2t23 = 130 - avgBGR;
set2t24 = 136 - avgBGR;
set2t25 = 115 - avgBGR;
set2t26 = 121 - avgBGR;
set2t27 = 138 - avgBGR;
set2t28 = 109 - avgBGR;
set2t29 = 123 - avgBGR;
set2t30 = 105 - avgBGR;
set2t31 = 100 - avgBGR;
set2t32 = 142 - avgBGR;
set2t33 = 96 - avgBGR;
set2t34 = 104 - avgBGR;
```

```
set2t35 = 109 - avgBGR;
set2t36 = 99 - avgBGR;
set2t37 = 111 - avgBGR;
set2t38 = 83 - avgBGR;

(*Set 2 corrected counts as list*)
set2Counts = {set2t0, set2t1, set2t2, set2t3, set2t4, set2t5, set2t6, set2t7, set2t8,
   set2t9, set2t10, set2t11, set2t12, set2t13, set2t14, set2t15, set2t16, set2t17,
   set2t18, set2t19, set2t20, set2t21, set2t22, set2t23, set2t24, set2t25, set2t26,
   set2t27, set2t28, set2t29, set2t30, set2t31, set2t32, set2t33, set2t34, set2t35};

(*natural log of corrected counts as list*)
set2LnCounts = Log[set2Counts];

(*uncertainty of natural log of corrected counts as list*)
σSet2 = Sqrt[set2LnCounts] / set2LnCounts;

In[993]:= (*Time intervals to corresponding data points*)
x = {0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190,
   200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 340, 350, 355};
y = set2LnCounts;
σ = σSet2;
L = Length[σSet2];
yerr = Around[VectorAround[y, σ]];
xydata = {};
For[i = 1, i < L + 1, i++, AppendTo[xydata, {x[[i]], yerr[[i]]}];]

In[1000]:= xydata

Out[1000]= {{0, 6.8 ±0.4}, {10, 6.7 ±0.4}, {20, 6.5 ±0.4}, {30, 6.5 ±0.4}, {40, 6.3 ±0.4}, {50, 6.2 ±0.4},
  {60, 6.0 ±0.4}, {70, 5.9 ±0.4}, {80, 5.8 ±0.4}, {90, 5.6 ±0.4}, {100, 5.4 ±0.4},
  {110, 5.5 ±0.4}, {120, 5.3 ±0.4}, {130, 5.1 ±0.4}, {140, 5.1 ±0.4}, {150, 5.0 ±0.4},
  {160, 4.9 ±0.5}, {170, 4.7 ±0.5}, {180, 4.8 ±0.5}, {190, 4.7 ±0.5}, {200, 4.2 ±0.5},
  {210, 4.3 ±0.5}, {220, 4.0 ±0.5}, {230, 3.9 ±0.5}, {240, 4.0 ±0.5}, {250, 3.5 ±0.5},
  {260, 3.7 ±0.5}, {270, 4.0 ±0.5}, {280, 3.3 ±0.5}, {290, 3.7 ±0.5}, {300, 3.2 ±0.6},
  {310, 2.9 ±0.6}, {320, 4.1 ±0.5}, {340, 2.7 ±0.6}, {350, 3.1 ±0.6}, {355, 3.3 ±0.5}}
```

In[1001]:=

$$J = \sum_{i=1}^{L} \left(\frac{x[[i]]}{\sigma[[i]]}\right)^2;$$

$$M = \sum_{i=1}^{L} \frac{x[[i]]}{\sigma[[i]]^2};$$

$$P = \sum_{i=1}^{L} \frac{x[[i]]\, y[[i]]}{\sigma[[i]]^2};$$

$$G = \sum_{i=1}^{L} \frac{1}{\sigma[[i]]^2};$$

$$H = \sum_{i=1}^{L} \frac{y[[i]]}{\sigma[[i]]^2};$$

In[1006]:=
$$\Delta = J\,G - M^2;$$
$$m = \frac{P\,G - M\,H}{\Delta};$$
$$b = \frac{J\,H - P\,M}{\Delta};$$
$$\delta m = \frac{\sqrt{\sum_{i=1}^{L}\left(\frac{G\,x[[i]] - M}{\sigma[[i]]}\right)^2}}{\Delta};$$
