Determination of the Half-Life of Potassium-40

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Introduction

All matter is made up of small particles which we call atoms. The atoms of each element are composed of two parts, a nucleus, at the center of the atom, and energy levels around the nucleus. The main subatomic particles that make up the atoms are protons and neutrons, found in the nucleus, and electrons which occupy the energy levels outside the nucleus.

Each chemical element has a unique identity that is determined by the number of protons in its nucleus. Since protons have a positive charge, and like charges repel each other, to hold the protons together there are neutrons which are also located in the nucleus. For most light elements, the number of protons and neutrons are approximately equal, but as the nuclear charge of the atoms increase, the number of neutrons increases by a larger amount in order to stabilize the nucleus. For example, an atom of helium normally contains 2 protons and 2 neutrons in its nucleus, an atom of potassium normally contains 19 protons and 20 neutrons in its nucleus, and an atom of uranium usually contains 92 protons and 146 neutrons in its nucleus.

There is a large number of atoms of elements that have the same number of protons, but different numbers of neutrons in their nuclei. Such atoms are known as *isotopes*. Isotopes of an element generally have the same physical and chemical properties, except they have a different atomic mass. Some of the isotopes of some atoms, however, are not stable and, within some time period, which can range from microseconds to millions of years, their nucleus will fall apart, or disintegrate, losing a small piece. Such atoms are said to be *radioactive*. The disintegration is called *nuclear or radioactive decay*.

No matter what the element is, when natural nuclear disintegration takes place, two types of particles are most commonly emitted: alpha particles (α) or beta particles (β). These are usually accompanied by a third type of radiation in the form of gamma (γ) rays.

Alpha particles, α, are positively charged and are identified as helium nuclei. They are relatively large in mass and interact strongly with matter, being absorbed by as little as a sheet of paper.

Beta particles, β, are negatively charged and are identified as fast electrons. They are small in mass and interact less with matter than α particles and can easily penetrate paper and cardboard, but are absorbed by metal sheets.

The third type of radiation, gamma rays, γ, are not particles but very high energy photons, similar to x-rays, but more energetic. They interact with matter much less strongly than do alpha and beta particles and consequently their penetrating power is very high.

In this experiment, you will determine the background radiation, the half-life of a radioactive element, and the half-life of potassium-40.

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SAFETY PRECAUTIONS for Handling Radioactive Materials

The samples and materials used in this experiment are low level radioactive emitters and are considered to be safe quantities of radioactive substances. In this experiment, salt substitute, a food additive, is used. We will, however, treat this material with the respect due to any radioactive substance.

Do not handle radioactive materials unless you are required to do so. They should be removed from their containers when needed for a procedure, taken to the work area, and then returned to their containers or disposed of when the procedures are completed.

Always handle radioactive materials with extreme care using the smallest quantity necessary for your experiment. Remember that you cannot see or feel the radiation coming from that innocent looking sample, you will only feel the effects at a later time - then, it is too late!

Always wear gloves and any other applicable safety clothing when working with radioactive materials. For these procedures, disposable gloves will be used.

Any pregnant students, or individuals who are trying to become pregnant, should avoid radioactive materials, no matter how safe they claim to be. Please inform your instructor so you may be excused from the laboratory for this experiment.

When removing disposable gloves, hold them at the cuff and remove them turning them inside out so that any traces of radioactive materials are on the inside of the glove. Do not reuse the gloves. Dispose of the gloves as directed.

Do not eat, drink, chew gum, or wear cosmetics when working with radioactive materials. All edible materials are banned from areas where radioactive materials are used.

Any cut or wound arising during work with radioactive materials should get immediate medical attention.

All radioactive wastes should be stored in appropriately labeled containers until properly stored or disposed of.

All personnel must wash their hands and face and survey their person for any contamination before leaving the laboratory.

The laboratory should be surveyed for any contamination after cleaning up.

DISPOSAL

All waste materials must be placed in the properly labeled containers in the laboratory.

All glassware used to hold radioactive isotopes must be placed in the location provided near the waste containers.

How to Use the Aware Electronics Model RM-60 Micro Roentgen Radiation Monitor

Attach the Radiation Monitor to the laboratory laptop computer using the appropriate adapter.

