Find The Activity Of A Sample Containing 4e-6 G Of (= 5.27 Years). (use 59.93 U As The Mass Of .)

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Understanding the activity of a radioactive sample is crucial in nuclear physics, radiology, environmental science, and various industrial applications. When given a small mass of a radioactive isotope, such as 4 micrograms (4e-6 g), and a known half-life, such as 5.27 years, it becomes essential to determine its activity, often expressed in units like Becquerels (Bq) or Curies (Ci). This article provides a comprehensive guide to calculating the activity of a radioactive sample with detailed explanations and formulas, ensuring clarity for learners and professionals alike.

Introduction to Radioactivity and Activity

Radioactivity is the spontaneous emission of particles or electromagnetic radiation from the nucleus of an unstable atom. The activity of a radioactive sample quantifies how many nuclei decay per unit time, providing a measure of its radioactivity.

Key Concepts:

- **Radioactive Decay:** The process by which unstable nuclei emit radiation to become more stable.
- **Half-life ($T_{1/2}$):** The time required for half of the radioactive nuclei in a sample to decay.

- **Activity (A):** The rate of decay, given in Becquerels (1 Bq = 1 decay per second).
- **Number of Nuclei (N):** The total number of radioactive atoms present in the sample.

Given Data and Objective

Given the problem:

- Mass of sample, **m** = 4e-6 grams (4 micrograms)
- Half-life, $\mathbf{T_{1/2}}$ = 5.27 years
- Atomic mass of the isotope, **μ** = 59.93 u (atomic mass units)

Our goal is to find the activity (A) of this sample, typically expressed in Becquerels (Bq). To achieve this, we need to determine the number of radioactive nuclei present and relate it to the decay rate using the decay constant.

Step-by-Step Calculation Process

1. Convert Mass to Moles

The first step is to find the number of moles of the isotope in the sample.

- Atomic mass (μ) in grams per mole: Since 1 u = 1 g/mol, the atomic mass in g/mol is approximately 59.93 g/mol.
- Number of moles (n):

$$ n = \frac{\text{Mass of sample (g)}}{\text{Atomic mass (g/mol)}} $$

$$ n = \frac{4 \times 10^{-6} \text{ g}}{59.93 \text{ g/mol}} \approx 6.67 \times 10^{-8} \text{ mol} $$

2. Calculate the Total Number of Nuclei (N)

Using Avogadro's number (NA = 6.022 × 1023 mol-1):

$$ N = n \times N_A $$

$$ N = 6.67 \times 10^{-8} \times 6.022 \times 10^{23} \approx 4.012 \times 10^{16} \text{ nuclei} $$

3. Determine the Decay Constant (λ)

The decay constant relates to the half-life:

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

- Convert T1/2 from years to seconds:

$$ T_{1/2} = 5.27 \text{ years} \times 365.25 \text{ days/year} \times 24 \text{ hours/day} \times 3600 \text{ seconds/hour} $$

$$ T_{1/2} \approx 5.27 \times 365.25 \times 24 \times 3600 \approx 1.664 \times 10^{8} \text{ seconds} $$

- Calculate λ:

$$ \lambda = \frac{\ln 2}{1.664 \times 10^{8}} \approx 4.16 \times 10^{-9} \text{ s}^{-1} $$

4. Calculate the Activity (A)

The activity is given by:

$$ A = \lambda N $$

$$ A = 4.16 \times 10^{-9} \times 4.012 \times 10^{16} \approx 167,000 \text{ Bq} $$

Thus, the activity of the sample is approximately 167 kBq.

Understanding the Results and Practical Implications

The calculated activity indicates how many decay events occur per second in the sample. For practical purposes:

- In Medical Applications: This activity level might be suitable for diagnostic imaging or radiotherapy, depending on the isotope.
- Environmental Monitoring: Small activity levels like this are typical in environmental samples, requiring sensitive detection equipment.
- Industrial Use: Radioactive sources for calibration or tracing should be characterized by their activity to ensure safety and efficacy.

Additional Considerations

Effect of Isotope Purity and Sample Composition

In real-world scenarios, samples may contain multiple isotopes or impurities. Proper purification and characterization are essential for accurate activity determination.

Measurement Techniques

Activities are often measured using scintillation counters, Geiger-Müller counters, or liquid scintillation spectrometry. These methods detect emitted radiation and relate it back to the sample's activity.

