Experiment 13: Radioactivity

Pre-lab questions

1. (1 point) What is *half-life* of a radioactive isotope?

   a. The time it takes for half of the nuclei to decay.

   b. Half the time it takes for all the nuclei to decay.

   c. The average time you will live after being exposed to the radiation.

2. (1 point) In Activity 1, you will simulate radioactive decay of different isotopes by rolling painted cubes. In any turn, what is the probability that a given cube will land with a blue face up?

   a. 1/6.

   b. 1/2.

   c. 1/3.

   d. 1/4.

3. (1 point) In Activity 2, "Distance and Shielding", what will you measure?

   a. The distance from one end of a radioactive source to the other.

   b. The energy of the radiation emitted from a source.

   c. The rate the detector detects radiation.

   d. The number of radioactive atoms in the source.

4. (1 point) In Activity 3, "Uses and Risks of Radioactivity", what is the ratio N_d/N_p?

   a. The ratio of daughter atoms to parent atoms.

   b. The age of the sample in years.

   c. The half-life of the isotope being studied.

   d. The radioactivity of the sample.

These questions are provided for your convenience. Submit your answers to these questions on Sakai before the first lab period begins. Do not submit them in your lab section.

EXPERIMENT 13. RADIOACTIVITY

13.1 Problem

- To gain familiarity with radioactive decay, its usefulness and potential dangers

13.2 Equipment

25 small color-marked cubes (one side red, two sides blue, three sides white), Geiger counters, cloud chamber, small radioactive sources, ruler, sheets of paper, book

13.3 Background

Stable atomic nuclei balance the attraction of the *strong nuclear force* between protons and neutrons against the repulsion of protons due to the *electric force*. Only specific combinations of protons and neutrons effectively balance these forces and remain stable through time. Unstable combinations of protons and neutrons exist in nature, however, and periodically nuclei transmute into more stable combinations by emitting particles and energy. The particles released by radioactive decay are very energetic and they wreak havoc on the electron shells of surrounding atoms and molecules as they collide with them.

During any period of time, an unstable nucleus has some chance that it will decay. The decay probability depends only on what particular isotope the nucleus is, that is, on the number of protons and neutrons it contains. The decay probability does not change with time: a five-year old nucleus of cobalt-60 has exactly the same chance of decaying in the next minute as a three-day old cobalt-60 nucleus. If both nuclei survive the next minute, their chances of decaying in the following minute will still be exactly the same as their chances were in the previous minute.

The rate of decay for a radioactive isotope is often expressed in terms of half life—the time for one half of a radioactive quantity to decay. Half life is inversely related to the probability of decay in a particular time interval: a nucleus with a high probability of decay in a 1-minute period has a short half life, while a nucleus that is very unlikely to decay in the same period has a correspondingly longer half life. Each radioactive isotope has its own characteristic half life (see table below). For example, the most common naturally occurring isotope of uranium, uranium-238, decays into thorium-234 with a half life of 4.51×10^9 years. This means that only half of an original amount of ^{238}U remains after this time. After another 4.51×10^9 years half of this decays, leaving only one fourth of the original amount remaining. Compare this with the decay of polonium-214, which has a half life of 1.6×10^{-4} seconds. With such a short half life, any sample of polonium-214 will quickly disintegrate.

Half-Lives of Some Nuclei

Element	**Half Life**
Uranium-238	4.51×10^9 years
Plutonium-239	2.44×10^4 years
Carbon-14	5730 years
Lead-210	20.4 years
Bismuth-210	5.0 days
Polonium-214	1.6×10^{-4} seconds

The half life of an isotope can be calculated by the amount of radiation coming from a known quantity. In general, the shorter the half life of a substance, the faster it decays, and the more radioactivity per amount is detected.

This lab includes a demonstration of radioactivity in the world around us and three activities. Be sure to complete all of the activities and turn in your completed report before you leave.

