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Daniel Pagliaroli: All of the code, results, analysis, methods, discussion, appendix, conclusion

Ethan Savage: abstract, introduction, references

Pylab Radioactive decay

Abstract:

In this experiment, we will be exploring Radioactive decay using Nonlinear and linear fitting methods and Random Number Analysis. The first part involves diving into curve fitting techniques, focusing on both a linear regression and non-linear regression model. The radioactive decay data will be collected. This data will be analyzed through the use of linear and non-linear regression models, as well as poisson and gaussian functions. This will be used for the fast decaying data, and slow decaying data, respectively.

Introduction:

Radioactive decay is a fundamental process in which unstable atomic nuclei transform into more stable states by emitting radiation. It primarily occurs in specific isotopes of elements, which are inherently unstable due to an imbalance of protons and neutrons in their nuclei. The decay rate is generally quantified by the half-life, a measure of the time it takes for half of a sample to decay, and can vary widely across different isotopes. Radioactive decay plays a crucial role in fields such as radiometric dating and the estimation of the age of materials or artifacts. It's also important for nuclear power generation, where controlled nuclear fission of radioactive isotopes produces heat for electricity. Another reason to understand radioactive decay is important is that exposure to ionizing radiation from radioactive decay can have health implications, including the risk of radiation sickness and cancer. In addition, understanding radioactive decay is essential for nuclear weapons development, since it provides the basis for harnessing the rapid release of energy from unstable isotopes for destructive purposes. Overall, radioactive decay is a fundamental natural process that has broad-ranging scientific, medical, and industrial applications, with both beneficial and potentially harmful consequences.

Methods:

For the geiger counter experiment, a use of a radioactive element such as Barium(Ba-137m), was used. Such radioactive decay must be prepared through the use of a decaying material. The rate of emissions of the decaying radioactive element is then measured through the use of the Geiger counter("Radioactive Decay"). Computer software is also required to track the number of emissions of the decaying radioactive element. Keep track of the time interval of the decaying radioactive element. After such data is collected, the use of any data analysis software or python is used. Such data analysis includes the use of fitting models to predict a proper fit for the half life of the radioactive decay, while also looking at the sample count of another slow decaying process, to fit a poisson and gaussian distribution to data.

Results:

Figure 1:

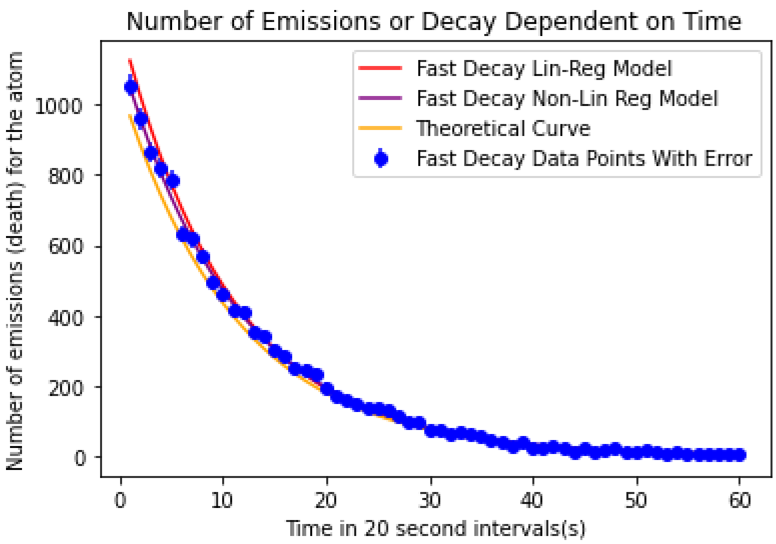

Figure 1: The blue dots with the error (cannot see some of them, too small), represents the actual data set points for the fast decaying plate without the background radiation. The red line represents the linear regression model used when putting the exponential model of y = y0 x e^ax, where y0 is the initial number of emissions. The brown line indicates the non-linear regression model, taking into account the exponential function y= a^x + b, as the model function. The theoretical curve takes into account the given half of 2.6 minutes, and this shows the best model plotted against the predicted models.

