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An Exploration on the Activity of a Cesium-137 Source and the Inverse Square Law

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Abstract

The purpose of this experiment was to measure the count rate of a Cs-137 source at a known distance (6.14cm) using a Geiger counter. This was done using a variety of experimental techniques with varying run times, repetitions and samples rates. The data was then fitted to both Gaussian distributions and Poisson distributions. An average count rate of 2.816 ± 0.001 decays per 0.1 s was determined. Poisson distributions were relied on in this experiment for their ability to describe data that is infrequent and independent. This measurement was then compared to the average count rate at a further distance to verify the inverse square law.

1 Introduction

The objective of this experiment is to determine the average count rate of a cesium-137 radioactive source. By measuring average count rate at different distances from the source, the inverse square law was confirmed. This experiment utilizes Poisson distribution and explores the parameters of the Poisson distribution with the goal of finding the most precise average count rate.

Cesium-137 is an unstable isotope that decays into Barium-137 via emission of a γ-ray [1]. This decay has a half life of 30 years. The decay events are sufficiently rare and occur independently from each other. These are the required criteria for data that the Poisson distribution analyzes well.

The Poisson distribution is defined by the equation:

$$P(x;\mu) = \frac{\mu^x e^{-\mu}}{x!} \tag{1}$$

where P is the probability of x number of events occurring during a sample, and μ is the average rate of the events. The standard deviation of a Poisson distribution (σ) depends on its average rate:

$$\sigma = \sqrt{\mu}. \tag{2}$$

The inverse square law is a prevalent physical phenomena that affects the propagation of sound, light, radiation, gravitational forces and electromagnetic forces. It is characterized by propagation that is inversely proportional to the square of the distance between source and measurement. Newtons law of gravitation for instance obeys the inverse square law. Measuring activity some distance away from a radioactive source will similarly display the inverse square law. By measuring activity at different distances, this experiment will verify this.

2 Materials

Geiger Counter, Cesium-137 Source, Retort Stand, Test-tube Clamp, PASCO, Computer.

3 Methodology

1. Background Activity of room was measured wit Geiger Counter.
2. Using retort stand and clamp, Cesium source was placed at an initial distance from Geiger-Muller tube of Geiger counter.
3. Four different sections of this experiment were conducted, each with different run-times, repetitions, sampling rates and distances between the cesium source and Geiger Counter. The four different sections are summarized in Table 1.

Table 1: Summary of conditions for the four parts of the experiment outlined in **??**

Experiment	Run-time (min)	Repetitions	Sampling Rate(Hz)	Source Distance(cm)
Part 1	5	3	5	6.14
Part 2	5	3	0.5	6.14
Part 3	1	20	10	6.14
Part 4	5	5	10	16.84
Lab Tech.	90	1	5	4

4 Results

Figure 1: Figure 1: Gaussian and Poisson Fits of Geiger Counts Observed with a 10Hz Sampling Rate (Part 3)

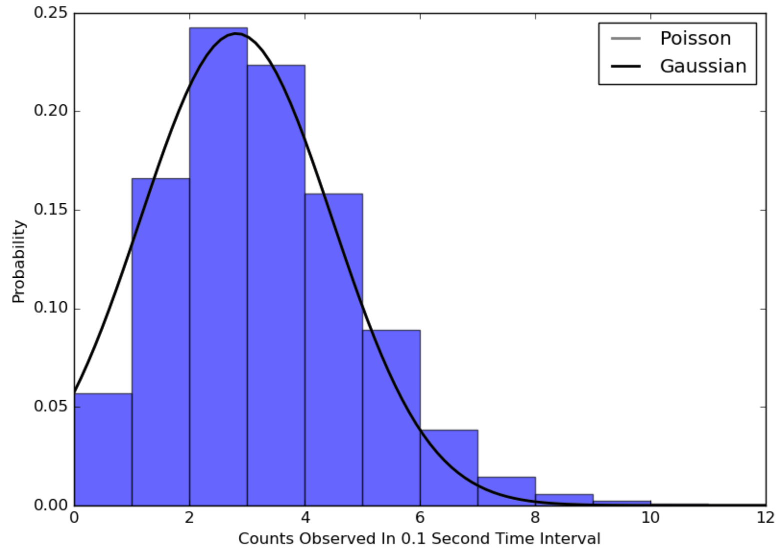


Figure 2: Figure 2: Gaussian and Poisson Fits of Combined Data of 20 Trials Observing Geiger Counts with a 10Hz Sampling Rate (Part 3)