13.4 Activities

Activity 1: To Half or Half Not

(from *Conceptual Physical Science (3rd ed.) Laboratory Manual* by Hewitt, Suchocki, and Hewitt, pp. 107–110.)

In this activity, you will investigate three hypothetical substances, each represented by a color on the face of a cube. The first substance, represented by red, is marked on only one side of the cube. The second substance, represented by blue, is marked on two sides of the cube, and the third substance, represented by white, is marked on the remaining three sides. The process of decay for these substances is simulated by rolling a large number of these identically painted cubes. As a substance's color turns face up, it is considered to have decayed and is removed from the pile. This process is repeated until all of the cubes have been removed. Since the color of the first substance is only on one side, this substance will decay the slowest, that is, its color will fall face up least frequently and it will take the longest before all the cubes are removed. The second substance, marked on two sides, will decay faster requiring fewer rolls before all the cubes are removed. The third substance, marked on three sides, will decay the fastest. After tabulating and graphing the numbers of cubes that decay in each roll for these simulated substances, you will be able to determine their half-lives.

Procedure:

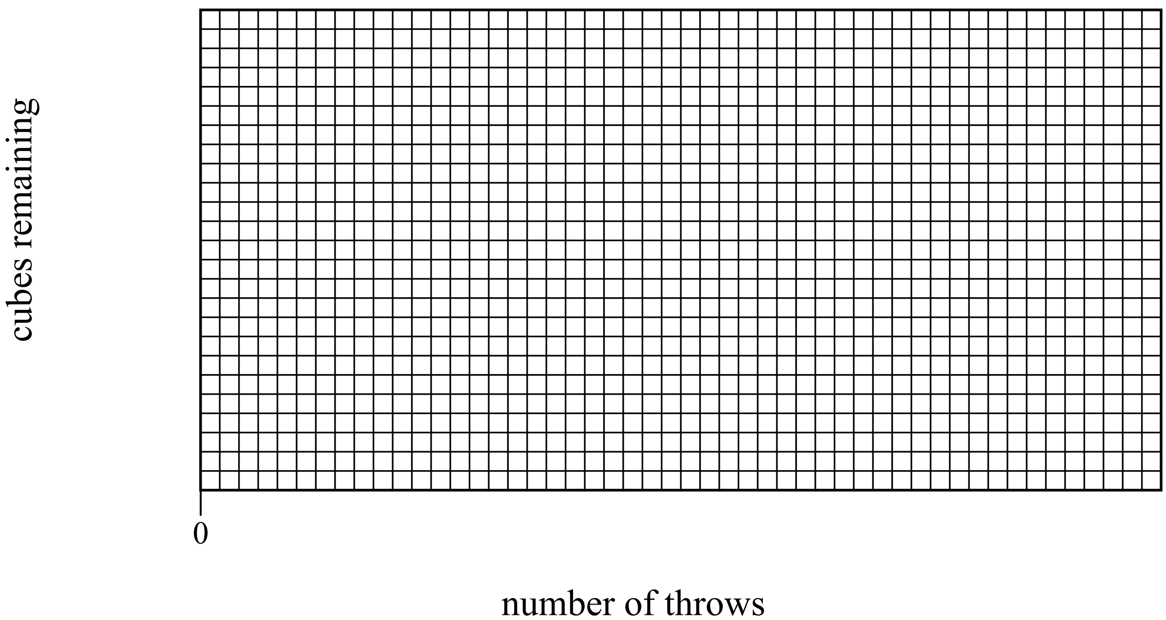
1. Shake the cubes in a container and roll them onto a flat surface.
2. Count the red faces that are up and record this number under "Removed" in Table 1.

3. Remove the red cubes to a pile off to the side.
4. Record the number of cubes remaining in the “Remaining” column.
5. Gather the remaining cubes back into the container and roll them again.
6. Repeat steps 2-4 until all cubes have been counted, tabulated and set aside.
7. Repeat steps 1-5 removing cubes that show the blue faces up.
8. Repeat steps 1-5 removing cubes that show the white faces up.

