An Electron Moving Parallel To A Uniform Magnetic Field Of 5 Tesla Covers A Distance Of 25 Cm. Calculate

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Understanding the motion of charged particles in magnetic fields is a fundamental aspect of electromagnetism, with wide-ranging applications in physics, engineering, and medical sciences. In this article, we focus on a specific scenario: an electron moving parallel to a uniform magnetic field of 5 Tesla, covering a distance of 25 centimeters. Our goal is to derive the key parameters governing this motion, such as velocity, time taken, and the nature of the electron's trajectory. To do so, we will explore the principles of Lorentz force, uniform circular motion, and the relevant equations of motion for charged particles in magnetic fields.

Fundamental Concepts and Principles

Charged Particle Motion in Magnetic Fields

When a charged particle such as an electron enters a magnetic field, it experiences a force known as the Lorentz force. The magnitude of this force is given by:

- $F = qvB \sin \theta$

where:

- q is the charge of the particle,
- v is the velocity of the particle,
- B is the magnetic flux density (magnetic field strength),
- θ is the angle between the velocity vector and the magnetic field.

In our case, since the electron is moving parallel to the magnetic field, the angle θ is 0°, and $\sin 0° = 0$. Therefore, the magnetic force acting on the electron is zero, which profoundly influences the nature of the electron's motion.

Motion of a Charged Particle Parallel to a Magnetic Field

When a charged particle moves parallel or antiparallel to a uniform magnetic field, the magnetic force does not alter the particle's speed or kinetic energy. Instead, the force acts perpendicular to the velocity, which in this case is zero because the velocity is aligned with the magnetic field. As a result, the particle continues its motion without any deflection or change in speed solely due to magnetic effects.

Analyzing the Scenario

Initial Assumptions and Data

Given data for the problem include:

- Magnetic field strength, $B = 5\, \text{Tesla}$
- Distance covered, $d = 25\, \text{cm} = 0.25\, \text{m}$

Other relevant quantities we need to determine include:

1. The initial velocity of the electron, v
2. The time taken to cover the distance, t

Key Observations

- Since the electron moves parallel to the magnetic field, the magnetic force does not influence its motion.
- The electron's velocity remains constant if no other forces act on it (assuming an ideal, frictionless environment).
- Therefore, the problem reduces to calculating the velocity based on the distance and time, or vice versa.

Calculating the Electron's Velocity

Using Basic Kinematic Relations

The simplest approach is to assume that the electron moves with a constant velocity v, covering a distance $d = 0.25\, \text{m}$ in time t. The relation is:

- $v = \frac{d}{t}$

However, since the problem does not specify the time or initial velocity, we can explore possible scenarios. For instance, if the electron is accelerated to a certain velocity before entering the magnetic field, or if the velocity is given, we can proceed accordingly.

Determining Electron Velocity from Energy Considerations

If the electron is accelerated through a potential difference V, its kinetic energy $K.E.$ is given by:

- $K.E. = eV$

where e is the elementary charge ($1.6 \times 10^{-19}\, \text{C}$). The velocity v then becomes:

- $v = \sqrt{\frac{2 e V}{m}}$

with m being the mass of the electron ($9.11 \times 10^{-31}\, \text{kg}$).

Example Calculation (Assuming a Given Potential Difference)

Suppose the electron is accelerated through a potential difference of $V = 100\, \text{V}$:

- $v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 100}{9.11 \times 10^{-31}}}$

Calculating numerator:

- $2 \times 1.6 \times 10^{-19} \times 100 = 3.2 \times 10^{-17}$

Calculating velocity:

- $v = \sqrt{\frac{3.2 \times 10^{-17}}{9.11 \times 10^{-31}}} = \sqrt{3.51 \times 10^{13}}$

- $v \approx 5.93 \times 10^{6}\, \text{m/s}$

Thus, the electron would be moving at approximately $5.93\, \text{million meters per second}$ if accelerated through 100 V.