$$\delta b = \frac{\sqrt{\sum_{i=1}^{L}\left(\frac{J - M\,x[[i]]}{\sigma[[i]]}\right)^2}}{\Delta};$$

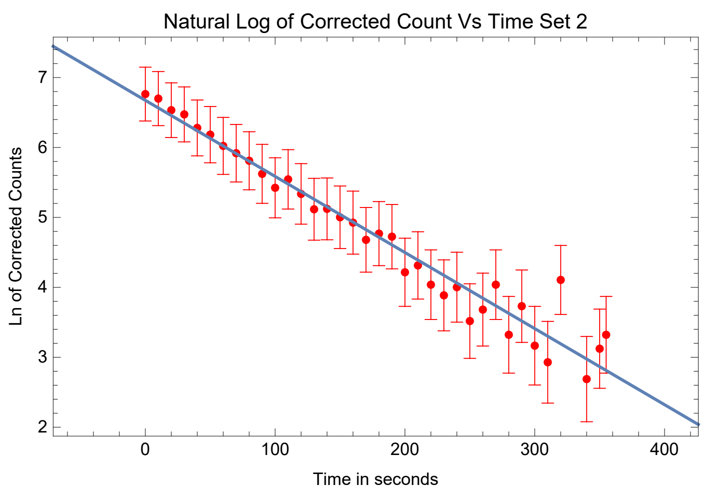
In[1011]:=
```
Grid[{{"Slope m", N[m]}, {"Uncertainty δm", N[δm]},
  {"Intercept b", N[b]}, {"Uncertainty δb", N[δb]}}, Frame → All]
```

Out[1011]=

Slope m	-0.0108817
Uncertainty δm	0.000745176
Intercept b	6.67436
Uncertainty δb	0.135779

In[1012]:=
```
xrng = MinMax[x, Scaled[0.2]];
yrng = MinMax[y, Scaled[0.2]];
P1 = ListPlot[xydata, PlotStyle → Red, PlotRange → {xrng, yrng},
   Frame → True, Axes → False, FrameLabel → {"Time in seconds", "Ln of Corrected Counts"},
   PlotLabel → "Natural Log of Corrected Count Vs Time Set 2"];
P2 = Plot[m x + b, {x, Min[xrng], Max[xrng]}];
Show[P1, P2]
```

Out[1016]=



In[1017]:=
```
(*Determination of Half life of ²²⁰Rn *)
```
$$\text{HalfLifeRn220Set2} = \frac{\text{Log}[2]}{\text{N}[m]}$$

Out[1017]= -63.6982

In[1018]:=
```
ErrorSet2Rn220HalfLife =
 Abs[HalfLifeRn220Set2 - Rn220HalfLifeAccepted] / Rn220HalfLifeAccepted
```
Out[1018]= 2.14545

In[1019]:=
```
δHRn220Set2 = Abs[HalfLifeRn220Set2 / N[m]] * N[δm]
```
Out[1019]= 4.36202

```
(*Thorium decay rate*)
Th232DecayRateSet2 =
```

Set 3 Data and Analysis

In[1020]:=
```
(*Set 3 counts upon Thorium Decay in each
 exposure period (minus average background radiation)*)
set3t0 = 1161 - avgBGR;
set3t1 = 959 - avgBGR;
set3t2 = 864 - avgBGR;
set3t3 = 846 - avgBGR;
set3t4 = 725 - avgBGR;
set3t5 = 615 - avgBGR;
set3t6 = 591 - avgBGR;
set3t7 = 526 - avgBGR;
set3t8 = 467 - avgBGR;
set3t9 = 426 - avgBGR;
set3t10 = 396 - avgBGR;
set3t11 = 406 - avgBGR;
set3t12 = 329 - avgBGR;
set3t13 = 263 - avgBGR;
set3t14 = 263 - avgBGR;
set3t15 = 283 - avgBGR;
set3t16 = 249 - avgBGR;
set3t17 = 226 - avgBGR;
set3t18 = 201 - avgBGR;
set3t19 = 189 - avgBGR;
set3t20 = 151 - avgBGR;
set3t21 = 167 - avgBGR;
set3t22 = 159 - avgBGR;
set3t23 = 162 - avgBGR;
set3t24 = 139 - avgBGR;
set3t25 = 141 - avgBGR;
set3t26 = 123 - avgBGR;
set3t27 = 125 - avgBGR;
set3t28 = 112 - avgBGR;
set3t29 = 128 - avgBGR;
set3t30 = 103 - avgBGR;
set3t31 = 119 - avgBGR;
set3t32 = 87 - avgBGR;
set3t33 = 102 - avgBGR;
set3t34 = 119 - avgBGR;
set3t35 = 109 - avgBGR;
set3t36 = 109 - avgBGR;
```

In[1057]:=
```
(*Set 3 corrected counts as list*)
set3Counts = {set3t0, set3t1, set3t2, set3t3, set3t4, set3t5, set3t6, set3t7, set3t8,
   set3t9, set3t10, set3t11, set3t12, set3t13, set3t14, set3t15, set3t16, set3t17,
   set3t18, set3t19, set3t20, set3t21, set3t22, set3t23, set3t24, set3t25, set3t26,
