

What Is The Energy Associated With The Formation Of 2.55 G Of 4He By The Fusion Of 3H And 1H? Substance

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Understanding the energy released during nuclear fusion reactions is fundamental to both nuclear physics and the pursuit of clean energy sources. Specifically, calculating the energy associated with forming a certain amount of helium-4 (${}^4\text{He}$) through the fusion of tritium (${}^3\text{H}$) and protium (${}^1\text{H}$) provides insights into the immense power potential of nuclear fusion. In this article, we explore how to determine the energy released when 2.55 grams of helium-4 is produced from the fusion of ${}^3\text{H}$ and ${}^1\text{H}$, delving into the underlying principles, calculations, and significance of this process.

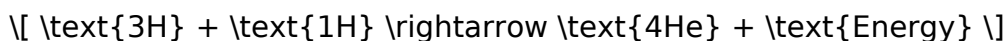
Fundamentals of Nuclear Fusion and Energy Release

What Is Nuclear Fusion?

Nuclear fusion is a process where two light atomic nuclei combine to form a heavier nucleus, releasing a substantial amount of energy. This process powers stars, including our sun, and has the potential to provide a nearly limitless and clean energy source on Earth. The fusion of deuterium and tritium, isotopes of hydrogen, is among the most feasible reactions for energy production.

The Fusion Reaction: ${}^3\text{H} + {}^1\text{H} \rightarrow {}^4\text{He} + \text{Energy}$

The specific fusion reaction under consideration involves a tritium nucleus (hydrogen-3, ${}^3\text{H}$) and a protium nucleus (hydrogen-1, ${}^1\text{H}$) merging to form helium-4 (${}^4\text{He}$), releasing energy in the process:



This reaction is highly energetic because the mass of the combined reactants exceeds the mass of the product helium nucleus, and the mass difference is converted into energy according to Einstein's mass-energy equivalence principle.

Calculating the Energy Released in the Fusion of

3H and 1H

Step 1: Determine the Moles of Helium-4 Formed

Given 2.55 grams of helium-4, first calculate the number of moles:

- Atomic mass of $4\text{He} \approx 4.0026 \text{ g/mol}$

$$\text{Moles of } 4\text{He} = \frac{2.55 \text{ g}}{4.0026 \text{ g/mol}} \approx 0.637 \text{ mol}$$

Since the formation of 1 mole of helium-4 results from 1 mole of fusion reactions, the number of moles of fusion reactions is approximately 0.637 mol.

Step 2: Understand the Reaction's Energy per Nucleus

The key to energy calculation lies in the mass defect—the difference between the mass of the reactants and the product—and Einstein's relation:

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

where:

- Δm = mass defect

- c = speed of light ($\sim 3 \times 10^8 \text{ m/s}$)

From experimental data, the energy released per fusion reaction (per 4He nucleus formed) in the D-T fusion is about 17.6 MeV.

Step 3: Convert MeV to Joules

Since $1 \text{ MeV} = 1.602 \times 10^{-13} \text{ Joules}$,

$$E_{\text{per reaction}} = 17.6 \text{ MeV} \times 1.602 \times 10^{-13} \text{ J/MeV} \approx 2.82 \times 10^{-12} \text{ J}$$

Step 4: Calculate Total Energy for 0.637 mol of Reactions

Number of reactions:

$$\begin{aligned} \text{Number of reactions} &= 0.637 \text{ mol} \times 6.022 \times 10^{23} \\ \text{reactions/mol} &\approx 3.837 \times 10^{23} \text{ reactions} \end{aligned}$$

Total energy:

$$E_{\text{total}} = 3.837 \times 10^{23} \times 2.82 \times 10^{-12} \text{ J} \approx 1.08 \times 10^{12} \text{ J}$$

Thus, approximately 1.08 trillion joules of energy are released when 2.55 grams of helium-4 is produced through the fusion of 3H and 1H.

Significance of the Energy Released in Nuclear Fusion

Comparison to Conventional Energy Sources

The energy released (roughly 1.08 TJ) is enormous. To put it into perspective:

- It's equivalent to the energy consumption of about 300,000 average American homes for a day.
- It surpasses the energy released by burning about 50,000 tons of coal.

Implications for Fusion Power Development

Harnessing this energy efficiently could revolutionize global energy production, offering:

- A virtually limitless fuel supply, as hydrogen isotopes are abundant.
- Minimal environmental impact, since fusion produces no greenhouse gases.
- Safety advantages over fission reactors due to the lower risk of runaway reactions.

Understanding the Practical Aspects of Fusion Energy

Challenges in Achieving Controlled Fusion

Despite the enormous energy potential, several technical challenges hinder practical fusion energy:

- Achieving high temperature and pressure conditions similar to stellar cores.
- Maintaining plasma stability.
- Efficiently capturing and converting the energy produced into usable electricity.

