What Volume Of Kr-93 (at 25 C And 1.0 Atm) Is Produced When 1.90 G Of U-235undergoes This Fission Reaction?

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Understanding the amount of specific radioactive isotopes produced during nuclear fission is crucial for various applications, including nuclear energy production, radiochemistry, and nuclear safety. In this article, we will explore how to determine the volume of krypton-93 (Kr-93) gas generated when 1.90 grams of uranium-235 (U-235) undergoes fission under standard conditions—specifically at 25°C and 1.0 atm pressure. We will walk through the nuclear reactions involved, the stoichiometric calculations, and the ideal gas law application to arrive at the final volume.

Fundamentals of Nuclear Fission of U-235

What Is U-235 and Its Fission Process?

Uranium-235 is a fissile isotope, meaning it can sustain a chain reaction when bombarded with neutrons. When a U-235 nucleus absorbs a neutron, it becomes unstable and splits into smaller nuclei, known as fission fragments, along with additional neutrons and energy release.

The primary fission reaction is as follows:

```
U-235 + n → Fission fragments + 2-3 neutrons + energy
```

The fission fragments are typically radioactive isotopes, some of which are noble gases like Kr-93. The neutrons released can induce further fission in other U-235 nuclei, sustaining a chain reaction.

Fission Products and Kr-93

In the multitude of possible fission products, krypton isotopes, such as Kr-93, are common. Kr-93 is a radioactive noble gas isotope produced directly or via decay chains. Its formation depends on the specific fission pathways and the distribution of fission fragments.

For simplicity, we assume Kr-93 is produced directly in the fission of U-235, with an average yield per fission event.

Calculating the Number of U-235 Nuclei in 1.90 g

Molar Mass of U-235

The molar mass of uranium-235 is approximately 235.0439299 g/mol.

Number of Moles of U-235

Given mass (m):

$$
\text{m} = 1.90\, \text{g}
$$

Number of moles (n):

$$
n_{U-235} = \frac{m}{M} = \frac{1.90\, \text{g}}{235.0439\, \text{g/mol}} \approx 0.00807\, \text{mol}
$$

Number of U-235 Nuclei

Using Avogadro's number ($N_A = 6.022 \times 10^{23}$ nuclei/mol):

$$
N_{U-235} = n_{U-235} \times N_A \approx 0.00807 \times 6.022 \times 10^{23} \approx 4.86 \times 10^{21}\ \text{nuclei}
$$

This is the total number of U-235 nuclei available for fission.

Estimating the Number of Kr-93 Nuclei Produced

Fission Yield of Kr-93

The fission yield of Kr-93, which is the fraction of fissions resulting in this isotope, is typically expressed as a percentage or per mille value based on experimental data.

For the purpose of this calculation, assume an average fission yield of Kr-93 of approximately 3%

(0.03) per fission event. This value can vary, but 3% is a reasonable estimate based on nuclear data tables.

Number of Fission Events

Each U-235 nucleus undergoing fission results in one fission event. Therefore, the total number of fission events is approximately:

$$
N_{fission} \approx N_{U-235} \approx 4.86 \times 10^{21}
$$

Assuming all the U-235 nuclei undergo fission (which is idealized), the number of Kr-93 atoms produced is:

$$
N_{Kr-93} = N_{fission} \times \text{fission yield} = 4.86 \times 10^{21} \times 0.03 \approx 1.46 \times 10^{20}
$$

This is the total number of Kr-93 atoms generated.

Converting the Number of Kr-93 Atoms to Moles

Number of moles of Kr-93:

$$
n_{Kr-93} = \frac{N_{Kr-93}}{N_A} \approx \frac{1.46 \times 10^{20}}{6.022 \times 10^{23}} \approx 2.43 \times 10^{-4}\ \text{mol}
$$

This is the amount of Kr-93 in moles produced during the fission.

Calculating the Volume of Kr-93 Gas at Standard Conditions

Using the Ideal Gas Law

The ideal gas law relates the volume (V) of a gas to the number of moles (n), temperature (T), and pressure (P):

\[

$$
PV = nRT
$$

Where:

- $P = 1.0\, \text{atm}$
- $T = 25^\circ C = 298\, \text{K}$
- $R = 0.082057\, \text{L·atm/(mol·K)}$

Rearranged for volume:

$$
V = \frac{nRT}{P}
$$

Plugging in the values:

$$
V = \frac{(2.43 \times 10^{-4}\ \text{mol}) \times 0.082057\ \text{L·atm/(mol·K)} \times 298\, \text{K}}{1.0\, \text{atm}}
$$

Calculating numerator:

$$
2.43 \times 10^{-4} \times 0.082057 \times 298 \approx 5.96 \times 10^{-3}\ \text{L}
$$

Thus:

$$
V \approx 5.96 \times 10^{-3}\ \text{L} = 5.96\, \text{mL}
$$

Final volume of Kr-93 gas produced: approximately 5.96 milliliters.

