CHAPTERS 27 AND 28 NOTES

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Contents

27 Magnetic Field and Magnetic Forces

But the *fundamental* nature of magnetism is the interaction of moving electric charges. Unlike electric forces, which act on electric charges whether they are moving or not, magnetic forces act only on *moving charges.*

27.1 Magnetism.

Remark. The earth itself is a magnet. Its north geographic pole is close to a magnetic south pole, which is why the north pole of a compass needle points north. The earth's magnetic axis is not quite parallel to its geographic axis (the axis of ro- tation), so a compass reading deviates somewhat from geographic north. This deviation, which varies with location, is called *magnetic declination or magnetic variation.*

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Remark. While isolated positive and negative charges exist, there is no experimental evidence that one isolated magnetic pole exists; poles always appear in pairs. If a bar magnet is broken in two, each broken end becomes a pole

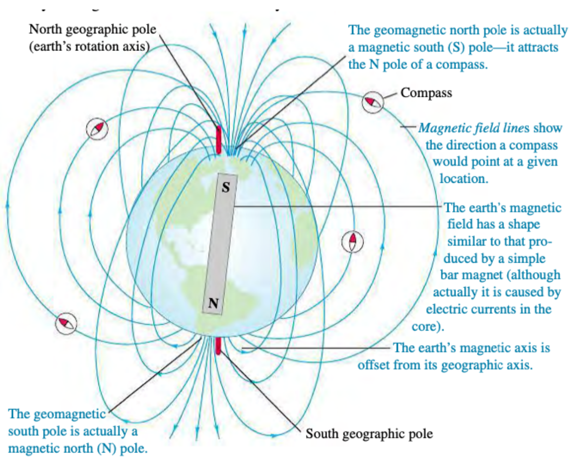

FIGURE 1. Depiction of Magnetic Field

27.2 Magnetic Field.

Definition 1. Summary of Electric interactions:

(1) A distribution of electric charge creates an electric field $\vec{E}$ in the surrounding space.
(2) The electric field exerts a force $\vec{F} = q\vec{E}$ on any other charge q that is present in the field.

Definition 2. Summary of Magnetic interactions:

(1) A moving charge or a current creates a **magnetic field (B)** in the surrounding space (in addition to its *electric* field).
(2) The magnetic field exerts a force $\vec{F}$ on any other moving charge or current that is present in the field.

Magnetic Field strength can be found by the equation

$$B = \frac{\mu_0 I}{2\pi r}$$

where μ_0 is the permeability of free space$(4\pi \cdot 10^{-7}\ T \cdot m/A)$ and r is the seperation.

Remark. Like electric field, magnetic field is a vector field–that is, a vector quantity associated with each point in space. We will use the symbol $\vec{B}$ for magnetic field.

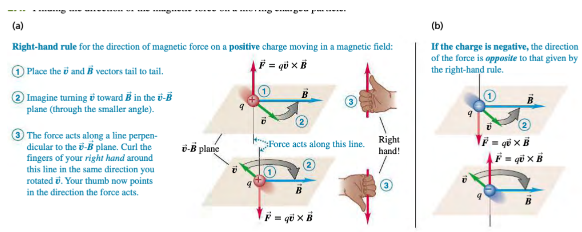

FIGURE 2. Right-Hand Rule

27.2.1 Magnetic Forces on Moving Charges.

Definition 3. Key Characteristics of Magnetic Force on Moving Charges:

(1) Force Magnitude is proportional to the magnitude of the charge.
(2) The magnitude of the force is also propor- tional to the magnitude, or "strength," of the field.
(3) The magnetic force depends on the particle's velocity.
(4) The magnetic force $\vec{F}$ does not have the same direction as the magnetic field $\vec{B}$ but instead is always perpendicular to both $\vec{B}$ and the velocity $\vec{v}$.

The Magnetic force can be found by the equation

$$F = |q|v \times B = |q|vBsin\phi$$

where ϕ is the angle between the direction of velocity and direction of the magnetic field and the magnitude is measured in teslas ($1T = 1N/A \cdot m$) or in Gauss(1G = 10^{-4}T)

Remark. The magnetic field of the earth is 10^{-4}T 1 Gauss.

Remark. When a charged particle moves through a region of space where both electric and magnetic fields are present, *both fields exert forces on the particle*. The total force $\vec{F}$ is the vector sum of the electric and magnetic forces:

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

27.3 Magnetic Field Lines and Magnetic Flux.

Definition 4. Magnetic Field Lines: Just like an electric field, a magnetic field can be represented through field lines. The more lines there are in a given area the stronger the field , and they never intersect. Magnetic Field Lines are not lines of force, just direction.