Time Taken to Cover 25 Cm

Calculating Time Using Velocity

Once the velocity is known, the time to cover 25 cm is straightforward:

- $t = \frac{d}{v}$

Using the example velocity $v \approx 5.93 \times 10^{6}\, \text{m/s}$:

- $t = \frac{0.25}{5.93 \times 10^{6}} \approx 4.22 \times 10^{-8}\, \text{s}$

This extremely small time reflects the high velocity of electrons accelerated through modest potentials.

Implications of Motion Parallel to Magnetic Field

Minimal Influence of Magnetic Field

Since the electron moves exactly parallel to the magnetic field, it experiences no magnetic force (as $\sin 0° = 0$). Consequently:

- The magnetic field does not alter the electron's velocity or trajectory.

- The electron continues in a straight line at constant speed.

Potential Effects if the Electron Had a Perpendicular Component

If, however, the electron had any component of velocity perpendicular to the magnetic field, it would undergo circular or helical motion due to the Lorentz force, with radius r given by:

- $r = \frac{m v_{\perp}}{q B}$

where $v_{\perp}$ is the perpendicular component of velocity. But in our case, since the motion is parallel, this does not apply.

Summary and Final Calculations

Key Results

- The velocity of the electron depends on its initial acceleration, which can be calculated if the potential difference is known.
- In the absence of additional data, assuming an initial acceleration of 100 V yields a velocity of approximately $5.93 \times 10^{6}\, \text{m/s}$.
- The time to traverse 25 cm at this velocity is roughly $42\, \text{nanoseconds}$.
- The magnetic field does not affect the electron's straight-line motion when moving parallel to the field.

Concluding Remarks

This analysis demonstrates the importance of understanding the orientation of charged particle motion relative to magnetic fields. For electrons moving parallel to the magnetic field, the magnetic force does not influence their speed or direction. Therefore, their motion remains uniform, and calculations primarily depend on their initial energy or acceleration mechanism. This principle is fundamental in devices such as cathode ray tubes and particle accelerators, where precise control of electron trajectories is essential.

Frequently Asked Questions

An electron moves parallel to a uniform magnetic field of 5 Tesla over a distance of 25 cm. What is the force experienced by the electron in this scenario?

Since the electron moves parallel to the magnetic field, the magnetic force is zero because the force depends on the component of velocity perpendicular to the magnetic field. Therefore, the force experienced by the electron is 0 N.

If an electron moves parallel to a magnetic field of 5 Tesla, does it undergo any change in kinetic energy during the 25 cm movement?

No, because the magnetic force does no work on the electron when moving parallel to the magnetic field, so its kinetic energy remains unchanged.

What is the significance of the electron's movement being parallel to the magnetic field in terms of its trajectory?

When moving parallel to the magnetic field, the electron's trajectory remains straight with no deflection, as magnetic force acts only perpendicular to velocity.

Given the electron's initial velocity, how can we calculate the time taken to cover 25 cm along the magnetic field?

If the initial velocity is v, then time t = distance / velocity = 0.25 m / v. Without the velocity value, the exact time cannot be determined.

Does a magnetic field of 5 Tesla influence the electron's motion if it moves parallel to the field? Why or why not?

No, because magnetic force acts perpendicular to the velocity, and when moving parallel to the field, the force is zero, so the magnetic field does not influence the electron's motion in this case.

How would the situation change if the electron's velocity had a component perpendicular to the magnetic field?

If there is a perpendicular component, the electron would undergo circular or helical motion due to the magnetic force, resulting in a curved trajectory instead of a straight line.

What is the expression for the magnetic force on an electron moving with velocity v in a magnetic field B?

The magnetic force is given by $F = qvB \sin\theta$, where θ is the angle between velocity and magnetic field. When $\theta = 0°$ (parallel), force is zero.

Calculate the radius of the electron's circular path if it had a perpendicular velocity component in a 5 Tesla magnetic field.

The radius r = mv / (qB). Without specific velocity and mass values, the radius cannot be calculated precisely.

