A Charged Particle Of Mass 0.0020 Kg Is Subjected To A 6.0 T Magnetic Field Which Acts At A Right Angle

Introduction

A Charged Particle Of Mass 0.0020 Kg Is Subjected To A 6.0 T Magnetic Field Which Acts At A Right Angle describes a fundamental scenario in electromagnetism, illustrating how charged particles behave in magnetic fields. Such situations are common in various applications, from particle accelerators to magnetic confinement in plasma physics. Understanding the motion of a charged particle in a magnetic field involves concepts like Lorentz force, circular motion, and the relationship between velocity, magnetic field, and radius of the particle's trajectory. This article explores the physics principles governing the motion of the charged particle, the calculations involved, and the practical implications of such a setup.

Fundamental Concepts

Magnetic Force on a Moving Charge

The force exerted on a charged particle moving in a magnetic field is given by the Lorentz force law:

- **$F = qvB \sin\theta$**

where:

1. **F** is the magnetic force (in Newtons)
2. **q** is the charge of the particle (in Coulombs)
3. **v** is the velocity of the particle (in meters per second)
4. **B** is the magnetic flux density or magnetic field strength (in Tesla)
5. **θ** is the angle between the velocity vector and the magnetic field

When the magnetic field acts at a right angle ($\theta = 90°$), the sine term becomes 1, and the force simplifies to:

- **$F = qvB$**

Motion of the Charged Particle in a Magnetic Field

If the magnetic field is perpendicular to the velocity of the particle, the resulting force is always perpendicular to the velocity. This causes the particle to undergo uniform circular motion, with constant speed but changing direction. The key parameters involved in this motion include:

- **Radius of the circular path (r)**
- **Period of revolution (T)**
- **Centripetal force**

Deriving the Radius of the Circular Path

When a charged particle moves in a circle due to the magnetic force, the magnetic force acts as the centripetal force required for circular motion. Equating these forces yields:

$$qvB = mv^2 / r$$

Rearranging for the radius (r):

$$r = (mv) / (qB)$$

This formula indicates that the radius depends on the mass and velocity of the particle, as well as the charge and magnetic field strength.

Calculating the Velocity of the Particle

Energy Considerations and Particle Acceleration

In many practical scenarios, the particle is initially accelerated through an electric potential difference before entering the magnetic field. If the particle is accelerated through a potential difference V, its kinetic energy is given by:

$$KE = qV$$

which equals the kinetic energy:

$$KE = (1/2)mv^2$$

Thus, the velocity v can be determined by:

```
v = sqrt(2qV / m)
```

Knowing the charge q and the potential difference V allows calculation of v, which can then be used to find the radius of the particle's trajectory in the magnetic field.

Assumptions for Calculation

- The particle is singly charged (e.g., an electron or proton). For this example, assume it is a proton with $q = 1.6 \times 10^{-19}$ C.
- The particle is accelerated through a certain voltage V, which should be specified or assumed for calculation purposes.

Practical Example: Calculating the Radius

Given Data:

- Mass of particle, m = 0.0020 kg
- Magnetic field, B = 6.0 T
- Charge of particle, $q = 1.6 \times 10^{-19}$ C (assuming a proton)
- Potential difference, V = 1000 V (assumption for this example)

Calculating Velocity:

```
v = sqrt(2 × 1.6 × 10⁻¹⁹ C × 1000 V / 0.0020 kg)
= sqrt(3.2 × 10⁻¹⁶ / 0.0020)
= sqrt(1.6 × 10⁻¹³)
≈ 1.26 × 10⁻⁶ m/s
```

The low velocity indicates that either the assumed voltage is small or the particle is very massive. For high-energy particles, V would typically be much larger. For illustrative purposes, consider V = 1,000,000 V (1 MV):

```
v = sqrt(2 × 1.6 × 10⁻¹⁹ C × 1,000,000 V / 0.0020 kg)
= sqrt(3.2 × 10⁻¹³ / 0.0020)
= sqrt(1.6 × 10⁻¹⁰)
≈ 1.26 × 10⁻⁵ m/s
```

>Note: The actual speed depends heavily on the acceleration voltage. The higher the voltage, the higher the velocity.

Calculating Radius:

Using the velocity from the second calculation:

$$r = (0.0020 \text{ kg} \times 1.26 \times 10^{-5} \text{ m/s}) / (1.6 \times 10^{-19} \text{ C} \times 6.0 \text{ T})$$
$$= (2.52 \times 10^{-8} \text{ kg·m/s}) / (9.6 \times 10^{-19} \text{ C·T})$$
$$\approx 2.63 \times 10^{1}0 \text{ m}$$

> The large radius signifies that for typical laboratory magnetic fields, very high velocities or energies are required to produce a manageable radius of curvature.

