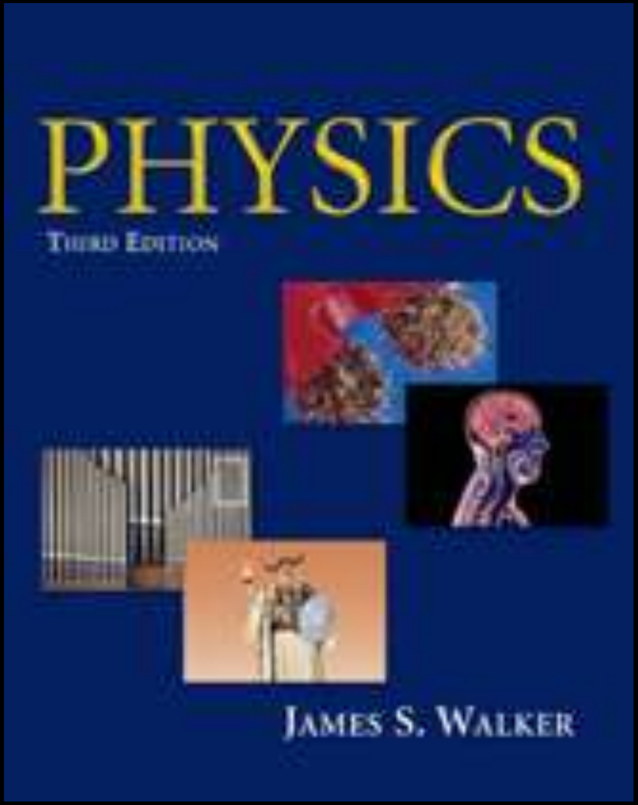


Lecture Outlines

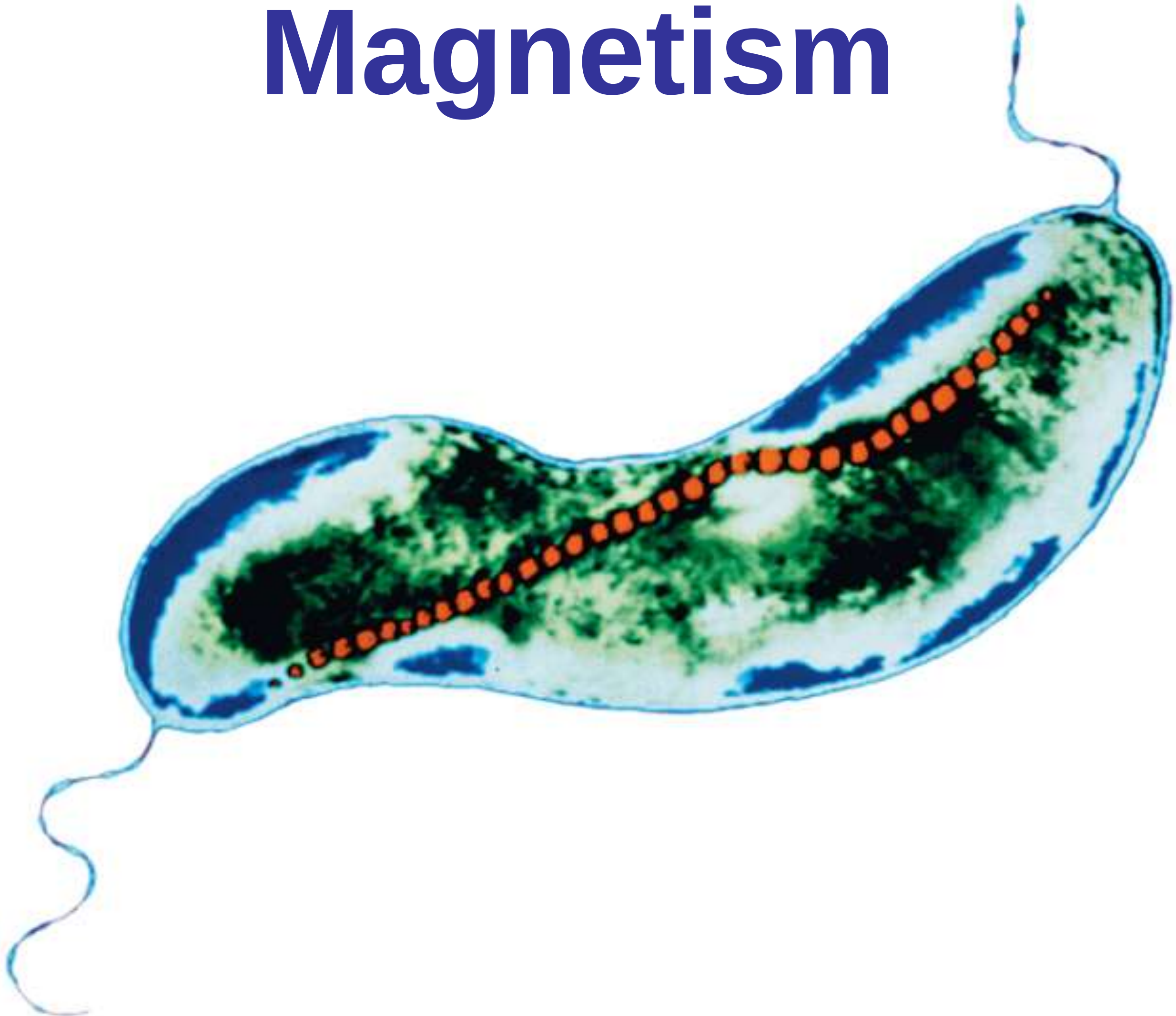
Chapter 22

Physics*, *3rd Edition

James S. Walker

Chapter 22

Magnetism



Units of Chapter 22

- The Magnetic Field
- The Magnetic Force on Moving Charges
- The Motion of Charged Particles in a Magnetic Field
- The Magnetic Force Exerted on a Current-Carrying Wire
- Loops of Current and Magnetic Torque

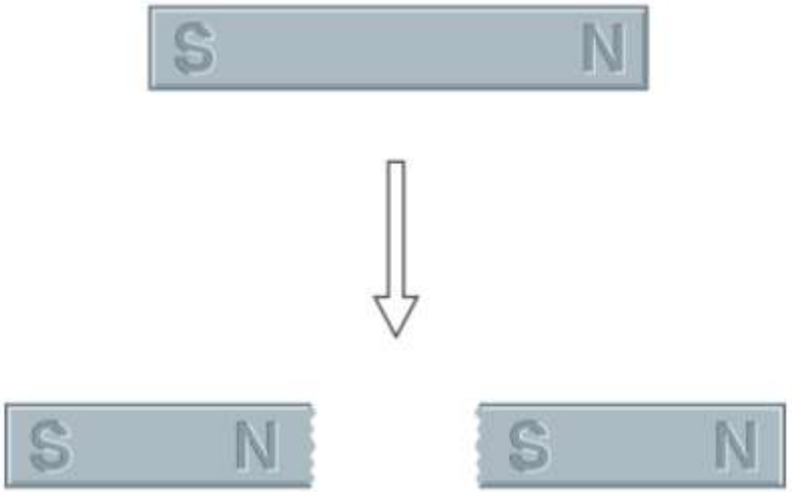
Units of Chapter 22

- Electric Currents, Magnetic Fields, and Ampère’s Law
- Current Loops and Solenoids
- Magnetism in Matter

22-1 The Magnetic Field

Permanent bar magnets have opposite poles on each end, called north and south. Like poles repel; opposites attract.

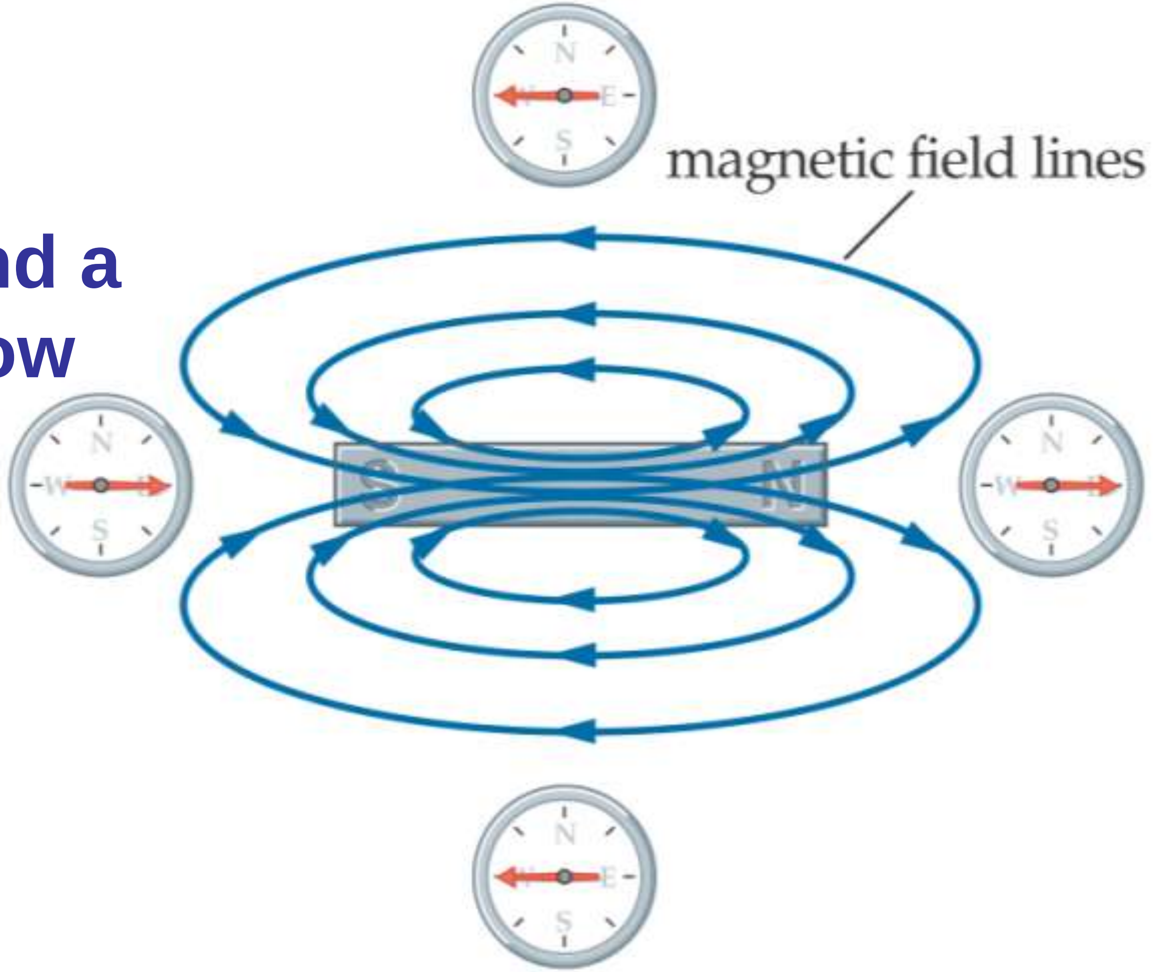
If a magnet is broken in half, each half has two poles:



22-1 The Magnetic Field

The magnetic field can be visualized using magnetic field lines, similar to the electric field.

