Radioactive Decay Lab

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1 Results and Analysis

1.1 Part 1 Data

Table 1: Radiation counts emitted by a Caesium-Barium sample measured by a Geiger counter every 20 seconds over the course of 20 minutes.

Sample Number	Number of Counts	Sample Number	Number of Counts
1	191	31	22
2	188	32	13
3	181	33	16
4	162	34	8
5	147	35	7
6	139	36	9
7	142	37	10
8	117	38	15
9	110	39	9
10	106	40	14
11	86	41	7
12	77	42	8
13	92	43	3
14	77	44	11
15	67	45	8
16	56	46	8
17	53	47	6
18	44	48	5
19	41	49	3
20	41	50	10
21	40	51	6
22	27	52	3
23	24	53	3
24	32	54	4
25	30	55	3
26	23	56	2
27	19	57	5
28	21	58	4
29	15	59	6
30	23	60	6

Table 2: Background radiation measured by a Geiger counter every 20 seconds over the course of 20 minutes.

Sample Number	Number of Counts	Sample Number	Number of Counts
1	2	31	3
2	2	32	1
3	3	33	5
4	7	34	3
5	1	35	2
6	1	36	3
7	2	37	7
8	2	38	3
9	5	39	4
10	3	40	1
11	2	41	9
12	4	42	4
13	1	43	2
14	4	44	0
15	3	45	5
16	3	46	4
17	4	47	8
18	4	48	3
19	4	49	1
20	3	50	5
21	7	51	5
22	2	52	2
23	4	53	1
24	3	54	5
25	1	55	2
26	5	56	3
27	3	57	7
28	6	58	3
29	4	59	4
30	4	60	5

The mean background radiation is $\mu = 3.48 \approx 3$. Then by subtracting these values from the counts, we plot the data along with the curve-fit for parameters found by linearlized data and parameters found by non-linear fit.

The uncertainty in the counts is found by,
$u(Counts) = \sqrt{(191/20 + background)}$
$u(Counts) = \sqrt{(9.55 + 3.48/20)}$
$u(Counts) = 3.12 \approx 3$ counts

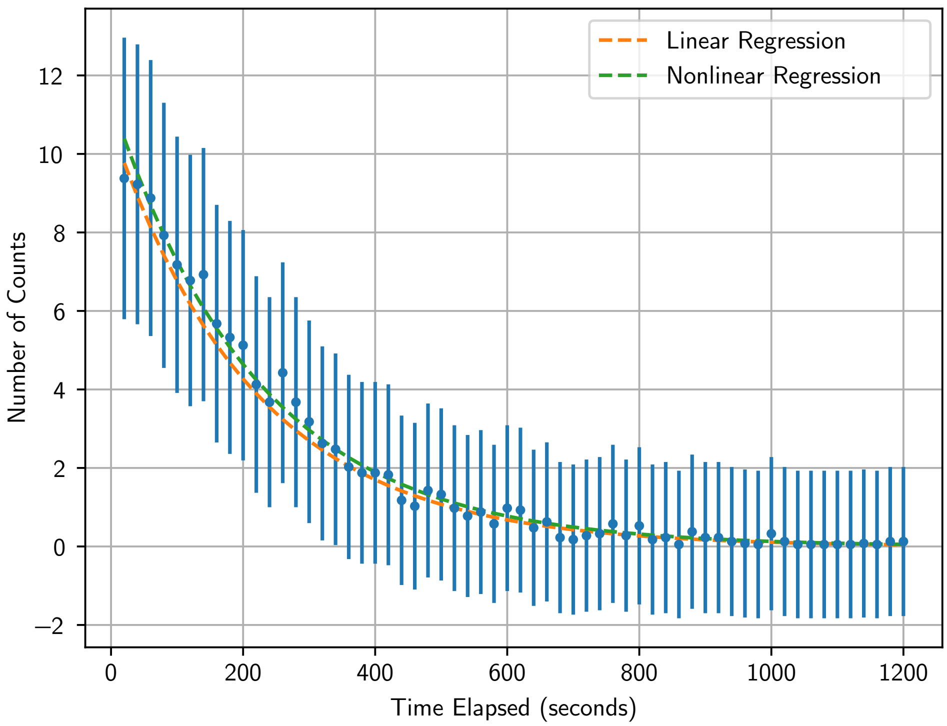

Figure 1: Curve of Best Fit of Decay of Barium-137 Figure created with `matplotlib`.

