Example Data and Analysis for Geiger Counter Lab

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Abstract

In this document, we exhibit and explain the data and analysis expected of a student to complete the Geiger Counter, Counting Statistics, and Artificial Radioactivity Lab. Analyses accessible directly from the new GC Analysis software include Poisson- and Gaussian-regime measurements and histograms, as well as interval histograms. With minimal additional effort, students can calculate the dead time of the Geiger counter and the lifetimes of the artificial radioactivity sample. With the assistance of a tool such as Python/SciPy/MatPlotLib or Matlab, students can perform fits to their data and superimpose exact Poisson or Gaussian curves onto their graphs. We recommend that students use the Python suite because it integrates more cleanly with GC Analysis.

1 Introduction

There are a few goals for the Geiger Counter lab:

- measure the count rate distributions for high-rate and low-rate sources and thereby distinguish from Gaussian and Poisson statistics
- differentiate between the time interval distributions for high-rate and low-rate sources
- measure the dead time of the Geiger counter
- measure the lifetimes of the two artificial isotopes of ^{116}In.

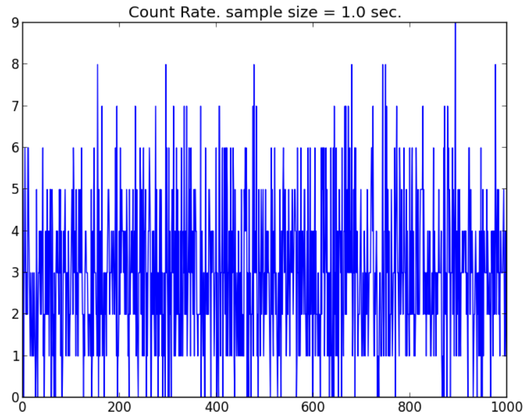
Almost all of this analysis is achievable using the GC Analysis software with minimal use of an external analysis tool such as Python or Mathematica.

2 Count Rate Distributions

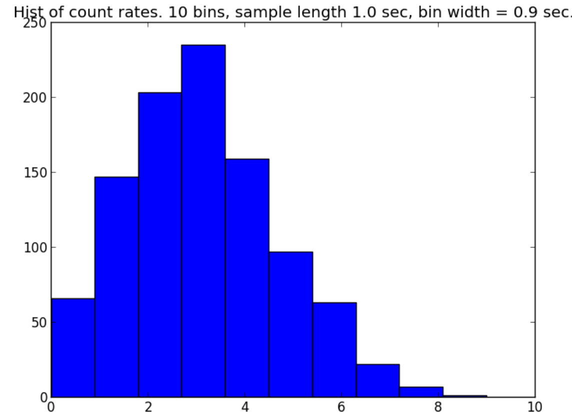
Students should be able to generate histograms and count rate vs. time plots for various samples. Figure 1 shows the count rate as a function of time and the corresponding histogram for a low-count-rate sample with an average count rate of 3.1 Hz calculated by total counts divided by total time over a 16 min data sample. Figure 2 shows similar plots for a high-count-rate sample with an average count rate of 67.75 Hz.

3 Time Interval Distributions

There is explicit functionality for plotting the distribution of time intervals between consecutive counts. Figure 3 displays histograms of time intervals for low-count-rate and high-count-rate sources. They are both supposed to be exponential decays, although it is evident that the low-count-rate source did not exactly adhere to this distribution in the near-zero region. Nonetheless, the general shape of an exponential holds for both.

