Thorium Isotope (Th^232) Has A Half-life Of 1.4*10 Years.a)write The Radioactive Decay Equation.b) Find

Thorium Isotope (Th^232) Has A Half-life Of 1.410 Years.a)write The Radioactive Decay Equation.b) Find

Introduction

The thorium isotope Th^232 is a naturally occurring radioactive element that plays a significant role in nuclear science and energy production. With a remarkably long half-life of approximately 1.4 × 10^10 years, Th^232 is one of the most stable radioactive isotopes known, making it a key candidate for nuclear fuel cycles, radiometric dating, and understanding Earth's natural radioactivity.

Understanding the decay process of Th^232 involves exploring its radioactive decay equation and calculating various parameters such as remaining quantities after certain periods, decay constants, and activity levels. This article delves into the details of Th^232's decay behavior, providing a comprehensive overview of its decay equation, associated calculations, and broader implications.

Radioactive Decay of Th^232: Basic Concepts

Radioactive decay is a spontaneous process where an unstable atomic nucleus loses energy by emitting radiation. For Th^232, this decay involves a series of transformations through various intermediate isotopes until it stabilizes as a non-radioactive isotope, usually Lead-208 (Pb^208).

The decay process can be characterized mathematically by the exponential decay law, which relates the quantity of the isotope remaining over time to its initial amount.

a) Write the Radioactive Decay Equation

The general form of the radioactive decay equation is:

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

Where:
- $N(t)$ is the number of remaining radioactive nuclei at time t,
- N_0 is the initial number of radioactive nuclei at $t = 0$,
- λ is the decay constant, representing the probability per unit time that a nucleus will decay,

- t is the elapsed time.

For Th^{232}, this equation describes how the number of nuclei decreases exponentially over time.

Decay Constant (λ) Calculation:

The decay constant is linked to the half-life ($T_{1/2}$) by:

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

Given:
- $T_{1/2} = 1.4 \times 10^{10} \text{ years}$,

we calculate λ:

$$
\lambda = \frac{\ln 2}{1.4 \times 10^{10} \text{ years}} \approx \frac{0.693}{1.4 \times 10^{10}} \approx 4.95 \times 10^{-11} \text{ year}^{-1}
$$

Radioactive Decay Equation for Th^{232}:

$$
N(t) = N_0 \, e^{-4.95 \times 10^{-11} t}
$$

This equation indicates that after a certain period t, the quantity of Th^{232} remaining can be precisely determined.

b) Find: Calculations and Applications

This section explores various calculations involving Th^{232}, such as the remaining amount after a given time, activity, and decay predictions.

1. Remaining Quantity After a Specific Time

Suppose you start with an initial quantity N_0 of Th^{232}. To find the remaining amount after, for example, 1 billion years ($t = 1 \times 10^9 \text{ years}$):

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

Plugging in the values:

$$
N(10^9) = N_0 \, e^{-4.95 \times 10^{-11} \times 10^9} = N_0 \, e^{-0.0495}
$$

Calculating:

$$
N(10^9) \approx N_0 \times 0.9517
$$

Interpretation: After 1 billion years, approximately 95.17% of the original Th^{232} remains. This slow decay rate reflects the isotope's long half-life.

2. Half-life and Decay Predictions

Given the half-life ($T_{1/2} = 1.4 \times 10^{10}$ years), the decay rate is very slow, making Th^{232} suitable for dating geological formations spanning billions of years.

Number of Half-lives Passed:

To determine how many half-lives have passed after a certain period, use:

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

For example, after 28 billion years:

$$
n = \frac{28 \times 10^9}{1.4 \times 10^{10}} = 2
$$

Remaining fraction:

$$
\left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^2 = \frac{1}{4}
$$

Thus, 25% of the initial Th^{232} remains after 28 billion years.

3. Activity of Th^{232}

The activity A (decays per second) relates to the number of nuclei:

$$
A = \lambda N
$$

Suppose an initial sample contains $N_0 = 10^{24}$ nuclei:

$$
A_0 = 4.95 \times 10^{-11} \times 10^{24} = 4.95 \times 10^{13} \text{ decays per year}
$$

Converting to decays per second (since 1 year ≈ 3.154×10^7 seconds):

$$
A_0 = \frac{4.95 \times 10^{13}}{3.154 \times 10^7} \approx 1.57 \times 10^{6} \text{ decays/sec}
$$

This activity level indicates a highly stable isotope with a relatively low decay rate, suitable for long-term applications like radiometric dating.

