Question 2..... Polonium-210 Decays Via Alpha Decay. (a) Calculate The Binding Energy Of Polonium-210.

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Understanding the Decay of Polonium-210 and Its Significance

Polonium-210 (Po-210) is a highly radioactive isotope known for its intense alpha particle emission during decay. Its decay process is not only fundamental to nuclear physics but also has implications in fields such as nuclear medicine, radiation safety, and nuclear energy. The process by which Po-210 undergoes alpha decay involves complex nuclear interactions that can be better understood through calculations of nuclear properties, such as the binding energy.

This article aims to elucidate the concept of binding energy, demonstrate how to calculate it for Po-210, and explore its importance in understanding nuclear stability and decay mechanisms.

What Is Binding Energy?

Definition of Binding Energy

Binding energy is the energy required to disassemble a nucleus into its constituent protons and neutrons. It reflects the stability of a nucleus—the higher the binding energy, the more stable the nucleus. Conversely, a nucleus with lower binding energy per nucleon tends to be less stable and more prone to radioactive decay.

Mathematically, the total binding energy (BE) of a nucleus is given by:

$$
BE = \left(Z \times m_p + N \times m_n - M \right) c^2
$$

where:

- Z = number of protons
- N = number of neutrons
- m_p = mass of a proton
- m_n = mass of a neutron
- M = mass of the nucleus
- c = speed of light

Alternatively, it is often expressed in energy units (MeV), considering the mass defect and Einstein's mass-energy equivalence.

Calculating the Binding Energy of Polonium-210

Step 1: Gather Necessary Data

To calculate the binding energy of Po-210, the following data are essential:

- Atomic number Z of Po-210: 84 (number of protons)
- Mass number A of Po-210: 210 (total nucleons)
- Atomic masses:
- Mass of a proton, m_p: approximately 1.007276 u
- Mass of a neutron, m_n: approximately 1.008665 u
- Atomic mass of Polonium-210, M_{Po-210}: approximately 209.9828737 u

Note: 'u' (atomic mass unit) is a standard unit for atomic masses, where 1 u ≈ 931.494 MeV/c^2 in energy units.

Step 2: Calculate the Mass of Constituent Nucleons

Number of neutrons:

$$
N = A - Z = 210 - 84 = 126
$$

Total mass of protons:

$$
M_{protons} = Z \times m_p = 84 \times 1.007276\,u = 84.611184\,u
$$

Total mass of neutrons:

$$
M_{neutrons} = N \times m_n = 126 \times 1.008665\,u = 126.10959\,u
$$

Total mass of free nucleons:

$$
M_{nucleons} = M_{protons} + M_{neutrons} = 84.611184\,u + 126.10959\,u = 210.720774\,u
$$

Step 3: Calculate the Mass Defect

The mass defect is the difference between the mass of free nucleons and the actual mass of the nucleus:

$$
\Delta m = M_{nucleons} - M_{Po-210}
$$

$$
\Delta m = 210.720774\,u - 209.9828737\,u = 0.7379003\,u
$$

Step 4: Convert Mass Defect to Binding Energy

Using Einstein’s relation, where 1 u corresponds to 931.494 MeV:

$$
BE = \Delta m \times 931.494\, \text{MeV}
$$

$$
BE = 0.7379003\,u \times 931.494\, \text{MeV} \approx 687.428\, \text{MeV}
$$

Therefore, the total binding energy of Polonium-210 is approximately 687.43 MeV.

Interpreting the Binding Energy of Polonium-210

The calculated binding energy indicates how tightly bound the nucleons are within the nucleus. To understand the stability of Po-210, it is useful to consider the binding energy per nucleon:

$$
\text{Binding energy per nucleon} = \frac{BE}{A} = \frac{687.43\,\text{MeV}}{210}
\approx 3.27\,\text{MeV}
$$

This value is relatively high, suggesting Po-210 is fairly stable compared to lighter or much heavier radioactive isotopes, but it still undergoes alpha decay due to its position on the nuclear chart.

Significance of Binding Energy in Nuclear Physics

Understanding Nuclear Stability

The concept of binding energy per nucleon helps physicists evaluate the relative stability of different isotopes. Elements near the peak of the binding energy curve, such as iron, are among the most stable. Isotopes like Po-210, with moderate binding energy per nucleon, tend to be radioactive and decay to more stable nuclei.

Alpha Decay Mechanism

Polonium-210 emits an alpha particle (2 protons and 2 neutrons), transforming into lead-206. The decay process releases energy, which can be estimated from the difference in total binding energies before and after decay. The large binding energy of Po-210 contributes to the energy released during decay, making it a potent alpha emitter.