Figure 2:

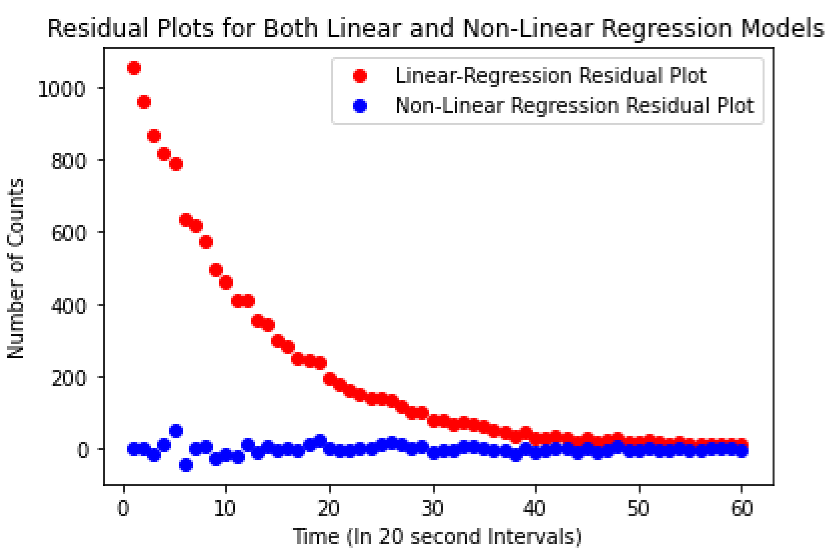

Figure 2: This represents a residual plot taking the values from the data set without the background radiation and subtracting it with the linear regression model values. Similarly, for the non-linear regression model. The better fit in this case is indicated as the non-linear regression model, since the residuals are near 0 for the graph, indicating a much better fit than the plot of the linear-regression model.

Figure 3:

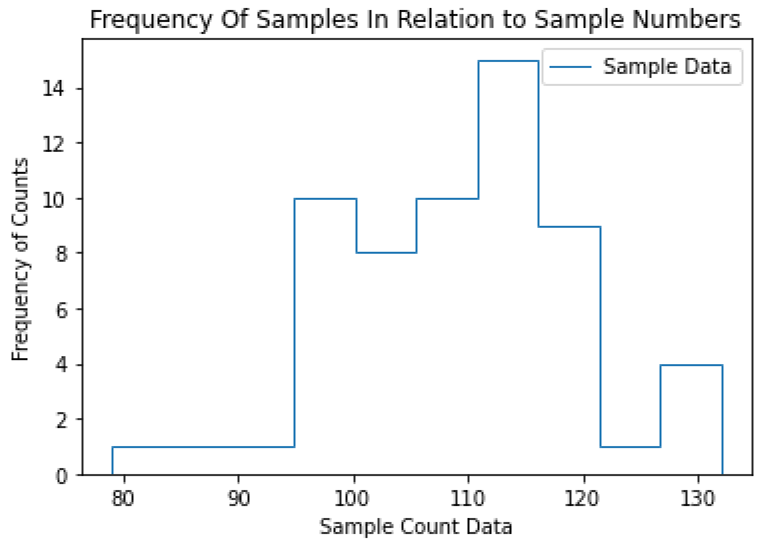

Figure 3: This is the frequency of counts of the sample count data for the fiesta plate. This shows the range of the number of times a certain count data range falls into.

Figure 4:

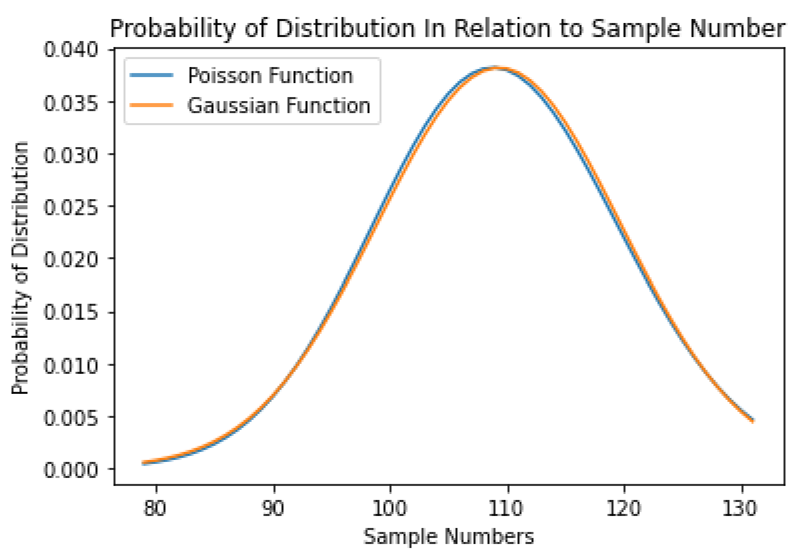

Figure 4: This is the probability of distribution for the sample numbers using both the poisson and gaussian functions. The poisson function is done by taking the mean of the sample data without the background radiation. This is used for the u value of the poisson function. The k value is the arrangement from the lowest number in the

sample data, to the highest number sorted without background radiation. This graph, if multiplied by 100, shows the number of times that an event will occur, in this case the sample being counted for as repeated. Similarly, the gaussian function shows the mean distribution as well , with the mean leaning towards roughly the 110 range for the sample count.