In the context of this problem, what is the importance of the electron's charge and mass?

The charge (q) and mass (m) of the electron are essential for calculating forces, accelerations, and motion characteristics, especially when considering components perpendicular to the magnetic field.

What assumptions are made when calculating the electron's motion over 25 cm in a magnetic field of 5 Tesla?

Assumptions include that the magnetic field is uniform, the electron's velocity remains constant if moving parallel to the field, and external forces such as electric fields or collisions are negligible.

Additional Resources

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In the realm of electromagnetism, understanding the motion of charged particles within magnetic fields is fundamental to both theoretical physics and practical applications such as particle accelerators, magnetic resonance imaging, and cosmic ray studies. When an electron moves in the presence of a magnetic field, its trajectory is governed by the Lorentz force, leading to characteristic motion patterns that can be precisely analyzed through classical mechanics and electromagnetic principles. In this article, we delve into a specific scenario: an electron moving parallel to a uniform magnetic field of 5 Tesla and covering a distance of 25 centimeters, culminating in a comprehensive calculation of relevant parameters such as velocity, time taken, and the nature of its motion.

Fundamentals of Electron Motion in Magnetic Fields

1. The Lorentz Force and Its Implications

The motion of a charged particle in a magnetic field is dictated by the Lorentz force, expressed as:

$$\vec{F} = q (\vec{v} \times \vec{B})$$

where:

- q is the charge of the particle (for an electron, $q = -1.602 \times 10^{-19}$ C),
- $\vec{v}$ is the velocity vector,
- $\vec{B}$ is the magnetic field vector.

A key insight is that the magnetic force acts perpendicular to both the velocity and the magnetic field, causing the particle to undergo circular or helical motion depending on the initial velocity components.

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2. Motion Components Relative to the Magnetic Field

- Parallel component: If the initial velocity $v_{||}$ is parallel to the magnetic field $\vec{B}$, then $\vec{v} \parallel \vec{B}$, and the magnetic force $(\vec{v} \times \vec{B})$ becomes zero. Consequently, the electron experiences no magnetic force along this component, allowing it to move uniformly in that direction.
- Perpendicular component: If there is a component of velocity perpendicular to $\vec{B}$, the electron undergoes circular motion around the magnetic field lines, with a radius called the cyclotron radius.

In the scenario under consideration, the electron is moving parallel to the magnetic field, which simplifies the dynamics significantly.

Scenario Overview: Electron Moving Parallel to a 5 Tesla Magnetic Field

Suppose an electron is initially moving in a direction parallel to a uniform magnetic field of 5 Tesla. The question posed is: If it covers a distance of 25 cm along this field, what are the associated parameters such as velocity and time?

This problem involves understanding the nature of the electron's motion, calculating its velocity based on the distance covered, and analyzing whether any magnetic forces influence its motion in this configuration.

Analyzing the Motion: Key Assumptions and Conditions

Before proceeding with calculations, it is essential to clarify some assumptions:

- The electron moves along the magnetic field lines, i.e., parallel to $\vec{B}$.
- There are no other forces acting on the electron (such as electric fields, gravitational forces, or

collisions).
- The magnetic field is uniform and constant at 5 Tesla.

Under these conditions, the electron's motion simplifies, as the magnetic force does not act along the direction of movement.

Calculating the Electron's Velocity

Given that the electron covers 25 cm (which is 0.25 meters) along the magnetic field, and assuming it does so at a constant velocity (since no magnetic force acts along the direction of movement), the key unknown is the velocity v.

Step 1: Determine the velocity v.

The basic relation connecting distance, velocity, and time is:

$$v = \frac{\text{distance}}{\text{time}}$$

However, since the problem does not specify the time taken or the initial conditions, the calculation can proceed by considering typical scenarios:

- If the electron's initial velocity is known or assumed, the distance covered can be used to find the time.
- Alternatively, if the time is known or deduced from context, the velocity can be calculated.

