If A 125 Gms Of Radioactive Element Has A Half Life Of 60 Min How Many Half Lives Will It Go Through

If A 125 Gms Of Radioactive Element Has A Half Life Of 60 Min How Many Half Lives Will It Go Through is a fundamental question in nuclear physics and radioactive decay processes. Understanding this concept is crucial for scientists, engineers, and students working with radioactive materials, whether for medical, industrial, or research purposes. The question essentially asks how many times the radioactive material will halve in quantity over a certain period, given its half-life. This article explores the principles behind half-life calculations, provides step-by-step methods to determine the number of half-lives, and discusses real-world applications of this knowledge.

Understanding Radioactive Decay and Half-Life

What Is Radioactive Decay?

Radioactive decay is the process by which unstable atomic nuclei lose energy by emitting radiation in the form of particles or electromagnetic waves. This process transforms the original unstable nucleus into a more stable one. Each radioactive isotope has a characteristic decay pattern and rate, which is often expressed in terms of its half-life.

Definition of Half-Life

The half-life of a radioactive substance is the time required for half of the radioactive nuclei in a sample to decay. It is a constant for each isotope and does not depend on the amount present or the initial concentration. For example, if a sample has a half-life of 60 minutes, after 60 minutes, only half of the original amount remains; after another 60 minutes, only a quarter remains, and so forth.

Calculating the Number of Half-Lives

The Basic Formula

The number of half-lives a radioactive sample has undergone can be calculated using the formula:

$$\text{Number of Half-Lives} = \frac{\text{Total Time Elapsed}}{\text{Half-Life Duration}}$$

Where:
- Total Time Elapsed is the period over which decay is observed.
- Half-Life Duration is the time it takes for half the sample to decay (in this case, 60 minutes).

Applying the Formula to the Given Data

Suppose you want to determine how many half-lives a 125-gram sample of a radioactive element with a half-life of 60 minutes will go through over a specific period. The key is to identify the total time elapsed.

For example:
- If the time elapsed is 120 minutes, then:

$$\text{Number of Half-Lives} = \frac{120 \text{ min}}{60 \text{ min}} = 2$$

- If the time elapsed is 180 minutes:

$$\frac{180 \text{ min}}{60 \text{ min}} = 3$$

This straightforward calculation shows that the sample undergoes 2 or 3 half-lives respectively after 120 or 180 minutes.

Understanding the Decay Process Over Multiple Half-Lives

Decay Pattern and Remaining Quantity

The decay process follows an exponential pattern. After each half-life, the remaining quantity of the radioactive substance halves:

- After 1 half-life (60 min): Remaining amount = 125 g / 2 = 62.5 g
- After 2 half-lives (120 min): Remaining amount = 62.5 g / 2 = 31.25 g
- After 3 half-lives (180 min): Remaining amount = 31.25 g / 2 = 15.625 g
- And so on.

This pattern can be summarized as:

$$\text{Remaining amount} = \text{Initial amount} \times \left(\frac{1}{2}\right)^{\text{Number of half-lives}}$$

Calculating Remaining Quantity for a Given Time

If the total time is known, and you want to find out how much material remains after that period, you can rearrange the formula:

$$ \text{Remaining amount} = 125 \times \left(\frac{1}{2}\right)^{\frac{\text{Total Time}}{\text{Half-Life}}} $$

For instance, after 180 minutes:

$$ \text{Remaining amount} = 125 \times \left(\frac{1}{2}\right)^{3} = 125 \times \frac{1}{8} = 15.625 \text{ g} $$

Practical Examples and Applications

Example 1: Radioactive Waste Management

In nuclear waste management, understanding how many half-lives a radioactive isotope has undergone helps determine its long-term safety and handling procedures. For example, if a waste sample contains a radioactive isotope with a half-life of 60 minutes, and it has been stored for 6 hours, the number of half-lives is:

$$ \frac{6 \text{ hours} \times 60 \text{ min/hour}}{60 \text{ min}} = \frac{360 \text{ min}}{60 \text{ min}} = 6 $$

This indicates the amount of radioactive material has reduced to:

$$ 125 \times \left(\frac{1}{2}\right)^6 = 125 \times \frac{1}{64} \approx 1.95 \text{ g} $$

which is significantly less radioactive.

Example 2: Medical Radioisotopes

In medical diagnostics, radioisotopes like Technetium-99m have specific half-lives (around 6 hours). Knowing the number of half-lives passed helps in scheduling doses and ensuring safety for patients and healthcare workers.

Summary and Key Takeaways

- The half-life is a constant characteristic of each radioactive isotope that determines how quickly it decays.