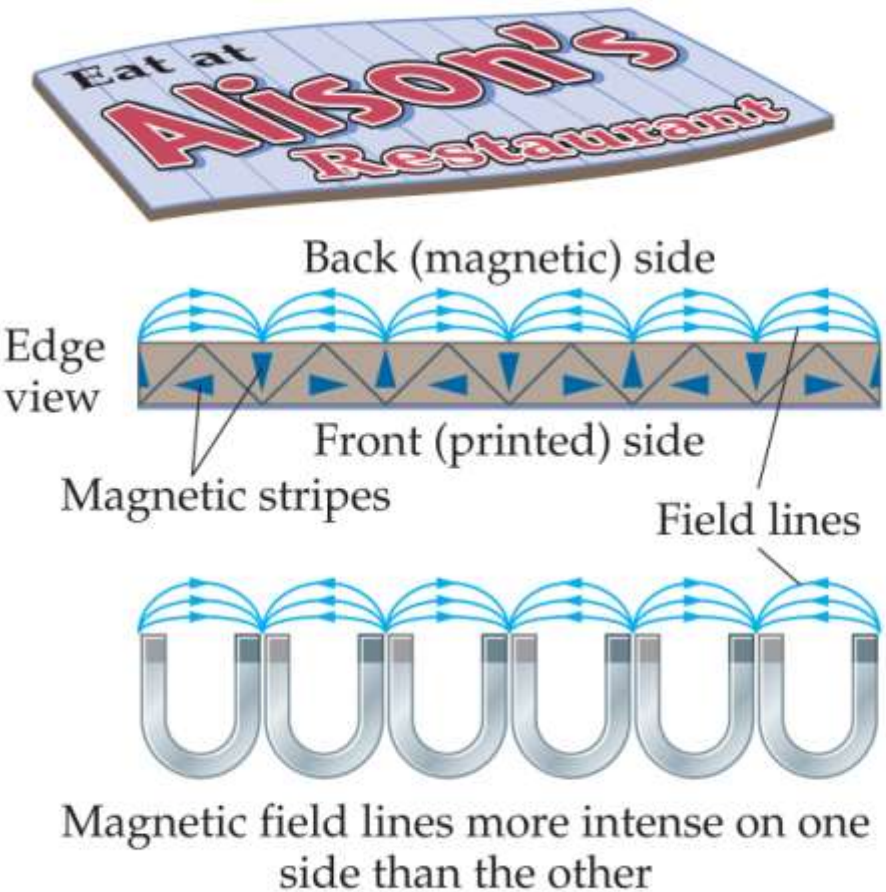
If iron filings are allowed to orient themselves around a magnet, they follow the field lines.



22-1 The Magnetic Field

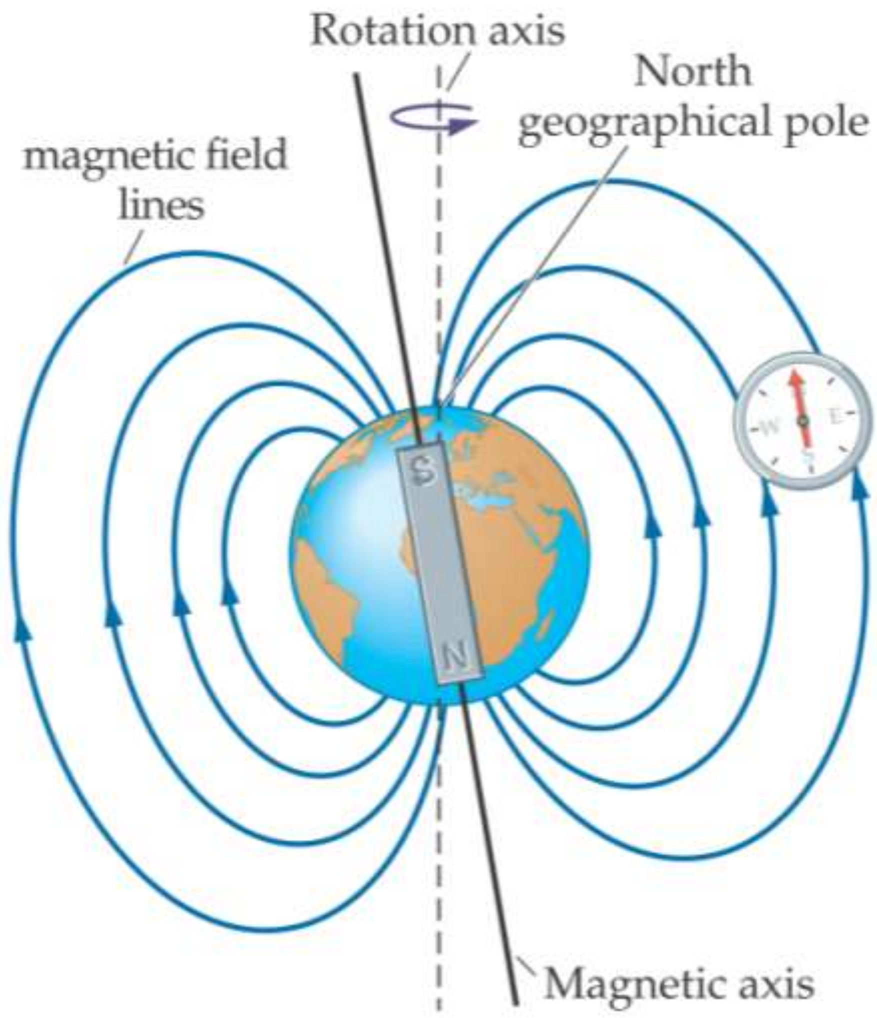
By definition, magnetic field lines exit from the north pole of a magnet and enter at the south pole.

Magnetic field lines cannot cross, just as electric field lines cannot.



22-1 The Magnetic Field

The Earth's magnetic field resembles that of a bar magnet. However, since the north poles of compass needles point towards the north, the magnetic pole there is actually a south pole.



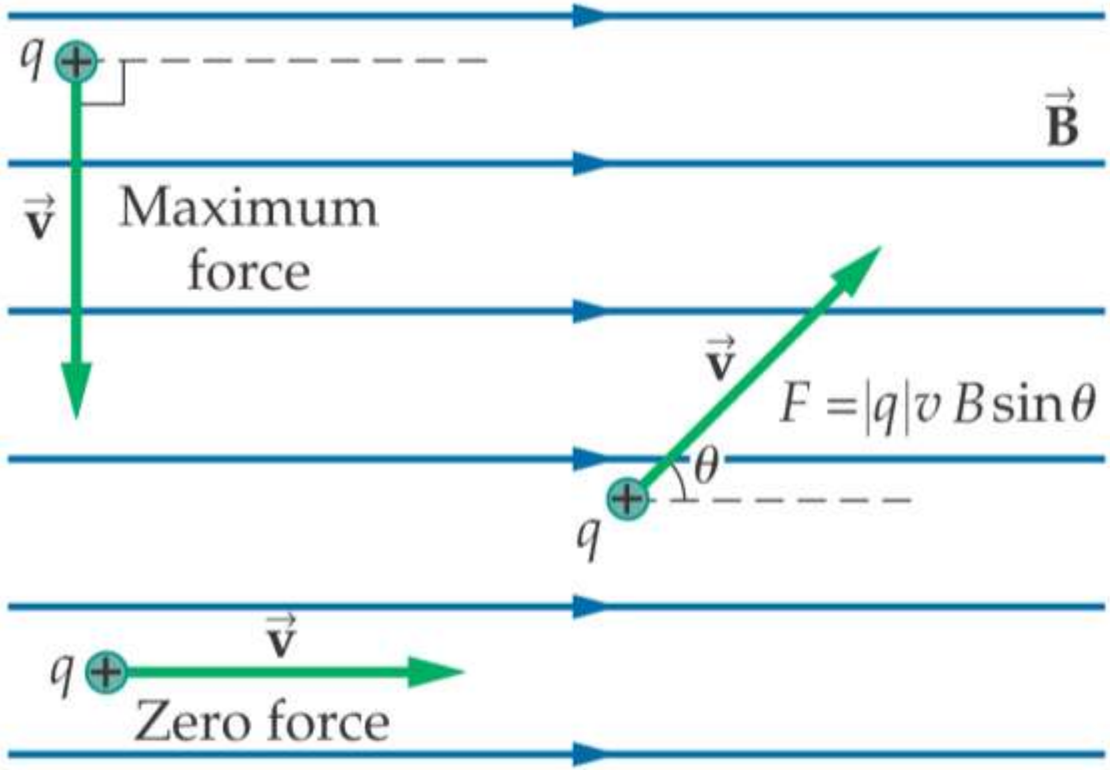
22-2 The Magnetic Force on Moving Charges

Magnitude of the Magnetic Force, *F*

$$F = |q|vB \sin\theta$$

SI unit: newton, N

This is an experimental result – we observe it to be true. It is not a consequence of anything we've learned so far.



