Calculate The Mass, Radius, And Density Of The Nucleus Of (a) 7 Li And (b) 207 Pb. Give All Answers In

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Understanding the fundamental properties of atomic nuclei is crucial in fields such as nuclear physics, chemistry, and astrophysics. Calculating the mass, radius, and density of nuclei like lithium-7 (7 Li) and lead-207 (207 Pb) provides insight into their structure and behavior. This article aims to guide you through the detailed process of determining these properties, presenting all answers in appropriate units for clarity and precision.

Overview of Atomic Nuclei Properties

Before delving into calculations, it is essential to understand the basic parameters involved:

Mass of Nucleus

The mass of a nucleus is primarily determined by the sum of the masses of protons and neutrons it contains, accounting for the mass defect due to nuclear binding energy.

Radius of Nucleus

The radius generally follows the empirical formula:
$$ R = R_0 \times A^{1/3} $$
where R_0 is approximately 1.2 to 1.3 femtometers (fm), and A is the mass number.

Density of Nucleus

Density is calculated as:
$$ \text{Density} = \frac{\text{Mass}}{\text{Volume}} $$
The volume is derived from the radius assuming a spherical shape.

Calculating the Properties of Lithium-7 (7 Li)

Mass of Lithium-7 Nucleus

- Atomic Composition: Lithium-7 contains 3 protons and 4 neutrons.
- Mass of Proton (m_p): approximately 1.007276 u.
- Mass of Neutron (m_n): approximately 1.008665 u.
- Atomic Mass of 7 Li: approximately 7.016 u.

Note: The atomic mass includes electrons; however, for nuclear calculations, we focus on the nucleus, removing electron mass.

- Mass of Nucleus:

$$
M_{7Li} \approx (3 \times m_p + 4 \times m_n) - \text{mass defect}
$$

For simplicity, using the atomic mass:

$$
M_{7Li} \approx 7.016 \text{ u}
$$

Conversion to kilograms:

$$
1 \text{ u} = 1.660539 \times 10^{-27} \text{ kg}
$$

$$
M_{7Li} = 7.016 \times 1.660539 \times 10^{-27} \approx 1.165 \times 10^{-26} \text{ kg}
$$

Radius of Lithium-7 Nucleus

- Empirical formula:

$$
R = R_0 \times A^{1/3}
$$

where $R_0 \approx 1.2 \text{ fm}$, and $A=7$.

- Calculation:

$$
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$$
R_{7Li} = 1.2 \text{ fm} \times 7^{1/3}
$$

$$
7^{1/3} \approx 1.913
$$

$$
R_{7Li} \approx 1.2 \times 1.913 \approx 2.2956 \text{ fm}
$$

Density of Lithium-7 Nucleus

- Volume of the nucleus:

$$
V = \frac{4}{3} \pi R^3
$$

$$
R = 2.2956 \text{ fm} = 2.2956 \times 10^{-15} \text{ m}
$$

$$
V_{7Li} = \frac{4}{3} \pi (2.2956 \times 10^{-15})^3
$$

$$
V_{7Li} \approx \frac{4}{3} \pi \times 12.124 \times 10^{-45} \text{ m}^3
$$

$$
V_{7Li} \approx 50.88 \times 10^{-45} \text{ m}^3 = 5.088 \times 10^{-44} \text{ m}^3
$$

- Density calculation:

$$
\rho_{7Li} = \frac{1.165 \times 10^{-26} \text{ kg}}{5.088 \times 10^{-44} \text{ m}^3} \approx 2.29 \times 10^{17} \text{ kg/m}^3
$$

Calculating the Properties of Lead-207 (207 Pb)

Mass of Lead-207 Nucleus

- Atomic composition: 82 protons and 125 neutrons.
- Atomic mass of 207 Pb: approximately 206.98 u (including electrons).

Note: For nucleus-only calculations, subtract the electrons' mass (~0.0005 u), but as the difference is negligible at this scale, we proceed with the atomic mass.

- Mass in kg:

$$
M_{207Pb} \approx 206.98 \times 1.660539 \times 10^{-27} \approx 3.435 \times 10^{-25} \text{ kg}
$$

Radius of Lead-207 Nucleus

- Using empirical formula:

$$
R_{207Pb} = 1.2 \text{ fm} \times 207^{1/3}
$$

$$
207^{1/3} \approx 5.927
$$

$$
R_{207Pb} \approx 1.2 \times 5.927 \approx 7.112 \text{ fm}
$$

Density of Lead-207 Nucleus

- Volume:

$$
R = 7.112 \times 10^{-15} \text{ m}
$$

$$
V_{207Pb} = \frac{4}{3} \pi (7.112 \times 10^{-15})^3
$$

$$
V_{207Pb} \approx \frac{4}{3} \pi \times 359.4 \times 10^{-45} \text{ m}^3
$$

\[

$$
V_{207Pb} \approx 1504.9 \times 10^{-45} \text{ m}^3 = 1.5049 \times 10^{-42} \text{ m}^3
$$

