Answer Key: Investigating Exponential Decay

Objective
To understand the concept of half-life.

Background
Large atomic nuclei, with a disproportionate ratio of neutrons to protons, are unstable and will "decay" over time. When radioactive decay occurs, energy is lost and carried off by gamma, alpha, or beta particles. Not all atoms of a substance do this at the exact same moment, but by studying a quantity of a radioactive substance, scientists are able to determine the time it takes for half of the nuclei in a given sample to decay. This is called the half-life.

The parent nuclei decay into more stable “daughter” nuclei. Uranium-238 decays through a series of elements to become lead-206. Once stable, the atom is no longer considered radioactive.

If the half-life of a certain substance is 3 days and you begin with 40 grams, after 3 days you will have 20 grams of radioactive substance, and 20 grams of stable substance. After another 3 days, or the second half-life, you will have 10 grams of radioactive substance and 30 grams of stable substance. So, after 2 half-lives, you have 10g out of the original 40g, or one-fourth of your original radioactive substance.

<table>
<thead>
<tr>
<th>Original amount = 40 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>After one half-life, or 3 days = 40g x 1/2 = 20g</td>
</tr>
<tr>
<td>After second half-life, or 6 days = 40g x 1/2 x 1/2 = 10g</td>
</tr>
<tr>
<td>30g is now stable after 6 days, but 10g is still radioactive.</td>
</tr>
</tbody>
</table>

Let's see how this works with some practice.

Materials
- **Part A:**
  - Scissors
  - 1 sheet of paper
  - pencil or pen
- **Part B**
  - Twenty Skittles
  - cup
  - paper towel or sheet of paper

Part A
Activity Procedure and Questions
1. Cut a large circle out of a piece of paper. This represents 100% of your radioactive material.
2. Let's say one half-life goes by. Cut your circle in half. Label one side "decayed" and set it aside.
3. Now you have “half” of your original material, or ½, or 50% that is still radioactive.
4. Cut the radioactive piece in half, making it look like 2 identical wedges. This represents another half-life. Label one wedge "decayed" and set it aside.
5. Now you are left with ¼ or 25% of your original material. How many half-lives have gone by? ______2______
6. A third half-life goes by. Demonstrate this with your radioactive wedge. What fraction of the original amount is left? Draw the wedge below: 1/8th of the circle
7. If a fourth half-life went by, what fraction of radioactive substance would be left?  
\[
\frac{1}{16}
\]

8. Demonstrate the fourth half-life by cutting the wedge in half.

9. Do you see that even after 4 half-lives you still have radioactive material? Yes!

10. Try this problem: You have 50 grams of a radioactive substance and two half-lives go by. How much mass of the original substance would still be radioactive?  

\[
12.5 \text{ grams}
\]

11. Try this problem: The half-life of radon-222 is 3.824 days. After what time will one fourth of the original amount of radon remain?  

\[
7.648 \text{ days}
\]

12. Another example: The half-life of iodine-131 is 8.040 days. What percentage of an iodine-131 sample will remain after 24.12 days?  

\[
12.5\%\
\]

**Part B**

**Activity Procedure and Questions**

1. Place 20 Skittles in the cup. These are the parent nuclei.

2. Decide if "S" side-up will be the radioactive or decayed particles. Record the designated 'radioactive' side of the candy: ___ answers will vary ____________

3. Put the lid on the container (or use your hand if no lid is provided) and shake the cup so that the Skittles will change position and tumble about.

4. Carefully pour the items onto a sheet of paper. Separate the particles by designated side-up.

5. Put aside the particles that are "decayed". Count the "radioactive" particles and record in the data table for "1" half-life.

6. Put only the radioactive particles back into the container. Shake it, and again pour the contents onto your sheet of paper.

7. Separate the particles like before, setting aside the decayed particles, and counting the radioactive particles. Record the number of radioactive particles in the data table under "2" half-lives.

8. Repeat procedure 7, recording the data in the appropriate place, until there are no radioactive particles left.

9. Graph the number of parent nuclei versus the number of half-lives on the graph paper provided below.

10. Draw a smooth line that best fits the points. Describe what your graph looks like:

\[
\text{It should be a downward sloping exponential decay graph}
\]

11. Is there a relationship between the number of radioactive particles remaining and the number of shakes? Explain.

Yes, as the number of shakes increase, the number of radioactive particles decreases. It’s an inverse relationship.
12. Cobalt-60 has a half-life of 10.47 minutes. How many milligrams of cobalt-60 remain after 52.35 minutes if you start with 10.0mg?

0.3125 mg

13. The half-life of polonium-218 is 3.0 minutes. If you start with 24.0 mg, how long will it be before only 3.0 mg remain?

9.0 minutes

14. Explain the concept “half-life”:

The time it takes for half of a radioactive substance to decay.

Sample Data Table (Add more columns if needed)

<table>
<thead>
<tr>
<th>Shake number/ half-life</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of radioactive nuclei remaining</td>
<td>20 (starting amount)</td>
<td>11</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Graph (Label and number the axes)

Sample Data