Line of best fit from linearized parameters is,

$$-0.0046x + 2.3717$$

Which gives a half-life of,

$$t_{1/2} = \frac{ln 0.5}{-0.0046} = 150.6 \text{ s}$$

$$u(t_{1/2}) = \sqrt{\frac{u(a)}{a^2}}$$

$$= \sqrt{\frac{0.0008}{(-0.0046)^2}} = 6.5 \text{ s}$$

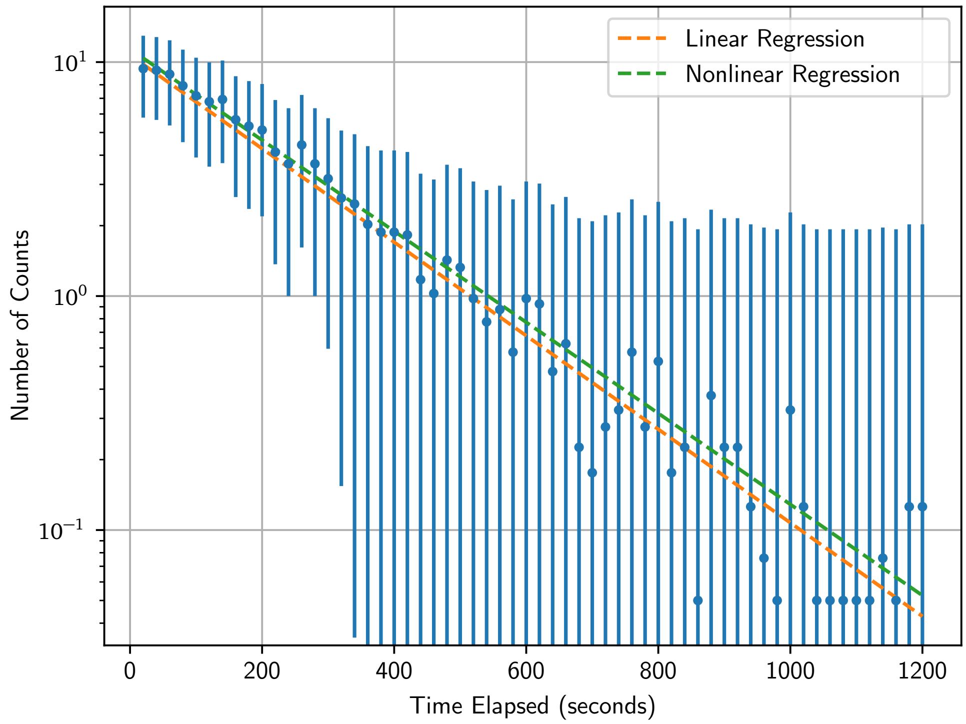

Figure 2: Curve of Best Fit of Decay of Barium-Caesium in accordance with a Log scale. Figure created with `matplotlib`.

1.2 Part 1 Analysis

Using linear regression, we found a best fit line of $-0.0046x + 2.3717$, which was plotted to the graph in log form. This correlates to a half-life of 150.6 seconds and an error of 6.5 seconds. This is around 2 minutes and 30 seconds, or 2.51 minutes. With the error bounds, the literature value does lie within the range.

Using non-linear regression, we found a best fit line of $11.3665x^{-0.004}$, which correlates to a half-life of 154.7 seconds with an error of 6.7 seconds. This is around 2 minutes and 35 seconds, or 2.58 minutes. With the error bounds, the literature value does lie within the range. The non-linear regression gave a half-life closer to the expected literature value of 2.6 minutes.