   set3t27, set3t28, set3t29, set3t30, set3t31, set3t32, set3t33, set3t34, set3t35};

(*Natural log of counts set 2 as list*)
set3LnCounts = Log[set3Counts];

(*Uncertainty of natural log of corrected counts as list*)
```

$$\sigma Set3 = \frac{Sqrt[set3LnCounts]}{set3LnCounts};$$

In[1060]:=
```
(*Time intervals to corresponding data points*)
x = {0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190,
   200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 340, 350, 355};
y = set3LnCounts;
σ = σSet3;
L = Length[σSet3];
yerr = Around[VectorAround[y, σ]];
xydata = {};
For[i = 1, i < L + 1, i++, AppendTo[xydata, {x[[i]], yerr[[i]]}];]
```

In[1067]:=
```
xydata
```

Out[1067]=
```
{{0, 7.0 ± 0.4}, {10, 6.8 ± 0.4}, {20, 6.7 ± 0.4}, {30, 6.6 ± 0.4}, {40, 6.5 ± 0.4}, {50, 6.3 ± 0.4},
 {60, 6.2 ± 0.4}, {70, 6.1 ± 0.4}, {80, 6.0 ± 0.4}, {90, 5.8 ± 0.4}, {100, 5.8 ± 0.4},
 {110, 5.8 ± 0.4}, {120, 5.5 ± 0.4}, {130, 5.2 ± 0.4}, {140, 5.2 ± 0.4}, {150, 5.3 ± 0.4},
 {160, 5.1 ± 0.4}, {170, 5.0 ± 0.4}, {180, 4.8 ± 0.5}, {190, 4.7 ± 0.5}, {200, 4.2 ± 0.5},
 {210, 4.5 ± 0.5}, {220, 4.4 ± 0.5}, {230, 4.4 ± 0.5}, {240, 4.1 ± 0.5}, {250, 4.1 ± 0.5},
 {260, 3.7 ± 0.5}, {270, 3.8 ± 0.5}, {280, 3.4 ± 0.5}, {290, 3.8 ± 0.5}, {300, 3.1 ± 0.6},
 {310, 3.6 ± 0.5}, {320, 1.7 ± 0.8}, {340, 3.0 ± 0.6}, {350, 3.6 ± 0.5}, {355, 3.3 ± 0.5}}
```

In[1068]:=

$$J = \sum_{i=1}^{L} \left(\frac{x[[i]]}{\sigma[[i]]}\right)^2;$$

$$M = \sum_{i=1}^{L} \frac{x[[i]]}{\sigma[[i]]^2};$$

$$P = \sum_{i=1}^{L} \frac{x[[i]]\, y[[i]]}{\sigma[[i]]^2};$$

$$G = \sum_{i=1}^{L} \frac{1}{\sigma[[i]]^2};$$

$$H = \sum_{i=1}^{L} \frac{y[[i]]}{\sigma[[i]]^2};$$

In[1073]:=

$$\Delta = J\,G - M^2;$$

$$m = \frac{P\,G - M\,H}{\Delta};$$

$$b = \frac{J\,H - P\,M}{\Delta};$$

$$\delta m = \frac{\sqrt{\sum_{i=1}^{L}\left(\frac{G\,x[[i]] - M}{\sigma[[i]]}\right)^2}}{\Delta};$$

$$\delta b = \frac{\sqrt{\sum_{i=1}^{L}\left(\frac{J - M\,x[[i]]}{\sigma[[i]]}\right)^2}}{\Delta};$$

In[1078]:=

```
Grid[{{"Slope m", N[m]}, {"Uncertainty δm", N[δm]},
  {"Intercept b", N[b]}, {"Uncertainty δb", N[δb]}}, Frame → All]
```

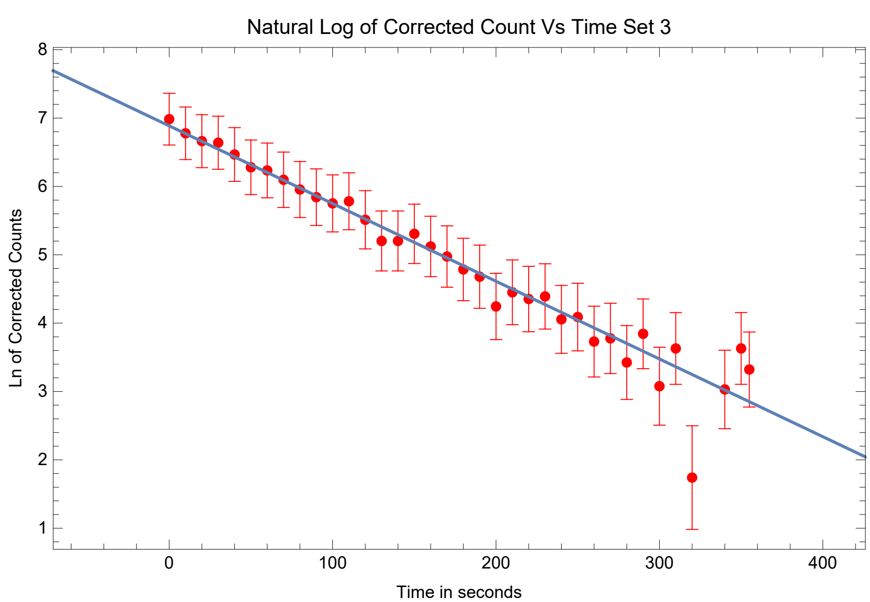
Out[1078]=

Slope m	-0.011368
Uncertainty δm	0.000742562
Intercept b	6.88622
Uncertainty δb	0.134267

In[1079]:=

```
xrng = MinMax[x, Scaled[0.2]];
yrng = MinMax[y, Scaled[0.2]];
P1 = ListPlot[xydata, PlotStyle → Red, PlotRange → {xrng, yrng},
   Frame → True, Axes → False, FrameLabel → {"Time in seconds", "Ln of Corrected Counts"},
