Aluminum Half-Life Experiment

Definition of half-life ($t_{½}$):

The half-life of any declining population is the time required for the population to decrease by a factor of 50%. Radioactive isotopes represent a declining population and therefore have a characteristic half-life that can be measured in the laboratory.

Neutron Activation:

Naturally occurring radioactive isotopes have such long half lives that it is impractical to utilize one of them for a simple laboratory experiment. Generating a short lived radioactive nuclide requires altering the proton / neutron ratio of a existing isotope. One method for creating radioactive isotopes is the addition of a neutron to a stable isotope through neutron activation.

The OSU Radiation Center houses a General Atomic TRIGA Mark II Reactor. This reactor is fueled with ^{235}U which produces neutrons as the fuel is consumed. The equation below represents a typical fission reaction.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{56}Ba + ^{93}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$

Fission of ^{235}U produces 0 to 7 neutrons with an average of 3 neutrons per fision. The design of the TRIGA reactor makes it an effective instrument for the production of radioactive isotopes. Samples introduced into the reactor core through one of the various TRIGA sample loading facilities will be exposed to a field of neutrons. The neutron field has been measured at 3×10^{13} neutrons / cm^2 / second at the pneumatic terminal when the reactor is operating at 1 Megawatts.

Aluminum foils with a mass of 12 mg each (2.7×10^{20} atoms) have been prepared for this laboratory experiment. These foils will be sealed in a polyethylene vile for insertion into the TRIGA reactor utilizing a pneumatic (rabbit) transfer system. The reactor will be operating at a power level of 100 Watts with a neutron flux of 1×10^9 neutrons / cm^2 /sec. for this activation. The sample will remain in the core for 1 minute. When aluminum is placed in a field of (thermal) neutrons the following process occurs.

$$^{27}_{13}Al + ^{1}_{0}n \rightarrow ^{28}_{14}Al + \gamma \qquad (1)$$

The ^{28}Al isotope is unstable. It will decay into silicon with the release beta particles and gamma photons as illustrated below:

$$^{28}_{13}Al \rightarrow ^{28}_{14}Si + ^{0}_{-1}\beta + \gamma \qquad (2)$$

At the end of the irradiation each foil will contain 4×10^6 radioactive ^{28}Al atoms.

Radioactive Decay:

Nuclear decay is a spontaneous process in which the rate of decay is proportional to the number of unstable nuclides in the sample. The decay rate is the number of nuclear disintegrations per unit time. The mathematical expression for the decay rate is

$$\frac{-dn}{dt} = kN \qquad (3)$$

where:

1. dn = a differential of counts
2. dt = a differential of time
3. k = the first order rate constant
4. N = the number of unstable radioactive nuclides

Integration of this first order rate equation results in a useful equation

$$\ln(N) = -kt + \ln(N_0) \qquad (4)$$

where $\mathbf{N_0}$ is the initial number of unstable nuclei and **N** represents the number of unstable nuclei at some later time **t**. This equation predicts that a plot of **ln(N)** vs. **time** should result in a straight line with **slope = -k**.

$$slope = \frac{\ln(y_2) - \ln(y_1)}{x_2 - x_1} = -k \qquad (5)$$

Another useful constant that can be derived from k is the half-life or $t_{½}$. By definition, when $t = t_{½}$, $N_0 = 1$, and N =½. Substituting these values into the previous equation results in the following:

$$\ln(½) = -kt_{½} + \ln(1) \qquad (6)$$

Solving this equation for $t_{½}$ gives us the equation:

$$t_{½} = 0.693 / k \qquad (7)$$

From this we can conclude that $t_{½}$ is dependent only on the rate constant k. The half-life is not dependent on the original sample activity.

Experimental Procedure

Safety Considerations:

Safety equipment is not required for this laboratory. The levels of radiation are not significantly above background levels. A safety orientation is required for participation in the experiment. It is extremely important that you remain with the group at all times while in the Radiation Center facility.

<u>Part 1</u>: Preparation for the Experiment

1. Read this document before beginning the experiment.
2. Supplies needed: This experiment, graph paper, pencil, straight edge and scientific calculator.
3. The Radiation Center is located at 35th and Jefferson in Corvallis. Parking is available on Jefferson Street west of 35th Street. A temporary permit is available when parking in the <u>student section</u> of the Radiation Center parking lot. Please inquire at the front desk.

<u>Part 2:</u> Laboratory and Tour

1. The laboratory instructor will escort the class to C120 to begin the safety orientation. Work in groups of 2 or 3. The instructor will provide a review of the experiment and will conduct a demonstration of the equipment.
2. Begin the 20 minute background count before leaving for the reactor tour. Stay with the group when being escorted to and from the TRIGA conference room.

<u>Part 3:</u> Data Collection, Calculations and Plot

1. When you return from the tour, record the background count. The low count rate represents the “background” radiation entering the counter from various sources: stray impurities, cosmic particles, radionuclides in or on nearby objects. Compute the background counts per minute (cpm) by dividing the number of counts recorded by the time interval in minutes. Record the results in the background data table and place the calculated Background CPM value in column 5 of the aluminum data table.
2. After your sample has been mounted, begin counting as directed by the instructor. Set the count window ( ) t) for 0.2 minutes. Collect one value every minute resetting the counter after each count.
3. Record the aluminum sample counting events in the counting table. Calculate the Gross CPM for aluminum by dividing the Gross Counts by 0.2 minutes. Calculate the Net CPM for aluminum by subtracting the Background CPM from Gross CPM as in the example below:

Example of Aluminum Sample Counting Table

Clock Time	Gross Counts	Count Time) t (min)	Gross CPM	Background CPM	Net CPM	ln(Net CPM)	Time (min)
09:33	1070	0.2	5350	18	5332	8.581	0
9:34	877	0.2	4385	18	4367	8.381	1

Background Counting Table		
Total Background Counts	Background Count Time	Background CPM
	20 minutes	

Aluminum Sample Counting Table							
Clock Time	Gross Counts	Count Time) t (min)	Gross CPM	Background CPM	Net CPM	ln(Net CPM)	Time (min)
		0.2					0
		0.2					1
		0.2					2
		0.2					3
		0.2					4
		0.2					5
		0.2					6
		0.2					7
		0.2					8
		0.2					9
		0.2					10
		0.2					11
		0.2					12
		0.2					13
		0.2					14

4. Construct a plot of the data using either (1) Net CPM on semilog graph paper, and / or (2) ln(Net CPM) on normal linear graph paper (teachers option). Set scales to utilize the complete page of graph paper. Draw a best fit line through the data points with equal numbers of points above and below the line. Compute the slope of the line by selecting points at either end of the line. Read the coordinate values from the line.

Slope = ______________

5. Convert the slope to a RATE CONSTANT, k, in min^{-1}.

k = ______________

6. From the rate constant, k, calculate the half-live of ^{28}Al in minutes.

$t_{½}$ = ______________

7. Check your results by finding the half-life directly from your graph. Place marks on the x axis of your graph where your line crosses 1000 CPM (ln(1000) = 6.91) and then at 500 CPM (ln(500)=6.21). The difference in time between these two marks is the half-life of aluminum.

$t_{½}$ from graph = ______________

8. Calculate the reliability of this experiment using the calculated half-life value for all of the groups in the class. Average all half- life results. Calculate a deviation for each half-life. Average the absolute value of the deviations.

Group #	$t_{½}$	Average	Absolute Value of Deviation	Average Deviation
1				
2				
3				
4				
5		______________		______________
6				
7				
8				
Sum of t½:		Sum of Dev.		

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