# : A Proton Is Accelerated From Rest Through 0.50 KV. It Then Enters A Uniform Magnetic Field Of 0.30

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Introduction

Understanding the behavior of charged particles, such as protons, in electric and magnetic fields is fundamental in physics, especially in areas like particle physics, electromagnetism, and applications like cyclotrons and mass spectrometers. Consider a scenario where a proton is initially at rest and is accelerated through a potential difference, then subsequently enters a uniform magnetic field. This setup allows us to explore key concepts such as kinetic energy transfer, magnetic force, circular motion, and the calculation of related parameters like velocity, radius, and period of motion.

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The Scenario in Focus

A proton is accelerated from rest through 0.50 kV. It then enters a uniform magnetic field of 0.30 T. This process involves several steps:

1. The proton gains kinetic energy due to the electric potential difference.
2. The resulting velocity of the proton is calculated.
3. When entering the magnetic field, the proton experiences a magnetic force.
4. The magnetic force causes the proton to undergo circular motion.
5. Various parameters such as radius of the circular path, period, and angular velocity are determined.

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Fundamental Concepts

Before delving into calculations, it's vital to understand some core principles:

- Electric Potential and Kinetic Energy: When a charged particle is accelerated through a potential difference, it gains kinetic energy equal to the work done by the electric field.
- Magnetic Force on Moving Charges: A moving charge in a magnetic field experiences a force perpendicular to its velocity and the magnetic field, leading to circular or helical paths.
- Centripetal Force and Circular Motion: The magnetic force acts as the centripetal force, maintaining the particle’s circular trajectory.

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Step 1: Calculating the Proton's Velocity After Acceleration

Given Data:

- Potential difference, $V = 0.50\, \text{kV} = 500\, \text{V}$
- Proton charge, $q = 1.602 \times 10^{-19}\, \text{C}$
- Proton mass, $m = 1.673 \times 10^{-27}\, \text{kg}$

Energy Conversion:

The work done on the proton:

$$\text{Work} = qV$$

which converts into kinetic energy:

$$KE = qV$$

Calculating Kinetic Energy:

$$
KE = 1.602 \times 10^{-19}\, \text{C} \times 500\, \text{V} = 8.01 \times 10^{-17}\, \text{J}
$$

Determining Velocity:

Using the kinetic energy formula:

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

$$
v = \sqrt{\frac{2 KE}{m}}
$$

$$
v = \sqrt{\frac{2 \times 8.01 \times 10^{-17}}{1.673 \times 10^{-27}}}
$$

$$
v \approx \sqrt{\frac{1.602 \times 10^{-16}}{1.673 \times 10^{-27}}}
$$

$$
v \approx \sqrt{9.58 \times 10^{10}} \approx 9.79 \times 10^{5}\, \text{m/s}
$$

Result:

The proton's velocity after acceleration is approximately 979,000 m/s.

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Step 2: Magnetic Force and Circular Motion

When the proton enters the magnetic field of 0.30 T perpendicular to its velocity:

- The magnetic force acts as the centripetal force, causing the proton to move in a circle.

Magnetic Force:

$$
F_B = q v B \sin \theta
$$

Since the velocity is perpendicular to the magnetic field:

$$
\sin \theta = 1
$$

$$
F_B = q v B
$$

Centripetal Force:

$$
F_{c} = \frac{m v^2}{r}
$$

Equating magnetic and centripetal forces:

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

Solving for radius $r$:

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

Calculating Radius:

$$
r = \frac{1.673 \times 10^{-27}\, \text{kg} \times 9.79 \times 10^{5}\, \text{m/s}}{1.602 \times 10^{-19}\, \text{C} \times 0.30\, \text{T}}
$$

$$
r \approx \frac{1.638 \times 10^{-21}}{4.806 \times 10^{-20}} \approx 0.0341\, \text{m}
$$

\]

Result:

The proton follows a circular path with a radius of approximately 3.41 cm.

