RADIOACTIVITY - MEASUREMENT OF HALF-LIFE

Purpose: To measure the half-lives of Ag-108 and Ag-110. To study the relative absorption of radiation in matter.

Apparatus: activated silver foil, Geiger-Mueller counter, digital clock timer.

References:

Introduction:

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 (Radioactive Decay of Silver 108 and 110). 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:

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

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, is the following:

$$T_{½} = (\ln 2)\,\tau = 0.693\,\tau \qquad (2)$$

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

$$N(t) = N_o\, e^{-0.693\, t / T_{½}} \qquad (3)$$

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):

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

where $R_o = 0.693\, N_o / T_{1/2}$.

Graph A (p.58) 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. Graph B (p.58) is a plot of the same data as is used for Graph A; however, it is now plotted on semi-log paper. Why and to what advantage? Taking the ln of both sides of eq. 4 gives

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

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

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.

Warning: Do not exceed the Voltage setting for the GM tube as listed for each instrument. 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 silver isotopes are bombarded by neutrons and made into radioactive isotopes of silver.

In the room adjacent to the laboratory is located a large tub of water, the hydrogen of which absorbs neutrons. This tub of water serves as a protective shield against neutrons. In the center of the tub of water is a small amount of polonium, which is radioactive and emits alpha particles (helium nuclei). The alpha particles strike a beryllium target and produce neutrons by the following nuclear reaction:

$$\text{Beryllium}\,(9) + \alpha\,(4) \longrightarrow \text{neutron}\,(1) + \text{Carbon}\,(12)$$

When the silver foil is inserted into the tub, 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) Ag-107 + neutron ----> Ag-108 ----> Cd-108 $T_{½}$ (Ag-108) = 2.41 min.

(ii) Ag-109 + neutron ----> Ag-110 ----> Cd-110 $T_{½}$ (Ag-110) = 24.4 sec.

<u>Procedure - Part I.</u>

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 (your instructor will demonstrate).

After each 10-second counting interval, record the information and clear the counter during the next 10-second interval. <u>Do not stop the clock timer</u> !! 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.

Turn on the voltage for the Geiger-Mueller tube, being very careful to set it at the correct voltage listed on your apparatus. Ask your instructor to check. 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 found in the construction material of the building.

The silver foils 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 foil is given to you. Remember, in one minute the silver-110 isotope will have been decaying for almost three half-lives, leaving about an eighth of the active material with which you started. The instructor will review procedures for handling activated foils and taking data.

1. Measure background radiation. A sample data sheet which will help you in the experiment is included. Turn on the clock and simultaneously start the counter. <u>Do not turn off the clock for the entire period during which you are making a measurement.</u> After 10 seconds stop the counter. In the next 10 second interval, record the number of counts and reset the counter. Repeat the procedure until you have obtained 10 data points for the background. 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.

2. Measure the activity from the activated silver foil using the same procedure as in (1). Record the data for at least 8 minutes.

3. If your data do not look sensible or if you miss too many counting intervals then you should repeat the measurement in (2) using a freshly activated silver foil.

4. After subtracting the average background count for 10 seconds from each of the data points of (2), plot your data on semi-log graph paper as illustrated in Graph B.

Data Analysis and Interpretation of Data:

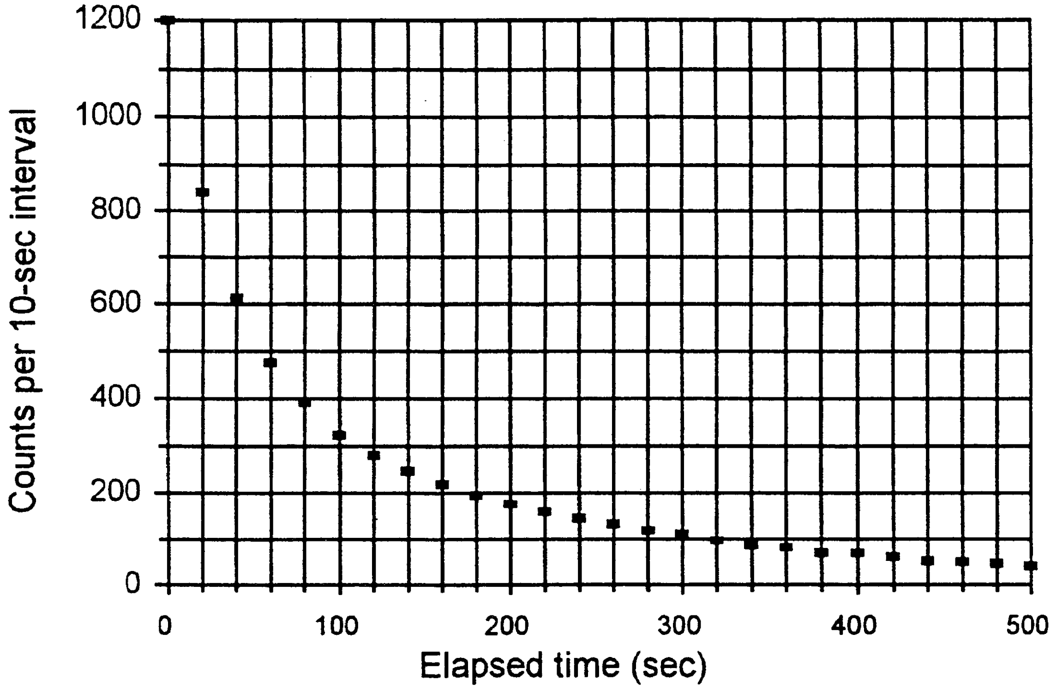
There are two silver isotopes which have been activated, each having a different half-life. Referring to Graph B, determine the longer half-life by drawing the best straight line through the data points in the time interval of data taken from about three to eight minutes (In the report discuss why). This is illustrated as line (1) on the graph. On line (1), choose values of $N(t_1)$ and $N(t_2) = N(t_1)/2$. For example, referring to the sample data below, we might choose points "a" and "b" 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 (Ag-108); in this example it is (220 - 78) sec = 142 sec = 2.37 minutes. **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. 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 (Ag-110).