- Density:

$$
\rho_{207Pb} = \frac{3.435 \times 10^{-25}}{1.5049 \times 10^{-42}} \approx 2.28 \times 10^{17} \text{ kg/m}^3
$$

Summary of Results

Property	Lithium-7 (7 Li)	Lead-207 (207 Pb)
Mass	approximately 1.165 × 10^{-26} kg	approximately 3.435 × 10^{-25} kg
Radius	approximately 2.30 fm	approximately 7.11 fm
Density	approximately 2.29 × 10^{17} kg/m^3	approximately 2.28 × 10^{17} kg/m^3

Note: The densities of these nuclei are remarkably similar, highlighting the nearly constant density characteristic of nuclear matter across different elements.

Conclusion

Calculating the mass, radius, and density of atomic nuclei like 7 Li and 207 Pb involves understanding their composition, applying empirical formulas, and performing unit conversions carefully. These calculations reveal that despite differences in size and mass, atomic nuclei maintain a near-constant density, underscoring the uniformity of nuclear matter. Such insights are fundamental in nuclear physics and help deepen our understanding of atomic structure and nuclear interactions.

End of Article

Frequently Asked Questions

What is the approximate mass of the nucleus of 7 Li in atomic mass units (amu)?

The mass of the nucleus of 7 Li is approximately 7 amu.

How can the radius of the 7 Li nucleus be estimated?

The radius can be estimated using the empirical formula $R = R_0 \times A^{(1/3)}$, where $R_0 \approx 1.2$ fm and A=7 for 7 Li, so $R \approx 1.2 \times 7^{(1/3)}$ fm.

What is the calculated density of the 7 Li nucleus?

Density = Mass / Volume; using mass ≈ 7 amu and volume derived from the radius, the density is approximately 2.3×10^{17} kg/m³.

What is the approximate mass of the 207 Pb nucleus in atomic mass units (amu)?

The mass of the 207 Pb nucleus is approximately 207 amu.

How do you determine the radius of the 207 Pb nucleus?

Use the empirical formula $R = R_0 \times A^{(1/3)}$, with A=207 and $R_0 \approx 1.2$ fm, giving $R \approx 1.2 \times 207^{(1/3)}$ fm.

What is the estimated density of the 207 Pb nucleus?

Calculating similarly, the density is approximately 2.5×10^{17} kg/m³, indicating nuclei have roughly constant density.

Why are the mass, radius, and density of nuclei important in nuclear physics?

They help understand nuclear structure, stability, and the forces at play within the nucleus, which are fundamental to nuclear reactions and applications in energy, medicine, and astrophysics.

Additional Resources

Calculate The Mass, Radius, And Density Of The Nucleus Of (a) 7 Li And (b) 207 Pb: A Comprehensive Analysis

Understanding the fundamental properties of atomic nuclei is a cornerstone of nuclear physics, providing insights into atomic structure, stability, and nuclear reactions. In this detailed review, we will explore how to determine the mass, radius, and density of the nuclei of two isotopes: Lithium-7 (7Li) and Lead-207 (207Pb). We will approach each step systematically, incorporating relevant nuclear physics principles, mathematical calculations, and contextual explanations to ensure clarity and depth.

Introduction to Nuclear Properties

Before diving into calculations, it is essential to understand the basic concepts:

- Nuclear Mass: The total mass of protons and neutrons within the nucleus, typically expressed in atomic mass units (amu) or kilograms.
- Nuclear Radius: The approximate size of the nucleus, often modeled using the empirical formula $R = R_0 A^{1/3}$, where $R_0 \approx 1.2$-1.3 femtometers (fm).
- Nuclear Density: The ratio of the mass to the volume of the nucleus, providing an average density that reveals the compactness of nuclear matter.

Part A: Calculating for Lithium-7 (7Li)

1. Determining the Nuclear Mass of 7Li

a. Atomic Composition:

- Lithium-7 has:
- Protons (Z): 3
- Neutrons (N): 4 (since 7 - 3 = 4)

b. Atomic Mass:

- The atomic mass of 7Li is approximately 7.016004 u.
- However, for nuclear calculations, it's preferable to use the nuclear mass, which accounts for binding energy.

c. Mass of Constituent Particles:

- Proton mass (m_p): 1.007276 u
- Neutron mass (m_n): 1.008665 u

d. Calculating the Sum of Constituent Masses:

$$
\text{Total mass of free nucleons} = (Z \times m_p) + (N \times m_n) = (3 \times 1.007276) + (4 \times 1.008665)
$$

$$
= 3.021828 + 4.03466 = 7.056488\, \text{u}
$$

e. Nuclear Binding Energy and Mass Defect:

- The actual nuclear mass is less than the sum of free nucleons due to binding energy.
- For 7Li, the experimental atomic mass is approximately 7.016004 u.
- To approximate the nuclear mass, subtract the electron masses and binding energy effects, but for simplicity and typical practice, the atomic mass can be used directly, noting that the mass defect manifests as binding energy.

f. Final Nuclear Mass:

- Convert atomic mass to kilograms:

$$
1\, \text{u} = 1.660539 \times 10^{-27}\, \text{kg}
$$

$$
\text{Mass of 7Li nucleus} \approx 7.016004\, \text{u} \times 1.660539 \times 10^{-27}\, \text{kg/u} \approx 1.165 \times 10^{-26}\, \text{kg}
$$

---

2. Calculating the Radius of 7Li

a. Empirical Formula:

The nuclear radius is commonly approximated by:

$$
R = R_0 A^{1/3}
$$

where:

- R_0 ≈ 1.2 to 1.3 fm (femtometers)
- A = mass number (here, 7)

b. Calculation:

Using $R_0 = 1.2\, \text{fm}$:

$$
R_{7Li} = 1.2 \times 7^{1/3}\, \text{fm}
$$

Calculate $7^{1/3}$:

$$
7^{1/3} \approx e^{(1/3) \ln 7} \approx e^{(1/3) \times 1.9459} \approx e^{0.6486} \approx 1.912
$$

Thus:

$$
R_{7Li} \approx 1.2 \times 1.912 \approx 2.294\, \text{fm}
$$

c. Interpretation:

- The nucleus of 7Li has an approximate radius of 2.29 femtometers.
- Note: Using $R_0 = 1.3\, \text{fm}$ would yield a slightly larger radius (~2.49 fm), but 1.2 fm is standard for such calculations.

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3. Calculating the Density of 7Li

a. Volume of the Nucleus:

Assuming a spherical shape:

$$
V = \frac{4}{3} \pi R^3
$$

$$
V_{7Li} = \frac{4}{3} \pi (2.294\, \text{fm})^3
$$

Calculate R^3:

$$
(2.294)^3 \approx 12.09\, \text{fm}^3
$$

Thus:

$$
V_{7Li} \approx \frac{4}{3} \pi \times 12.09 \approx 50.8\, \text{fm}^3
$$

b. Density Calculation:

Density (ρ) is mass divided by volume:

$$
\rho_{7Li} = \frac{\text{Mass}}{\text{Volume}} = \frac{1.165 \times 10^{-26}\, \text{kg}}{50.8 \times 10^{-45}\, \text{m}^3}
$$

Note: 1 fm = 10^{-15} m, so:

$$
1\, \text{fm}^3 = 10^{-45}\, \text{m}^3
$$

Calculate:

$$
\rho_{7Li} \approx \frac{1.165 \times 10^{-26}}{50.8 \times 10^{-45}} = \frac{1.165}{50.8} \times 10^{19} \approx 0.0229 \times 10^{19} = 2.29 \times 10^{17}\, \text{kg/m}^3
$$

c. Final Density:

The nuclear density of 7Li is approximately 2.29 × 10^{17} kg/m³, aligning with the typical nuclear matter density (~2.3 × 10^{17} kg/m³).

Part B: Calculating for Lead-207 (207Pb)

1. Determining the Nuclear Mass of 207Pb

a. Atomic Composition:

- Lead-207 has:
- Protons (Z): 82
- Neutrons (N): 125 (since 207 - 82)

b. Atomic Mass:

- The atomic mass of 207Pb is approximately 207.976652 u.
- Similar to 7Li, this includes electrons, but for nuclear calculations, the atomic mass can be used directly, adjusting for electron mass if needed.

c. Mass of Constituent Particles:

- Total mass of free nucleons:

$$
\[

$$
(82 \times 1.007276) + (125 \times 1.008665) = 82.598632 + 126.0831 = 208.681732\, \text{u}
$$

d. Mass Defect and Binding Energy:

- The experimental atomic mass (207.976652 u) is less than the sum of free nucleons (208.68 u), indicating a significant binding energy.

e. Conversion to Kilograms:

$$
\text{Mass of 207Pb nucleus} \approx 207.976652\, \text{u} \times 1.660539 \times 10^{-27}\, \text{kg/u} \approx 3.455 \times 10^{-25}\, \text{kg}
$$

---

2. Calculating the Radius of 207Pb

a. Empirical Formula:

$$
R_{207Pb} = 1.2 \times A^{1/3}\, \text{fm}
$$

Calculate $207^{1/3}$:

$$
207^{1/3} \approx e^{(1/3) \times \ln 207} \approx e^{(1/3) \times 5.332} \approx e^{1.777} \approx 5.913
$$

Thus:

$$
R_{207Pb} \approx 1.2 \times 5.913 \approx 7.095\, \text{fm}
$$

b. Interpretation:

- The approximate radius of the 207Pb nucleus is 7.10 femtometers.

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3. Calculating the Density of 207Pb

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