Experiment: Nuclear Chemistry

Introduction
Radiation is all around us. There are two main types of radiation: ionizing and non-ionizing. We will focus on radioactivity or ionizing radiation (though non-ionizing radiation, such as ultraviolet, can also be harmful.) Radioactivity results from unstable nuclei decaying to more stable isotopes. The Sun produces cosmic rays, there are radioactive isotopes in the walls and air around us, and even people are radioactive. This natural radioactivity is called background radiation, and life on Earth has adapted to it. The variety of life probably comes from the mutations caused by radioactivity.

Nuclear reactions are different from chemical reactions primarily in the fact that the chemical identity of atoms can change. Nuclear reactions involve the spontaneous emission of nuclear particles or high energy, in the form of alpha, beta, or gamma radiation. These emissions can be detected by means of a Geiger counter. Individual atoms may decay at any time, but with a large enough sample, it can be stated that in a certain period of time, half of the sample will decay. This is called the half life, and is characteristic of each radioisotope. We will model half life decay to observe how this happens and learn about sample size and experimental error bars.

Objectives
In this experiment, you will
✓ Use the terminology of radioactivity and describe instruments that detect it
✓ Detect and measure radioactivity with a Geiger counter
✓ Measure the local intensity of background radiation
✓ Determine the difference in penetrating power between different radioactive particles
✓ Simulate the process of half life using tossed pennies
✓ Graph your results and gain an understanding of probability and error analysis

Hazards
No hazardous chemicals or glassware are to be used, so goggles are not required. Nuclear samples should not be handled with bare skin. Use the forceps in your drawers. The quantity of nuclear material is very small and within acceptable exposure limits. If you have any questions or health concerns, let the instructor know.

Procedure
Carry out each of the following in any order recommended by your instructor. Note: This lab works well when half the class starts with Part A and the other half starts with Part B, due to the supply of radiation monitors (6 max).

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1 We thank Cascadia Community College and Vernier Software and Technology for permission to modify and use this laboratory experiment.
Part A: MEASURING RADIOACTIVITY

1. Use of the Geiger counter (radiation monitor) and Radioactive Samples
You will connect the radiation monitor to the Lab Quest Pro which will give you an activity reading called “counts per minute (cpm)” Ask your instructor if you have trouble with the setup and use of the Geiger counter or Lab Quest Pro. Use the instructions sheet which comes with the Geiger Counter. Record the isotope for each source in the data table. Using tongs remove one sample at a time from the sample case and place it about a yard from the other sources to cut down on interference. Record cpm with the radiation monitor 1 cm away from the source, and again when it is 10 cm away from the source. **Make sure the window of the radiation monitor is facing the sample!**

2. Background Radiation
Move the radiation monitor away from the sample case, perhaps to the window or take it out to the window in the hallway. Record the cpm. Repeat three more times and average the data. The actual radiation of a sample is measured by using the observed radiation for the sample minus the background radiation. Does this make sense?

3. OPTIONAL: Shielding (design your own experiment!)
The greater the penetrating power of the radiation, the more likely the radiation is to go through a material. Which materials are better shields (less penetration)? Select ONE of the radiation sources to use (alpha, beta, or gamma). Select at least three different types of materials provided by your instructor (or ones you have, such as clothing or paper) to devise your own experiment to answer this question. Record your method and data on the report sheet.

Part B: DEMONSTRATION OF HALF LIFE

1. Obtain 100 pennies from your instructor and a tub provided in the classroom. Arrange the pennies in a single layer on the bottom of the tub. Carefully lift the tub and give it one shake straight up and down so that some of the pennies jump, but none are lost out of the tub. (Practice a few times before you start counting.)

2. Place the pennies all facing heads up in the bottom of the tub. Give the tub one shake. Remove all the pennies that are not heads up. This is one “flip”. **Record the number of heads left in the tub on the report sheet for this flip.** Make sure this number decreases with each flip. Shake again and remove the tails for one more flip. Record the data for each successive flip going down the column. A total of 10 flips will be done for that sample. Repeat the whole process for a total of three samples of 100 pennies each.

3. Graph the data
Calculate the average value of heads up coins at each flip for all of your samples combined. Graph the average number of heads versus flip # (use graphing area provided on report sheet or use a spreadsheet in the lab computers).
Guidelines for a “good” graph:

- Use as much area of the graph paper as possible: Count all the squares in the x- and y- axes, and use these totals to estimate the values you should assign for each square along the axes.
- Label these divisions in appropriate increments considering your data (e.g., 0, 5, 10, etc.)
- Include units on your axes.
- Include a title for your graph which describes what your graph conveys.
- Don’t make your data points too small or too big. For example, • or ⬤
- Don’t connect the data points! Use a best fit line where appropriate (see below).
  In this case, the relationship is not linear, so approximate a best-fit curve.