Summary and Considerations

- The calculation assumes 100% efficiency, meaning all uranium atoms undergo fission, which is unlikely in practical scenarios but appropriate for theoretical estimation.
- The fission yield of Kr-93 is taken as 3%; actual yields may vary based on nuclear data.
- The produced Kr-93 atoms are considered to occupy a volume at standard temperature and pressure, adhering to the ideal gas law.
- The result indicates that approximately 6 mL of Kr-93 gas would be generated under the specified conditions from 1.90 g of U-235.

Additional Factors and Real-World Implications

- Radioactive Decay: Kr-93 has a half-life of about 1.46 hours, so in real-world applications, decay rates would influence the measurable volume shortly after production.
- Fission Chain Reaction Efficiency: Not all U-235 nuclei will necessarily undergo fission; thus, actual yields might be lower.
- Gas Collection and Separation: In nuclear reactors, noble gases like Kr-93 are often collected for waste management or radiometric analysis.
- Safety Considerations: Krypton isotopes are radioactive and require proper handling due to their radiological hazards.

Conclusion

Calculating the volume of Kr-93 produced during the fission of uranium-235 involves understanding nuclear reaction yields, stoichiometry, and gas laws. Under ideal conditions—assuming complete fission of 1.90 grams of U-235, a fission yield of about 3% for Kr-93, and standard temperature and pressure—the expected volume of Kr-93 gas is approximately 6 milliliters. This calculation underscores the scale of nuclear reactions and the importance of precise data for safety, environmental assessments, and technological applications in nuclear science.

References

- Knoll, G. F. (2010). Radiation Detection and Measurement. John Wiley & Sons.
- National Nuclear Data Center (NNDC). (2023). Fission Yield Data. [Online Database]
- Lamarsh, J. R., & Baratta, A. J. (2001). Introduction to Nuclear Engineering. Prentice Hall.
- IAEA. (2008). Handbook of Nuclear Data for Applications. International Atomic Energy Agency.

Note: The actual fission yield and specific isotope production can vary depending on the reactor type, fuel composition, and fission fragment distribution. Always consult current nuclear data tables for precise calculations.

Frequently Asked Questions

What is the reaction involved when U-235 undergoes fission to produce Kr-93?

When U-235 undergoes fission, it splits into smaller nuclei, including Krypton-93 (Kr-93), along with other fission products and free neutrons.

How do you calculate the number of moles of U-235 in 1.90 g?

The number of moles is calculated by dividing the mass by the molar mass of U-235: moles = 1.90 g / 235.04 g/mol ≈ 0.00807 mol.

What is the approximate number of Kr-93 atoms produced from 0.00807 mol of U-235?

Assuming each U-235 nucleus produces one Kr-93 atom upon fission, the number of Kr-93 atoms is 0.00807 mol × Avogadro's number (6.022×10^{23}) ≈ 4.86×10^{21} atoms.

How do you determine the volume of Kr-93 gas at 25°C and 1 atm from the number of atoms produced?

First, convert the number of atoms to moles, then use the ideal gas law (PV=nRT) to find the volume: V = nRT/P, where n is moles of Kr-93.

What is the final volume of Kr-93 produced at standard conditions?

Calculating with the ideal gas law, the volume V = (4.86×10^{21} atoms / 6.022×10^{23}) mol × 0.0821 L·atm/(mol·K) × 298 K / 1 atm ≈ 39.8 liters.

Why is understanding the volume of Kr-93 important in nuclear chemistry?

Knowing the volume helps in managing radioactive gases, designing containment systems, and understanding the scale of fission product release during nuclear reactions.

Additional Resources

What Volume Of Kr-93 (at 25°C And 1.0 Atm) Is Produced When 1.90 G Of U-235 Undergoes This Fission Reaction?

Understanding the intricacies of nuclear fission reactions is crucial for both scientific research and practical applications such as nuclear energy production. When uranium-235 (U-235) undergoes fission, it produces a variety of fission fragments, including noble gases like krypton-93 (Kr-93). A common question that arises in nuclear physics and engineering is: "What volume of Kr-93 (at 25°C and 1.0 atm) is produced when 1.90 g of U-235 undergoes fission?" This article provides a comprehensive step-by-step guide to answer this question, integrating principles from nuclear chemistry, stoichiometry, and gas laws.

Introduction to U-235 Fission and Fission Products

Uranium-235 is a well-known fissile isotope, capable of sustaining a chain reaction upon absorption of a neutron. When U-235 absorbs a neutron, it becomes highly unstable and splits into smaller nuclei, called fission fragments, along with additional neutrons and energy. The specific fission products vary, but among them are isotopes of noble gases such as krypton (Kr) and xenon (Xe).

Key facts:
- U-235 fission releases approximately 200 MeV per event.
- The fission yields (probability of producing a specific isotope) vary for different isotopes.
- Kr-93 is one of the krypton isotopes produced during fission.

Step 1: Understanding the Fission Reaction and Kr-93 Yield

The first step is to identify how many U-235 atoms are involved and how many Kr-93 atoms are produced per fission event.

