

## CHAPTERS 27 AND 28 NOTES

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### 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 rotation), 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

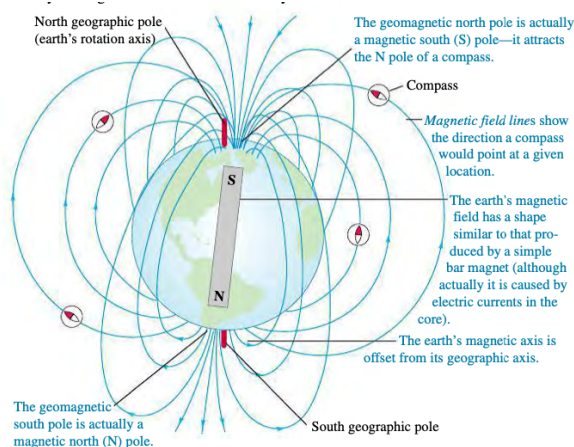


FIGURE 1. Depiction of Magnetic Field

## 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** ( $\mathbf{B}$ ) 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  $\mu_0$  is the permeability of free space ( $4\pi \cdot 10^{-7} \text{ T} \cdot \text{m/A}$ ) and  $r$  is the separation.

**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.

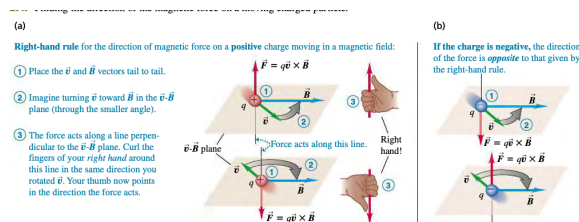


FIGURE 2. Right-Hand Rule

### 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 proportional 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

$$F = |q|v \times B = |q|vB\sin\phi$$

where  $\phi$  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( $\Phi_B$ ):** 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 · m<sup>2</sup> = 1 N · 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.

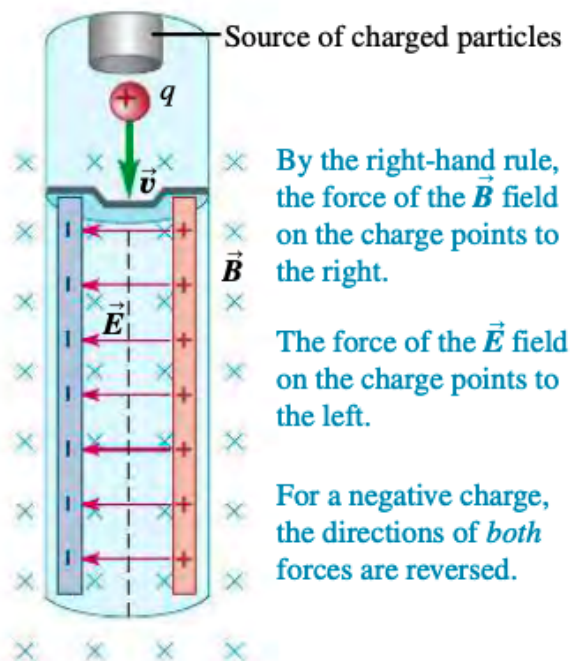
**(a) Schematic diagram of velocity selector**

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,  $\vec{F} = |q|vB\sin\phi$ , by factoring that the total force would be the force per charge multiplied by the amount of charges in the wire:

$$\vec{F} = |q|vB\sin\phi = (nAl)(qvB\sin\phi) = IlB\sin\phi$$

and for infinitesimal 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  $I$ .

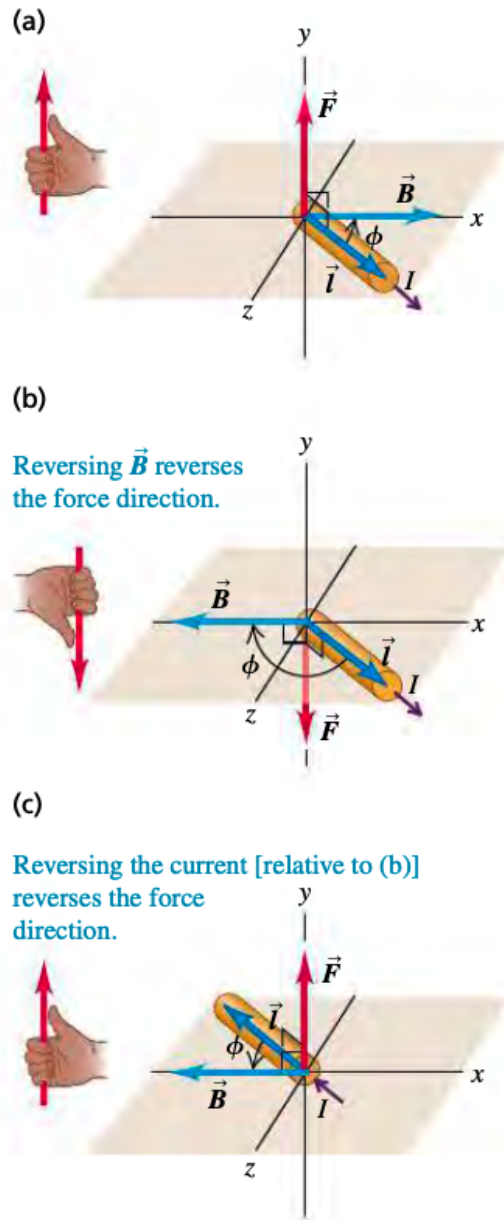


FIGURE 4. Right-Hand Rule for a Current-Carrying Wire

### 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 ( $\tau$ ):** 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  $\phi$  is the area normal to loop plane and field direction.

**Definition 8. Magnetic Dipole Moment( $\mu$ ):** 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:

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

where  $\phi$  is the angle between  $\mu$  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 magnetic field is the sum of the torques of the individual turns, or

$$\tau = NIABsin\phi$$

where  $\phi$  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*.

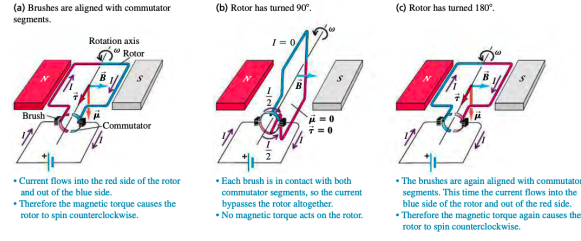


FIGURE 5. Model of a Motor

**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  $n$ .

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