Figure 5:

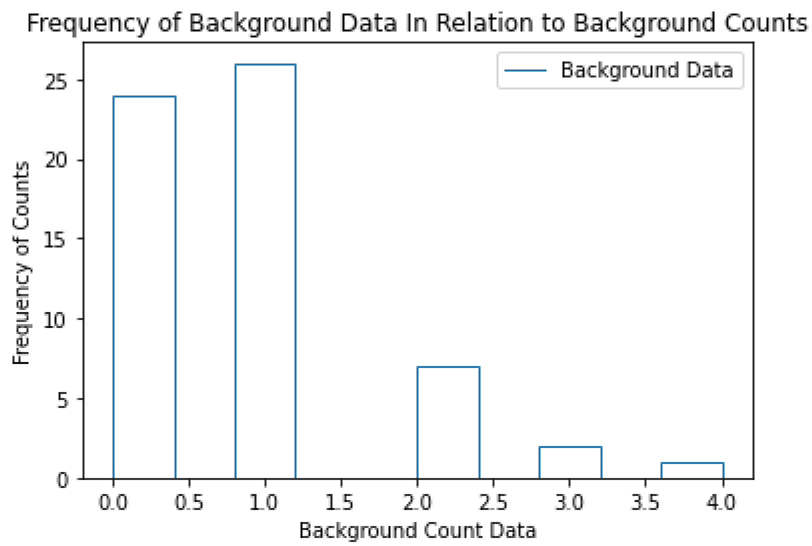

Figure 5: This is similar to figure 3, in which the count data is shown over a range with the frequency of counts. The bars represent a certain number of intervals. Over these intervals, the number of counts that are repeated, or the frequency in this case, is shown on the y-axis.

Figure 6:

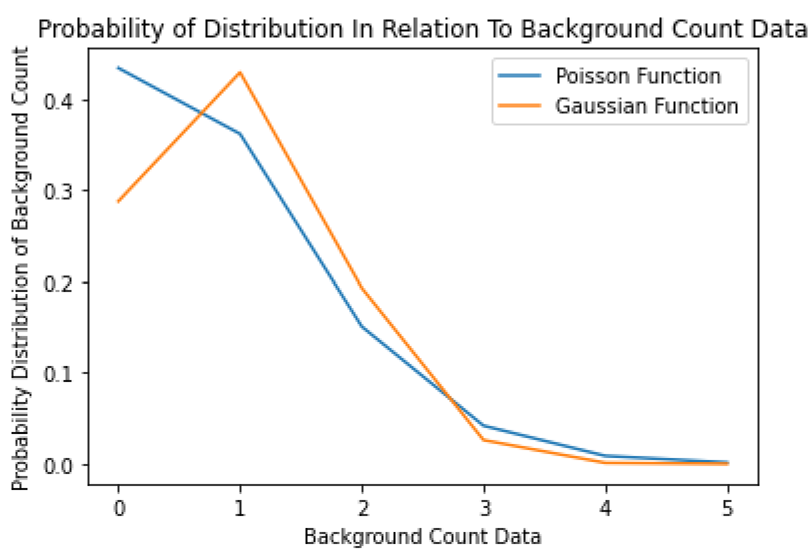

Figure 6: This is the poisson distribution and gaussian distribution for the background data itself, which is similar to the data that is in figure 4. However, the poisson and gaussian distributions are less similar in this case.

Uncertainties for the graphs, are evident in the calculations in the appendix. The fast decay plate and slow decay plate used uncertainty in the geiger counter for their uncertainties.

