MENLO SCHOOL

EXPERIMENTALLY DETERMINING THE HALF LIFE OF BARIUM-137

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ABSTRACT

An experiment was devised to determine the half life of Barium-137 and further explore the topics of radioactive decay and error analysis. Using a Geiger counter and RStudio, the half life was determined to be 2.5 min +0.22/-0.18 +/- 0.24.

INTRODUCTION

To perform the experiment, a background source of radiation was mounted to a block of wood. A vial of rapidly decaying radioactive material was placed adjacent to the background source. The Geiger counter was positioned closely in front of both sources (Figure 1).

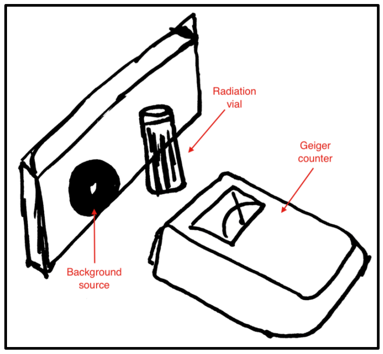


Figure 1: Experimental set-up. Not pictured: Vernier LabQuest connected to Geiger counter to collect data.

Radioactive decay is the process by which the nucleus of an unstable atom releases alpha particles, beta particles or gamma rays. The process occurs when the atom "wants" to move to a lower and stabler energy level. In this experiment, we measured the half life of Barium-137m, which is accepted to be 2.552 minutes. Barium-137m emits gamma radiation, which is electromagnetic radiation with wavelengths less than one nanometer.

$$\text{Ba-137m} \rightarrow \text{Ba-137} + 0\gamma 0$$

To continually produce Barium-137m in an isotope generator, water, an eluting solution, flows through decaying Caesium-137.

$$\text{Cs-137} \rightarrow \text{Ba-137m} + \text{-1e0}$$

This decay creates a water solution saturated with Barium atoms. Because the isotope generator contains Caesium 137 (half life 30.17 +/- 0.03 years), but produces Barium 137m (half life 2.552 minutes), the generator can stay operational for years while having products that may be observed in a class period.

RESULTS

By subtracting the background radiation from our raw data, we were able to isolate the source and calculate its half life given the levels of gamma decay at the selected time intervals.

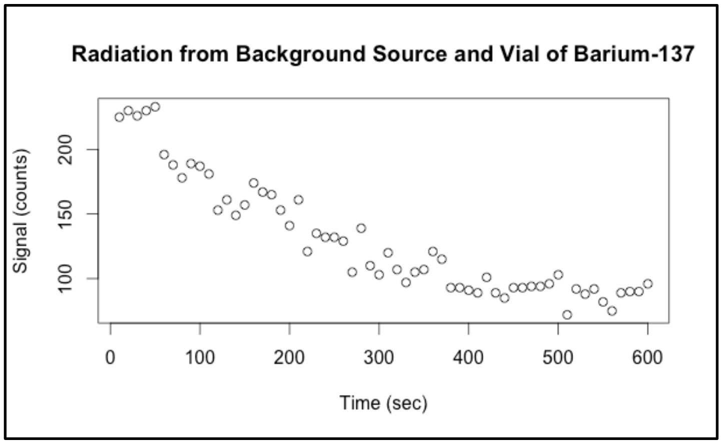


Figure 2: Raw data recorded by Geiger counter of radiation from background source and vial of Barium-137.

