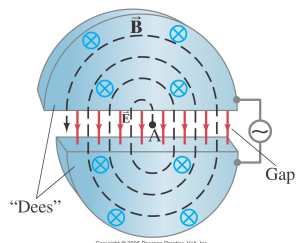


Chapter 27 Magnetism



Units of Chapter 27

- 27.1 Magnets and Magnetic Fields
- 27.2 Electric Currents Produce Magnetic Fields
- 27.3 Force on an Electric Current in a Magnetic Field; Definition of B: 1 & 2
- 27.4 Force on Electric Charge Moving in a Magnetic Field: 3, 4, 5, 6, & 7

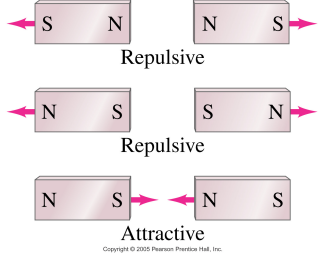
Units of Chapter 27

- 27.5 Torque on a Current Loop; Magnetic Dipole Moment: 8 & 9
- 27.6 Applications: Galvanometers, Motors, Loudspeakers: 10
- †27.7 Discovery and Properties of the Electron: 11 & 12
- †27.8 The Hall Effect: 13
- 27.9 Mass Spectrometer: 14 & 15

27.1 Magnets and Magnetic Fields

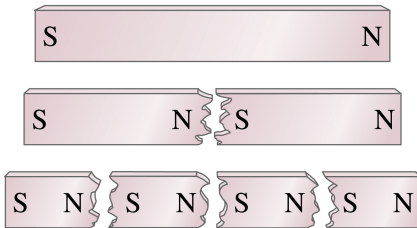
Magnets have two ends – poles – called north and south.

Like poles repel; unlike poles attract.



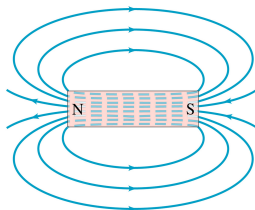
27.1 Magnets and Magnetic Fields

However, if you cut a magnet in half, you don't get a north pole and a south pole – you get two smaller magnets.



27.1 Magnets and Magnetic Fields

Magnetic fields can be visualized using magnetic field lines, which are always closed loops.

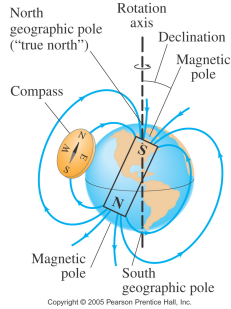


(b)
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27.1 Magnets and Magnetic Fields

The Earth's magnetic field is similar to that of a bar magnet.

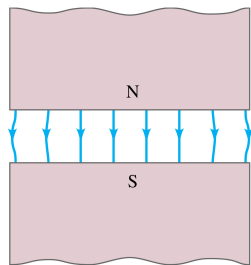
Note that the Earth's "North Pole" is really a south magnetic pole, as the north ends of magnets are attracted to it.



27.1 Magnets and Magnetic Fields

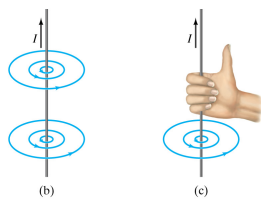
A uniform magnetic field is constant in magnitude and direction.

The field between these two wide poles is nearly uniform.



27.2 Electric Currents Produce Magnetism

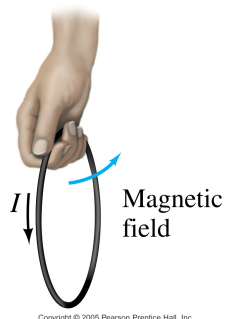
Experiment shows that an electric current produces a magnetic field.



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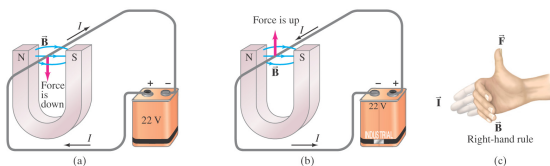
27.2 Electric Currents Produce Magnetism

The direction of the field is given by a right-hand rule.



27.3 Force on an Electric Current in a Magnetic Field; Definition of B

A magnet exerts a force on a current-carrying wire. The direction of the force is given by a right-hand rule.



27.3 Force on an Electric Current in a Magnetic Field; Definition of B

The force on the wire depends on the current, the length of the wire, the magnetic field, and its orientation.

$$F = I l B \sin \theta$$

This equation defines the magnetic field B.

27.3 Force on an Electric Current in a Magnetic Field; Definition of B

Unit of B: the tesla, T.
 $1 \text{ T} = 1 \text{ N/A}\cdot\text{m}$.

Another unit sometimes used: the gauss (G).
 $1 \text{ G} = 10^{-4} \text{ T}$.

