

An Electron Is Moving In A Circle In The Xy Plane Perpendicular To A B Field Of $10^{-4} \text{ T}(\hat{k})$. What Is The

An Electron Is Moving In A Circle In The Xy Plane Perpendicular To A B Field Of $10^{-4} \text{ T}(\hat{k})$. What Is The phenomenon governing its motion, and how can we analyze the physical principles involved? This article provides an in-depth exploration of the motion of an electron in a magnetic field, focusing on the fundamental physics concepts, calculations, and real-world applications. Whether you're a student, educator, or physics enthusiast, understanding the behavior of charged particles in magnetic fields is crucial to grasping many modern technologies and natural phenomena.

Introduction to Electron Motion in Magnetic Fields

Charged Particles and Magnetic Forces

Electrons are fundamental particles carrying a negative electric charge of approximately (-1.602×10^{-19}) coulombs. When a charged particle like an electron enters a magnetic field, it experiences a force described by the Lorentz force law:

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

Where:

- q is the charge of the particle,
- $\vec{v}$ is its velocity vector,
- $\vec{B}$ is the magnetic field vector.

This force acts perpendicular to both the velocity of the particle and the magnetic field, resulting in circular or helical trajectories depending on the initial velocity components.

Magnetic Field Orientation and Electron Trajectory

In this scenario, the magnetic field $\vec{B}$ is oriented along the positive z-axis, denoted as $\vec{B} = 10^{-4} \text{ T} \hat{k}$. The electron moves in the xy-plane, perpendicular to $\vec{B}$, indicating its initial velocity $\vec{v}$ lies entirely in the xy-plane.

Since the magnetic force is always perpendicular to the velocity, the electron undergoes uniform circular motion in the xy-plane. The radius and frequency of this motion depend on the electron's speed and the magnetic field strength.

Fundamental Concepts and Equations

Lorentz Force and Circular Motion

The key to understanding the electron's movement is recognizing that the magnetic force provides the centripetal force required for circular motion:

$$F_{\text{mag}} = F_{\text{centripetal}}$$

Expressed mathematically as:

$$q v B = \frac{m v^2}{r}$$

Where:

- m is the mass of the electron (9.109×10^{-31} , kg),
- v is the speed of the electron,
- r is the radius of the circular path.

From this, the radius r can be derived:

$$r = \frac{m v}{q B}$$

Alternatively, if the electron's speed is known, the radius can be calculated directly.

Calculating Electron Velocity

Depending on the context, the electron's initial velocity can be specified or derived from energy considerations. For example, if electrons are accelerated through a potential difference V , their velocity is given by:

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

Where:

- e is the elementary charge (1.602×10^{-19} , C),
- V is the accelerating voltage in volts.

In many practical situations, the electron's speed is controlled or measured, allowing for precise calculations of its trajectory.

Calculations and Analysis

Determining the Electron's Speed

Suppose the electron is accelerated through a potential difference of 100 volts. Its velocity v can be computed as:

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

Calculating numerator:

$$2 \times 1.602 \times 10^{-19} \times 100 = 3.204 \times 10^{-17}$$

Calculating the velocity:

$$v = \sqrt{\frac{3.204 \times 10^{-17}}{9.109 \times 10^{-31}}} \approx \sqrt{3.517 \times 10^{13}} \approx 5.93 \times 10^6, \text{ m/s}$$

This speed is approximately 5.93 million meters per second.

Calculating the Radius of the Electron's Path

Using the radius formula:

$$r = \frac{m v}{q B}$$

Substituting known values:

$$r = \frac{9.109 \times 10^{-31} \times 5.93 \times 10^6}{1.602 \times 10^{-19} \times 10^{-4}}$$

Compute numerator:

$$9.109 \times 10^{-31} \times 5.93 \times 10^6 \approx 5.4 \times 10^{-24}$$

Compute denominator:

$$1.602 \times 10^{-19} \times 10^{-4} = 1.602 \times 10^{-23}$$

Calculate radius:

$$r \approx \frac{5.4 \times 10^{-24}}{1.602 \times 10^{-23}} \approx 0.337, \text{ m}$$

Thus, the electron moves in a circle with a radius of approximately 33.7 centimeters.

Implications and Applications

Electron Beam Steering and Devices

Understanding how electrons behave in magnetic fields is fundamental to designing devices like cathode ray tubes, electron microscopes, and mass spectrometers. In these applications, magnetic fields are used to steer, focus, or analyze electron beams with high precision.

Magnetic Confinement in Fusion Reactors

The principles of charged particle motion in magnetic fields are crucial in plasma confinement devices such as tokamaks, where magnetic fields keep hot plasma contained to facilitate nuclear fusion.

