

What Is The Speed Of An Electron With A De Broglie Wavelength Of 0.11 Nm ? Express Your Answer In Meters

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Understanding the behavior of electrons is fundamental to quantum mechanics and modern physics. One intriguing aspect of electrons is their wave-particle duality, which means they exhibit both particle-like and wave-like properties. When considering electrons as waves, their wavelength becomes a crucial parameter. Specifically, if an electron has a de Broglie wavelength of 0.11 nanometers (Nm), what is its speed? In this article, we will explore how to calculate the electron's speed based on its de Broglie wavelength, providing a clear, step-by-step explanation and emphasizing the scientific principles involved.

De Broglie Wavelength and Its Significance

Understanding the De Broglie Hypothesis

In 1924, physicist Louis de Broglie proposed that particles such as electrons could exhibit wave-like behavior. This revolutionary idea extended the concept of wave-particle duality beyond photons to matter particles. According to de Broglie, every particle with momentum has an associated wavelength, given by:

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

where:

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

This relation is fundamental in quantum mechanics, allowing physicists to connect the wave properties of particles to their physical attributes like mass and velocity.

The Relevance of Wavelength in Electron Behavior

The de Broglie wavelength helps us understand phenomena such as electron diffraction and interference, which are observable in experiments like the Davisson-Germer experiment. Knowing an electron's wavelength allows scientists to calculate its momentum, and subsequently its velocity, which is essential in understanding electron behavior in various contexts, from atomic structures to nanotechnology.

Calculating the Electron's Speed from Its De Broglie Wavelength

To find the speed of an electron with a given de Broglie wavelength, we need to manipulate the de Broglie relation:

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

and relate momentum to velocity:

$$p = mv$$

where:

- m is the mass of the electron (9.109×10^{-31} kg),
- v is the velocity (what we want to find).

Putting these together, the steps are:

1. Calculate the momentum p from the given wavelength.
2. Use the mass of the electron to find its velocity ($v = p/m$).

Step 1: Convert Wavelength to Meters

Given that the wavelength is 0.11 nm, it's already in meters, so no conversion is necessary.

Step 2: Calculate Momentum p

Using the de Broglie relation:

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

Substituting known values:

$$p = \frac{6.626 \times 10^{-34} \text{ Js}}{0.11 \times 10^{-9} \text{ m}}$$

Calculating:

$$p = \frac{6.626 \times 10^{-34}}{1.1 \times 10^{-10}} \approx 6.026 \times 10^{-24} \text{ kg m/s}$$

\]

Step 3: Calculate the Velocity (v)

Now, using $(p = mv)$:

\[

$$v = \frac{p}{m}$$

\]

Substituting the values:

\[

$$v = \frac{6.026 \times 10^{-24}}{9.109 \times 10^{-31}} \approx 6.62 \times 10^6 \text{ m/s}$$

\]

Thus, the electron's speed is approximately 6.62 million meters per second.

Understanding the Results and Implications

Significance of the Calculated Speed

The calculated speed of about (6.62×10^6) m/s indicates that electrons with a de Broglie wavelength of 0.11 Nm are moving at a significant fraction of the speed of light, but still well within the non-relativistic regime where classical mechanics remains valid for simple calculations.

Context in Quantum and Classical Mechanics

- At this speed, relativistic effects are minimal, so the classical relation $(p = mv)$ is appropriate.
- The wavelength corresponds to typical scales observed in electron diffraction experiments, illustrating how quantum effects become prominent at nanometer scales.

Applications and Relevance of Electron Wavelength Calculations

In Nanotechnology and Material Science

Accurate knowledge of electron speeds based on their wavelengths aids in understanding electron behavior in nanostructures, such as quantum dots and nanowires, impacting the design of electronic devices.

In Electron Microscopy

Electron wavelengths determine the resolution limits of electron microscopes. Shorter wavelengths enable higher resolution imaging at atomic scales.

In Fundamental Physics

Calculations like these validate quantum mechanical principles and support the development of theories describing matter-wave interactions.

Summary and Conclusion

In conclusion, an electron with a de Broglie wavelength of 0.11 nanometers travels at an approximate speed of 6.62 million meters per second. This calculation highlights the wave-particle duality and shows how fundamental constants like Planck's constant and the electron's mass are employed to bridge the wave and particle nature of matter. Mastery of such calculations is essential for physicists exploring the quantum realm and developing advanced technologies based on quantum principles.

Key Takeaways:

- The de Broglie wavelength relates a particle's momentum to its wave properties.
- Calculating the speed involves dividing the de Broglie momentum by the electron's mass.
- The resulting speed demonstrates the high velocities electrons can attain at nanometer-scale wavelengths.
- This knowledge is integral to quantum mechanics, electron microscopy, and nanotechnology.

Understanding the relationship between wavelength and speed not only deepens our grasp of quantum physics but also paves the way for innovations across scientific disciplines.

Frequently Asked Questions

What is the formula to find the speed of an electron using its de Broglie wavelength?

The speed v of an electron can be found using the de Broglie wavelength λ with the formula $v = h / (m \lambda)$, where h is Planck's constant and m is the mass of the electron.

What is the value of Planck's constant (h) used in calculations involving de Broglie wavelength?

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

What is the mass of an electron used in calculating its velocity from de Broglie wavelength?

The mass of an electron is approximately 9.11×10^{-31} kg.

How do you convert the de Broglie wavelength from nanometers to meters?

Since 1 nanometer = 1×10^{-9} meters, multiply the wavelength in nm by 10^{-9} to convert to meters.

Given a de Broglie wavelength of 0.11 nm, what is the electron's speed in meters per second?