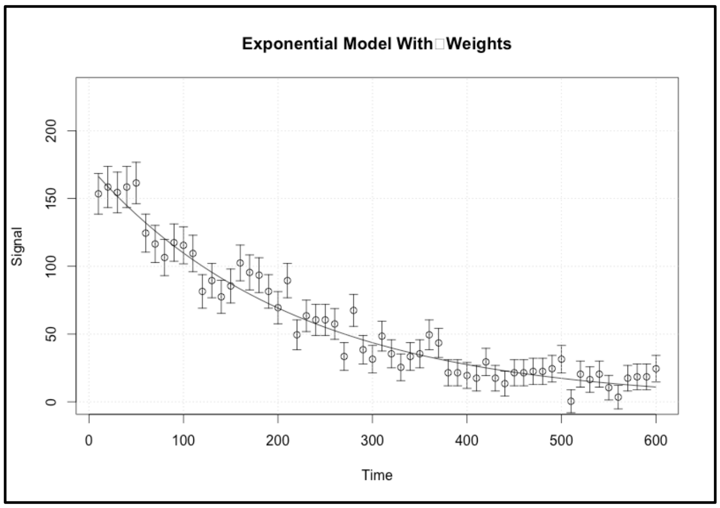


Figure 3: Signal of decaying Barium-137. Found by subtracting background radiation from raw data, applying a curve fit and adding error bars.

Calculated Half Life for Barium-137: **2.5 min +0.22/-0.18 +/- 0.24**

Error Analysis

The error bars in Figure 3 represent the statistical error for each point. This comes from the fluctuations in the particle decay due to quantum mechanics, which is based on probabilities rather than linear functions. The statistical error for a specific data point, say Bin 1, would be sqrt(# of counts + bkg): in this case, sqrt(153.45 + 71.53) = +/-17.22. The error for the entire curve fit is +0.22/-0.18. The systematic error was measured by using a quadrature derived by three different sources of systematic error: background, bin size, and cosmic ray radiation. The total systematic error, outlined in Appendix A was +/- 0.24 minutes.

The background, shown in Appendix B, was measured using three different estimations for the background radiation and then finding the average percent difference between each pair. The first method to estimate the background was taking an average of the data collected from background source, the second was fitting a Gaussian curve to the data and using the mean of it, and the third was fitting the tail of the raw data to a line with slope zero and taking the y-intercept. Each of these estimations were used to calculate the half life of the Barium-137 which were, respectively, 150.23 seconds, 143.78 seconds, and 130.00 seconds. The average percent difference was 9.61%.

The bin size error was calculated by changing the bin sizes of the signal data two times, determining the half life for each, and then finding the average percent difference between each pair. The half lives found were 152.64 seconds, 152.37 seconds, and 150.23 seconds, using bin sizes 30 seconds, 20 seconds, and 10 seconds respectively. The average background was used for calculations in this analysis. The average percent difference was 1.06%

The cosmic ray radiation, shown in Appendix C, was measured by placing a Geiger counter in Whitaker lab and measuring the amount of radiation. When fit with a Gaussian curve, the mean came out to be 2.05. When subtracting this value off the average background count and raw data, it yielded a new half life of 151.44 seconds and a percent difference of 0.803%.

If the Geiger counter had missed 10% of particle decays, it would not have affected the decay constant and in fact would have decreased error by decreasing the count at each point. If the background was not constant, it would have been necessary to use the decay constant of the source to calculate an appropriate amount to subtract from each raw data point.

Conclusion

In this experiment, we found Barium-137 to have a half life of 2.5 min +0.22/-0.18. This is a 95% asymmetrical confidence interval, meaning that 95% of the time samples are taken, the true mean for the Barium-137 half life will fall within the calculated confidence interval. In some of the plots, the curve fit did not weight the data by error bars. This would have reduced the accuracy of the calculated half life because imprecise observations with high amounts of error would have been treated the same as precise observations with low amounts of error. Thus, the fact the some observations were clearly more valuable in finding the true half life would have been disregarded. The value we found compared well with the theoretical value, with 2.552

minutes falling within our confidence interval. It is unclear whether cosmic rays from space were an issue in this experiment. When measuring ambient background radiation, much of the signal could have been coming from appliances such as cell phones, computers, microwaves, or other appliances that emit radiation. The fact that there was space between creating the radiation sample and measuring it was an insignificant factor. This is because the decay constant would still remain the same, no matter what interval it is measured in. This experiment could be made more precise by not using an interfering background source.