Click on the AW-RADW icon on the desktop.

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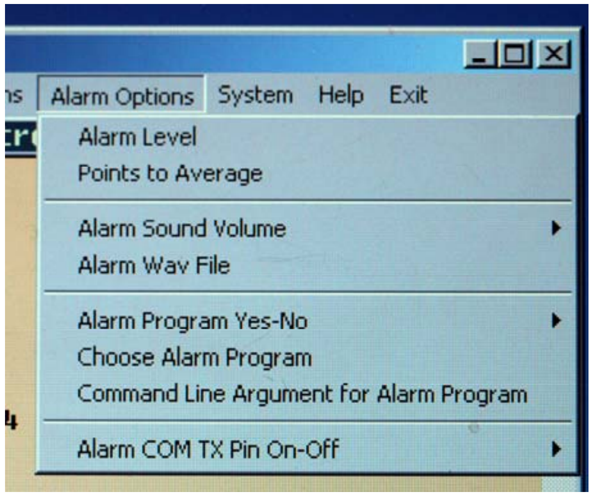
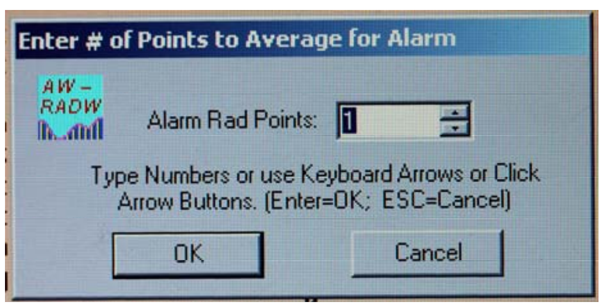
On the opening screen, click on **Alarm Options**.



Click on **Alarm Level** and set the Alarm Level to zero. Then click OK.

On the **Alarm Options** menu, click on Points to Average. Set the Alarm Rad Points to 1. Click OK.



On the **Alarm Options** menu, click on **Alarm Sound Volume**. Set the Alarm Sound Off.

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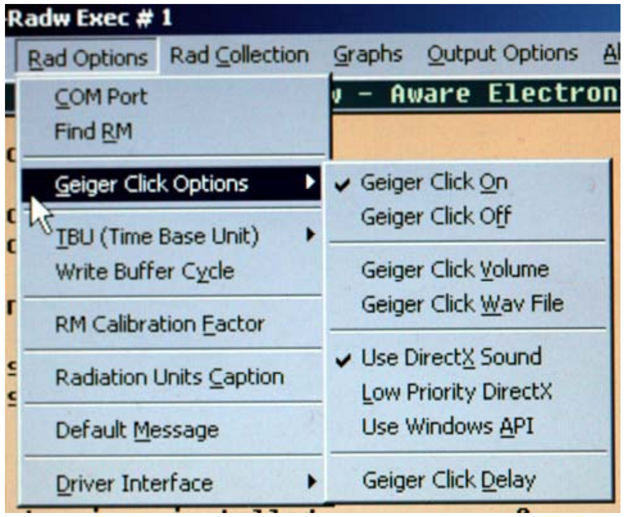
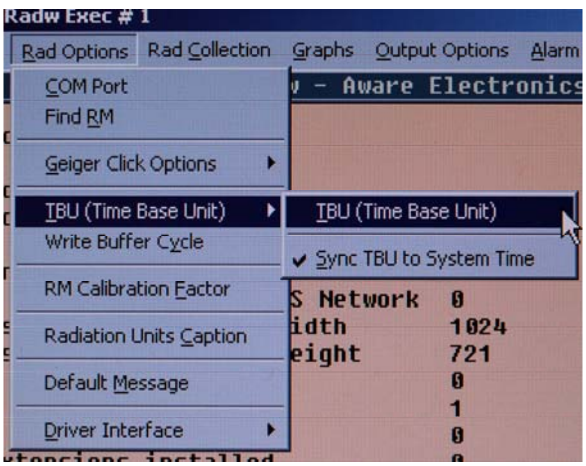
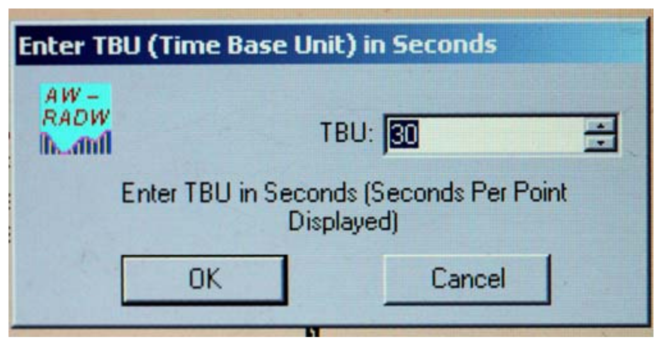
On the **Main Screen**, click on **Rad Options**. Click on Geiger Click Options and turn Geiger Click On.