27.4 Force on Electric Charge Moving in a Magnetic Field

The force on a moving charge is related to the force on a current:

$$F = qvB \sin \theta$$

Once again, the direction is given by a right-hand rule.

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27.4 Force on Electric Charge Moving in a Magnetic Field

If a charged particle is moving perpendicular to a uniform magnetic field, its path will be a circle.

Path of electron \vec{B} is into the page




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27.4 Force on Electric Charge Moving in a Magnetic Field

Problem solving: Magnetic fields – things to remember

1. The magnetic force is perpendicular to the magnetic field direction.
2. The right-hand rule is useful for determining directions.
3. Equations in this chapter give magnitudes only. The right-hand rule gives the direction.

27.4 Force on Electric Charge Moving in a Magnetic Field

Summary of Right-hand Rules (= RHR)			
Physical Situation	Example	How to Orient Right Hand	Result
1. Magnetic field produced by current (RHR-1)		Wrap fingers around wire with thumb pointing in direction of current I	Fingers point in direction of B
2. Force on electric current I due to magnetic field (RHR-2)		Fingers point straight along current I , then bent along magnetic field B	Thumb points in direction of force
3. Force on electric charge $+q$ due to magnetic field (RHR-3)		Fingers point along particle's velocity v , then along B	Thumb points in direction of force

27.5 Torque on a Current Loop; Magnetic Moment

The forces on opposite sides of a current loop will be equal and opposite (if the field is uniform and the loop is symmetric), but there may be a torque.

The magnitude of the torque is given by:

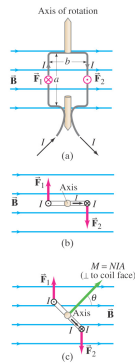
$$\tau = NIAB \sin \theta$$

The quantity $NI A$ is called the magnetic dipole moment, μ :

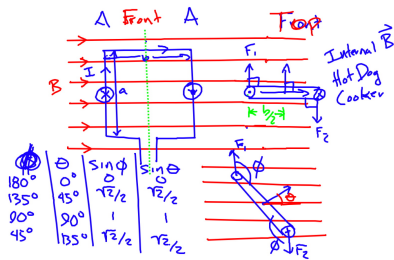
$$\mu = NI A$$

27.5 Torque on a Current Loop; Magnetic Moment

The forces on opposite sides of a current loop will be equal and opposite (if the field is uniform and the loop is symmetric), but there may be a torque.



27.5 Torque on a Current Loop; Magnetic Moment: Magnetic Dipole



27.5 Torque on a Current Loop; Magnetic Moment: Magnetic Dipole

$F = I l B \sin \theta$
 $l = a$
 $F_1 = I a B$
 $F_2 = I a B$

$ab = A_{loop}$

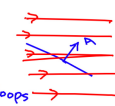
$\tau = r \times F = r F \sin \phi$ (Recall $\sin \phi = \sin \theta$)
 $\tau_1 = \frac{1}{2} I a B \sin \theta$ $\tau_2 = \frac{1}{2} I a B \sin \theta$
 $\tau = \tau_1 + \tau_2 = \frac{1}{2} I a B \sin \theta + \frac{1}{2} I a B \sin \theta = I a B \sin \theta = I A_{loop} B \sin \theta = I A_{loop} \times B$

27.5 Torque on a Current Loop; Magnetic Moment: Magnetic Dipole

$$\tau = IA_{loop} \times B$$
 For a coil of wire w/ N loops

$$\tau_{net} = N IA_{loop} \times B = \mu \times B$$
 * Magnetic Dipole Moment: " μ "

$$\tau_{net} = \vec{p} \times \vec{E}$$



27.5 Torque on a Current Loop; Magnetic Moment: Magnetic Dipole

$$\int_{\theta_0}^{\theta} U = \int \tau d\theta = \int NIAB \sin\theta d\theta$$

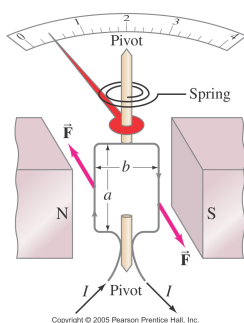
$$U - U_0 = -NIAB \cos\theta + C$$
 We choose $U_0 = 0$ at $\cos\theta_0 = 0$

$$U - 0 = -NIAB \cos\theta - (-NIAB \cos\theta_0)$$

$$U = -NIAB \cos\theta = -\mu B \cos\theta = -\mu B$$
 (our mag. current loops, compass)

27.6 Applications: Galvanometers, Motors, Loudspeakers

A galvanometer takes advantage of the torque on a current loop to measure current.



