

The Lead Nucleus Has A Diameter Of 14.2 Fm .

What Is The Density Of Matter In A Lead Nucleus?

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Understanding the density of matter within atomic nuclei is fundamental to nuclear physics and helps us comprehend the behavior of matter at the smallest scales. Specifically, the lead nucleus, with its well-defined size and composition, offers an excellent case study for exploring nuclear density. In this article, we will delve into the concept of nuclear density, analyze the lead nucleus's dimensions, and calculate its matter density step by step.

What Is Nuclear Density?

Nuclear density refers to the mass per unit volume of an atomic nucleus. It provides insight into how tightly packed protons and neutrons (collectively called nucleons) are within the nucleus. Unlike everyday objects, nuclear matter is extraordinarily dense, with nucleons packed at extremely close distances.

Nuclear density is typically expressed in units of grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3). It is important to note that nuclear matter density remains relatively consistent across different elements, a phenomenon known as “nuclear saturation density.”

Dimensions of the Lead Nucleus

The lead nucleus, specifically isotope Pb-208, is a common example in nuclear physics studies. The diameter of the lead nucleus is approximately 14.2 femtometers (fm), where:

- 1 femtometer (fm) = 1×10^{-15} meters

Knowing the size of the nucleus is essential for calculating its volume and, subsequently, its density.

What Is a Femtometer?

A femtometer, also known as a fermi, is a unit of length used in nuclear physics to measure nuclear dimensions. It reflects the scale of atomic nuclei, which are on the order of 1-15 femtometers in diameter.

Calculating the Volume of the Lead Nucleus

Assuming the nucleus is spherical, which is a reasonable approximation, the volume can be calculated using the formula for the volume of a sphere:

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

Where:

- V = volume

- r = radius of the nucleus

Given the diameter (d):

$$r = \frac{d}{2} = \frac{14.2 \text{ fm}}{2} = 7.1 \text{ fm}$$

Now, convert femtometers to meters:

$$r = 7.1 \times 10^{-15} \text{ m}$$

Calculating the volume:

$$V = \frac{4}{3} \pi (7.1 \times 10^{-15} \text{ m})^3$$

$$V \approx \frac{4}{3} \times 3.1416 \times (3.58 \times 10^{-43} \text{ m}^3)$$

$$V \approx 4.1888 \times 3.58 \times 10^{-43} \text{ m}^3$$

$$V \approx 1.5 \times 10^{-42} \text{ m}^3$$

Thus, the approximate volume of the lead nucleus is $(1.5 \times 10^{-42} \text{ m}^3)$.

Mass of the Lead Nucleus

To find the density, we need the mass of the nucleus. The lead nucleus, specifically Pb-208, contains:

- 82 protons
- 126 neutrons

Total nucleons: 208

Atomic Mass of Lead-208

The atomic mass of lead-208 is approximately 207.2 atomic mass units (amu). Since:

- 1 amu = $1.6605 \times 10^{-27} \text{ kg}$

The mass of the nucleus:

$$m_{\text{nucleus}} = 207.2 \times 1.6605 \times 10^{-27} \text{ kg}$$

$$[m_{\text{nucleus}} \approx 3.44 \times 10^{-25} \text{ kg}]$$

This is the approximate mass of a single lead-208 nucleus.

Calculating the Density of the Lead Nucleus

Now, using the mass and volume:

$$[\text{Density } (\rho) = \frac{\text{Mass}}{\text{Volume}}]$$

$$[\rho = \frac{3.44 \times 10^{-25} \text{ kg}}{1.5 \times 10^{-42} \text{ m}^3}]$$

$$[\rho \approx 2.29 \times 10^{17} \text{ kg/m}^3]$$

Converting to grams per cubic centimeter:

$$- 1 \text{ kg/m}^3 = 0.001 \text{ g/cm}^3$$

Therefore:

$$[\rho \approx 2.29 \times 10^{17} \times 0.001 \text{ g/cm}^3]$$

$$[\rho \approx 2.29 \times 10^{14} \text{ g/cm}^3]$$

Final Result:

The density of matter in a lead nucleus is approximately $2.3 \times 10^{14} \text{ g/cm}^3$.

Understanding Nuclear Density and Its Significance

This immense density underscores how nuclear matter is vastly more compact than ordinary matter.

To put this into perspective:

- The density of water is about 1 g/cm^3 .
- The density of lead at the macroscopic scale is around 11.34 g/cm^3 .
- The nuclear density is roughly 10^{14} times higher than water.