On the **Rad Options** menu, click on **TBU** (Time Base Unit). Set the TBU to 30 seconds. Click OK.





You are now ready to measure the radiation of your samples.

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Part 1. Determination of the Background Radiation

There is radiation all around us. It comes from the sun, from distant stars or other sources in space, from radioactive isotopes in the air, and from radioactive isotopes in the soil. This radiation will vary with your location on the Earth, but no place is 100% nuclear radiation free. All this radiation is known as *background radiation*. In order to measure radioactivity of our samples, the background radiation must be determined.

Figure 1. Aware Electronics Model RM-60 Geiger tube.

Materials Needed:

Aware Electronics Geiger counter tube interfaced with a laboratory computer. (See Figure 1.)

Stand for the Aware Electronics Geiger tube. (See Figure 2)

Procedure:

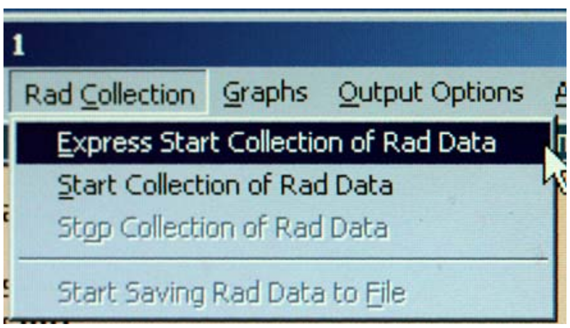
Remove all radioactive materials from your work area.

Set the Geiger tube apparatus in a stand.

Figure 2. Geiger tube with stand.

Using the computer program for the Geiger tube, set the time interval for 60 seconds.

On the Main Screen, click on Rad Collection. Select Express Start Collection of Rad Data.



On the next screens either press on OK or Save. No other entries are needed. Collection of data is started when you see the graph screen.

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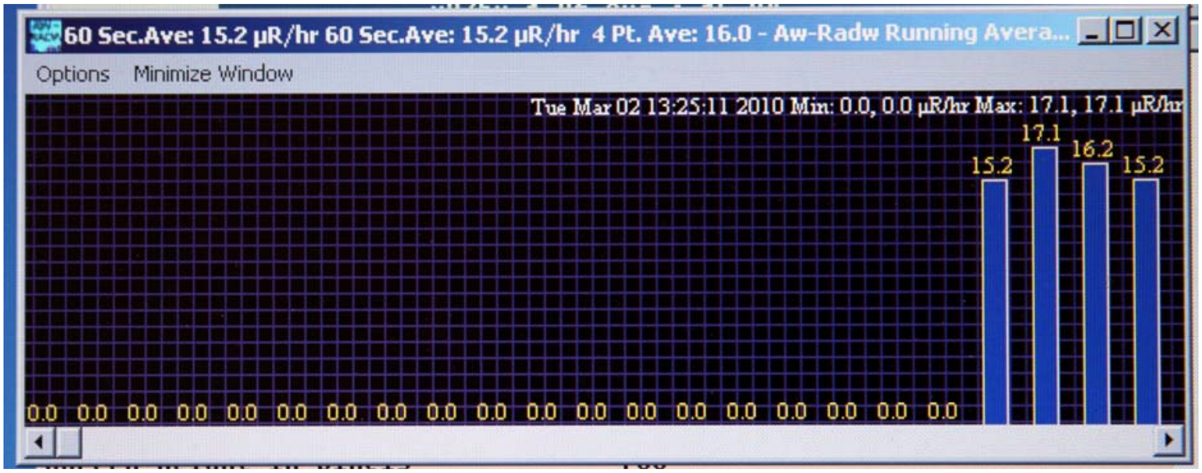
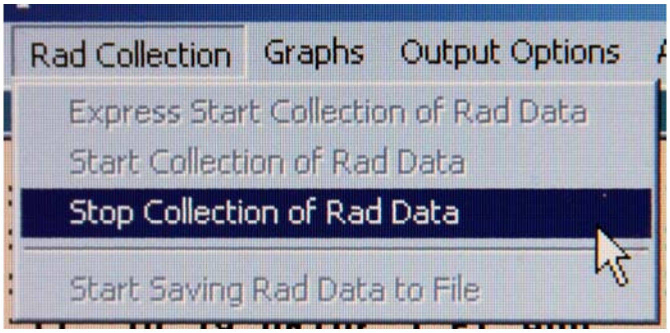
Record background activity for at least 3 minutes. The number of counts appears on top of each bar in the bar graph. If desired, you can expand the graph to full screen.



