

Calculate The Wavelengths Of The Following Objects.a) A 75 Kg Athlete Running A 5.0-minute Mile:b) Earth

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Understanding the concept of wavelength extends beyond the realm of light and sound; it also applies intriguingly to massive objects like athletes and planets. By applying principles from quantum mechanics and classical physics, we can calculate the wavelength associated with various objects, revealing fascinating insights into their wave-like properties. In this comprehensive article, we will explore how to determine the wavelengths of a 75 kg athlete running a 5.0-minute mile and the Earth itself, emphasizing their significance within physics and their implications in scientific understanding.

What Is Wavelength and Why Is It Important?

Before delving into specific calculations, it's essential to understand what wavelength signifies and its relevance.

Definition of Wavelength

Wavelength (λ) is the distance over which a wave's shape repeats. In physics, it is typically associated with waves, including electromagnetic waves, sound waves, and matter waves.

De Broglie Wavelength

For particles and objects, the concept of wavelength arises from quantum mechanics, specifically via the de Broglie hypothesis, which states:

- Every moving particle exhibits wave-like properties.
- The wavelength (λ) is inversely proportional to the particle's momentum (p):

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

where:

- h = Planck's constant (6.626×10^{-34} , Js)
- p = momentum of the object ($p = mv$), with m as mass and v as velocity

This principle allows us to calculate the wavelength associated with any moving object, regardless of its size, although the resulting wavelength for macroscopic objects is typically unimaginably small.

Calculating the Wavelength of a 75 Kg Athlete Running a 5.0-minute Mile

Let's explore how to determine the de Broglie wavelength of a human athlete.

Step 1: Identify Known Values

- Mass of the athlete, $m = 75$, kg
- Time to run a mile, $T = 5.0$, $\text{minutes} = 300$, seconds

Step 2: Calculate the Velocity of the Athlete

A standard mile is approximately 1,609.34 meters. Running this distance in 300 seconds yields:

$$v = \frac{\text{distance}}{\text{time}} = \frac{1609.34 \text{ m}}{300 \text{ s}} \approx 5.365 \text{ m/s}$$

Step 3: Compute the Momentum ($p = mv$)

$$p = 75 \text{ kg} \times 5.365 \text{ m/s} \approx 402.375 \text{ kg}\cdot\text{m/s}$$

Step 4: Apply the de Broglie Equation

$$\lambda = \frac{h}{p} = \frac{6.626 \times 10^{-34} \text{ Js}}{402.375 \text{ kg}\cdot\text{m/s}} \approx 1.65 \times 10^{-36} \text{ meters}$$

Conclusion for the Athlete

The de Broglie wavelength of a 75 kg athlete running at about 5.4 m/s is approximately 1.65×10^{-36} meters. This value is unfathomably small, illustrating that quantum wave properties are negligible at macroscopic scales.

Calculating the Wavelength of Earth

Now, let's examine how to compute Earth's wavelength based on its mass and orbital velocity.

Step 1: Identify Known Values

- Mass of Earth, $(m = 5.972 \times 10^{24} \text{ kg})$
- Orbital velocity around the Sun, $(v \approx 29,780 \text{ m/s})$ (average orbital speed)

Step 2: Calculate Earth's Momentum

$$p = m \times v = 5.972 \times 10^{24} \text{ kg} \times 29,780 \text{ m/s} \approx 1.78 \times 10^{29} \text{ kg}\cdot\text{m/s}$$

Step 3: Apply the de Broglie Wavelength Formula

$$\lambda = \frac{h}{p} = \frac{6.626 \times 10^{-34} \text{ Js}}{1.78 \times 10^{29} \text{ kg}\cdot\text{m/s}} \approx 3.73 \times 10^{-63} \text{ meters}$$

Conclusion for Earth

The de Broglie wavelength of Earth in its orbital motion is approximately 3.73×10^{-63} meters, an unimaginably tiny number, emphasizing the classical behavior of planetary bodies.

Implications of These Calculations

The calculations highlight the profound difference between microscopic and macroscopic objects regarding wave-like properties:

- For humans and planets, the de Broglie wavelength is so minuscule that quantum effects are practically nonexistent, reaffirming classical physics' dominance at large scales.
- At atomic and subatomic levels, wavelengths are significant and observable, underpinning quantum phenomena.

Key points:

- The wavelength of macroscopic objects is astronomically small, making their wave nature negligible.
- Quantum effects are only significant when the wavelength is comparable to the size of the object or the system being studied.

Broader Applications of Wavelength Calculations

Understanding the wave properties of objects has practical applications in various fields:

- Quantum mechanics and particle physics: Determining particle behavior at atomic scales.
- Astrophysics: Analyzing the wave nature of celestial bodies for theoretical models.
- Nanotechnology: Manipulating particles at quantum scales where wave properties are significant.
- Material science: Studying electron wavelengths to understand conductivity and other properties.