Safety Precautions

Handling radioactive samples requires adherence to safety protocols, including shielding, minimizing exposure, and proper disposal.

Conclusion

Calculating the activity of a radioactive sample involves understanding the relationships between mass, atomic mass, number of nuclei, decay constant, and activity. For a sample containing 4 micrograms of an isotope with a half-life of 5.27 years and an atomic mass of 59.93 u, the activity is approximately 167 kBq. This detailed approach ensures accurate and reliable results, essential in scientific research, medical applications, and industrial processes.

Summary of Key Formulas

1. Number of moles: $n = \frac{m}{\mu}$
2. Total nuclei: $N = n \times N_A$
3. Decay constant: $\lambda = \frac{\ln 2}{T_{1/2}}$
4. Activity: $A = \lambda N$

By mastering these calculations, professionals can accurately assess the radioactivity of various samples and apply this knowledge across multiple fields.

Note: Always verify the units and conversions when performing calculations, and use precise constants for high-accuracy requirements.

Frequently Asked Questions

How do I calculate the activity of a sample containing 4e-6 g of a radioactive isotope with a half-life of 5.27 years?

To calculate the activity, first determine the number of moles of the sample using its mass and molar mass, then find the number of nuclei, and finally apply the decay constant to find activity: $A = \lambda N$.

What is the decay constant (λ) for a isotope with a half-life of 5.27 years?

The decay constant λ is calculated as $\lambda = \ln(2) / T_{1/2}$. For $T_{1/2}$ = 5.27 years, $\lambda \approx 0.1314$ year^{-1}.

How do I convert the mass of the sample (4e-6 g) to the number of nuclei?

First, divide the mass by the molar mass of the isotope to find moles, then multiply by Avogadro's number (6.022e23) to get the number of nuclei.

Given the mass of 59.93 U as the molar mass, how do I proceed with

the calculation?

Use 59.93 g/mol as the molar mass; compute the number of moles as (4e-6 g) / (59.93 g/mol), then multiply by Avogadro's number to get total nuclei.

What is the final formula to find the activity of the sample?

The activity A = □ × N, where N is the total number of nuclei in the sample. Calculate N as (mass / molar mass) × Avogadro's number, then multiply by □.

Why is understanding activity important in nuclear physics and radiometric dating?

Activity quantifies the rate of radioactive decay, which is essential for determining the age of samples, understanding decay processes, and applications in medicine and industry.

Additional Resources

Find The Activity Of A Sample Containing 4e-6 G Of (= 5.27 Years). (use 59.93 U As The Mass Of .)

In the realm of nuclear science and radiometric dating, accurately determining the activity of a radioactive sample is vital for applications spanning geology, archaeology, medicine, and environmental sciences. Today, we delve into a specific case: calculating the activity of a tiny sample weighing 4 micrograms (4e-6 grams) of a radioactive isotope with a half-life of approximately 5.27 years, and a total mass of 59.93 units (U). This exploration not only underscores the fundamental principles of nuclear decay but also demonstrates practical methods used by scientists to quantify radioactivity in small samples.

Understanding how to derive the activity from given data involves integrating concepts such as half-life, decay constant, and the relationship between mass and number of nuclei. The process is essential for applications like radiocarbon dating, medical isotope preparation, and nuclear safety assessments.

In this article, we will systematically dissect the problem, starting from fundamental definitions and progressing through detailed calculations, to arrive at the activity expressed in units of Becquerel (Bq) – the SI unit of radioactivity.

Fundamental Concepts in Radioactive Decay

Before tackling the calculation, it's crucial to grasp some core principles:

Radioactive Isotopes and Decay

Radioactive isotopes, or radioisotopes, are variants of elements with unstable nuclei that decay spontaneously, emitting radiation in the process. The rate at which a sample decays is characterized by its activity, which is the number of decays per unit time.

Half-life ($T_{1/2}$)

The half-life is the time taken for half of the radioactive nuclei in a sample to decay. In our case, T1/2 = 5.27 years.

Decay Constant (λ)

The decay constant (λ) represents the probability per unit time that a nucleus will decay. It relates to the half-life via:

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

where T1/2 must be in consistent units (seconds for SI units).

Activity (A)

The activity of a sample is given by:

$$
A = \square N
$$

where N is the total number of radioactive nuclei present.

Step 1: Converting Half-life to SI Units

Given T1/2 = 5.27 years.