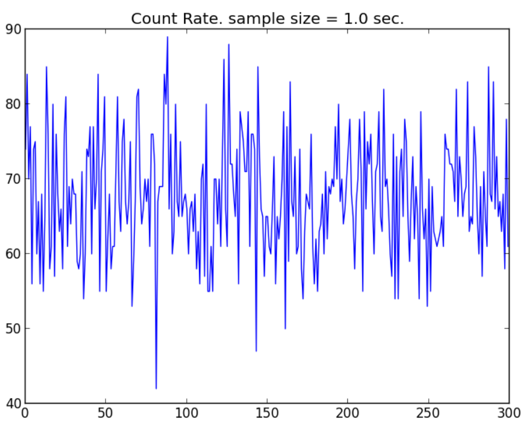


(a) Count rate vs. time curve

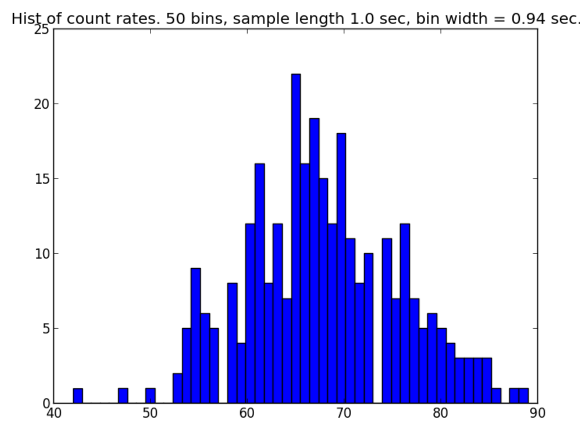


(b) Corresponding histogram showing a Poisson distribution with a mean of 3 Hz

Figure 1: Poisson statistics

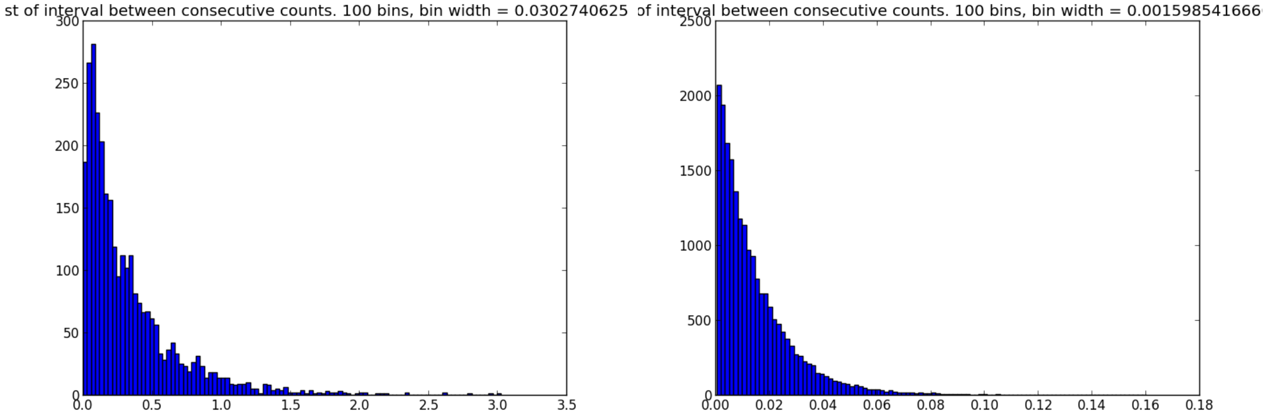


(a) Count rate vs. time curve



(b) Corresponding histogram showing a Gaussian distribution with a peak/mean of $\sim 65\,\mathrm{Hz}$

Figure 2: Gaussian statistics



(a) Low count rate sample (Poisson-style)

(b) High count rate sample (Gaussian-style)