Table 1. Simulated radioactive decay (4 points)

Throw	Red		Blue		White	
	Removed	Remaining	Removed	Remaining	Removed	Remaining
Initial Count	0		0		0	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

9. (0.8 point) Plot the number of cubes remaining vs. the number of throws for each substance on a graph. Use a different color to graph the results for each substance. For each color, draw a single smooth line or curve that approximately connects all points. Include a legend with the graph to tell which line color corresponds to which face color. Don't forget to scale the graph to use as much of the horizontal axis as you can.



Questions:

1. (0.3 point) How many rolls did it take for the number of cubes of each color to be reduced by half? These are your half-life readings.

Red __________ Blue __________ White ___________

2. (0.3 point) In each case, how many rolls did it take to remove all of the cubes?

Red __________ Blue __________ White ___________

3. (0.4 point) If each of these three hypothetical substances emitted exactly the same radiation with each decay, which would be the most harmful in terms of radioactivity? Explain your answer.

4. a) (0.2 point) Are the lines in your graph fairly straight or do they curve?

b) (0.2 point) Do these lines result from a constant or changing rate of decay? (*Hint:* Rate of decay = Δnuclei/Δt = slope of the plot.)

5. (0.8 point) If substance X has a half-life of 10 years, how much of an initial sample of 1000 g of substance X will be left after:

10 years?

20 years?

50 years?

100 years?

Activity 2: Distance and Shielding

The amount of radiation per time received from a source depends on the amount and type of radiation emitted by the source, the distance from the source, and absorption of the radiation by intervening materials. You will briefly investigate these different factors using a Geiger counter and actual radioactive samples.

Geiger Counter operation

The wand generates an electrical signal when a radioactive decay particle strikes a foil window. The signal is received by the meter, which outputs it as a "click" on the loudspeaker and as a deflection of the display needle. The "high voltage" knob adjusts the sensitivity of the wand. Keep its setting constant.

The "range" selector switch adjusts the response of the display needle. Increasing the setting decreases the sensitivity of the meter. If the range selector is set to 500 or 2000, read the meter as indicated. If the range selector is set to 5000 or 20,000, multiply the reading on the dial 10 ×. If the range selector is set to 50,000, multiply the dial reading by 100 ×. Do not set the selector to High Voltage.

The display needle moves slowly, so that it displays an average event rate over the last several seconds. This works well when there are so many decay events that the number does not change much from second to second. When the decay rate is slow, it becomes necessary to count each click.

Measurements

1. Hold the wand of the Geiger counter away from solid objects and especially away from any known radiation sources. Adjust the voltage and amplification of the Geiger counter so that you hear slow, irregular clicking. This is the background emitted by cosmic rays and radioactive elements in the air. The background event rate is too slow for the display needle to show a reliable average. To find the background rate, manually count the clicks for 60 s. Record it in Table 2.

2. There are several radioactive sources in the lab. Place the windowed side of the wand directly against a source and wait for the Geiger counter's needle to reach an approximately steady value. If the needle pegs, select a higher display range. Record this count rate in Table 2.
3. While holding the windowed side of the wand toward the radioactive source, measure the count rate 2 cm, 5 cm, 10 cm, and 20 cm from the source. Record these values in Table 2. Also record the count rate measured with the detector as close as possible to the source but with three sheets of paper and with a book between the source and the detector wand. Adjust the display range as needed to obtain a reliable measurement.
4. Repeat these measurements with the different types of radioactive sources available.

Table 2. Count Rates (4 points)

units: ___________________							
background: _____________							
	distance (cm)					**shielding**	
Source	**0**	**2**	**5**	**10**	**20**	**paper**	**book**

Questions:

1. (1 point) How is the count rate affected by distance from the source? Answer for each individual source. Is the count rate influenced by distance in the same way for all sources?