Period and Frequency of the Particle's Motion

Period of Revolution (T)

The period T is the time taken for one complete revolution:

$$T = 2\pi r / v$$

Using the calculated radius and velocity, this period can be determined. The frequency f is the reciprocal:

$$f = 1 / T$$

Implications of Motion

- The particle traces out a circular path in the plane perpendicular to the magnetic field.
- The radius of curvature is directly proportional to the particle's momentum (mv).
- The motion is uniform, with the magnetic force providing the centripetal acceleration.

Applications and Practical Considerations

Particle Accelerators

Understanding how charged particles move in magnetic fields is fundamental to designing particle accelerators such as cyclotrons and synchrotrons. The radius of the particle’s path determines the size of the accelerator and the energy of the particles.

Mass Spectrometry

Mass spectrometers utilize magnetic fields to separate ions based on their mass-to-charge ratio. The radius of their path in the magnetic field allows identification of different particles.

Magnetic Confinement in Plasma Physics

In fusion reactors, strong magnetic fields confine plasma particles, relying on similar principles to control high-energy particles.

Limitations and Practical Challenges

- High magnetic fields require advanced superconducting magnets, which are expensive and complex to maintain.
- Achieving high particle velocities necessitates substantial energy input.
- Relativistic effects become significant at very high energies, requiring corrections to classical equations.
- Precise control over initial conditions is essential for predictable motion.

Conclusion

The scenario of a charged particle with a given mass subjected to a perpendicular magnetic field encapsulates fundamental physics principles. By analyzing the Lorentz force, the resulting circular motion, and the parameters influencing the particle's trajectory, one gains insight into the behavior of particles in magnetic environments. Such understanding is crucial for technological advancements in particle physics, medical imaging, and space science. While simplified calculations provide a basis, real-world applications often involve complex factors such as relativistic effects, electromagnetic field configurations, and energy considerations. Nonetheless, the core principles remain central to the study and application of electromagnetism in modern science and engineering.

Frequently Asked Questions

What is the force experienced by a charged particle in a magnetic field when the particle moves perpendicular to the field?

The force is given by $F = qvB$, where q is the charge, v is the velocity, and B is the magnetic field strength. When moving perpendicular to the magnetic field, the force acts perpendicular to the velocity, causing circular motion.

How can the radius of the circular path of the charged particle be calculated in a magnetic field?

The radius r is given by $r = (mv)/(qB)$, where m is the mass, v is the velocity, q is the charge, and B is the magnetic field strength.

What is the significance of the magnetic field acting at a right angle to the particle's velocity?

When the magnetic field is perpendicular to the particle's velocity, it causes uniform circular motion without doing work on the particle, maintaining its speed but changing its direction.

How do you determine the angular frequency of a charged particle moving in a magnetic field?

The angular frequency ω is given by $\omega = qB/m$, which indicates how fast the particle completes one revolution in the magnetic field.

Given a particle of mass 0.0020 kg in a 6.0 T magnetic field, how do you find its kinetic energy if its velocity is known?

Kinetic energy $KE = (1/2) mv^2$. Once the velocity v is known, substitute to find KE.

What is the role of the charge of the particle in its motion within a magnetic field?

The magnitude and sign of the charge determine the force's strength and direction, influencing the radius of the circular path and the direction of the particle's deflection.

If a charged particle completes a circular orbit in a magnetic field, how do you calculate its period of revolution?

The period T is given by $T = 2\pi r/v$, or alternatively, $T = 2\pi m/(qB)$, using the relation between mass, charge, magnetic field, and velocity.

What conditions are necessary for the particle to undergo pure circular motion in a magnetic field?

The particle must have a velocity component perpendicular to the magnetic field, and there should be no electric fields or other forces acting on it that alter its motion.

Additional Resources

Charged Particle in a Magnetic Field: An In-Depth Analysis

Understanding the motion of charged particles within magnetic fields is fundamental to numerous applications in physics and engineering, from particle accelerators to astrophysical phenomena. In this detailed review, we explore the behavior of a charged particle with a mass of 0.0020 kg subjected to a magnetic field of 6.0 T that acts at a right angle to its initial velocity. We will dissect the physics principles involved, derive relevant equations, analyze the particle's motion, and discuss practical implications and applications.

Fundamental Concepts and Principles

Before delving into calculations and specific behaviors, it is essential to establish the foundational physics principles underpinning the scenario.

Lorentz Force and Motion of Charged Particles

The motion of a charged particle in a magnetic field is governed by the Lorentz force, which is given by:

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

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

Key characteristics:
- The magnetic force is always perpendicular to both the velocity and the magnetic field.
- The force does no work on the particle because it is perpendicular to the velocity, hence the particle's kinetic energy remains constant in ideal conditions.