27.6 Applications: Galvanometers, Motors, Loudspeakers

Additional Notes Online

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27.6 Applications: Galvanometers, Motors, Loudspeakers: Galvanometers

Galvanometers

$$\tau_{loop} = NIAB \sin \theta$$

$\tau_{spring} = k \phi$ (Hooke's Law) *stays constant*

$$k \phi = NIAB \sin \theta \Rightarrow \phi = \frac{NIAB \sin \theta}{k} \phi \propto I$$

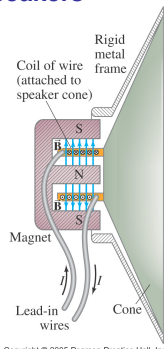
27.6 Applications: Galvanometers, Motors, Loudspeakers

An electric motor also takes advantage of the torque on a current loop, to change electrical energy to mechanical energy.

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27.6 Applications: Galvanometers, Motors, Loudspeakers

Loudspeakers use the principle that a magnet exerts a force on a current-carrying wire to convert electrical signals into mechanical vibrations, producing sound.



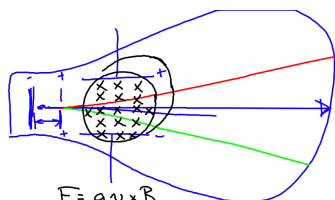
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27.7 Discovery and Properties of the Electron

Thomson, The Cathode Ray Tube, Charge to Mass Ratio, and Millikan's Oil Drop Experiment

Additional Notes online

27.7 Discovery and Properties of the Electron: JJ Thomson



$$F = qv \times B$$

$$F = qE$$

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

27.7 Discovery and Properties of the Electron: Charge-to-Mass Ratio

$$F = qvB = -evB$$

$$F = \frac{mv^2}{r} \quad F = q(E + v \times B)$$

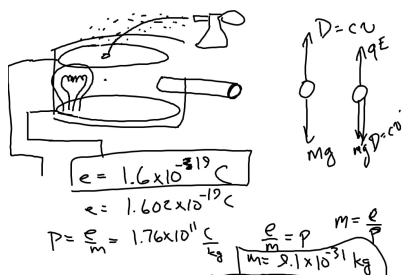
$$\frac{mv^2}{r} = evB \quad F_n = qE$$

$$\frac{e}{m} = \frac{v}{rB} \quad F_d = qvB$$

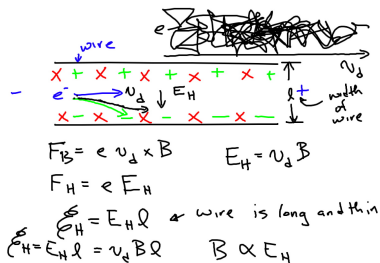
$$\frac{e}{m} = \frac{E}{B^2 r} = 1.76 \times 10^{11} \frac{C}{kg}$$

$$qE = qvB \Rightarrow v = \frac{E}{B}$$

27.7 Discovery and Properties of the Electron: Millikan's Oil Drop Experiment



27.8 The Hall Effect



27.8 The Hall Effect

IMPORTANT NOTE: n is equal to the number of free electrons per unit volume (aka. Free Electron Density). It is NOT the number of electrons!

$$I = \frac{\Delta Q}{\Delta t} = -n e A v_d$$

Macroscopic $V = IR$
 Ohm's law $\vec{j} = \frac{1}{R} \vec{E}$ \vec{E} Field $\vec{E} = \vec{j} \rho$
 \uparrow current density \uparrow resistivity \uparrow Before there was \vec{j}

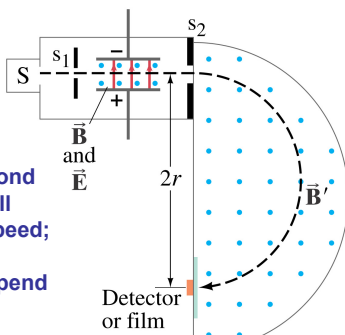
27.9 Mass Spectrometer

A mass spectrometer measures the masses of atoms. If a charged particle is moving through perpendicular electric and magnetic fields, there is a particular speed at which it will not be deflected:

$$v = \frac{E}{B}$$

27.9 Mass Spectrometer

All the atoms reaching the second magnetic field will have the same speed; their radius of curvature will depend on their mass.



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27.9 Mass Spectrometer

I.P. MS

$qE = qvB$
 $v = \frac{E}{B}$
1836

All the atoms reaching the second magnetic field will have the same speed; their radius of curvature will depend on their mass.

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

$\frac{2}{183}$

S, s₁, s₂, Fe, B, E, 2r, Detector or film, 235, 238

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Summary of Chapter 27

- Magnets have north and south poles
- Like poles repel, unlike attract
- Unit of magnetic field: tesla
- Electric currents produce magnetic fields
- A magnetic field exerts a force on an electric current:

$$F = I l B \sin \theta$$

Summary of Chapter 27

- A magnetic field exerts a force on a moving charge:

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

- Torque on a current loop:

$$\tau = N I A B \sin \theta$$
