# Radioactivity:
## Detection and Measurement

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# Radiation detection and measurement

## 1 Introduction

### 1.1 What is radioactivity?

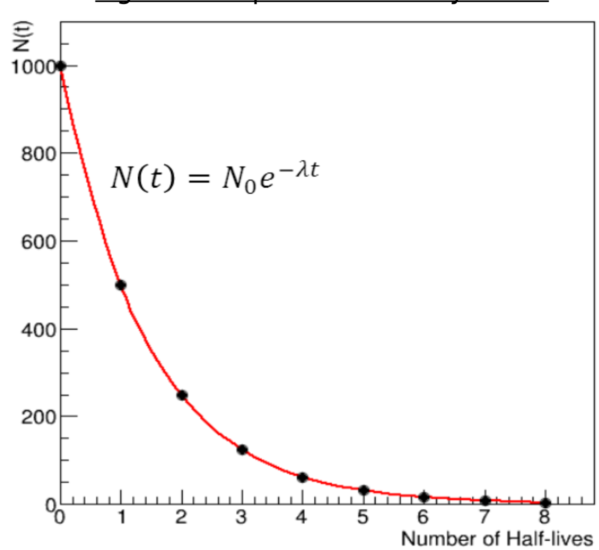
Radioactive atoms have unstable nuclei – these nuclei spontaneously emit energy. The released energy could be either a particle (or particles), electromagnetic radiation, or both.

Radioactive nuclei can be classified according to their half-life. The half-life is the amount of time it takes for half of the original nuclei to decay. If you pick out a random radioactive nucleus, either man-made or from what exists naturally, the half-life could be anywhere from $10^{-22}$ s to $10^{24}$ yrs!

### 1.2 The Mathematics of Radioactive Decay

The nuclear half-life is a constant, the same regardless of the amount of radioactive atoms present. The amount of radioactive atoms we have on hand at any time is undergoing a consistent, continuous change. Say we start off with 1000 radioactive nuclei. After 1 half-life, we'll have 500 nuclei left. After 2 half-lives, we'll have 250 left. And so forth. If we plot the number of radioactive nuclei as a function of the time gone by, it would look like the black data points in Figure 1.

Figure 1: Exponential decay curve




Since the half-life is a constant, sometimes it is rewritten as the 'decay constant', λ .

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

The decay follows an exponential decay, which means that an exponential function can allow us to calculate the number of radioactive atoms we have left. This is the red line in Figure 1.

If we know the number of atoms present and their decay constant (probability of decay per unit time), then we can calculate how many atoms will remain at any future time. This can be written as the equation

$$N(t) = N_0 e^{-\lambda t} \quad (1)$$

Where N(t) is the number of radioactive atoms that will be present at time t, $N_0$ is the number of atoms present currently, λ is the decay constant, and t is the elapsed time.

If we take the logarithm in Equation (1):

$$\ln(N(t)) = \ln(N_0 e^{-\lambda t}) \quad (2)$$

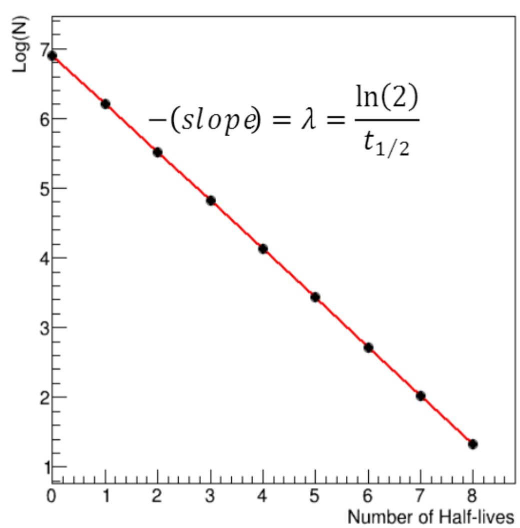
And rearranging terms

$$\ln(N(t)) = \ln N_0 - \lambda t \quad (3)$$

This equation corresponds to a straight line whose slope is directly the decay constant λ (Fig. 2)

The observed activity of a sample as detected by a Geiger counter is proportional to the number of radioactive atoms, it is not necessary to know exactly how many atoms are present to determine either the half-life or the decay constant. Any quantity of sample providing a suitable activity may be used.