Definition 5. Magnetic Flux(Φ_B): A measurement of the total magnetic field which passes through a given area. The total magnetic flux through the surface is the sum of the contributions from the individual area elements. Can be found using the following equation:

$$\Phi_B = \int B cos\phi dA = \int \vec{B} \cdot d\vec{A}$$

Magnetic Flux is scalar and its units are Weber(1 Wb = 1 $T \cdot m^2 = 1$ $N \cdot m/A$)

27.4 Motion of Charged Particles in a Magnetic Field.

Remark. Motion of a charged particle under the action of a magnetic field alone is always motion with constant speed.

Remark. When velocity and magnetic field are perpendicular, the particle exhibits circular motion. This relation is shown by

$$F = |q|vb = m\frac{v^2}{R}$$

whose radius can be found by

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

and whose angular speed can be found by

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

27.5 Applications of Motion of Charged Particles.

27.5.1 Velocity Selector.

Definition 6. Velocity Selector: An arrangement of electric and magnetic fields that can be used to select only particles of a specific speed. Only particles with speed equal to E/B can pass through without being deflected, and this process works for electrons and protons.

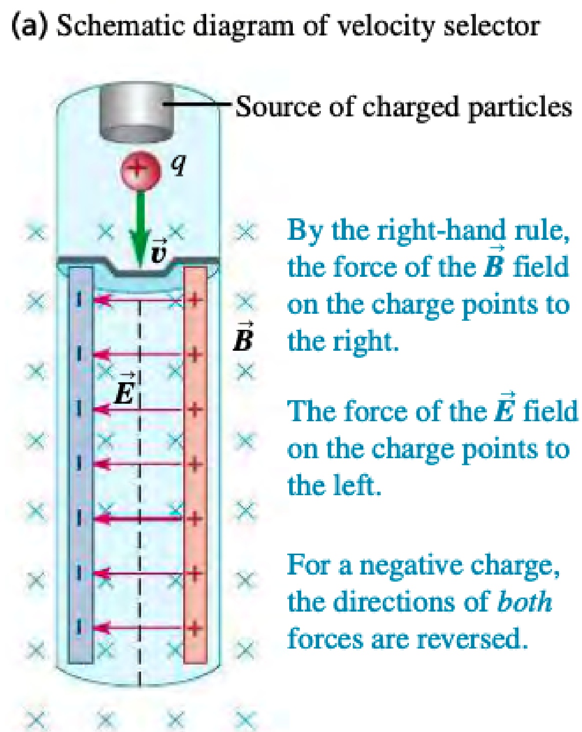

FIGURE 3. Model of Velocity Selector

27.6 Magnetic Force on a current-carrying Conductor.

Remark. Magnetic fields are caused by moving charges, and thus exist around a current carrying wire. We can manipulate the equation for single charges for currents, $\vec{F} = |q|vBsin\phi$, by factoring that the total force would be the force per charge multiplied by the amount of charges in the wire:

$$\vec{F} = |q|vBsin\phi = (nAl)(qvBsin\phi) = IlBsin\phi$$

and for infinitesmal wire segments:

$$d\vec{F} = Id\vec{l} \times \vec{B}$$

27.27 Magnetic field $\vec{B}$, length $\vec{l}$, and force $\vec{F}$ vectors for a straight wire carrying a current I.

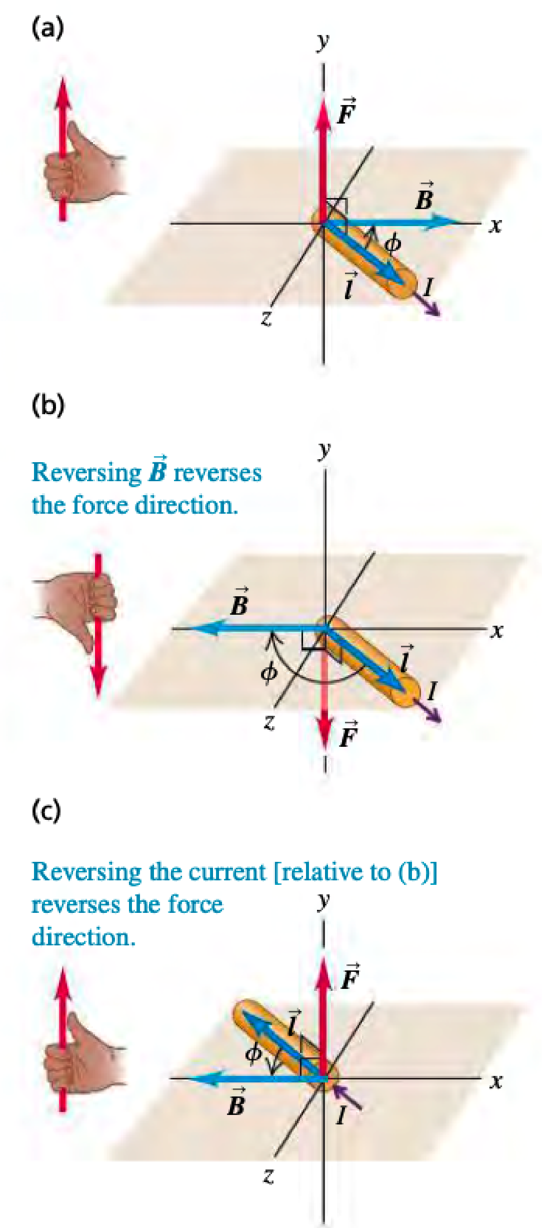

FIGURE 4. Right-Hand Rule for a Current-Carrying Wire

27.7 Force and Torque on a Current Loop.

Remark. The net force on a current loop in a uniform magnetic field is zero. However, the net torque is not in general equal to zero.

Definition 7. Torque on a Current Loop (τ): In a uniform field the total force is zero but torque is not necessary, as in a dipole. The magnitude of the magnetic torque can be found using the equation

$$\tau = IBAsin\phi$$

where A is the area of the loop within the field and ϕ is the area normal to loop plane and field direction.

Definition 8. Magnetic Dipole Moment(μ): Also called the **Magnetic Moment**, this is the product IA and is analogous to the electric dipole moment by having a north and south poles. A current loop or any body that experiences a magnetic torque is called a **Magnetic Dipole**.

27.7.1 Potential Energy for a Magnetic Dipole.

Definition 9. Potential Energy for a Magnetic Dipole(U): When a dipole changes orientation the field does work on it. Because potential energy is the negative of total work, the equation for finding U is the parallel of the potential energy in an electric field:

$$U = -\vec{\mu} \cdot \vec{B} = -\mu Bcos\phi$$

where ϕ is the angle between μ and B.

27.7.2 Magnetic torque: Loops and Coils.

Definition 10. Solenoid: A helical winding of wire, such as a coil wound on a circular cylinder. The total torque on a solenoid in a megnetic field is the sum of the torques of the individual turns, or

$$\tau = NIABsin\phi$$

where ϕ is the angle between the axis of the solenoid and the direction of the field.

27.8 Direct-Current Motor.

Definition 11. Parts of Motor: The moving part of the motor is the *rotor*, a length of wire formed into an open-ended loop and free to rotate about an axis. The ends of the rotor wires are attached to circular conducting segments that form a *commutator*.

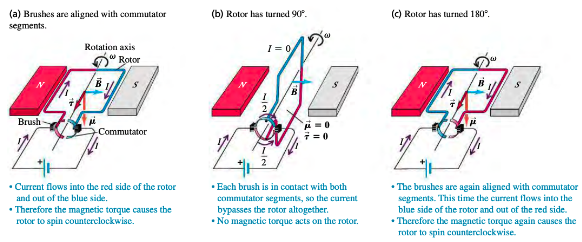

Figure 5. Model of a Motor

Remark. In a dc motor a magnetic field exerts a torque on a current in the rotor. Motion of the rotor through the magnetic field causes an induced emf called a back emf. For a series motor, in which the rotor coil is in series with coils that produce the magnetic field, the terminal voltage is the sum of the back emf and the drop Ir across the internal resistance.

27.9 The Hall Effect.

Definition 12. The Hall Effect: A potential difference perpendicular to the direction of current in a conductor, when the conductor is placed in a magnetic field. The Hall potential is determined by the requirement that the associated electric field must just balance the magnetic force on a moving charge. Hall-effect measurements can be used to determine the sign of charge carriers and their concentration n.

$$nq = \frac{-J_x B_y}{E_z}$$

where J_x is the current density or I/A

28 Sources of Magnetic Field