Radioactivity

Workshop #12 **Physics 102** **April 17-19, 2008**
Name: ___________________ **Name of Instructor: _______________**
Name(s) of Lab Partner(s):________________Time/Day of Workshop: ________

Review

As you know, atoms consist of a nucleus at its center, plus electrons bound to it. The nucleus holds the positive charge of the atom. This charge results from the fact that *protons* are one of its two inhabitants. Each proton is positively charged. Its charge-magnitude is equal to that of the electron.

The nucleus has a second inhabitant, called the *neutron*. The neutron has zero electric charge.

Most atoms in nature are neutral. In a neutral atom, the number of electrons bound to the nucleus is equal to the number of protons within the nucleus.

As an example, consider *hydrogen*. By definition, all hydrogen atoms contain one proton in its nucleus. The most prevalent form of hydrogen contains zero neutrons in its nucleus. This is "ordinary" hydrogen. Its symbol is $^1H_1$. The subscript is the number of protons (one) in the nucleus. The superscript is the **sum total** of protons and neutrons (also one).

If a hydrogen nucleus contains 1 neutron, we call the nucleus *deuterium*. Hence, its symbol is $^2H_1$, as there are two particles in the nucleus. If the nucleus contains two neutrons, it is called *tritium*. The symbol, then, is $^3H_1$.

The term *isotope* denotes nuclei that contain the same number of protons, but differing numbers of neutrons. Thus, ordinary hydrogen, deuterium, and tritium are all isotopes of hydrogen, as the nuclei of all three contain just one proton.

Consider again the three isotopes of hydrogen – ordinary, deuterium and tritium.
It happens that the tritium nucleus is unstable. It breaks up, *(*called *decay)* spontaneously. It decays into $^3He_2$. In the process of this change, an electron is released. The electron is one example of what is called a *beta particle*.

Whenever a nucleus spontaneously emits a particle, the nucleus is termed *radioactive.* Hence, tritium is an example of a radioactive nucleus.

Another element with radioactive isotopes is *potassium* (symbol K). About 93% of the potassium on earth is of the isotope $^{39}K_{19}$. This means there are 19 protons (this defines potassium) and that the sum of the number of protons and neutrons is 39.

This prevalent isotope is not radioactive. But 0.012% of all potassium on the earth is the isotope $^{40}K_{19}$. This isotope *is* radioactive. Note that it has one more neutron (twenty one) than does $^{39}K_{19}$. When $^{40}K_{19}$ undergoes radioactive decay, a high-energy beta particle (electron) is emitted from its nucleus. One of its neutrons is transformed into a proton.

What is the resulting nucleus? Since there are now 20 protons, the nucleus is now represented by the symbol $^{40}Ca_{20}$. Note that calcium (symbol Ca) is defined by the fact that there are 20 protons in its nucleus. Note: the superscript does not change - a neutron is transformed into a proton, leaving their sum unchanged. Also, $^{40}Ca_{20}$ is stable.

Every second of the day, your body is bombarded by high energy radiation. Its origin is from the sun, or from other celestial objects. You cannot escape this radiation. This radiation is called *background radiation*. Today, you will investigate this radiation. You will then investigate some properties of radioactive $^{40}K_{19}$.

Equipment: Potassium chloride, Geiger tubes, counters, a ruler, a calculator.
Set of barriers: paper, cardboard, aluminum foil, aluminum slab, and lead slab.
Potassium Chloride.

Purpose: To learn methods for detecting and counting background radiation and also detecting particles emitted by deliberately-placed radioactive sources. Also, to learn some of the properties of radioactivity.

Part A. Geiger Counter Setup

Familiarize yourself with the Geiger counter. It is a device that is sensitive to high energy particles. If a high energy particle enters the counter, it produces ions in the gas that fill the tube. These ions then produce an electrical pulse. The electrical pulse then produces an audio pulse, and also registers a count on the counter.

Plug in the counter. Make sure that the switch on the back is set to 900 [V], and that the audio is in the **ON** position. Set the count mode to **Continuous**.

Turn on the Geiger counter. You should hear beeps. Each beep corresponds to the passage of a high energy particle passing through the tube. If you do not hear beeps, bring it to the attention of your instructor.