Figure 2: The data from Figure 1, plotted as the natural log.




## 1.3 Radiation and You

Stable nuclei do not decay. Most of the matter we're used to thinking about is made of atoms with stable nuclei. However, radioactive isotopes are very common. We have carbon in our bodies, which has 6 protons. When carbon has 6 neutrons, ie $^{12}C$, it is stable. However, carbon with 8 neutrons, 14C, also exists naturally and in our bodies, and it's radioactive with a half life of 5700 years. Bananas, concrete, the calcium in our bones, all contain some atoms which are radioactive. So radiation is not necessarily dangerous. The amount of radiation you are exposed to – the dose - is what makes the difference. Dose depends on the number of radioactive nuclei, the half-life, the amount of time you are exposed, and the distance between you and the radiation. Living on the earth, you are exposed to about 400 mRem of radiation per year, or about 0.1mRem during the next three hours. An average banana will expose you to roughly 0.01 mRem of radiation. Today's experiment will expose you to about 0.000000001 mRem of radiation, in a silver coin. Still, because you are handling a radioactive 'source', practice care with the coins.

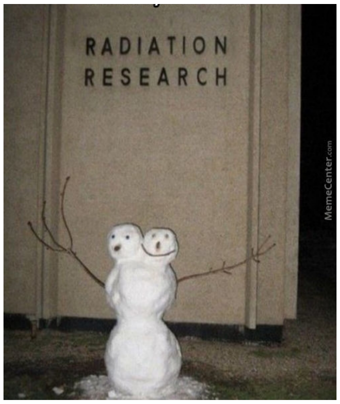



Figure 3: Snowman with two heads, because radiation physicists have a sense of humor

## 1.4 Types of radiation

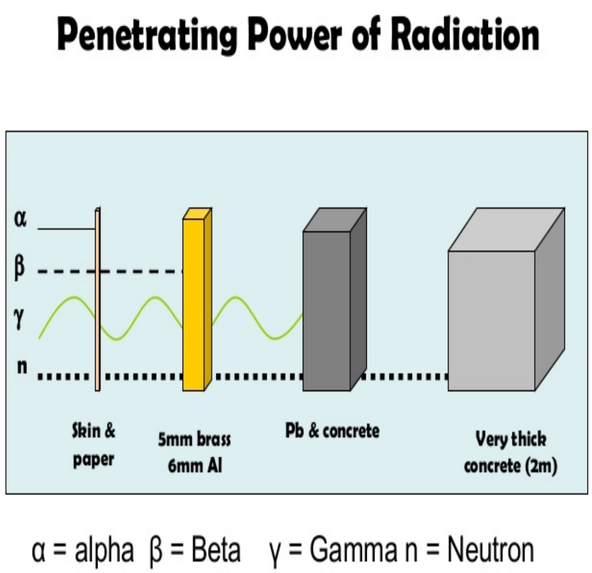
The radiation one typically encounters is one of four types: alpha radiation, beta radiation, gamma radiation, and neutron radiation.

**Alpha Radiation**

Alpha radiation produces a heavy, very short-range particle and is actually an ejected helium nucleus (helium has 2 protons and 2 neutrons).

Most alpha radiation is not able to penetrate human skin, cannot penetrate clothing, and only travels a few inches in air.

Examples of some alpha emitters: radium, radon, uranium, thorium.




**Beta Radiation**

Beta radiation is an ejected electron or positron. Electrons or positrons are light, short-range particles.

Beta radiation may travel several feet in air and is moderately penetrating.

Examples of some pure beta emitters: strontium-90, carbon-14, tritium, and sulfur-35. Potassium-40 is not a pure beta emitter, but predominantly beta decays and is naturally in bananas.

**Gamma and X Radiation**

Gamma radiation and x rays are very light, but highly penetrating electromagnetic radiation (they are like visible light, radio waves, and ultraviolet light, but have more energy).