2. (1 point) Is the radiation from the different sources affected differently by the two different types of shielding? If so, what are the differences?

Activity 3: Uses and Risks of Radioactivity

Since its discovery in the early 1900's, radioactivity has been used in many ways. These include radiometric dating (determining the age of the solar system, Earth, geologic events, age of human artifacts, etc.), atomic bombs, nuclear power, and medical imaging. In the following problems you will explore a few of these techniques and risks.

1. The first technique we will examine is radioactive dating. With each radioactive decay, an atom of one element, the "parent," is transformed into an atom of a different element, the "daughter." This can be used as a clock. Over time, the number of parent atoms decreases and the number of daughter atoms increases. If the present-day ratio of daughter atoms to parent atoms ($\mathbf{N}_d/\mathbf{N}_p$) is measured and the decay rate is known, then the length of time the clock has been running can be calculated.
2. Using the graph below, find the number of half-lives that have elapsed since each event. Enter in Table 3.
3. Multiply the number of half-lives by the length of a half-life. (Lengths of half-lives can be found in the background section.) Enter this value into Table 3 as well.

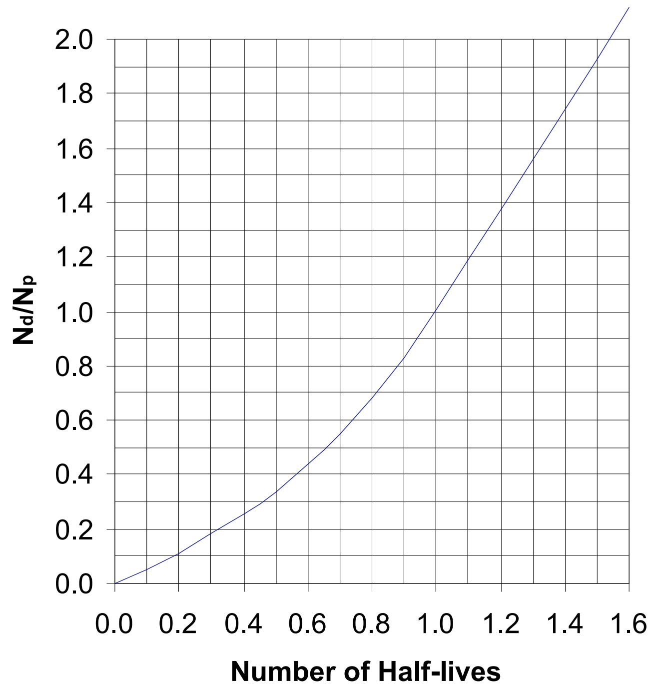


Table 3. Radioisotope Dates (2 points)

Event/Material	Parent	N_d/N_p	half-lives	Age (yr)
a. Age of the Moon and Meteorites	^{238}U	1.01		
b. Oldest known rock on Earth	^{238}U	0.78		
c. Single-celled life	^{238}U	0.56		
d. Oldest hard-shelled fossil	^{238}U	0.07		
e. Last Ice age	^{14}C	2		
f. Great Flood of Black Sea	^{14}C	1.4		
g. Egyptian pyramids	^{14}C	0.75		

4. (1 point) One medical application of radioactive tracers is to test cardiac health by establishing the portions of the heart that are active during exertion and inversely which portions aren't. The test involves giving the patient a radioactive thallium tracer in solution (^{200}Tl, half-life 26.1 hours), then performing a stress test on the heart. The portions of the heart muscle that are active will take up the thallium during exercise and the heart can be imaged in 3-D. Bright patches indicate healthy active heart muscle; dull patches indicate unhealthy portions. The thallium is created in a nuclear reactor on Mondays and tests are generally conducted on Thursdays. The solution cannot be used the following week. Using the concept of half-life and the change in radioactivity with time, explain why the thallium must be created anew each week.