Analysis:

Radioactive decay is known to have a certain half value for each isotope. In this case, we used a linear and non-linear regression model in order to predict the half life of Barium,(Ba-137m)("Radioactive Decay"). The non-linear regression model gives a better fit with a closer expected half life value for radioactive decay since the residuals were closer to zero for the non-linear regression model than the linear regression model. This is due to the capabilities that the nonlinear regression model has. It is able to take into account a greater complexity of a data set, and have a more appropriate fit. For radioactive decay data with sample counts going up and down randomly, the non-linear regression is better. The differences in the plots are gathered through the use of the residual plots. The residual plot for the non-linear regression shows values closer to 0, meaning this is a better fit. The half life values computed, being close to 3.5 minutes for both plots, with the uncertainty of each being around 1, does put the half life into the range, only for the linear-regression fit. The linear regression fit with a half life of 3.57, and uncertainty of +-1.41, is closer than the non-linear regression plot of 3.75, with an uncertainty of +-0.944. This may have occurred due to the lacking number of measurements taken for the radioactive decay, as through the residual plots, the non-linear fit seems to be a better fit. Increasing the number of the samples taken, would allow for a more accurate fitting process. For the linear regression, the chi squared model is 1.1, with the non-linear regression being 0.8. This aligns with the assumption for the lacking number of sample points taken, since the value is below one for the non-linear regression model fit. The 1.1 for the linear-regression could indicate that such values are too complex for a linear regression model to be accurate. The poisson and gaussian functions both look similar for the sample count data, but not for the background radiation data. The background radiation data has such a low mean value, as compared to the actual fiesta plate. Due to this, the mean value used in the poisson distribution is skewed. A greater mean value would provide a closer resemblance between both fits.

Discussion:

For the data in terms of the proper fit and theory, the data set should have been taken over a wider range of values. Although the uncertainties for the sample count themselves are low, the fitting of the non-linear regression model seems to be a worse fit than the linear-regression in reference to the chi-squared values, as well as the nominal half life value comparison. In future experiments, the use of a greater number of sample counts, allows for a non-linear regression model fit to prove to be superior. The Poisson probability mass function puts into picture the mean distribution of the fiesta plate itself. Since the fiesta plate includes discrete sample count values, the poisson function provides a visual representation of the mean distribution. Similar to the Gaussian fit, it allows for a clearer indication of sets of points. This allows students to clearly see the main source of distribution in the number of samples. The uncertainty in the geiger counters, allows for the human error aspect to be present. The geiger counter is not perfect when taking samples, which is in accordance with the error that humans are able to produce throughout experiments. The uncertainty in the emission or sample counts is able to represent such errors in the counter.

Conclusion:

Overall, this experiment was effective in demonstrating how radioactive decay occurs in an isotope. The use of the linear regression model and non-linear regression model provides an indication of the importance of choosing a correct fit for the fast decaying plate. The histograms of the fiesta plate or slow decaying plate, and background data, provide a visual indication of the range of values of the sample counts. Both the poisson and gaussian function fits provide mean distribution of values to properly visualize the majority of value distribution for the sample and background data. The use of models such as chi-reduced squared and regression models were used to evaluate the correctness of the fits for all the sample data.

Appendix:

Uncertainty Calculations:

For the fast decay and slow decay, the uncertainty was calculated using the square root of the sample count data added to the mean background radiation.

Let u be the uncertainty in the calculation, and let N be the sample number for the radioactive Decay. B represents the average background radiation data.

$$u = (N + B)^{0.5}$$

For example, let N be 110, and B be an average of 2.3.

$$u = (110 + 2.3)^{0.5}$$

$$u = +- 10. \ (Rounded\ to\ 2\ sig\ figs)$$

Uncertainty for the Rate Counter Itself:

NB = number of samples without background radiation

u(R) = uncertainty in the rate counter.

$u(R) = (NB/Time\ interval) + (NB/Time\ interval)^{0.5})^{0.5}$

Let NB be 93.

Let the time interval be 20 seconds.

$u(R) = (93/20) + (93/20)^{0.5})^{0.5}$

$u(R) = +- 3\ (Rounded\ to\ 1\ sig\ fig)$

Uncertainty for Variance of Parameters:

Such values used in this equation were used through the pcov and popt values being estimated for the functions created to estimate the half life. However, sample calculations with popt and pcov values will be provided.

$U(c) = (K/(O^2))^{0.5}$

Let K be (pcov or variance)

Let O be popt(or prediction of half life in this case)

Sample:

K = 50

O = 20

$U(c) = (50/(20^2))^{0.5}$

$U(c) = +- 0.4(Rounded\ to\ 1\ sig\ fig)$

References:

"Radioactive Decay". Practical Physics 1, 14 October, 2023. University of Toronto, Toronto