   PlotLabel → "Natural Log of Corrected Count Vs Time Set 3"];
P2 = Plot[m x + b, {x, Min[xrng], Max[xrng]}];
Show[P1, P2]
```

Out[1083]=



In[1084]:=
```
(*Determination of Half life of ²²⁰Rn *)
HalfLifeRn220Set3 = Log[2] / N[m]
```
Out[1084]= -60.9736

In[1085]:=
```
ErrorSet3Rn220HalfLife  =
 Abs[HalfLifeRn220Set3 - Rn220HalfLifeAccepted] / Rn220HalfLifeAccepted
```
Out[1085]= 2.09645

In[1086]:=
```
(*Uncertainty in halfLife Rn220 Set 2*)
δHRn220Set3 = Abs[HalfLifeRn220Set3 / N[m]] * N[δm]
```
Out[1086]= 3.98282

Discussion

In this lab, we used an apparatus that would allow a small amount of Thorium oxide to enter a chamber of a lower pressure which is set up with a zinc sulfide coating, allowing for the emission of photons as a quantifier for a count of particles within the chamber. The chamber, also containing a photomultiplier, converts the photon into a current which can be amplified and eventually read by a counter instrument and displayed to us. Our goal was accomplished of experimentally deriving a value for the half life of both Rn_{220} and Th_{232}. The average background radiation measured before taking the radioactive count sets was 81.3. The average background radiation was found to be 81.3 counts. The Total volume of the system containing radioactive isotopes was found to be around 0.16 meters^3. The half life of Rn 220 for sets 1, 2 and 3 respectively were found to be: -62.9634 seconds, -63.6982 seconds, and -60.9736 seconds. The uncertainty for the half life of Rn 220 of sets 1, 2 and 3 respectively were found to be: 4.04686, 4.36202, and 3.98282 (in seconds). Comparing these results to the accepted value for the half life of Rn_{220} of 55.61 second with an uncertainty of 0.4 seconds, we cannot say that our experimental value agrees with the accepted value. It is relatively close, but the uncertainty is not large enough to agree. The experimental half life calculated for Thorium 232 was found to be 4.2021×10^{11} in years. I had a difficult time finding the proper way to calculate uncertainty for this value. The standard deviation of the mean for R_0 was much higher than expected, at 52.1. When propagating this value in the way I interpreted from the Error Analysis textbook, the error blew up and seems to be an inappropriate value for uncertainty. This may be because using the code provided for the weighted linear fit is difficult for me to understand and I have not been