
SOME PROPERTIES OF NUCLEAR RADIATION - Th-232

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Objectives:

After completing this experiment, you should be able to . . .

- define the term "standard deviation" and use it to determine the "standard error" on a set of measurements.
- use the "square root" of a series of collected counts of a radioactive sample to bracket experimental data points to show their uncertainty.
- differentiate between beta and gamma radiation, and estimate the range of beta radiation in common materials.
- define the term "half life," and determine the half life of an electron-storage device and a radioactive isotope by examination of experimental data.

Overview:

Radioactive materials played an important role in the discovery of the atom and in the ending of World War II, and may play an important role in providing energy for mankind. Because the unresolved problem of storage of nuclear waste is limiting the use of nuclear power, environmental and health concerns may soon directly collide with the world's desire for more energy. To make intelligent decisions about this problem requires, in part, some knowledge about the properties of alpha, beta, and gamma radiation, and about the concept of "half life."

Text References:

Be sure to read the background information from your text concerning the following:

- The story of the discovery of natural radioactivity and the role of alpha particles as a probe used to discover the nucleus of the atom.
- The operation of radiation detectors.
- Information concerning the penetrating ability of beta and gamma
- The concept of half life, which is one of the most significant factors concerned in the storage of nuclear wastes.

Detection of Nuclear Radiation:

Nuclear radiation is detected by observing its interaction with matter. Since the energy of nuclear radiation is so high -- several hundred thousand times as much as the energy produced by a flashlight battery -- the passage of alpha, beta, or gamma radiation through matter knocks many electrons from the atoms near the

path of the radiation. Detection of radiation can be accomplished by simply collecting and counting these electrons.

The Geiger-Mueller tube is one of the simplest and most common detectors of nuclear radiation. The counter you will use in this experiment uses this kind of detector. A G-M tube consists of a cylindrical glass or metal envelope with a wire stretched down the center. This wire is connected to a very high voltage -- usually on the order of 400 volts. The return lead from the battery is connected to the metal coating on the inside of the tube. The tube is filled with a gas such as argon.

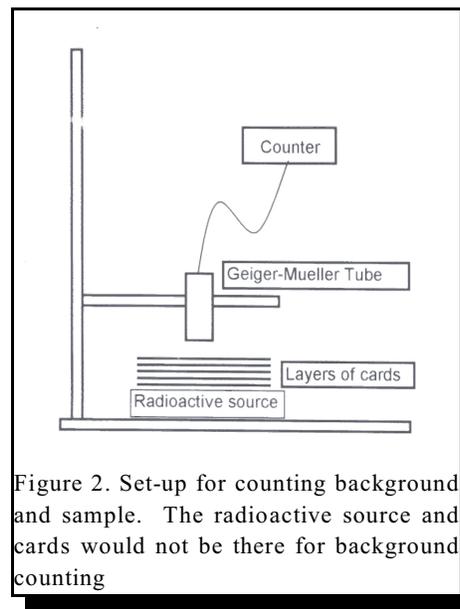
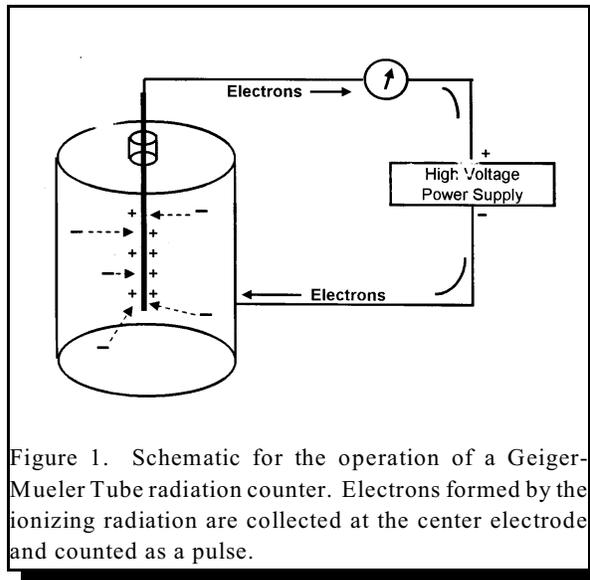
Each time nuclear radiation passes through the tube, atoms are ionized and free electrons are produced. These electrons are collected at the central wire electrode and passed through the counting circuits to the battery. An equal number of electrons are pushed out the negative side of the battery to the case of the G-M tube, where they recombine with the positive ions which were formed in the tube. In a Geiger counter, the counting circuits count individual groups of electrons collected with the passage of each beta particle or gamma ray (alpha particles cannot penetrate the thin window of the Geiger tube.)

