

A Nonrelativistic Free Particle Has A Mass Of 4.4×10^{-27} Kg And A Kinetic Energy Of 2.5×10^{-14} J. What

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Introduction

A nonrelativistic free particle has a mass of 4.4×10^{-27} kg and a kinetic energy of 2.5×10^{-14} joules. These parameters are fundamental in understanding the particle's behavior in classical mechanics and quantum physics. Such a particle could represent an atom, a molecule, or even a tiny subatomic entity moving at speeds much less than the speed of light. This article explores the physics behind these properties, how to determine the particle's velocity, momentum, and de Broglie wavelength, and their significance in various scientific contexts.

Understanding the Basic Concepts

What Is a Nonrelativistic Particle?

A nonrelativistic particle is one whose speed is significantly less than the speed of light (approximately 3×10^8 m/s). Under these conditions, classical mechanics provides accurate models for its motion, and relativistic effects like time dilation or length contraction are negligible.

Importance of the Particle's Mass and Kinetic Energy

The mass and kinetic energy of a particle are critical parameters that influence its motion, interactions, and wave properties. Knowing these allows physicists to predict the particle's velocity, momentum, and quantum behavior.

Calculating the Particle's Velocity

Formula for Kinetic Energy

The classical kinetic energy (KE) of a particle is given by:

$$[KE = \frac{1}{2} m v^2]$$

Where:

- (KE) is the kinetic energy,
- (m) is the mass,
- (v) is the velocity.

Deriving the Velocity

Rearranging the formula to solve for (v) :

$$[v = \sqrt{\frac{2 KE}{m}}]$$

Substituting Known Values

Given:

- $(KE = 2.5 \times 10^{-14})$ Joules,
- $(m = 4.4 \times 10^{-27})$ kg,

Calculate:

$$[v = \sqrt{\frac{2 \times 2.5 \times 10^{-14}}{4.4 \times 10^{-27}}}]$$

$$[v = \sqrt{\frac{5 \times 10^{-14}}{4.4 \times 10^{-27}}}]$$

$$[v = \sqrt{1.13636 \times 10^{13}}]$$

$$[v \approx \sqrt{1.13636} \times 10^{6.5}]$$

$$[v \approx 1.066 \times 10^{6.5}]$$

Since $(10^{6.5} \approx 3.16 \times 10^6)$, then:

$$[v \approx 1.066 \times 3.16 \times 10^6]$$

$$[v \approx 3.37 \times 10^6 \text{ m/s}]$$

Interpretation

The particle is moving at approximately 3.37 million meters per second, which is about 1.1% of the speed of light. This confirms the nonrelativistic approximation is valid, as the velocity is much less than (3×10^8) m/s.

Calculating Momentum

Classical Momentum Formula

Momentum (p) is calculated by:

$$p = m v$$

Using the computed velocity:

$$p = 4.4 \times 10^{-27} \times 3.37 \times 10^6$$

$$p \approx 1.4828 \times 10^{-20} \text{ kg}\cdot\text{m/s}$$

Significance of Momentum

This value indicates the particle's resistance to changes in motion and is crucial in scattering experiments, quantum mechanics, and understanding particle dynamics.

Quantum Mechanical Perspective: De Broglie Wavelength

Introduction to de Broglie Wavelength

According to quantum theory, particles exhibit wave-like properties characterized by the de Broglie wavelength (λ):

$$\lambda = \frac{h}{p}$$

Where:

- (h) is Planck's constant (6.626×10^{-34} Js),
- (p) is the particle's momentum.

Calculating the Wavelength

Substituting the known momentum:

$$\lambda = \frac{6.626 \times 10^{-34}}{1.4828 \times 10^{-20}}$$

$$\lambda \approx 4.47 \times 10^{-14} \text{ meters}$$

Implications

A wavelength of approximately 44.7 femtometers (fm) suggests that the particle exhibits wave-like behavior at the atomic or subatomic scale, relevant in electron diffraction and quantum tunneling phenomena.

Significance in Scientific Research and Applications

Particle Physics and Atomic Physics

Understanding the properties of such particles aids in:

- Modeling atomic interactions,
- Designing experiments involving particle scattering,
- Developing quantum theories of matter.

Nanotechnology and Material Science

At nanoscale dimensions, wave-like properties influence how particles interact with materials, impacting the development of new nanomaterials.

Quantum Computing and Electronics

Knowledge of particle wavelengths and momenta informs the design of quantum devices where quantum coherence and particle wave properties are exploited.

Additional Considerations

Validity of Classical Approximations

While classical formulas suffice here, at smaller scales or higher energies, relativistic effects or quantum mechanics become essential.

Potential for Experimental Measurement

Determining the velocity, momentum, and wavelength experimentally requires sophisticated techniques such as velocity selectors, particle accelerators, and diffraction experiments.

Role of Particle Mass

The relatively small mass (comparable to an atom or small molecule) underscores the importance of

quantum effects in its behavior.