logically able to decipher how to properly calculate uncertainty in R, which was the chosen resulting slope, λ of the best resulting set. I chose the slope from set 3 as this set resulted in the closest value for half life of Rn_{220}. THe total uncertainty was calculated to be 1.92649×10^{15}, which is unreasonable at best. What may be the most helpful, since I have had such trouble with this value for uncertainty, is examining the error value itself, which is 4.0881×10^{11}. If we take the uncertainty at face value, we can say that our experimental value for the half life of Th_{232} agrees with the accepted value. This may not be an appropriate conclusion however, considering that the experimental half life for Rn_{220} was in fact not agreeable with the accepted value and the half life of Th_{232} was derived from these results. Unfortunately, not much more can be said about these results. I would need to verify the accuracy of my calculations and uncertainty with someone who would know better than I. A possible sources of error for this experiment could be a misrepresentation of background radiation from the trials done before the experiment. If more trials were conducted of background radiation, it may have been a smaller or larger amount, which would effect each individual count and shape the weighted linear regression differently. The slope/decay constant then may have been different, leading to a different outcome for both half lives. The Daughter activities of Rn_{220} are gaseous and shoudl not interfere with the measurements. There should be just as many decays as new particles being created, leading to secular equilibrium. Therefore, this would not contribute to sources of error. One strange thing we did notice in our data, which may somehow connect to error was how towards the end of each decay set, the counts began jumping up and down sporadically. This was not something we expected to see, as it does not necessarily represent exponential decay the way I understand it. However, it was a consistent behavior between all three of the data sets, and would have shaped the overall weighted linear regression, and thus our results. This behavior could be seen in favor of contributing to error, as both of the experimental values for half life of Rn_{220} and Th_{232} were *higher than the accepted values.* This in tandem with a higher background radiation than was originally recorded are decent candidates for sources of error.