22-2 The Magnetic Force on Moving Charges

The magnetic force on a moving charge is actually used to define the magnetic field:

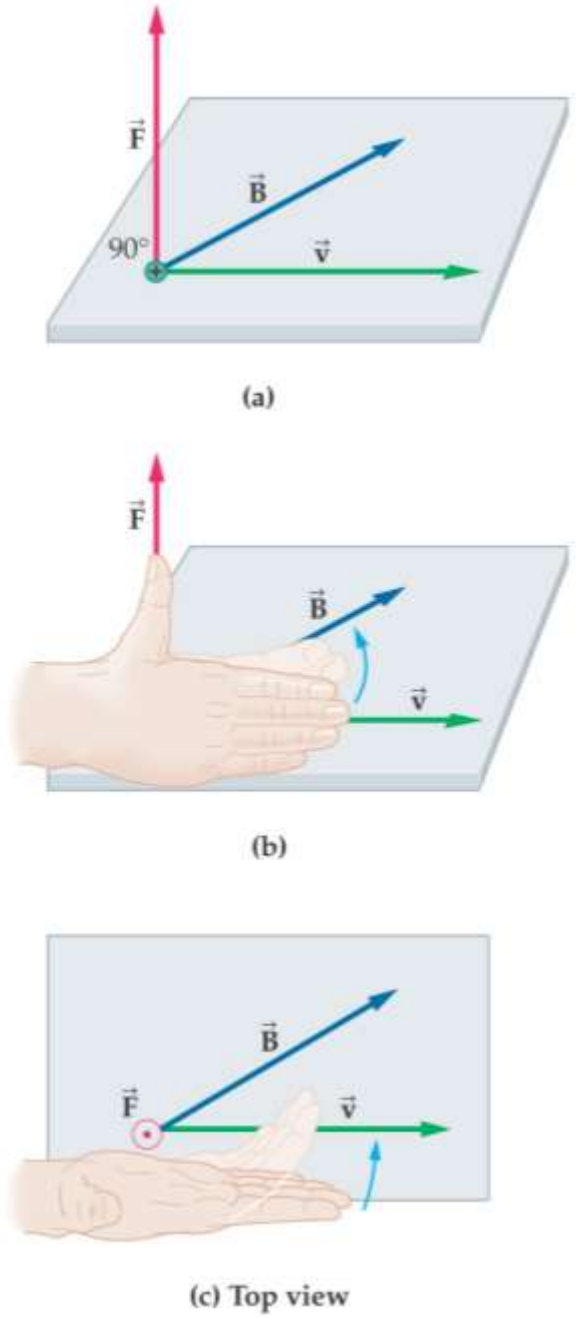
Definition of the Magnitude of the Magnetic Field, *B*

$$B = \frac{F}{|q|v\sin\theta}$$

SI unit: 1 tesla = 1 T = 1 N/(A · m)

22-2 The Magnetic Force on Moving Charges

In order to figure out which direction the force is on a moving charge, you can use a right-hand rule. This gives the direction of the force on a positive charge; the force on a negative charge would be in the opposite direction.



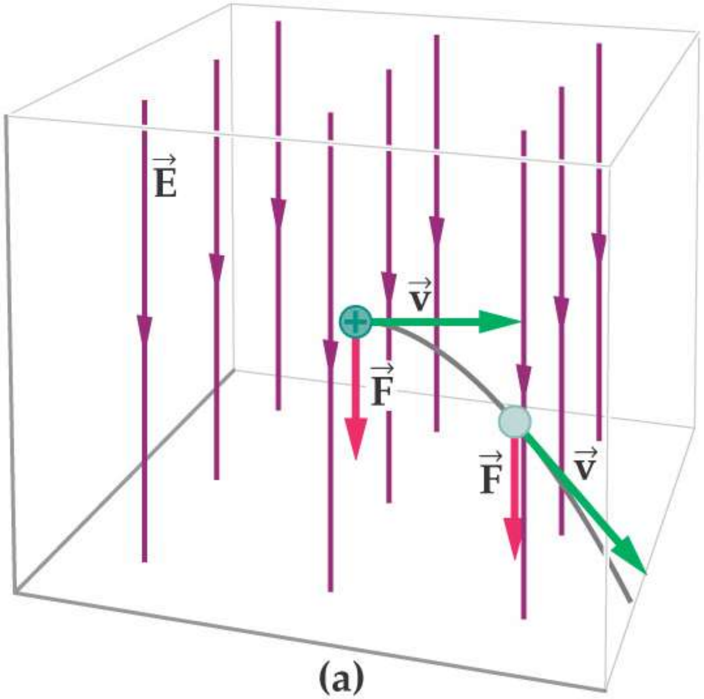
22-2 The Magnetic Force on Moving Charges

This relationship between the three vectors – magnetic field, velocity, and force – can also be written as a vector cross product:

$$\vec{\mathbf{F}} = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

22-3 The Motion of Charged Particles in a Magnetic Field

A positively charged particle in an electric field experiences a force in the direction of the field; in a magnetic field the force is perpendicular to the field. This leads to very different motions:



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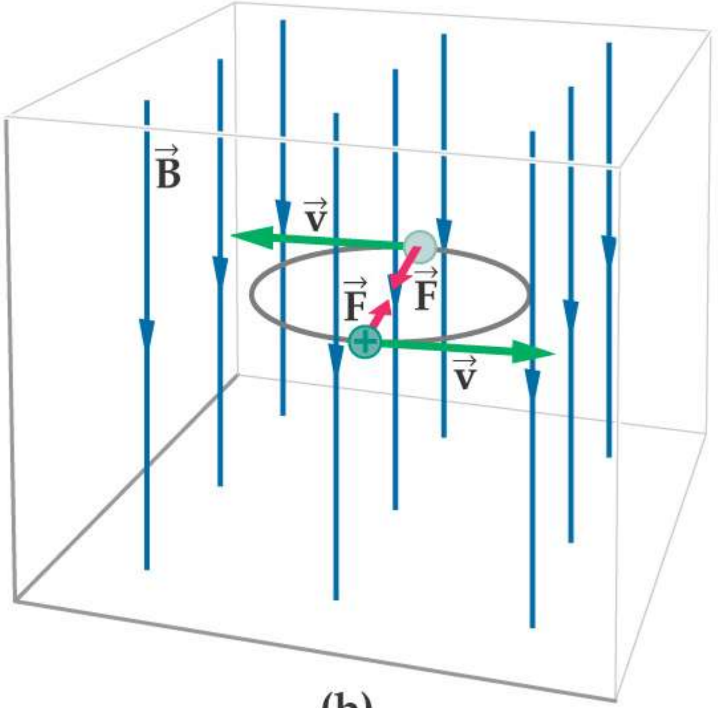


(b)

22-3 The Motion of Charged Particles in a Magnetic Field

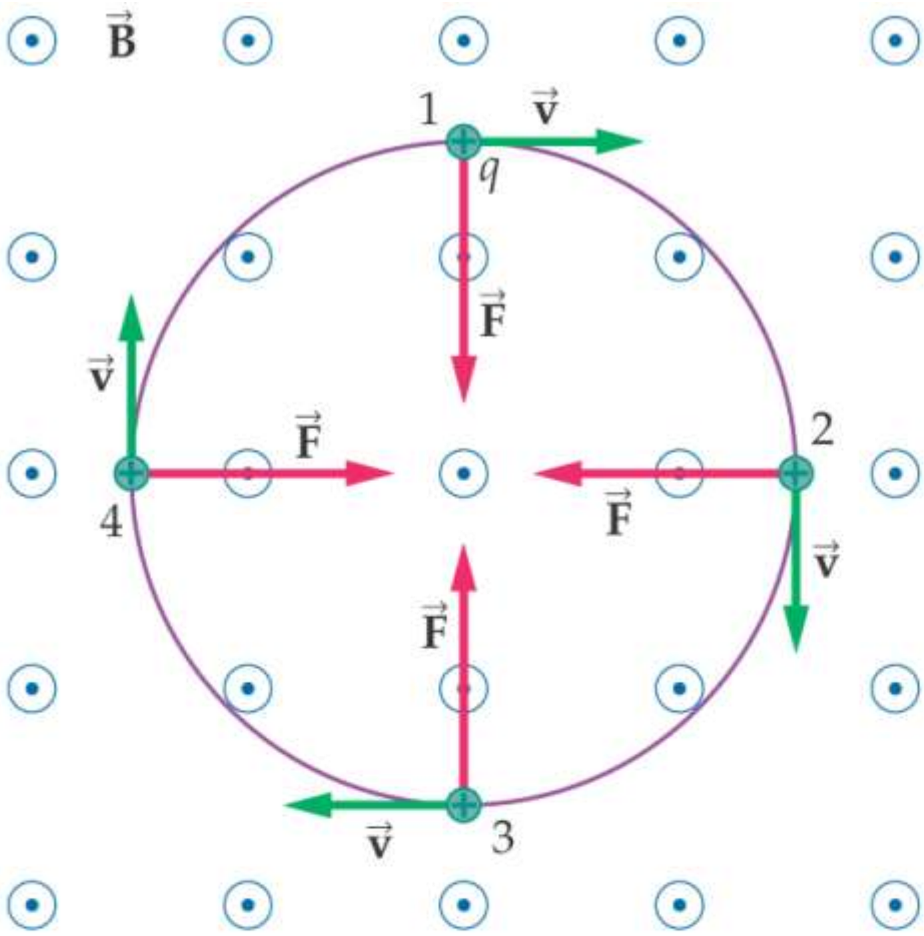
Because the magnetic force is always perpendicular to the direction of motion, the path of a particle is circular.

Also, while an electric field can do work on a particle, a magnetic field cannot – the particle's speed remains constant.