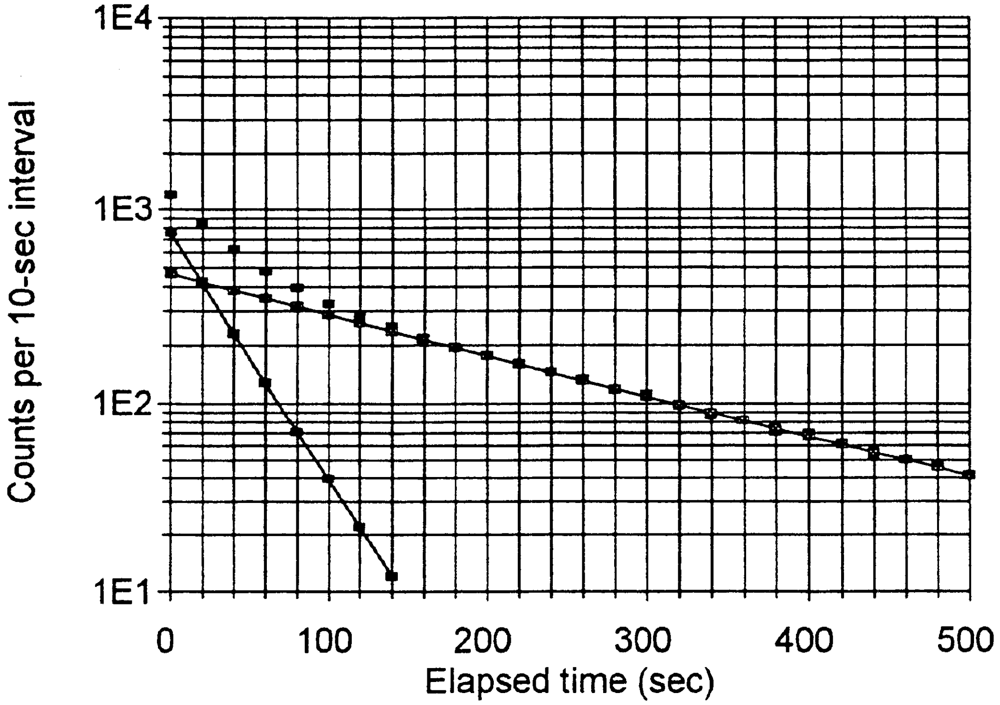
Compare your experimental results with the accepted values given for the two isotopes of silver. Calculate the percent deviations.

The example below illustrates the procedure for data analysis. The graphs (A and B) are for the data given in the following table. Background counts have been subtracted.

Time (sec)	N - Bkgd.	Straight Line Fit to Tlong	Difference (Tshort)		Time (sec)	N - Bkgd.	Straight Line Fit to Tlong	Difference (Tshort)
0	1200	464	736		260	134	132	2
20	841	421	419		280	119	120	-1
40	614	382	231		300	112	109	3
60	476	347	129		320	98	99	-1
80	392	315	77		340	87	89	-3
100	323	286	37		360	82	81	0
120	282	259	22		380	71	74	-3
140	248	235	12		400	70	67	3
160	219	214	5		420	62	61	1
180	196	194	1		440	53	55	-3
200	177	176	0		460	51	50	0
220	161	160	1		480	47	45	1
240	146	145	0		500	42	41	0



Graph A. Linear Plot of Radioactive Decay of Silver 108 and 110



Graph B. Semi-Logarithmic Plot of Radioactive Decay of Silver 108 and Silver 110

Radioactive Decay of Silver Data Sheet Experiment # 13

Count Interval Sec.	Elapsed Time Sec.	Backgnd Counts	Trial 1 Counts	Trial 2 Counts
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			
490-510	500			

Part II of this experiment is optional, at the discretion of your instructor. It is described on the following page.

Part II.

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 entirely 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 one of the shields , i.e., paper in the slot next to the GM tube and again measure the number of counts for one minute.
Repeat with the Al and separately the lead shields.
Using the other disc, repeat all of the above.

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

Beta Absorption Data: No Shield________; Paper________; Al________; Lead________

Gamma Absorption Data: No Shield________; Paper________; Al________; Lead________

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