Geiger Counter Experiments and
The Statistics of Nuclear Decay

This experiment consists of 3 parts: determining the proper operating voltage of the Geige Counter, measuring the efficiency of the Geiger Counter, and examining the statistical uncertainties involved in radiation detection.

1. Operating Voltage of the Geiger Counter

In order to determine the proper operating voltage for our Geiger Counter tubes, we will measure the counts recorded as a function of the tube voltage. Warning: **Do not put too much voltage across the tube**, or the tube will break. For the small tubes, do not exceed 500 volts, and for the larger tubes do not exceed 900 volts. Note: **Before turning the power on be sure the voltage is set to zero!**

a) Place a source under the Geiger counter tube. It really doesn't matter which source you use as long as it is fairly active (greater than 1 μCi). Use a Cs^{137} source if we have enough to go around, or use one of the more active sources available in the lab (i.e. Co^{60}) that the instructor gives you.

b) Set the timer to count for ten minutes.

c) **Before turning the power on, be sure the voltage to zero**. Slowly turn up the voltage until the counter starts to record counts. This is the "starting voltage". Record this voltage.

d) Take 1 minute readings, increasing the voltage by about 10 or 20 volts each time. Make a table of your data.

Note: to prevent damaging the tube, do not increase the voltage more than 150 volts beyond the starting voltage, and certainly not more than 1000 volts.

e) Graph your results on linear paper, and determine the proper operating voltage. Also, on your graph, label the starting voltage and the plateau region.

In order to assist you (and to prevent damaging the tube), your graph should look something like the one shown in the introduction on Geiger Counters.

2. Efficiency of the Geiger Counter

In this part, you will estimate the efficiency of the Geiger-Mueller tube for a particular source. The efficiency of the Geiger counter will depend on the sample, so be sure to record the date of calibration and activity of the sample you used. We will define the efficiency, ε, as follows:

$$\varepsilon = \frac{Number\ of\ Counts\ Detected}{Number\ of\ particles\ emitted} \tag{1}$$

For the Geiger Counter, our value for the efficiency will not be very accurate. This is because we cannot tell which type of particle we are detecting. We will do a much better job measuring the efficiency of our gamma detectors in Experiment 3. However, this exercise will give us an estimate of the Geiger Counter's efficiency. Throughout the experiments use the operating voltage that you determined in Part 1.

a) Place your source as close to the tube as you can, and record counts for 2 minutes.

b) From the activity written on the source, use the half-life formula to determine the activity in decays/sec of your source today.

c) Determine the efficiency of the Geiger-Mueller tube for your source-detector set-up. For this calculation, we will assume that the number of particles emitted is equal to the number of decays. That is, we will assume that one particle is emitted per decay. This is not a good assumption, but it is the best we can do in this case.

d) Write your value for the efficiency, ε, on the board for comparison with the rest of the class.

3. Statistics of Nuclear Counting

In this part of the experiment, we will examine the statistical properties of radiation detection. You will take 40 one minute recordings with the Geiger counter. Each group will take their data with different counting rates. We will post our values on the board, and use each others results to investigate how the standard deviation of the counts depends on the average number of counts. Be sure to take good data, since the rest of the class will use your results. **Throughout the experiment, use the operating voltage you determined in Part 1.**

a) Take 40 one minute recordings with your sample at an appropriate distance from the detector. Keep the distance the same for each recording. We will label each value as x_1, x_2, ... , x_i, ... , x_{40}

b)Calculate the average number of counts, $\bar{x}$ of your data.

$$\bar{x} = \frac{\sum_{i=1}^{i=40} x_i}{40} \tag{2}$$

c) Calculate the experimental standard deviation of the x_i's about their average value, $\bar{x}$.

$$\sigma_{exp} = \sqrt{\frac{\sum_{i=1}^{i=40} (x_i - \bar{x})^2}{39}} \tag{3}$$

d) Calculate $\sigma_{th} = \sqrt{\bar{x}}$. Calculate the reliability factor R, which is defined as:

$$R \equiv \frac{\sigma_{exp}}{\sigma_{th}} \tag{4}$$

Is your value for R within the expected range? Discuss why (or why not) you think your Geiger Counter is operating properly.

In future experiments, when we measure the number of counts (C), we will use $\sigma = \sqrt{C}$ for the statistical uncertainty of our data.

4. Frequency Plot of Geiger Counter Times

In this final part of experiment 1, we will record the times between successive Geiger Counter pulses.

a) Collect around 50000 successive times, and save the times in text format. The instructor will show you how to do this.

b) Import the text file of successive times into a spreadsheet (e.g. Excel). Make a frequency plot of the data. The instructor will guide you through the Excel data analysis software. It will be important to choose an appropriate bin size for your frequency plot.

c) In your frequency plot, you will notice that very short times between pulses are not measurable. This is because there is a dead time for the Geiger Counter tube. From the graph, make an estimate of what the dead time is.

d) Consider only times greater than the dead time, and try an exponential fit of these times. How well is the data fit by an exponential function? What principle of physics does (or does not) this data support? What is the meaning of the fitting parameters?

Report for Experiment 1

Be sure and turn in the following in your report:

1. (2 points) A table and graph of Counts vs. voltage for your Geiger counter tube. Label on your graph the starting voltage, operating voltage and the plateau region.

2. (1 point) Show your data and calculations for determining the efficiency of your Geiger counter.

3. (3 points) Show the calculation (you can use excel or another speadsheet) of your average and standard deviation for your 40 one minute recordings. Discuss your value of R.

4. (2 points) Make a frequency plot of the times between successive Geiger Counter pulses. What is your best estimate of the dead time of the system? What principle of physics does your data support? What is the meaning of the fitting parameters?

Answer the Following Questions: Maximum 4 points, one point for each correctly answered question. That is, choose any 4 of the following 5 questions.

5. Add up the counts for all of the 40 one minute counts, and consider the sum as the number of counts for one 40 minute recording. That is, pretend that you took one 40 minute recording of data, and the number of counts you recorded is equal to the sum of the 40 one minute counts. For this case, what is the counting rate and the statistical uncertainty in units of counts/minute?

6. Derive the relationship $\sigma_{th} = \sqrt{\bar{C}}$. Show all your steps. You can use the method that we used in lab to derive $\bar{C} = pN$.

7. The half-life of an isotope is 2 minutes. If we have 1000 isotopes at time $t = 0$, how many on the average do we expect to have after 2 minutes? What is the standard deviation of this average? (Note: you might not be able to use the simple formula from Poisson statistics.)

8. In the game of craps, 2 dice (each with 6 sides) are thrown. If the 2 dice add to 7 of 11, the thrower wins. What is the probability for this to happen.

9. In the California Lottery, you pick 6 numbers from 1 to 49. You get $5 if you get three of the numbers correct. What is the probability for getting three numbers correct?