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Nuclear Decay and Measuring Non-Linear Regression

Introduction:

This lab explores the nuclear decay of Barium (Ba-137m). The importance of this lab is to calculate the half-life of nuclear decay by measuring the intensity of radiation. We also explore curve fitting tools with non-linear (specifically exponential) models in Python, and apply them to find the half-life.

Method:

Materials:

1. Geiger counter
2. Barium (Ba-137m)

Experiment:

For this experiment, the Geiger counter is used to measure the Barium at 20 seconds/sample. For this lab we did not follow the experimental procedure, and instead were given the data from 2018.

Results:

Table 1:

Given Data: Background Radiation

Sample Number	Count Number
1	4
2	6
3	5
4	1
5	3
6	2
7	4
8	4
9	4
10	4
11	5
12	5

13	1
14	9
15	6
16	5
17	5
18	5
19	4
20	3
21	2
22	6
23	6
24	6
25	5
26	1
27	1
28	3
29	5
30	6
31	4
32	4
33	1
34	1
35	6
36	4
37	2
38	3
39	2
40	7
41	2
42	3
43	3
44	4
45	3
46	2
47	2
48	4
49	5
50	0

51	1
52	4
53	2
54	2
55	5
56	2
57	2
58	2
59	5
60	3

Table 2

Given Data: Measured Data

Sample Number	Count Number
1	2229
2	2065
3	1871
4	1767
5	1541
6	1451
7	1379
8	1230
9	1174
10	1101
11	946
12	858
13	840
14	722
15	652
16	652
17	544
18	503
19	504
20	486
21	410
22	385
23	346
24	328
25	242
26	285

27	253
28	226
29	190
30	155
31	163
32	158
33	136
34	129
35	122
36	103
37	91
38	109
39	75
40	70
41	60
42	84
43	70
44	64
45	42
46	43
47	47
48	40
49	42
50	32
51	27
52	40
53	17
54	27
55	30
56	26
57	18
58	16
59	18
60	18

Analysis:

The equations used in this lab are $I = I_0 * \frac{1}{2}^{\frac{t}{t_{1/2}}}$ (where I is the intensity of the radiation and t is time) to measure the radiation intensity. To measure the uncertainty of a logged value, I used $\sigma_z = \left|\frac{\sigma_y}{y}\right|$ (where y is the number being logged, σ_y is the uncertainty of y and σ_z is the uncertainty of the logged value), for the count rate $R = \frac{N}{\Delta t} \pm \frac{\sqrt{N}}{\Delta t}$ (where R is the count rate, N is the radiation measured and Δt is the change in time) .To calculate the total radiation we would use $N_S = N_T - N_B$ (Where N_T is the total radiation measured, N_B is the background radiation and N_S is the radiation of the compound measured) and to calculate the uncertainty of the radiation we used $\sigma_s = \sqrt{\sigma_T{}^2 + \sigma_B{}^2} = \sqrt{N_T + N_B}$ (where σ_S is the uncertainty of the measured radiation of the compound, σ_T is the uncertainty of the total measured radiation and σ_B is the background radiation). The reduced chi equation used was $\chi^2_{red} = \frac{1}{N-m}\sum_{i=1}^{N}(\frac{y_i - y(x_i)}{\sigma_i})^2$.

For the linear fit the calculated half life is 157.6 ± 2.7 seconds. The reduced chi squared is 729121. For the non-linear fit the half life calculated is 162.1 ± 1.7 seconds. The reduced chi squared is 354421.

