

Determine The Magnitude And Direction Of The Force On An Electron Travelling 7.75×10^5 M/s Horizontally

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Understanding the behavior of electrons in electric and magnetic fields is fundamental in physics, especially in fields like electromagnetism, particle physics, and engineering applications such as cathode ray tubes, particle accelerators, and magnetic resonance imaging. In this article, we will explore how to determine the magnitude and direction of the force acting on an electron moving at a specific velocity, particularly 7.75×10^5 meters per second horizontally.

Whether you're a student preparing for exams or a professional working on related projects, this guide aims to clarify the principles involved, provide step-by-step calculations, and discuss the physical implications of the forces involved.

Fundamental Concepts for Electron Motion in Fields

Before diving into calculations, it's essential to understand the basic principles governing the forces on charged particles.

Charge of an Electron

- The elementary charge (e) of an electron is approximately:
- $e = -1.602 \times 10^{-19}$ coulombs
- The negative sign indicates the charge is negative, which affects force directions when considering electric and magnetic fields.

Lorentz Force Law

The total force F acting on a charged particle in electric and magnetic fields is given by the Lorentz force law:

$$\mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

Where:

- q = charge of the particle (for an electron, $q = -e$)
- E = electric field vector
- v = velocity vector of the particle
- B = magnetic field vector
- $\times$ = vector cross product

This law indicates that the total force depends on the electric and magnetic fields and the particle's velocity.

Determining the Force: Step-by-Step Approach

To evaluate the force on the electron, you need to know the electric and magnetic fields present, as well as the electron's velocity vector.

Step 1: Define the Environment

- Identify the electric field E (magnitude and direction)
- Identify the magnetic field B (magnitude and direction)
- Confirm the velocity vector v (given as horizontal)

Suppose the electron is moving horizontally along the x-axis, i.e.,

$$\mathbf{v} = v_x \hat{i} = 7.75 \times 10^5 \text{ m/s} \hat{i}$$

The directions of E and B are crucial because the cross product depends on the orientation of these vectors.

Step 2: Gather Field Data

Without specific field values, we can analyze different scenarios:

- Scenario A: There is only a magnetic field
- Scenario B: There is only an electric field
- Scenario C: Both electric and magnetic fields are present

Let's explore each case to understand how they influence the force.

Scenario A: Magnetic Field Only

Suppose the magnetic field B points vertically, say along the y-axis:

$$\mathbf{B} = B_y \hat{j}$$

- The magnitude of B is given or assumed.

The magnetic force is:

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

Since v is along the x-axis and B along y:

$$\mathbf{v} = v_x \hat{i}$$

$$\mathbf{B} = B_y \hat{j}$$

The cross product:

$$\mathbf{v} \times \mathbf{B} = v_x \hat{i} \times B_y \hat{j} = v_x B_y (\hat{i} \times \hat{j})$$

Knowing that:

$$\hat{i} \times \hat{j} = \hat{k}$$

Therefore,

$$\mathbf{v} \times \mathbf{B} = v_x B_y \hat{k}$$

The magnetic force:

$$\mathbf{F}_B = q v_x B_y \hat{k}$$

Since q is negative, the force direction is opposite to $\hat{k}$.

Magnitude of the magnetic force:

$$|\mathbf{F}_B| = |q| v_x B_y$$

Numerical Example:

Assuming $(B_y = 1 \text{ Tesla})$:

$$|\mathbf{F}_B| = (1.602 \times 10^{-19}) \times (7.75 \times 10^5) \times 1$$
$$|\mathbf{F}_B| \approx 1.242 \times 10^{-13} \text{ N}$$

The force acts vertically, in the direction opposite to the positive k -axis, i.e., downward if $\hat{k}$ is upward.

Scenario B: Electric Field Only

Suppose an electric field E exists along the x -axis:

$$\mathbf{E} = E_x \hat{i}$$

The electric force:

$$\mathbf{F}_E = q \mathbf{E}$$

Magnitude:

$$|\mathbf{F}_E| = |q| E_x$$

Numerical Example:

If $(E_x = 10^3 \text{ V/m})$:

$$|\mathbf{F}_E| = 1.602 \times 10^{-19} \times 10^3 = 1.602 \times 10^{-16} \text{ N}$$

The force is directed along the electric field; since the charge is negative, the force points opposite the electric field direction.