It appears that the linear regression was consistently returning higher y-values than the non-linear regression. In addition, when the log scale was plotted to make the curves linear, it was seen that the plots of data-points in the log scaled graph seem to 'scatter' after an amount of time. This is because on the log scale, small differences at small values seem larger.

Our χ^2_{red} values were 0.01082 and 0.05257, respectively. These are very small measurements, which could suggest an over-fit or a lack of samples.

1.3 Part 2 Data

As the collected data set is too large ($\approx$ 400 samples) below we give the processed data of number of counts in and its frequency.

Table 3: Radiation counts emitted by a Fiesta Plate, measured every 3 seconds for 20 minutes, and the frequency of counts

Count in 3 Seconds	**Number of Counts**	**Count in 3 Seconds**	**Number of Counts**
22	1	40	21
23	1	41	21
24	1	42	17
25	2	43	21
26	2	44	26
27	2	45	23
28	2	46	20
29	7	47	12
30	4	48	10
31	6	49	3
32	15	50	7
33	11	51	8
34	21	52	3
35	25	53	3
36	24	55	1
37	21	56	1
38	31	59	1
39	26	-	-

However, given the open experiment setup, we know that background radiation has an impact on this data-set. Thus, to account for this in some manner, we subtract from each count in 3 seconds, the average background radiation in 3 seconds. From the background radiation data, we know that the mean value is ≈ 3. Subtracting the mean background radiation off the data, we plot the following normalized histogram.

Although not plotted in the histogram, the uncertainty in the counts is,
$u(Counts) = \sqrt{(22/3 + background)}$
$u(Counts) = \sqrt{(7.33 + 3/20)}$
$u(Counts) = 2.7355 \approx 3$ counts

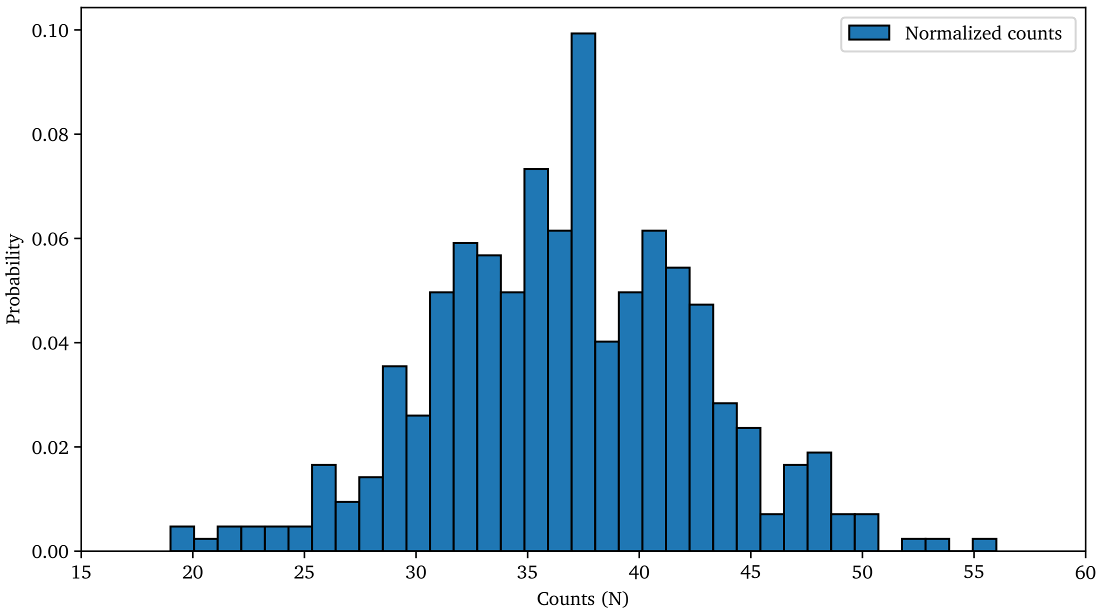

Figure 3: Normalized histogram of radiation counts without mean background radiation, every 3 seconds for 20 minutes. Figure created with `matplotlib`.