Step 2: Relate the velocity to the parameters of the magnetic field.

In the absence of other forces, the electron's motion is uniform, and its velocity component parallel to the magnetic field remains constant. The magnetic field does not influence the speed along its direction; it only affects motion perpendicular to it.

Calculating the Time Taken to Cover 25 cm

Suppose we are asked to find the time taken by the electron to traverse 25 cm along the field.

Scenario 1: If the velocity v is known, then:

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

where:
- $d = 0.25\, \text{m}$,
- v is the velocity of the electron.

Scenario 2: If the initial velocity v is unknown, but certain parameters are given, then further data or assumptions are needed.

Estimating Electron Velocity in Typical Conditions

In many practical situations, electrons are accelerated through potential differences and attain high velocities. For example, in cathode ray tubes or particle accelerators, electrons are accelerated through known voltages:

$$ v = \sqrt{\frac{2 e V}{m}} $$

where:
- $e = 1.602 \times 10^{-19}$ C (electron charge),
- V is the accelerating voltage,
- $m = 9.109 \times 10^{-31}$ kg (electron mass).

Example Calculation:

- For an accelerating voltage of 100 V:

$$
v = \sqrt{\frac{2 \times 1.602 \times 10^{-19} \times 100}{9.109 \times 10^{-31}}}
$$

$$
v \approx \sqrt{\frac{3.204 \times 10^{-17}}{9.109 \times 10^{-31}}} \approx \sqrt{3.517 \times 10^{13}} \approx 5.94 \times 10^{6}\, \text{m/s}
$$

Thus, the electron travels at approximately 5.94×10^{6} m/s under 100 V acceleration.

Time to cover 25 cm:

$$
t = \frac{0.25\, \text{m}}{5.94 \times 10^{6}\, \text{m/s}} \approx 4.21 \times 10^{-8}\, \text{s}
$$

or roughly 42 nanoseconds.

This estimate demonstrates how high velocities translate into extremely short transit times over small distances, characteristic of electron dynamics in high-voltage environments.

Impact of Magnetic Field on Electron Trajectory

Since the electron moves parallel to the magnetic field, the magnetic force $\vec{F} = q (\vec{v} \times \vec{B})$ is zero because the cross product of parallel vectors is zero:

$$
\vec{v} \parallel \vec{B} \Rightarrow \vec{v} \times \vec{B} = 0
$$

This implies:

- The magnetic field does not alter the electron's speed or its linear motion along the field lines.
- The electron's motion remains unaffected in magnitude, only maintaining constant velocity unless other forces act.

In contrast, if the electron had a velocity component perpendicular to $\vec{B}$, it would undergo circular motion with radius:

$$
r = \frac{m v_{\perp}}{|q| B}
$$

but that is not relevant here because the motion is purely parallel.

Additional Considerations: Relativistic Effects and Practical Implications

While classical equations suffice for many low-energy scenarios, high-energy electrons approaching relativistic speeds require corrections to account for relativistic mass increase. The relativistic velocity v relates to the accelerating voltage through:

$$
\text{Total energy } E = \gamma m c^2 = e V + m c^2
$$

where:

- $\gamma = \frac{1}{\sqrt{1 - v^2 / c^2}}$,
- $c = 3 \times 10^8\, \text{m/s}$.

If the electrons attain velocities close to c, relativistic effects significantly impact the calculations, and the simple non-relativistic formula becomes inadequate.

In practical devices like electron microscopes or particle accelerators, engineers must account for these effects to accurately control electron trajectories and energies.

Summary of Key Calculations and Conclusions

- Velocity Estimation: Assuming electrons are accelerated through a certain voltage, their velocity can be estimated using classical energy equations.
- Time to Cover 25 cm: For electrons traveling at approximately 6×10^6 m/s, the transit time over 25 cm is on the order of tens of nanoseconds.
- Magnetic Field Influence: Since the electron moves parallel to the magnetic field, the magnetic force does not influence its speed or direction along the

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