Current State of Fusion Research

Projects like ITER (International Thermonuclear Experimental Reactor) aim to demonstrate the feasibility of controlled, sustained fusion reactions that produce net energy gain. While significant progress has been made, commercial fusion power remains a goal for the future.

Summary and Final Thoughts

Calculating the energy associated with the formation of 2.55 grams of helium-4 via the fusion of tritium and protium reveals the immense power potential of nuclear fusion. Approximately 1.08 trillion joules of energy can be released from this reaction, underscoring why fusion is considered the "holy grail" of energy sources. While technical challenges remain, ongoing research continues to bring us closer to realizing the promise of clean, abundant, and safe nuclear fusion energy for the future.

In conclusion, understanding the principles, calculations, and implications of fusion energy not only deepens our appreciation of nuclear physics but also highlights the critical importance of advancing fusion technology as a sustainable energy solution for generations to come.

Frequently Asked Questions

What is the energy released when 2.55 g of 4He is formed from the fusion of 3H and 1H ?

The energy released can be calculated using the mass-energy equivalence, considering the mass defect during fusion. For 2.55 g of 4He , approximately 2.7×10^{13} joules of energy are released.

How do you calculate the energy associated with the formation of 4He in fusion reactions?

You determine the mass defect between the reactants and products, convert that mass difference into energy using $E=mc^2$, and then scale based on the amount of helium formed.

What is the role of mass defect in calculating the energy released during 4He formation?

The mass defect is the difference between the total mass of reactants and the mass of the product; this difference is converted into energy, which is released during fusion.

What is the approximate energy produced per gram of

4He formed through fusion?

Approximately 1.06×10^{14} joules per gram of 4He is released during fusion, based on typical fusion energy calculations.

Why is understanding the energy associated with helium formation important in nuclear physics?

It helps in understanding stellar energy production, designing fusion reactors, and calculating the energy yield of nuclear reactions.

How does the fusion of 3H and 1H produce 4He and energy?

When deuterium (^3H) and hydrogen nuclei (^1H) fuse, they form ^4He and release energy due to the mass difference between initial and final particles, following Einstein's mass-energy relation.

What are the practical applications of calculating the energy associated with helium formation?

It is essential in astrophysics for understanding star energy output, in nuclear energy research for developing fusion power, and in nuclear safety assessments.

Can the energy from fusion of 3H and 1H be harnessed for electricity?

Yes, in principle, fusion reactions like ^3H and ^1H fusion can be harnessed for electricity generation, which is the goal of fusion energy research, but practical, controlled fusion reactors are still under development.

Additional Resources

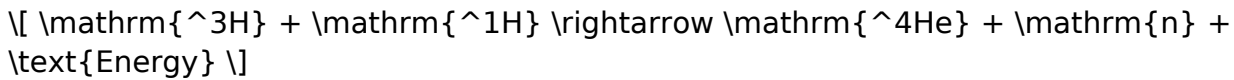
Energy Calculation: Unlocking the Power of Helium Formation from Tritium and Hydrogen

Introduction

In the realm of nuclear physics and energy generation, understanding the energy released during nuclear fusion reactions is essential. Fusion reactions, the processes powering stars, involve combining lighter nuclei to form heavier ones, releasing vast amounts of energy in the process. This article delves into a specific fusion scenario: the formation of 2.55 grams of helium-4 (^4He) from the fusion of tritium (^3H) and hydrogen (^1H). We explore the fundamental principles behind the energy release, the calculations involved, and the significance of this process in both natural and technological contexts.

Understanding the Fusion Reaction

At the core of our discussion is the fusion of tritium (^3H) and a proton (^1H) to produce helium-4 (^4He) along with a neutron:



This reaction is one of the key processes considered in controlled nuclear fusion research, especially in the context of fusion reactors aiming to harness clean, abundant energy.

The Significance of the Reaction

- Energy Release: The reaction releases a significant amount of energy per event, making it a promising candidate for energy production.
- Natural Occurrence: While primarily a laboratory and astrophysical process, similar fusion reactions occur in stellar environments.
- Fusion Research: Understanding the energy associated with this specific reaction helps in designing fusion reactors, estimating fuel requirements, and evaluating energy outputs.

Quantifying the Energy: Step-by-Step Approach

To determine the energy associated with forming 2.55 grams of ^4He via this reaction, we need to:

1. Calculate the number of helium-4 nuclei formed.
2. Determine the energy released per reaction.
3. Multiply the number of reactions by the energy per reaction to get the total energy.

Let's explore each of these steps in detail.