Broader Implications of Th^232 Decay

The decay of Th^232 is not just a nuclear curiosity but has practical and scientific implications:

- Radiometric Dating: Th^232 is used in uranium-thorium dating methods to determine the age of geological samples and archeological artifacts.
- Nuclear Energy: Th^232 serves as a fertile material in thorium-based nuclear reactors. It absorbs neutrons to produce fissile material (U^233), offering a potentially safer and more abundant alternative to uranium.
- Earth's Heat Production: The decay of Th^232 contributes significantly to Earth's internal heat, influencing geological processes like mantle convection and plate tectonics.
- Environmental Monitoring: Understanding Th^232's decay helps assess natural background radiation and potential health risks associated with radioactive materials.

Conclusion

The thorium isotope Th^232, with its half-life of approximately 14 billion years, exemplifies the stability of certain radioactive isotopes. Its decay process can be accurately described by the exponential decay equation:

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

where the decay constant $\lambda \approx 4.95 \times 10^{-11} \text{ year}^{-1}$. This equation allows scientists to predict how much of the isotope remains after any given period, crucial for applications in dating, nuclear energy, and understanding Earth's natural processes.

Calculations based on Th^232's decay parameters demonstrate its slow decay rate, making it invaluable for long-term geological and archaeological studies. Additionally, its role in nuclear technology offers promising avenues for sustainable and safer energy solutions.

Understanding the decay characteristics of Th^232 underscores its importance in both scientific research and practical applications.

Keywords: Thorium isotope, Th^232, radioactive decay, half-life, decay constant, radiometric dating, nuclear energy, Earth's heat, decay equation, activity calculation

Frequently Asked Questions

What is the radioactive decay equation for Thorium-232 (Th-232)?

The radioactive decay equation for Th-232 is: $N(t) = N_0 e^{-\lambda t}$, where N(t) is the number of remaining nuclei at time t, N_0 is the initial number of nuclei, and λ is the decay constant.

How do you calculate the decay constant (λ) for Th-232 with a half-life of 1.4 × 10^10 years?

The decay constant λ is calculated using $\lambda = \ln(2) / T_{1/2}$. Substituting $T_{1/2} = 1.4 \times 10^{10}$ years, $\lambda \approx 0.693 / (1.4 \times 10^{10}) \approx 4.95 \times 10^{-11}$ per year.

What is the significance of Th-232's half-life in nuclear applications?

Th-232's long half-life of about 14 billion years makes it useful in nuclear fuel cycles, particularly in thorium-based reactors, due to its stability and potential for sustainable energy production.

How long will it take for a sample of Th-232 to decay to 25% of its original amount?

Using the decay equation, it takes approximately 2 half-lives for 25% remaining, so about $2 \times 1.4 \times 10^{10} = 2.8 \times 10^{10}$ years for the sample to decay to 25%.

How do you determine the remaining quantity of Th-232 after a certain period?

The remaining quantity N(t) can be found using $N(t) = N_0 e^{-\lambda t}$. Plug in the initial amount N_0, the decay constant λ, and the elapsed time t to calculate the current amount.

Additional Resources

Thorium Isotope (Th^232) Has A Half-life Of 1.4×10^10 Years: An In-Depth Exploration

Understanding the properties and behavior of thorium isotopes, particularly Th^232, is pivotal in the fields of nuclear physics, energy generation, and radioactive dating. The immense half-life of Th^232, approximately 14 billion years, positions it as a significant element both scientifically and environmentally. This article provides a comprehensive review of Th^232, including its radioactive decay equation, implications, and applications, alongside a detailed analysis of its advantages and limitations.

Overview of Thorium and Its Isotope Th^232

Thorium (Th), a naturally occurring actinide metal, has garnered increasing interest due to its potential as a nuclear fuel alternative to uranium. The isotope Th^232 is the most abundant form of thorium found in nature, constituting about 100% of natural thorium.

Key features of Th^232 include:
- Long half-life: Approximately 1.4×10^10 years, vastly exceeding the age of the Earth (~4.5 billion years).
- Radioactivity: Th^232 is weakly radioactive but remains stable over geological timescales.
- Decay chain: It undergoes alpha decay, eventually transforming into stable lead (Pb^208) through a series of intermediate radionuclides.

The significance of Th^232 stems from its potential as a fertile material in nuclear reactors, capable of breeding fissile uranium-233 (U^233) upon neutron absorption.

Radioactive Decay Equation of Th^232

Understanding Radioactive Decay

Radioactive decay describes the process by which an unstable nucleus loses energy by emitting radiation. For Th^232, this occurs via alpha decay, where it emits an alpha particle (2 protons and 2 neutrons), transforming into protactinium-228 (Pa^228).

