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Understanding radioactive decay and half-life is fundamental in fields ranging from nuclear physics to environmental science. Polonium-210 (Po-210) is a highly radioactive element with significant implications for health, safety, and scientific research. When examining such a substance, one of the key questions is: given an initial amount, how much of the radioactive material remains after a certain period? Specifically, if we start with a 5-kilogram sample of Po-210, how much will be left after a specified number of years? Let's delve into the concepts of half-life, decay calculations, and practical applications to answer this question comprehensively.

Understanding Radioactive Decay and Half-life

Radioactive decay is a stochastic process where unstable atomic nuclei lose energy by emitting radiation. This process is characterized by a property called half-life, the time required for half of the radioactive atoms in a sample to decay. Each isotope has a unique half-life, which remains constant regardless of the sample's size or initial amount.

What Is Half-life?

- Definition: The period in which half of the radioactive atoms in a sample decay.
- Significance: It helps determine the rate at which a radioactive isotope diminishes over time.
- Units: Typically measured in seconds, years, or days, depending on the isotope.

Po-210 and Its Half-life

- Po-210: A radioactive isotope of polonium, known for its high radioactivity.
- Half-life: Approximately 140 years.
- Implications: Its decay rate influences its use in scientific research, as well as safety considerations, due to its toxicity and radiation emission.

Decay Calculation Fundamentals

To determine how much of the original sample remains after a given period, we utilize the exponential decay formula:

$$ N(t) = N_0 \times \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} $$

Where:
- $N(t)$ = remaining mass after time t
- N_0 = initial mass
- $T_{1/2}$ = half-life of the isotope
- t = elapsed time

This formula assumes the decay process follows first-order kinetics, which is typical for radioactive decay.

Applying the Formula

Given:
- Initial mass $N_0 = 5\,kg$
- Half-life $T_{1/2} = 140\,years$
- Time t (variable depending on the question)

We can calculate the remaining mass after any number of years by substituting the values into the formula.

Calculating Remaining Po-210 After a Given Period

Suppose we want to find out how much Po-210 remains after a certain number of years, for example, 280 years, which is twice its half-life.

Example Calculation: Remaining Mass After 280 Years

- $t = 280\,years$
- $N_0 = 5\,kg$
- $T_{1/2} = 140\,years$

Applying the formula:

$$ N(280) = 5\,kg \times \left(\frac{1}{2}\right)^{\frac{280}{140}} = 5\,kg \times \left(\frac{1}{2}\right)^2 $$

$$ N(280) = 5\,kg \times \frac{1}{4} = 1.25\,kg $$

Result: After 280 years, approximately 1.25 kg of the original 5 kg of Po-210 will remain.

General Formula for Various Timeframes

- For any number of years t, the remaining mass can be calculated directly.
- For example, after 70 years:

$$ N(70) = 5\,kg \times \left(\frac{1}{2}\right)^{\frac{70}{140}} = 5\,kg \times \left(\frac{1}{2}\right)^{0.5} $$

$$ N(70) \approx 5\,kg \times 0.7071 \approx 3.535\,kg $$

This demonstrates how the decay progresses over different periods.

Understanding Decay Over Multiple Half-lives

Radioactive decay is exponential, meaning the remaining amount halves after each half-life period. This pattern helps to quickly estimate remaining quantities without complex calculations.

Decay Pattern Summary:

- After 1 half-life (140 years): 50% remains (2.5 kg)
- After 2 half-lives (280 years): 25% remains (1.25 kg)
- After 3 half-lives (420 years): 12.5% remains (0.625 kg)
- After 4 half-lives (560 years): 6.25% remains (0.3125 kg)

This pattern highlights the rapid decrease in quantity over successive half-lives.

Practical Implications of Po-210's Decay

Po-210's decay characteristics have significant practical implications, particularly in areas such as:
- Medical and scientific research: Its radioactive properties are utilized in certain applications, but safety protocols are vital.
- Environmental safety: Understanding decay helps assess long-term contamination risks.
- Nuclear safety and waste management: Knowledge of decay rates informs storage and disposal strategies.

Safety Considerations

- Po-210 is highly toxic and emits alpha particles, which can cause severe damage if ingested or inhaled.
- The decay process reduces its radioactivity over time, but the long half-life means it remains hazardous for centuries.
- Proper handling, storage, and disposal are critical to prevent environmental contamination and health risks.

Conclusion: How Much Will Remain of a 5 Kg Po-210 Sample?