This extraordinary density results from the strong nuclear force that binds protons and neutrons together, overcoming electromagnetic repulsion between positively charged protons.

Why Is Nuclear Density Important?

- Nuclear Stability: Understanding density helps explain the stability of nuclei and nuclear reactions.
- Nuclear Models: It informs models like the liquid drop model, which treats the nucleus as a drop of incompressible nuclear fluid.
- Astrophysics: Insights into nuclear density are crucial in understanding neutron stars, which are essentially giant nuclei with densities several times higher than terrestrial nuclei.

Summary and Key Takeaways

- The lead nucleus has a diameter of approximately 14.2 femtometers.
- Assuming a spherical shape, its volume is about $(1.5 \times 10^{-42} \text{ m})^3$.
- The mass of a lead-208 nucleus is roughly $(3.44 \times 10^{-25} \text{ kg})$.
- The resulting matter density within the lead nucleus is approximately $(2.3 \times 10^{14} \text{ g/cm}^3)$.

This calculation highlights the extreme density of nuclear matter—an aspect critical to the fields of nuclear physics, astrophysics, and understanding the fundamental properties of matter.

Further Reading and Resources

- Nuclear Physics Textbooks: For in-depth explanations of nuclear structure and properties.
- Research Articles: Explore recent studies on nuclear density and high-density astrophysical objects.
- Educational Websites: Such as the National Nuclear Data Center or physics educational platforms for visualizations and interactive models.

By comprehending the density of the lead nucleus, scientists continue to unravel the mysteries of atomic structure and the fundamental forces that govern our universe.

Frequently Asked Questions

How is the density of matter in a lead nucleus calculated given its diameter?

The density is calculated by dividing the mass of the nucleus by its volume. Using the nuclear mass and volume derived from the diameter, the density can be determined with the formula: $\text{density} = \text{mass} / \text{volume}$.

What is the approximate mass of a lead nucleus with a diameter of 14.2 fm?

The mass of a lead nucleus (Pb-208) is approximately 208 atomic mass units, which is about 3.45×10^{-25} kg.

How do you calculate the volume of a lead nucleus with a diameter of 14.2 fm?

The volume of a spherical nucleus is given by $V = \frac{4}{3}\pi r^3$. Since the diameter is 14.2 fm, the radius $r = 7.1$ fm. Plugging in the radius, $V = \frac{4}{3}\pi (7.1 \text{ fm})^3$.

What is the typical density of nuclear matter, and how does lead compare?

The typical nuclear matter density is about $2.3 \times 10^{17} \text{ kg/m}^3$. Calculations for lead's nucleus with a diameter of 14.2 fm yield a similar order of magnitude, confirming lead's high density at the nuclear scale.

Why is the density of a lead nucleus so high compared to everyday materials?

Because nuclear matter is incredibly compact, with protons and neutrons packed tightly within a tiny volume, resulting in densities many orders of magnitude higher than typical materials like solids or liquids.

What significance does knowing the density of a lead nucleus have in nuclear physics?

Understanding the density helps in studying nuclear interactions, stability, and reactions, as well as in modeling nuclear matter under extreme conditions relevant in astrophysics and nuclear energy applications.

Additional Resources

The Lead Nucleus Has A Diameter Of 14.2 Fm. What Is The Density Of Matter In A Lead Nucleus?

Understanding the density of matter within atomic nuclei is fundamental to nuclear physics, shedding light on the intricate structure of matter at the smallest scales. When we consider the lead nucleus, which has a diameter of approximately 14.2 femtometers (fm), questions naturally arise about how densely packed the protons and neutrons are within such a tiny volume. In this article, we will explore how to determine the density of matter in a lead nucleus, breaking down the steps, underlying principles, and significance of this calculation.

Introduction to Nuclear Density

The concept of density in classical physics is straightforward: mass per unit volume. However, when applied to atomic nuclei, it provides insights into how tightly nucleons (protons and neutrons) are packed, revealing the nature of nuclear forces and the stability of elements. The density of matter in a lead nucleus is notably high, reflecting the strong nuclear force that holds nucleons tightly together despite the nucleus's small size.