Natural Phenomena and Space Physics

Electrons moving in Earth's magnetic field produce phenomena like auroras. The Earth's magnetic field guides charged particles from solar winds toward the poles, creating luminous displays in the sky.

Factors Affecting Electron Motion

Magnetic Field Strength

Increasing the magnetic field (B) reduces the radius (r) , resulting in tighter electron spirals. Conversely, decreasing (B) allows electrons to travel in larger circles.

Initial Electron Velocity

Higher initial velocities lead to larger radii, influencing how electrons are manipulated in devices.

Electric Fields and Other Forces

In real-world scenarios, electric fields and other forces can modify the electron's trajectory, leading to complex motion patterns such as helices.

Conclusion

In summary, an electron moving in a circle in the xy-plane, perpendicular to a magnetic field of (10^{-4}) T, exhibits uniform circular motion governed by the Lorentz force. By understanding the fundamental physics equations, such as the relationship between charge, mass, velocity, magnetic field, and radius, scientists and engineers can predict and manipulate electron trajectories for various technological and scientific purposes. The precise calculation of electron speed and radius in specific settings enables the design of advanced instruments and deepens our understanding of natural electromagnetic phenomena.

References and Further Reading

- Griffiths, D. J. (2017). Introduction to Electrodynamics. Cambridge University Press.
- Serway, R. A., & Jewett, J. W. (2014). Physics for Scientists and Engineers. Brooks Cole.
- NASA's Electron Dynamics in Magnetic Fields: [NASA Technical Reports](<https://ntrs.nasa.gov/>)
- Online simulation tools for charged particle motion in magnetic fields

By mastering these concepts, you can better appreciate the elegant physics that govern the microscopic world and their broad applications in technology and nature.

Frequently Asked Questions

What is the radius of the electron's circular motion in a magnetic field of 10^{-4} T?

The radius can be calculated using $r = (mv) / (qB)$, where m is the electron mass, v is its velocity, q is the charge, and B is the magnetic field. Without velocity, the radius cannot be determined precisely.

What is the nature of the electron's trajectory when moving perpendicular to a magnetic field?

The electron undergoes uniform circular motion in the plane perpendicular to the magnetic field due to the Lorentz force acting perpendicular to its velocity.

How does the magnetic field strength of 10^{-4} T influence the electron's motion?

A magnetic field of 10^{-4} T causes the electron to move in a circular path with a radius proportional to its velocity; stronger fields result in smaller radii for the same velocity.

What is the frequency of the electron's circular motion in this magnetic field?

The frequency (cyclotron frequency) is given by $f = qB / (2\pi m)$. Plugging in the values, $f \approx (1.6 \times 10^{-19} \text{ C})(10^{-4} \text{ T}) / (2\pi)(9.11 \times 10^{-31} \text{ kg}) \approx 2.8 \times 10^7 \text{ Hz}$.

What is the direction of the electron's circular motion relative to the

magnetic field?

The electron moves in a plane perpendicular to the magnetic field (+k direction), and the direction of rotation is determined by the right-hand rule, which indicates the electron's motion is counterclockwise when viewed from the positive z-axis.

Additional Resources

An Electron Is Moving In A Circle In The Xy Plane Perpendicular To A B Field Of 10^{-4} T (+k). What Is The?

Understanding the motion of charged particles in magnetic fields is fundamental to many areas of physics, from fundamental research to practical applications like magnetic resonance imaging (MRI), particle accelerators, and plasma confinement. In this article, we delve into a specific scenario: an electron moving in a circular path within the xy-plane, under the influence of a magnetic field directed along the positive z-axis, with a magnitude of 10^{-4} Tesla. We will explore the physics governing this motion, derive key quantities such as the electron's velocity and the radius of its orbit, and discuss the implications of these parameters.

Fundamentals of Charged Particle Motion in Magnetic Fields

Basic Principles

Charged particles, such as electrons, experience a force when moving through a magnetic field. This force is described by the Lorentz force law:

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

Where:

- q is the particle's charge,
- $\mathbf{v}$ is its velocity vector,
- $\mathbf{B}$ is the magnetic field vector.

For an electron:

- $q = -1.602 \times 10^{-19} \text{ C}$,
- $m = 9.109 \times 10^{-31} \text{ kg}$.

If the electron's velocity is perpendicular to the magnetic field, the force acts perpendicular to the velocity, causing circular motion.

Conditions for Circular Motion

When the electron moves perpendicular to the magnetic field, the magnetic Lorentz force provides the necessary centripetal force to sustain circular motion:

$$|\mathbf{F}| = \frac{mv^2}{r}$$

Where:

- v is the speed of the electron,
- r is the radius of the circular path.

