Lab Notes: Lab 2

Lab: PHY 105N - Lab 2
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Part 1: Methods

In this experiment, we are investigating detecting radioactivity, and analyzing whether the model $\mu = \sigma^2$ is true with the statistics and dependence on other variables. We were able to measure the radioactivity of household items such as a smoke detector and a marble. Ionizing radiation is a random process, meaning we are not able to predict exact moments of radiation. We are able to use the Poisson Probability Distribution model as a way to describe random processes such as the one we are testing in the lab: $P(k) = \frac{(rt)^k e^{-rt}}{k!}$. The physical model we will be using for this lab is $\mu = \sigma^2$, where we'll conclude if the behavior of the ionizing radiation is consistent with the Poisson distribution. We predict that the Poisson Distribution will hold true and prove that the radioactivity is a random process, and that the sources are radioactive compared to our background. We will be taking background radiation into consideration by finding the ambient radiation in the room. To do this we are utilizing a Greiger Counter and the PASCO Capstone application on the lab desktop computer. The objects we chose to be in the experimental systems are air/empty space, Polonium-210, a marble, and a smoke detector. To reduce uncertainty, each trial is an average count rate from five measurements taken at 10 second intervals which reduces variation and increases credibility of the calculated mean values. So, each trial took 50 seconds to complete and has an averaged count rate of radiation. For analysis, the mean, standard deviation, uncertainty and t-score were calculated to determine it is consistent with the Poisson process/distribution. For the t-score analysis, indistinguishability is indicated if $t < 1$, while $1 < t < 3$ indicates inconclusiveness, and $t > 3$ indicates distinguishability where the larger the t score, the higher the discrepancies.

- **Equipment**
    - Geiger Counter: used to detect ionizing radiation of various objects
    - Marble: made of Uranium Glass; used as an experimental source of radiation
    - Polonium-210: radioactive isotope; used as an experimental source of radiation
    - Smoke Detector: contains Americium (radioactive); used as an experimental source of radiation
- **Variables**
    - Independent Variable: type of material tested (Polonium-210, marble, smoke detector)
    - Dependent Variable: average count rate (c/s) measured by Geiger counter
    - Constant Variable: trial length, detector used, environment
    - σ^2: the square of the standard deviation of the value of counts of detected radiation in a given time period
    - μ : the mean value of counts of detected radiation in a given time period
- **Statistical and Analytical Tools**
    - Poisson Distribution: $\mu = \sigma^2$

- Used to determine whether radioactivity is a random process or not
- Mean: $\bar{\chi} = \frac{\Sigma \chi_i}{N}$
  - Used to calculate the mean value from the repeated trials for each radiation source
- Standard Deviation: $\sigma_x = \sqrt{\frac{\Sigma(\chi-\mu)^2}{N-1}}$
  - Used to find the variation of the data from the trials around the mean
- T-score: $t = \frac{|\bar{x}_s - \bar{x}_b|}{\sqrt{(\delta\bar{x}_s)^2 + (\delta\bar{x}_b)^2}}$
  - Used to ultimately find if results were distinguishable or not
- Associated Uncertainty: $\bar{\chi} = \frac{\sigma}{\sqrt{N}}$
  - Used to find uncertainty due to variation from multiple trials

Part 1: Data

Air/Empty Space		
Trials	Time (s)	Avg. Count Rate (c/s)
1	50	1.000
2	50	2.600
3	50	1.800
4	50	1.400
5	50	3.200
Average	2.000	
Standard Deviation	0.8944	
Uncertainty	0.4000	
T-scores	1.7321	
T_dist	null since this is our baseline	

Table 1. Background Radiation (Air/Empty Space)

Polonium-210		
Trials	Time (s)	Avg. Count Rate (c/s)
1	50	137.0
2	50	148.6

3	50	172.0
4	50	194.6
5	50	217.6
Average	174.0	
Standard Deviation	32.95	
Uncertainty	14.74	
t-scores	1.187	
T_dist	11.66	

Table 2. Radioactivity of Polonium-210

Uranium Glass Marble		
Trials	Time (s)	Avg. Count Rate (c/s)
1	50	4.300
2	50	2.000
3	50	3.000
4	50	2.600
5	50	2.400
Average	2.860	
Standard Deviation	0.8820	
Uncertainty	0.3945	
t-scores	3.076	
T_dist	1.531	

Table 3. Radioactivity of Marble (Uranium Glass)

Smoke detector		
Trials	Time (s)	Avg. Count Rate (c/s)
1	50	5.800
2	50	4.600
3	50	3.800
4	50	5.000

5	50	4.200
Average	4.680	
Standard Deviation	0.7694	
Uncertainty	0.3441	
t-scores	7.544	
T_dist	5.079	

Table 4. Radioactivity of Smoke Detector (Americium source)

Sample Calculation:
Using the data from the Air/Empty Space data set of n = 5 trials, we can verify the validity of the Poisson distribution:

$$\bar{x} = \frac{1 + 2.6 + 1.8 + 1.4 + 3.2}{5} = 2.0000\ c/s$$

$$s^2 = \frac{\Sigma(x_i - \bar{x})^2}{n-1} = 0.8000,\ s = \sqrt{0.8000} = 0.89442719$$

