RADIOACTIVITY

Purpose

a. To measure the half-lives of ^{28}Al, ^{108}Ag, and ^{110}Ag.

b. To study the relative absorption of radiation in matter.

Theory

One way of looking at a nucleus is to think of it as a box, in which there are many particles, each with some energy. These particles continually exchange energy and, in some cases, an individual particle may acquire sufficient energy to penetrate the walls of the box. In the case of stable nuclei, the particles cannot get out of the box and the nuclei "live" forever. In the case of unstable nuclei, a particle does eventually get out of the box. Some unstable nuclei have high, thick walls - these are the long-lived nuclei. Others have low, thin walls - these are the short-lived nuclei, those that have a high probability of emitting particles and changing into different, more stable nuclei.

For all radioactive isotopes one finds that the "decay" curve (i.e., the plot of the number of disintegrations per second as a function of time) appears as shown in the graph below (Fig.1). When there are very many radioactive nuclei in a sample, then the number of disintegrations per second can be described extremely well by a probability curve. Even though each decay is a random event, the totality of events is described by a well-defined equation. In the case of nuclear decay, the equation describing the number of nuclei remaining at time *t* is an exponential decay curve:

$$N(t) = N_0 e^{-t/\tau} \qquad (1)$$

where *t* is the elapsed time, $N(t)$ is the number of nuclei that have not decayed after the time *t*, N_0 is the number of radioactive nuclei present at time $t = 0$, and τ is the mean lifetime of the nucleus. Frequently, it is more convenient to express the exponential decay in terms of the "half-life" of the nucleus, the time required for half of the nuclei to disintegrate. The relationship between the half-life, $T_{½}$, and the mean life, τ, is the following:

$$T_{1/2} = (\ln 2)\,\tau = 0.693\,\tau \qquad (2)$$

so we can write the decay equation in terms of $T_{½}$:

$$N(t) = N_0 e^{-0.693t/T_{1/2}} \qquad (3)$$

Note that the clock can be started at any instant. Hence, in a time $T_{½}$, half the starting number of nuclei will have decayed regardless of when the clock was started. The magnitude of the decay rate, $R(t) = dN/dt$ (number of disintegrations per second), is simply related to equation (3):

$$R(t) = R_0 e^{-0.693t/T_{1/2}} \qquad (4)$$

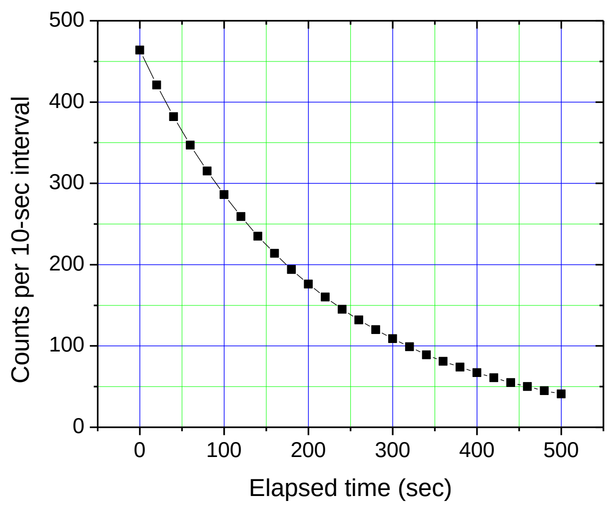

Fig. 1. Typical Linear plot of radioactive decay.

where $R_0 = 0.693\, N_0 / T_{½}$. Figure 1 shows a plot of data on linear scale graph paper. One can extract information about exponential behavior as linear information by using semi-logarithmic scale graph paper. Figure 2 is a plot of the same data as is used for Fig. 1; however, it is now plotted on semi-log paper. Why and to what advantage?

Taking the *ln* of both sides of Eq. 4 gives

$$\ln R(t) = \ln R_0 - 0.693t / T_{1/2} \qquad (5)$$

which is an equation of a straight line of the form $y = m\,x + b$. This makes analysis of the data to determine the half-life much simpler, especially when there are two or more radioactive isotopes present. Data analysis will be discussed in detail later.