Next we plot the Poisson and Gaussian probability mass function (PMF) using μ to be the average count value, $\mu \approx 37$ and the standard deviation to be $\sigma = \sqrt{\mu} \approx 6.1$.

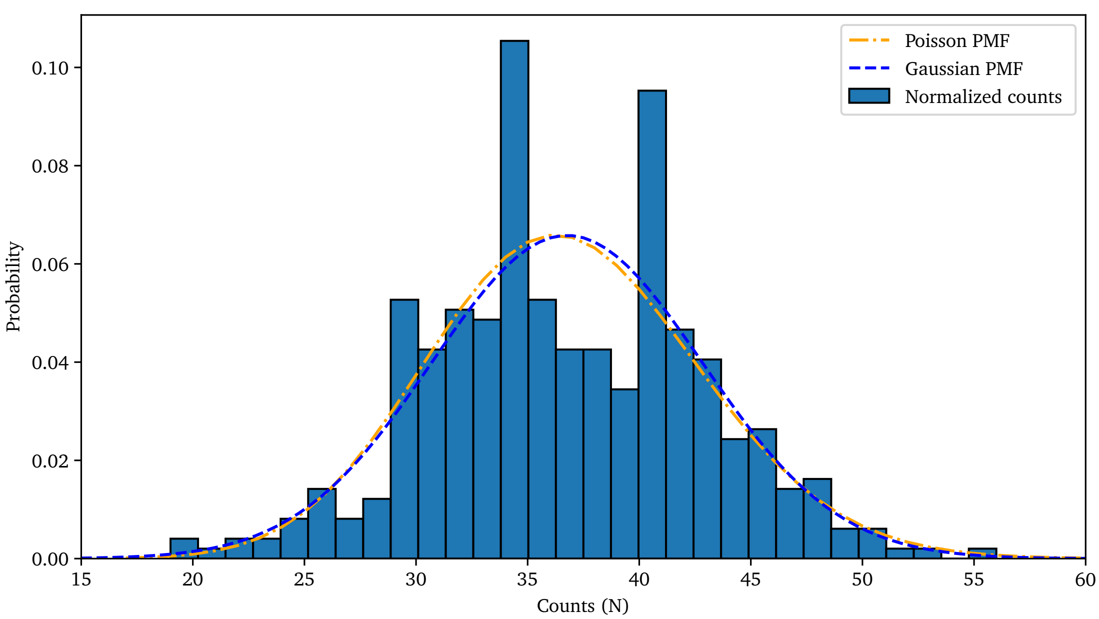

Figure 4: Normalized histogram of radiation counts without mean background radiation, and a Poisson and Gaussian PMF. Figure created with `matplotlib` and PMF from `scipy.stats`.

The x scale was picked such that the Gaussian curve stretched 4σ on either side of the mean, as this contains $\approx$ 99.994% of the total probability. However, since this is a discrete sample, 4σ is large enough to fit all the data.

Notice that the Poisson PMF and Gaussian PMF are almost identical but vary slightly. From Central Limit Theorem, we know that as number of events $\to \infty$ then Poisson and Gaussian PMF approach each other. However, since we only have 400 data points, this slight difference is expected. We also notice that the Poisson PMF is "behind" the Gaussian (which acts as the theoretical fit). This happens since the frequency of getting about 34 counts was much higher than expected, which impacts the Poisson PMF.

1.4 Analysis on Background Radiation Data

Carrying out a similar analysis on just the background radiation data, we get the following histogram plotted with Poisson and Gaussian PMF. This data-set was sampled every 20 seconds for 20 minutes.

