

A Scientist Has 50 Grams Of A Radioactive Element. The Amount Of Radioactive Element Remaining After

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When working with radioactive materials, understanding how they decay over time is crucial for safety, measurement, and scientific research. A common scenario in nuclear physics and radiochemistry involves a scientist starting with a known quantity of a radioactive element—say, 50 grams—and then monitoring how much of it remains after a certain period. This article explores the principles behind radioactive decay, how to calculate remaining quantities, and the factors influencing decay processes.

Understanding Radioactive Decay

Radioactive decay is a spontaneous process where an unstable atomic nucleus loses energy by emitting radiation. This process transforms the original nucleus into a different element or a different isotope of the same element. The key characteristics of radioactive decay include:

- Unpredictable individual decay events but predictable decay rates over large numbers of atoms.
- Radioactive half-life, the time it takes for half of the radioactive atoms to decay.
- Decay constant, a probability rate at which a single atom decays per unit time.

Key Concepts in Radioactive Decay

Half-Life ($t_{1/2}$)

The half-life is a fundamental property of each radioactive isotope and is given by:

- The time required for 50% of the initial radioactive material to decay.
- It remains constant regardless of the amount of material present.

Example:

If a radioactive isotope has a half-life of 10 hours, then after 10 hours, only half of the original amount remains; after 20 hours, a quarter remains; and so forth.

Decay Constant (λ)

The decay constant relates to the half-life through the formula:

$$\lambda = \ln(2) / t_{1/2}$$

Where:

- $\ln(2) \approx 0.693$
- $t_{1/2}$ is the half-life.

This constant represents the probability per unit time that a single atom will decay.

Radioactive Decay Law

The amount of radioactive material remaining at any time t can be modeled by:

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

Where:

- N_0 is the initial quantity.
- $N(t)$ is the remaining quantity after time t .
- λ is the decay constant.
- e is Euler's number (~ 2.718).

Calculating Remaining Radioactive Material

Suppose a scientist begins with 50 grams of a radioactive element. To determine how much remains after a certain period, follow these steps:

Step 1: Identify the Half-Life or Decay Constant

- Find the isotope's half-life from reference data.
- Calculate λ if only half-life is known.

Step 2: Use the Decay Law

- Plug known values into the decay formula to find remaining mass.

Example Calculation

Assuming:

- Initial amount, $N_0 = 50$ grams

- Half-life, $t_{1/2} = 5$ hours
- Time elapsed, $t = 15$ hours

Step 1: Calculate λ :

$$\lambda = \ln(2) / t_{1/2} = 0.693 / 5 \approx 0.1386 \text{ hr}^{-1}$$

Step 2: Find $N(t)$:

$$N(t) = 50 e^{-0.1386 \cdot 15} \approx 50 e^{-2.079} \approx 50 \cdot 0.125 \approx 6.25 \text{ grams}$$

Result: After 15 hours, approximately 6.25 grams of the original radioactive element remain.

Factors Affecting Radioactive Decay

While decay is a nuclear process unaffected by external conditions, certain factors can influence the decay rate or the measurement accuracy:

1. Isotope Properties

- Different isotopes have varying half-lives.
- Some decay via alpha emission, others via beta or gamma.

2. External Conditions

- Generally, decay rates are unaffected by temperature, pressure, or chemical state.
- Exceptions exist for some isotopes where external electrons influence decay (e.g., electron capture).

3. Measurement Techniques

- Accurate measurement of decay requires proper instrumentation.
- Errors in measurement can lead to incorrect estimations of remaining quantities.

4. Environmental Radioactive Background

- Background radiation can interfere with measurements.
- Shielding and calibration are essential for precision.

Practical Applications of Radioactive Decay Calculations

Understanding how much of a radioactive material remains over time is essential in various fields:

1. Nuclear Medicine

- Determining safe dosages based on isotope decay.
- Planning treatment schedules for radioactive therapies.

2. Radiometric Dating

- Estimating the age of archaeological artifacts by measuring remaining radioactive isotopes.

3. Nuclear Power Plant Operations

- Managing fuel burn-up and waste decay.
- Calculating safe storage times for radioactive waste.

4. Environmental Monitoring

- Tracking contamination levels over time.
- Assessing long-term environmental impact.

Safety Considerations When Handling Radioactive Materials

Handling radioactive elements like those involved in decay calculations must adhere to strict safety protocols:

- Use of shielding to protect from radiation.
- Proper storage to prevent contamination.
- Monitoring radiation levels continuously.
- Training in safe handling procedures.