Types of Nuclear Radiation:

The most common types of radioactive decay involve emission of alpha particles, beta particles, and gamma radiation. These types of radiation are quite different in size and charge. Alpha particles are composed of two protons and two neutrons. They have an atomic mass of four, and a charge of +2. Because they are relatively large and highly charged, they interact greatly with atoms that they pass, and lose their energy very rapidly when they enter any absorbing material, their penetration into matter is only a few millimeters.

Beta particles are electron-sized (1/1837 atomic mass unit), and carry a minus one charge. Because they are much smaller than alpha particles, and because their charge is half as great, beta particles must interact with many more atoms to lose their energy. Beta particles will penetrate several cm into most matter.

Gamma radiation is an electromagnetic radiation, like light, but much more energetic. It carries no mass and no charge, and will only interact with atoms if it strikes an electron or a nucleus. Gamma radiation thus easily penetrates through most matter.



EXPERIMENT 1: STATISTICS

Random factors in a measurement appear as a scattering of data points, even when one makes the same measurement over and over. One of the best examples of this is the decay of naturally radioactive nuclei. This simple experiment will involve collection of twenty counts of thirty-seconds each of the nuclear radiation coming from a sample of a radioactive compound.

Clamp the tube from your Geiger counter about 1.5 cm above a sample of a radioactive compound. This set-up is illustrated in Figure 2, which also shows how to insert paper index cards which we will use in the next part of this experiment to determine the penetrating ability of gamma and beta radiation.

For now, it is only important that the Geiger tube and the radioactive sample remain firmly in place while we make our twenty measurements.

We will first collect 20 thirty-second background counts without the radiation source in place in order to determine when a radioactive sample has been effectively depleted. We will then collect twenty samples of thirty-second counts from the radioactive source. Use the *MicroLAB* program *Radiation* to collect this data into the *MicroLAB* spreadsheet. **Right-click** on the column A, select **Column Statistics**, and from the displayed information, determine the mean and standard deviation of all of the values in Column A. **Print this frequency distribution graph for both the background and the radioactive sample for inclusion in your report.**

You should also print out the *MicroLAB* Main Screen for each of the five experiments as follows:

1. While holding the **Control** button down, press the **Print Screen** button. This will capture the open window on the computer monitor.
2. Click **Start**, then **Programs**, then **Accessories**, then **WordPad**, then click **Ctrl-V** to copy the main screen image into Wordpad.
3. Now click **Ctrl-P** to print the WordPad page. This will give a black and white image of the main screen on the printed page.
4. **Be sure to save each of these data files under a unique name, e.g., GM.Bckgrnd.11.04.DH, where 11.04 is the date, and DH is your initials.**

The *Standard Deviation* is the range plus and minus from the mean within which 2/3 of the data should fall. Use your mean and standard deviation information to compute this range for this experiment. (**Q1:** For both the background and the radioactive sample, how many of your samples occur outside (greater than, or less than) this range?) It should be about 1/3 times 20 or 6 or 7 data points outside of the range. Ninety-five percent of the data should fall within two standard deviations from the mean. Make this calculation. (**Q2:** From your data, how many data points fall outside the 95 percent range) You should have about one data point of your twenty points outside of this range.

The point of this exercise is this: when there is a random factor involved in your data, the same measurement repeated many times will result in different measured values. If 95% of your data is within two standard deviations of the mean, there is only a 5 percent chance that a real change has taken place.

Now take the square root of the mean value. When the count size is reasonable (more than several hundred), the square root of the number of counts is usually a reasonable approximation of the standard deviation. You can use the square root of a reasonable sized count as an estimate of the standard deviation, without going through many measurements. This can be quite useful to estimate quickly whether or not two or more successive measurements really represent a change, or if you are just observing randomness in the same phenomena.

Experiment II: Comparing the penetration of beta and gamma radiation in paper.

Set up your Geiger counter and radioactive source as illustrated in Figure 2 with the radioactive source in place. We will determine the range of beta and gamma radiation through paper index cards by stacking the cards between the sealed radioactive source and the Geiger tube. Note that you will collect a lot more beta particles and gamma rays if your tube is mounted quite close to the source. One and a half cm might be a reasonable distance.

Obtain 60 cards and divide them into groups of three. Use the program provided to record you counts, make your first 30-second count with zero absorbers. Then place three cards between the source and detector, and make another 30-second count. Continue adding cards in sets of three until you have all sixty cards in place. This will give you twenty data points, and will take about fifteen minutes of counting.

After you have obtained your data, carefully examine the graph to determine when all of the beta radiation has been absorbed? (Q3: How many cards are required to apparently eliminate the beta radiation? Q4: What is the approximate half-thickness of index cards for the beta radiation?) Make a table consisting of each of your data points in one column, and the square root of the collected counts in the second column. When the square root gets as large as the background counts, all points lying within this range are not significantly different from each other. (See Figure 4 for a graphical representation of this data table.) (Q5: At what count level does the standard deviation get as large as the background counts?)

