

An Electron Is Released From Rest In A Uniform Electric Field. If The Electric Field Is 1.25 KN/C, At

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Understanding the behavior of electrons in electric fields is fundamental to many areas of physics and engineering, including electronics, electromagnetism, and particle physics. When an electron is released from rest within a uniform electric field, it experiences a force that accelerates it according to the principles of Coulomb's law and Newton's second law. This article explores the detailed physics behind this scenario, focusing on an electric field strength of 1.25 kN/C, and provides insights into the calculations, implications, and real-world applications.

Basic Concepts and Principles

Before diving into the specific scenario, it is essential to understand the foundational concepts involved:

Electric Field (E)

- A vector quantity representing the force per unit charge exerted on a test charge placed within the field.
- Measured in volts per meter (V/m) or newtons per coulomb (N/C).
- A uniform electric field has a constant magnitude and direction throughout its region.

Force on an Electron in an Electric Field

- Given by Coulomb's law: $F = qE$
- Where:
- q = charge of the electron (-1.602×10^{-19} C)
- E = electric field strength

Electron's Motion

- Since the electron is initially at rest, its subsequent motion is governed by Newton's second law:
- $\frac{d^2x}{dt^2} = \frac{F}{m}$

$$F = ma$$

\]

- \(\ m \) = mass of electron (\(9.109 \times 10^{-31} \) kg)

- \(\ a \) = acceleration

Scenario Overview: Electron in a 1.25 kN/C Electric Field

The specific case considers an electron released from rest into a uniform electric field of magnitude:

\[

$$E = 1.25 \text{ kN/C} = 1250 \text{ N/C}$$

\]

This value indicates a relatively strong electric field, leading to significant acceleration of the electron over short distances.

Calculating the Force Acting on the Electron

The force exerted on the electron can be computed as:

\[

$$F = qE$$

\]

Substituting the known values:

\[

$$F = (-1.602 \times 10^{-19} \text{ C}) \times 1250 \text{ N/C} = -2.0025 \times 10^{-16} \text{ N}$$

\]

Note: The negative sign indicates the force direction is opposite to the electric field's direction because the electron carries a negative charge.

Determining the Electron's Acceleration

Applying Newton's second law:

$$a = \frac{F}{m}$$

$$a = \frac{-2.0025 \times 10^{-16} \text{ N}}{9.109 \times 10^{-31} \text{ kg}} \approx -2.20 \times 10^{14} \text{ m/s}^2$$

This enormous acceleration reflects the electron's tiny mass and the strength of the electric field.

Analyzing Electron's Motion: Distance and Time

Assuming the electron starts from rest and moves under constant acceleration, we can explore its behavior over time and displacement.

Displacement After a Given Time

The basic kinematic equation:

$$s = ut + \frac{1}{2} a t^2$$

- Initial velocity $(u = 0)$

$$s = \frac{1}{2} a t^2$$

Time to Reach a Specific Velocity

The velocity at time (t) :

$$v = u + a t = a t$$

So,

$$t = \frac{v}{a}$$

Practical Calculations and Examples

Let's consider an example: How far does the electron travel in 1 nanosecond?

- Time $(t = 1 \times 10^{-9})$ s

Calculating displacement:

$$s = \frac{1}{2} a t^2 = \frac{1}{2} \times (-2.20 \times 10^{14}) \times (1 \times 10^{-9})^2$$

$$s = 0.5 \times -2.20 \times 10^{14} \times 1 \times 10^{-18} = -1.10 \times 10^{-4} \text{ m}$$

The negative sign indicates direction opposite to the electric field.

Result: The electron travels approximately 0.11 mm in 1 nanosecond under the given electric field.