Given the half-life of Po-210 is 140 years, if you start with a 5 kg sample, the remaining amount after a certain period can be estimated using the exponential decay formula. For example:
- After 140 years (one half-life), approximately 2.5 kg remains.
- After 280 years (two half-lives), about 1.25 kg remains.
- After 420 years (three half-lives), roughly 0.625 kg remains.

This predictable decay pattern allows scientists and safety personnel to estimate the longevity and hazards associated with radioactive materials. Understanding these principles ensures safe handling and effective management of radioactive substances like Po-210, safeguarding health and the environment for generations to come.

In summary, the decay of Po-210 is a slow but steady process governed by its 140-year half-life. Starting with 5 kg, the amount remaining diminishes by half every 140 years, making long-term storage and safety considerations crucial. Whether for scientific research, medical applications, or environmental safety, knowledge of half-life and decay calculations remains a cornerstone of nuclear science and radiological safety.

Frequently Asked Questions

What is the half-life of Po-210?

The half-life of Po-210 is 140 years.

If the initial mass of a Po-210 sample is 5 kg, how much remains after 140 years?

After 140 years, half of the initial 5 kg will remain, so 2.5 kg.

How do you calculate the remaining mass of Po-210 after a certain period?

Use the half-life formula: Remaining mass = initial mass × (1/2)^(time / half-life).

What is the decay process for Po-210?

Po-210 undergoes radioactive decay, transforming into stable lead (Pb-206) over time.

How many half-lives will pass in 420 years?

In 420 years, three half-lives will pass because 420 ÷ 140 = 3.

What will be the remaining mass of a 5 kg Po-210 sample after 420 years?

After 420 years (3 half-lives), the remaining mass will be 0.625 kg.

Why is knowledge of half-life important in handling radioactive materials like Po-210?

Understanding half-life helps determine safety protocols, storage durations, and decay expectations for radioactive substances.

Additional Resources

The Half-life Of Po-210 Is 140 Years. If The Initial Mass Of The Sample Is 5 Kg, How Much Will Remain

Understanding radioactive decay is essential not only in scientific research but also in applications spanning medicine, industry, and environmental safety. One such radioactive isotope that has garnered attention due to its potent radioactivity is Polonium-210 (Po-210). With a half-life of 140 years, Po-210 exemplifies how radioactive substances diminish over time, following predictable decay patterns. This article explores the concept of half-life in the context of Po-210, delves into the mathematics behind radioactive decay, and calculates how much of a 5 kg sample would remain after a certain period.

What Is Polonium-210 and Its Significance?

Polonium-210 is a rare and highly radioactive element discovered by Marie Curie in 1898. It belongs to the group of alpha emitters, meaning it primarily emits alpha particles during decay. Despite its scarcity, Po-210 has notable applications, including:

- Scientific Research: Used in nuclear physics and radiochemistry to study decay processes.
- Industrial Uses: Employed in static eliminators and as a heat source in space missions.
- Historical and Security Concerns: Its high radioactivity also makes it a subject of concern regarding radiation safety and security, given its potential use as a poison.

The half-life of Po-210 is 140 years, indicating that after this period, half of the initial radioactive atoms in a sample will have decayed into other elements or isotopes.

The Concept of Half-life in Radioactive Decay

Defining Half-life

Half-life, denoted as $T_{1/2}$, is the time required for half of the radioactive atoms in a sample to decay. It is a characteristic property of each isotope, unaffected by the amount of material or external conditions. This predictable decay pattern allows scientists to estimate the age of materials, determine radiation exposure levels, and manage radioactive materials safely.

Decay Law Fundamentals

The decay of radioactive isotopes follows an exponential decay law, mathematically expressed as:

$$
N(t) = N_0 \times e^{-\lambda t}
$$

where:

- $N(t)$: Number of undecayed atoms at time t
- N_0: Initial number of atoms
- λ: Decay constant (probability per unit time that an atom decays)
- t: Time elapsed

The decay constant λ relates directly to the half-life through:

$$
\lambda = \frac{\ln 2}{T_{1/2}}
$$

This relationship makes it straightforward to calculate remaining quantities after given time frames.

Applying the Decay Law to Po-210

Calculating the Decay Constant for Po-210

Given the half-life $T_{1/2} = 140$ years, the decay constant λ is calculated as:

$$
\lambda = \frac{\ln 2}{140} \approx \frac{0.6931}{140} \approx 0.00495 \text{ per year}
$$

This means, on average, approximately 0.495% of the remaining Po-210 atoms decay each year.