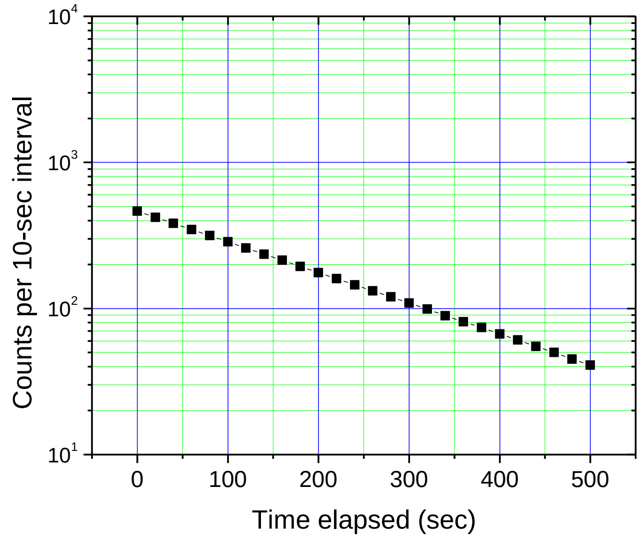

Fig. 2. Typical Semi-logarithmic plot of radioactive decay.

Apparatus

Activated aluminum discs, activated silver discs, Geiger-Mueller counter, digital clock timer, linear graph paper, semi-log graph paper, rulers, β source, γ source.

Description of Apparatus

The Geiger-Mueller Counter: One of the first devices used to detect radioactivity was a Geiger-Mueller tube, which is a gas-filled cylinder with a very thin metal wire down its center. A voltage difference is maintained between the center wire and the cylinder. If radiation interacts with the gas in the cylinder, ionization of the gas atoms takes place. Because of the voltage difference, the electrons move toward the center wire and the positive ions move toward the outer cylinder. This is an electrical discharge producing a pulse of current which can be counted. Each pulse indicates that a nucleus has decayed and the decay rate, $R(t)$, is measured by the number of pulses per second.

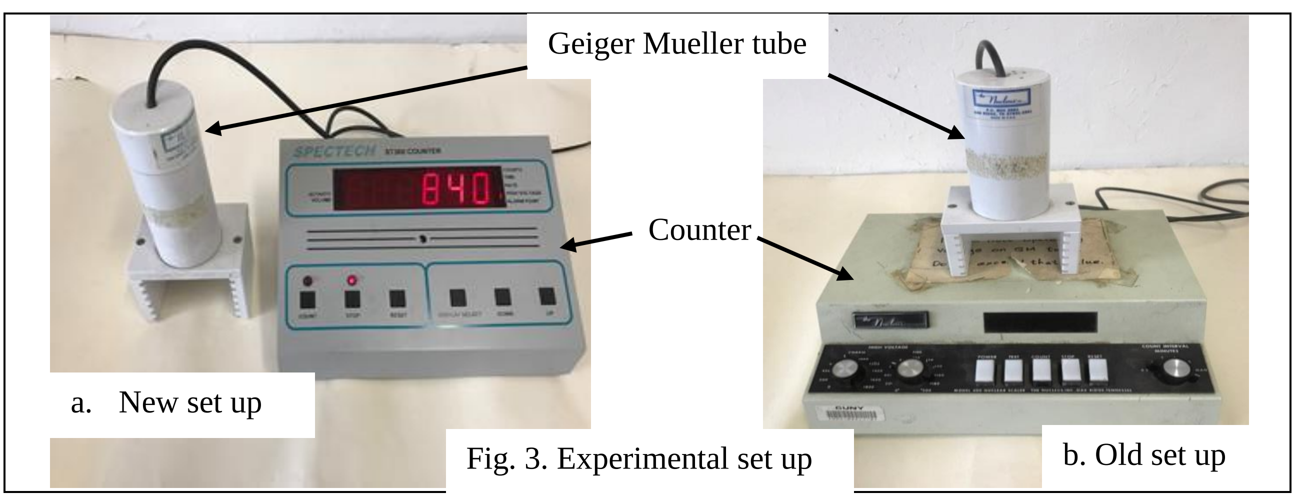

Fig. 3. Experimental set up

Warning: The voltage setting for the GM tube should be 840 volts. **Do not** exceed that.
Note the very thin beryllium window on the front of the tube. This window is fragile - keep all objects away from it.