Gamma radiation or x rays are able to travel many feet in air and readily penetrate most materials. Dense materials are needed for shielding from gamma radiation.

Gamma radiation and/or characteristic x rays frequently accompany the emission of alpha and beta radiation during radioactive decay.

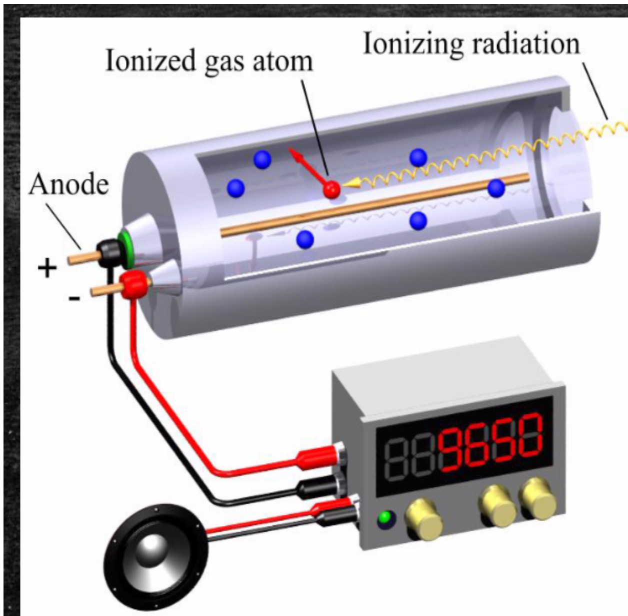
Examples of some gamma emitters: iodine-131, cesium-137, cobalt-60, radium-226, and technetium-99m.

**Neutron Radiation**

Neutron Examples of some gamma emitters: iodine-131, cesium-137, cobalt-60, radium-226, and technetium-99m.

# 2 The Geiger-Müller Counter

Figure 5: The  Geiger Mueller tube




"Geiger-Muller-counter-en" by Svjo-2 - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons.

Geiger-Müller (GM) counters were invented by H. Geiger and E.W. Müller in 1928, and are used to detect radioactive particles ( α and β) and rays (γ and x). A GM tube usually consists of an airtight metal cylinder closed at both ends and filled with a gas that is easily ionized (usually neon, argon, and halogen). One end consists of a “window” which is a thin material, mica, allowing the entrance of alpha particles. A wire, which runs lengthwise down the center of the tube, is positively charged with a relatively high voltage and acts as an anode. The tube acts as the cathode. The anode and cathode are connected to an electric circuit that maintains the high voltage between them.

When the radiation enters the GM tube, it will ionize some of the atoms of the gas. Due to the large electric field created between the anode and cathode, the resulting positive ions and negative electrons accelerate toward the cathode and anode, respectively. Electrons move or drift through the gas at a speed of about $10^4$ m/s, which  is about $10^4$ microseconds after they are created, while the positive ions take a few milliseconds to travel to the cathode. As the electrons travel toward the anode they ionize other atoms, which produces a cascade of electrons called gas multiplication or a (Townsend) avalanche. The multiplication factor is typically $10^6$ to $10^8$. The resulting discharge current causes the voltage between the anode and cathode to drop. The counter (electric circuit) detects this voltage drop and recognizes it as a signal of a particle’s presence. There are additional discharges triggered by UV photons liberated in the ionization process that start avalanches away from the original ionization site.

These discharges are called Geiger-Müller discharges. These do not affect the performance as they are short-lived.