Conclusion

A particle with a mass of 4.4×10^{-27} kg and a kinetic energy of 2.5×10^{-14} J moves at approximately 3.37 million meters per second, possesses a momentum of about 1.48×10^{-20} kg·m/s, and exhibits a de Broglie wavelength of roughly 44.7 femtometers. These properties bridge classical mechanics and quantum physics, offering insights into the particle's behavior and its applications across various scientific fields. Whether in understanding atomic interactions, designing nanodevices, or exploring fundamental physics, such calculations are pivotal in advancing our knowledge of the microscopic world.

References

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Frequently Asked Questions

What is the velocity of the nonrelativistic free particle with a mass of 4.4×10^{-27} kg and a kinetic energy of 2.5×10^{-14} J?

Using the kinetic energy formula $KE = (1/2) m v^2$, we solve for v : $v = \sqrt{(2 KE / m)} = \sqrt{(2 \times 2.5 \times 10^{-14} \text{ J} / 4.4 \times 10^{-27} \text{ kg})} \approx 1.07 \times 10^6 \text{ m/s}$.

Is the calculated velocity of the particle relativistic or nonrelativistic?

Since the velocity ($\sim 1.07 \times 10^6 \text{ m/s}$) is less than approximately 10% of the speed of light ($\sim 3 \times 10^8 \text{ m/s}$), the particle's motion can be considered nonrelativistic.

What is the significance of knowing the mass and kinetic energy of a particle in quantum mechanics?

Knowing the mass and kinetic energy helps determine the particle's wavelength via de Broglie relations, which is essential for understanding its quantum behavior and wave properties.

How does the particle's mass affect its quantum wavelength at this energy level?

A larger mass results in a smaller de Broglie wavelength for a given kinetic energy, influencing the particle's quantum behavior and the scale at which quantum effects become significant.

Can this particle be considered classical based on its kinetic energy and velocity?

Yes, since its velocity is well below the speed of light and quantum effects are typically negligible at such scales, the particle can be modeled using classical mechanics.

What practical applications might involve particles with these characteristics?

Particles with similar masses and energies are relevant in fields like atomic physics, nanotechnology, and electron microscopy, where understanding particle behavior at small scales is essential.

Additional Resources

Kinetic Energy Analysis of a Nonrelativistic Free Particle with Mass 4.4×10^{-27} kg

Introduction

Imagine delving into the microscopic world, where particles dance to the tune of quantum mechanics and classical physics blends seamlessly in the nonrelativistic regime. Today, we explore a fascinating scenario involving a free particle—one that's unbound by external forces—possessing a specified mass and kinetic energy. This inquiry provides a window into fundamental principles of physics, offering insights into particle dynamics, energy calculations, and the underlying concepts that govern motion on the atomic scale.

This article takes a detailed, expert-level look at a nonrelativistic free particle with a mass of 4.4×10^{-27} kg and a kinetic energy of 2.5×10^{-14} J, unpacking what these values imply, how they relate to each other, and what they reveal about the particle's velocity and behavior.

Understanding the Context: Nonrelativistic Particles

Before diving into calculations, it's vital to clarify what "nonrelativistic" entails. In physics, a particle is

considered nonrelativistic when its velocity v is much less than the speed of light ($c \approx 3 \times 10^8 \text{ m/s}$). Typically, this means $v \ll c$, often less than about 10% of c .

Why is this distinction important? Because in the nonrelativistic regime, classical mechanics provides accurate descriptions of motion, and relativistic effects—like time dilation and mass increase—are negligible. This simplifies analysis and allows us to use familiar formulas without relativistic corrections.

Dissecting the Given Data

The core parameters we have are:

- Mass (m): $4.4 \times 10^{-27} \text{ kg}$
- Kinetic Energy (K): $2.5 \times 10^{-14} \text{ J}$

The goal is to analyze what these values tell us about the particle's velocity, momentum, and potential physical identity.

Calculating the Velocity of the Particle

Fundamental Relation:

In classical mechanics, the kinetic energy (K) of a particle with mass m moving at velocity v is given by:

$$\begin{aligned} &\backslash[\\ K &= \frac{1}{2} m v^2 \\ &\backslash] \end{aligned}$$

Rearranged to find v :

$$\begin{aligned} &\backslash[\\ v &= \sqrt{\frac{2K}{m}} \\ &\backslash] \end{aligned}$$

Step-by-step Calculation:

Plugging in the given values:

$$v = \sqrt{\frac{2 \times 2.5 \times 10^{-14} \text{ J}}{4.4 \times 10^{-27} \text{ kg}}}$$

Calculating numerator:

$$2 \times 2.5 \times 10^{-14} = 5 \times 10^{-14}$$

Dividing numerator by denominator:

$$\frac{5 \times 10^{-14}}{4.4 \times 10^{-27}} = \frac{5}{4.4} \times 10^{13} \approx 1.136 \times 10^{13}$$

Taking the square root:

$$v \approx \sqrt{1.136 \times 10^{13}} \approx \sqrt{1.136} \times 10^{6.5} \approx 1.07 \times 10^{6.5}$$

Expressed explicitly:

$$v \approx 1.07 \times 10^6 \times \sqrt{10} \approx 1.07 \times 10^6 \times 3.16 \approx 3.39 \times 10^6 \text{ m/s}$$

Result:

$$\boxed{v \approx 3.39 \times 10^6 \text{ m/s}}$$

Assessing the Velocity: Is It Truly Nonrelativistic?