Basic Data and Constants

Before delving into calculations, it's essential to gather the relevant data:

- Diameter of lead nucleus (d): 14.2 femtometers (fm)
- Radius of lead nucleus (r): $d/2 = 7.1 \text{ fm}$
- Number of nucleons (A): For lead (Pb), atomic number $Z=82$, and mass number $A=208$
- Mass of a proton or neutron: approximately $1.6726 \times 10^{-27} \text{ kg}$
- Conversion factor: $1 \text{ fm} = 1 \times 10^{-15} \text{ meters}$

Step 1: Calculating the Volume of the Lead Nucleus

The nucleus is approximately spherical; thus, its volume (V) can be estimated using the sphere volume formula:

$$V = (4/3)\pi r^3$$

Calculations:

- Convert radius to meters:

$$r = 7.1 \text{ fm} = 7.1 \times 10^{-15} \text{ m}$$

- Compute the volume:

$$V = (4/3) \times \pi \times (7.1 \times 10^{-15} \text{ m})^3$$

$$V \approx (4/3) \times 3.1416 \times (3.58 \times 10^{-43} \text{ m}^3)$$

$$V \approx 4.1888 \times 3.58 \times 10^{-43} \text{ m}^3$$

$$V \approx 1.5 \times 10^{-42} \text{ m}^3$$

This is the approximate volume occupied by the entire lead nucleus.

Step 2: Determining the Total Mass of the Nucleus

The total mass (M) of the nucleus is the sum of the masses of its nucleons:

- Number of nucleons: $A=208$

- Average nucleon mass: approximately 1.6749×10^{-27} kg (using average between proton and neutron masses)

Calculation:

$$M = A \times \text{mass of one nucleon}$$

$$M = 208 \times 1.6749 \times 10^{-27} \text{ kg}$$

$$M = 3.484 \times 10^{-25} \text{ kg}$$

This mass represents the total matter content within the lead nucleus.

Step 3: Calculating the Nuclear Matter Density

Using the fundamental definition:

$$\text{Density } (\rho) = \text{Mass} / \text{Volume}$$

Substituting the values:

$$\rho = (3.484 \times 10^{-25} \text{ kg}) / (1.5 \times 10^{-28} \text{ m}^3)$$

$$\rho = 2.32 \times 10^{11} \text{ kg/m}^3$$

This indicates that the matter density in a lead nucleus is approximately 2.3×10^{11} kg/m³.

Significance of Nuclear Density

This density is astronomically higher than typical densities experienced in everyday materials. For comparison:

- Water density: 1000 kg/m^3
- Steel density: $\sim 7,800 \text{ kg/m}^3$
- Nuclear density: roughly 10^{17} kg/m^3

The high density reflects the strong nuclear force's capacity to confine nucleons within a femtometer-scale volume, illustrating the tightly bound nature of atomic nuclei. Such densities are comparable across different elements, with slight variations due to nuclear sizes and configurations.

Additional Considerations

While the calculation above provides a solid approximation, real-world nuclear densities can vary slightly due to factors such as:

- Nuclear deformation
- Nuclear shell effects
- Variations in nucleon distributions

Advanced models, such as the shell model or liquid drop model, incorporate these nuances, but the fundamental approach remains similar: estimate volume and total nucleon mass.

Why Is Knowing Nuclear Density Important?

Understanding nuclear density has profound implications:

- Nuclear stability: High density correlates with strong nuclear forces that determine stability and decay modes.
- Nuclear reactions: Densities influence reaction cross-sections and energy release.
- Astrophysics: Densities in neutron stars reach orders of magnitude higher, providing context for nuclear matter under extreme conditions.
- Material science: Insights into nuclear matter inform the development of nuclear energy and medical isotopes.

Summary of Key Steps

Step	Description	Calculation/Formula	Result
1	Calculate radius from diameter	$r = d/2$	7.1 fm
2	Convert radius to meters	$r = 7.1 \times 10^{-16} \text{ m}$	$7.1 \times 10^{-16} \text{ m}$
3	Compute volume	$V = (4/3)\pi r^3$	$\sim 1.5 \times 10^{-45} \text{ m}^3$
4	Determine total mass	$M = A \times \text{nucleon mass}$	$\sim 3.484 \times 10^{-26} \text{ kg}$
5	Calculate density	$\rho = M / V$	$\sim 2.3 \times 10^{17} \text{ kg/m}^3$

Final Thoughts

The calculation of the density of matter in a lead nucleus illustrates the extraordinary compactness of nuclear matter. Despite the tiny size—just 14.2 femtometers across—the nucleus contains a mass comparable to that of a small grain of sand compressed into a femtometer-scale volume. This high density is a testament to the strong nuclear force's power and the complex structure of matter at the atomic core.

Understanding these fundamental properties not only satisfies scientific curiosity but also paves the way for advancements in nuclear energy, medical imaging, and our comprehension of the universe's most extreme environments.

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