Figure 3: Time interval distributions for Poisson and Gaussian-level statistics

4 Dead Time Measurement

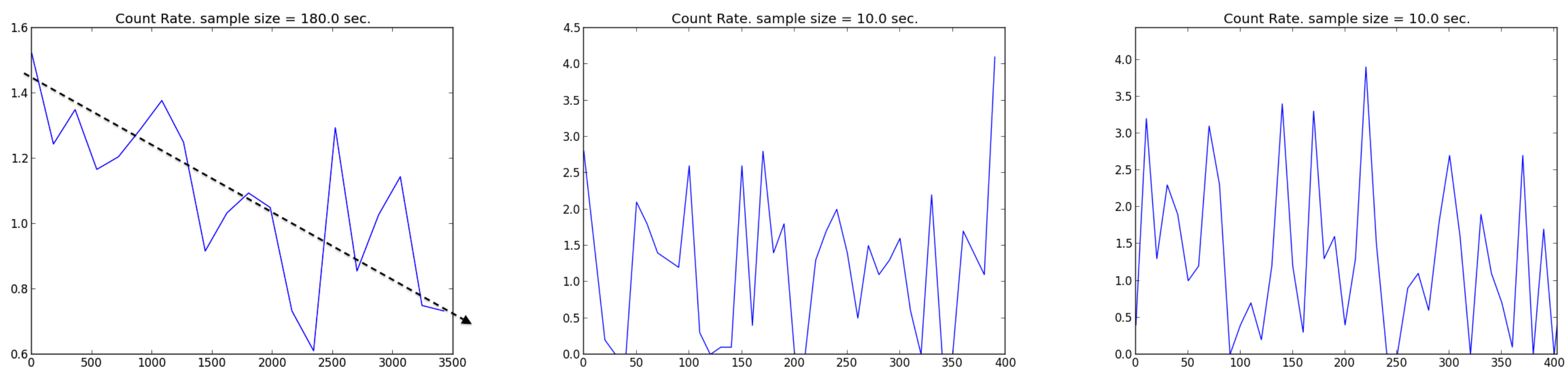
The dead time is easily recovered via Rainwater and Wu's formula of $\tau = \frac{n_1+n_2-n_{12}}{2n_1n_2}$, where n_1 and n_2 are the background-subtracted count rates of two separate sources and n_{12} is the background-subtracted count rate of the two sources combined. (Note: we measured a background rate of 0 over the course of 10 min.) The error is given as $\sigma = \frac{1}{n_1n_2}\left(\frac{n_{12}}{2T}\right)^{1/2}$, where T is the duration of the time sample. In one measurement we took, $T = 300\,\mathrm{s}$, $n_1 = 15.513\,\mathrm{Hz}, n_2 = 51.66\,\mathrm{Hz}, n_{12} = 67.747\,\mathrm{Hz}$, and $\tau = -2.95 \times 10^{-4}\,\mathrm{s}$, which we realize is a negative number. Indeed, $n_1 + n_2 - n_{12} = -0.473\,\mathrm{Hz}$, so it seems that by a slim margin, we had more counts than we would expect to have on average when we measured both samples together. The error on our measurement is $\sigma = 4.19 \times 10^{-4}\,\mathrm{s}$, meaning that our measurement is still within one standard deviation of being positive (and hence at least statistically speaking it is reasonable). Presumably, with larger T and higher count rates, students will be able to measure the dead time more accurately.

5 Artificial Radioactivity

The two lifetimes of irradiated ^{116}In can be calculated by comparing the initial count rate with the count rate after 1 min; and the rate after 5 min with the rate after 1 hr. Figure 4 shows the average count rate as a function of time for the long and short half-lives. The long half-life measurement seems to be successful since the count rate dropped by about half over the course of an hour, as expected. The short half-life measurement was not successful–it looks just like the zoomed-in long half life plot, probably because we were unable to start taking data right after removing the sample from the irradiation chamber. By the time we started taking data, the short half-life was probably mostly decayed. It is also important to note that the count rates are significantly reduced for their expected values, based on experimental limitations related to the geometry of the Geiger counter. However, we still received an expected signal for the longer half-life sample, so we may conclude that it was not a major source of error.

6 Conclusion

With this analysis, we have completed the goals of this lab. Furthermore, we have demonstrated that our the GC Analysis software package is both accurate and effective. While the experiment could still use some improvement, such as a new Geiger tube that has better geometry for the artificial radioactivity section, it now appears to be in a suitable state for students to use for the course.



(a) The long half-life: from $\sim 1.45\,\text{Hz}$ to $\sim 0.75\,\text{Hz}$ in $1\,\text{hr}$

(b) The short half-life

(c) A zoomed-in version of the long half life curve

Figure 4: Count rates evolving over time for artificially irradiated ^{116}In