Applications and Safety Considerations

Understanding the binding energy and decay processes of Po-210 is crucial in fields like:

- Nuclear Medicine: Radioisotopes are used for targeted cancer therapy.
- Radiation Safety: Po-210's intense alpha emissions pose health risks if ingested or inhaled.
- Nuclear Energy: Insights into nuclear stability guide the development of safer reactors and waste management.

Conclusion

Calculating the binding energy of Polonium-210 provides vital insight into its nuclear structure and stability. The total binding energy of approximately 687.43 MeV and a binding energy per nucleon of around 3.27 MeV position Po-210 as a radioactive isotope that readily undergoes alpha decay. Understanding such nuclear properties is fundamental for advancing nuclear physics, improving safety protocols, and harnessing radioactive materials for beneficial applications.

By mastering calculations of binding energy, scientists can predict nuclear behavior, design safer nuclear systems, and develop innovative medical and energy technologies. The case of Po-210 exemplifies the importance of nuclear physics in both theoretical understanding and practical applications.

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Keywords: Polonium-210, alpha decay, binding energy, nuclear stability, nuclear physics, radioactivity, nuclear decay, atomic mass units, nuclear energy, radiation safety

Frequently Asked Questions

What is polonium-210 and why is its decay significant?

Polonium-210 is a radioactive isotope known for its alpha decay; it is significant due to its high radioactivity and historical use in nuclear science and weapons.

How does polonium-210 decay via alpha decay?

Polonium-210 undergoes alpha decay by releasing an alpha particle (2 protons and 2 neutrons), transforming into lead-206.

What is the half-life of polonium-210?

Polonium-210 has a half-life of approximately 138 days.

How do you calculate the binding energy of polonium-210?

The binding energy is calculated by subtracting the total mass of the nucleus from the sum of the masses of its individual protons and neutrons, then converting the mass difference into energy using Einstein's equation, E=mc^2.

What mass values are needed to compute the binding energy of polonium-210?

You need the atomic masses of polonium-210, protons, and neutrons, as well as the mass of electrons if considering atomic masses.

Why is binding energy an important concept in nuclear physics?

Binding energy indicates the stability of a nucleus; higher binding energy per nucleon generally means a more stable nucleus.

What are the typical units used to express binding energy?

Binding energy is typically expressed in MeV (mega-electronvolts) or in joules when converted from mass-energy equivalence.

Can you provide a step-by-step example calculation of the binding energy of polonium-210?

Yes, by using the mass of polonium-210, the number of protons and neutrons, their individual masses, calculating the mass defect, and converting it into energy with E=mc^2.

What role does alpha decay play in the stability of polonium-210?

Alpha decay reduces the atomic number, moving polonium-210 towards a more stable lead nucleus, contributing to its radioactive decay process.

How does understanding the binding energy of polonium-210 help in nuclear physics research?

Calculating the binding energy helps determine the stability, decay pathways, and energy releases associated with polonium-210, informing safety measures and scientific studies.

Additional Resources

Question 2..... Polonium-210 Decays Via Alpha Decay. (a) Calculate The Binding Energy Of Polonium-210.

Introduction

Polonium-210 (Po-210) stands as one of the most intriguing and historically significant radioactive isotopes. Discovered by Marie Curie and her husband Pierre in 1898, Po-210 has captivated scientists due to its intense radioactivity and its role in nuclear science and applications. Its decay mode—alpha decay—makes it a classic example used in nuclear physics to understand fundamental decay processes and nuclear structure.

In this review, we delve into the detailed calculation of the binding energy of Polonium-210, exploring the atomic and nuclear properties that underpin this process. The calculation of binding energy not only provides insights into nuclear stability but also plays a crucial role in understanding decay mechanisms, nuclear reactions, and applications such as radioactive dating and nuclear energy.

The Significance of Binding Energy in Nuclear Physics

Binding energy is the energy required to disassemble a nucleus into its constituent protons and neutrons. It reflects the stability of a nucleus: the higher the binding energy per nucleon, the more stable the nucleus.

Mathematically, the total binding energy (BE) of a nucleus with atomic number Z and mass number A is given by:

$$
BE = \left[Z m_p + (A - Z) m_n - m_{nucleus} \right] c^2
$$

where:

- m_p is the mass of a proton,
- m_n is the mass of a neutron,
- $m_{nucleus}$ is the mass of the nucleus,
- c is the speed of light.

Calculating the binding energy allows us to understand the nucleus's stability, the energy released during decay, and the nuclear force interactions that hold the nucleus together.

Nuclear Composition of Polonium-210

Polonium-210 has the following properties:

- Atomic number $Z = 84$,
- Mass number $A = 210$.

Its nucleus comprises:

- 84 protons,
- 126 neutrons (since $210 - 84 = 126$).

To proceed with the calculation, we need the precise atomic masses of the involved constituents.