Uniform Circular Motion in a Magnetic Field

When a charged particle enters a magnetic field perpendicular to its velocity, it undergoes uniform circular motion due to the Lorentz force acting as a centripetal force:

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

where:
- m is the mass,
- v is the speed,
- r is the radius of the circular path.

Rearranged to find the radius:

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

This fundamental relationship indicates that the radius of the particle's circular motion depends on its mass, charge, velocity, and the magnetic field strength.

Analyzing the Given Scenario

Let's analyze the specific details provided:

- Mass of the particle, $m = 0.0020 \, \text{kg}$
- Magnetic field strength, $B = 6.0 \, \text{T}$
- Magnetic field acts at a right angle to the initial velocity (perpendicular entry).

To fully understand the particle's behavior, we need to consider additional parameters such as:
- The particle's charge q,
- Its initial velocity v.

Since these are not explicitly provided, we will explore the behavior in general terms and consider typical values or conditions.

Determining the Particle's Motion

Initial Velocity and Its Direction

Assuming the particle enters with an initial velocity v_0 perpendicular to the magnetic field (say along the x-axis), the magnetic force acts perpendicular to both the velocity and the magnetic field (say along the z-axis), resulting in circular motion in the xy-plane.

Key points:
- The particle's speed remains constant if only magnetic forces are acting.
- The trajectory is a circle with radius r:

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

- The period T of revolution:

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

- The angular frequency ω:

$$
\omega = \frac{2 \pi}{T} = \frac{q B}{m}
$$

This frequency is independent of the particle's speed, depending solely on charge, magnetic field, and mass.

Calculating the Radius of the Circular Path

Suppose the particle's charge q is known or typical for a specific particle:

- For example, if the particle is a proton, $q = 1.6 \times 10^{-19} \, \text{C}$.

Using this, the radius:

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

Given:
- $m = 0.0020 \, \text{kg}$
- $B = 6.0 \, \text{T}$

If initial velocity v is specified or assumed, the radius can be directly calculated.

Example:
Suppose $v = 10^3 \, \text{m/s}$:

$$
r = \frac{0.0020 \times 10^3}{1.6 \times 10^{-19} \times 6.0} \approx \frac{2}{9.6 \times 10^{-19}} \approx 2.08 \times 10^{18} \, \text{m}
$$

This enormous radius indicates that for such a small charge (like a proton), at relatively low velocity, the circular path is extremely large, practically linear over small distances.

Implications and Practical Significance

The physics of a charged particle in a magnetic field has profound applications:

Particle Accelerators and Detectors

- Magnetic fields are used to steer and focus charged particle beams.
- The radius of curvature helps determine the particle's momentum:

$$
p = m v = q B r
$$

where p is the relativistic or classical momentum.

Application:
- Measuring the radius of curvature in a magnetic spectrometer allows determination of particle charge-to-mass ratio.

Astrophysics and Cosmic Rays

- Cosmic charged particles are deflected by magnetic fields in space, influencing their trajectories.
- Understanding their motion informs models of cosmic ray propagation.

Magnetic Confinement in Fusion Devices

- Magnetic fields confine plasma in devices like tokamaks.
- Charged particles within the plasma follow helical or circular paths, critical for maintaining plasma stability.

Advanced Considerations

While the basic analysis assumes ideal conditions, real-world scenarios include additional factors:

Electric Fields and Combined Forces

- When electric fields are present, the particle undergoes more complex motion, including drift velocities.
- The combined Lorentz force becomes:

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

hence, the particle's trajectory can be a helix with a component along the electric field.

Relativistic Effects

- At high velocities approaching the speed of light, relativistic mass increase must be considered.
- The equations modify to incorporate relativistic momentum:

$$
p = \gamma m v
$$

where:

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

and c is the speed of light.

Energy Conservation and Work

- In a pure magnetic field, the particle's kinetic energy remains constant.
- If electric fields or other forces are involved, energy exchange occurs.

Conclusion and Summary

The behavior of a charged particle with a mass of 0.0020 kg in a 6.0 T magnetic field, acting at a right angle, is a classical illustration of magnetic forces influencing particle motion. The key takeaways are:

- The particle undergoes uniform circular motion due to the Lorentz force.
- The radius of the circular path is directly proportional to the particle's velocity and inversely proportional to its charge and magnetic field strength.
- The period and angular frequency depend only on the charge-to-mass ratio and magnetic field.
- Practical applications span from particle physics to astrophysics and plasma confinement.

Understanding these fundamental principles allows engineers and physicists to design devices, interpret cosmic phenomena, and manipulate particles with precision. It underscores the elegance of classical electromagnetism in describing and predicting the motion of charged particles under magnetic influences.

Note: For precise calculations, the actual charge of the particle must be known. If the charge differs from that of a proton or electron, the relevant value must be used. The general principles, however, remain consistent across different charged particles.

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