

The Fission Of 1 Kg Of Uranium Produces 8.0×10^{13} J Of Energy.a- Calculate The Mass, In Grams, Converted

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Introduction

Nuclear fission is a process that releases a tremendous amount of energy by splitting the nucleus of an atom, typically uranium-235, into smaller nuclei, along with neutrons and a significant amount of energy. This process forms the backbone of nuclear power plants and atomic reactors, enabling large-scale electricity generation. A key aspect of understanding nuclear fission involves calculating how much mass is converted into energy during the process, given the amount of energy produced.

In this article, we analyze a specific case: the fission of 1 kilogram of uranium that produces 8.0×10^{13} joules of energy. Our goal is to determine the mass converted into energy during this process, expressed in grams. This calculation is grounded in Einstein's famous equation, $E = mc^2$, which relates energy (E) to mass (m) via the speed of light (c).

Background Concepts

Understanding Nuclear Fission

Nuclear fission involves splitting a heavy nucleus into lighter nuclei, releasing energy according to mass-energy equivalence. For uranium-235, nuclear fission typically involves absorbing a neutron, leading to the nucleus splitting into two smaller nuclei, along with additional neutrons and energy.

Einstein's Mass-Energy Equivalence

The foundational principle for calculating the mass converted during fission is Einstein's equation:

$$[E = mc^2]$$

Where:

- E is the energy released (in joules)
- m is the mass converted (in kilograms)
- c is the speed of light in vacuum ($\sim 3 \times 10^8$ m/s)

This relation indicates that a small amount of mass can be converted into a large amount of energy, explaining the efficiency of nuclear reactions.

Step-by-Step Calculation of Converted Mass

1. Given Data

- Total energy produced (E): 8.0×10^{13} joules
- Initial mass of uranium (m_{initial}): 1 kilogram (which is 1000 grams)
- Speed of light (c): 3.0×10^8 m/s

2. Applying Einstein's Equation

Rearranged to find the mass converted (m):

$$m = \frac{E}{c^2}$$

3. Performing the Calculation

Plugging in the values:

$$m = \frac{8.0 \times 10^{13} \text{ J}}{(3.0 \times 10^8 \text{ m/s})^2}$$

Calculating the denominator:

$$(3.0 \times 10^8)^2 = 9.0 \times 10^{16} \text{ m}^2/\text{s}^2$$

Now, compute the mass:

$$m = \frac{8.0 \times 10^{13}}{9.0 \times 10^{16}} \text{ kg}$$

$$m \approx 8.89 \times 10^{-4} \text{ kg}$$

To convert this into grams:

$$1 \text{ kg} = 1000 \text{ grams}$$

$$m \approx 8.89 \times 10^{-4} \times 1000 = 0.889 \text{ grams}$$

\]

4. Interpretation

Approximately 0.889 grams of mass is converted into energy during the fission of 1 kilogram of uranium to produce 8.0×10^{13} joules of energy.

Understanding the Significance of the Result

How Much of the Uranium Is Actually Converted?

Though 1 kilogram of uranium undergoes fission, less than 1 gram of its mass is converted directly into energy. The majority of the uranium mass remains as nuclear fragments and other particles. The energy release corresponds to the tiny fraction of mass lost during the process, illustrating the incredible energy density of nuclear reactions.

Energy Density of Uranium

- The energy released per kilogram is approximately 8.0×10^{13} joules.
- For comparison, burning fossil fuels releases significantly less energy per unit mass, highlighting nuclear power's efficiency.

Additional Considerations

Efficiency of the Fission Process

- Not all uranium atoms in 1 kg will undergo fission simultaneously.
- The actual energy yield depends on factors like reactor design, fuel enrichment, and neutron economy.
- The calculated mass conversion represents the theoretical minimum mass loss corresponding to the energy produced.

Conservation of Mass and Energy

- In nuclear reactions, mass is conserved overall, but some mass is converted into energy, following Einstein's equation.
- The tiny mass loss (~ 0.889 grams) accounts for the entire energy output, emphasizing the mass-energy relationship's power.