Thermal Neutron Activation: Some radioactive isotopes occur in nature. Some stable isotopes, when bombarded with nuclear particles of appropriate energy, may be converted to different isotopes which are unstable (radioactive). In this exercise, stable aluminum and silver isotopes are bombarded by neutrons and made into radioactive isotopes of aluminum and silver. In the room adjacent to the laboratory is located a "neutron howitzer" which holds a source of neutrons, and paraffin which slows down the neutrons. When the **aluminum** discs are inserted into a cavity in the howitzer, some of the Al nuclei will capture a neutron thus creating a new isotope which is radioactive:

$$^{27}_{13}Al + ^{1}_{0}n \dashrightarrow ^{28}_{13}Al \dashrightarrow ^{28}_{14}Si + \beta^- , \qquad T_{1/2}(^{28}_{13}Al) = 2.24\, min.$$

When the **silver** foil is inserted into the howitzer, some of the silver nuclei will capture a neutron thus creating a new isotope which is radioactive. There are **two** stable isotopes of silver that can capture neutrons and become radioactive:

(i) $^{107}_{47}Ag + ^{1}_{0}n \dashrightarrow ^{108}_{47}Ag \dashrightarrow ^{108}_{48}Cd + \beta^- \quad T_{1/2}(^{108}_{47}Ag) = 2.37 min.$

(ii) $^{109}_{47}Ag + ^{1}_{0}n \dashrightarrow ^{110}_{47}Ag \dashrightarrow ^{110}_{48}Cd + \beta^- \quad T_{1/2}(^{110}_{47}Ag) = 24.6\, s$

SAFETY: Do not touch any radioactive material. Make sure that potentially-contaminated objects are not placed in the mouth. **Do not eat, drink**, apply cosmetics, or place fingers, pens and pencils in your mouth.

Procedure

Part I: Measuring the half-life of ^{28}Al

a. For those with the old style Geiger counters only (Fig. 3b, right side):

Familiarize yourself with the apparatus. Check to see that the voltage for the Geiger-Mueller tube is **off**. Practice synchronizing the starting and stopping of the counter with the clock timer, using the counter in the **test** mode. In the test mode, the counter generates 60 counts/sec internally. Let the clock timer run continuously as you start and stop the counter, alternately counting for 10 seconds and waiting for 10 seconds as described below.

After each 10-second counting interval, stop the counter. In the next 10 second interval, record the number of counts in the data sheet and reset the counter. **Do not stop the clock timer!!** The clock is recording the total elapsed time. You must be prepared to restart the counter at the beginning of the next 10-second interval, and repeat this process, without stopping the clock, until the measurement has been completed. Practice this technique until you can reliably get close to 600 counts for each 10-second interval of counting in the test mode.

b. For those with the new style Geiger counters only (Fig. 3a, left side):

Familiarize yourself with the apparatus. Turn on the voltage for the Geiger-Mueller tube, being very careful to set it at 840 volts. Ask your instructor to check. Practice synchronizing the starting and stopping of the counter with the clock timer. Let the clock timer run continuously as you start and stop the counter, alternately counting for 10 seconds and waiting for 10 seconds as described below.

Turn on the clock and simultaneously start the counter. Do not turn off the clock for the entire period during which you are making a measurement. After each 10-second counting interval, stop the counter. In the next 10 second interval, record the number of counts in the data sheet and reset the counter. **Do not stop the clock timer!!.** The clock is recording the total elapsed time. You must be prepared to restart the counter at the beginning of the next 10-second interval, and repeat this process, without stopping the clock, until the measurement has been completed. Practice this technique for 4 minutes. Expect to get between approximately 2 and 10 counts for each 10-second interval of counting, although it may be somewhat different.

c. For all students:

You are now ready to begin the **background** measurement as described below. During the background counting there should be no radioactive sources in the vicinity of your equipment. The major source of the background counts is cosmic radiation and decay of radioactive isotopes that might be found in the construction material of the building.