Energy Considerations

The kinetic energy gained by the electron:

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

Given the acceleration and time:

$$v = a t = -2.20 \times 10^{14} \times 1 \times 10^{-9} = -2.20 \times 10^5 \text{ m/s}$$

\]

Kinetic energy:

\[

$$KE = 0.5 \times 9.109 \times 10^{-31} \times (2.20 \times 10^5)^2$$

\]

\[

$$KE \approx 0.5 \times 9.109 \times 10^{-31} \times 4.84 \times 10^{10} \\ \approx 2.21 \times 10^{-20} \text{ J}$$

\]

This energy corresponds to approximately 138 eV (since $1 \text{ eV} = (1.602 \times 10^{-19} \text{ J})$):

\[

$$\text{Energy in eV} = \frac{2.21 \times 10^{-20}}{1.602 \times 10^{-19}} \\ \approx 0.138 \text{ eV}$$

\]

Implication: The electron gains enough energy to potentially cause ionization or excitation in certain materials if it interacts with them.

Factors Influencing Electron Behavior in Electric Fields

While the calculations above assume a perfect uniform field and neglect other effects, real-world scenarios involve additional factors:

- **Field Uniformity:** Deviations can cause non-uniform acceleration.
- **Initial Conditions:** If the electron is released with any initial velocity, calculations need to account for that.
- **Quantum Effects:** At very small scales, quantum mechanics governs electron motion, and classical physics becomes approximate.
- **Material Interactions:** Interactions with atoms or molecules can cause scattering, energy loss, or other phenomena.
- **Relativistic Effects:** At very high velocities (approaching the speed of light), relativistic physics must be considered.

Applications of Electron Acceleration in Electric Fields

Understanding how electrons behave in electric fields has numerous practical applications:

1. Electron Microscopy

- Electrons are accelerated through electric fields to generate high-resolution images of microscopic structures.

2. Particle Accelerators

- Electrons are accelerated to high energies for fundamental physics research.

3. Vacuum Tubes and Cathode Ray Tubes

- Electric fields accelerate electrons to produce images or signals.

4. Semiconductor Devices

- Electric fields control electron movement in transistors and diodes, fundamental to electronics.

5. Radiation Therapy

- Accelerated electrons are used in medical treatments to target cancer cells.

Safety and Limitations

While the calculations indicate significant acceleration and energy gain, real-world implementations must consider safety and material limitations:

- Excessive electric fields can cause dielectric breakdown and damage equipment.

- Electron beams must be carefully controlled to prevent unintended exposure.
- Shielding and safety protocols are essential in environments involving high electric fields and electron acceleration.

Summary and Conclusion

Releasing an electron from rest in a uniform electric field of 1.25 kN/C results in rapid acceleration, with the electron reaching velocities on the order of hundreds of thousands of meters per second within nanoseconds. The force exerted on the electron is approximately (-2.00×10^{-16}) N, leading to an acceleration of about (-2.20×10^{14}) m/s². These calculations highlight the enormous influence electric fields have on charged particles, illustrating foundational principles vital to physics, engineering, and technology.

Understanding these principles allows scientists and engineers to design devices that leverage electron behavior, from microscopes to particle accelerators. Moreover, recognizing the energy transfer and motion dynamics of electrons in electric fields is essential for advancing scientific knowledge and technological innovation.

In conclusion, the scenario of an electron released in a 1.25 kN/C electric field exemplifies fundamental electromagnetic principles and demonstrates the remarkable effects such fields can produce on

Frequently Asked Questions

An electron is released from rest in a uniform electric field of 1.25 kN/C. What is the initial acceleration of the electron?

The initial acceleration can be calculated using Newton's second law: $a = F/m$. The force $F = eE$, where $e \approx 1.6 \times 10^{-19}$ C and $E = 1.25 \times 10^3$ N/C. So, $a = (1.6 \times 10^{-19} \text{ C} \times 1.25 \times 10^3 \text{ N/C}) / 9.11 \times 10^{-31} \text{ kg} \approx 2.19 \times 10^{14} \text{ m/s}^2$.

How long does it take for the electron to reach a speed of 1×10^6 m/s in this electric field?

Using $v = a t$, $t = v / a = (1 \times 10^6 \text{ m/s}) / (2.19 \times 10^{14} \text{ m/s}^2) \approx 4.57 \times 10^{-9}$ seconds.

What is the kinetic energy gained by the electron after accelerating for 5 nanoseconds in this field?