The General Fission Reaction:

When one U-235 nucleus absorbs a neutron:

$$ \text{U-235} + n \rightarrow \text{Fission fragments} + \text{neutrons} + \text{energy} $$

The typical number of neutrons released is about 2-3 per fission, and the fission fragments include various isotopes, including Kr-93.

Fission Yield of Kr-93:

Fission yield is the fraction of fissions that produce a particular isotope. For Kr-93, the cumulative yield is approximately 0.6% (or 0.006 in decimal form). This means that, on average, about 0.6% of all fission events produce Kr-93.

Note: For precise calculations, consult nuclear data tables for exact yields; here, we use an approximate value.

Step 2: Calculating the Number of U-235 Atoms in 1.90 g

To determine how many Kr-93 atoms are produced, we first need to calculate the number of U-235 atoms that undergo fission.

Atomic mass of U-235:

- Approximately 235.0439 g/mol.

Number of moles of U-235:

$$
\text{Moles of U-235} = \frac{\text{Mass of U-235}}{\text{Atomic mass}} = \frac{1.90\, \text{g}}{235.0439\, \text{g/mol}} \approx 0.00808\, \text{mol}
$$

Number of U-235 atoms:

$$
N_{U-235} = \text{moles} \times N_A = 0.00808\, \text{mol} \times 6.022 \times 10^{23}\, \text{atoms/mol} \approx 4.87 \times 10^{21}\, \text{atoms}
$$

Assumption: All U-235 undergoes fission, which is an idealized scenario for this calculation.

Step 3: Determining the Number of Kr-93 Atoms Produced

Fission events:

Since each U-235 atom fissions once:

$$
\text{Number of fission events} \approx 4.87 \times 10^{21}
$$

Number of Kr-93 atoms produced:

Using the fission yield:

$$
\text{Kr-93 atoms} = \text{Number of fission events} \times \text{Yield}
$$

$$
= 4.87 \times 10^{21} \times 0.006 \approx 2.92 \times 10^{19}
$$

Thus, approximately 2.92×10^{19} Kr-93 atoms are produced.

Step 4: Converting Atom Count to Moles

To use the ideal gas law, we need the amount in moles:

$$
\text{Moles of Kr-93} = \frac{\text{Number of atoms}}{N_A} = \frac{2.92 \times 10^{19}}{6.022 \times 10^{23}} \approx 4.85 \times 10^{-5}\, \text{mol}
$$

Step 5: Applying the Ideal Gas Law to Find Volume

The ideal gas law:

$$
PV = nRT
$$

Where:

- $P = 1.0\, \text{atm}$
- $V = ?$ (volume in liters)
- $n = 4.85 \times 10^{-5}\, \text{mol}$
- $R = 0.082057\, \text{L·atm/(mol·K)}$
- $T = 25^\circ C = 298.15\, \text{K}$

Solving for volume:

$$
V = \frac{nRT}{P}
$$

$$
V = \frac{4.85 \times 10^{-5}\, \text{mol} \times 0.082057\, \text{L·atm/(mol·K)} \times 298.15\, \text{K}}{1.0\, \text{atm}}
$$

Calculating numerator:

$$
4.85 \times 10^{-5} \times 0.082057 \times 298.15 \approx 1.19 \times 10^{-3}\, \text{L}
$$

Therefore:

$$
V \approx 0.00119\, \text{L} = 1.19\, \text{mL}
$$

Final Result:

The volume of Kr-93 (at 25°C and 1 atm) produced by the fission of 1.90 g of U-235 is approximately 1.19 milliliters.

Additional Considerations and Real-World Implications

Assumptions and Limitations:

- The calculation assumes 100% fission efficiency of U-235, which is unlikely in practical scenarios.
- The fission yield used is approximate; actual yields vary based on neutron energy and other factors.
- Gas behaves ideally; deviations at high pressures or low temperatures may occur.

- Only Kr-93 is considered, but multiple fission fragments are produced simultaneously.

Practical Applications:

Understanding the volume of noble gases produced in fission is vital for:

- Reactor design: Managing gaseous fission products to prevent pressure buildup.
- Radioactive waste management: Recognizing the quantities and types of gases released.
- Safety protocols: Monitoring noble gases that could pose health hazards if released.

Summary

In this detailed guide, we have:

- Calculated the number of U-235 atoms in 1.90 g.
- Applied typical fission yields to estimate Kr-93 production.
- Converted atoms to moles, then applied the ideal gas law to find the gas volume.
- Arrived at an approximate volume of 1.19 mL of Kr-93 at standard conditions.

This comprehensive approach combines nuclear chemistry, stoichiometry, and gas laws to provide a clear understanding of the amount of krypton-93 generated during uranium-235 fission under specified conditions.

References

- Nuclear Data Sheets and Fission Yield Databases.
- "Introductory Nuclear Physics" by Kenneth S. Krane.
- Standard values for gas laws and atomic weights.

Understanding the quantities of fission products like Kr-93 not only deepens our knowledge of nuclear reactions but also informs safety, environmental, and engineering considerations in nuclear technology.

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