Calculate The Energy (in Joules) Released Per Mole For The Nuclear Fusion Reaction 2 1h 3 1h -------

Calculate The Energy (in Joules) Released Per Mole For The Nuclear Fusion Reaction 2 1H + 3 1H -------

Understanding nuclear fusion is essential for grasping the fundamental processes powering stars and the potential for clean energy sources on Earth. The reaction involving hydrogen isotopes, specifically deuterium (2 1H) and tritium (3 1H), is one of the most studied fusion reactions due to its high energy yield and relative feasibility. In this article, we will explore how to calculate the energy released per mole of the fusion reaction: 2 1H + 3 1H → (products) + energy. We will delve into the principles of nuclear physics, mass defect calculations, and energy conversion methods to provide a comprehensive understanding of this process.

Understanding Nuclear Fusion and Its Significance

What is Nuclear Fusion?

Nuclear fusion is a process where two light nuclei combine to form a heavier nucleus, releasing vast amounts of energy. Unlike nuclear fission, which splits heavy nuclei, fusion mimics the processes that power stars, including our Sun.

Why Focus on Hydrogen Isotopes?

Hydrogen isotopes, deuterium (^2H or D) and tritium (^3H or T), are prime candidates for fusion because:

- They are abundant and can be extracted from water and other sources.
- Their fusion reactions release significant energy.
- The reaction cross-sections are relatively high at achievable temperatures.

Significance of Calculating Fusion Energy

Quantifying the energy released per mole of fuel helps in:

- Designing and optimizing fusion reactors.
- Estimating the feasibility of fusion as a sustainable energy source.
- Understanding the fundamental physics governing stellar processes.

The Fusion Reaction of Interest: 2 1H + 3 1H

Reaction Equation and Products

The specific fusion reaction involving hydrogen isotopes can be written as:

$^{2}H + ^{3}H \rightarrow ^{4}He + n + \text{energy}$

This reaction involves deuterium (^{2}H) and tritium (^{3}H) combining to produce a helium-4 nucleus (alpha particle), a neutron, and a significant amount of energy.

Reaction Details

- Reactants: 2 1H + 3 1H (or $^{2}H + ^{3}H$)
- Products: ^{4}He (helium nucleus) + neutron (n)
- Energy Release: The energy released is primarily carried by the helium nucleus and neutron.

Calculating the Energy Released Per Reaction

Principle of Mass-Energy Equivalence

Einstein’s mass-energy equivalence principle, $E=mc^2$, states that mass can be converted into energy. In nuclear reactions, the slight difference in mass between reactants and products (mass defect) results in energy release.

Steps to Calculate Energy Per Reaction

1. Identify the atomic masses of reactants and products.

2. Calculate the total mass of reactants and products.

3. Determine the mass defect (difference between reactants and products).

4. Convert the mass defect into energy using $E=mc^2$.

Atomic Masses and Data Sources

For accurate calculations, use atomic mass units (u) or unified atomic mass units, commonly obtained from nuclear data tables:
- ^1H (proton): approximately 1.007825 u
- ^2H (deuterium): approximately 2.013553 u
- ^3H (tritium): approximately 3.016049 u
- ^4He (helium-4 nucleus): approximately 4.002603 u
- Neutron (n): approximately 1.008665 u

Calculating the Mass Defect for the Reaction

Step 1: Mass of Reactants

Since the reaction involves one deuterium and one tritium nucleus:

Mass of reactants = mass of ^2H + mass of ^3H
= 2.013553 u + 3.016049 u
= 5.029602 u

Step 2: Mass of Products

The products are ^4He and a neutron:

Mass of products = mass of ^4He + mass of n
= 4.002603 u + 1.008665 u
= 5.011268 u

Step 3: Mass Defect

The mass defect is the difference:

Δm = mass of reactants - mass of products
= 5.029602 u - 5.011268 u
= 0.018334 u

This small difference represents the mass converted into energy during the reaction.

Converting Mass Defect to Energy

Using Einstein's Equation

The energy released per reaction is:

$$E = \Delta m \times c^2$$

Where:
- Δm is the mass defect in kilograms.
- c is the speed of light ($\sim 3\times10^8$ m/s).

Converting Atomic Mass Units to Kilograms

1 atomic mass unit (u) = 1.660539×10^{-27} kg.

Thus,

$$\Delta m \text{ (kg)} = 0.018334 \text{ u} \times 1.660539 \times 10^{-27} \text{ kg/u}$$
$$\approx 3.046 \times 10^{-29} \text{ kg}$$

Calculating Energy per Reaction

Plugging into $E=mc^2$:

$$E = 3.046 \times 10^{-29} \text{ kg} \times (3 \times 10^8 \text{ m/s})^2$$
$$= 3.046 \times 10^{-29} \text{ kg} \times 9 \times 10^{16} \text{ m}^2/\text{s}^2$$
$$\approx 2.741 \times 10^{-12} \text{ Joules}$$

Therefore, each fusion reaction releases approximately 2.74 picojoules of energy.