Part B: Quantitative Determination of the Background Radiation

i) Here, we will measure the background radiation around us. Use your watch to measure the number of counts which the Geiger counter records in a 60 second time interval. To do this, first, hold the RESET button. When you are ready to begin timing, let go of the RESET button. After 60 seconds, record the number of counts in Table 1 below. Repeat this 5 times.

Table 1

Trial	Number of Counts
1	
2	
3	
4	
5	
Average	

ii) Using the data from i), compute the average background radiation rate in counts per minute. You can use:

Rate (counts per minute) = Number of counts/time interval (in minutes).

Part C. Effect of the Tube-to-Source Distance on the Count Rate

Now examine the Geiger counter and its holder. You will notice that the plastic holder has six slots notched in its sides. These notches support a shelf which slides in and out. In the diagram below, the upper-most shelf is in position 1, and the bottom-most slot is in position 6.

i) Measure the distance from the opening to the tube, to the middle of each slot. Fill in your measurement-results in Table 2 below.

ii) Get about 1 teaspoon of potassium chloride (KCl) and place it on the shelf of position 1. Measure the number of counts which occur in 120 seconds. Then, repeat, for positions 2, 4, and 6. Don't forget to RESET after each measurement. Record your data in Table 2.

Table 2: Raw Count-Rates from KCl.

Shelf Position	Distance (cm)	# of Counts	Uncertainty in # of Counts	Count-Rate (in counts per minute)	Uncertainty (in counts per minute)
1					
2					
3					
4					
6					

The **uncertainty** in the number of counts can be shown, for radioactive decay, to be approximately equal to the *square-root of the number of counts*. Compute the uncertainties and fill in their values in the table.

The **count-rate** is obtained as before. Simply divide the number of counts by the time-interval. To get the count-rate uncertainty, divide the count uncertainty by the time interval. Fill in these last two columns of Table 2.

On Chart 1 on the next page, make a graph of the **count-rate** versus distance d. Draw circles to represent the points on this graph. Also, draw vertical lines through the center of the points, to indicate the uncertainty in your measurement. Refer to Figure 1 below, for an illustration of how to graph your data points.

Figure 1: Sample of the drawing of a data point and its uncertainty. In the Figure, we have graphed a fictitious measurement of a count-rate of 24 counts per minute, at a position of 1.9 cm from the opening to the Geiger tube. The uncertainty is 3 counts per minute.

Chart 1: The Graph of Count-Rate versus distance from radioactive source to the Geiger Tube

Part D: Computing the KCl Count-Rate.

The data you have collected (when KCl was on a shelf) includes more than the radiation from KCl. It also includes radiation from the background. To get the rate from just KCl, it is necessary to subtract out the background rate.

i) Refer to your results from Part B, for the background rate. Note the average value of your results for this entry. Then compute and record the "background-subtracted" count-rate (for KCl alone).

Note: The uncertainty-rate is the same as you found in Table 2.

Table 3: Background Subtraction of the KCl Count-rates

Shelf Position	Distance (cm)	Total Count-rate counts per minute	Background rate	Count-rate for KCl alone	Uncertainty rate
1					
2					
3					
4					
6					

ii) On Chart 2, given on the next page, graph the "background-subtracted" count-rate versus d.

iii) Do you observe that the KCl count-rate *increases, decreases*, or *remains the same* as d increases?

iv) If you found that the count-rate changes as d changes, is the change **linear** or **non-linear**?

Note: When we say that a change is *linear*, it means the following: You make a change in one variable. Call it Δx. Then, you observe the change resulting in the other variable. Call this change Δy. You then repeat the process, using the same Δx, but starting at some other value of x. If you get the same value for Δy as before, then the dependence is **linear**. This must be true, no matter what value of x you start with.

Graphically, it means that the graph is a straight line.

Chart 2

Part E: Effects of Barriers on the Counting Rate

You will now determine whether the beta particles (usually written as ß particles) emitted by KCl can penetrate various materials. The materials used as barriers will be paper, cardboard, aluminum foil, a thin aluminum slab, and a lead slab.

Place the KCl salt in Position 2. Measure the number of counts in a two-minute interval. Fill in your result in the row labeled *None* in Table 3 below.

Repeat the experiment with various barriers placed into Position 1 so as to block the path of the ß particles. Fill in your results in the Table.