Appendix

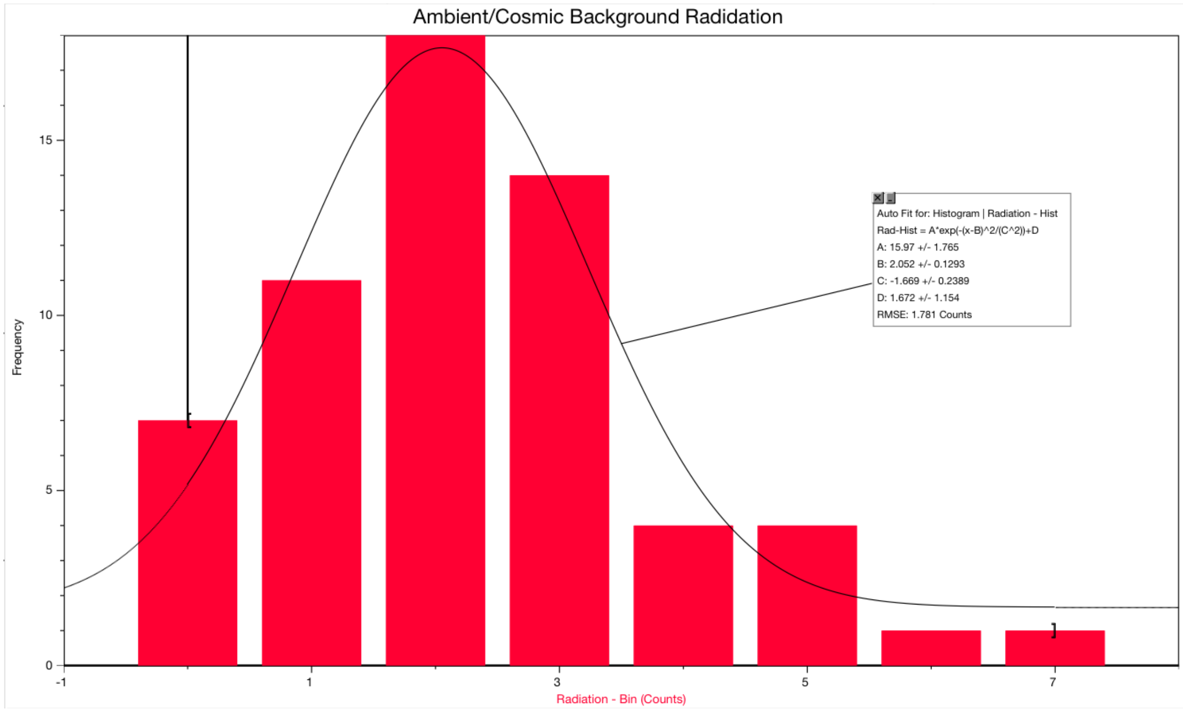
Appendix A. Total Systematic Error

Systematic	**%error**
Bin size	9.61
Bkg subtraction	1.06
Ambient/cosmic background radiation	0.803
Total	9.70