Practical Implications

Nuclear Power Plants

- Understanding how much mass converts to energy helps in fuel management and efficiency optimization.

- For example, in commercial reactors, the amount of fissile material needed to produce a certain energy output can be calculated using similar principles.

Safety and Waste Management

- Knowing the energy-mass relationship aids in handling nuclear waste, as only a tiny fraction of fuel mass is actually transformed into energy.
- Waste products contain residual radioactive isotopes, unrelated to the mass-energy conversion, but important for safety considerations.

Summary

- The fission of 1 kg of uranium releasing 8.0×10^{13} joules of energy results in approximately 0.889 grams of mass being converted into energy.
- This calculation demonstrates Einstein's mass-energy equivalence in a real-world context.
- The process highlights the incredible energy density of nuclear reactions, making nuclear power a potent energy source.

Conclusion

The calculation of the converted mass during nuclear fission provides insight into the efficiency and power of nuclear energy. The tiny fraction of mass converted into energy underscores the potential of nuclear reactions for large-scale energy production. As technology advances, understanding these fundamental principles remains crucial for developing safer, more efficient, and sustainable nuclear energy systems.

References

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Note: All calculations assume ideal conditions and do not account for energy losses or inefficiencies in real-world reactors.

Frequently Asked Questions

What is the amount of energy produced from 1 kg of uranium during fission?

8.0×10^{13} joules.

How do you convert the energy produced in uranium fission into the mass converted?

Use Einstein's mass-energy equivalence formula: $\text{mass} = \text{energy} / c^2$, where c is the speed of light.

What is the value of the speed of light used in calculations?

Approximately 3.0×10^8 meters per second.

How do you set up the calculation to find the mass converted in grams?

$\text{Mass (kg)} = \text{Energy (J)} / c^2$; then convert kilograms to grams by multiplying by 1000.

What is the calculation for the mass converted from 8.0×10^{13} J of energy?

$\text{Mass} = (8.0 \times 10^{13} \text{ J}) / (3.0 \times 10^8 \text{ m/s})^2 = (8.0 \times 10^{13}) / (9.0 \times 10^{16}) \text{ kg} \approx 8.89 \times 10^{-4} \text{ kg}.$

What is the mass in grams that corresponds to this energy?

Approximately 0.889 grams.

Why is only a small amount of uranium mass converted during fission?

Because a large amount of energy is released from a very small amount of mass due to the mass-energy equivalence principle.

How accurate is the approximation used in these calculations?

The calculation is an approximation assuming all energy comes from mass conversion; real nuclear processes may have slight variations.

What does this calculation tell us about the efficiency of uranium fission?

It shows that a tiny amount of mass is converted into a huge amount of energy, demonstrating the high efficiency of nuclear fission.

Can this calculation be used to estimate the energy output of larger quantities of uranium?

Yes, by scaling proportionally, it provides a basis for estimating energy from larger masses of uranium.

Additional Resources

The Fission Of 1 Kg Of Uranium Produces 8.0×10^{13} Joules Of Energy: A Detailed Calculation of Mass Conversion

Nuclear energy has revolutionized the way we think about power generation, offering a potent source of energy derived from the nucleus of atoms. The statement that the fission of 1 kg of uranium produces 8.0×10^{13} Joules of energy encapsulates the immense power stored within atomic nuclei and the transformative potential of nuclear reactions. In this article, we will explore how to calculate the mass of uranium actually converted into energy during fission, using Einstein's famous equation, $E = mc^2$, and derive insights into the efficiency and fundamental physics behind nuclear fission.

Understanding Nuclear Fission and Energy Release

Before diving into calculations, it's essential to understand what nuclear fission entails. Fission is a nuclear reaction where a heavy nucleus, such as uranium-235, splits into smaller nuclei, releasing a tremendous amount of energy in the process. This energy arises from the difference in mass between the original nucleus and the fission products, which is converted into energy according to Einstein's mass-energy equivalence principle:

$$E = mc^2$$

Where:

- E is the energy released,
- m is the mass converted into energy,
- c is the speed of light in a vacuum ($\sim 3.00 \times 10^8$ m/s).