Calculating Energy Released Per Mole of Reactants

Number of Reactions per Mole

- Avogadro’s Number: 6.022×10^{23} particles/mole.
- Since each reaction involves one deuterium and one tritium nucleus, one mole of each isotope can participate in 6.022×10^{23} reactions.

Energy per Mole

Total energy released per mole:

Energy per mole = energy per reaction × number of reactions
$= 2.741 \times 10^{-12}$ J $\times 6.022 \times 10^{23}$
$\approx 1.651 \times 10^{12}$ Joules

This is about 1.65 trillion Joules per mole, an enormous amount of energy.

Implications and Practical Considerations

Comparison with Other Energy Sources

- The energy per mole from fusion far exceeds chemical reactions, such as combustion.
- For perspective, burning one mole of methane releases about 890 kJ, which is negligible compared to fusion energy.

Feasibility in Energy Generation

- Achieving and sustaining the high temperatures (~100 million Kelvin) required for fusion is technologically challenging.
- Containment methods, like magnetic confinement in tokamaks, are under development.
- The energy gain (ratio of energy produced to energy input) is a critical factor for practical fusion power plants.

Challenges and Future Outlook

- Managing neutron radiation damage.
- Developing materials capable of withstanding intense radiation.

- Achieving net energy gain in fusion reactors.

Summary and Key Takeaways

- The fusion reaction between deuterium and tritium releases approximately 2.74×10^{-12} Joules per reaction.
- Per mole, this reaction releases roughly 1.65×10^{12} Joules.
- This immense energy output underscores fusion's potential as a clean, high-yield energy source.
- Real-world application requires overcoming significant scientific and engineering challenges.

Final Thoughts

Calculating the energy released per mole in nuclear fusion reactions helps scientists and engineers understand the immense potential of fusion power. While the calculations demonstrate the high energy density of fusion fuel, translating this into practical energy generation remains an ongoing pursuit. Advances in plasma physics, materials science, and reactor design are essential to harness this power sustainably and safely.

References:

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Frequently Asked Questions

What is the nuclear fusion reaction involving 2 1H and 3 1H?

The reaction involves two isotopes of hydrogen: deuterium (^2H) and tritium (^3H), which fuse to produce helium-4 and a neutron.

How do you calculate the energy released in Joules per mole for the fusion reaction?

You subtract the total mass of reactants from the total mass of products to find the mass defect, then multiply by c^2 (speed of light squared) for energy per atom, and finally multiply by Avogadro's number to get energy per mole.

What is the mass defect in the fusion reaction ^2H + ^3H?

The mass defect is approximately 0.01827 atomic mass units (amu) per reaction, representing the difference between the sum of reactant masses and product masses.

How do you convert mass defect from atomic mass units to Joules?

Multiply the mass defect in amu by 1.6605×10^{-27} kg (mass in kg), then multiply by c^2 (9×10^{16} m^2/s^2) to get energy in Joules.

What is the approximate energy released per fusion reaction in Joules?

Approximately 17.6 MeV, which converts to about 2.82×10^{-11} Joules per reaction.

How many Joules are released per mole of the fusion reaction?

Multiplying the energy per reaction (2.82×10^{-11} J) by Avogadro's number (6.022×10^{23}) yields roughly 17 million Joules, or about 17 MJ per mole.

Why is calculating energy release important in nuclear fusion?

It helps determine the energy efficiency and potential power output of fusion reactors, essential for developing sustainable fusion energy sources.

What factors can affect the accuracy of calculating energy released in fusion reactions?

Factors include precise mass measurements, nuclear binding energies, and the assumptions made in mass-energy equivalence calculations.

Additional Resources

Calculate The Energy (in Joules) Released Per Mole For The Nuclear Fusion Reaction 2 1H → 3 1H

Introduction

Nuclear fusion has long been heralded as the future of clean energy, promising an abundant and sustainable source of power by mimicking the processes that fuel stars. The specific fusion reaction under scrutiny here involves the fusion of two isotopes of hydrogen: deuterium (^2H) or D and tritium (^3H) or T. However, the reaction notation "2 1H → 3 1H" appears to be a simplified or possibly misrepresented notation; typically, the most studied and practical fusion reaction involves deuterium and tritium:

$$^2H + ^3H \rightarrow ^4He + n + 17.6\, \text{MeV}$$

Note: For the purpose of this analysis, we will interpret the reaction as the fusion of deuterium (^2H) and tritium (^3H) to form helium (^4He) and a neutron, releasing 17.6 MeV of energy per reaction, as it is the most relevant and well-understood fusion process.

Understanding the Fusion Reaction

The Standard Deuterium-Tritium Fusion Reaction

The primary fusion reaction studied in controlled environments is:

$$^2H + ^3H \rightarrow ^4He + n + 17.6\, \text{MeV}$$

- Reactants:
- Deuterium (^2H): a stable isotope of hydrogen with one proton and one neutron.
- Tritium (^3H): a radioactive isotope of hydrogen with one proton and two neutrons.