$$\delta\bar{x} = \frac{s}{\sqrt{n}} = \frac{0.89442719}{\sqrt{5}} = 0.4000000$$

$$\delta s^2 = s^2\sqrt{\frac{2}{n-1}} = 0.8\sqrt{\frac{2}{4}} = 0.56568542$$

$$t = \frac{|\bar{x} - s^2|}{\sqrt{(\delta\bar{x})^2 + (\delta s^2)^2}}$$

Part 1: Conclusion
We've concluded from our background measurements (air or the empty space in this case) are consistent with the Poisson process/distribution: the check using t-score statistics returned $t = 1.73,\ |t| < 3$, so $\mu \approx \sigma^2$ within uncertainty. Using the lab distinguishability t-score (T_{dist}), $t = \frac{|\bar{x}_s - \bar{x}_b|}{\sqrt{(\delta\bar{x}_s)^2 + (\delta\bar{x}_b)^2}}$ with $\delta\bar{x} = \frac{s}{\sqrt{n}}$, we compared each sample's average count rate to background ($|t| < 1$, distinguishable; $1 < |t| < 3$, inconclusive; $|t| > 3$ distinguishable). Polonium-210 is clearly above background ($t_{dist} = 11.66$ →distinguishable). The smoke detector was also above background ($t_{dist} = 5.079$ →distinguishable); however, the marble was not resolved to relative to background ($t_{dist} = 1.531$ →inconclusive). Overall, the background randomness agrees with the Poisson model, and among tested items only Polonium-210 and the smoke detector are measurably radioactive under our measurement conditions; additional trials would be needed to decide the marble definitively. Some sources of error within the experiment could be the detector sensitivity so the Geiger counter might be extremely sensitive to radioactivity increasing the activity inputted. In addition, another source of error could be detector placement as different areas of the material could have more radioactivity. Some ways to improve the experiment for future experiments is to increase the counting time and compare the results with different

detector types. In conclusion, the model is theoretically valid, but experimental error was too much to support it.

Part 2: Methods

For the second part of our experiment, we will be testing radioactivity as a function of distance. To do this we will be using a goniometer to measure the distance between the Geiger Counter and the experimental radiation source. We will be measuring radioactivity at increasing increments of 0.5 centimeters, furthering the distance for each trial. The trials are determined using the same process from Part 1: each trial is 50 seconds long, count rate being an average of 5 count rates at 10 second intervals. We predicted that as the distance between our source and the Geiger Counter increases, the radioactivity will decrease which is consistent with the inverse square law ($I \propto 1/r^2$). We are predicting this based on strong force decreasing significantly as distance increases. To test our hypothesis we decided to use a known highly radioactive source, Polonium-210. We will be determining the uncertainty using the following equation: $\delta R = \sqrt{\frac{R}{10}}$. *R* will represent the average count rate for each trial. As previously mentioned, we will be limiting uncertainty by doing multiple trials that each occur in 50 seconds. For analysis, the mean, standard deviation, uncertainty and t-score were calculated to compare each measured distance to the baseline. For the t-score analysis, indistinguishability is indicated if t < 1, while 1 < t < 3 indicates inconclusiveness, and t > 3 indicates distinguishability where the larger the t score, the higher the discrepancies.

- **Equipment:**
    - Geiger Counter: used to detect ionizing radiation of various objects
    - Goniometer: used to measure distance between Geiger Counter and radiation source
    - Polonium-210: radioactive isotope; used as an experimental source of radiation
- **Variables**
    - Independent Variable: distance from the source (cm)
    - Dependent Variable: average count rate (c/s)
    - Constant Variable: material/source type, trial length, settings, environment
    - R**:** the average count rate calculated from each trial (c/s)
    - δR**:** the uncertainty associated with the average count rate calculated for each trial
- **Statistical and Analytical Tools**
- T-score: $t = \frac{|\overline{x}_s - \overline{x}_b|}{\sqrt{(\delta\overline{x}_s)^2 + (\delta\overline{x}_b)^2}}$
    - Used to find distinguishability against our previous calculated background from Part 1
- Uncertainty: $\delta R = \sqrt{\frac{R}{10}}$
    - Used to find any uncertainty associated with the average count rate of radiation in the trials

Part 2: Data

Polonium-210				
Trials	Distance of Grieger Counter (cm)	Avg. Count Rate (R) (c/s)	$\delta R = \sqrt{\frac{R}{10}}$ (c/s)	t-score(distance)
1	0	290.2	5.387	53.35
2	0.5	65.20	2.553	24.45
3	1	26.40	1.628	14.58
4	1.5	4.600	0.678	3.302
5	2	2.800	0.5292	1.206

Table 5. Polonium-210 Count Rate as a Function of Distance

Sample Calculation:
Using the data from our background (baseline) against our Polonium-210 data set, we can verify the validity of the radioactivity of our object:

$$\delta R(1.5) = \sqrt{\frac{R(1.5)}{T}} = \sqrt{\frac{4.6}{10}} = 0.678233\ c/s$$, where T is time

$$t = \frac{|R(1.5) - R_b|}{\sqrt{(\delta R(1.5))^2 + (\delta R_b)^2}} = \frac{|4.6 - 2.0|}{\sqrt{0.678233^2 + 0.4^2}} = \frac{2.6}{0.78709} = 3.302$$, where R_b is the average count rate of the baseline (background).

Part 2: Conclusion
We concluded that as the distance increased, the measured average count rate fell steeply. Using the lab's distinguishability t-score against the background, the source was clearly above background at the distances of 0.0, 0.5, 1.0, and 1.5 cm ($|t| > 3$). At 2.0 cm, the result was determined inconclusive ($|t| = 1.2060$) with our current statistics. All in all, the data shows the expected drop in intensity with distance that resoundingly confirms that Polonium-210 is measurably radioactive at close ranges. Some sources of errors could be variability between the radioactivity in the Polonium-210 and the placement of the detector; additional trials or longer counting times at larger distances would reduce uncertainty and provide a better test for the inverse-square trend for future iterations of this experiment.