To stop collection of data, open Rad Collection and click on Stop Collection of Data.



The graph can be printed.

Do not close the graph or open new options until you have printed or recorded your data.

The average background rate is determined by taking the total number of counts recorded and dividing by the number of minutes.

Record the background radiation value.

Part 2. Determination of the Half-Life of a Radioactive Isotope

The half-life of a radioactive isotope is the time it takes for one-half of the atoms present to decay. The half-life can range from a fraction of a second to millions of years. It is not necessary to wait the full half-life to determine its values. Taking reading over a period of time will allow the half-life to be calculated.

SAFETY PRECAUTIONS for Handling the $^{137}Cs/^{137}Ba$ Isogenerator

Wear disposable gloves to handle the Isogenerator and any containers with eluted ^{137}Ba solution.

Your instructor will elute 2 mL of the ^{137}Ba solution into a 10 mL beaker.

Report any spills of the ^{137}Ba solution immediately.

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DISPOSAL

At the conclusion of this procedure, place the beaker containing the ^{137}Ba sample in the location provided near the waste containers.

Materials Needed:

Radioactive source: $^{137}Cs/^{137}Ba$ Isogenerator (see Figure 3) or other source of radiation.
Eluting solution for Isogenerator
Syringe for eluting solution
Aware electronic Geiger counter interfaced with a laboratory computer.
Stand for Geiger tube
10 mL beaker
Wash bottle with distilled water
Disposable rubber or vinyl gloves

Figure 3. The $^{137}Cs/^{137}Ba$ Isogenerator

Procedure:

NOTE: If you are using the $^{137}Cs/^{137}Ba$ Isogenerator, DO NOT ELUTE any isotope from the Isogenerator until you are ready to start your measurements.

Remove all radioactive materials from your work area.

Using the computer program for the Geiger tube, set the time interval for 60 seconds.

Enter a file name, but do not start your measurements.

Put on a pair of gloves.

Obtain your radioactive source and place it under the Geiger tube mounted on a stand.

If you are using the isotope from the $^{137}Cs/^{137}Ba$ Isogenerator , elute 2 mL of ^{137}Barium into a 10 mL beaker. Quickly, but carefully, take the beaker and place it under the Geiger tube and start your measurements.

Start recording. Record the radioactivity measurements for at least 6 minutes.

Correct all recorded counts for background radiation by subtracting the average background counts from each measurement. Record the corrected counts per minute.