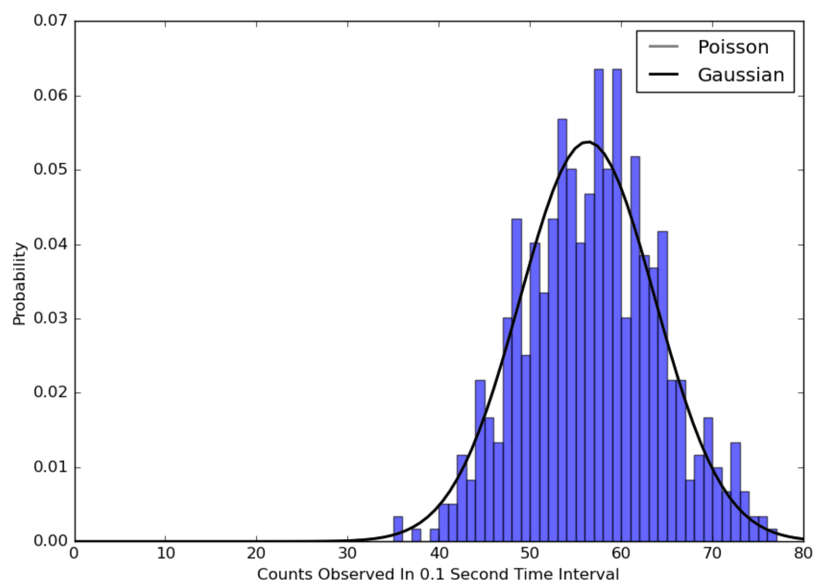


Table 2: Summary of Average Count Rates Obtained by Various Conditions of Measurements and Data Analysis.

Experiment	Poisson Distribution Fit	Gaussian Distribution Fit
Part 1	μ (counts per 0.1s)	μ (counts per 0.1s)
Run 1	2.8 ± 0.1	3.0 ± 0.2
Run 2	2.8 ± 0.1	2.8 ± 0.2
Run 3	2.7 ± 0.1	2.7 ± 0.2
Horizontal Sum	2.80 ± 0.02	2.82 ± 0.03
Part 2	μ (counts per 0.1s)	μ (counts per 0.1s)
Run 1	2.85 ± 0.02	2.86 ± 0.2
Run 2	2.96 ± 0.02	2.96 ± 0.2
Run 3	2.89 ± 0.02	2.89 ± 0.2
Horizontal Sum	2.847 ± 0.001	2.910 ± 0.002
Part 3	μ (counts per 0.1s)	μ (counts per 0.1s)
Horizontal Sum	2.784 ± 0.001	2.855 ± 0.005
Vertical Sum	2.81 ± 0.01	2.81 ± 0.01
Part 4	μ (counts per 0.1s)	μ (counts per 0.1s)
Combined	0.346 ± 0.005	0.36 ± 0.01
Horizontal Sum	0.217 ± 0.002	0.219 ± 0.003

5 Discussion

The results of this experiment indicate that at a distance of 6.14cm from the Cesium-137 source, the Geiger Counter measured an average count rate of 2.816 ± 0.001 decays per 0.1 s. This value was obtained by averaging the two most precise measurements of this experiment: The horizontal sum of both part 2 and part 3 analyzed using a Poisson distribution (as seen in Table 2). Poisson distributions and Gaussian distributions. Overall, using Poisson distributions produced average count rate values that were more precise than the Gaussian fits. This is likely because the decay of Cs-137 are infrequent and independent events, which are conditions the Poisson distributions deals with better. Gaussian fits also mostly produced values greater than the Poisson fits.

The measurement of average count rate made in part 4 can be used to verify the inverse square law. In part 4, the source was placed 2.74 times farther than in parts 1-3. The inverse square law predicts:

$$FurtherAverageCountRate = \frac{2.816 \pm 0.001}{2.61^2} = (0.3744 \pm 0.0001)/0.1s. \tag{3}$$

Comparing this predicted value $(0.3744 \pm 0.0001)/0.1$s to the experimental data from part 4, it is in strong agreement with $(0.36 \pm 0.01)/0.1$s and it in reasonable agreement with $(0.346 \pm 0.005)/0.1$s (Table 2). This makes sense, as the γ-rays released by the source spread out over a greater area proportional to the distance squared. This is why less detections are made by the Geiger-Counter, because the Geiger-Muller tube only occupies so much area. The results of this experiment therefore confirm the inverse square law.

6 Conclusions

The average count rate of the Cs-137 was determined to be 2.816 ± 0.001 decays per 0.1 s when measured at a distance of 6.14cm. The inverse square law was also verified to affect distribution of radioactivity as expected by comparing to the average count rate measured at a distance 2.61 times further. Poisson distributions proved useful for analyzing the data of collected in this experiment due to the infrequent and independent nature of Cs-137 decays.

