

An Electron Is Accelerated By A Potential Difference Of 1.5mv (1.5106 Volts). What Is The Momentum Of

An Electron Is Accelerated By A Potential Difference Of 1.5mv (1.5106 Volts). What Is The Momentum Of an electron in this scenario? Understanding the momentum of an electron subjected to a specific potential difference is fundamental in fields like quantum physics, electronics, and particle physics. This article explores the principles behind electron acceleration, how to calculate the electron's momentum, and the significance of this calculation in scientific and technological contexts. Whether you're a physics student, researcher, or enthusiast, this comprehensive guide provides an in-depth explanation to help you grasp the concepts and perform related calculations with confidence.

Understanding Electron Acceleration and Potential Difference

What Happens When Electrons Are Accelerated?

Electrons, which are subatomic particles with a negative charge, can be accelerated when subjected to an electric potential difference (voltage). This process involves converting electrical potential energy into kinetic energy, causing the electron to gain velocity and momentum.

Key points:

- An electron's energy increases as it moves through a potential difference.
- The amount of energy gained depends on the voltage applied.
- The relationship between voltage and kinetic energy is fundamental to many applications in physics and engineering.

The Role of Potential Difference in Electron Dynamics

The potential difference (V) provides the energy source for accelerating electrons:

- When an electron moves through voltage V, it gains kinetic energy (KE).
- The energy gained is directly proportional to the voltage, given by the equation:

$$[KE = eV]$$

where:

- e is the elementary charge (1.602×10^{-19} Coulombs),
- V is the potential difference in volts.

Calculating the Electron's Kinetic Energy

Given Data: Voltage and Electron Charge

In our scenario:

- Voltage, $V = 1.5106$ volts (equivalent to 1.5 millivolts),
- Elementary charge, $e = 1.602 \times 10^{-19}$ C.

Step-by-step Calculation:

1. Compute the kinetic energy (KE) gained by the electron:

$$KE = eV = (1.602 \times 10^{-19} \text{ C}) \times (1.5106 \text{ V})$$

2. Performing the multiplication:

$$KE = 2.419 \times 10^{-19} \text{ J}$$

This is the kinetic energy acquired by the electron after acceleration through the given potential difference.

Relating Energy to Electron Momentum

Classical vs. Relativistic Considerations

At energies associated with small voltage differences like 1.5 millivolts, the electron's velocity is generally non-relativistic, meaning classical physics suffices for calculations. However, as energies increase, relativistic effects become significant and must be considered.

In the present case:

- The kinetic energy is extremely small ($\sim 10^{-19}$ Joules),
- The electron's velocity will be much less than the speed of light ($\sim 3 \times 10^8$ m/s),
- Non-relativistic formulas are applicable.

Calculating Electron Momentum (p)

The momentum of an electron is related to its kinetic energy via the classical kinetic energy formula:

$$KE = \frac{p^2}{2m}$$

where:

- p is the momentum,
- m is the mass of the electron (9.109×10^{-31} kg).

Rearranged to solve for p :

$$p = \sqrt{2 m KE}$$

Step-by-Step Calculation of Electron Momentum

1. Insert known values:

$$p = \sqrt{2 \times 9.109 \times 10^{-31} \text{ kg} \times 2.419 \times 10^{-19} \text{ J}}$$

2. Calculate the product inside the square root:

$$2 \times 9.109 \times 10^{-31} \times 2.419 \times 10^{-19} = 4.410 \times 10^{-49}$$

3. Compute the square root:

$$p = \sqrt{4.410 \times 10^{-49}} \approx 6.64 \times 10^{-25} \text{ kg} \cdot \text{m/s}$$

Result:

The electron's momentum after acceleration by 1.5 millivolts is approximately 6.64×10^{-25} kg·m/s.

Significance of Electron Momentum Calculation

Applications in Physics and Technology

Understanding the momentum of an electron in this context has numerous practical and theoretical implications:

- Electron Beam Physics: Designing electron microscopes or particle accelerators requires precise momentum calculations.
- Quantum Mechanics: Electron momentum relates to wave-particle duality and de Broglie wavelength.
- Electronics: Semiconductor device operation often involves understanding electron dynamics at the microscopic level.
- Radiation and Particle Physics: Electron momentum informs scattering experiments and radiation emission models.

De Broglie Wavelength and Quantum Effects

Using the de Broglie relation:

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

where h is Planck's constant ($6.626 \times 10^{-34} \text{ Js}$), we can find the wavelength associated with the electron's momentum:

$$\lambda = \frac{6.626 \times 10^{-34}}{6.64 \times 10^{-25}} \approx 9.97 \times 10^{-10} \text{ meters}$$

This wavelength (~ 1 nanometer) demonstrates the quantum nature of the electron at this energy level, relevant in nanoscale physics and electron microscopy.