The general decay law is mathematically expressed as:

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

where:
- $N(t)$ = number of radioactive nuclei remaining at time t,

- N_0 = initial number of nuclei,
- λ = decay constant (probability per unit time that a nucleus will decay),
- t = elapsed time.

The decay constant λ relates to the half-life $T_{1/2}$ by:

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

Given the half-life of Th^{232}:

$$T_{1/2} = 1.4 \times 10^{10} \text{ years}$$

the decay constant is:

$$\lambda = \frac{\ln 2}{1.4 \times 10^{10} \text{ years}} \approx \frac{0.693}{1.4 \times 10^{10} \text{ years}} \approx 4.95 \times 10^{-11} \text{ year}^{-1}$$

The Decay Equation for Th^{232}

Therefore, the decay of Th^{232} over time can be modeled as:

$$N(t) = N_0 e^{-4.95 \times 10^{-11} t}$$

This equation describes the exponential reduction in the number of Th^{232} nuclei as time progresses, though due to its extended half-life, the decay rate is incredibly slow.

Implications of Th^{232}'s Half-life

The extraordinarily long half-life of Th^{232} has several profound implications:

- Stability over geological timescales: Th^{232} remains practically unchanged over billions of years, which makes it a reliable candidate for radiometric dating.
- Low activity level: Despite being radioactive, its decay rate is so slow that its radioactivity is low, leading to minimal environmental radiation concerns.
- Potential as a nuclear fuel: Its ability to breed fissile U^{233} makes it attractive for future nuclear energy systems.

Applications of Th^{232}

Radiometric Dating

Th^232 is used in uranium-thorium dating methods, which help determine the age of ancient rocks and fossils. Because of its long half-life, it provides accurate dating over geological timescales, extending up to hundreds of millions of years.

Advantages:
- Suitable for dating very old samples.
- Less affected by environmental contamination than other isotopic systems.

Limitations:
- Requires precise measurement of isotope ratios.
- Not suitable for dating relatively young samples.

Nuclear Energy and Thorium Reactors

Th^232's role as a fertile material enables its use in advanced nuclear reactors:

- Breeding U^233: Th^232 absorbs neutrons to produce U^233, a fissile material.
- Advantages of thorium-based reactors:
- Abundance of thorium in Earth's crust.
- Reduced production of long-lived radioactive waste.
- Enhanced safety features in some reactor designs.

- Challenges:
- Requires development of specialized reactor technology.
- Handling and processing of U^233 involve proliferation concerns.

Environmental and Safety Aspects

Due to its long half-life and low specific activity, Th^232 poses minimal immediate health risks. However, the decay chain includes several radioactive progeny that can be hazardous if ingested or inhaled. Proper containment and handling are essential in applications.

Pros and Cons of Th^232

Features and Benefits:

- Abundant and naturally occurring: Easily accessible in Earth's crust.
- Long half-life: Ideal for dating and long-term applications.
- Potential for clean energy: Can generate fissile U^233 with minimal waste.
- Low environmental radioactivity: Due to slow decay, poses less immediate radiation risk.

Limitations and Challenges:

- Slow decay rate: Not suitable for applications requiring rapid decay or short-term monitoring.
- Requires advanced technology: For nuclear fuel cycle and reactor development.
- Proliferation concerns: Production of U^233 can be misused for weapons.
- Radioactive progeny: Some decay chain elements are hazardous and require careful handling.

Conclusion

Thorium-232, with its remarkable half-life of approximately 14 billion years, stands as a fascinating element with diverse scientific and practical significance. Its decay process, governed by the exponential decay law, underscores its stability over cosmological timescales. As a nuclear fuel, Th^232 offers promising avenues for sustainable and cleaner energy production, leveraging its ability to breed fissile U^233.

While its low radioactivity and abundance make it an attractive resource, the technological and proliferation challenges associated with thorium-based reactors must be carefully managed. Its role in radiometric dating continues to contribute valuable insights into Earth's history, cementing Th^232's importance in both scientific research and future energy solutions.

In summary, the unique properties of Th^232—long half-life, potential for energy generation, and suitability for dating—highlight its significance across multiple disciplines. Continued research and technological advancements could unlock its full potential, making thorium a cornerstone of next-generation nuclear energy and geological sciences.

Note: This review provides a detailed understanding of Th^232's decay equation, features, and applications, emphasizing its importance and the considerations necessary for its use.

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