Relating Mass to Atomic Count

Radioactive decay calculations often involve the number of atoms, but since we start with mass, we need to convert the initial mass into a number of atoms. The relationship is:

$$
N = \frac{\text{Mass} \times N_A}{\text{Atomic mass}}
$$

where:

- N_A: Avogadro's number (6.022×10^{23} atoms/mol)
- Atomic mass of Po-210: approximately 209.98 g/mol
- Initial mass: 5 kg = 5000 g

Calculating the initial number of atoms:

$$
N_0 = \frac{5000 \text{ g} \times 6.022 \times 10^{23}}{209.98 \text{ g/mol}} \approx \frac{5000 \times 6.022 \times 10^{23}}{209.98}
$$

$$
N_0 \approx 1.43 \times 10^{25} \text{ atoms}

\]

This enormous number underscores the microscopic scale at which radioactive decay occurs.

Estimating Remaining Mass After a Given Time

Calculating the Remaining Number of Atoms

Suppose we want to determine how much of the initial sample remains after, for example, 280 years (equivalent to two half-lives). The decay law gives:

$$
N(t) = N_0 \times e^{-\lambda t}
$$

Plugging in the numbers:

$$
N(280) = 1.43 \times 10^{25} \times e^{-0.00495 \times 280}
$$

$$
N(280) = 1.43 \times 10^{25} \times e^{-1.386}
$$

$$
N(280) \approx 1.43 \times 10^{25} \times 0.250
$$

$$
N(280) \approx 3.57 \times 10^{24} \text{ atoms}
$$

Since each atom has an atomic mass close to 210 g/mol, the remaining mass $M(t)$ is:

$$
M(t) = \frac{N(t) \times \text{Atomic mass}}{N_A}
$$

Calculating this:

$$
M(280) = \frac{3.57 \times 10^{24} \times 209.98 \text{ g/mol}}{6.022 \times 10^{23}}
$$

$$
M(280) \approx \frac{7.49 \times 10^{26} \text{ g}}{6.022 \times 10^{23}} \approx 1243 \text{ g}
$$

This indicates that after 280 years, approximately 1.243 kg of the original 5 kg sample remains.

Generalized Formula for Remaining Mass

The calculation can be generalized for any elapsed time t:

$$
M(t) = M_0 \times \left(\frac{1}{2}\right)^{t / T_{1/2}}
$$

Where:

- M_0 is the initial mass
- t is the elapsed time
- $T_{1/2}$ is the half-life

Applying this formula simplifies the calculation process and provides quick estimates.

Implications and Practical Considerations

Decay Over Time: The Power of Half-lives

Using the half-life formula:

- After 1 half-life (140 years): 2.5 kg remains.
- After 2 half-lives (280 years): 1.25 kg remains.
- After 3 half-lives (420 years): 0.625 kg remains.

This exponential decay means that even after several centuries, a considerable amount of radioactive material persists, although it diminishes rapidly in the initial periods.

Safety and Handling of Po-210

Given its high radioactivity and toxicity, handling Po-210 requires strict safety protocols. Knowledge of its decay properties helps in:

- Designing storage that accounts for the decay over time.
- Estimating the activity (radioactive emission rate) remaining in a sample.
- Planning for long-term waste management.

Environmental and Security Concerns

Po-210's potent alpha radiation and long half-life make it both dangerous and a potential security concern. Proper decay calculations assist authorities in:

- Assessing contamination risks.
- Planning decontamination or disposal timelines.
- Understanding the longevity of radioactive waste.

Conclusion: The Journey of Radioactive Decay

Understanding the fate of a radioactive sample like Po-210 over time is rooted in fundamental principles of nuclear physics. With a half-life of 140 years, the decay process is predictable, allowing scientists and safety officials to estimate remaining quantities decades or even centuries into the future. Starting with a 5 kg sample, approximately 1.24 kg would remain after 280 years—roughly two half-lives. This exponential decline underscores both the power and the persistent nature of radioactive materials.

The precise calculations rooted in decay laws and atomic physics not only deepen our understanding of nuclear science but also play a vital role in ensuring safety, environmental protection, and the responsible use of radioactive substances. As we continue to explore and utilize such materials, knowledge of their decay behavior remains an essential tool in balancing scientific progress with safety considerations.

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