Kinetic energy $KE = (1/2) m v^2$. First, $v = a t = 2.19 \times 10^{14} \text{ m/s}^2 \times 5 \times 10^{-9} \text{ s} \approx 1.095 \times 10^6 \text{ m/s}$. Then, $KE \approx 0.5 \times 9.11 \times 10^{-31} \text{ kg} \times (1.095 \times 10^6 \text{ m/s})^2 \approx 5.46 \times 10^{-19} \text{ Joules}$.

What is the potential difference experienced by the electron as it accelerates over a distance of 1 mm?

The work done $W = KE = e \Delta V$. $KE \approx 5.46 \times 10^{-19} \text{ J}$, so $\Delta V = KE / e \approx (5.46 \times 10^{-19} \text{ J}) / (1.6 \times 10^{-19} \text{ C}) \approx 3.41 \text{ Volts}$. The electron gains about 3.41 V over 1 mm.

If the electron is released from a point 2 mm away from a plate with the electric field of 1.25 kN/C, what is the change in potential energy?

Potential difference ΔV over 2 mm: $\Delta V = E \times d = 1.25 \times 10^3 \text{ N/C} \times 0.002 \text{ m} = 2.5 \text{ V}$. The change in potential energy $\Delta U = e \times \Delta V \approx 1.6 \times 10^{-19} \text{ C} \times 2.5 \text{ V} \approx 4.0 \times 10^{-19} \text{ Joules}$.

What is the significance of the uniform electric field in the motion of the electron?

A uniform electric field exerts a constant force on the electron, resulting in a uniformly accelerated motion. This simplifies calculations of acceleration, velocity, and displacement over time.

How does the magnitude of the electric field affect the electron's acceleration and velocity?

The acceleration is directly proportional to the electric field strength; increasing the field increases the force and thus accelerates the electron more rapidly, leading to higher velocities over the same time interval.

Additional Resources

Electrons under Electric Fields: An Expert Analysis of Electron Dynamics in a Uniform Electric Field

Introduction

In the realm of physics, understanding the behavior of electrons subjected to

electric fields is fundamental, with profound implications spanning from classical electromagnetism to quantum mechanics. When an electron is initially at rest within a uniform electric field—specifically one of strength 1.25 kN/C—the resulting motion encapsulates core concepts such as force, acceleration, and energy transfer that underpin many modern technological applications. This article delves deeply into this scenario, offering a comprehensive exploration of the physics involved, the mathematical framework, and practical implications, all presented with the clarity and rigor befitting an expert review.

The Electric Field: Setting the Stage

Electric Field Strength: 1.25 kN/C

The electric field in question is specified as 1.25 kilonewtons per coulomb, which translates to:

$$E = 1.25 \text{ kN/C} = 1250 \text{ N/C}$$

This magnitude is significant, representing a strong but realistic field that could be encountered in controlled laboratory environments or specialized applications like electron guns or cathode ray tubes.

Fundamental Concepts

What Is an Electric Field?

An electric field (E) is a vector quantity that describes the force experienced by a unit positive charge placed at a point in space. It is a fundamental concept that embodies the influence of charges or changing magnetic fields, dictating how other charges move within that space.

The Electron's Initial Conditions

- Rest State: The electron begins at rest, with initial velocity $(v_0 = 0)$.
- Charge of Electron: $(q = -1.602 \times 10^{-19})$ C.
- Mass of Electron: $(m = 9.109 \times 10^{-31})$ kg.

Note that the negative charge of the electron influences the direction of the force relative to the electric field direction.

Dynamics of an Electron in a Uniform Electric Field

Force Acting on the Electron

The force (F) experienced by the electron due to the electric field is given by Coulomb's Law:

$$F = qE$$

Given the charge's sign, the force direction is opposite to the electric field if the charge is negative:

$$F = - (1.602 \times 10^{-19} \text{ C}) \times 1250 \text{ N/C} = -2.0025 \times 10^{-16} \text{ N}$$

The negative sign indicates that the force acts opposite to the electric field direction if the field is defined as positive in a certain direction.