1. Measure the background radiation. Turn on the voltage for the Geiger-Mueller tube, being very careful to set it at 840 volts. Ask your instructor to check. Turn on the clock and simultaneously start the counter. Stop counting after 4 minutes. Divide the number of counts by 24 to get the average number of counts per 10 seconds. Record the counts in data sheet. Stop the clock and re-zero it, reset your counter and be prepared to begin measuring the activated sample **as soon as it is given to you.** The sample should be placed at the middle of the sample holder inserted in the upper-most slot.

2. Measure the activated **aluminum** radiation. The **aluminum** discs will be activated by bombarding with neutrons for about five minutes. This will be done by the instructor. Be prepared to start taking data **as soon as an activated disc is given to you**. Remember, in **two** minutes the $^{28}_{13}\mathbf{Al}$ isotopes will have been decaying for almost one half-life, leaving about one half of the active material with which you started. Measure the activity from the activated aluminum disc using the following procedure.

   Do not turn off the clock for the entire period during which you are making a measurement. After each 10-second counting interval, stop the counter. In the next 10 second interval, record the number of counts in the data sheet and reset the counter. **Do not stop the clock timer!!** The clock is recording the total elapsed time. You must be prepared to restart the counter at the beginning of the next 10-second interval, and repeat this process, without stopping the clock, until the measurement has been completed. You are taking data in each 20-second intervals (!). Record the data in table 1 for at least 8 minutes. **It is essential that there be no gaps in the counting.** *If for some reason you are unable to record a count for a given interval, leave a blank space on the data sheet and proceed to the next interval.*

3. If your data do not look sensible or if you miss too many counting intervals then you should repeat the measurement in step 2 above using a freshly activated **aluminum** disc.

Part II : Measuring the half-lives of ^{108}Ag, and ^{110}Ag

Repeat *Part I* **c**, except this time for silver instead of aluminum and record the data in table 2. Since one isotope of silver has a half-life of only 24.6 s, it is imperative that you begin the counting procedure in **c.** 2 above ***IMMEDIATELY*** upon receiving the silver sample, as the radioactivity of the short-lived isotope will dissipate rather rapidly.

Computation

a. For Aluminum

Subtract the average background count for l0 seconds from each of the data points in table 1. Plot your data on linear graph paper as illustrated in Fig. 1 and then on the semi-log graph paper as illustrated in Fig. 2.

Why do the graphs appear different for the same data?

Referring to Fig. 2, determine the half-life by drawing the best-fit straight line through the data points in the time interval of data taken. The half-life is simply the value of *t* on the line where the ordinate is $\frac{1}{2}N_0$, where N_0 is the ordinate of the **line** at $t = 0$. Compare your experimental results with the accepted value given for the isotope $^{28}_{13}Al$. Calculate the percent error. If your result is quite different from the accepted value, you should repeat the measurement using a freshly activated aluminum foil.

b. For Silver

After subtracting the average background count for l0 seconds from each of the data points in table 2, plot your data on the semi-log graph paper as illustrated in Graph below (Fig. 4).

There are two silver isotopes which have been activated, each having a different half-life. Referring to the Graph in Fig. 4, determine the longer half-life by drawing the best straight line through the data points in the time interval of data taken from about three to eight minutes. (In the report discuss why.) Name this line "line (1)". **On line (1)**, choose values of $N(t_1)$ and $N(t_2) = \frac{1}{2} N(t_1)$. For example, referring to the sample data below, we might choose points "a" and "b" on line (1) with $N(t_1) = 320$ and $N(t_2) = 160$. The time interval $(t_2 - t_1)$ is the half-life of the longer-lived isotope ^{108}Ag; in this example it is (220 - 78) s = 142 s = 2.37 min. Repeat this determination for 2 other pairs of points on the curve and take the average of the 3 determinations. Estimate the experimental uncertainty in your measured value for the half-life.