Conclusion

The process of calculating how much radioactive material remains after a certain period is fundamental in nuclear science and related disciplines. Starting with a known quantity—such as 50 grams—the decay law provides a mathematical framework for predicting remaining amounts over time. By understanding the isotope's half-life, decay constant, and applying the

exponential decay formula, scientists can make precise estimates critical for safety, research, and practical applications. Whether in medicine, archaeology, energy, or environmental science, mastering these calculations ensures responsible and effective use of radioactive materials.

Further Resources

- Nuclear Decay Data: Refer to nuclear data sheets for isotope-specific half-lives.
- Decay Calculator Tools: Online tools for quick decay calculations.
- Safety Guidelines: Consult regulatory bodies like the IAEA or NRC for handling procedures.

Remember: Radioactive decay follows natural laws, making it predictable over large populations of atoms but inherently random at the single-atom level. Understanding these principles allows scientists and safety professionals to harness nuclear processes effectively and responsibly.

Frequently Asked Questions

How do you calculate the remaining amount of a radioactive element after a certain period?

You can calculate the remaining amount using the exponential decay formula: $N = N_0 (1/2)^{(t / t_{1/2})}$, where N_0 is the initial amount, t is the elapsed time, and $t_{1/2}$ is the half-life of the element.

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

The half-life is the time it takes for half of the radioactive substance to decay. It helps determine how long a sample remains radioactive and is crucial for calculating remaining quantities over time.

If a radioactive sample has a half-life of 10 hours, how much remains after 30 hours?

After 30 hours, which is three half-lives, the remaining amount is 50 grams $(1/2)^3 = 50 \text{ grams } 1/8 = 6.25 \text{ grams}$.

How can we determine the age of a sample using its remaining radioactive material?

By measuring the current amount of the radioactive element and knowing its half-life, we can use decay equations to estimate the time elapsed since the sample was formed or last purified.

What are practical applications of understanding radioactive decay in science and medicine?

Radioactive decay principles are used in radiometric dating to determine geological ages, in medical imaging and cancer treatment, and in nuclear power generation.

How does the initial amount of a radioactive element affect its remaining quantity over time?

The initial amount determines the absolute quantity remaining after decay. The decay process is exponential, so larger initial amounts decay proportionally over time but the rate depends on the half-life.

Can the remaining amount of a radioactive element ever become zero?

No, radioactive decay is asymptotic; the amount approaches zero but never truly reaches it. Practically, after many half-lives, the remaining amount becomes negligible.

Additional Resources

A Scientist Has 50 Grams Of A Radioactive Element: The Dynamics of Radioactive Decay

Introduction

Radioactivity, a phenomenon discovered over a century ago, continues to intrigue scientists and researchers due to its complex nature and profound implications in fields ranging from medicine to nuclear energy. When a scientist possesses a fixed quantity of a radioactive isotope—such as 50 grams—the question naturally arises: How much of that element remains after a certain period? Understanding this decay process is fundamental for applications like radiometric dating, nuclear medicine, and radioactive waste management. This comprehensive review explores the principles governing radioactive decay, the mathematical models used to predict remaining quantities, and the critical factors influencing decay over time.

Fundamentals of Radioactive Decay

Radioactive decay is an intrinsic property of unstable atomic nuclei. It involves the spontaneous transformation of an atom into a different element or isotope, accompanied by the emission of radiation such as alpha particles, beta particles, or gamma rays.

Key Characteristics of Radioactive Decay:

- Randomness: Each atom decays independently, with no predictable timing for

individual atoms.

- Statistical Nature: While individual decay times are unpredictable, the overall decay rate for a large number of atoms follows a well-defined pattern.
- Decay Constant (λ): The probability per unit time that a single atom will decay.

Decay Law:

The number of radioactive atoms ($N(t)$) remaining at time (t) can be expressed as:

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

where:

- (N_0) is the initial number of atoms,
- (λ) is the decay constant,
- (t) is elapsed time.

Quantitative Analysis of Radioactive Decay

Given an initial mass of 50 grams, the fundamental task is to determine how much of the radioactive element remains after a specified period. This involves converting mass to the number of atoms and applying the decay law.

Converting Mass to Number of Atoms

Suppose the element has:

- Atomic mass (M) (grams per mole),
- Avogadro's number ($N_A = 6.022 \times 10^{23}$) atoms/mole.