Summary and Key Takeaways

- An electron accelerated through a potential difference of 1.5 millivolts gains a specific amount of kinetic energy.
- The kinetic energy can be calculated using $KE = eV$, resulting in approximately $2.419 \times 10^{-19} \text{ Joules}$.
- Electron momentum is derived from kinetic energy via $p = \sqrt{2 m KE}$, giving roughly $6.64 \times 10^{-25} \text{ kg}\cdot\text{m/s}$.
- The associated de Broglie wavelength ($\sim 1 \text{ nm}$) is significant in quantum physics and nanotechnology applications.
- Understanding these calculations is crucial in designing electronic devices, studying fundamental particles, and exploring quantum phenomena.

Final Thoughts

Calculating the momentum of an electron accelerated by a small potential difference like 1.5 millivolts may seem straightforward, but it encapsulates fundamental principles of physics that bridge classical

and quantum realms. From the conversion of electrical energy into kinetic energy to the quantum implications of the resulting momentum and wavelength, this process underscores the importance of precise measurement and calculation in advancing scientific knowledge and technological innovation.

Whether you're delving into electron microscopy, designing microelectronic components, or exploring the quantum world, understanding how to determine an electron's momentum after acceleration is an essential skill. This article provides the foundational knowledge and step-by-step methodology to empower your exploration of particle physics and related fields.

Keywords for SEO:

Electron momentum calculation, acceleration of electrons, potential difference and electron energy, de Broglie wavelength, quantum physics, electron velocity, electron kinetic energy, physics calculations, small voltage electron acceleration, electron microscopy, particle physics, non-relativistic electron physics.

Frequently Asked Questions

What is the kinetic energy gained by an electron when accelerated through a potential difference of 1.5 mV?

The kinetic energy gained by the electron is equal to the charge times the potential difference: $KE = eV$. With $e = 1.602 \times 10^{-19} \text{ C}$ and $V = 1.5 \times 10^{-3} \text{ V}$, $KE \approx 2.403 \times 10^{-22} \text{ Joules}$.

How do you calculate the momentum of an electron accelerated by a potential difference of 1.5 mV?

The momentum p of the electron can be found using the relation $p = \sqrt{2mE}$, where E is the kinetic energy gained (eV). Convert the energy to joules and plug in the electron mass ($9.11 \times 10^{-31} \text{ kg}$) to compute the momentum.

What is the approximate value of the momentum of the electron after acceleration through 1.5 mV?

Calculating from $KE \approx 2.403 \times 10^{-22} \text{ J}$, the momentum $p \approx \sqrt{2 \cdot 9.11 \times 10^{-31} \text{ kg} \cdot 2.403 \times 10^{-22} \text{ J}} \approx 6.63 \times 10^{-16} \text{ kg}\cdot\text{m/s}$.

Why is the momentum of an electron small after being accelerated through such a low potential difference?

Because the potential difference (1.5 mV) imparts only a very small amount of energy to the electron, resulting in a correspondingly small momentum. The electron's mass and the low energy transfer keep the momentum minimal.

How does increasing the potential difference affect the momentum of the accelerated electron?

Increasing the potential difference increases the kinetic energy gained by the electron, which in turn increases its momentum, following the relation $p = \sqrt{2mE}$.

Can relativistic effects be ignored at a potential difference of 1.5 mV when calculating electron momentum?

Yes, because the electron's speed remains far below the speed of light at such low energy levels, so non-relativistic formulas for momentum are sufficient.

Additional Resources

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Introduction

In the realm of atomic and subatomic physics, understanding the behavior of electrons under various energy conditions is fundamental. Electrons, as elementary particles with a negative charge, exhibit wave-particle duality and are influenced significantly by electric potentials. When an electron is subjected to a potential difference—no matter how small—its kinetic energy changes, consequently affecting its momentum. This article delves into the detailed physics behind an electron accelerated through a potential difference of 1.5 millivolts (mV), equivalent to approximately 1.5106 volts, analyzing how this energy transfer influences its momentum. We explore the principles governing electric potential energy conversion, the relativistic and non-relativistic considerations, and the implications of such phenomena in scientific applications.

Fundamental Concepts: Electric Potential Difference and Electron Dynamics

What Is Electric Potential Difference?

Electric potential difference, also known as voltage, is the work done per unit charge to move a charge between two points in an electric field. Measured in volts (V), it indicates the energy transferred to or from a charge as it moves through an electric potential.

- Voltage (V): The energy per unit charge, expressed as Joules per Coulomb (J/C).
- Potential Difference: When an electron moves through a potential difference, it gains or loses kinetic energy proportional to that voltage.

Electron's Charge and Rest Mass

The fundamental properties of an electron are:

- Charge (e): approximately 1.602×10^{-19} Coulombs.
- Rest Mass (m_0): approximately 9.109×10^{-31} kilograms.

Energy Transfer During Acceleration

When an electron is accelerated through a potential difference (V) , the energy gained (or lost) is given by:

$$\Delta E = eV$$

For small potential differences like 1.5 mV, this energy is minimal, but still significant in certain experimental contexts, such as electron microscopes or particle accelerators.