Next, subtract the value of line (1) from each of your data points. Example for this data analysis is given on next page. Plot the results of the subtraction on the graph and draw the best straight line through these points, i.e., line (2). Determine the half-life of the second isotope from line (2) in the same manner as you did for line (1). The second isotope is the shorter-lived one (^{110}Ag).

Compare your experimental results with the accepted values given for the two isotopes of silver. Calculate the percent errors.

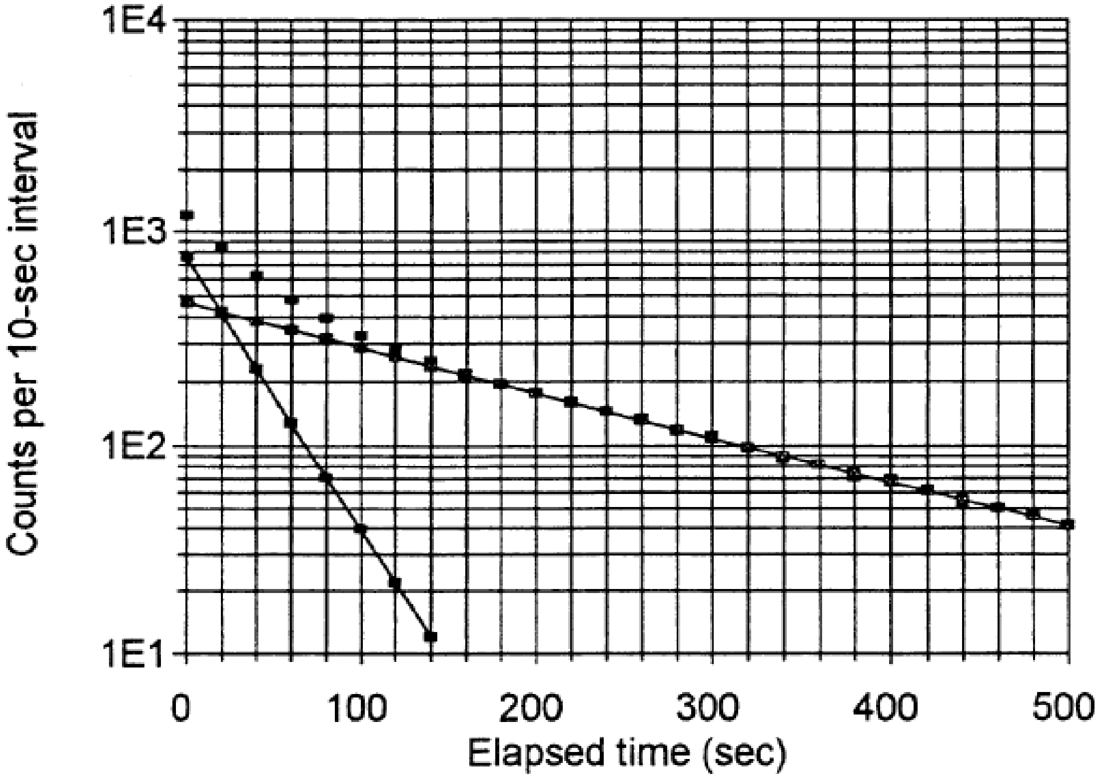

Fig. 4. Semi-Logarithmic plot of radioactive decay of Silver 108 and Silver 110.

The example below illustrates the procedure for data analysis. The graph is for the data given in the following table. Background counts have been subtracted.

Time (sec)	N- Bkgd.	Straight Line Fit to T_{long}	Difference (T_{short})		Time (sec)	N- Bkgd.	Straight Line Fit to T_{long}	Difference (T_{short})
0	1200	464	736		260	134	132	2
20	841	421	420		280	119	120	-1
40	614	382	232		300	112	109	3
60	476	347	129		320	98	99	-1
80	392	315	77		340	87	89	-2
100	323	286	37		360	82	81	1
120	282	259	23		380	71	74	-3
140	248	235	13		400	70	67	3
160	219	214	5		420	62	61	1
180	196	194	2		440	53	55	-2
200	177	176	1		460	51	50	1
220	161	160	1		480	47	45	2
240	146	145	1		500	42	41	1