Table 3: Effects of barriers in blocking the ß particles.

Barrier	# of Counts	Count Rate (units of counts per minute)
None		
Paper		
Cardboard		
Aluminum Foil		
Aluminum Slab		
Lead Slab		

Part F: Questions

1. How many protons, how many neutrons and how many electrons does $^{40}K_{19}$ have? Explain.

2. How does the KCl (alone) count-rate compare to the background rate? Answer this question for each observed value of d.

3. From the experiments, which materials were most effective at stopping the ß particles? Which material was the least effective?

4. Some of the background radiation has its origin in the sun. Other background radiation originates from other stars, or other celestial objects.

If ß particles are stopped by a piece of aluminum, then how might the background radiation from the sun or other celestial objects get through the roof, and into the room, and finally into the Geiger tube?

Hint: The background radiation might not be electrons!

5. Which of the two curves drawn in the graph below most closely resembles the shape of your graph of the KCl count-rate versus d, in Chart 2?

6. In the graph of Question 5, the straight-line graph represents a linear decrease with d. In contrast, the curved graph represents a dependence of the vertical coordinate on d that varies as $1/d^2$.

Which of these two dependences, (if either) would you expect for radioactive decay? To answer this question, first consider, for a moment another problem.

Paint is sprayed from a paint gun. Examine the paint that squirts out in a particular cone that emanates from the gun. It is intercepted by a square placed at varying distances from the gun. This is illustrated in the Figure below.

Suppose that we position the patch so that it is on a sphere of radius one meter from the gun. The paint then travels one meter. Suppose that it then happens to produce a patch of paint that is 1 millimeter thick.

How thick would the patch of paint be, if the experiment is done instead with the patch at a distance of two meters from the gun? Explain.

7. Based on the analogy with the paint spray problem, what dependence do you expect for the KCl count-rate on d? Why?

8. From inspection of your graph in Chart 2, is your data roughly consistent with your answer to Question 7? Explain how you came to your conclusion.

9. A characteristic time that tells you how unstable is a radioactive nucleus is the **half-life,** denoted as $\mathbf{T_{1/2}}$**.** This is the time it takes for half of an original quantity of a radioactive isotope to decay. For example, radium-226 (radium with a total of 226 protons and neutrons) has a half-life of 1,620 years. This means that half of any given specimen of radium-226 will be converted into other elements by the end of 1,620 years.

In contrast, $^{40}K_{19}$ has a much longer half-life of 1,260,000,000 years or 1.26×10^9 years.

Suppose you succeed in assembling 1 kilogram of pure $^{40}K_{19}$. The graph below gives the mass remaining, as time varies. Fill in the values on the time axis at the points indicated by the dashed lines.

10. Draw a rough sketch (qualitative, not quantitative) on the above graph to indicate the amount of radium-226 remaining, as time varies. Again, assume we start with 1 kilogram of radium-226.

11. The **mean life** τ of a radioactive nucleus can be defined by the relation

$$\tau = T_{1/2}/0.693.$$

More precisely, τ is the average lifetime of a radioactive nucleus.

The number of decays per time of a sample is called the **activity** A.
Precisely, it is defined by

$$\text{Activity A} = \Delta N/\Delta t.$$

Here, ΔN is the number of decays in the time-interval Δt.

It is not difficult to derive the basic result that enables easy computation of the activity:

$$\text{Activity A} = N/\tau.$$

Here, N is the number of radioactive nuclei in the sample.

Use this information to solve the following problem:

A typical human adult contains 140 grams of potassium, of which 0.0118 % is the radioactive isotope ^{40}K. This corresponds to about 2.5 x 10^{20} nuclei of K^{40}. It is the most radioactive part of the human body.

From this information, compute the number of disintegrations (i.e., the activity) in one second of ^{40}K in a typical adult.

Express your answer in the Standard International unit for activity – the **Becquerel (Bq).**
It is defined by

1 Bq = 1 disintegration per second.

12. A more traditional unit for activity is the **curie** (with abbreviation **Ci**).
Its definition is:

1 Ci = 3.70 x 10^{10} disintegrations per second, or 1 Ci = 3.70 x 10^{10} Bq.

Express the activity you found in Question 11 in terms of curi
e.