References

[1] The University of Tennessee Knoxville. Lab 8: The Radioactive Half-life of Ba-137. Phys 250 Laboratories. Accessed March 7 2022. http://electron6.phys.utk.edu/phys250/Laboratories/radioactive_halflife_of_ba.htm 1

A First Appendix: Author Contribution Statements

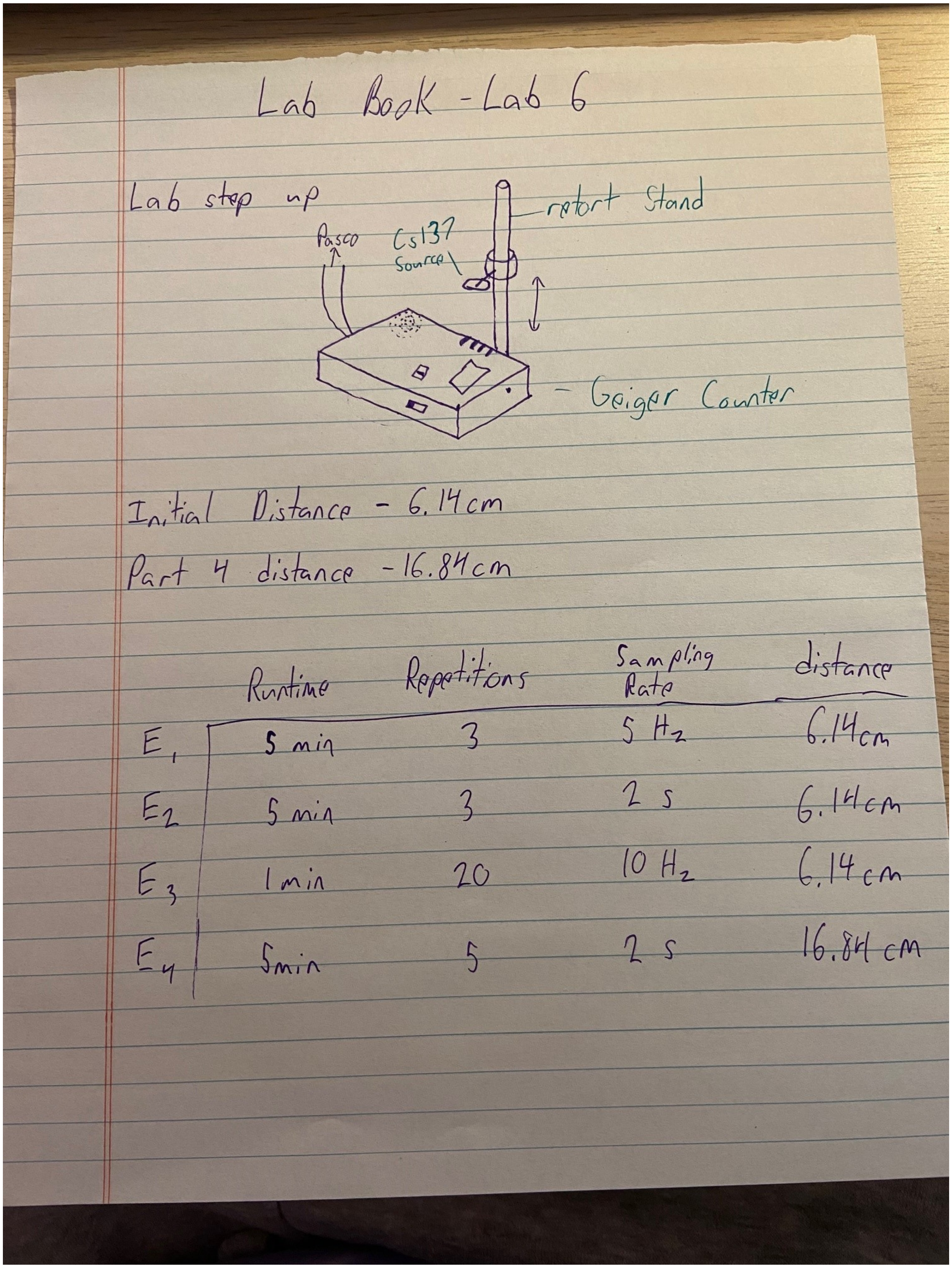
Monte Mahlum

M.M contributed by taking raw data, analyzing this data via Data Analysis prompts, answering lab questions, writing the Lab Report, and completing the assignment.

Evan Henderson

E.H contributed by taking raw data, analyzing this data via Data Analysis prompts, answering lab questions, writing the Lab Report, and completing the assignment.

B Second Appendix: Lab Book



Lab Book - Lab 6

Lab step up

Pasco

Cs137 Source

retort Stand

Geiger Counter

Initial Distance - 6.14 cm

Part 4 distance - 16.84 cm

	Runtime	Repetitions	Sampling Rate	distance
E_1	5 min	3	5 Hz	6.14 cm
E_2	5 min	3	2 s	6.14 cm
E_3	1 min	20	10 Hz	6.14 cm
E_4	5 min	5	2 s	16.84 cm

Figure 3: Lab Book page one