Acceleration of the Electron

Applying Newton's Second Law:

$$F = ma \Rightarrow a = \frac{F}{m}$$

Substituting the known values:

$$a = \frac{-2.0025 \times 10^{-16}}{9.109 \times 10^{-31}} \approx -2.20 \times 10^{14} \text{ m/s}^2$$

This enormous acceleration reflects the electron's tiny mass and high charge-to-mass ratio, making it highly responsive to electric fields.

Kinematic Analysis: Electron Motion Over Time

Basic Equations

Since the electron starts from rest, its velocity $v(t)$ and displacement $x(t)$ after a time t can be expressed as:

$$v(t) = v_0 + a t = 0 + a t = a t$$

$$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2 = 0 + 0 + \frac{1}{2} a t^2$$

Assuming the initial position as the origin ($x_0 = 0$):

$$x(t) = \frac{1}{2} a t^2$$

Time to Reach a Specific Velocity

Suppose we want to determine how long it takes for the electron to reach a certain velocity—say, $(v = 1 \times 10^6 \text{ m/s})$:

$$t = \frac{v}{a} = \frac{10^6}{2.20 \times 10^{14}} \approx 4.55 \times 10^{-9} \text{ s}$$

This indicates that in just a few nanoseconds, the electron attains extremely high velocities.

Energy Considerations

Work Done by the Electric Field

The work (W) done on the electron over a displacement (x) is:

$$W = q E x$$

Since the electron accelerates, its kinetic energy ($K.E.$) at any point is:

$$K.E. = \frac{1}{2} m v^2$$

Equating work and kinetic energy:

$$q E x = \frac{1}{2} m v^2$$

This relation confirms the conversion of electric potential energy into kinetic energy as the electron accelerates.

Practical Implications and Applications

Electron Acceleration in Devices

- Cathode Ray Tubes: High electric fields accelerate electrons to produce images on screens.
- Electron Microscopes: Precise control of electric fields manipulates electron trajectories for high-resolution imaging.
- Particle Accelerators: Fields of similar magnitude are employed to accelerate electrons to relativistic speeds.

Limitations and Considerations

- Relativistic Effects: At velocities approaching the speed of light ($c = 3 \times 10^8 \text{ m/s}$), classical physics no longer suffices, and relativistic mechanics must be employed.
- Air Breakdown and Vacuum Conditions: Extremely high fields can cause ionization and electrical breakdown unless maintained in vacuum or controlled environments.
- Material Constraints: In real-world devices, insulation, field uniformity, and precise control are critical.

Advanced Topics

Electron Trajectory in Varying Fields

While the current discussion assumes a uniform electric field, real systems often involve non-uniformities, leading to complex electron trajectories influenced by magnetic fields, potential barriers, or space charge effects.

Quantum Effects

At very small scales, quantum behavior such as tunneling or wave-particle duality can influence how electrons respond to electric fields, especially in semiconductors or quantum devices.

Summary and Conclusions

The scenario of an electron released from rest in a uniform electric field of 1.25 kN/C encapsulates core principles of electromagnetism and particle physics. The key takeaways include:

- The force acting on the electron is significant due to its high charge-to-mass ratio.
- The acceleration is extraordinarily high ($\sim 2.20 \times 10^{14} \text{ m/s}^2$), leading to rapid velocity increases.
- The electron's kinetic energy increases proportionally with displacement,

illustrating the energy transfer from the electric field.

- Practical applications leverage these principles for technologies requiring precise electron control, such as in display devices, microscopy, and accelerators.

Understanding these dynamics not only enriches our grasp of fundamental physics but also drives innovation in electronic and quantum technologies. The interplay of electric fields and electrons remains a cornerstone of modern science and engineering, demonstrating how fundamental concepts translate into powerful technological tools.

Final Remarks

In conclusion, the behavior of electrons in uniform electric fields exemplifies the elegant simplicity and profound complexity of electromagnetism. As technology advances, mastery over such fundamental interactions continues to enable groundbreaking innovations, reaffirming the importance of detailed physical analysis and rigorous scientific understanding.

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