Chapter 19 Magnetism

Magnetic Field
Electric Current and Magnetic field
Force on an Electric Current in a Magnetic Field
Force on an Moving Electric Charge in a Magnetic Field

Magnetic Resonance Imaging (MRI)

An imaging technique used primarily in medical settings to produce high quality images of the inside of the human body. MRI is based on the principles of nuclear magnetic resonance (NMR).

The human body is primarily fat and water. Fat and water have many hydrogen atoms which make the human body approximately 63% hydrogen atoms. Hydrogen nuclei have an NMR signal. For these reasons magnetic resonance imaging primarily images the NMR signal from the hydrogen nuclei.

National High Magnetic Field Laboratory
Tallahassee, Florida
Magnetic Force

The forces that come into being when electric currents interact are called magnetic forces, or magnetic forces arise from the interactions of moving charges. (The electrical force is between two charges at rest)

There is only a single interaction between charges, electromagnetic interaction. It is always possible to separate the force on a charge into an electric part, which is independent of its motion, and a magnetic part, which is proportional to its speed relative to the observer.

Earth's Magnetic Field

- The Earth’s magnetic field resembles that achieved by burying a huge bar magnet deep in the Earth’s interior

The combination of heat and the Earth’s rotation makes the molten outer core swirl around, creating massive electrical currents that generates the magnetic field by the electromagnetic effect.
A Moving Charge in Magnetic Field

Magnetic field, $B$, is defined in terms of the magnetic force $F$ on a moving charge:

- Magnetic field magnitude: $B = \frac{F}{Qv\sin\theta}$ or $F = BQv\sin\theta$

(electric field: $E = \frac{F}{Q}$)

No force acts on a charge moving in the direction of $B$ ($Q = 0$)

$F_{\text{max}} = BQv$ if $\theta = 90^\circ$ or $\sin\theta = 1$

Direction of $B$: Right-hand rule

Unit: 1 tesla $= 1$ T $= 1$ N/A·m ($1\ T = 10^4$ gauss ($G$))

The magnitude of the earth's $B$ is $3 \times 10^{-5}$ T

Engineer Nikola Tesla (1856-1943)

Quick Quiz 19.1

A charged particle moves in a straight line through a certain region of space. The magnetic field in that region (a) has a magnitude of zero, (b) has a zero component perpendicular to the particle's velocity, or (c) has a zero component parallel to the particle's velocity.

Quick Quiz 19.1 Answer

(b). The force that a magnetic field exerts on a charged particle moving through it is given by $F = qvB \sin \theta = qvB_z$, where $B$ is the component of the field perpendicular to the particle's velocity. Since the particle moves in a straight line, the magnetic force (and hence $B$, since $qv \neq 0$) must be zero.

Quick Quiz 19.2

The north-pole end of a bar magnet is held near a stationary positively charged piece of plastic. Is the plastic (a) attracted, (b) repelled, or (c) unaffected by the magnet?
**QUICK QUIZ 19.2 ANSWER**

(c). The magnetic force exerted by a magnetic field on a charge is proportional to the charge’s velocity relative to the field. If the charge is stationary, as in this situation, there is no magnetic force.

**Question:** An electron traveling horizontally enters a region where a uniform magnetic field is directed into the plane of the paper as shown. Which one of the following phrases most accurately describes the motion of the electron once it has entered the field?

(a) upward and parabolic
(b) upward and circular
(c) downward and circular
(d) upward, along a straight line
(e) downward and parabolic

**Question:** All magnetic fields originate in

(a) iron
(b) permanent magnets
(c) magnetic domains
(d) moving electric charges

Answer: d

**Question:** Magnetic fields do not interact with

(a) stationary electric charges
(b) moving electric charges
(c) stationary permanent magnets
(d) moving permanent magnets

Answer: a

**QUICK QUIZ 19.3**

As a charged particle moves freely in a circular path in the presence of a constant magnetic field applied perpendicular to the particle’s velocity, its kinetic energy (a) remains constant, (b) increases, or (c) decreases.

**QUICK QUIZ 19.3 ANSWER**

(a). The magnetic force acting on the particle is always perpendicular to the velocity of the particle, and hence to the displacement the particle is undergoing. Under these conditions, the force does no work on the particle and the particle’s kinetic energy remains constant.
Two charged particles are projected into a region in which a magnetic field is perpendicular to their velocities. After they enter the magnetic field, you can conclude that (a) the charges are deflected in opposite directions, (b) the charges continue to move in a straight line, (c) the charges move in circular paths, or (d) the charges move in circular paths but in opposite directions.

(c). Anytime the velocity of a charged particle is perpendicular to the magnetic field, it will follow a circular path. The two particles will move in opposite directions around their circular paths if their charges have opposite signs, but their charges are unknown so (d) is not an acceptable answer.

Example: Alpha particles of charge q=+2e and mass m=6.6x10^-27 kg and emitted from a radioactive source at a speed of 1.6x10^7 m/s. What magnetic field strength would be required to bend these into a circular path of radius r=0.25 m?

Solution: To have a circular path, the magnetic field has to be perpendicular to the velocity, i.e. Θ=90° or sinΘ=1. The magnetic force provides the centripetal acceleration:

qvB=mv^2/r

thus

B=mv^2/rqv

=(6.6x10^-27 kg)(1.6x10^7 m/s)^2/(0.25m)(2x1.6x10^-19C)(1.6x10^7 m/s)

=1.3 T

Question: Can you set a resting electron into motion with a magnetic field? With an electric field?

Answer: The magnetic force on the electron is zero since v=0 (F=qvBsinΘ). An electric field will accelerate the electron.

Which one of the following statements concerning the magnetic force on a charged particle in a magnetic field is true?

(a) It is a maximum if the particle is stationary.
(b) It is zero if the particle moves perpendicular to the field.
(c) It is a maximum if the particle moves parallel to the field.
(d) It acts in the direction of motion for a positively charged particle.
(e) It depends on the component of the particle's velocity that is perpendicular to the field.

A charged particle is moving in a uniform, constant magnetic field. Which one of the following statements concerning the magnetic force exerted on the particle is false?

(a) It does no work on the particle. X
(b) It increases the speed of the particle. X
(c) It changes the velocity of the particle.
(d) It can act only on a particle in motion.
(e) It does not change the kinetic energy of the particle. X
An Electric Current in a Magnetic Field

A magnet exerts a magnetic force on a current-carrying wire:

\[ B = \frac{F}{I \sin \Theta} \quad \text{or} \quad F = I l B \sin \Theta \]

(for moving charge \( F = q v B \sin \Theta \))

Direction: Right-hand rule

\( F = 0 \) when \( \Theta = 0^\circ \)

\( F_{\text{max}} = I l B \) when \( \Theta = 90^\circ \)

Example: The force on a wire carrying 25 A is a maximum of 4.14 N when placed between the pole faces of a magnet. If the pole faces are 22 cm in diameter, what is the approximate strength of the magnetic field?

Solution: A maximum \( F \) means \( \sin \Theta = 1 \), or \( \Theta = 90^\circ \)

\[ F_{\text{max}} = I l B \text{ or } B = \frac{F_{\text{max}}}{I l} = \frac{4.14 \text{ N}}{(25 \text{ A})(0.22 \text{ m})} = 0.753 \text{ T} \]