Calculating the Electron's Kinetic Energy Post-Acceleration

Non-Relativistic Approximation

For potential differences where the kinetic energy gained is much less than the electron's rest energy (approximately 0.511 MeV), a classical, non-relativistic approximation suffices.

$$\text{Kinetic Energy } (K) = eV$$

Given:

$$V = 1.5106 \text{ V}$$

$$e = 1.602 \times 10^{-19} \text{ C}$$

The kinetic energy:

$$K = eV = (1.602 \times 10^{-19} \text{ C})(1.5106 \text{ V}) = 2.420 \times 10^{-19} \text{ J}$$

Converting Energy to Electronvolts

Since $1 \text{ eV} = (1.602 \times 10^{-19} \text{ J})$:

$$K = \frac{2.420 \times 10^{-19} \text{ J}}{1.602 \times 10^{-19} \text{ J/eV}} \approx 1.51 \text{ eV}$$

This confirms that the electron gains approximately 1.51 eV of kinetic energy after acceleration.

Determining the Electron's Momentum

Classical (Non-Relativistic) Momentum

In classical physics, the momentum (p) of a particle with mass (m) and velocity (v) is:

$$p = mv$$

Using the kinetic energy expression:

$$K = \frac{1}{2}mv^2$$

we can solve for (v) :

$$v = \sqrt{\frac{2K}{m}}$$

Substituting known values:

$$v = \sqrt{\frac{2 \times 2.420 \times 10^{-19} \text{ J}}{9.109 \times 10^{-31} \text{ kg}}}$$

$$v = \sqrt{\frac{4.84 \times 10^{-19}}{9.109 \times 10^{-31}}} \approx \sqrt{5.31 \times 10^{11}} \approx 7.28 \times 10^5 \text{ m/s}$$

The momentum:

$$p = mv = (9.109 \times 10^{-31} \text{ kg})(7.28 \times 10^5 \text{ m/s}) \approx 6.64 \times 10^{-25} \text{ kg}\cdot\text{m/s}$$

Relativistic Considerations

Given the velocity ($\sim 728,000$ m/s), which is about $0.0024c$ (where (c) is the speed of light $(\approx 3 \times 10^8 \text{ m/s})$), relativistic effects are minimal but non-negligible for high-precision applications.

The relativistic momentum:

$$p = \gamma m_0 v$$

where

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Calculating γ :

$$v/c \approx 7.28 \times 10^5 / 3 \times 10^8 \approx 0.00243$$

$$\gamma \approx 1 + \frac{1}{2} \left(\frac{v}{c} \right)^2 \approx 1 + 2.95 \times 10^{-6} \approx 1.000003$$

The relativistic momentum:

$$p_{\text{rel}} = \gamma m_0 v \approx 1.000003 \times 6.64 \times 10^{-25} \text{ kg}\cdot\text{m/s} \approx 6.64 \times 10^{-25} \text{ kg}\cdot\text{m/s}$$

Thus, relativistic correction is negligible at this energy scale, and the non-relativistic calculation suffices.

Physical Implications of the Momentum

Small but Significant

While the momentum calculated ($\sim 6.64 \times 10^{-25}$ kg·m/s) is incredibly small compared to macroscopic scales, in quantum physics and materials science, even such minute momentum changes are crucial. They underpin phenomena like diffraction patterns in electron microscopy, where even tiny variations in electron momentum influence imaging resolution.

Impact on Electron Beams

In electron microscopes, electrons are accelerated through potentials of several kilovolts, resulting in relativistic velocities and momenta. Although a 1.5 mV potential difference yields negligible relativistic effects, understanding this scale helps refine models for electron behavior in ultra-sensitive devices.

Relevance in Particle Physics

In high-energy particle physics, electrons are accelerated through much larger potentials, and their relativistic momentum becomes a dominant factor. Nonetheless, the fundamental relationship

between potential difference, energy, and momentum remains the same, exemplifying the universality of physical laws across energy scales.

Broader Context: Applications and Significance

Electron Microscopy and Nanotechnology

Electrons accelerated through small potentials are often used in high-resolution imaging techniques. Precise knowledge of their momentum allows scientists to optimize imaging conditions, improve resolution, and understand interactions at the atomic scale.

Particle Accelerators and Fundamental Physics

While the potential difference discussed here is small, understanding such processes is foundational for designing accelerators, where electrons are pushed to relativistic speeds through high voltages, enabling experiments probing the fundamental structure of matter.

Quantum Mechanics and Wave-Particle Duality

The small momentum transfer illustrates the quantum nature of electrons, where even minimal energy changes can influence their wavefunctions, interference patterns, and observable phenomena.

Conclusion

Accelerating an electron through a potential difference of 1.5 mV (approximately 1.5106 volts) results in a modest increase in kinetic energy and momentum. Calculations grounded in classical physics, supplemented with relativistic considerations, reveal that the electron's momentum is approximately (6.64×10^{-25}) kg·m/s. While this value is minuscule on macroscopic scales, it is critical in understanding electron behavior in various scientific and technological applications, from electron microscopy to quantum physics. Recognizing how such small potential differences influence particle dynamics underscores the delicate interplay of energy, momentum, and quantum phenomena at the microscopic level, reaffirming the profound interconnectedness of physical principles across all scales of the universe.

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