Given that $c \approx 3 \times 10^8 \text{ m/s}$, the calculated velocity is:

$$\left[\frac{v}{c} \approx \frac{3.39 \times 10^6}{3 \times 10^8} \approx 0.0113 \right]$$

or about 1.13% of the speed of light.

Implication: Since $v \ll c$, the particle is comfortably within the nonrelativistic regime. This justifies using classical kinetic energy formulas without relativistic corrections.

Estimating the Particle's Momentum

Momentum (p) is a fundamental quantity in physics, representing the quantity of motion. For classical particles:

$$\left[p = m v \right]$$

Calculating:

$$\left[p = 4.4 \times 10^{-27} \text{ kg} \times 3.39 \times 10^6 \text{ m/s} \approx 1.4916 \times 10^{-20} \text{ kg}\cdot\text{m/s} \right]$$

Approximate value:

$$\left[\boxed{p \approx 1.49 \times 10^{-20} \text{ kg}\cdot\text{m/s}} \right]$$

This small magnitude reflects the microscopic scale of the particle, consistent with particles like electrons or protons.

Physical Identity and Significance of the Particle

The mass of 4.4×10^{-27} kg is intriguing. To put it into context:

- Electron mass: approximately 9.11×10^{-31} kg
- Proton mass: approximately 1.67×10^{-27} kg

Comparing:

$$\left[\frac{4.4 \times 10^{-27}}{1.67 \times 10^{-27}} \approx 2.63 \right]$$

This indicates the particle's mass is roughly 2.6 times that of a proton, situating it somewhere between a proton and a heavier nucleus, or perhaps an exotic particle.

Possible interpretations:

- A heavy nucleus fragment or ion.
- A subatomic particle with a mass similar to that of a neutron or heavier isotope.
- A hypothetical or composite particle in experimental physics.

Given its mass, it's unlikely to be a simple electron; more plausibly, it could be a fragment of a nucleus or an atom in a specific state.

Energy and Momentum Relations in the Quantum Realm

In quantum mechanics, particles are described by wavefunctions, with the de Broglie wavelength:

$$\left[\lambda = \frac{h}{p} \right]$$

where h is Planck's constant (6.626×10^{-34} Js).

Calculating:

$$\left[\right]$$

$$\lambda = \frac{6.626 \times 10^{-34}}{1.49 \times 10^{-20}} \approx 4.45 \times 10^{-14} \text{ m}$$

Implication: The particle’s de Broglie wavelength is on the order of 10-14 meters, comparable to atomic nucleus scales. This underscores the quantum nature of the particle and its potential to exhibit wave-like properties.

Broader Implications and Potential Applications

Understanding the kinetic energy and velocity of such a particle is pivotal in areas like:

- Nuclear physics: where particles with similar masses are involved in fusion, fission, or decay processes.
- Particle physics experiments: designing detectors to measure particles with these energies.
- Quantum mechanics: studying wave-particle duality at the nuclear or subnuclear level.
- Material science: understanding how such particles interact with matter, which influences radiation shielding or imaging techniques.

Summary of Key Findings

Parameter	Calculated Value	Significance
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Velocity (v)	$\sim 3.39 \times 10^6 \text{ m/s}$	Nonrelativistic; confirms classical approximation validity
Momentum (p)	$\sim 1.49 \times 10^{-20} \text{ kg}\cdot\text{m/s}$	Small, consistent with atomic-scale particles
de Broglie wavelength (λ)	$\sim 4.45 \times 10^{-14} \text{ m}$	Quantum wavelength comparable to nuclear dimensions
Velocity ratio to c	$\sim 1.13\%$	Deep within nonrelativistic regime

Final Thoughts

This exploration underscores the elegance of classical physics in describing microscopic particles under certain energy regimes. While the particle's mass and energy suggest a subatomic entity—potentially a proton or a similar heavy nucleus fragment—the precise identity depends on the context of the experiment or system.

The calculations reveal that with a modest kinetic energy, such a particle attains a velocity comfortably below relativistic thresholds, simplifying analysis and enabling classical formulas to provide accurate insights. The wave-like nature inferred from the de Broglie wavelength further bridges the classical and quantum worlds, illustrating the layered complexity of particles at the atomic scale.

Understanding these parameters not only deepens our grasp of fundamental

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