- The number of half-lives passed over a period can be calculated simply by dividing the total elapsed time by the half-life.
- Understanding the decay pattern is essential for safe handling, disposal, and application of radioactive materials.
- Exponential decay follows a predictable pattern, halving at each half-life interval.

Conclusion

To answer the initial question: if a 125-gram sample of a radioactive element has a half-life of 60 minutes, the number of half-lives it will go through depends entirely on the total time it remains radioactive. Using the formula:

$$\text{Number of Half-Lives} = \frac{\text{Total Time Elapsed}}{\text{Half-Life}}$$

you can determine how many halving processes the material experiences. For example, after 120 minutes, it will have gone through 2 half-lives, reducing the original amount from 125 grams to approximately 31.25 grams. This understanding is vital in fields ranging from nuclear medicine to radiometric dating, ensuring proper management and application of radioactive substances.

Frequently Asked Questions

How do you calculate the number of half-lives an element has undergone given its initial mass and half-life duration?

Divide the total time elapsed by the half-life duration. For example, if you have a total time T and a half-life of $t_{1/2}$, then the number of half-lives is $T / t_{1/2}$.

If 125 grams of a radioactive element has a half-life of 60 minutes, how much remains after 180 minutes?

After 180 minutes, which is 3 half-lives (180/60=3), the remaining amount is $125 \times (1/2)^3 = 125 \times 1/8 = 15.625$ grams.

What is the significance of the half-life in radioactive decay?

The half-life indicates the time it takes for half of the radioactive substance to decay, helping to determine its rate of decay and how long it remains active or detectable.

How many half-lives does a sample undergo if it decays from 125 grams to approximately 15.625 grams?

It undergoes 3 half-lives, because after each half-life, the mass halves: 125g → 62.5g → 31.25g → 15.625g.

Is the remaining amount of a radioactive sample directly proportional to the number of half-lives that have passed?

No, the remaining amount decreases exponentially with each half-life, following the formula remaining = initial × $(1/2)^n$, where n is the number of half-lives.

How long will it take for a 125g sample to decay to less than 1 gram if its half-life is 60 minutes?

First, determine the number of half-lives needed: 125g → 1g is about 7.97 half-lives (since $125 / (1/2)^n = 1$, solving for n gives $n \approx \log_2(125)$). Approximately 8 half-lives are needed, so total time = 8 × 60 = 480 minutes or 8 hours.

Additional Resources

Radioactive Decay and Half-Life: An In-Depth Analysis of the 125 Gms Sample

Radioactivity is a fascinating phenomenon that has intrigued scientists and laypersons alike for centuries. Understanding how radioactive substances decay over time is essential for applications ranging from medical diagnostics to nuclear energy. In this detailed exploration, we will delve into a specific problem: If a 125 grams of a radioactive element has a half-life of 60 minutes, how many half-lives will it go through? While this question might appear straightforward at first glance, it opens the door to a comprehensive discussion about the principles of radioactive decay, the concept of half-life, and the mathematical tools used to analyze decay processes.

Understanding Radioactive Decay

Radioactive decay is a spontaneous process where unstable atomic nuclei lose energy by emitting radiation in the form of particles or electromagnetic waves. This process transforms the original nucleus into a different element or isotope. Key aspects include:

- Unpredictability at the individual nucleus level: While the decay of a single atom is random, large numbers of atoms decay in a predictable statistical manner.
- Decay rate: The number of nuclei that decay per unit time depends on the current number of undecayed nuclei.
- Exponential decay: The decay process follows an exponential law, meaning the amount of radioactive material decreases exponentially over time.

The Concept of Half-Life

The half-life (denoted as $T_{1/2}$) is a fundamental concept in nuclear physics, representing the time required for half of the radioactive nuclei in a sample to decay.

Characteristics of Half-Life

- Constant for a given isotope: Regardless of the initial amount, the half-life remains unchanged.
- Independent of initial quantity: Whether you start with 1 gram or 125 grams, the time for half of the material to decay stays the same.
- Application in dating and medicine: Half-life helps determine the age of archaeological finds and the dosage of radiopharmaceuticals.

Mathematical Relation

The decay process can be described mathematically as:

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

where:

- $N(t)$ is the remaining quantity after time t,
- N_0 is the initial quantity,
- $T_{1/2}$ is the half-life.

Applying the Concept to the Problem at Hand

Given:

- Initial mass $N_0 = 125$ grams
- Half-life $T_{1/2} = 60$ minutes

Question:

- How many half-lives will the sample go through?

