Stochastic Nature of Radioactivity

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Abstract

The stochastic nature of radiation an experiment in which we measured the radiation put off by the beta decay of cesium. A stochastic process is a process that is non-deterministic or random. We measured the radiation output of the sample in micro rads per second. The data was taken in ten second intervals and a RM-60 Geiger tube that was connected to the computer recorded the average ionization energy. We used a program called *Aw-Radw* to record the data. We discovered that the amount of radiation detected by the detector varied by the spatial orientation of the sample. When the side if the sample with the radiation symbol was facing the detector, there was a higher ionization energy recorded than when the radiation symbol was facing away from the detector.

Introduction

In classical physics, experiments are deterministic, for example, if you drop a ball off a table, we know that it will drop towards the ground, accelerating at 9.8 m/s by gravity. However, the emission of radiation from an atom, is a stochastic process and non-deterministic. In reference the previous example of ball being dropped off a table, in a non-deterministic system, the ball would float, stay suspended in midair, or drop.

We will use two different forms of distributions the Poisson distribution and the Gaussian distribution. The Poisson distribution is used to compare relatively few events when compared to the number used in the Gaussian distribution. In addition, the Poisson distribution requires several observations while the Gaussian distribution only requires one observation.

In performing this experiment, we measured the beta (β) decay of cesium. Beta decay occurs when a neutron in an atom's nucleus breaks apart into a proton and an electron that is ejected from the atom. The decay can be expressed by the equation

$$^{137}_{55}Cs \rightarrow ^{137}_{56}Ba + \beta^{-}. \tag{1}$$

In performing the Poisson distribution, we used the equation

$$f(k,\lambda) = \frac{e^{-\lambda} \cdot \lambda^{n}}{n!}, \tag{2}$$

where λ is the expected number of occurrences that occur during the given interval and n is number of occurrences. In performing the Gaussian distribution, we used the equation,

$$P(x) = \frac{1}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\frac{(x-\mu)^2}{(2 \cdot \sigma^2)}}. \tag{3}$$

The chi-squared (χ^2) test is given by,

$$\chi^2 = \sum \left[\frac{(O-E)^2}{E} \right], \tag{4}$$

where O is the observed value and E is the expected value. The confidence of the χ^2 test can be determined by if the χ^2 values are above a certain level, which is given by,

$$\chi^2 \geq 1.645 \cdot \sqrt{2 \cdot (k-1)} + k - 1, \tag{5}$$

where k is number of categories that are measured.

Experimental Procedures

In performing this experiment, we used a RM-60 Geiger tube that was connected to a computer to measure the radioactive cesium source. We used the program *Aw-Radw* to record the radiation output. *Aw-Radw* outputs the data into a text file that includes the time and ionization energy. *Aw-Radw* also outputs to the computer screen the ionization energy and the number of counts, the average number of radioactive particles detected by the RM-60 Geiger tube. In order to convert the ionization energy into the number of counts, a linear regression was performed on the data outputted to the screen. In doing this, one can find that the number of counts is related to the ionization energy by the equation,

$$Counts = 0.174994 \cdot I_E + 0.00238. \quad (6)$$

Figure 1 shows experimental set up used in performing this experiment.