Using the formula $v = h / (m \lambda)$, the speed is approximately 67,312 meters per second.

Why is the de Broglie wavelength important in understanding electron behavior?

The de Broglie wavelength relates to the wave nature of electrons, helping explain phenomena like diffraction and interference at the quantum scale.

Can the speed of an electron be directly measured from its de Broglie wavelength?

Not directly; the de Broglie wavelength allows calculation of the electron's momentum and thus its speed using quantum formulas.

What units should the final answer for the electron's speed be expressed in?

The speed should be expressed in meters per second (m/s).

What assumptions are made when calculating the electron's speed from its de Broglie wavelength?

It is assumed that the electron behaves as a free particle with negligible interactions, and relativistic effects are ignored at these speeds.

Additional Resources

Electron Speed Calculation Based on De Broglie Wavelength: An Expert Overview

Understanding the microscopic world requires a blend of quantum mechanics and classical physics principles. When examining particles such as electrons, their wave-like nature becomes significant, especially when considering their momentum and velocity. One intriguing aspect of this behavior is encapsulated in the De Broglie wavelength, which offers a gateway to determine an electron's speed from its wave properties. Here, we will delve into an in-depth analysis of how to compute the speed of an electron given its De Broglie wavelength, specifically a wavelength of 0.11 nanometers (nm), and express the result in meters.

De Broglie Wavelength: The Quantum Bridge

What Is the De Broglie Wavelength?

The De Broglie wavelength, named after the French physicist Louis de Broglie, is a fundamental concept in quantum mechanics that assigns wave-like properties to particles traditionally considered as matter. According to De Broglie's hypothesis, every particle with momentum (p) has an associated wavelength (λ) , given by the relation:

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

Where:

- (λ) = De Broglie wavelength
- (h) = Planck's constant ($6.62607015 \times 10^{-34} \text{ Js}$)
- (p) = momentum of the particle

This revolutionary idea bridges the gap between classical and quantum physics, implying that particles like electrons exhibit wave-like properties under certain conditions.

Significance in Electron Dynamics

In practical scenarios, understanding the wavelength helps determine various particle characteristics, including velocity, energy, and behavior in different environments such as electron microscopes or quantum wells. For an electron, which is a fundamental particle with well-known mass, the wavelength directly relates to its momentum and, consequently, its speed.

Calculating Electron Speed from the De Broglie Wavelength

Given Data and Objective

- De Broglie wavelength (λ) : 0.11 nm
- Mass of an electron (m_e) : $(9.10938356 \times 10^{-31} \text{ kg})$
- Planck's constant (h) : $(6.62607015 \times 10^{-34} \text{ Js})$

Objective: Determine the speed (v) of the electron in meters per second (m/s) .

Step 1: Convert Wavelength to Meters

Since the wavelength is given in nanometers, convert it to meters to maintain SI consistency:

$$0.11 \text{ nm} = 0.11 \times 10^{-9} \text{ m} = 1.1 \times 10^{-10} \text{ m}$$

Step 2: Express Momentum in Terms of Wavelength

Rearranging De Broglie's relation:

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

Plugging in the numbers:

$$p = \frac{6.62607015 \times 10^{-34} \text{ Js}}{1.1 \times 10^{-10} \text{ m}} \approx 6.0246 \times 10^{-24} \text{ kg} \cdot \text{m/s}$$

Step 3: Calculate Electron Velocity

Since the electron's momentum (p) is related to its mass and velocity:

$$p = m_e v$$

Rearranged to solve for (v) :

$$v = \frac{p}{m_e}$$

Substituting known values:

$$v = \frac{6.0246 \times 10^{-24}}{9.10938356 \times 10^{-31}} \approx 6.618 \times 10^6 \text{ m/s}$$

Interpreting the Results

The calculated speed of approximately 6.62 million meters per second (or about 6.62 Mm/s) reveals the high-energy, relativistic nature of electrons at such small wavelengths. To contextualize:

- Compared to the speed of light: $(c \approx 3 \times 10^8 \text{ m/s})$, this electron moves at roughly 2.2% of the speed of light.
- In practical applications: Electrons in electron microscopes often achieve similar energies, illustrating the importance of quantum mechanics in designing and understanding advanced imaging technologies.

Additional Considerations

Relativistic Effects

At speeds exceeding a significant fraction of the speed of light ($\sim 10\%$), relativistic effects become non-negligible. The classical calculation assumes non-relativistic mechanics, which is valid here given the approximate 2% of light speed. However, for higher velocities or smaller wavelengths, incorporating Einstein's theory of relativity would be essential for precise results.

Limitations and Assumptions

- The calculation assumes a free electron in a vacuum, ignoring potential interactions or external fields.
- The electron is treated as a point particle with a well-defined mass.
- Quantum uncertainties are ignored; the calculation presumes a precise wavelength measurement.

Summary and Final Insights

- The wavelength-to-speed calculation leverages fundamental quantum mechanics principles, particularly De Broglie's relation.
- Result: An electron with a wavelength of 0.11 nm travels at approximately 6.62 million meters per second.
- Implication: Such high velocities underscore the wave-particle duality and the importance of quantum effects in nanotechnology, electron microscopy, and condensed matter physics.

Final Remarks

Understanding the relationship between wavelength and velocity not only deepens our grasp of microscopic phenomena but also informs technological advancements. Whether designing electron microscopes or exploring quantum computing, this fundamental calculation exemplifies how classical constants and quantum principles intertwine to reveal the behavior of particles at the smallest scales.

In conclusion: The speed of an electron with a De Broglie wavelength of 0.11 nm is approximately 6.62×10^6 meters per second—a number that encapsulates the fascinating wave-particle duality central to modern physics.

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