22-3 The Motion of Charged Particles in a Magnetic Field

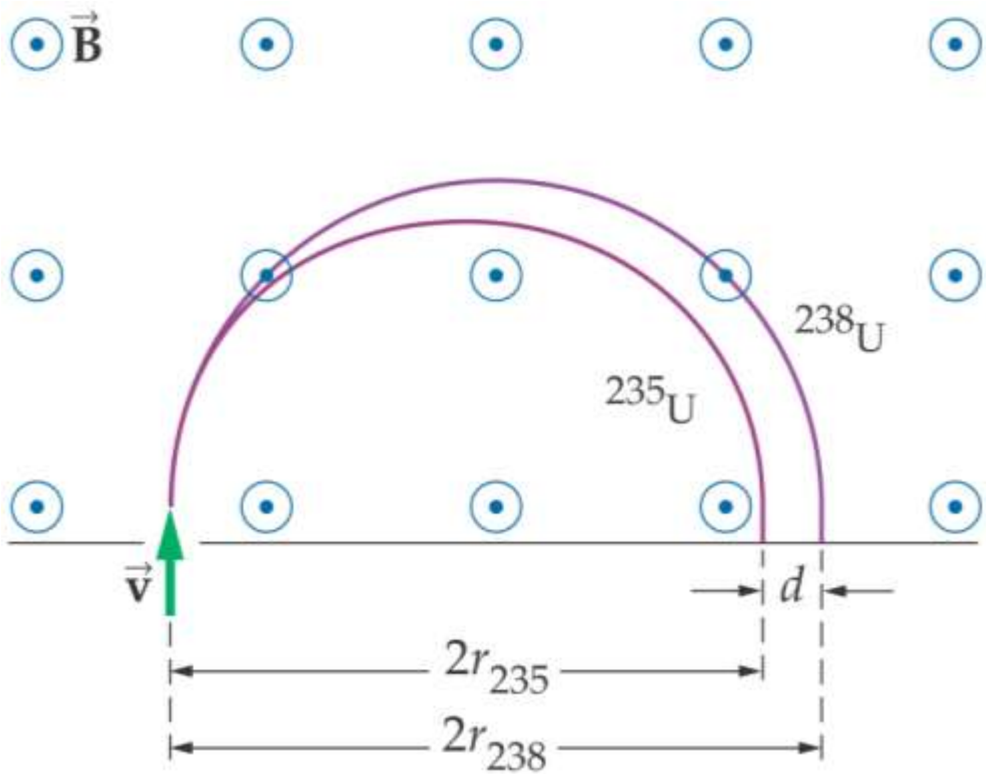
For a particle of mass *m* and charge *q*, moving at a speed *v* in a magnetic field *B*, the radius of the circle it travels is:

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



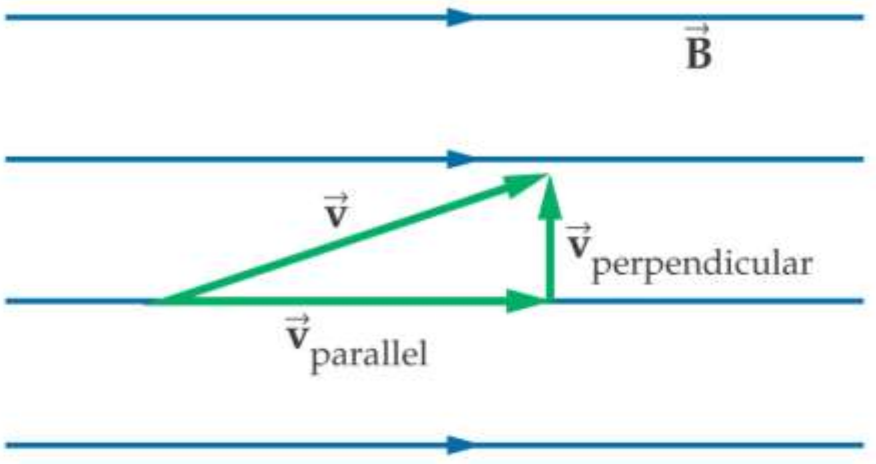
22-3 The Motion of Charged Particles in a Magnetic Field

In a mass spectrometer, ions of different mass and charge move in circles of different radii, allowing separation of different isotopes of the same element.



22-3 The Motion of Charged Particles in a Magnetic Field

If a particle's velocity makes an angle with the magnetic field, the component of the velocity along the magnetic field will not change; a particle with an initial velocity at an angle to the field will move in a helical path.



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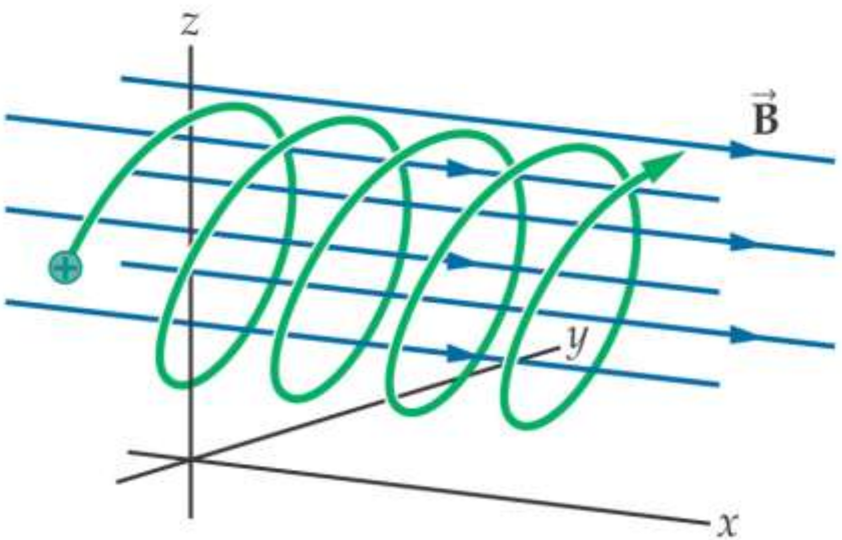


(b)

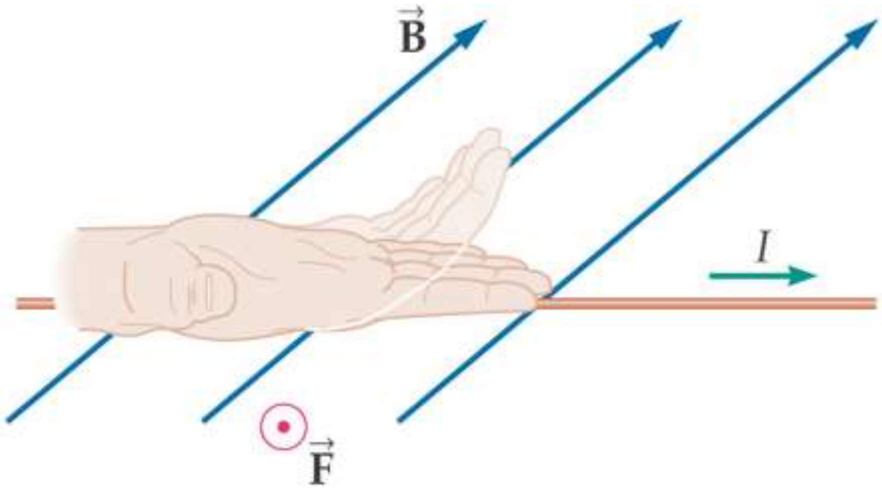
22-4 The Magnetic Force Exerted on a Current-Carrying Wire

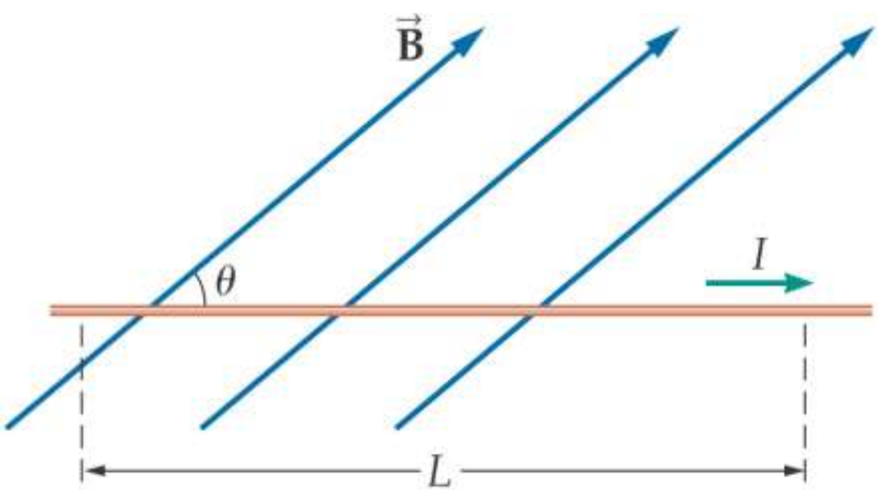
The force on a segment of a current-carrying wire in a magnetic field is given by:

Magnetic Force on a Current-Carrying Wire

$$F = ILB \sin \theta$$

SI unit: newton, N

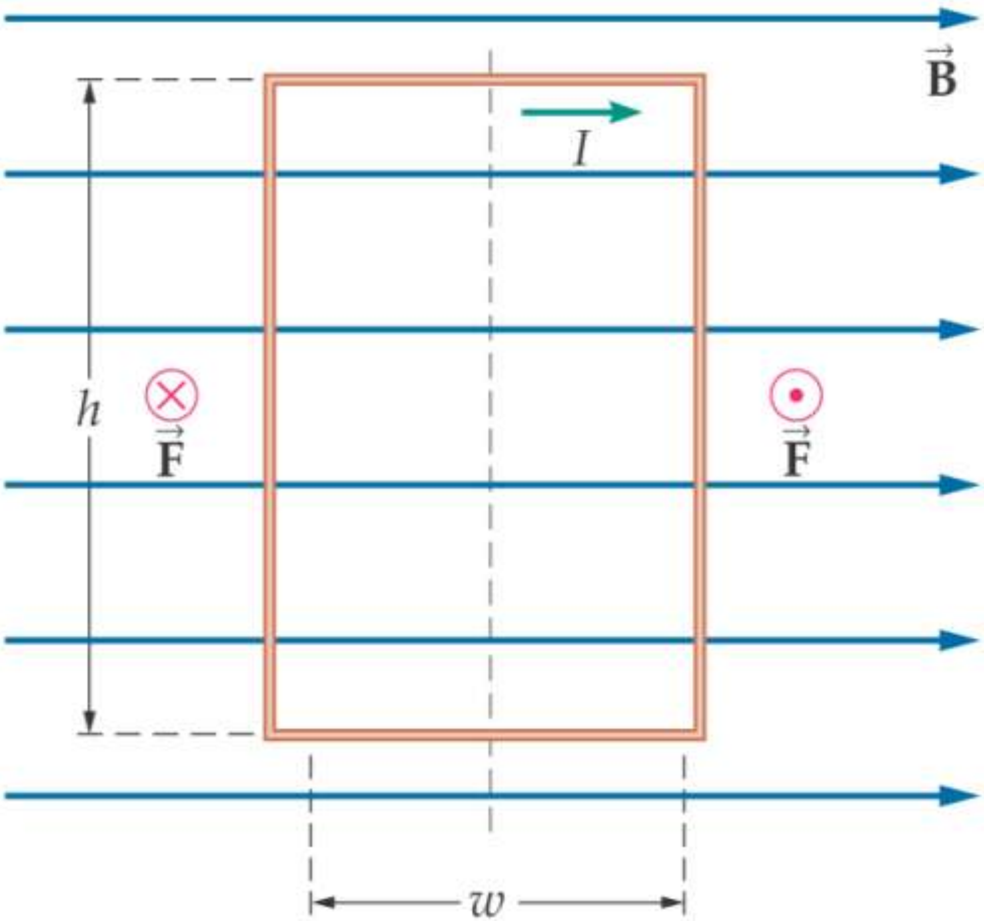




22-5 Loops of Current and Magnetic Torque

In the current loop shown, the vertical sides experience forces that are equal in magnitude and opposite in direction.