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Step 3: Period and Frequency of the Proton's Motion

The period $T$ (time for one complete revolution):

$$
T = \frac{2 \pi r}{v}
$$

$$
T = \frac{2 \pi \times 0.0341\, \text{m}}{9.79 \times 10^{5}\, \text{m/s}}
$$

$$
T \approx \frac{0.214\, \text{m}}{9.79 \times 10^{5}\, \text{m/s}} \approx 2.19 \times 10^{-7}\, \text{s}
$$

The frequency $f$:

$$
f = \frac{1}{T} \approx 4.57 \times 10^{6}\, \text{Hz}
$$

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Additional Key Concepts

a. Implications of the Proton's Motion

- The radius of the proton's circular path depends directly on its velocity, magnetic field strength, and inversely on its charge and mass.
- Increasing the magnetic field strength reduces the radius, tightening the circular path.
- The high velocity indicates relativistic effects are negligible at this speed, but for higher energies, relativistic mechanics may be necessary.

b. Applications of Proton Motion in Magnetic Fields

- Cyclotrons: Accelerate protons in a spiral path using magnetic fields.
- Mass Spectrometers: Separate particles based on their mass-to-charge ratios.
- Magnetic Confinement: Used in fusion devices to contain plasma.

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Practical Considerations

- Energy Losses: In real-world setups, factors like collisions and electromagnetic interference can affect particle trajectories.
- Magnetic Field Uniformity: Ensuring a uniform magnetic field is crucial for predictable motion.
- Detection and Measurement: Devices like scintillation counters or Faraday cups can detect the particles after their circular motion.

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Summary

- A proton accelerated through 0.50 kV attains a velocity of approximately $9.79 \times 10^5$ m/s.
- Upon entering a uniform magnetic field of 0.30 T perpendicular to its velocity, it moves in a circle with a radius of about 3.41 cm.
- The period of this circular motion is approximately 0.22 microseconds, with a frequency of roughly 4.57 MHz.
- These calculations demonstrate fundamental electromagnetic principles and are pivotal in designing devices like cyclotrons, mass spectrometers, and particle accelerators.

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Conclusion

This comprehensive analysis of a proton's behavior when accelerated through a potential difference and subjected to a magnetic field underscores the interplay between electric and magnetic forces in particle dynamics. Mastery of these concepts is essential for advancements in physics research and various technological applications, highlighting the importance of precise calculations and understanding of electromagnetic principles.

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References

- Tipler, P. A., & Mosca, G. (2008). Physics for Scientists and Engineers. W. H. Freeman.
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- Halliday, D., Resnick, R., & Walker, J. (2014). Fundamentals of Physics. Wiley.

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Note: All calculations are approximate and assume ideal conditions without relativistic effects or other external influences.

# Frequently Asked Questions

## What is the kinetic energy gained by the proton after being

## accelerated through 0.50 kV?

The kinetic energy is equal to the electric potential energy: $KE = qV = (1.6 \times 10^{-19}\ C)(500\ V) = 8.0 \times 10^{-17}$ Joules.

## What is the speed of the proton after acceleration through 0.50 kV?

Using $KE = (1/2)\ mv^2$, $v = \mathrm{sqrt}(2\ KE / m)$. With $m \approx 1.67 \times 10^{-27}$ kg, $v \approx \mathrm{sqrt}(2 \times 8.0 \times 10^{-17} / 1.67 \times 10^{-27}) \approx 9.8 \times 10^4$ m/s.

## What is the radius of the proton's circular path in the magnetic field of 0.30 T?

Using $r = mv / (qB)$, $r \approx (1.67 \times 10^{-27}\ kg \times 9.8 \times 10^4\ m/s) / (1.6 \times 10^{-19}\ C \times 0.30\ T) \approx 3.4$ cm.