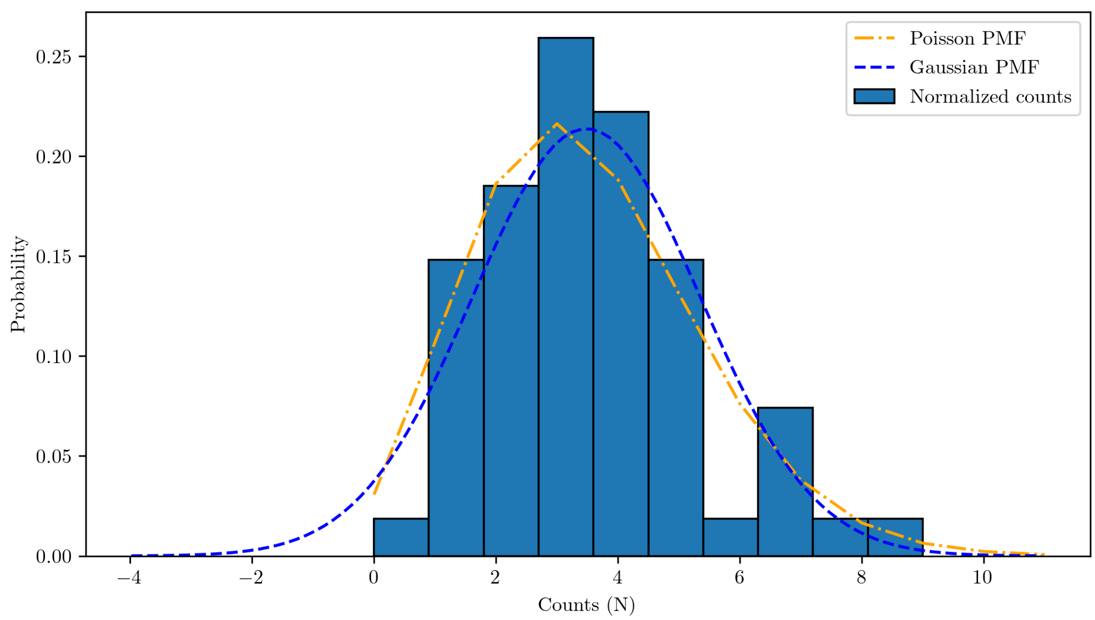

Figure 5: Normalized histogram of background radiation counts and a Poisson and Gaussian PMF. Figure created with `matplotlib` and PMF from `scipy.stats`.

Here we used $\mu \approx 3.5$ and $\sigma \approx 1.9$. Similar to the Fiesta data, notice that the Poisson PMF is "behind" the Gaussian, but with a larger difference. This is due to the fact that we have fewer data points in the background data-set ($\approx$ 100).

2 Conclusion

In this experiment, we performed two measurements, one for the decay of Barium-137 and another for the radiation measurement for a Fiesta plate. To ensure that background radiation was taken into account, we measured background radiation for 20 minutes at 20 seconds intervals and subtracted the mean background radiation from every data-point.

Analysing the data from the first experiment we found that the half-life of Barium-137 was 2.51 minutes (using linear curve-fit on linearized data) and 2.58 minutes (using non-linear curve-fit), with an uncertainty of 7 seconds in both values. The theoretical half-life of Barium-137 is 2.6 minutes, which landed within our uncertainty ranges.

In the second experiment, after subtracting off the background counts, we plotted the radiation counts of the plate and found that it fit the Poisson PMF very accurately, and only slightly deviating from the theoretical Gaussian curve. Performing the same analysis on the background radiation, we found that the Poisson PMF deviated significantly more from the Gaussian curve, however this was expected given the few data-points we had.

From the curves, we can tell that the mean count for the plate is $\mu = 37$ with a standard deviation of $\sigma = 6.1$. And similarly from the background radiation curve, we can approximate the mean to be $\mu = 3.5$ with a standard deviation of $\sigma = 1.9$.