They do not operate at the same point, so they create a torque around the vertical axis of the loop.



22-5 Loops of Current and Magnetic Torque

The total torque is the sum of the torques from each force:

$$\tau = (IhB)\left(\frac{w}{2}\right) + (IhB)\left(\frac{w}{2}\right) = IB(hw)$$

Or, since $A = hw$,

$$\tau = IAB$$

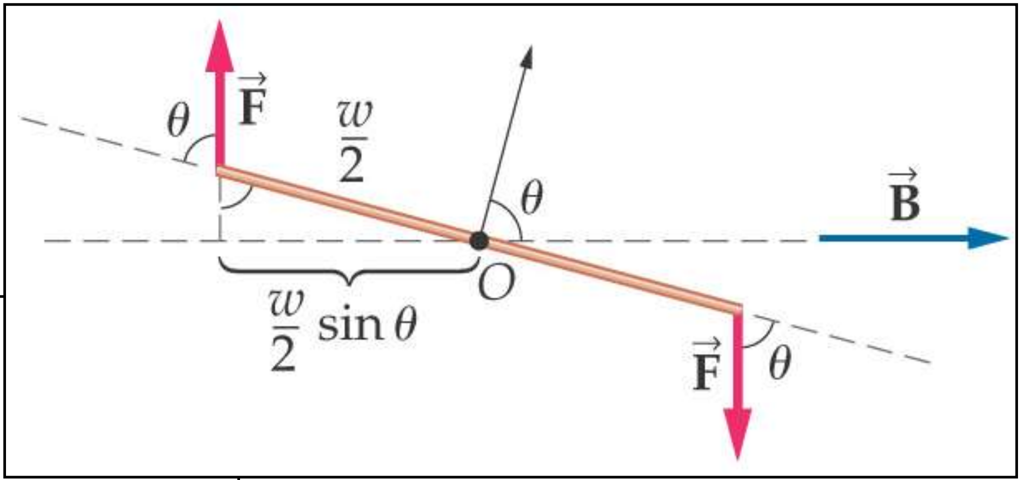
22-5 Loops of Current and Magnetic Torque

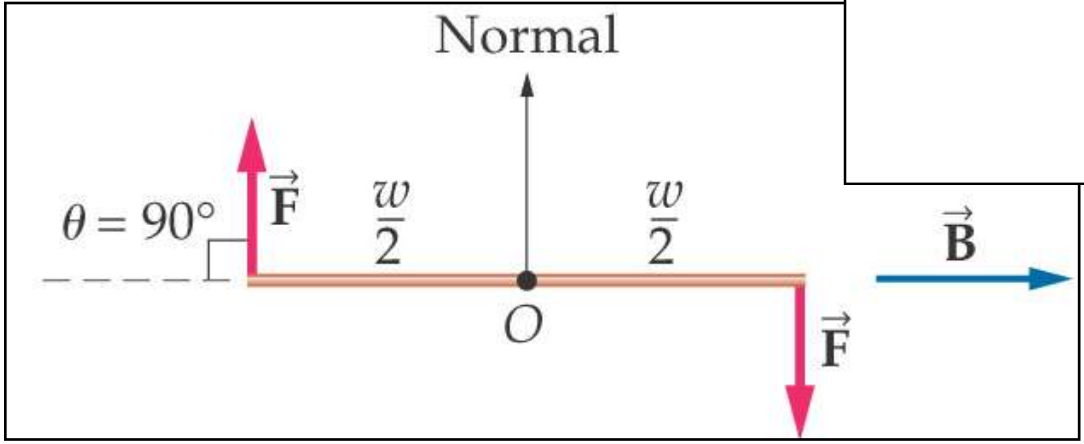
If the plane of the loop is at an angle to the magnetic field,

Torque Exerted on a Rectangular Loop of Area *A*

$$\tau = IAB\sin\theta$$

SI unit: $N \cdot m$





22-5 Loops of Current and Magnetic Torque

To increase the torque, a long wire may be wrapped in a loop many times, or "turns." If the number of turns is N, we have

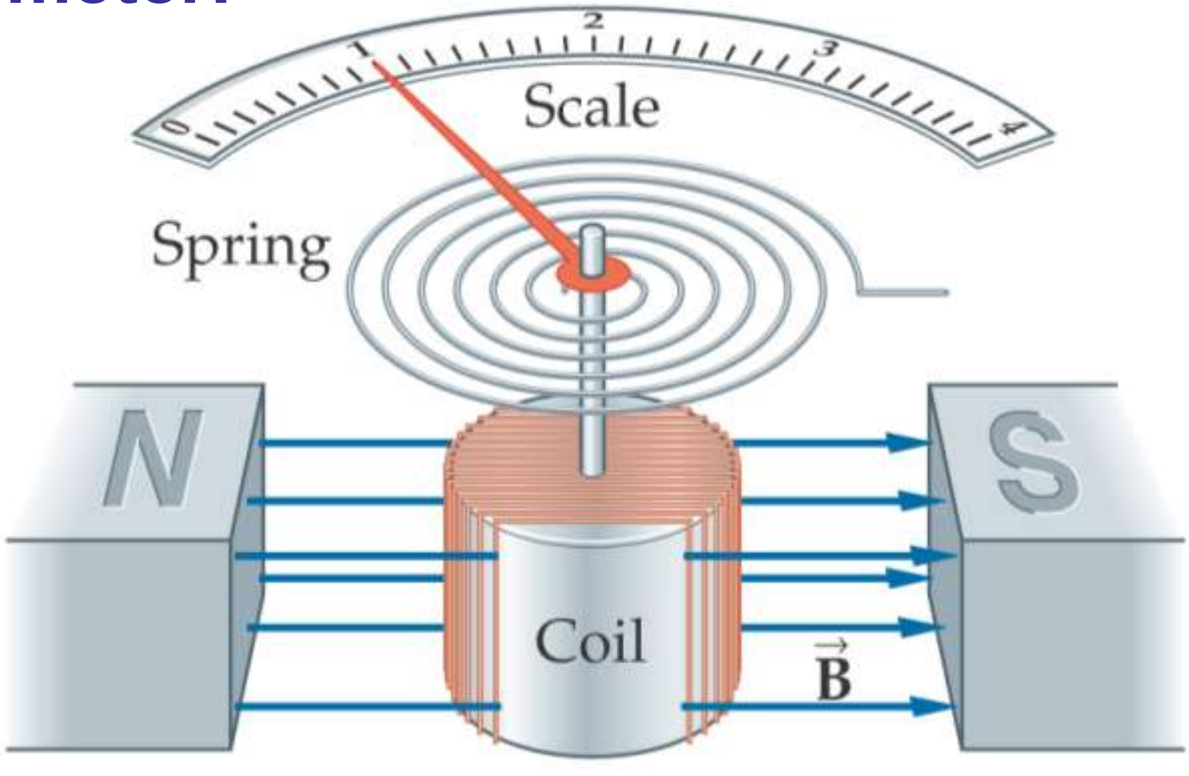
Torque Exerted on a General Loop of Area A and N Turns

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

SI unit: $\mathrm{N \cdot m}$

22-5 Loops of Current and Magnetic Torque

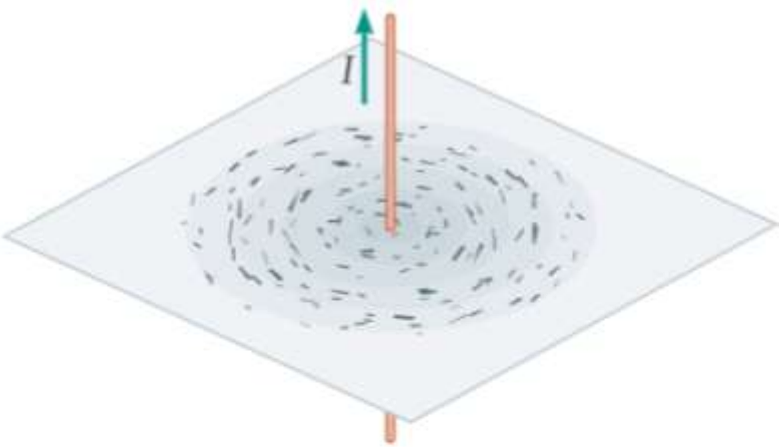
The torque on a current loop is proportional to the current in it, which forms the basis of a variety of useful electrical instruments. Here is a galvanometer:



22-6 Electric Currents, Magnetic Fields, and Ampère's Law

Experimental observation: Electric currents can create magnetic fields.

These fields form circles around the current.