EXPERIMENT III: Determination of the half life of an electron-storage device.

Many natural phenomena exhibit a characteristic known as "half life." In these phenomena, something leaves the system at a rate that is proportional to the number of the items present at that time. Thus, as objects leave, the number of objects decreases, and the rate of departure decreases. One example of this is the presence of a medical drug in one's blood. Blood pressure medicine, for example, is gradually used up by the reactions that limit blood pressure. Thus, immediately after a dose of the medicine, the concentration of drug molecules in the blood might be quite high. The probability of a drug molecule colliding with the appropriate reactant would be quite high. But, as the drug molecules collide with their reactant molecules and are used up, the concentration of the drug molecules decreases, and the chance of a readable collision goes down. This is why drugs are often taken several times during a day, or administered with timed release capsules.

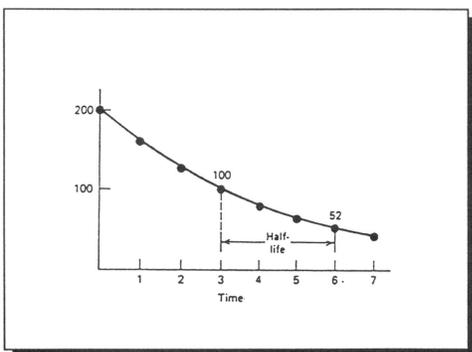


Figure 4. Half life is the time required for half of the material (electrons, in this case) to leave the system.

The time for half of the drug molecules to react and be removed is called the "half life" (Figure 4). No matter how many drug molecules are present, half of them will react in the period of time known as the half life. In the next period of time equal to a half life, half of the remaining molecules will react, and so on until so few molecules are left that the statistical probability of an appropriate collision becomes impossible to predict. For practical purposes, in about ten half lives a material is considered to be gone.

Another example of half life occurs with radioactive elements. If you have a lot of radioactive atoms, quite a few will decay in a given period of time. But as they decay and you have fewer radioactive atoms, fewer decay during the same amount of time. During a "half life," half of those atoms present at the beginning of the period will decay. This can be described mathematically by the following equation:

$$A_t = A_0 e^{-kt}, \quad (1)$$

where " A_0 " is the initial number of atoms, " A_t " is the number of atoms at some future time " t ," and " k " is the decay rate, or the proportionality constant. This equation is more useful in another form, by taking the natural logarithm of both sides to obtain:

$$\ln(A_t) = \ln(A_0) - k t \quad (2) \quad \text{rearranging, results in} \quad \ln(A_0/A_t) = k t \quad (3)$$

This allows the calculation of " k " when both " A_0 " and " A_t " are known, and the calculation of the half life, $t_{1/2}$, when " k " is known by

$$t_{1/2} = \ln 2/k \quad (4)$$

Electron storage devices exhibit the same "half life" behavior as do drugs and radioactive elements. Electrons can be stored on a storage device called a *capacitor*. A capacitor is simply two rolled up sheets of thin conducting foil with an insulator between them. One can use a battery to force electrons onto one sheet, and to pull them off the other sheet. When you connect the sheets together, electrons will run from the side of excess electrons (- charge) to the side of a deficiency of electrons (+ charge). The pressure

exerted on these electrons to move is proportional to the number of electrons remaining on the plate at that time, and also follows the half life principle.

Our investigation of half life will begin with a look at the behavior of electron storage devices, and then observation of the decay of a live radioisotope. To investigate this behavior of electron storage devices, a small capacitor and resistor wired to a banana plug will be connected to the **CAT-5A** input of your lab interface through a voltage cable. **Be sure to** connect the **black lead** of the voltage probe to the banana plug prong that **HAS** the little black ridge above the prong. This ridge denotes the **Ground** side, or **negative** side of the system. The **Red lead** will be touched to the alternate prong at the beginning of the experiment. The program **Half-life** will record the voltage and time as the electrons leave the capacitor after you charge it and then remove the charging wire.

Open the **Half-life** program and make sure the voltage lead is properly connected to the **MicroLAB CAT-5A** input, and that the **negative (black)** lead to the resistor-capacitor as described above, and press enter to start the experiment running. After your data begins to collect, touch the **Red voltage** lead to the alternate prong of the capacitor and hold it there until the voltage jumps up to about 2000 millivolts. Remove your test lead, and watch as the graph shows the electrons leaving the storage device through the resistor placed across the capacitor's leads.

Let this experiment run until the voltage falls to about 1/8 of its original value, or about 250 millivolts. Save your data when you stop the experiment. Observe the shape of the top graph -- the rate at which the electrons leave slows down as fewer electrons are left.

In the left window of pair number 1, click and select the highest round number value near the beginning of the experiment. Divide this by two, and in the right window, find a value close to this farther down the data.