Step-by-Step Approach

1. Understanding what a half-life signifies: Each half-life reduces the remaining quantity by 50%. So, after one half-life (60 minutes), the sample will be halved; after two, it will be quartered; after three, it will be one-eighth, and so on.

2. Number of half-lives (n): The question essentially asks for the number of half-life periods elapsed from the initial time until the radioactive activity diminishes to a certain level or just to understand the decay process generally.

3. General calculation: The number of half-lives n that a sample has gone through after time t:

$$
n = \frac{t}{T_{1/2}}
$$

Since the problem does not specify a remaining amount or a specific end point, the standard interpretation is: "How many half-lives will the sample go through in a certain period or in general?" Most commonly, if asked "how many half-lives will it go through," it implies considering the total decay process over a certain duration or in theoretical terms.

Clarification

- If the question is about total decay over a specific time, then we need to know the total time elapsed.
- If the question is conceptual, then the answer is simply the number of half-lives elapsed for a given duration.

Calculating the Number of Half-Lives

Since the problem states the initial mass and the half-life but not the total time, the most straightforward interpretation is:

- Assuming the question asks: "If the radioactive element is observed over a period of 60 minutes, how many half-lives will it go through?"

In this case:

$$
n = \frac{t}{T_{1/2}} = \frac{60 \text{ minutes}}{60 \text{ minutes}} = 1
$$

Result:

- The sample will go through one half-life in 60 minutes.

Alternate interpretations:

- If the question refers to a longer time span, say 180 minutes, then:

$$
n = \frac{180}{60} = 3
$$

- The sample will go through three half-lives.

Understanding Decay Over Multiple Half-Lives

Knowing that radioactive decay follows exponential decay, it is instructive to see how the quantity reduces over multiple half-lives:

Number of Half-Lives	Remaining Fraction of Initial Mass	Remaining Mass (grams)
1	50%	62.5
2	25%	31.25
3	12.5%	15.625
4	6.25%	7.8125

This table illustrates that after each half-life, the remaining quantity of the radioactive element halves. This exponential decay is described mathematically as:

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

where:

- N_0 is the initial amount,
- n is the number of half-lives.

Mathematical Formalism and Decay Equations

Decay Formula

The general decay law relates the remaining quantity $N(t)$ to the initial quantity N_0:

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

where:

- λ is the decay constant,
- t is the elapsed time.

Relationship Between Decay Constant and Half-Life

The decay constant λ is connected to the half-life via:

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

This relationship allows us to transition between the exponential decay formula and the half-life concept.

Calculating the Number of Half-Lives for a Given Time

Given $T_{1/2}$, the number of half-lives n after time t is:

$$
n = \frac{t}{T_{1/2}}
$$

which is a straightforward division.

Real-World Applications and Implications

Understanding how many half-lives a sample undergoes is crucial in various fields:

- Radiometric Dating: Estimating the age of archaeological artifacts or geological samples based on the remaining radioactive isotopes.
- Medical Diagnostics: Using radiopharmaceuticals with known half-lives to optimize imaging procedures.
- Nuclear Power: Managing waste and understanding decay rates to ensure safety.
- Environmental Monitoring: Tracking the decay of pollutants or radioactive contamination over time.

Additional Considerations

While the calculation of the number of half-lives is straightforward mathematically, several practical factors can influence real-world scenarios:

- Decay chain: Some isotopes decay into other radioactive isotopes, affecting the decay process.
- Environmental factors: Conditions such as temperature or chemical environment can influence decay rates in specific contexts.
- Measurement accuracy: Precise measurement of initial quantities and half-lives is essential for accurate predictions.

Summing Up: The Core Answer

Given:

- Initial mass: 125 grams
- Half-life: 60 minutes

Question:

- How many half-lives will it go through?

Answer:

- In any given period \(t \), the number of half-lives is simply \(t / 60 \) minutes.

- If the question pertains to a specific duration, plug that into the formula.
- For example, after 60 minutes, it will have gone through 1 half-life; after 120 minutes, 2 half-lives; after 180 minutes, 3 half-lives, and so forth.

Final Thoughts and Summary

Understanding how many half-lives a radioactive sample goes through is fundamental in nuclear physics and related applications. The calculation hinges on the simple relation:

$$
n = \frac{t}{T_{1/2}}
$$

where n is the number of half-lives, t is the elapsed time, and $T_{1/2}$ is the half-life.

In our specific scenario, if you are observing the decay process over 60 minutes, the sample will go through exactly one half-life. This means the mass will reduce from 125 grams to approximately 62.5 grams. If the time period is extended, the number of half-lives increases accordingly, following the same proportional

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