Conclusion

In conclusion, neither the experimental value for the half life of Rn_{220} nor the half life for Th_{232} agreed with the accepted values within our uncertainty. However Rn_{220} half life was nearly within the uncertainty. There were a couple valid possible sources of error including some strange decay behavior, and a possible nonrepresentative set of background radiation.

Scanned Sheets from Lab Notebook

Radioactive Decay of ^{220}Rn & ^{232}Th Physics 2150 Experiment 10
University of Colorado.

11/2/2021

Cassidy Bliss

Lab partner: Sean Gopalakrishnan

Background Radiation (N_0)

trial 1: 84
trial 2: 84
trial 3: 78
trial 4: 88
trial 5: 90
trial 6: 79
trial 7: 89
trial 8: 76
trial 9: 78
trial 10: 72

11/2/2021

Set 1

Counts

t	N
0	962
1	872
2	685
3	666
4	599
5	515
6	465
7	424
8	371
9	401
10	346
11	301
12	287
13	273
14	243
15	192
16	211
17	181
18	195
19	169

t	N
20	167
21	152
22	147
23	160
24	117
25	121
26	119
27	116
28	135
29	114
30	113
31	97
32	116
33	123
34	96
35	92
36	90
37	98

t	N
38	99
39	106
40	103
41	103
42	88
43	106
44	97