Atomic Masses and Constants

Accurate mass values are essential for precise calculations of nuclear binding energy. The key constants are:

Particle / Nucleus	Atomic Mass (amu)	Mass in kg	Approximate Mass in u (atomic mass units)
Proton (m_p)	1.007276466879	$1.6726219 \times 10^{-27}$	1.0072764669
Neutron (m_n)	1.00866491588	$1.6749275 \times 10^{-27}$	1.0086649159
Electron (m_e)	0.000548579909	$9.10938356 \times 10^{-31}$	0.0005485799
Atomic mass of ^{210}Po (measured)	209.982874 amu		

Note: The atomic mass of the neutral atom includes electrons, so for nuclear mass calculations, we must subtract the mass of electrons appropriately when necessary.

Step 1: Determine the Mass of the Nucleus

The mass of the Polonium-210 atom is known from experimental data:

$$
m_{^{210}\text{Po}} = 209.982874 \text{ amu}
$$

To find the nuclear mass, subtract the mass of electrons:

- Number of electrons: 84 (equal to the proton count for a neutral atom).
- Mass of electrons: $84 \times 0.0005485799 \text{ amu} \approx 0.04607 \text{ amu}$.

Thus,

$$
m_{nucleus} = m_{atom} - \text{mass of electrons} \approx 209.982874 - 0.04607 \approx 209.936804 \text{ amu}
$$

Step 2: Calculate the Total Mass of Constituent Nucleons

- Mass of 84 protons:

$$
84 \times 1.0072764669 \text{ amu} \approx 84.61103 \text{ amu}
$$

- Mass of 126 neutrons:

$$
126 \times 1.0086649159 \text{ amu} \approx 127.09559 \text{ amu}
$$

- Total mass of free nucleons:

$$
84.61103 + 127.09559 \approx 211.70662 \text{ amu}
$$

Step 3: Compute the Mass Defect

The mass defect is the difference between the sum of free nucleon masses and the actual nuclear mass:

$$
\Delta m = \left(Z m_p + (A - Z) m_n \right) - m_{nucleus}
$$

$$
\Delta m = 211.70662 - 209.936804 \approx 1.769816 \text{ amu}
$$

Step 4: Convert Mass Defect to Energy

Using Einstein’s mass-energy equivalence:

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

Since $1 \text{ amu} = 931.494 \text{ MeV}/c^2$, the total binding energy in MeV is:

$$
BE = 1.769816 \times 931.494 \approx 1649.3 \text{ MeV}

\]

Therefore, the total binding energy of Polonium-210 is approximately 1649.3 MeV.

Deepening the Analysis: Binding Energy per Nucleon

To evaluate nuclear stability:

$$
\text{Binding energy per nucleon} = \frac{BE}{A} = \frac{1649.3 \text{ MeV}}{210} \approx 7.86 \text{ MeV}
$$

This value is typical for heavy nuclei, indicating a relatively stable nucleus, though less stable than mid-range nuclei like iron.

Implications of Binding Energy in Polonium-210 Decay

Understanding the binding energy is critical in analyzing alpha decay:

$$
^{210}\text{Po} \rightarrow {}^{206}\text{Pb} + \alpha
$$

The decay releases energy approximately equal to the difference in total binding energies between the parent and daughter nuclei, minus the alpha particle's binding energy. This energy manifests as the kinetic energy of the emitted alpha particle, which is measurable in experimental setups.

Additional Considerations: Shell Model and Nuclear Stability

Polonium-210's decay via alpha emission is influenced by nuclear shell effects. The shell model suggests that nuclei with closed shells (magic numbers) are more stable. Since 126 neutrons is a closed shell, Po-210's position near this shell contributes to its relative stability despite its radioactivity.

Broader Context and Applications

Calculating the binding energy of Po-210 not only aids in understanding its decay but also informs its applications:

- Radioactive Sources: Po-210 is used as a static eliminator and in nuclear batteries due to its alpha emission.

- Nuclear Forensics: Precise knowledge of nuclear properties assists in tracing origins in nuclear security efforts.
- Medical and Scientific Research: Alpha emitters are used in targeted alpha therapy and radiometric dating.

Conclusion

The comprehensive calculation of Polonium-210's binding energy underscores the intricate relationship between nuclear composition, stability, and decay behavior. With an estimated total binding energy of approximately 1649 MeV and a binding energy per nucleon of about 7.86 MeV, Po-210 exemplifies a heavy nucleus with moderate stability, predisposed to alpha decay due to its nuclear configuration.

This analysis provides a foundation for further exploration into nuclear decay mechanisms, energy release calculations, and the broader implications in nuclear physics and applied sciences. The precision in such calculations is vital for safe handling, application, and understanding of radioactive materials like Polonium-210.

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