Scenario C: Both Electric and Magnetic Fields Present

When both fields are present, the total force is:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

The combined effect can lead to complex trajectories, such as circular or helical motion, especially if the electric and magnetic fields are perpendicular.

Key Point:

- The total force depends on the relative orientation of $\mathbf{E}$, $\mathbf{B}$, and $\mathbf{v}$.
- The net force vector can be found by vector addition, considering both electric and magnetic contributions.

Direction of the Force

The direction of the force is determined by the vector sum:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

- If only electric field exists, force points along or opposite the electric field depending on charge.
- If only magnetic field exists, force is perpendicular to both velocity and magnetic field.
- If both fields exist, the net force depends on their vector sum.

Special Cases:

- When $\mathbf{E}$ and $\mathbf{B}$ are perpendicular, and the velocity is such that:

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$$

the electron experiences no net force; this is the principle behind velocity selectors.

Physical Implications and Applications

Understanding the magnitude and direction of forces on electrons is vital in designing devices like:

- Mass spectrometers: where electric and magnetic fields separate particles based on their charge-to-mass ratio.
- Electron microscopes: where magnetic lenses focus electron beams.

- Particle accelerators: where precise control of electron trajectories is essential.
- Magnetic confinement in plasma physics: where magnetic forces confine charged particles.

In practical scenarios, knowing how electrons respond to these fields allows engineers and scientists to manipulate particle paths effectively.

Summary and Key Takeaways

- The force on an electron moving at $(7.75 \times 10^5 \text{ m/s})$ depends on the electric and magnetic fields present.
- The Lorentz force law provides the foundation for calculating the force.
- The magnetic force is perpendicular to both velocity and magnetic field.
- The electric force acts along the electric field direction.
- The combined effect can produce complex motion, including circular, helical, or drift trajectories.
- Accurate calculation requires knowledge of the field magnitudes and directions.

Conclusion

Determining the magnitude and direction of the force on an electron moving horizontally at a speed of $(7.75 \times 10^5 \text{ m/s})$ involves understanding the interplay of electric and magnetic fields and applying the Lorentz force law. By carefully analyzing the environment and applying vector operations, physicists and engineers can predict the behavior of electrons in various applications, leading to innovations in technology and a deeper understanding of fundamental physics.

Remember, in real-world problems, always verify the directions of the fields and velocities, and carefully perform vector calculations to ensure accurate results. This understanding forms the backbone of modern electromagnetism and its myriad applications.

Frequently Asked Questions

What is the formula to determine the force on an electron moving in a magnetic field?

The force on an electron in a magnetic field is given by the Lorentz force equation: $F = qvB \sin\theta$, where q is the charge of the electron, v is its velocity, B is the magnetic flux density, and θ is the angle between the velocity vector and the magnetic field.

How do you calculate the magnitude of the magnetic force on an electron moving at $7.75 \times 10^5 \text{ m/s}$?

To calculate the magnetic force magnitude, use $F = qvB \sin\theta$. If the magnetic field and its direction are known, substitute the charge of the electron ($q \approx 1.6 \times 10^{-19} \text{ C}$), the velocity (7.75×10^5

m/s), and the magnetic field strength, along with the angle θ .

What additional information is needed to determine the direction of the force on the electron?

You need to know the direction of the magnetic field and the velocity vector of the electron. Applying the right-hand rule (or left-hand rule for negative charges) helps determine the direction of the force relative to the magnetic field and velocity.

If the electron is traveling horizontally and the magnetic field is vertical, how does that affect the force calculation?

If the magnetic field is perpendicular to the velocity (e.g., vertical magnetic field and horizontal velocity), then $\theta = 90^\circ$, and $\sin\theta = 1$. The force magnitude becomes $F = qvB$, maximizing the magnetic force.

What is the significance of the electron's velocity being horizontal in determining the force?

The horizontal velocity indicates the direction of motion, which is essential for applying the right-hand rule to find the force direction, especially when combined with the magnetic field orientation.

How can the magnitude and direction of the force on the electron be experimentally verified?