Since $|\mathbf{F}| = |q|vB$ for perpendicular motion, setting these equal gives:

$$|q|vB = \frac{mv^2}{r}$$

From this, we can derive the radius of the electron's orbit:

$$r = \frac{mv}{|q|B}$$

This formula links the electron's velocity, magnetic field strength, and the radius of its circular path.

Calculating the Electron's Velocity and Radius

Given:

- Magnetic field $B = 10^{-4} \text{ T}$,
- The electron's charge $|q| = 1.602 \times 10^{-19} \text{ C}$,
- The electron's mass $m = 9.109 \times 10^{-31} \text{ kg}$,
- The problem states the electron moves in a circle but does not specify its velocity. To find specific values, we need either the velocity or the radius.

Assuming the Electron's Kinetic Energy or Velocity

In many practical scenarios, the electrons are accelerated to known energies before entering magnetic fields. Let's consider a common case: the electron has been accelerated through a potential difference V . The kinetic energy KE gained by the electron is:

$$KE = eV$$

And the velocity corresponding to this energy:

$$\left[KE = \frac{1}{2} m v^2 \rightarrow v = \sqrt{\frac{2 e V}{m}} \right]$$

Suppose the electron has been accelerated through 100 V (a typical energy in many experiments):

$$\left[V = 100 \text{ V} \right]$$

Then:

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

Calculating:

$$\left[v = \sqrt{\frac{3.204 \times 10^{-17}}{9.109 \times 10^{-31}}} \right]$$

$$\left[v = \sqrt{3.517 \times 10^{13}} \right]$$

$$\left[v \approx 5.93 \times 10^6 \text{ m/s} \right]$$

This velocity is roughly 2% of the speed of light, making non-relativistic calculations acceptable.

Calculating the Radius of the Electron's Path

Using the derived velocity:

$$\left[r = \frac{m v}{|q| B} \right]$$

Plugging in the values:

$$\left[r = \frac{9.109 \times 10^{-31} \times 5.93 \times 10^6}{1.602 \times 10^{-19} \times 10^{-4}} \right]$$

Calculations:

Numerator:

$$\left[9.109 \times 10^{-31} \times 5.93 \times 10^6 \approx 5.40 \times 10^{-24} \right]$$

Denominator:

$$\left[1.602 \times 10^{-19} \times 10^{-4} = 1.602 \times 10^{-23} \right]$$

Therefore:

$$\left[r = \frac{5.40 \times 10^{-24}}{1.602 \times 10^{-23}} \approx 0.337, \text{m} \right]$$

This indicates the electron's circular orbit has a radius of approximately 33.7 centimeters under these conditions.

Implications and Practical Considerations

Magnetic Radius and Electron Dynamics

The radius of the electron's path is directly proportional to its velocity and inversely proportional to the magnetic field strength. As the magnetic field increases, the radius decreases — meaning the electron's path curves more tightly. Conversely, higher initial energies (or velocities) lead to larger orbits.

In laboratory settings, magnetic fields of 10^{-4} T are common in devices like cathode ray tubes or certain spectrometers. The resulting electron trajectories are predictable, allowing precise control over electron beams.

Relativistic Effects and Limitations

At higher energies, electrons approach relativistic speeds, requiring corrections to classical formulas. The Lorentz factor γ becomes significant:

$$\left[\gamma = \frac{1}{\sqrt{1 - (v^2/c^2)}} \right]$$

However, at 5.93 million meters per second (~2% of the speed of light), relativistic effects are minimal but should still be considered for high-precision applications.

Practical Applications of Electron Circular Motion

- Mass Spectrometry: Magnetic fields bend electron paths, allowing separation based on mass-to-charge ratios.
- Cyclotron and Synchrotron Devices: Accelerate electrons in circular paths for high-energy physics experiments.
- Magnetic Confinement in Plasma Devices: Use magnetic fields to contain plasma in fusion reactors.
- Fundamental Physics Tests: Measure fundamental constants and test quantum electrodynamics.

Conclusion: The Significance of Electron Dynamics in Magnetic Fields

Understanding how electrons move in magnetic fields is essential for both theoretical physics and engineering applications. The scenario of an electron moving in a circular path within the xy-plane, under a magnetic field of 10^{-4} T along the z-axis, exemplifies the fundamental principles dictating charged particle motion. By calculating the velocity and the radius of the orbit, scientists can design experiments, develop technologies, and deepen our understanding of electromagnetic phenomena.

In this specific case, assuming an electron accelerated through 100 V, it achieves a velocity of about 5.93 million meters per second, resulting in a circular orbit roughly 0.34 meters in radius. These insights underscore the delicate interplay between electric energy, magnetic fields, and particle dynamics — a dance choreographed by the laws of physics that continues to inspire innovation and discovery.

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