JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
**Volume 15 Issue 05, May 2025**
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

# UNDERSTANDING MAGNETIC FIELDS: THEIR ESSENCE AND SCIENTIFIC FOUNDATIONS FOR STUDENTS.

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**Abstract:** Magnetic fields are fundamental to understanding numerous physical phenomena, from compass navigation to advanced technologies like MRI machines. This article provides an accessible explanation of magnetic fields, their properties, and their significance for secondary and undergraduate students. It explores the essence of magnetic fields as invisible forces generated by moving charges, their mathematical representation, and their applications. Contributions from scientists such as Hans Christian Ørsted, Michael Faraday, and James Clerk Maxwell are highlighted to contextualize the historical development of the field. The article incorporates qualitative descriptions, quantitative examples, and real-world applications to foster student engagement. An educational approach emphasizing inquiry-based learning is proposed to deepen students' understanding of magnetism.

**Keywords:** magnetic field, electromagnetism, magnetic force, Ørsted, Faraday, Maxwell, physics education

A magnetic field is an invisible force field surrounding magnets or electric currents, influencing charged particles and magnetic materials. Understanding magnetic fields is crucial for students studying physics, as they underpin technologies like electric motors, transformers, and medical imaging devices (Feynman, 1963). This article aims to demystify magnetic fields for students by explaining their essence, properties, and historical development through the contributions of pioneering scientists. By blending qualitative explanations with simple quantitative examples, the article seeks to make the topic accessible and engaging.

A magnetic field is a vector field that exerts a force on moving electric charges and magnetic materials. It is generated by:

- Permanent magnets, such as bar magnets, where aligned electron spins create a net magnetic effect.
- Electric currents, where moving charges (e.g., electrons in a wire) produce a magnetic field.

The strength and direction of a magnetic field are described by the magnetic field strength, B, measured in teslas (T). The field's direction is defined as the path a compass needle's north pole would follow.

Magnetic fields exhibit key properties:

- They form closed loops, with no true starting or ending point (unlike electric fields).
- They exert forces perpendicular to the velocity of a moving charge, as described by the Lorentz force law: $F = q(v \times B)$, where F is the force, q is the charge, v is the velocity, and B is the magnetic field vector (Griffiths, 2017).
- They can be visualized using magnetic field lines, where density indicates strength and arrows show direction.

Hans Christian Orsted (1820): Ørsted discovered that an electric current produces a magnetic field, establishing the link between electricity and magnetism. His experiments showed a compass needle deflecting near a current-carrying wire, laying the foundation for

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electromagnetism (Dibner, 1961).
Michael Faraday (1831): Faraday introduced the concept of magnetic fields and demonstrated electromagnetic induction, where a changing magnetic field induces an electric current. His work on field lines provided a visual framework for understanding magnetic interactions (Faraday, 1839).
James Clerk Maxwell (1865): Maxwell unified electricity and magnetism through his equations, describing magnetic fields mathematically. His work predicted electromagnetic waves, linking magnetic fields to light propagation (Maxwell, 1865).
To engage students, teachers can use analogies: a magnetic field is like an invisible “force bubble” around a magnet, pushing or pulling other magnets or charged particles. Demonstrations, such as sprinkling iron filings around a bar magnet to show field lines or using a compass to trace field directions, make the concept tangible. Real-world examples, like Earth’s magnetic field guiding migratory birds or protecting us from solar radiation, connect theory to practice.
For students with basic algebra skills, introduce simple calculations:
Magnetic force on a current-carrying wire: The force on a wire of length L carrying current I in a magnetic field B is $F = I L B \sin\theta$, where $\theta$ is the angle between the wire and field. For example, a 0.1 m wire with 2 A current in a 0.5 T field at 90° experiences $F = 2 \times 0.1 \times 0.5 \times 1 = 0.1$ N.
Magnetic field due to a current: A long, straight wire carrying current I produces a magnetic field at distance r, given by $B = (\mu_0 I)/(2\pi r)$, where $\mu_0 = 4\pi \times 10^{-7}$ T·m/A is the permeability of free space. For I = 10 A and r = 0.02 m, $B = (4\pi \times 10^{-7} \times 10)/(2\pi \times 0.02) = 10^{-4}$ T.
Inquiry-based learning encourages students to explore magnetic fields through experiments, such as building simple electromagnets or measuring field strength with sensors. Group discussions on applications (e.g., MRI machines, maglev trains) foster critical thinking. Teachers should address misconceptions, like confusing magnetic and electric fields, by emphasizing their distinct properties (Serway & Jewett, 2018).
Magnetic fields are integral to modern technology:
- Medical imaging: MRI scanners use strong magnetic fields (1–3 T) to align atomic nuclei, enabling detailed imaging.
- Energy generation: Generators rely on electromagnetic induction to convert mechanical energy into electricity.
- Transportation: Maglev trains use magnetic fields for levitation and propulsion, achieving high speeds with minimal friction.

These examples highlight the practical importance of magnetic fields, motivating students to appreciate their study (Halliday et al., 2014).
Magnetic fields, as invisible yet powerful forces, are a cornerstone of physics with wide-ranging applications. By leveraging the foundational work of Ørsted, Faraday, and Maxwell, educators can explain their essence through engaging demonstrations, mathematical examples, and real-world connections. An inquiry-based approach enhances student understanding, making magnetic fields accessible and relevant. Future educational research could explore integrating computational tools, like simulations, to further enrich learning experiences.
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