Summary and Final Thoughts

Calculating the wavelengths of objects ranging from a running athlete to the Earth reveals the immense scale differences and the relevance of quantum principles. While the de Broglie wavelength for a human or a planet is effectively negligible, these calculations serve as a vital reminder of the wave-particle duality that underpins the universe's fundamental structure.

In brief:

- The wavelength of a 75 kg athlete running a mile in 5 minutes is approximately 1.65×10^{-36} meters.
- The wavelength of Earth in its orbital motion is approximately 3.73×10^{-63} meters.
- These tiny wavelengths underscore why classical physics suffices for macroscopic phenomena, whereas quantum physics is essential at microscopic scales.

By understanding these calculations, students and enthusiasts gain deeper insight into the interconnectedness of physics across scales, reinforcing the importance of quantum mechanics in understanding the universe.

FAQs

1. Can macroscopic objects ever exhibit wave-like properties?

In principle, yes, but their wavelengths are so small that quantum effects are practically undetectable, making classical physics adequate for everyday purposes.

2. Why is Planck's constant important in these calculations?

Planck's constant relates energy and frequency in quantum mechanics and is central to calculating the de Broglie wavelength, connecting wave and particle properties.

3. Do these calculations have real-world applications?

While the wavelengths for large objects are negligible, understanding wave-particle duality is crucial in fields like quantum computing, nanotechnology, and particle physics.

By mastering the calculation of wavelengths for various objects, students and scientists can better appreciate the fundamental principles that govern the universe at all scales.

Frequently Asked Questions

What is the de Broglie wavelength of a 75 kg athlete running a mile in 5 minutes?

First, calculate the velocity: a mile is approximately 1609 meters, and 5 minutes is 300 seconds, so velocity $v = 1609/300 \approx 5.36$ m/s. The de Broglie wavelength $\lambda = h / (m v)$, where $h \approx 6.626 \times 10^{-34}$ Js. Thus, $\lambda \approx 6.626 \times 10^{-34}$

$\lambda = h / (mv) = (6.626 \times 10^{-34} \text{ J}\cdot\text{s}) / (75 \text{ kg} \cdot 5.36 \text{ m/s}) \approx 1.65 \times 10^{-36} \text{ meters}$, which is extremely small and practically unobservable.

Why is the wavelength of a running athlete so minuscule?

Because macroscopic objects like athletes have very large masses compared to atomic scales, their de Broglie wavelengths are exceedingly tiny, making quantum effects negligible at such scales.

How do you calculate the wavelength of Earth?

Using the de Broglie equation $\lambda = h / (mv)$. For Earth, assuming an orbital velocity of about 30 km/s ($3 \times 10^4 \text{ m/s}$), and mass approximately $5.97 \times 10^{24} \text{ kg}$, $\lambda \approx 6.626 \times 10^{-34} / (5.97 \times 10^{24} \text{ kg} \cdot 3 \times 10^4 \text{ m/s}) \approx 3.7 \times 10^{-62} \text{ meters}$, an unimaginably tiny wavelength.

Is it meaningful to calculate the wavelength of large objects like Earth?

While the calculation is possible mathematically, the resulting wavelength is so small that quantum effects are effectively nonexistent for such macroscopic objects, making the concept purely theoretical.

What factors influence the wavelength of an object in quantum mechanics?

The main factors are the object's mass and velocity; increasing velocity decreases the wavelength, while increasing mass results in an even smaller wavelength, especially for large objects.

Can any everyday object have a measurable de Broglie wavelength?

In practice, only very small particles like electrons and atoms have measurable wavelengths; for larger objects like humans or planets, their wavelengths are too tiny to detect with current technology.

How does the de Broglie wavelength relate to the wave-particle duality?

It illustrates that all matter exhibits wave-like properties, with the wavelength inversely proportional to momentum, bridging classical and quantum physics concepts.

What practical applications rely on calculating wavelengths of objects?

Such calculations are essential in quantum physics, nanotechnology, and electron microscopy, where understanding wave properties at microscopic scales is crucial.

Additional Resources

Calculate The Wavelengths Of The Following Objects.a) A 75 Kg Athlete Running A 5.0-minute Mile:b) Earth

In the fascinating intersection of quantum mechanics and classical physics, one intriguing question often arises: can everyday objects possess a wavelength? While quantum phenomena are typically associated with subatomic particles, the principles apply universally—albeit with dramatically different scales. Today, we'll explore how to calculate the de Broglie wavelengths of two vastly different objects: a 75 kg athlete running a mile in five minutes and the Earth itself. These calculations not only illustrate the profound differences in scale but also underscore the strange, yet fundamental, wave-particle duality that underpins our universe.

Understanding the Concept: De Broglie Wavelength

Before diving into calculations, it's essential to grasp what the de Broglie wavelength is. Formulated by Louis de Broglie in 1924, this principle states that every moving particle exhibits wave-like properties. The de Broglie wavelength (λ) is given by the formula:

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

where:

- h is Planck's constant (6.626×10^{-34} Js),
- p is the momentum of the object ($p = mv$),
- m is the mass,
- v is the velocity.

