A Carbon-12 Atom Has A Mass Defect Of 0.09564 Amu. What Is Its Nuclear Binding Energy? Round To 3 Significant

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Understanding the nuclear binding energy of an atom is fundamental to nuclear physics, as it provides insight into the stability of atomic nuclei. In this article, we will explore how to calculate the nuclear binding energy of a Carbon-12 atom given its mass defect, focusing on the concepts of mass defect, nuclear binding energy, and the process of converting atomic measurements into meaningful energy values. This comprehensive guide will break down each step involved in the calculation, ensuring clarity for students, educators, and enthusiasts alike.

What Is Mass Defect and Why Does It Matter?

Defining Mass Defect

Mass defect refers to the difference between the sum of the individual masses of protons and neutrons that make up a nucleus and the actual measured mass of the nucleus itself. This difference arises because some mass is converted into energy during nuclear formation, as described by Einstein's famous equation, $E=mc^2$.

The Significance of Mass Defect

The mass defect is directly related to the nuclear binding energy, which represents the energy required to disassemble a nucleus into its constituent protons and neutrons. The greater the mass defect, the more tightly bound the nucleus is, resulting in greater stability.

Understanding the Data for Carbon-12

The problem states:
- Mass defect (Δm) = 0.09564 atomic mass units (amu)

Our goal is to determine the nuclear binding energy corresponding to this mass defect.

Fundamental Concepts and Constants

Before performing calculations, it's essential to be familiar with the constants and conversions involved:

- **Atomic mass unit (amu):** 1 amu = $1.66053906660 \times 10^{-27}$ kg
- **Speed of light (c):** 3.00×10^{8} m/s
- **Energy equivalent of 1 amu:** 931.5 MeV

The last constant, 931.5 MeV, is particularly useful because it allows us to convert mass in amu directly to energy in MeV.

Calculating the Nuclear Binding Energy

Step 1: Understanding the Conversion

The key to calculating the nuclear binding energy from the mass defect is recognizing that each atomic mass unit (amu) corresponds to approximately 931.5 MeV of energy. This is a standard conversion factor in nuclear physics.

Step 2: Applying the Conversion

Given:
- Mass defect (Δm) = 0.09564 amu

The nuclear binding energy (E_b) can be calculated as:

$$E_b = \Delta m \times 931.5 \, \text{MeV}$$

Plugging in the values:

$$E_b = 0.09564 \times 931.5$$

Calculating:

$$E_b \approx 89.096 \, \text{MeV}$$

Rounding to three significant figures:

$$\boxed{E_b \approx 89.1 \, \text{MeV}}$$

Therefore, the nuclear binding energy of the Carbon-12 atom is approximately 89.1 MeV.

Interpreting the Result

The calculated binding energy indicates how much energy would be required to break the nucleus into its individual protons and neutrons. A high binding energy per nucleon corresponds to a more stable nucleus, and Carbon-12 is known to be quite stable, consistent with this high binding energy.

Additional Insights: Binding Energy Per Nucleon

While the total binding energy is informative, often physicists consider the binding energy per nucleon to compare stability across different nuclei.

Calculation:

- Number of nucleons in Carbon-12: 12
- Binding energy per nucleon:

$$\text{Binding energy per nucleon} = \frac{E_b}{A} = \frac{89.1\, \text{MeV}}{12} \approx 7.43\, \text{MeV}$$

This value is typical for stable nuclei around the middle of the binding energy curve, indicating a highly stable nucleus.

Summary and Key Takeaways

- The mass defect of a nucleus directly relates to its binding energy, which reflects its stability.
- For Carbon-12 with a mass defect of 0.09564 amu, the nuclear binding energy is approximately 89.1 MeV.
- The binding energy per nucleon for Carbon-12 is about 7.43 MeV, confirming its stability.
- Understanding these calculations is crucial for fields such as nuclear physics, astrophysics, and energy research.

Conclusion

Calculating the nuclear binding energy from the mass defect involves straightforward application of conversion factors rooted in Einstein's mass-energy equivalence. By knowing the mass defect and utilizing the conversion constant of 931.5 MeV per amu, one can determine how much energy is stored within the nucleus. This energy plays a vital role in nuclear reactions, including fusion and fission processes, and underpins the stability of elements in the universe. Accurate calculations like these help scientists explore the fundamental properties of matter and harness nuclear energy responsibly.

Remember, mastering these concepts enhances our understanding of atomic stability and the forces holding nuclei together, which remains at the heart of modern physics and energy sciences.

Frequently Asked Questions

What is the nuclear binding energy of a Carbon-12 atom with a mass defect of 0.09564 amu?

The nuclear binding energy is approximately 8.96 MeV.

How do you calculate the nuclear binding energy from the mass defect in amu?

Convert the mass defect to energy using $E = \Delta m \times 931.5$ MeV/amu.

What is the formula to find the binding energy given the mass defect for a nucleus?

Binding energy (MeV) = Mass defect (amu) × 931.5 MeV/amu.

Why is the binding energy important in nuclear physics?

It indicates the stability of a nucleus; higher binding energy means a more stable nucleus.

What does a mass defect of 0.09564 amu signify for a Carbon-12 atom?

It represents the mass difference between the sum of individual nucleons and the actual mass of the nucleus, corresponding to its binding energy.

How many MeV of energy are equivalent to a mass defect of 0.09564 amu?

Approximately 8.89 MeV, calculated as 0.09564 × 931.5.

Is the calculated binding energy rounded to three significant figures?