Image One:

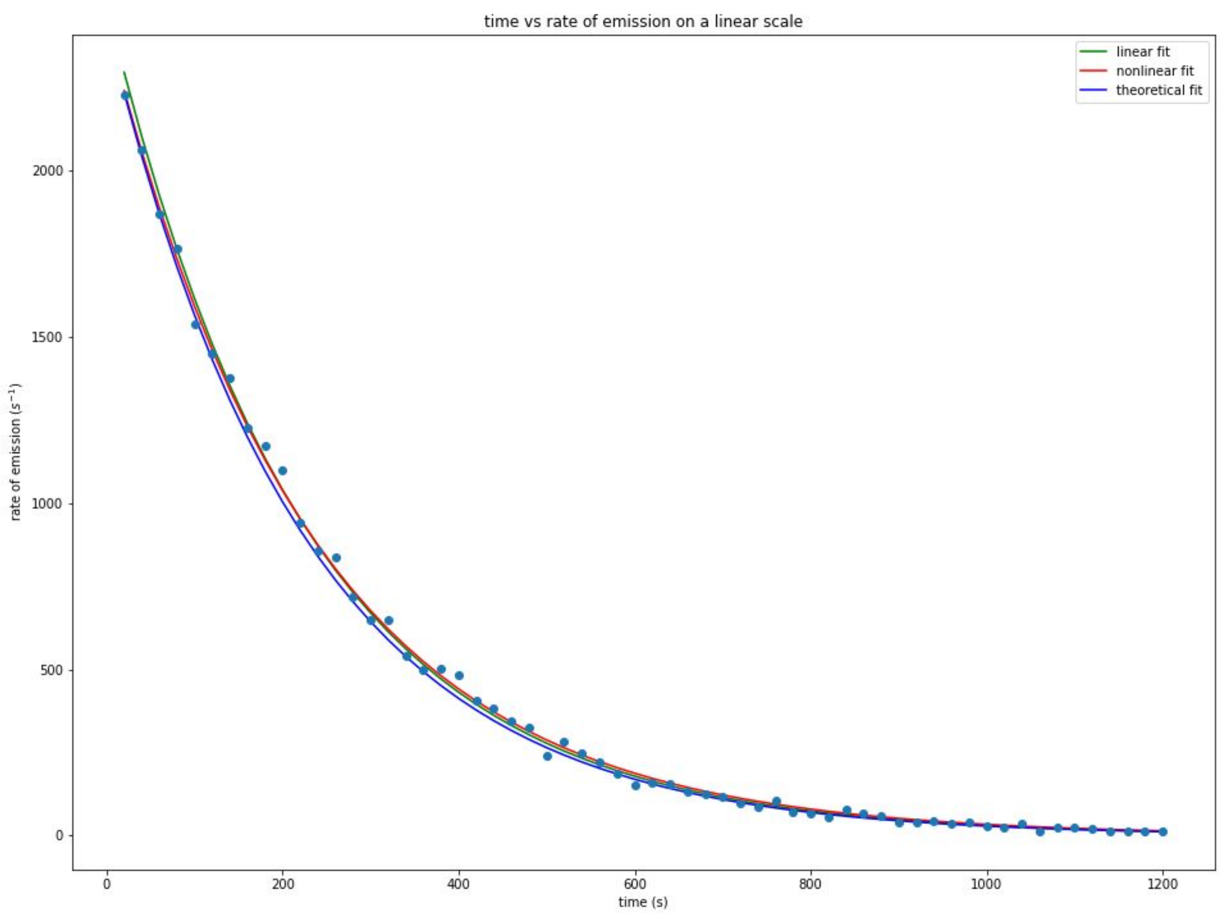
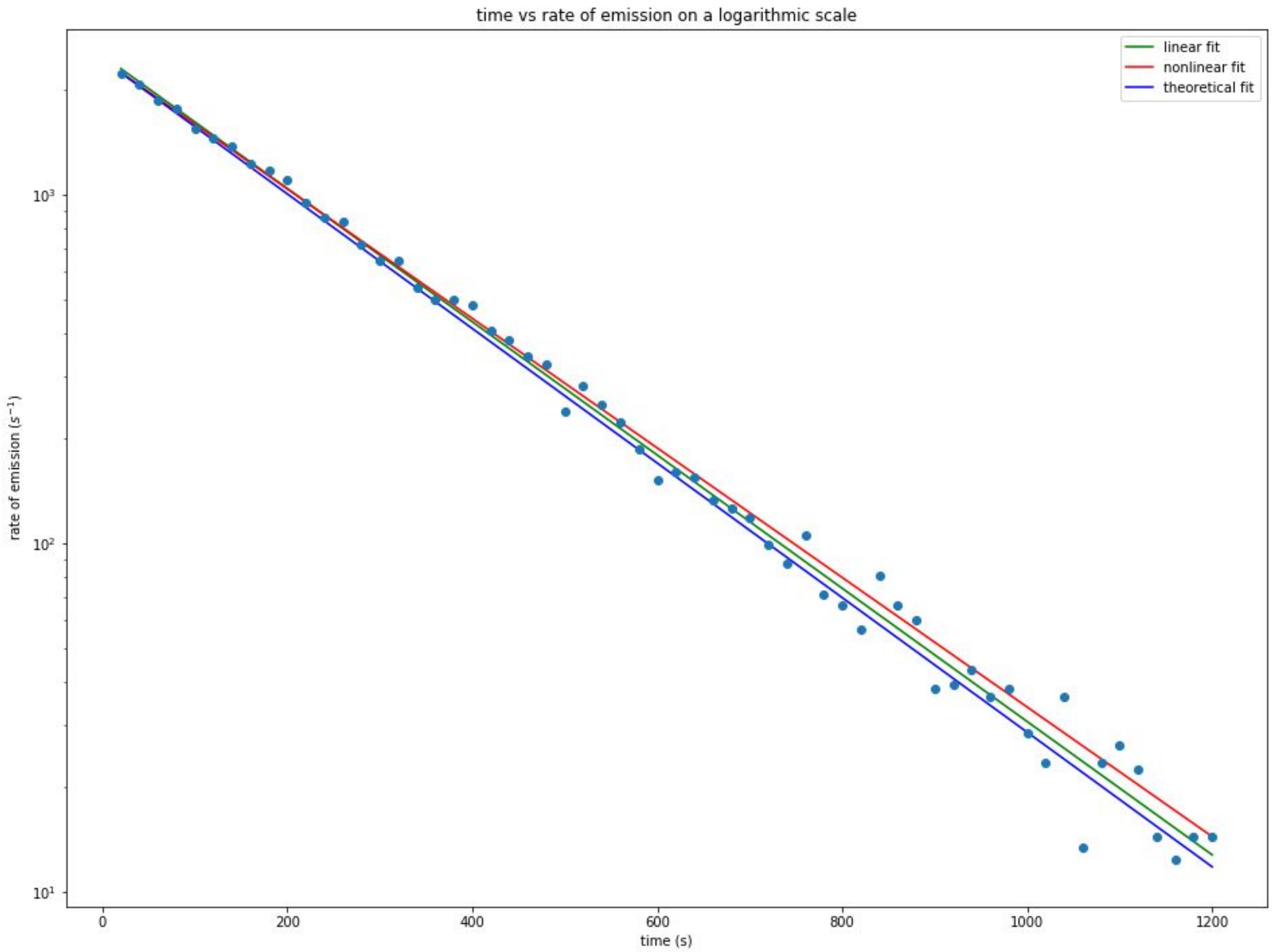


Image Two:



The half life calculated by the linear fit was closer to the expected half-life of 2.6 minutes (156 sec). The difference can be seen in the plots above. The nominal half-life does fall within the range of the linear fit, however not for the non-linear fit. The reduced chi squared value for both models is very large. This indicates that the model is a poor fit relative to the uncertainties, which were very small. Possible errors in calculating uncertainty can come from the barium being older, the measurements being taken over a small interval of time, and the background and total radiation being taken at different times. Other sources of errors can come from the environment, as it is not perfect and neither is the barium, so there are sources of errors coming from the non-perfect environment.

Conclusion:

The goal of this experiment was to calculate the half-life of nuclear decay of barium and look at the half-life in different scales. By measuring the total radiation and the background radiation, and then calculating the radiation of the barium over time, the decay becomes apparent. We then used Python to graph the relationship between the radiation and time. The difference between the theoretical, linear and nonlinear fits is noticeable. The linear fit, and the half-life calculated from it, is closer to the theoretical fit (and the reference value for half-life) than the non-linear fit is. However, due to various sources of uncertainty, neither model is perfect.