45	92
46	97
47	85
48	95
49	96
50	95
51	97
52	99
53	105
54	85
55	100
56	76

set 1 continued

t	N
57	76
58	110
59	71
60	120
61	99
62	92
63	95
64	83
65	97
66	85
67	86
68	91
69	79
70	99
71	91

Set 2

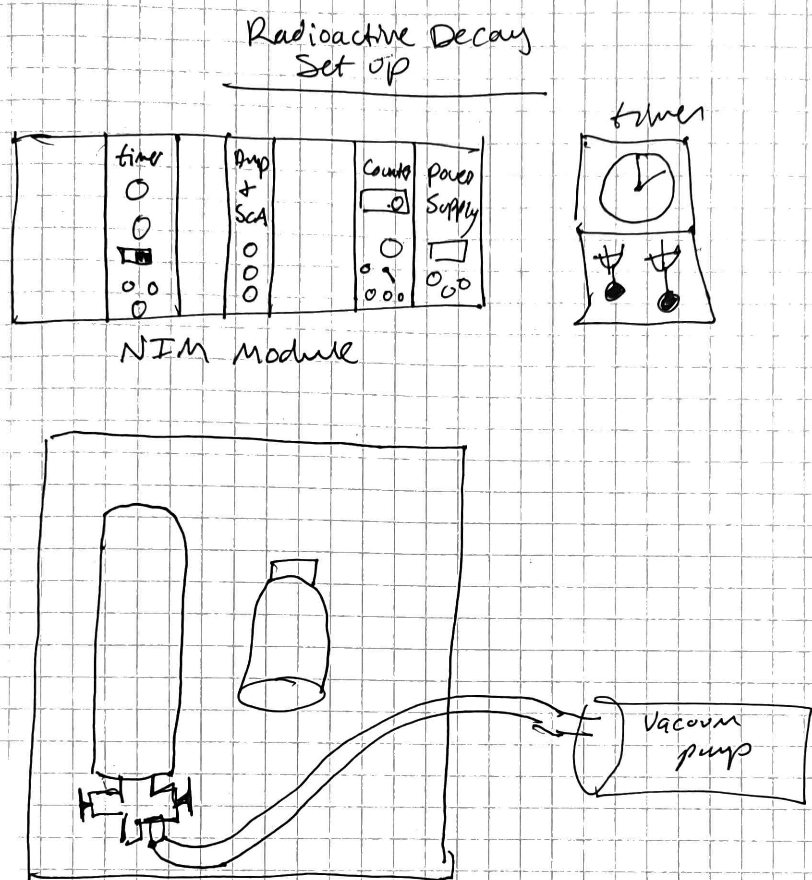
t	N
0	947
1	893
2	769
3	729
4	615
5	566
6	494
7	453
8	415
9	358
10	308
11	337
12	289
13	248
14	249
15	230
16	219
17	189
18	199
19	194
20	149
21	156
22	138
23	130
24	136
25	115
26	121
27	138
28	109
29	123
30	105
31	100
32	142
33	96
34	104
35	109
36	99
37	111
38	83

Set 3

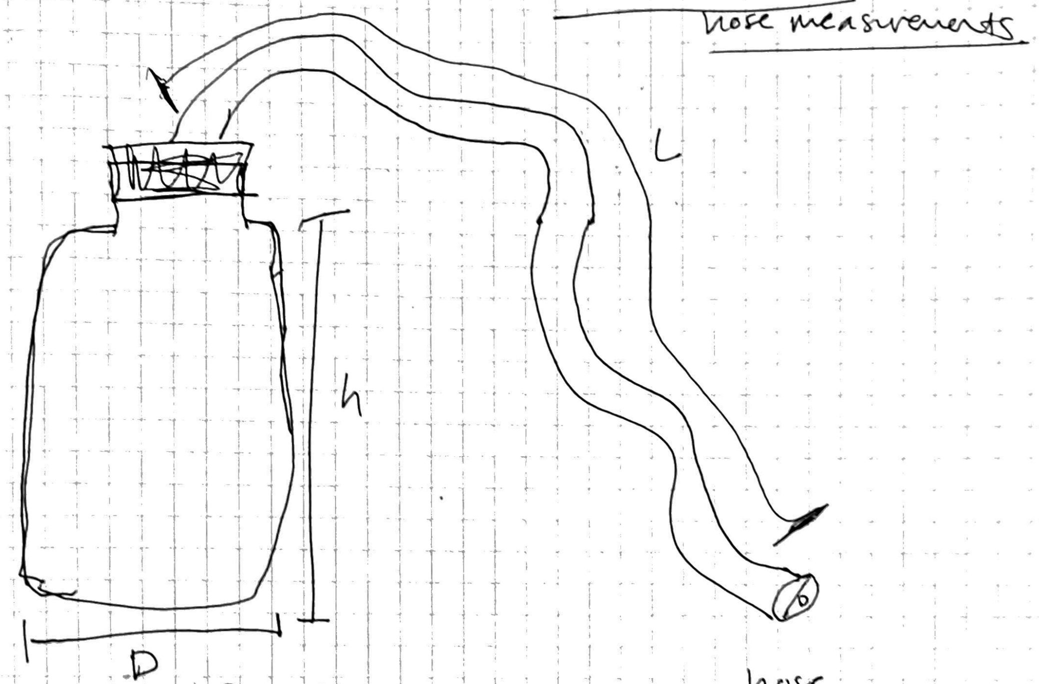
t	N
0	1161
1	959
2	869
3	846
4	725
5	615
6	591
7	526
8	467
9	426
10	396
11	406
12	329
13	263
14	263
15	283
16	249
17	226

t	N
18	201
19	189
20	151
21	167
22	159
21	162
22	139
23	141
24	123
25	125
26	112
27	128
28	103
29	119
30	87
31	102
32	119
33	109
34	94

t	N


Radioactive Decay
Set Up
timer
timer
Amp
&
SCA
Counter
Power
Supply
NIM Module
Vacoum
pump

Thorium Container & hose measurements



Bottle

Diameter: 6.6 ± 0.2 cm

height: 11.0 ± 0.1 cm

hose

Diameter: 0.5 ± 0.1 cm

Length: 50.0 ± 0.1 cm

TA:

11/2/2021