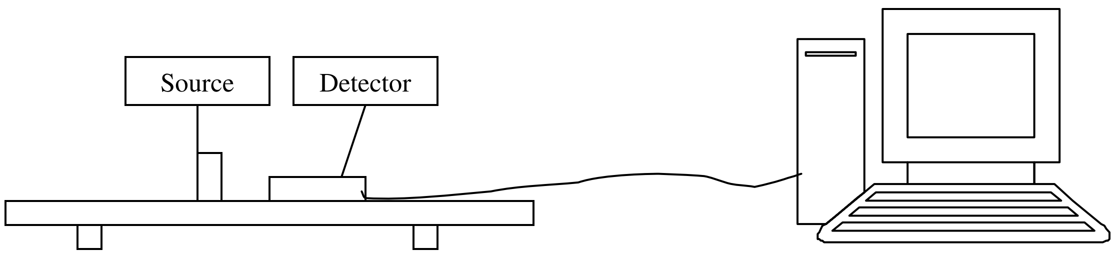


Fig. 1. Experimental setup

On our first attempt in gathering data, we failed to align the cesium source properly with the detector. Upon the discovery of this, we re took our data. In the first part of this experiment, we took a set of 400 data points with an average count value between eight and ten. We found that this occurred when the source was 9.6±0.1cm from the detector. A Poisson distribution was performed on this data and found that data matched the Poisson distribution rather well. Figure 2 shows the distribution of the Poisson distribution for all 400 data points. Figure 3 shows the distribution for the first 50 data points. Figure 4 shows the distribution for the first 100 data points and Figure 5 shows the distribution for the first 200 data points.

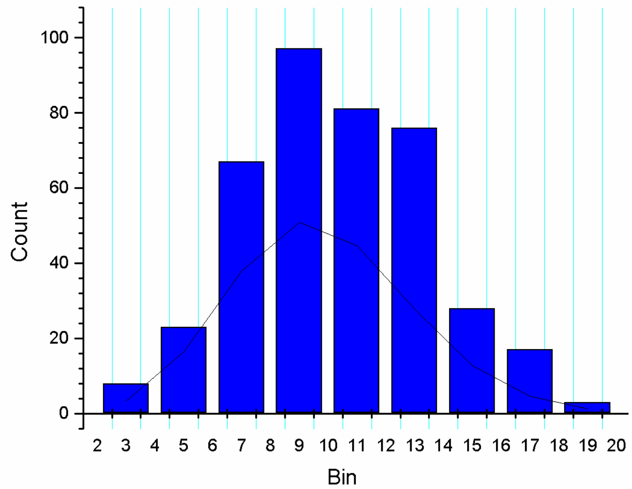
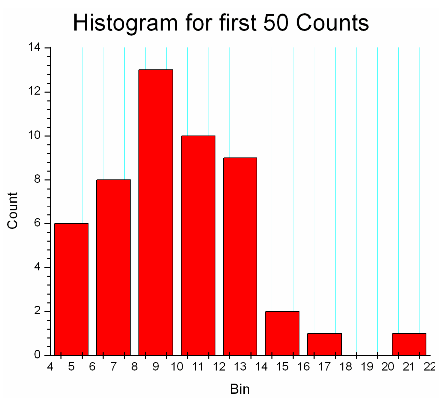
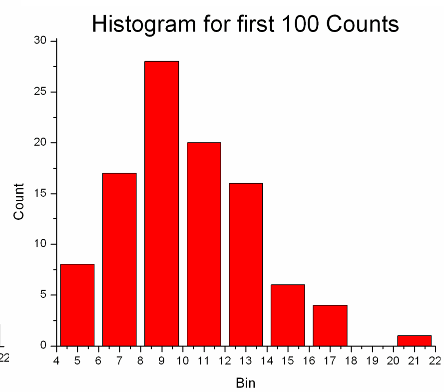


Fig. 2. Poisson distribution for all 400 data points





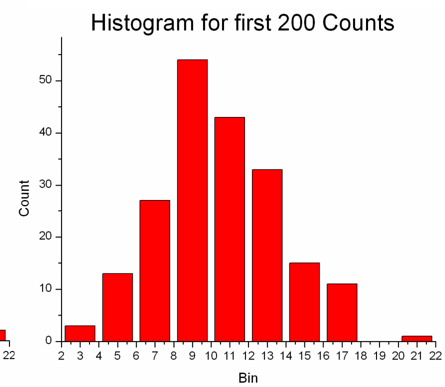


Fig. 3. First 50 counts

Fig. 4. First 100 counts

Fig. 5. First 200 counts

We then calculated the chi-squared (χ^2) value for the 400 data points. The χ^2 value for the number of counts is 426.314. These graphs and the χ^2 value show that the amount of radiation emitted by the sample is random and stochastic because the distribution fits the Poisson distribution well. The level of confidence in this χ^2 value is 15.98, therefore our assumption that the data is governed by a non-random process.