Plot the counts per minute (cpm) vs time in minutes. (see sample graph in Figure 4)

Plot log cpm vs time. (Use regular or semi-log paper) (see sample graph in Figure 4)

Calculate the value of the decay constant, k, for the radioactive element using:

$$\ln\frac{A_t}{A_0} = -kt$$

Where: A_t is the activity (counts per minute) at some time t
A_0 is the activity at time 0 (initial activity)
t is the time in minutes
k is the decay constant

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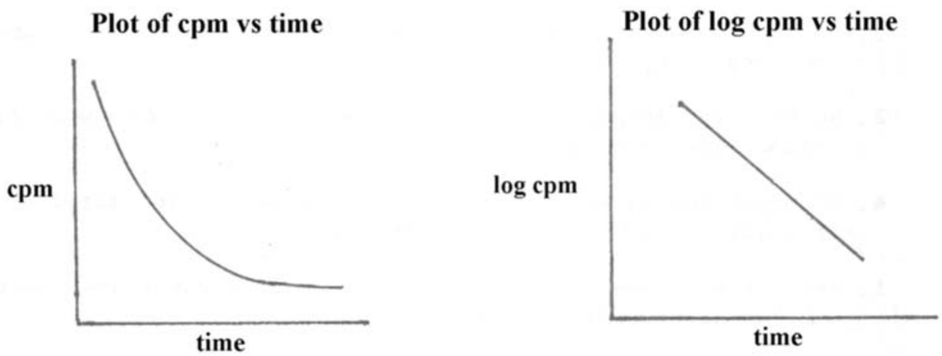

Figure 4. Graph of cpm vs. time (left) and log cpm vs. time (right)

Although you can use any set of values for A_t, A_o, and t, it is usually best to use the data for minute 1 (A_0) and minute 6 (A_6) or later. You will need to use logs to solve. Scientific calculators are available from the stockroom.

Use the value of the decay constant, *k*, to calculate the half-life, $t_{1/2}$ of the radioactive isotope.

$$t_{1/2} = \frac{0.693}{k}$$

Part 3. Determination of the Half-Life of a Potassium-40

The element potassium has 3 naturally occurring isotopes, ^{39}K, ^{40}K, and ^{41}K. Of these, only ^{40}K is radioactive. Potassium, in the form of potassium chloride is the main ingredient in salt substitutes sold as a food additive.

Potassium-40 is a rare example of an isotope that undergoes three types of decay processes. About 89.28% of the time, it decays by emission of a beta particle, (β^-), about 10.72% of the time it decays by electron capture, and rarely (about 0.001% of the time) it will decay to by emitting a positron (β^+). For this experiment, we are only considering beta decay.

SAFETY PRECAUTIONS for Handling the potassium-40 sample

Lite salt, a food additive, is safe to handle. As a precaution, wear disposable gloves to handle your sample.

DISPOSAL

At the conclusion of this procedure, place the weighing boat and the lite salt sample in white waste bucket for solid waste materials.

Materials Needed

Lite salt
Small plastic weighing boat
Aware electronic Geiger counter interfaced with a laboratory computer.
Stand for Geiger tube
Disposable rubber or vinyl gloves

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Procedure

1. Weigh out 5.0 g of salt substitute into a small plastic weighing boat. (A quantity between 4.90 and 5.10 g is acceptable.) Record the mass to 0.001 g.

2. Place the sample on a support on the top slot of the Geiger tube stand.

3. Record the counts for a minimum of 3 minutes.

4. Determine the average activity by taking the total number of counts recorded and dividing by the number of minutes.

Data Analysis

1. Determine the average activity of the salt substitute sample alone.

2. Assuming your sample consists of only potassium chloride, KCl, calculate the number of potassium nuclei in the sample.

3. The natural abundance of potassium-40 is 0.0117% in any sample of potassium. Determine the number of potassium-40 nuclei in your sample.

4. Calculate the half-life of potassium-40 using the following equation:

$$t_{1/2} = \left(\frac{0.693}{rate} \right) N_t$$

   Where: $t_{1/2}$ is the half-life of potassium-40
   rate is the average value of the potassium-40 activity x 5
   (Note: The Geiger counter only detects about 1/5 of the radiation from the sample.)
   N_t is the number of potassium-40 nuclei in your sample

   Express the half-life of the potassium-40 in years

5. Compare your calculated value of the half-life of potassium-40 to the published value. Calculate the % error.

6. Write the equations that illustrate the different types of radioactive decay potassium-40 can undergo.

7. How many different elements can be formed during the radioactive decay of potassium-40? What are they?

8. List three foods that you usually eat that contain potassium and how much potassium each contains.

9. What is the average amount of potassium in the human body?

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