# 3 The Experiment: Half-Life of $^{108}$Ag

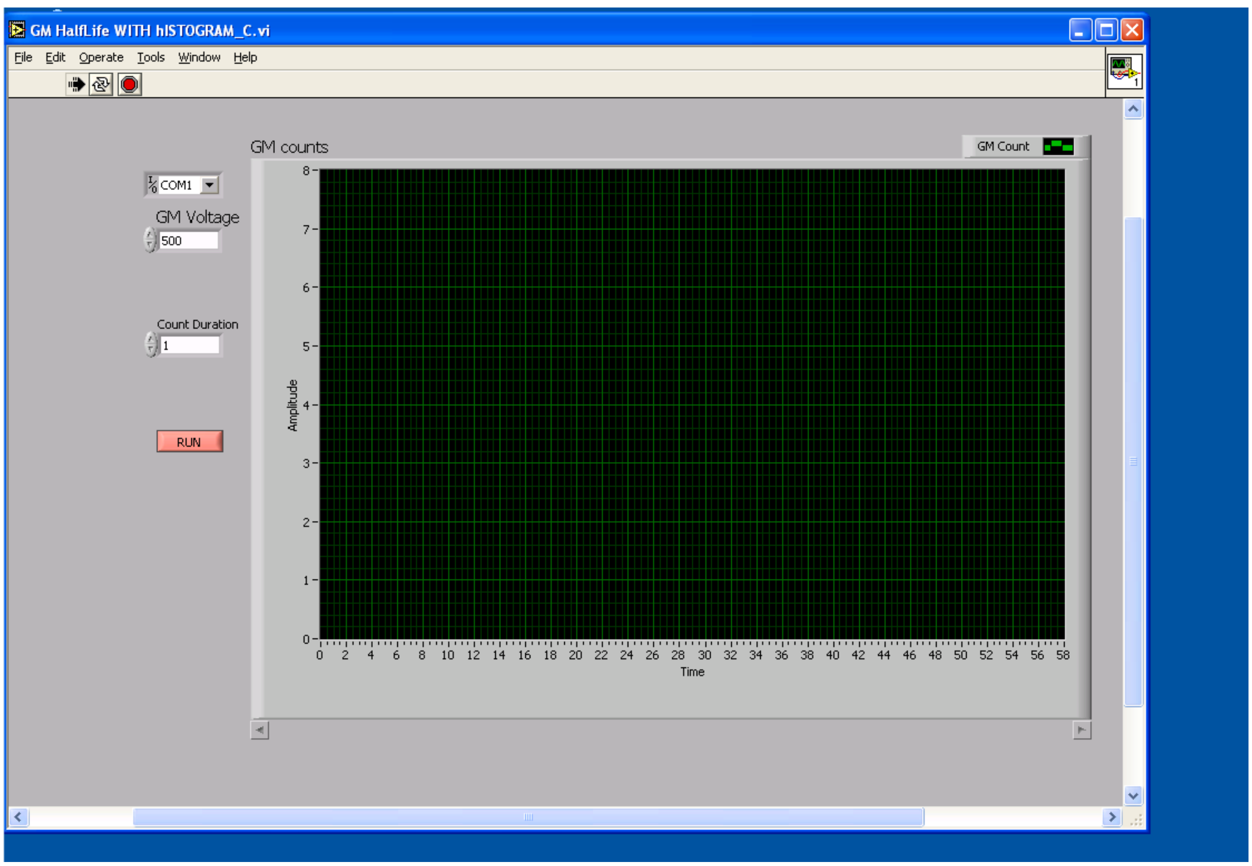
***YOUR OBJECTIVE***

To measure the half-life $^{108}$Ag (optional to measure half-life of $^{110}$Ag).

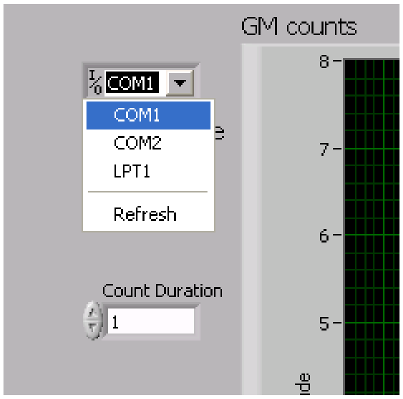
## 3.1 Procedure

1. Prepare the Geiger counter station as outlined in the Appendix.
2. The instructor will supply an activated Ag disk.
3. Immediately place the disk directly under the G-M counter. Click Start in data studio, and take data for 20+ minutes.
4. Record the data to a file on disk or into a data table.
5. Return the Ag disk to an instructor.