The next part of the experiment was to measure the amount of radiation given off by the cesium sample when the distance sample was from the detector varied. We moved the source from a distance of 0 mm to 20 mm in 2 mm increments. We recorded approximately ten observations at each location and took the average number of counts at each location. We then graphed this and discovered that the closer the source was to the detector, the more radiation was detected. Table 1 shows the data for the average number of counts and the distance from the detector.

Distance	Avg. Counts
0	946
2	854
4	627
6	463
8	357
10	274
12	219
14	177
16	144
18	119
20	107

Table 1. Distance and radioactive intensity data

It appears that the amount of radiation decreases exponentially as distance increases. However, the best fit of the data is a second order polynomial. I theorize that this is so because radiation follows an inverse square law that is the amount of radiation given off a distance *r* and has intensity *I*, the intensity at a distance 2*r* is *I*/4 and the intensity at a distance 3*r* is *I*/9. Therefore, the best fit of the data is a second order polynomial. Figure 6 shows the graph of the number of counts versus the distance from the counter.

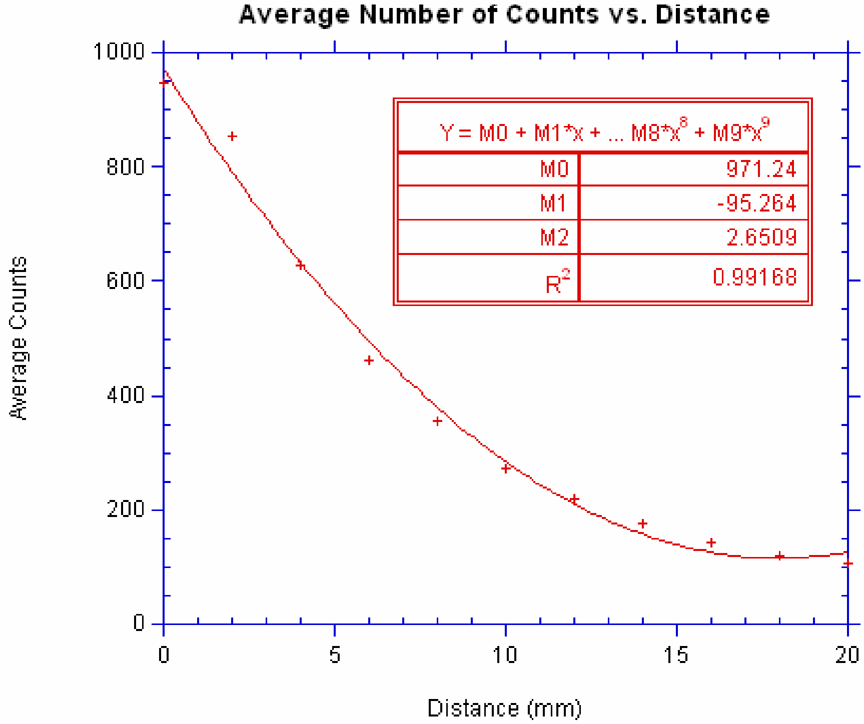


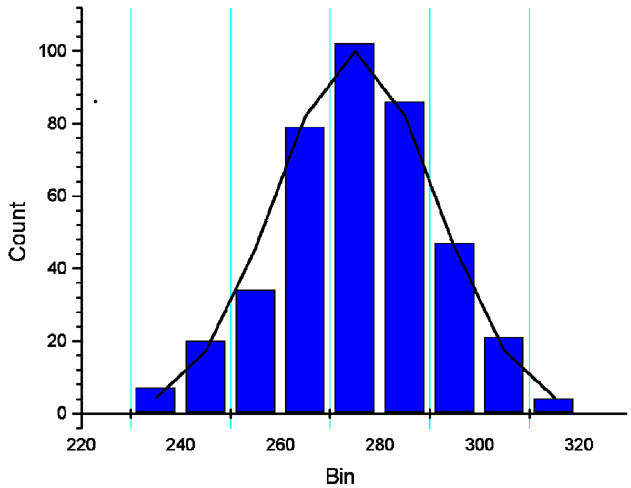
Fig. 6. Average counts vs. distance

For the next part of the experiment, the apparatus was adjusted so that it recorded approximately 300 counts per ten-second interval. The apparatus was left running overnight to gather 4000 data points. This chunk of 4000 data points was then broken into 10 sets of 400 data points and performed a Gaussian distribution on each set. Then the mean and standard deviation of each data set was found. Table 2 contains the data for the mean and standard deviation of each set. Figure 7 shows the distributions for each of the ten sets of data

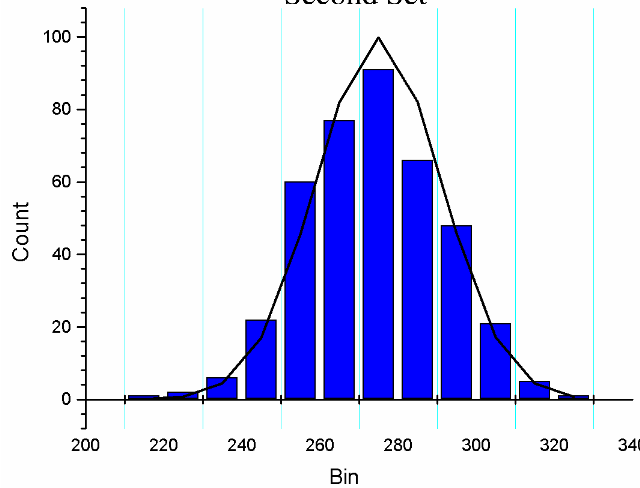
	mean	StDev
Data Set 1	275.046	15.9784
Data Set 2	273.359	17.406
Data Set 3	275.284	16.3212
Data Set 4	273.539	16.2738
Data Set 5	272.381	16.8832
Data Set 6	273.781	16.6606
Data Set 7	274.056	17.0682
Data Set 8	273.784	17.5777
Data Set 9	273.719	16.7576
Data Set 10	273.415	17.4422