This relationship implies that the wavelength is inversely proportional to the object's momentum: the faster and more massive the object, the shorter its wavelength.

While quantum effects are negligible for macroscopic objects, calculating these wavelengths helps deepen our understanding of the quantum-classical

boundary.

Part A: Calculating the Wavelength of a 75 kg Athlete Running a 5.0-minute Mile

Step 1: Define the parameters

- Mass (m): 75 kg
- Time to run a mile: 5.0 minutes = 300 seconds
- Distance of a mile: approximately 1.609 km or 1609 meters

Step 2: Calculate the velocity

The velocity (v) of the athlete can be determined using:

$$v = \frac{\text{distance}}{\text{time}} = \frac{1609 \text{ m}}{300 \text{ s}} \approx 5.36 \text{ m/s}$$

This is a typical running speed for an athlete completing a mile in five minutes.

Step 3: Calculate momentum (p)

$$p = mv = 75 \text{ kg} \times 5.36 \text{ m/s} \approx 402 \text{ kg} \cdot \text{m/s}$$

Step 4: Calculate the de Broglie wavelength (λ)

Using the de Broglie formula:

$$\lambda = \frac{h}{p} = \frac{6.626 \times 10^{-34} \text{ Js}}{402 \text{ kg} \cdot \text{m/s}} \approx 1.65 \times 10^{-36} \text{ meters}$$

\]

Interpretation: The wavelength is approximately (1.65×10^{-36}) meters, an unimaginably tiny value—far smaller than atomic nuclei, making quantum wave effects entirely negligible at this scale.

Part B: Calculating the Wavelength of Earth

Step 1: Define Earth's parameters

- Mass of Earth (m): approximately (5.972×10^{24}) kg
- Average orbital velocity around the Sun: about 29.78 km/s (or 29,780 m/s)

Alternatively, consider Earth's rotation or orbital motion as the basis for velocity, depending on the context. Here, we'll use Earth's orbital velocity for a comprehensive perspective.

Step 2: Calculate Earth's momentum (p)

[
 $p = mv = 5.972 \times 10^{24} \text{ kg} \times 29,780 \text{ m/s} \approx 1.78 \times 10^{29} \text{ kg} \cdot \text{m/s}$
]

Step 3: Compute Earth's de Broglie wavelength (λ)

[
 $\lambda = \frac{h}{p} = \frac{6.626 \times 10^{-34} \text{ Js}}{1.78 \times 10^{29} \text{ kg} \cdot \text{m/s}} \approx 3.73 \times 10^{-63} \text{ meters}$
]

Interpretation: The wavelength is approximately (3.73×10^{-63}) meters—an astronomically small value, effectively zero from any practical perspective.

The Implications of These Calculations

The stark difference in the calculated de Broglie wavelengths illustrates the core principle of quantum mechanics and classical physics. For macroscopic objects like humans and planets:

- Their wavelengths are so minuscule that wave-like behavior is unobservable.
- The classical description of their motion suffices for all practical purposes.

In contrast, particles with tiny masses—such as electrons—possess wavelengths comparable to atomic scales, which are observable and critical in quantum physics.

Why Do These Differences Matter?

Understanding why macroscopic objects don't exhibit observable wave properties involves acknowledging the role of scale and measurement. The de Broglie wavelength becomes significant only when the wavelength is comparable to the size of the object or the system's relevant length scales. For large masses and high momenta, the wavelength shrinks to negligible values, rendering wave effects practically undetectable.

Broader Applications and Significance

While calculating the de Broglie wavelength of a person or Earth might seem academic, these calculations serve as vital tools in fields like quantum physics, nanotechnology, and astrophysics.

- Nanotechnology: At nanoscale dimensions, quantum effects become significant, influencing the design of electronic components and materials.
- Astrophysics: Although Earth's quantum wavelength is negligible, understanding quantum effects in celestial phenomena helps explain the behavior of extremely dense objects like neutron stars or black holes.
- Quantum Computing: Manipulating particles with sizable wavelengths is fundamental in developing quantum bits (qubits).

Conclusion

Calculating the de Broglie wavelengths of objects as different as a running

athlete and the Earth underscores the universality of quantum principles. For everyday macroscopic objects, these wavelengths are so infinitesimal that wave-like behaviors are practically nonexistent. Conversely, at atomic and subatomic scales, wave properties dominate, shaping the very fabric of matter and energy.

These calculations reinforce the notion that quantum mechanics is not just an abstract theory but a foundational aspect of the universe. They also highlight the remarkable scale at which quantum effects become observable—a boundary that continues to challenge and inspire physicists today.

By understanding how to compute and interpret these wavelengths, we gain a deeper appreciation for the quantum world's subtlety and its profound implications across the cosmos.

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