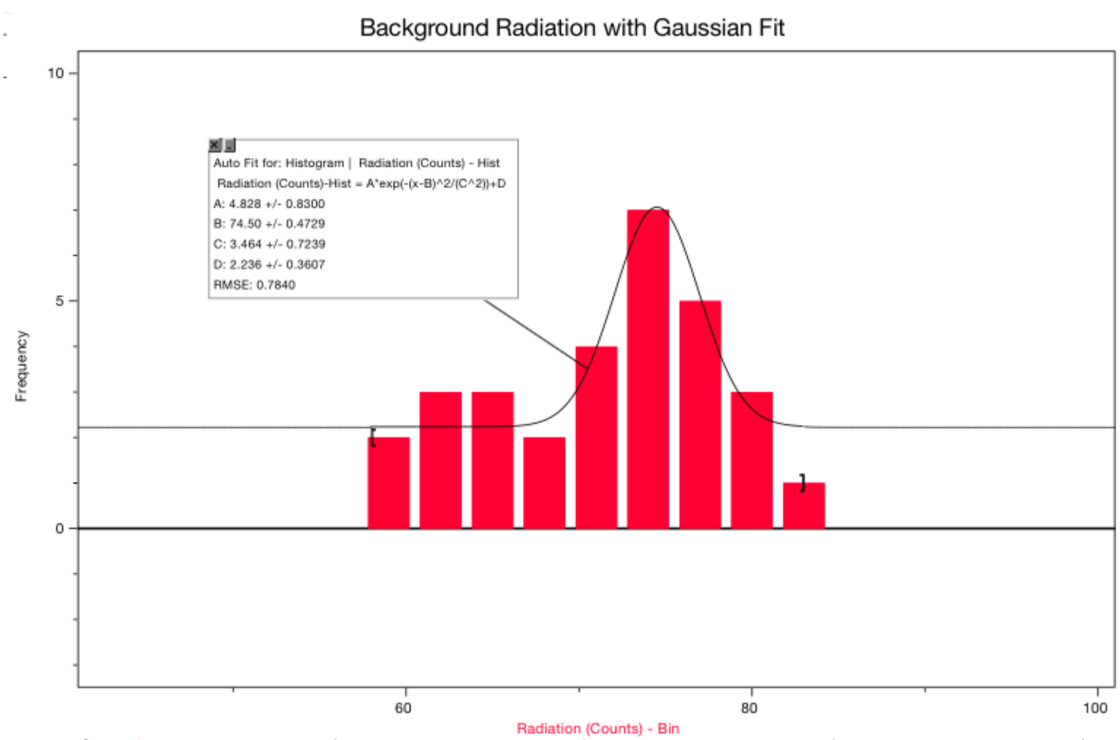
Appendix B. Background Estimations

Average	Gaussian Fit	Tail Fit
71.53	74.5	80.09

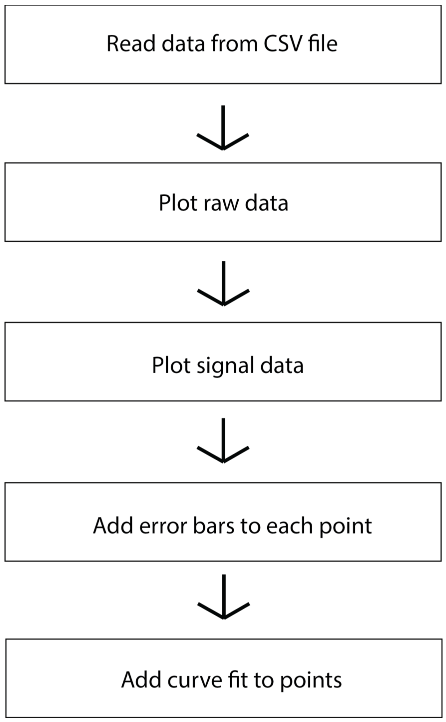
Appendix C. Ambient/Cosmic Background Radiation



Appendix D. Background Data with Gaussian Fit



Appendix E. Flow Chart of R Code



Appendix F. Raw Data

Time (s)	Radiation (Counts)	Time (s)	Radiation (Counts)	Time (s)	Radiation (Counts)
10	225	210	161	410	89
20	230	220	121	420	101
30	226	230	135	430	89
40	230	240	132	440	85
50	233	250	132	450	93
60	196	260	129	460	93
70	188	270	105	470	94
80	178	280	139	480	94
90	189	290	110	490	96
100	187	300	103	500	103

110	181	310	120	510	72
120	153	320	107	520	92
130	161	330	97	530	88
140	149	340	105	540	92
150	157	350	107	550	82
160	174	360	121	560	75
170	167	370	115	570	89
180	165	380	93	580	90
190	153	390	93	590	90
200	141	400	91	600	96