## How long does it take for the proton to complete one full circle in the magnetic field?

The period $T = (2\pi\ r) / v$. With $r \approx 3.4$ cm and $v \approx 9.8 \times 10^4$ m/s, $T \approx (2\pi \times 0.034\ m) / 9.8 \times 10^4\ m/s \approx 2.2\ \mu s$.

## What is the direction of the proton's circular motion in the magnetic field?

The direction is given by the right-hand rule: if the proton's velocity is initially in a certain direction and the magnetic field is perpendicular, the proton will move in a circular path perpendicular to the magnetic field, with the direction determined by the right-hand rule.

## How does increasing the magnetic field strength affect the radius of the proton's path?

The radius r is directly proportional to the magnetic field strength B; increasing B decreases r, causing the proton to follow a tighter circle.

## What is the significance of the proton being accelerated from rest through 0.50 kV in this context?

Accelerating the proton through 0.50 kV provides it with the initial kinetic energy necessary for it to follow a predictable circular path in the magnetic field, illustrating principles of electromagnetic motion and energy conversion.

# Additional Resources

Proton Acceleration and Magnetic Field Interaction: An Expert Overview

Understanding the behavior of charged particles like protons in electromagnetic fields is fundamental to numerous applications in physics, engineering, and even medical technologies. Today, we explore a scenario that combines electric acceleration with magnetic field interactions—a proton initially at rest being accelerated through a potential difference of 0.50 kV and subsequently entering a uniform magnetic field of 0.30 T. This analysis not only highlights core principles of physics but also offers insights into practical applications such as particle accelerators, magnetic resonance imaging, and space physics.

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# Introduction: The Journey of a Proton from Rest to Motion

Imagine a proton—a subatomic particle with a positive charge of approximately $+1.602 \times 10^{-19}$ coulombs—initially at rest within an experimental setup. It then encounters an electric potential difference of 0.50 kilovolts (kV), which accelerates it to a certain velocity. Following acceleration, the proton enters a region characterized by a uniform magnetic field of 0.30 Tesla (T). This sequence of events encapsulates fundamental physics concepts: energy transfer via electric potential, kinetic energy acquisition, and magnetic force interactions.

This scenario is akin to a simplified model of particle accelerators or detectors, where understanding the energy and trajectory of charged particles is crucial. Whether for probing the structure of matter or medical imaging, the principles demonstrated here form the backbone of modern technology.

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# Part 1: Accelerating the Proton Through a Potential Difference

## Understanding Electric Potential and Energy Transfer

When a proton is accelerated through an electric potential difference ($V$), it gains kinetic energy equal to the work done by the electric field. The fundamental relation is:

$$
\text{Kinetic Energy (KE)} = qV
$$

where:

- $q$ is the charge of the proton ($1.602 \times 10^{-19}$ C),
- $V$ is the potential difference (0.50 kV = 500 V).

Applying this:

$$
KE = (1.602 \times 10^{-19}\, \text{C}) \times 500\, \text{V} = 8.01 \times 10^{-17}\, \text{J}
$$

This energy corresponds to the proton's kinetic energy after acceleration.

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## Calculating the Proton's Velocity Post-Acceleration

To find the velocity ($v$) of the proton after acceleration, we use the classical kinetic energy relation:

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

where:
- $m$ is the mass of the proton (~$1.673 \times 10^{-27}$ kg).

Rearranged:

$$
v = \sqrt{\frac{2 \times KE}{m}}
$$

Plugging in the numbers:

$$
v = \sqrt{\frac{2 \times 8.01 \times 10^{-17}}{1.673 \times 10^{-27}}}
$$

$$
v = \sqrt{\frac{1.602 \times 10^{-16}}{1.673 \times 10^{-27}}}
$$

$$
v = \sqrt{9.58 \times 10^{10}}
$$

$$
v \approx 9.79 \times 10^{5}\, \text{m/s}
$$

This velocity (~979,000 m/s) is roughly 0.0033 times the speed of light, indicating non-relativistic conditions, thus classical physics suffices for this calculation.