Table 2. Mean and Standard Deviation for the 10 data sets

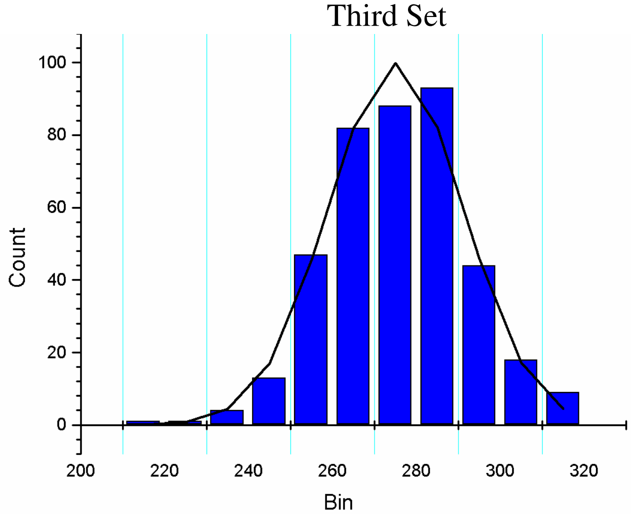
First Set



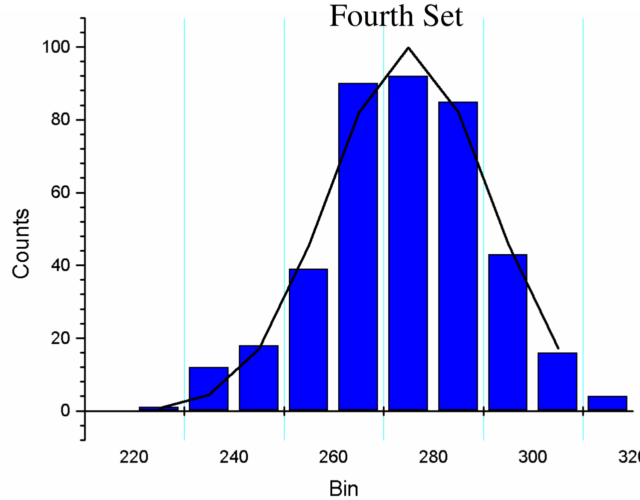
Second Set



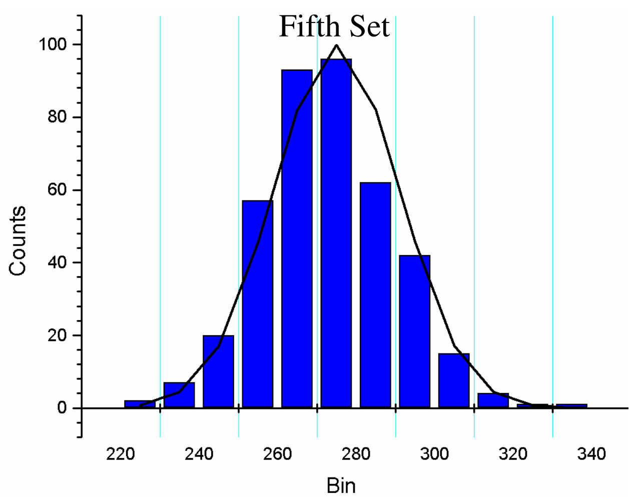
Third Set



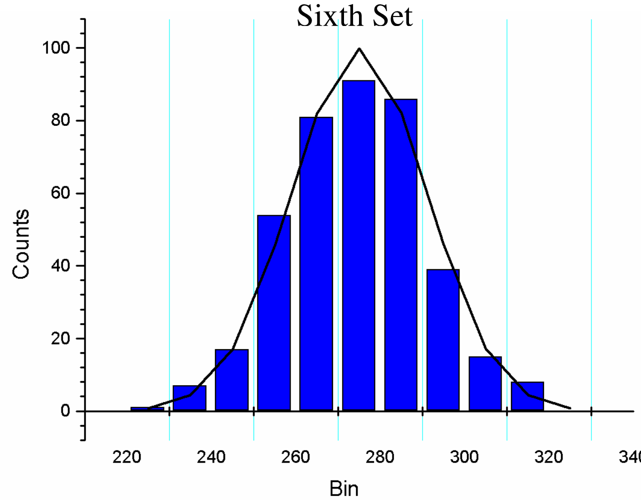
Fourth Set



Fifth Set



Sixth Set



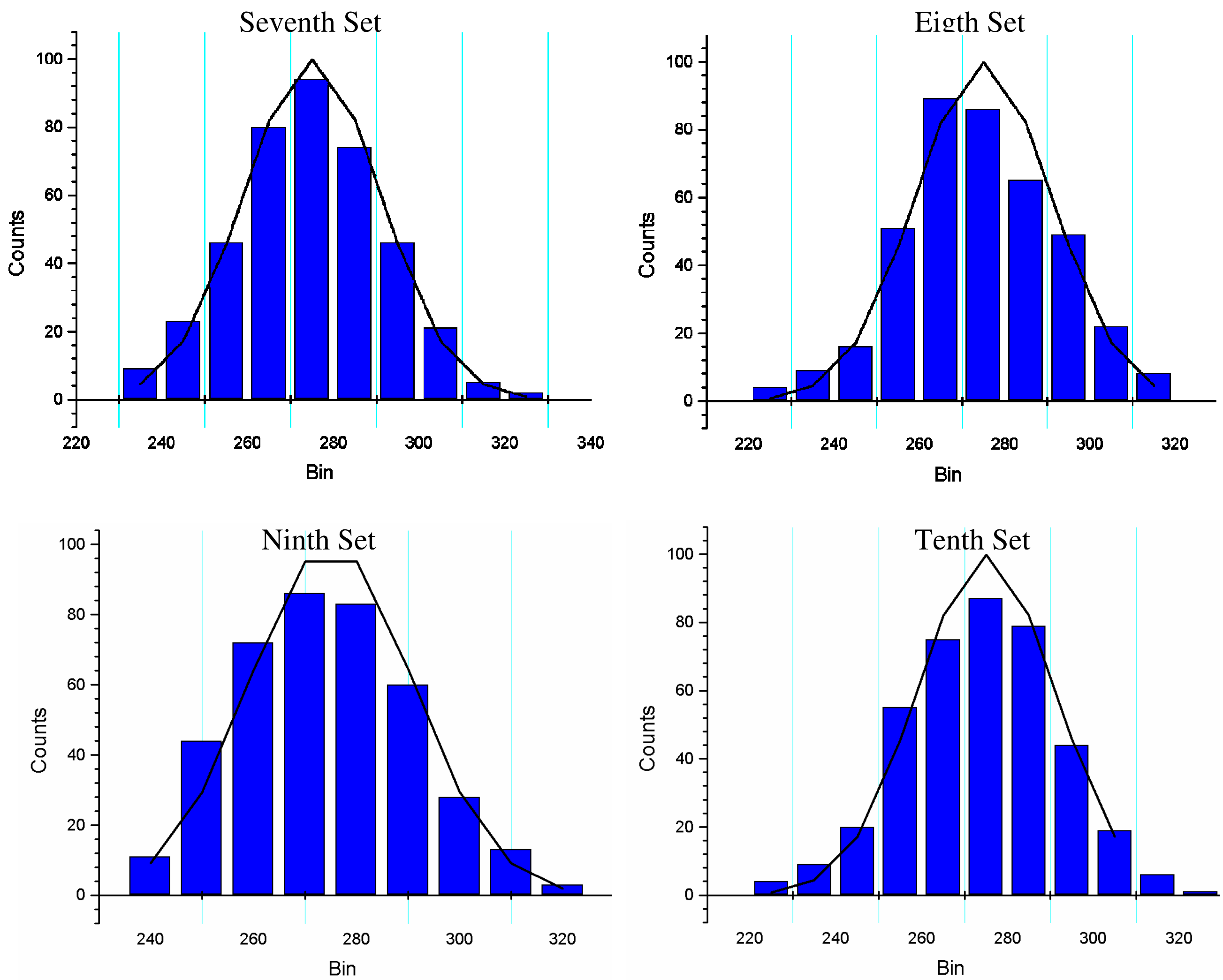


Fig. 7. 10 data sets for the Gaussian distribution

I was curious to know what would happen if I complied all of those ten data sets together into one set. I noticed that the Gaussian distribution becomes more pronounced and the estimated Gaussian fit follows the data closer than in the individual sets. Figure 8 shows the graph of all 4000 data points in the distribution.