Yes, the binding energy is approximately 8.96 MeV when rounded to three significant figures.

What role does the binding energy play in nuclear reactions?

It determines whether a nuclear reaction releases or absorbs energy, influencing nuclear stability and energy output.

Additional Resources

A Carbon-12 Atom Has A Mass Defect Of 0.09564 Amu. What Is Its Nuclear Binding Energy?

The concept of nuclear binding energy is fundamental to understanding the stability of atomic nuclei and the energy released in nuclear reactions. For a Carbon-12 (C-12) atom, which forms the backbone of organic life and is a standard in atomic mass measurements, calculating its nuclear binding energy provides insights into the forces holding its protons and neutrons together. In this article, we explore the process of determining the nuclear binding energy of a Carbon-12 atom given its mass defect, unraveling the principles of mass-energy equivalence, nuclear physics, and the significance of binding energy in the broader context of atomic science.

Understanding the Mass Defect and Its Significance

What Is Mass Defect?

Mass defect refers to the difference between the total mass of the individual protons and neutrons that compose a nucleus and the actual measured mass of the nucleus itself. When nucleons (protons and neutrons) bind together to form a nucleus, they release energy, and as a consequence, the combined mass of the nucleus is less than the sum of the masses of its constituent nucleons. This mass difference is the mass defect.

Mathematically, the mass defect (Δm) can be expressed as:

$$
\Delta m = \left(\text{Sum of masses of free nucleons}\right) - \text{Mass of the nucleus}
$$

The mass defect is measured in atomic mass units (amu) or unified atomic mass units, where 1 amu ≈ 1.6605 × 10^{-27} kg.

The Connection to Binding Energy

According to Einstein's mass-energy equivalence principle, $E=mc^2$, the mass defect corresponds directly to the energy required to disassemble the nucleus into its constituent protons and neutrons. This energy, known as the nuclear binding energy, indicates the stability of the nucleus—the higher the binding energy, the more stable the nucleus.

The relation between the mass defect and binding energy is:

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

where:

- E_b is the nuclear binding energy,
- Δm is the mass defect,
- c is the speed of light (~3.00 × 10^8 m/s).

Calculating the Nuclear Binding Energy of Carbon-12

Given Data and Known Constants

- Mass defect of Carbon-12: 0.09564 amu
- Speed of light, c: 3.00 × 10^8 m/s
- Conversion factor: 1 amu = 931.5 MeV/c^2

The key to calculating the binding energy is to convert the mass defect into energy units, typically MeV, which is more convenient in nuclear physics.

Step 1: Convert Mass Defect to Energy Units

Using the conversion factor:

$$
E_b = \Delta m \times 931.5\, \text{MeV}
$$

Substituting the given mass defect:

$$
E_b = 0.09564\, \text{amu} \times 931.5\, \text{MeV/amu}
$$

$$
E_b \approx 0.09564 \times 931.5 = 89.07\, \text{MeV}
$$

Result: The nuclear binding energy of a Carbon-12 atom is approximately 89.07 MeV.

Implications and Significance of the Binding Energy

Stability of Carbon-12

The calculated binding energy per nucleon for Carbon-12 provides valuable insights into its stability:

$$
\text{Binding energy per nucleon} = \frac{E_b}{A}
$$

where $A = 12$ is the mass number for Carbon-12.

$$
\frac{89.07\, \text{MeV}}{12} \approx 7.42\, \text{MeV}
$$

This value indicates a relatively high binding energy per nucleon, signifying that Carbon-12 is a stable isotope. It's close to the peak of the binding energy curve, which occurs around elements like Iron (Fe), known for their exceptional nuclear stability.

Relevance in Nuclear Reactions and Energy Production

Understanding the binding energy of Carbon-12 is critical in various contexts:

- Nuclear Fusion and Fission: The energy released during nuclear reactions depends on changes in binding energy. For example, fusion of lighter nuclei into Carbon-12 releases energy, while fission of heavier elements like Uranium involves the splitting into fragments with high binding energies.

- Astrophysics: Carbon-12's stability and binding energy are fundamental in stellar nucleosynthesis, where lighter nuclei fuse in stars to form heavier elements, releasing energy that powers stars.

- Radioactive Decay and Stability Analysis: Isotopic stability can be assessed by comparing binding energies across isotopes.

Broader Context and Applications

Comparison with Other Nuclei

When compared to other nuclei, Carbon-12's binding energy per nucleon (~7.42 MeV) indicates a high degree of stability, but not as high as Iron-56 (~8.8 MeV per nucleon), which is the most tightly bound nucleus. This comparison illustrates why elements lighter than iron tend to release energy during fusion, while heavier elements release energy during fission.

Significance in Nuclear Physics and Energy

The calculation exemplifies the core principles of nuclear physics, demonstrating how mass defects underpin the energy content of nuclei. This understanding has led to the development of nuclear energy technologies, medical isotopes, and advancements in astrophysics.

Conclusion

The exploration of the nuclear binding energy of a Carbon-12 atom, derived from its mass defect, underscores the profound relationship between mass and energy at the atomic scale. With a mass defect of 0.09564 amu, the binding energy is approximately 89.07 MeV, reflecting Carbon-12's notable stability and its pivotal role in both terrestrial and cosmic processes. This calculation not only exemplifies fundamental nuclear physics principles but also highlights their importance in diverse scientific and technological domains, from energy generation to understanding stellar evolution.

Understanding the nuances of mass defect and binding energy continues to be central to the advancement of nuclear science, influencing everything from energy policy to our comprehension of the universe's elemental composition.

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