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# Part 2: Magnetic Field Interaction — Trajectory and Force Analysis

## Entering the Magnetic Field: The Lorentz Force

Once the proton reaches the magnetic field region, its motion is governed by the Lorentz force:

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

Where:
- $q$ is the proton's charge,
- $\vec{v}$ is its velocity vector,
- $\vec{B}$ is the magnetic field vector.

Given that the proton's initial velocity is aligned perpendicular to the magnetic field, the magnetic force acts as a centripetal force, causing the proton to follow a circular trajectory.

## Determining the Proton's Radius of Curvature

The magnetic force provides the centripetal force necessary for circular motion:

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

Solving for the radius $r$:

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

Inputting known values:

$$
r = \frac{(1.673 \times 10^{-27}\, \text{kg}) \times (9.79 \times 10^{5}\, \text{m/s})}{(1.602 \times 10^{-19}\, \text{C}) \times 0.30\, \text{T}}
$$

Calculations:

$$
r = \frac{1.635 \times 10^{-21}}{4.806 \times 10^{-20}} \approx 34.0\, \text{mm}
$$

Thus, the proton will follow a circular path with a radius of approximately 34 mm upon entering the magnetic field.

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## Implications of the Proton's Trajectory

- Circular Motion: The proton describes a circular path with radius $r$. This behavior is central to devices like cyclotrons and mass spectrometers, where particle trajectories reveal information about their energies and masses.
- Direction of Motion: The force's direction is determined by the right-hand rule, pointing perpendicular to both the velocity and magnetic field vectors, resulting in uniform circular motion if the initial velocity is perpendicular to the magnetic field.
- Energy Conservation: The magnetic field does no work on the proton; it only redirects its motion. The kinetic energy remains constant within the magnetic field region.

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# Part 3: Broader Applications and Practical Considerations

## Relevance in Particle Accelerators

The principles outlined—electric acceleration followed by magnetic steering—are foundational in designing particle accelerators like cyclotrons and synchrotrons. Here, protons are accelerated to high energies and guided along circular paths, enabling collision experiments that probe the fundamental structure of matter.

Key design considerations include:

- Precise control of electric potentials to achieve desired energies.
- Magnetic field uniformity to maintain stable trajectories.
- Managing relativistic effects at higher energies.

## Medical and Technological Applications

- Proton Therapy: Medical radiation therapy uses proton beams for cancer treatment, relying on precise energy control and magnetic steering to target tumors while sparing healthy tissue.

- Mass Spectrometry: Magnetic fields are employed to separate ions based on their mass-to-charge ratios, critical in chemical analysis and biochemistry.

### Limitations and Assumptions

- The calculations assume non-relativistic physics; at higher energies, relativistic effects alter mass and velocity.
- The magnetic field is considered uniform, which simplifies real-world complexities.
- External factors like air resistance or field imperfections are neglected in this idealized model.

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## Conclusion: A Microcosm of Electromagnetic Principles in Action

This exploration of a proton accelerated through 0.50 kV and entering a 0.30 T magnetic field exemplifies the elegance of electromagnetic physics. The energy transfer from electric potential to kinetic energy, coupled with magnetic forces dictating the particle’s trajectory, provides a clear illustration of fundamental concepts that underpin a wide array of scientific and technological innovations.

From the calculations showing the proton's velocity and path to real-world applications in medicine and research, this scenario encapsulates the power of physics to explain and harness the behavior of particles at the microscopic level. Whether in the quest to understand the universe or to develop advanced medical treatments, the principles demonstrated here are central to progress in science and engineering.

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In essence, the journey of this proton—from rest, through acceleration, to magnetic deflection—serves as a compelling testament to the intertwined nature of electric and magnetic phenomena, showcasing their vital role in our understanding and manipulation of the microscopic world.

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