The Given Data and Objective

Given:

- Energy released during fission of 1 kg of uranium: 8.0×10^{13} Joules

Objective:

- Calculate the mass (in grams) that is actually converted into energy during this process.

Step-by-Step Calculation

Step 1: Recall Einstein's Equation

The fundamental relation:

$$E = mc^2$$

can be rearranged to solve for m:

$$m = \frac{E}{c^2}$$

This m represents the mass that is converted into energy during the fission process.

Step 2: Convert the Energy to SI Units

The energy is already given in Joules, which are SI units, so no conversion is required for E.

Step 3: Plug in the Values

Using:

$$E = 8.0 \times 10^{13} \text{ J}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Calculate:

$$m = \frac{8.0 \times 10^{13} \text{ J}}{(3.00 \times 10^8 \text{ m/s})^2}$$

$$m = \frac{8.0 \times 10^{13}}{9.00 \times 10^{16}}$$

$$m \approx 8.89 \times 10^{-4} \text{ kg}$$

Step 4: Convert Kilograms to Grams

Since 1 kg = 1000 grams:

$$m = 8.89 \times 10^{-4} \text{ kg} \times 1000 \text{ g/kg} = 0.889 \text{ g}$$

Final Answer: Approximately 0.889 grams of uranium is converted into energy during the fission of 1 kg of uranium producing 8.0×10^{13} Joules.

Interpreting the Results: What Does This Mean?

This calculation reveals a fascinating aspect of nuclear energy: only a tiny fraction of the uranium's mass is converted directly into energy. Specifically, less than 1 gram of uranium (about 0.889 grams) out of the entire 1 kg undergoes mass-to-energy conversion in the

fission process that results in the given energy output.

Key Takeaways:

- The vast majority of the uranium mass remains intact after fission; only a minuscule fraction is converted.
- The energy released per unit mass is immense—highlighting why nuclear power is so potent.
- This calculation underscores Einstein's principle that mass and energy are interchangeable, and even small amounts of mass can produce enormous energy.

Additional Insights: Efficiency and Real-world Considerations

While the theoretical calculation considers all the energy released from the fission of 1 kg of uranium, practical nuclear reactors do not convert all of the uranium into energy due to various inefficiencies:

- Fission yield: Not all uranium atoms undergo fission simultaneously.
- Energy losses: Some energy is lost as heat, radiation, or carried away by neutrons and gamma rays.
- Fuel utilization: Only a fraction of the uranium fuel is fissioned in typical reactor cycles.

However, the calculation provides a baseline for understanding the fundamental physics involved and the potential energy locked within nuclear fuel.

Broader Context: Comparing Nuclear Energy to Conventional Sources

To appreciate the magnitude of this energy:

- 1 kg of uranium can produce approximately 80 terajoules (8.0×10^{13} J).
- In comparison, burning 1 kg of coal releases roughly 24 MJ (2.4×10^7 J), highlighting the enormous energy density of uranium.

This comparison emphasizes why nuclear power is considered a highly efficient energy source and explains its role in meeting global energy demands with minimal fuel volume.

Summing Up: The Power of $E = mc^2$ in Nuclear Physics

In conclusion, the calculation demonstrates how Einstein's mass-energy equivalence enables us to quantify the actual mass converted during nuclear fission. For the fission of 1 kg of uranium, approximately 0.889 grams is transformed into energy, releasing 8.0×10^{13} Joules—a staggering amount of energy from a fraction of the original mass.

This profound interplay of mass and energy highlights the incredible potential harnessed in nuclear technology, as well as the importance of understanding fundamental physics

principles in practical applications. Whether for power generation, medical applications, or scientific research, the principles uncovered through such calculations continue to shape our technological landscape.

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