Part III: Relative absorption of radiation in matter

(This part of the experiment is optional at the discretion of your instructor)

Introduction: When any kind of radiation (α, β, γ) passes through matter, some of the radiation is absorbed or scattered. We use the term "attenuation" to refer to the reduction in intensity of the transmitted radiation. The attenuation depends on several factors:

i) the type of radiation

ii) the kind of material through which the radiation passes

iii) the thickness of the absorbing material

In this part of the experiment you will be studying the absorbing properties of several different materials for two types of radiation, β (energetic electrons) and γ (energetic photons corresponding to high-frequency electromagnetic radiation). The radiation is produced by standard radioactive sources which are labeled according to the type of radiation produced. They will be distributed by the instructor when you are ready to use them. Note that the sources are very weak and are safe to handle (but be sure to return them when you are finished!).

Procedure: Absorption of β-rays (yellow disc) and γ-rays (black disc).

Insert a disc two slots below the GM tube.

Measure the number of counts in one minute.

Insert a paper (cardboard) shield in the slot next to the GM tube and again measure the number of counts for one minute.

Repeat with the aluminum and separately the lead shields.

Using the other disc, repeat all of the steps above.

Record your data (number of counts in one minute) in Table 3.

In your report discuss the effectiveness of each shield as protection from each of the radiations.

Question:

Suppose a radioactive nucleus has a half-life of 2 min. and suppose the counting rate at $t = 0$ is 3000 counts/s.

a. What is the counting rate after 2 min?
b. After 6 min?
c. After 10 min?
d. After 20 min?
e. What is the mean life of this nucleus?
f. Suppose that the Geiger counter detects 10% of all the radioactive decays. What is the total number of radioactive nuclei at time $t = 0$?
g. What is the total number at $t = 2$ min?
h. How many nuclei decay in the first 2 minutes?
i. What is the initial decay rate?
j. Why is the answer in h. not equal to the answer in i. times 120 sec?

Data Sheet

Date experiment performed:

Name of the group members:

Table 1. Radioactive Decay of Aluminum

Background counts in 4 min ______ Average background in 10 s ________

Count interval (s)	Elapsed Time (s)	Trial 1 Counts	Trial 2 Counts	Counts – Bkgd. Trial 1	Counts – Bkgd. Trial 2
0 - 10	0				
20 - 30	20				
40 - 50	40				
60 - 70	60				
80 - 90	80				
100 - 110	100				
120 - 130	120				
140 - 150	140				
160 - 170	160				
180 - 190	180				
200 - 210	200				
220 - 230	220				
240 - 250	240				
260 - 270	260				
280 - 290	280				
300 - 310	300				
320 - 330	320				
340 - 350	340				
360 - 370	360				
380 - 390	380				
400 - 410	400				
420 - 430	420				
440 - 450	440				
460 - 470	460				
480 - 490	480				
500 - 510	500				

$T_{1/2}$ (^{28}Al) = ______________(from graph). % error = ________________

Table 2. Radioactive Decay of Silver

Background counts in 4 min ______ Average background in 10 s _______

Count Interval (s)	Elapsed Time (s)	Counts	Counts - Bkgd.	Straight line fit to T_{long}	Difference (T_{short})
0 - 10	0				
20 - 30	20				
40 - 50	40				
60 - 70	60				
80 - 90	80				
100 - 110	100				
120 - 130	120				
140 - 150	140				
160 - 170	160				
180 - 190	180				
200 - 210	200				
220 - 230	220				
240 - 250	240				
260 - 270	260				
280 - 290	280				
300 - 310	300				
320 - 330	320				
340 - 350	340				
360 - 370	360				
380 - 390	380				
400 - 410	400				
420 - 430	420				
440 - 450	440				
460 - 470	460				
480 - 490	480				
500 - 510	500				

$T_{1/2}$ (^{108}Ag) = __________*(from graph).* $T_{1/2}$ (^{110}Ag) = ____________*(from graph).*

% error = ___________________ % error = ___________________

Table 3. Relative absorption of radiation in matter

Number of counts in one minute

	No Shield	Paper	Al	Lead
β Absorption				
γ Absorption				