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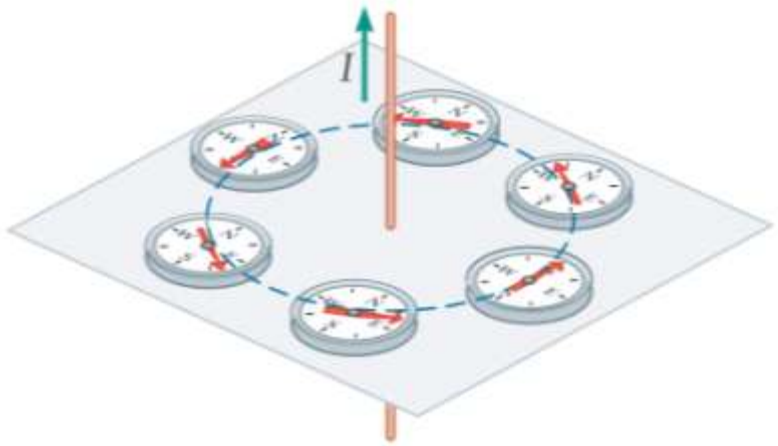

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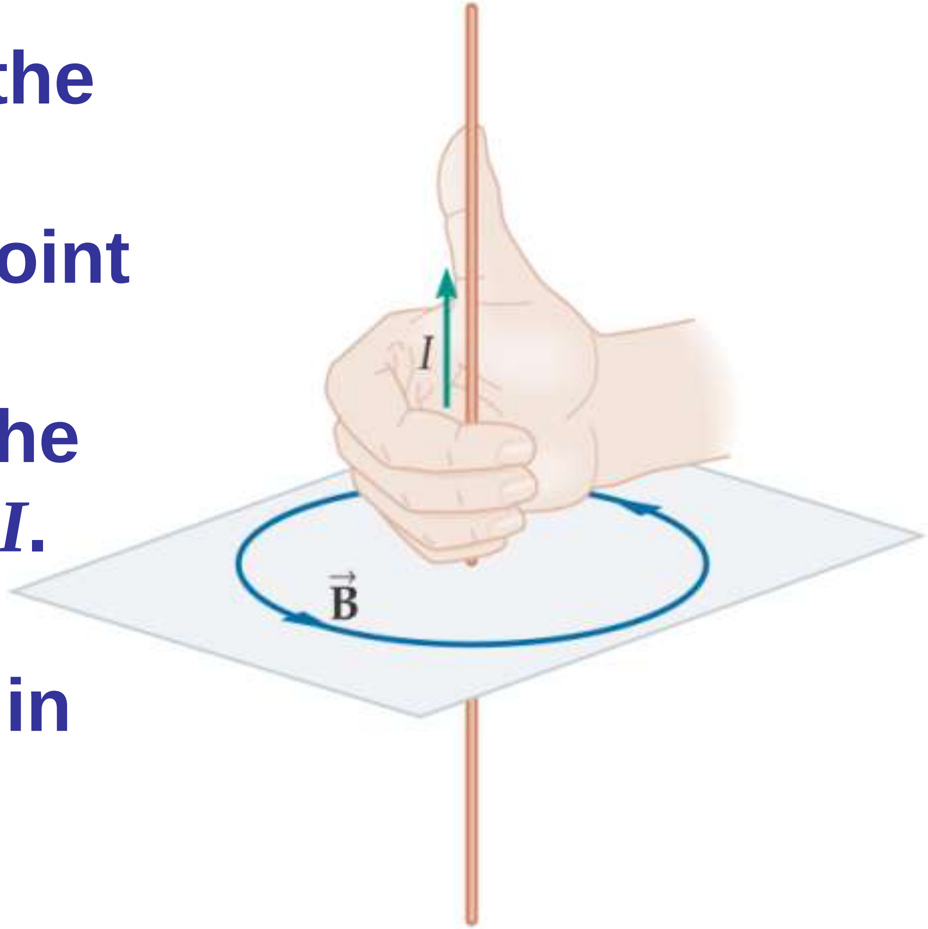
22-6 Electric Currents, Magnetic Fields, and Ampère's Law

To find the direction of the magnetic field due to a current-carrying wire, point the thumb of your right hand along the wire in the direction of the current *I*. Your fingers are now curling around the wire in the direction of the magnetic field.



22-6 Electric Currents, Magnetic Fields, and Ampère's Law

The magnetic field is inversely proportional to the distance from the wire:

$$B = (\text{constant})\frac{I}{r}$$

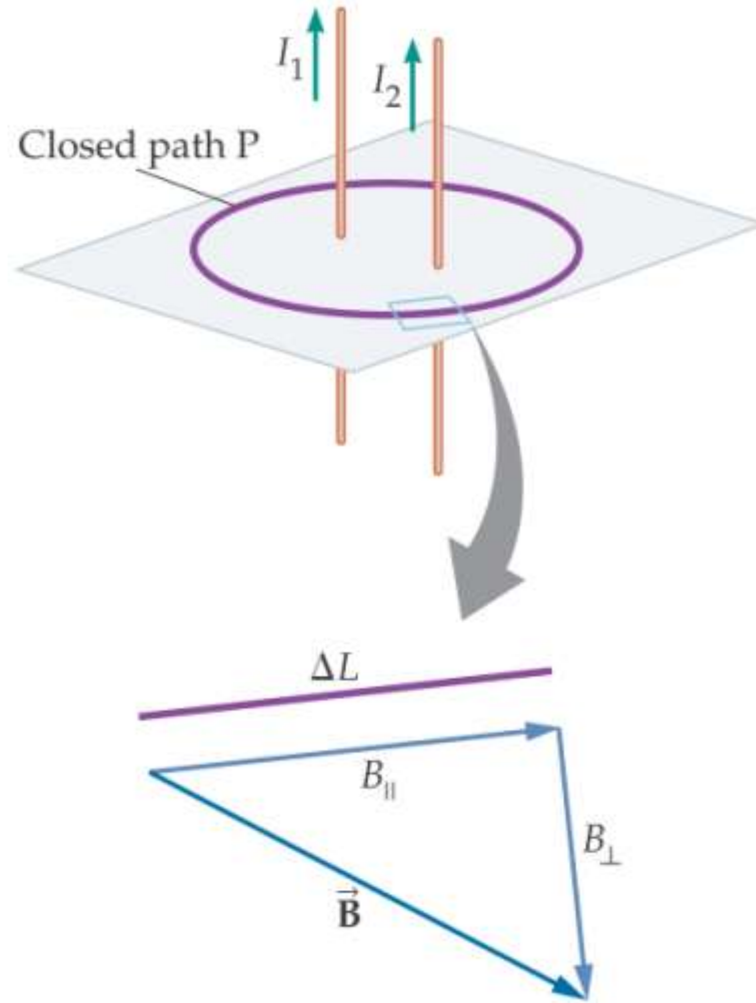
22-6 Electric Currents, Magnetic Fields, and Ampère's Law

Ampère's Law relates the current through a surface defined by a closed path to the magnetic field along the path:

Ampère's Law

$$\sum B_{\parallel}\,\Delta L = \mu_0 I_{\text{enclosed}}$$

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\cdot m/A}$$



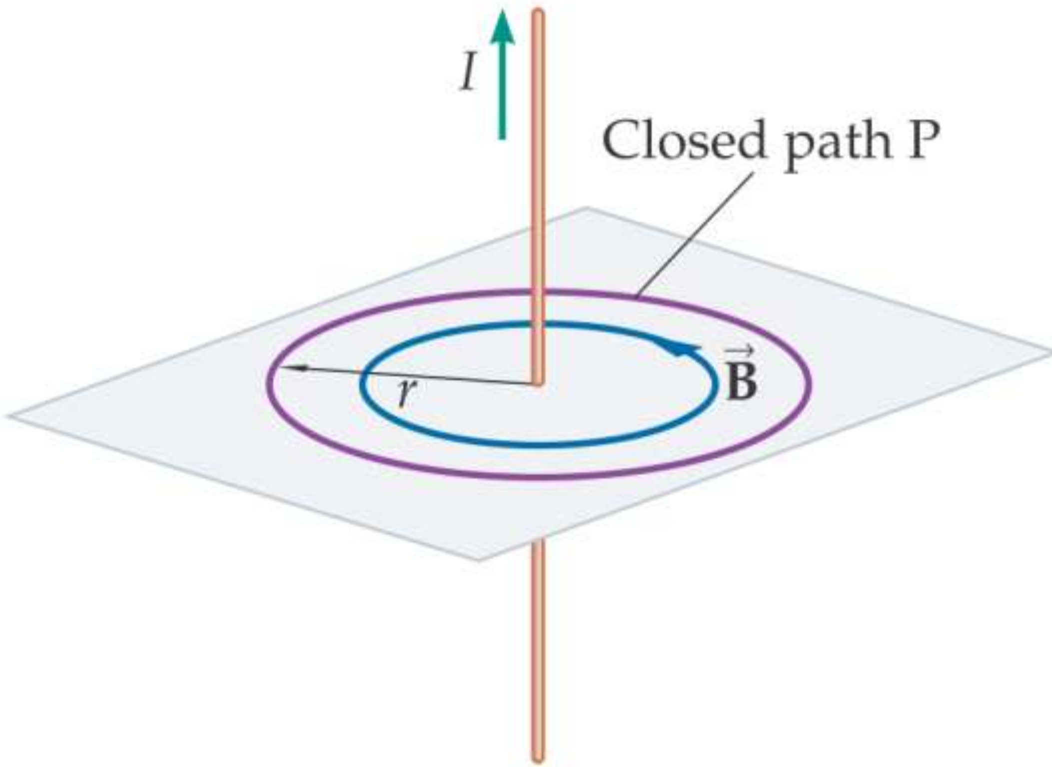
22-6 Electric Currents, Magnetic Fields, and Ampère's Law

We can use Ampère's Law to find the magnetic field around a long, straight wire:

Magnetic Field for a Long, Straight Wire

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

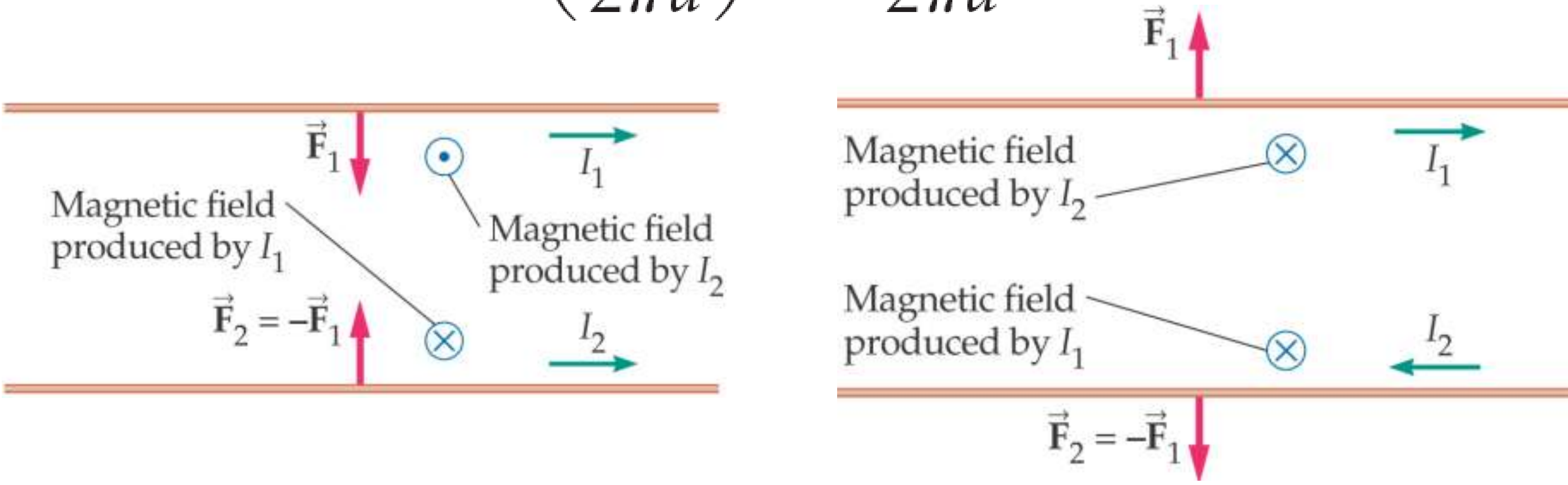
SI unit: tesla, T



22-6 Electric Currents, Magnetic Fields, and Ampère's Law

Since a current-carrying wire experiences a force in a magnetic field, and a magnetic field is created by a current-carrying wire, there is a force between current-carrying wires:

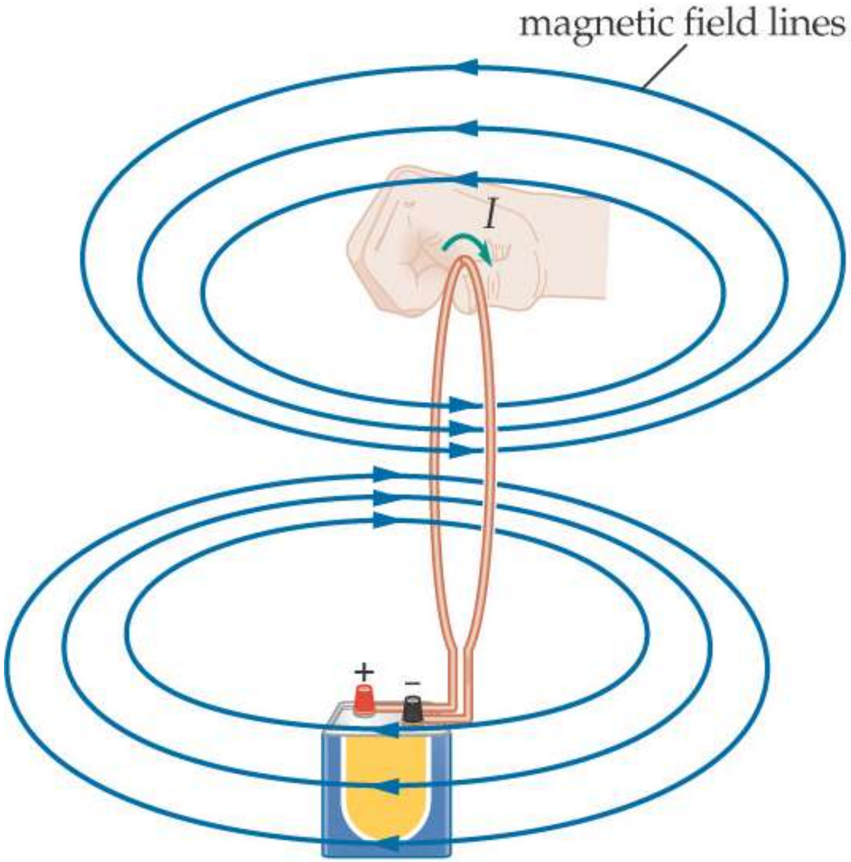
$$F = I_2 L B = I_2 L\left(\frac{\mu_0 I_1}{2\pi d}\right) = \frac{\mu_0 I_1 I_2}{2\pi d} L$$

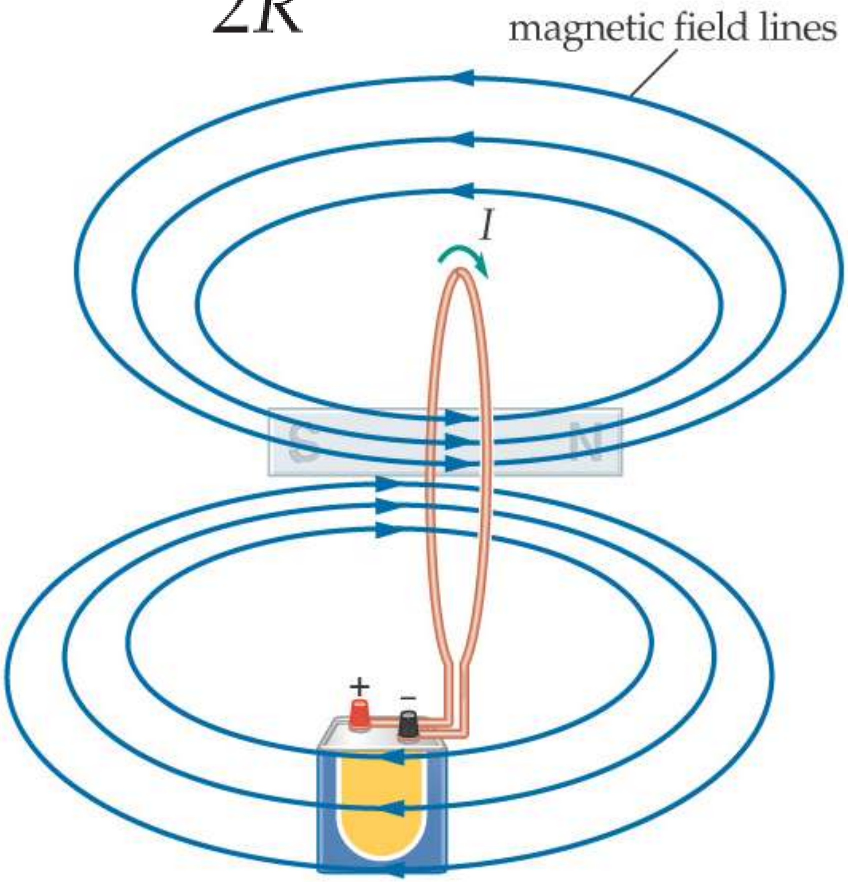


22-7 Current Loops and Solenoids

The magnetic field of a current loop is similar to the magnetic field of a bar magnet.

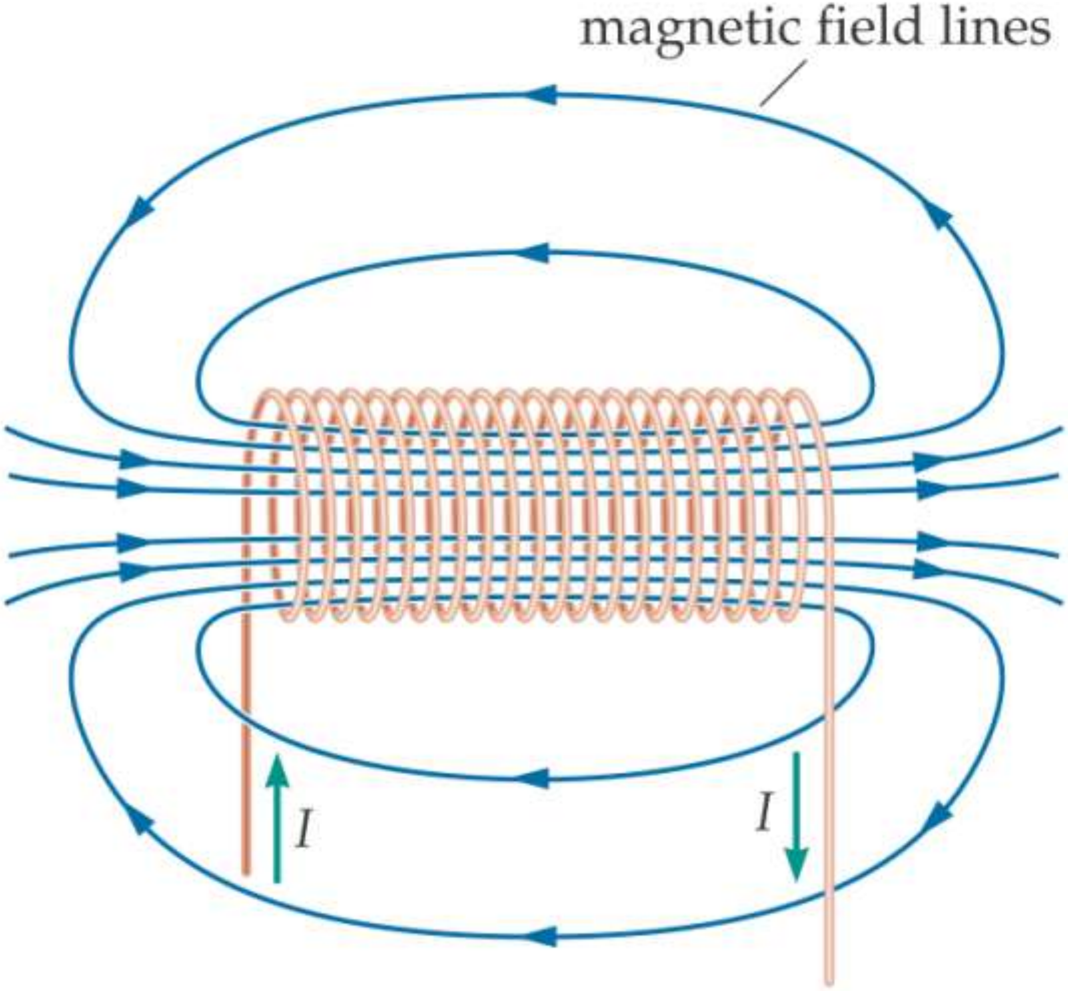
In the center of the loop, $$B = \frac{N\mu_0 I}{2R}$$





22-7 Current Loops and Solenoids

A solenoid is a series of current loops formed into the shape of a cylinder:



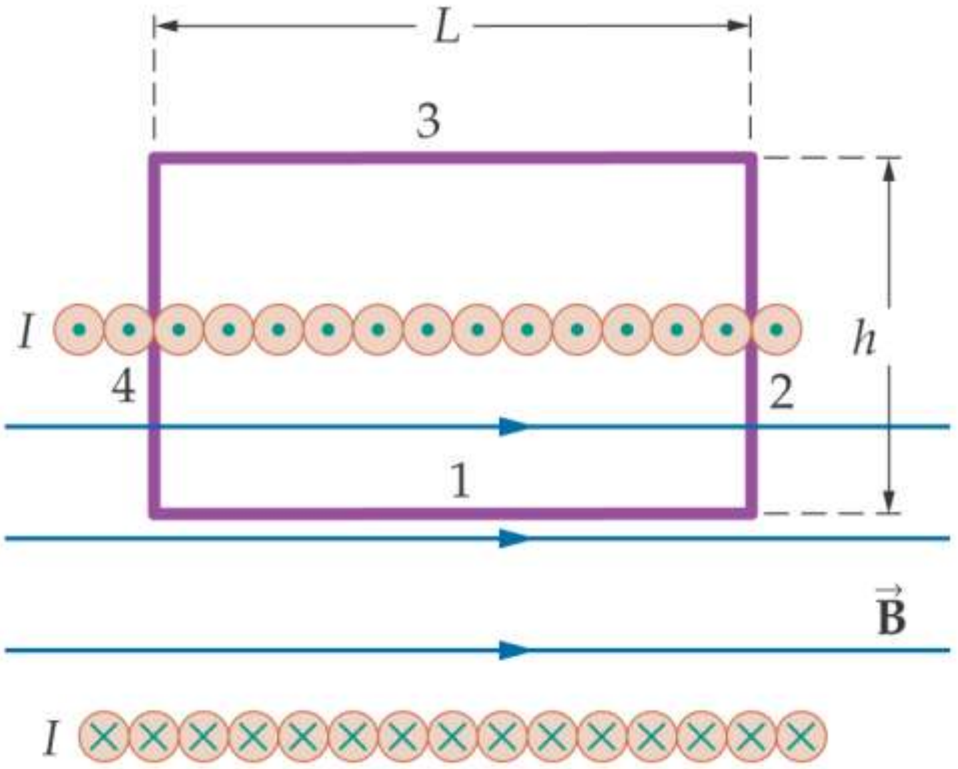
22-7 Current Loops and Solenoids

We can use Ampère's Law to find the field inside the solenoid:

Magnetic Field of a Solenoid

$$B = \mu_0\left(\frac{N}{L}\right)I = \mu_0 n I$$

SI unit: tesla, T



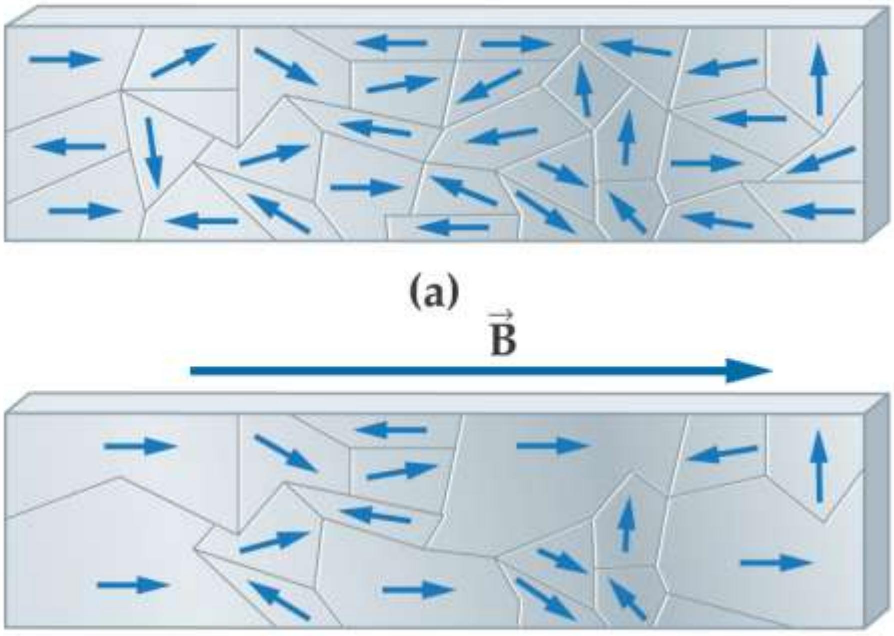
22-8 Magnetism in Matter

The electrons surrounding an atom create magnetic fields through their motion. Usually these fields are in random directions and have no net effect, but in some atoms there is a net magnetic field.

If the atoms have a strong tendency to align with each other, creating a net magnetic field, the material is called ferromagnetic.

22-8 Magnetism in Matter

Ferromagnets are characterized by domains, which each have a strong magnetic field, but which are randomly oriented. In the presence of an external magnetic field, the domains align, creating a magnetic field within the material.



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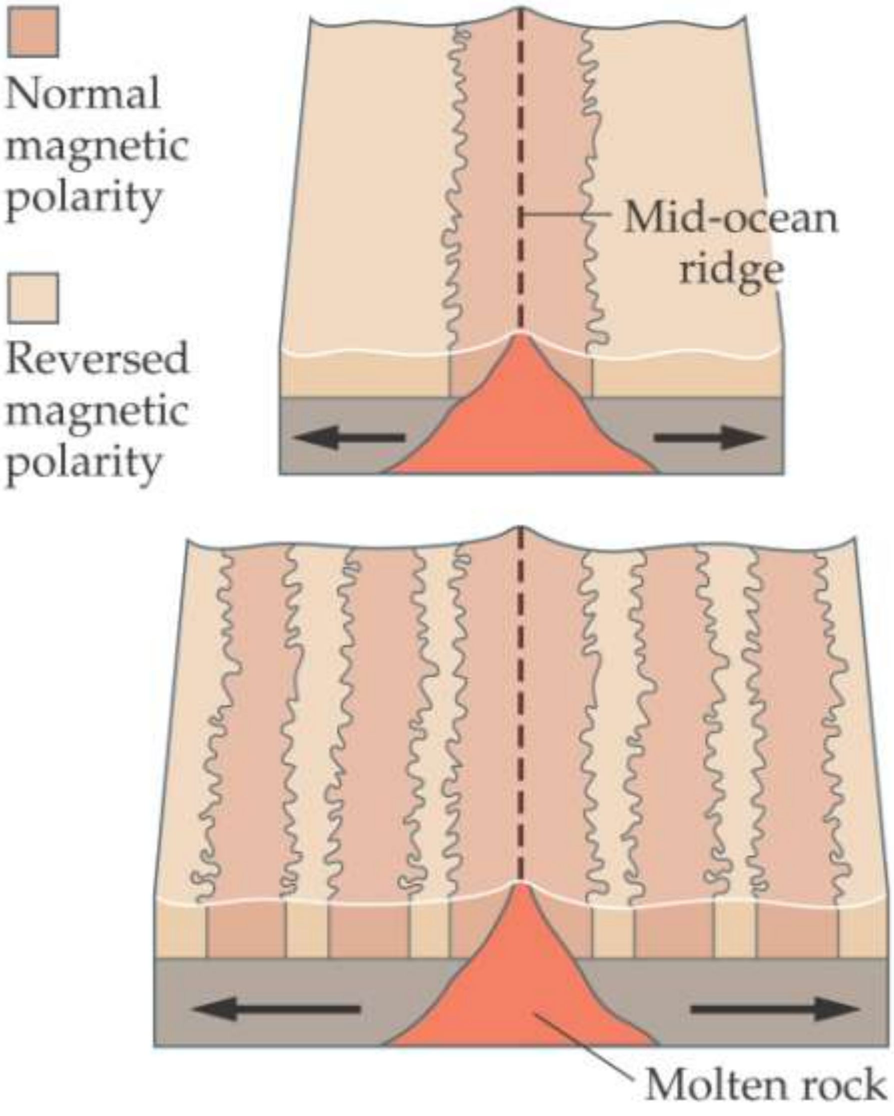
22-8 Magnetism in Matter

Permanent magnets are ferromagnetic; such materials can preserve a “memory” of magnetic fields that are present when the material cools or is formed.



22-8 Magnetism in Matter

Many materials that are not ferromagnetic are paramagnetic – they will partially align in a strong magnetic field, but the alignment disappears when the external field is gone.

22-8 Magnetism in Matter

Finally, all materials exhibit diamagnetism – an applied magnetic field induces a small magnetic field in the opposite direction in the material.

Summary of Chapter 22

- All magnets have two poles, north and south.
- Magnetic fields can be visualized using magnetic field lines. These lines point away from north poles and toward south poles.
- The Earth produces its own magnetic field.
- A magnetic field exerts a force on an electric charge only if it is moving:

$$F = |q|vB\sin\theta$$

- A right-hand rule gives the direction of the magnetic force on a positive charge.

Summary of Chapter 22

• If a charged particle is moving parallel to a magnetic field, it experiences no magnetic force.

• If a charged particle is moving perpendicular to a magnetic field, it moves in a circle:

$$r = mv/|q|B$$

• If a charged particle is moving at an angle to a magnetic field, it moves in a helix.

Summary of Chapter 22

- A wire carrying an electric current also may experience a force in a magnetic field; the force on a length L of the wire is:

$$F = ILB\sin\theta$$

- A current loop in a magnetic field may experience a torque:

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

Summary of Chapter 22

- **Electric currents create magnetic fields; the direction can be determined using a right-hand rule.**
- **Ampère's law:** $\sum B_{\parallel} \Delta L = \mu_0 I_{\text{enclosed}}$
- **Magnetic field of a long, straight wire:**

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

- **Force between current-carrying wires:**

$$F = \frac{\mu_0 I_1 I_2}{2\pi d} L$$

Summary of Chapter 22

- **The magnetic field of a current loop is similar to that of a bar magnet.**
- **The field in the center of the loop is:**

$$B = \frac{N\mu_0 I}{2R}$$

- **Magnetic field of a solenoid:**

$$B = \mu_0\left(\frac{N}{L}\right)I = \mu_0 n I$$

Summary of Chapter 22

- **A paramagnetic material has no magnetic field, but will develop a small magnetic field in the direction of an applied field.**
- **A ferromagnetic material may have a permanent magnetic field; when placed in an applied field it develops permanent magnetization.**
- **All materials have a small diamagnetic effect; when placed in an external magnetic field they develop a small magnetic field opposite to the applied field.**