To compute □, we need to convert years to seconds:

$$
1\, \text{year} = 365.25\, \text{days} \times 24\, \text{hours/day} \times 3600\, \text{seconds/hour} \approx 31,557,600\, \text{seconds}
$$

Therefore,

$$
T_{1/2} = 5.27\, \text{years} \times 31,557,600\, \text{seconds/year} \approx 166,560,271\, \text{seconds}
$$

\]

Step 2: Calculating the Decay Constant (λ)

Using the relation:

$$
\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.6931}{166,560,271\, \text{s}} \approx 4.16 \times 10^{-9}\, \text{s}^{-1}
$$

This decay constant indicates that each nucleus has an approximately 4.16 in a billion chance of decaying each second.

Step 3: Determining the Number of Nuclei (N)

The total activity depends on N, the number of radioactive atoms in the sample. To find N, we need to relate the given mass to the number of nuclei.

Mass of the Sample

Given: 4e-6 grams = 4 micrograms.

Mass of the Radioisotope

Assuming that the entire 4 micrograms is the radioactive isotope in question, and using molar mass data.

Suppose the isotope has an atomic mass (Am) – which is not specified explicitly in the problem. For the sake of a precise calculation, let's assume the isotope has an atomic mass similar to common isotopes used in radiometric dating, such as Carbon-14 (~14 g/mol).

Note: The problem statement mentions "use 59.93 U as the mass of .", which appears to refer to atomic mass in atomic mass units (u). Thus, Am = 59.93 u.

Since 1 u = 1.66053906660 × 10-24 grams,

$$
A_m = 59.93\, \text{u} \times 1.660539 \times 10^{-24}\, \text{g/u} \approx 9.96 \times 10^{-23}\, \text{g}
$$

Number of Nuclei (N)

$$
N = \frac{\text{Mass of sample}}{\text{Mass of one nucleus}} = \frac{4 \times 10^{-6}\, \text{g}}{9.96 \times 10^{-23}\, \text{g}} \approx 4.02 \times 10^{16}
$$

This calculation indicates approximately 40 quadrillion nuclei are present in the sample.

Step 4: Calculating the Activity (A)

Now, applying the fundamental relation:

$$
A = \lambda N
$$

$$
A = (4.16 \times 10^{-9}\, \text{s}^{-1}) \times (4.02 \times 10^{16}) \approx 1.67 \times 10^{8}\, \text{decays per second}
$$

Since 1 decay per second corresponds to 1 Becquerel (Bq), the activity of the sample is approximately:

$$
A \approx 1.67 \times 10^{8}\, \text{Bq}
$$

Expressing Activity in Curie Units

For context, activities are often expressed in curies (Ci), where:

$$
1\, \text{Ci} = 3.7 \times 10^{10}\, \text{Bq}
$$

Thus,

$$
A \approx \frac{1.67 \times 10^{8}}{3.7 \times 10^{10}} \approx 0.0045\, \text{Ci}
$$

The activity is about 4.500 millicuries (mCi), a typical magnitude for small samples used in medical or scientific applications.

Implications and Applications

The calculation demonstrates how a tiny mass of a radioactive isotope can produce a significant activity. Such precise calculations are fundamental in various fields:

- Radiocarbon Dating: Determining the age of archaeological samples by measuring the remaining C-14 activity.
- Medical Isotopes: Ensuring proper dosages based on activity levels.
- Nuclear Safety: Monitoring the decay rate and activity of radioactive waste or materials.
- Environmental Monitoring: Tracking radioactive contamination levels in ecosystems.

Accurate knowledge of activity helps in assessing safety, planning experiments, and understanding the natural or anthropogenic processes involving radioisotopes.

Conclusion

Calculating the activity of a radioactive sample entails a clear understanding of nuclear decay principles, precise unit conversions, and application of fundamental relationships between mass, number of nuclei, decay constant, and activity. In our specific case, a microgram-scale sample containing a radioisotope with a half-life of about 5.27 years exhibits an activity in the order of hundreds of millions of Becquerel, highlighting the potency of even minute quantities of radioactive materials.

This comprehensive approach underscores the importance of meticulous calculation steps, assumptions clarity (especially regarding atomic mass), and contextual understanding when working with nuclear data. Such skills are indispensable for scientists and engineers working across disciplines where radioactivity plays a crucial role.

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