- Products:
- Helium-4 (^4He): a stable, inert noble gas isotope.
- Neutron (n): a free neutron emitted during the reaction.

- Energy Release:
- The total energy released per reaction is approximately 17.6 MeV, primarily carried away by the neutron and the helium nucleus.

Significance of the Reaction

This reaction is favored because:

- It has a high cross-section at relatively modest temperatures (~100 million Kelvin).
- It produces a large amount of energy per reaction.
- The products are less radioactive than the initial isotopes, simplifying waste management.

Calculating Energy Released Per Mole

Step 1: Convert Energy per Reaction from MeV to Joules

The energy released per fusion event is:

$$ E_{reaction} = 17.6\, \text{MeV} $$

Recall that:

$$ 1\, \text{MeV} = 1.602176634 \times 10^{-13}\, \text{J} $$

Thus,

$$ E_{reaction} = 17.6 \times 1.602176634 \times 10^{-13}\, \text{J} $$

Calculating:

$$ E_{reaction} \approx 17.6 \times 1.602176634 \times 10^{-13} $$
$$ E_{reaction} \approx 2.818 \times 10^{-12}\, \text{J} $$

Step 2: Determine the Number of Reactions per Mole

Avogadro’s number:

$$ N_A = 6.022 \times 10^{23} \, \text{mol}^{-1} $$

Since each reaction involves one pair of nuclei, the number of reactions per mole of reactant pairs is equal to Avogadro’s number.

Key Point: One mole of reactions corresponds to 6.022×10^{23} fusion events.

Step 3: Calculate Total Energy Released Per Mole

Total energy per mole:

$$ E_{per\, mole} = E_{reaction} \times N_A $$

Plugging in the numbers:

$$ E_{per\, mole} = 2.818 \times 10^{-12}\, \text{J} \times 6.022 \times 10^{23} $$
$$ E_{per\, mole} \approx (2.818 \times 6.022) \times 10^{(-12 + 23)} $$
$$ E_{per\, mole} \approx 16.97 \times 10^{11} $$
$$ E_{per\, mole} \approx 1.697 \times 10^{12}\, \text{J} $$

Final Result:

> The energy released per mole of deuterium-tritium fusion reactions is approximately 1.70 trillion joules (1.70×10^{12} J).

Deep Dive: Assumptions and Considerations

1. Reaction Stoichiometry and Isotope Ratios

- The calculation assumes a pure molar quantity of reactant pairs, i.e., one mole of D-T pairs.
- In practical fusion scenarios, the fuel is often a mixture of isotopes, and reactions may involve other pathways.

2. Efficiency and Reactor Conditions

- Actual energy yield depends on reactor efficiency, confinement methods, and plasma conditions.
- Not all fuel atoms will undergo fusion; the calculation considers idealized total energy release per mole of reactant pairs.

3. Reaction Cross-Section and Temperature Dependence

- The likelihood of fusion depends on temperature and density.
- The 17.6 MeV energy output per reaction is a theoretical maximum per event.

4. Radioactivity and Waste Products

- Unlike fission, fusion produces minimal long-lived radioactive waste.
- Helium and neutrons are the primary products.

Comparisons and Contextualization

Fusion vs. Fission Energy Yield

- Fission of uranium-235 releases about 200 MeV per atom, translating to roughly 8.2×10^{13} J per mole.
- Fusion reactions like D-T produce less energy per event but are more abundant and cleaner.

Practical Implications

- The enormous amount of energy per mole indicates fusion's potential as an energy source.
- To harness this energy, reactors must achieve high temperatures, plasma confinement, and sustain reactions over time.

Challenges in Realizing Fusion Power

Technical Barriers

- Achieving and maintaining the necessary plasma temperatures (~100 million Kelvin).
- Containing the plasma to sustain reactions.
- Managing neutron radiation damage to reactor materials.

Economic and Safety Considerations

- Cost of building and maintaining fusion reactors.
- Ensuring safety protocols for handling tritium and neutron radiation.

Research and Development

- ITER and other experimental reactors aim to demonstrate net energy gain.
- Advances in magnetic confinement (tokamaks, stellarators) and inertial confinement are ongoing.

Conclusion

The calculation of the energy released per mole for the fusion reaction involving deuterium and tritium reveals an enormous potential energy reservoir—approximately 1.70 terajoules per mole of reactant pairs. This figure underscores the promise of nuclear fusion as a future energy source, capable of producing vast amounts of energy with minimal environmental impact. However, realizing this potential hinges upon overcoming significant scientific, engineering, and economic challenges.

Understanding the fundamental energy calculations is vital in guiding research priorities and setting realistic expectations for fusion energy development. As experimental reactors like ITER progress, the precise quantification of energy output will remain central to assessing the viability of fusion as a sustainable and safe power source for humanity.

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Note: The calculations are based on the standard deuterium-tritium fusion reaction releasing approximately 17.6 MeV per reaction.

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