Rates of Decay: Half Life & Radioactive Dating

Read from **Lesson 2: Rates of Decay** in the **Chemistry Tutorial** Section**, Chapter 19** of **The Physics Classroom**:
Part a: Half-Life Part b: Radioactive Dating

1. Introduction to Half-Life & Radioactive Dating

- **Radioactive decay is predictable for large numbers of atoms**, even though individual decay events are random.
- **Half-life ($t_{½}$)** is the time required for **half of a radioactive sample to decay**. This decay follows an **exponential pattern**, not linear.
- **Radioactive dating** uses the predictable decay of isotopes (especially **carbon-14**) to determine the age of once-living materials.

2. Half-Life

A. What Half-Life Represents

- After one half-life, $\frac{1}{2}$ or **50.00%** of the original sample remains.
- After two half-lives, $\frac{1}{4}$ or **25.00%** of the original sample remains.
- After three half-lives, $\frac{1}{8}$ or **12.50%** of the original sample remains.
- After four half-lives, $\frac{1}{16}$ or **6.25%** of the original sample remains.
- After five half-lives, $\frac{1}{32}$ or **3.125%** of the original sample remains.
- This divide-by-2 pattern continues indefinitely.

B. Example Problem:

- The half-life of Zn-71 is 2.4 minutes. If you start with 10.0 g, how many grams would remain after 7.2 minutes have elapsed? 7.2 minutes / 2.4 minutes/ $t_{½}$ = **3.0 $t_{½}$**

So, 10.0 g → 5.0 g is 1 **$t_{½}$** 5.0 g → 2.5 g is 1 **$t_{½}$** 2.5 g → 1.25 g is 1 **$t_{½}$** After 3 **$t_{½}$**, 1.25 g Zn-71 remain.

C. Equation

- $$N = N_0 \cdot \left(\frac{1}{2}\right)^{(t/t_{½})}$$

N: The final amount or quantity of the substance that still remains after time
N_0: The initial amount or quantity of the substance at the beginning (at t=0)
t: The total time that has elapsed.
$t_{½}$: The half-life of the substance, which is the time it takes for half of the substance to decay.

3. Radioactive Dating

Why Carbon-14 Works

- Constant production in the atmosphere via **cosmic ray interactions**.
- Living organisms maintain a constant **C-14/C-12 ratio** until death.
- After death, C-14 decays with **$t_{½}$ = 5730 years**.
- Limitations: Atmospheric C-14 levels vary slightly (fossil fuel dilution, nuclear testing).

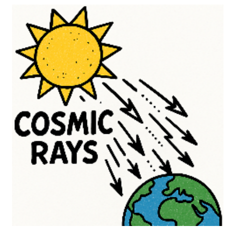
Example Problem:
A fossilized plant contains 4.2 decays/minute/g of C-14. We can assume that the activity was 15 decays/minute/g at the time of fossilization. Estimate its age using the exponential decay equation.
$t = -t_{½} \cdot \ln(N/N_0) / \ln(2) = -5730\ yr \cdot \ln(4.2/15) / \ln(2) = -5730\ yr \cdot (-1.966) = 11265\ yr \approx 11000\ years$

Nuclear Chemistry and Radiation

Questions

1. Why do isotopes with shorter half-lives tend to be more radioactive than those with longer half-lives?

2. How do cosmic rays contribute to the natural formation of carbon-14 in the atmosphere?



3. Why is carbon-14 dating unreliable for samples older than approximately 50,000 years?

4. Aaron Agin and Marie Curieous are discussing radioactive decay. Aaron claims that after six half-lives, all atoms of a radioisotope have disappeared. How can Marie clarify why this statement is incorrect?

5. A sample of a radioactive element has decayed to 12.5% of its original amount after 15.9 years.
   a. How many half-lives have passed?

   b. What is the half-life of this isotope?

   c. Based on the decay table from Part a of the recommended reading, which radioactive element matches this half-life?

Nuclear Chemistry and Radiation

6. Radioactive iodine (iodine-131) is commonly used to treat certain thyroid cancers. I-131 has a half-life of 8 days. A medical lab replaces its I-131 supply once it has decayed to 25% of the original amount. If a new shipment typically takes 5 days to arrive, how many days after receiving the current sample should the lab place the order for the next one?

7. A cloth sample taken from an Egyptian mummy shows a carbon-14 activity of 3.8 decays per minute per gram of carbon-14. At the time the mummy was embalmed, the activity would have been 15 decays per minute per gram. Using the exponential decay equation for carbon-14, determine the age of the cloth.

8. The Lemhi Pass region, located along the Idaho–Montana border, contains one of the richest thorium deposits in the United States. Thorium-232 gradually decays into lead-208 . The half-life of Th-232 is 1.4×10^{10} years. A rock sample collected from Lemhi Pass is found to contain 32.0 mg of Th-232 and 96.0 mg of Pb-208. Assuming all of the lead came from the radioactive decay of thorium, how old is the rock?