## 3.2 Recording Data

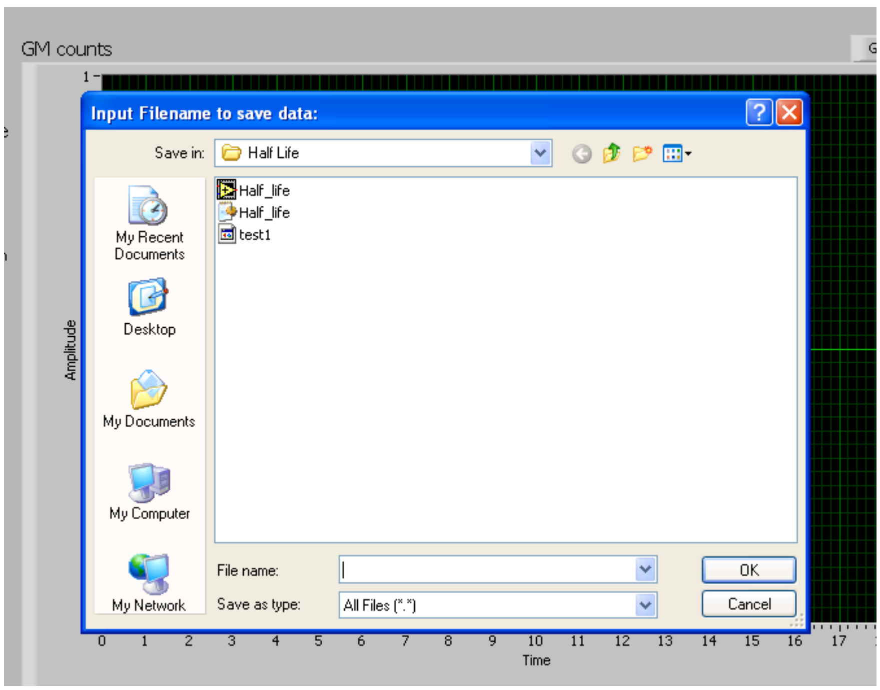



We'll use the Half_life program to record data. Set **the GM voltage to 1100 V**, the **Count Duration to 10 s**, and select the highest COM value (will likely be COM4 – see below).




Note that the correct COM value will not show up until the USB device has been properly installed and attached.

To begin recording data hit "RUN". **<u>WAIT!</u>** <u>It might take a while to show data on the screen.</u> If nothing happens after 5 minutes, get an instructor. When a run is ended you will be prompted to name the data file. **Make sure you save to the U-Drive.** **This is your ONLY CHANCE to save the data!**




This file is now stored in the same folder that contains the Half_life program. This is where you will find it when you are ready to read it in Excel.

## 3.3 Data analysis

1. Import or copy the data to an Excel spreadsheet (see appendix for help with Excel). The data you collected will be presented in two columns, one with the time and other with the counts registered on each time interval.

2. Make a graph of number of Counts vs. Time. From this graph, you will be able to see the true exponential nature of the decay and also be able to estimate approximate half-life.
3. Calculate the natural logarithm of the number of counts for each run. Use the **LN** function.
4. Make a graph of Natural Log (Ln) of Counts vs. Time.
5. The next task is to measure the slope of the decay curve of the longer lived isotope. To do this select two points near the end of the run and calculate their slope.
6. Calculate the slope for two more sets of points, ranging from the end of the curve (in time), to near where you believe the faster decay to be more dominant.
7. Use these slopes to calculate the half-life given the formula below.

$$-slope=\lambda=\frac{\ln 2}{t_{1/2}}$$

8. Determine the average half-life measured.

   (Note: Using this information you can subtract the contribution from the long lived Ag isotope from the total number of decays observed, and in turn determine the half-life of the shorter lived Ag isotope.)

9. Now find the percent error between your result and the true value of $t_{1/2}$ = 142 s. Use the following equation

$$\%\ error = \left|\frac{measured-true}{true}\right| * 100$$

## 3.4 Post-lab questions

1. Write your result with the error, i.e. 153 s ± 1 s. Is this result (statistically) good? Justify your judgment.
2. How was the slope best determined? Why?
3. How can the experiment be improved?
4. What more could be done?