Error Analysis

Record the **ranges** of values from **highest number to lowest number** for each flip. (Use the blank space in your data table.) Using the highest and lowest data from each trial, show the **ranges** you found for each flip with **vertical** (up and down) error bars through your average points. See sample below.

In a different color, and/or a different style of line, plot the **expected points** for half-life for each trial. (Trial 1 is the first half-life, how many pennies *should* be left?)

Label each line, for example:

```
# of heads up pennies

# of flips
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- = experimental data
- = expected half-life data
Part A Data: Geiger Counter and Samples

1. a. (α source) (β source) (γ source)

<table>
<thead>
<tr>
<th>Element (isotope):</th>
<th>_______</th>
<th>_______</th>
<th>_______</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counts per minute at 1 cm:</td>
<td>_______</td>
<td>_______</td>
<td>_______</td>
</tr>
<tr>
<td>Counts per minute at 10 cm:</td>
<td>_______</td>
<td>_______</td>
<td>_______</td>
</tr>
</tbody>
</table>

b. If your cpm for the gamma source is lower than alpha and/or beta, see your instructor.

2. a. Record the Background Counts for 60 seconds. (Do this 3 times.)

| Average Background Counts per minute | _______ |

b. Use this average background count to report the ACTUAL counts per minute for each sample.

<table>
<thead>
<tr>
<th>(α source)</th>
<th>(β source)</th>
<th>(γ source)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element (isotope):</td>
<td>_______</td>
<td>_______</td>
</tr>
<tr>
<td>Counts per minute at 1 cm:</td>
<td>_______</td>
<td>_______</td>
</tr>
<tr>
<td>Counts per minute at 10 cm:</td>
<td>_______</td>
<td>_______</td>
</tr>
</tbody>
</table>

3. (OPTIONAL) Describe your shielding experiment in 1-2 sentences (in enough detail someone else can replicate it). Create your own data table below for the Shielding experiments you devise.
### Part B Data
#### Half Life Demonstration with Pennies

<table>
<thead>
<tr>
<th></th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Average</th>
<th>Range (lowest to highest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flip 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flip 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Flip 3</td>
<td></td>
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<td>Flip 4</td>
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<td>Flip 5</td>
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<tr>
<td>Flip 6</td>
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<tr>
<td>Flip 7</td>
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<tr>
<td>Flip 8</td>
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<tr>
<td>Flip 9</td>
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<tr>
<td>Flip 10</td>
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</tbody>
</table>
Graphing: Average with Error Ranges

Refer to the guidelines on how to prepare a good graph under the “Graphing the data” section in the procedure. Do the error analysis for the actual plot (include the error bars), and include the theoretical plot as well. (See the instructions under “Error analysis” in the procedure.)
Post-lab Questions

Part A: Geiger counter and samples

1. Which of the packaged samples gave the most counts, (alpha, beta or gamma)? The least? Is this what you expected? Why?

2. (a) Using your most active sample, describe how the number of counts is affected by the distance of the sample from the counter. Why does this make sense?

(b) What are two ways you might protect yourself from a very active sample?

3. Complete the nuclear equations for the spontaneous decay of each sample you observed. (Use the conservation of mass/charge and periodic table to figure this out. Remember, the top number is the mass number and the bottom number is the number of protons or charge)

alpha emitter: \( ^{210}_{84}Po \rightarrow ____ + ^{4}_2He \) (alpha particle)

beta emitter: \( ^{90}_{38}Sr \rightarrow ____ + ^{0}_{-1}\beta \) (beta particle)

Shielding (OPTIONAL)

4. Briefly summarize your results and conclusions from the shielding experiment you conducted in a few sentences. Is it what you expected?
Part B: Half-Life demonstration

5. What does a “heads” penny represent and what does a “tails” penny represent?

6. a) Based on your data, how many flips were needed to get the number of pennies to ¼ of the original? (Hint: How many half-lives have passed for ¼ to remain?)

b) How many flips should it take to get to ¼ of the original, ideally (theoretically)?

c) If you started with 1000 pennies instead of 100, how many flips would it take to get to ¼ of the original, ideally (theoretically)?

Error analysis

7. Compare your actual plot to your theoretical plot. Does the theoretical plot fall within the error bars on your actual plot? Does this mean your results match or do not match the expected (theoretical) values?

8. It is unlikely the theoretical curve on the graph will exactly match the experimental curve. What is it about the nature of radioactivity that results in a difference between the theoretical and experimental plots?

9. If you did only one sample instead of an average of three samples, what effect would this have on your experimental plot compared to the theoretical?
1. Look up, in your textbook or other source, how a Geiger Counter works and describe it briefly below. Cite the source(s) you used.

2. What is background radiation? Where does it come from? List three sources of background radiation.

3. Define half-life in terms of radioactive isotopes.

4. If you have 100 radioactive atoms, will exactly 50 decay after one half life? (Hint: If you have 100 coins and you toss them simultaneously, will exactly 50 flip over?) Answer “yes” or “no” and explain your choice.