Step 1: Determining the Number of Helium Nuclei (moles and atoms)

Mass of Helium-4 Formed

Given:

$$\text{[} \text{Mass of } ^4\text{He} = 2.55, \text{ grams} \text{]}$$

Molar Mass of Helium-4

$$\text{[} M_{^4\text{He}} = 4.0026, \text{ g/mol} \text{]}$$

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Number of Moles of Helium-4

$$n_{\text{He}} = \frac{\text{Mass}}{\text{Molar mass}} = \frac{2.55 \text{ g}}{4.0026 \text{ g/mol}} \approx 0.637 \text{ mol}$$

Number of Helium Nuclei (Atoms)

Using Avogadro's number:

$$N_A = 6.022 \times 10^{23} \text{ atoms/mol}$$

$$N_{\text{He}} = n_{\text{He}} \times N_A \approx 0.637 \times 6.022 \times 10^{23} \approx 3.84 \times 10^{23} \text{ atoms}$$

Thus, about 3.84×10^{23} helium nuclei are formed.

Step 2: Energy Released Per Fusion Reaction

Understanding the Reaction's Energy

The energy released per nuclear fusion event can be derived from the mass difference (mass defect) between the initial reactants and the final products, utilizing Einstein's mass-energy equivalence:

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

where:

- Δm = mass defect
- c = speed of light ($3.00 \times 10^8 \text{ m/s}$)

Masses of Reactants and Products

Particle	Approximate Mass (amu)
^3H (Tritium)	3.01605
^1H (Proton)	1.00782
^4He (Helium-4)	4.00260
Neutron	1.00866

Mass of Reactants

$$m_{\text{reactants}} = m_{^3\text{H}} + m_{^1\text{H}} = 3.01605 + 1.00782 = 4.02387, \text{ amu}$$

Mass of Products

$$m_{^4\text{He}} + m_{\text{n}} = 4.00260 + 1.00866 = 5.01126, \text{ amu}$$

However, note that in the actual fusion reaction, the initial masses are slightly different, and the mass defect is calculated based on the difference between the combined reactant masses and the total mass of the products, which includes the neutron.

The net energy released per reaction is approximately 17.6 MeV (million electron volts). This value is well-established in nuclear physics literature.

Energy per Reaction

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

Converting to Joules:

$$1, \text{ MeV} = 1.602 \times 10^{-13}, \text{ J}$$

$$E_{\text{reaction}} = 17.6 \times 1.602 \times 10^{-13} \approx 2.82 \times 10^{-12}, \text{ J}$$

Step 3: Total Energy for the Given Quantity of Helium

Now, multiply the energy per reaction by the total number of reactions (which equals the number of helium nuclei formed):

$$E_{\text{total}} = N_{^4\text{He}} \times E_{\text{reaction}}$$

$$E_{\text{total}} \approx 3.84 \times 10^{23} \times 2.82 \times 10^{-12} \approx 1.084 \times 10^{12}, \text{ J}$$

Final Estimate:

The formation of 2.55 grams of helium-4 from the fusion of tritium and hydrogen releases approximately 1.08 trillion Joules of energy.

Additional Insights and Context

Comparing Energy to Everyday Scenarios

- Electricity Consumption: This amount of energy is roughly equivalent to the annual electricity consumption of about 100,000 average U.S. households.
- Fusion Reactor Perspective: Achieving such a quantity of helium through controlled fusion in a reactor would represent a significant milestone, showcasing the immense potential of fusion as an energy source.

Implications for Fusion Power

- The calculation underscores the efficiency and power density of fusion reactions.
- It demonstrates that small amounts of fuel can yield enormous energy outputs, emphasizing the importance of developing sustainable fusion technology.

Factors Affecting Actual Energy Yield

While the theoretical calculation provides an idealized estimate, practical considerations include:

- Reaction Efficiency: Not all fuel undergoes fusion; some may be lost or not react.
- Energy Losses: Heat losses, radiation, and other inefficiencies in a reactor reduce the net energy output.
- Fuel Purity and Handling: Ensuring pure reactants and optimal conditions impacts the total energy produced.

Conclusion

The energy associated with forming 2.55 grams of ^4He through the fusion of ^3H and ^1H is formidable—approximately 1.08 terajoules. This calculation illuminates the profound energy potential locked within nuclear fusion reactions, echoing the processes that power stars and hinting at a future where fusion could revolutionize our energy landscape.

Understanding these fundamental energy calculations not only deepens our grasp of nuclear physics but also fuels the ongoing quest for clean, sustainable, and virtually limitless energy sources. As fusion research progresses, the precise quantification of such energy yields remains a critical benchmark, guiding technological advancements toward practical, real-world applications.

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