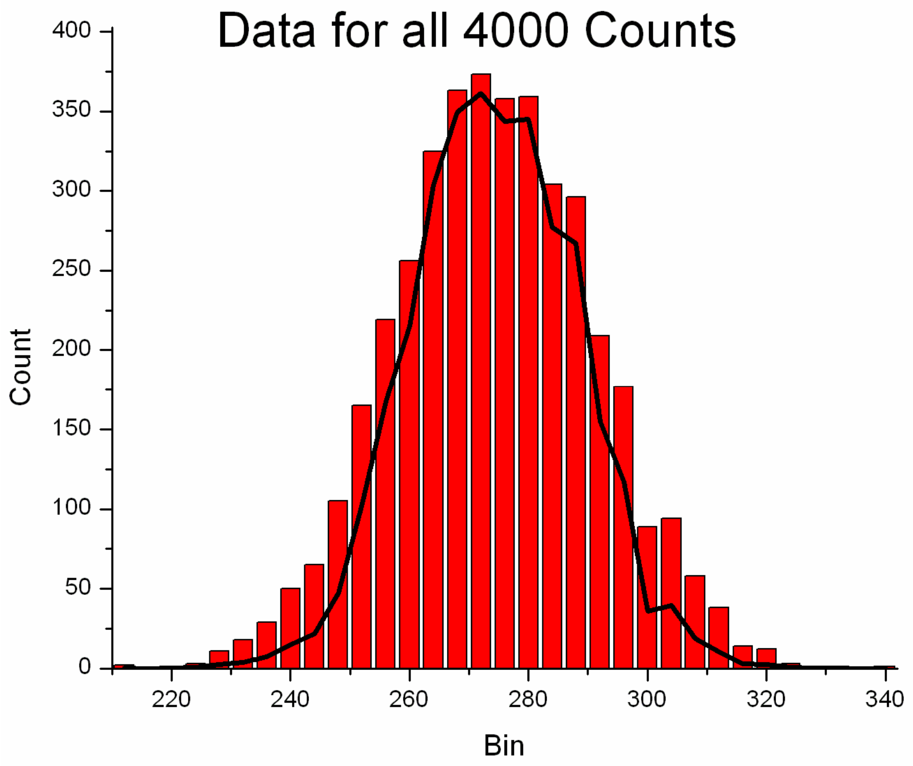


Fig. 8. Distribution for all 4000 counts

The calculated χ^2 values for each of the 10 data sets as well as for all 4000 data points.

Table 3 shows the χ^2 for each of data sets as well the whole.

First	370.3690073
Second	442.2198613
Third	386.0952681
Forth	386.3087216
Fifth	418.201702
Sixth	404.528136
Seventh	424.138950
Eighth	450.2851554
Ninth	409.3498499
Tenth	129.810472
All	4143.045574

Table 3. χ^2 values for the different data sets

The level of confidence in the χ^2 for all ten sets of data is between 32.9 and 40.3, which all the χ^2 are greater than. These χ^2 values show us that the distribution of the data is random and the values of the number of counts per interval are random and stochastic.

In another portion of the experiment, the amount of radiation was detected when the source was relatively far away. The radiation source was placed 72.24±0.01cm from the detector. There was radiation detected by the detector, but it was very low compared the previous recorded values. The average value for the radiation detected was five counts per ten-second interval. I believe that this background radiation can be ignored, because the radioactive source is still relatively close to the detector when compared to the distance between the earth and the sun. In addition, prior to performing the experiment, a standard Geiger counter was used to measure the radiation and room. A click was noticed approximately every 30 to 60 seconds. I believe that that reading is a better indication of the background radiation noise than in having a radioactive source relatively close to the detector.

In this experiment, the null hypothesis is that the nature of radiation can be explained and modeled by a classical process or by a simple equation. However, upon examination of the data and analyzing the distributions, one can assume that this hypothesis to be in error. The data itself shows that the amount of radiation that is emitted in a given interval cannot be modeled by an equation. In fact, after examining the distributions and the histograms, it appears that the best method in modeling the emission of radiation is in fact a random number generator. A random number generator is more precisely called a pseudorandom number generator, because it cannot be truly random, but it is random enough to serve our purposes. The random number generator uses and algorithm to pick a number between zero and one.

Most errors in this experiment are due to fact that the data itself is random and cannot be considered a source of error. Initially we failed to align the source and detector properly and we got faulty data. We corrected for this by properly aligning the source and the detector and our data was much better.

Conclusion

In this experiment, it was discovered that the emission of radiation from a radioactive source is a random process. It was also shown that the emission of radiation can be modeled using the Poisson and Gaussian distributions. The stochastic nature of radiation can be clearly seen upon the analysis of the available data. This experiment could have been improved by an introduction to statistics given in a lecture. Overall, this experiment was an interesting example of how to perform an experiment involving a stochastic process.