How many seconds are required for the force exerted on the electrons leaving the capacitor (the voltage) to fall to half of its initial value?

In the left window for pair number 2, pick another point farther down the table, and find the location of the point that is about half of this value. How many seconds does this "half life" require? Do this for the remainder of the paired windows, and each time determine the time required for the value to fall to half of your arbitrarily selected initial value. As you near the bottom of the data table, it will become more difficult to match the half-lives of the upper pairs because of the statistical nature of these kinds of measurements.

How do your several "half life" determinations compare with each other? (**Q6:** Is "half life" a quantity that always remains the same, regardless of when you begin your measurement?) This "half life" for the resistor/capacitor combination is called the "RC time constant," and is used as an inexpensive timing circuit in some devices.

EXPERIMENT IV: Radioactive Half Life

The decay of radioactive elements follows the same law. In this experiment we will take a series of 30-second counts, each time recording the total collected count and the time since the experiment began and enter this data in your spreadsheet. Because of the problems of handling radioactive solutions, This part of the experiment may be done by demonstration. Your laboratory instructor will separate a radioactive isotope from a naturally radioactive sample extracted from a thorium solution, place it under the Geiger tube and count it in the **Half-life** program used above for the electronic experiment, but **set the collection time to 30 seconds**. After the experiment is completed, he will save the data and each of you may obtain a copy of the data for analysis later. (**Q7:** Does this graph look like the electron half-life experiment graph?)

Analyze the half life data of the radioisotope just as you did with the electron storage experiment. (**Q8:** What is the **estimated** half-life for your radioactive isotope from these calculations?)

A more accurate way to determine the half-life is to plot the natural logarithm of counts versus time. The data in the above experiment was not corrected for the background count, but will give satisfactory results for this part without that correction. The lower graph illustrates the result of taking the natural logarithm of the number of counts for each 30 second period and graphing it against the total time. The slope of the regression line will give you the decay constant for this isotope, and the intercept should give you the initial instantaneous activity. (Q9: What is the decay constant for your radioactive isotope?) The half life can be precisely calculated by dividing the $\ln 2$ (0.693) by the decay constant as discussed above. (Q10 What is the half-life of your radioactive isotope when calculated this way? Q11: How does this value compare with the value on the lower graph? Q12: Based on your half-life, and a review of the half-lives listed on the Sargent-Welch periodic chart, report what isotope is being separated from the Cs-137 sample by your instructor? Q13: Calculate the initial instantaneous activity for your radioactive sample?)

Your report should consist of five sections, each with a brief introduction, procedure, observations and conclusions and a print out of the *MicroLAB* Main Screen for each experiment, as follows:

1. Your statistics data, and your calculations and conclusions concerning the standard deviation.
2. Your beta-gamma absorption data and your conclusion concerning the range of beta particles in paper index cards.
3. Your half life data for the electron storage device, and your estimation of the half life of this system.
4. Your half life data for the unknown radioisotopes, your estimation of the half life of this isotope, and your conclusion concerning its identity.
5. Your laboratory notes from your lab notebook.
6. Answers to the 12 questions posed within the experiment.

Isotope	Half Life
Thorium - 232	1.4×10^{10} years
Radium -228	6.7 years
Actinium-228	6.13 hours
Thorium-228	1.9 years
Radium-224	3.6 days
Radon-220	51 sec
Polonium-216	0.16 sec
Lead-212	10.6 hours
Bismuth-212	60 minutes
Thallium-208	3.1 minutes

Table 2. A list of possible radioisotopes.

ADDING ERROR BARS TO A DATA SERIES IN EXCEL

If your instructor requests that you work up the data from this experiment in EXCEL, error bars may be added to the EXCEL graph producing a very informative and nice looking graph, similar to the one in Figure 3. The error in each datum is the square root of the number of counts for that datum. Thus, in an adjacent column, take the square root of the "counts" column. After you have plotted the original data in EXCEL, do the following:

1. Activate the chart by clicking on it to obtain the square dots at the corners.
2. Select the data series to which you want to add the error bars by clicking on any of the data points.
3. From the insert menu, choose "Error Bars."
4. Under Display, select the type of error bars you want to use. (Y error bars for this experiment.)
5. Select the mode of calculation for the error bars. (Custom for this experiment)
6. With the cursor blinking in the "+" error bar window, click on the spreadsheet and click and drag down the square root column.
7. Press "tab" to move the cursor down to the "-" error bar window.
8. Click on the spreadsheet and click and drag down the square root column again.
9. Press "Enter" or click on "OK" to complete the process.
10. You should now have "Y" error bars on your graph.
11. You may need too reselect the data series to format the data symbol to the smallest option in order to be able to "see" the error bars effectively.