By observing the electron's deflection in a known magnetic field setup, measuring its trajectory deviation, and comparing it with theoretical predictions based on the Lorentz force equation, the magnitude and direction can be experimentally confirmed.

Additional Resources

Determine The Magnitude And Direction Of The Force On An Electron Travelling 7.75×10^5 M/s Horizontally

In the realm of electromagnetism, understanding how charged particles behave under the influence of electric and magnetic fields is fundamental. When an electron travels through a magnetic field, the forces acting upon it determine its trajectory, speed, and overall motion. Today, we explore a specific scenario: an electron moving horizontally at a velocity of 7.75×10^5 meters per second. Our goal is to determine both the magnitude and the direction of the force acting on this electron, considering the fundamental principles of physics that govern charged particle dynamics. This analysis not only deepens our understanding of electromagnetic interactions but also lays the groundwork for applications spanning from particle accelerators to magnetic resonance imaging.

Understanding the Physical Context

Before diving into calculations, it's essential to clarify the physical context and the assumptions involved.

Key Parameters and Variables

- Velocity of the electron (v): 7.75×10^5 m/s, directed horizontally.
- Charge of the electron (q): Approximately -1.602×10^{-19} coulombs.
- Mass of the electron (m): Approximately 9.109×10^{-31} kilograms.
- Magnetic field (B): The strength and orientation of the magnetic field are crucial. Since the problem statement doesn't specify the magnetic field, we will analyze the force in the context of a given magnetic field vector, which can be defined as needed.

Assumptions

- The electron moves in a uniform magnetic field.
- No electric field influences the electron.
- The velocity of the electron is constant in magnitude unless acted upon by a force.
- The magnetic field's direction is perpendicular to the electron's velocity for the maximum force scenario.

Understanding these parameters allows us to employ the Lorentz force law effectively to determine the force's magnitude and direction.

The Lorentz Force Law: The Foundation

The force acting on a charged particle moving in an electromagnetic field is described by the Lorentz force law:

$$\mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

Where:

- $\mathbf{F}$ is the force vector,
- q is the charge,
- $\mathbf{E}$ is the electric field vector,
- $\mathbf{v}$ is the velocity vector,
- $\mathbf{B}$ is the magnetic field vector,
- $\times$ denotes the vector cross product.

In our scenario, assuming no electric field ($\mathbf{E} = 0$), the force simplifies to:

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

This cross product indicates that the magnetic force is always perpendicular to both the velocity of the particle and the magnetic field.

Calculating the Magnitude of the Force

Given the simplified form of the Lorentz force, the magnitude of the magnetic force is:

$$|F| = |q| \times |v| \times |B| \times \sin(\theta)$$

Where:

- θ is the angle between the velocity vector and the magnetic field vector.

Case 1: Magnetic field perpendicular to velocity ($\theta = 90^\circ$)

This is the scenario that yields the maximum force, as $\sin(90^\circ) = 1$.

Case 2: Magnetic field parallel or antiparallel to velocity ($\theta = 0^\circ$ or 180°)

In this case, $\sin(0^\circ) = \sin(180^\circ) = 0$, and the force would be zero, meaning no magnetic force acts on the electron when the magnetic field is aligned with its velocity.

Determining the Magnitude

Assuming the magnetic field is perpendicular to the velocity (a common case for maximum deflection), we need to specify $|B|$. For illustrative purposes, let's consider a magnetic field strength of 0.01 Tesla (which is a typical small magnetic field used in laboratory settings).

Plugging in the values:

$$|F| = (1.602 \times 10^{-19} \text{ C}) \times (7.75 \times 10^5 \text{ m/s}) \times (0.01 \text{ T}) \times 1$$

Calculating:

$$|F| = 1.602 \times 10^{-19} \times 7.75 \times 10^5 \times 0.01$$

First, multiply 1.602×10^{-19} by 7.75×10^5 :

$$= 1.602 \times 7.75 \times 10^{(-19 + 5)}$$

$$= (1.602 \times 7.75) \times 10^{(-14)}$$

Calculating 1.602×7.75 :

$$\approx 12.43$$

Therefore:

$$|F| \approx 12.43 \times 10^{(-14)} \text{ N}$$

Or expressed more neatly:

$$|F| \approx 1.243 \times 10^{-13} \text{ N}$$

This is the magnitude of the magnetic force acting on the electron under these assumptions.