The initial number of atoms (N_0) is:

$$N_0 = \frac{m_0}{M} \times N_A$$

where ($m_0 = 50$) grams.

Example:

If the element is Uranium-238, with an atomic mass ($M \approx 238$, g/mol):

$$N_0 = \frac{50 \text{ g}}{238 \text{ g/mol}} \times 6.022 \times 10^{23} \approx 1.27 \times 10^{23} \text{ atoms}$$

Understanding Half-Life and Decay Constant

The decay constant λ relates to the half-life $T_{1/2}$ —the time it takes for half of the substance to decay:

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

Example:

For Uranium-238, $T_{1/2} \approx 4.468 \times 10^9$ years.

$$\lambda = \frac{\ln 2}{4.468 \times 10^9 \text{ years}} \approx 1.55 \times 10^{-10} \text{ year}^{-1}$$

Calculating Remaining Radioactive Material Over Time

Using the decay law, the remaining number of atoms after time t :

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

Correspondingly, the remaining mass $m(t)$:

$$m(t) = m_0 e^{-\lambda t}$$

Case Study: Decay Over 1 Million Years

Let's analyze the scenario where the scientist wants to know how much of the initial 50 grams remains after 1 million years.

Step 1: Calculate λ :

$$\lambda = 1.55 \times 10^{-10} \text{ year}^{-1}$$

Step 2: Calculate $N(t)$:


```
\[
N(t) = N_0 e^{\{-\lambda t\}}
\]
```

```
\[
N(1 \times 10^6) = 1.27 \times 10^{23} \times e^{\{-1.55 \times 10^{-10} \times
1 \times 10^6\}}
\]
```

```
\[
= 1.27 \times 10^{23} \times e^{\{-0.000155\}}
\]
```

```
\[
\approx 1.27 \times 10^{23} \times 0.999845 \approx 1.27 \times 10^{23}
\]
```

Result: After 1 million years, approximately 99.98% of the initial material remains—an almost negligible decay over this period for Uranium-238.

Implication: For radionuclides with very long half-lives, decay over geological timescales is minimal, allowing large quantities to persist in nature.

Factors Influencing Radioactive Decay and Measurement

While the decay law appears straightforward, several factors can influence the actual measurement and interpretation of radioactive decay:

1. Isotope Purity and Contamination

Impurities or contamination with other isotopes can affect decay measurements, especially if other isotopes have different half-lives or emission spectra.

2. Detection Efficiency

Measurement instruments' efficiency in detecting emitted radiation impacts the accuracy of decay rate assessments.

3. Environmental Conditions

External factors such as temperature, pressure, and chemical environment have minimal direct influence on decay rates but can affect measurement setups.

4. Decay Chain Dynamics

Some isotopes decay into other radioactive isotopes, creating decay chains that complicate decay calculations and require detailed chain models.

Applications of Radioactive Decay Calculations

Understanding how much of a radioactive element remains over time is essential across various domains:

- Radiometric Dating: Using decay rates to determine the age of geological samples.
- Nuclear Medicine: Calculating doses and timing based on half-lives.
- Nuclear Power: Managing fuel and waste based on decay dynamics.
- Environmental Monitoring: Tracking radioactive contamination decay.

Limitations and Considerations

While the exponential decay law provides a robust model, practical limitations include:

- Assumption of Closed System: No addition or removal of material.
- Constant Decay Rate: Decay constants are assumed invariant; however, extreme conditions might affect decay (though rare).
- Measurement Uncertainty: Instrument precision influences data quality.

Conclusion

The scenario of a scientist holding 50 grams of a radioactive element encapsulates core principles of nuclear physics and decay modeling. By converting mass to the number of atoms, understanding the decay constant, and applying the exponential decay law, scientists can accurately predict how much of that element remains after any given period. For long-lived isotopes like Uranium-238, decay over human timescales is negligible; however, for shorter-lived isotopes, decay can be significant over days, months, or years.

In practical applications, precise decay calculations underpin critical decisions in medicine, energy, and environmental safety. As research advances, models incorporating decay chains, environmental factors, and measurement techniques continue to refine our understanding of radioactive behavior, ensuring safe and effective utilization of nuclear materials.

References

- Krane, K. S. (1988). Introductory Nuclear Physics. Wiley.
- Glasstone, S., & Sesonske, A. (1994). Nuclear Reactor Physics. Springer.
- International Atomic Energy Agency. (2004). Radioactive Waste Management. IAEA Publications.
- Knoll, G. F. (2010). Radiation Detection and Measurement. Wiley.

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