Determining the Direction of the Force

The direction of the magnetic force on a moving charge is given by the right-hand rule for positive charges, but since the electron's charge is negative, the force direction will be opposite to the direction indicated by the right-hand rule.

Step-by-step approach:

1. Identify the vectors:

- Velocity vector $\mathbf{v}$ (say, pointing east).
- Magnetic field vector $\mathbf{B}$ (say, pointing north).

2. Apply the right-hand rule for a positive charge:

- Point your fingers in the direction of $\mathbf{v}$.
- Curl your fingers toward $\mathbf{B}$.
- Your thumb points in the direction of $\mathbf{v} \times \mathbf{B}$.

3. Adjust for the electron's negative charge:

- Since the charge is negative, the force will be in the opposite direction of $\mathbf{v} \times \mathbf{B}$.

Example:

- Suppose the electron moves east (positive x-direction).
- The magnetic field is directed north (positive y-direction).

Then:

- $\mathbf{v}$ = east (x-direction),
- $\mathbf{B}$ = north (y-direction).

Compute $\mathbf{v} \times \mathbf{B}$:

Using the right-hand rule:

- Fingers point east (x-direction),
- Curl toward north (y-direction),
- Thumb points upward (z-direction).

So, $\mathbf{v} \times \mathbf{B}$ points upward.

Since the electron has negative charge, the force $\mathbf{F}$ is downward.

Summary:

- The force magnitude is approximately 1.243×10^{-13} N.
- The force acts perpendicular to both the velocity and magnetic field.
- Its direction is opposite to the one indicated by the right-hand rule for a positive charge, which, in this case, would be downward if the velocity is east and the magnetic field is north.

Implications and Applications

Understanding the force on electrons moving in magnetic fields has profound implications in various scientific and technological domains:

- Particle accelerators: Magnetic fields are used to steer and focus electron beams.
- Magnetic resonance imaging (MRI): Precise control of charged particles and their forces is fundamental.
- Space physics: Electrons in Earth's magnetosphere experience forces that influence space weather phenomena.
- Electronics: Magnetic forces impact the behavior of electrons in devices like cathode-ray tubes and magnetic sensors.

Real-World Example:

In cathode-ray tubes, electrons are accelerated and deflected by magnetic fields to direct the electron beam precisely onto the screen. Calculating the force on these electrons helps engineers design magnetic coils that produce the desired deflections with accuracy.

Extending the Analysis: Variations and Complexities

While the simplified calculation offers insightful results, real-world scenarios often involve additional complexities:

- Electric fields: If present, they contribute to the Lorentz force, potentially altering the electron's trajectory.
- Non-uniform magnetic fields: Variations in magnetic field strength or direction lead to complex particle paths.
- Relativistic effects: At very high velocities approaching the speed of light, relativistic physics must be considered.
- Quantum considerations: At microscopic scales, quantum mechanics governs electron behavior, and classical force calculations may need adjustments.

Adjusting for different magnetic field strengths:

If the magnetic field strength varies, the force scales linearly with $|B|$. For example, doubling the magnetic field strength to 0.02 T would double the force magnitude to approximately 2.486×10^{-13} N.

If the magnetic field is aligned with the velocity:

The force becomes zero, and the electron continues its path unaffected by the magnetic field, illustrating the importance of the field's orientation.

Conclusion

Determining the magnitude and direction of the force on an electron traveling at a specific velocity involves fundamental electromagnetic principles. Using the Lorentz force law, one can calculate the force's size based on the charge, velocity, magnetic field strength, and the angle between the velocity and the magnetic field. In the example provided, with an electron moving at 7.75×10^5 m/s and a magnetic field of 0.01 T perpendicular to its motion, the force magnitude is approximately 1.243×10^{-13} N, directed perpendicular to both the velocity and magnetic field, with the direction dictated by the charge's sign and the right-hand rule.

This calculation exemplifies the elegant interplay of electric and magnetic forces shaping the dynamics of charged particles, a cornerstone of modern physics and engineering. Whether in advanced research laboratories or everyday electronic devices, understanding these forces enables us to harness electromagnetic phenomena effectively. As technology advances

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