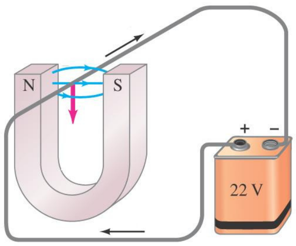
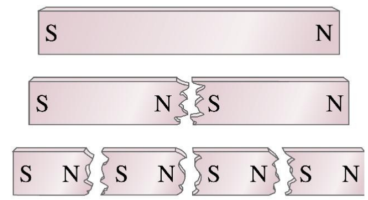
Magnetism



Lecture Notes

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.



Chapter 20 Topics

Magnets and Magnetic Fields

Electric Currents Produce Magnetic Fields

Force on an Electric Current in a Magnetic Field

Force on Electric Charge Moving in a Magnetic Field

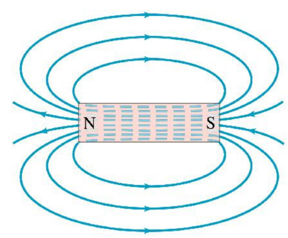
Magnetic Field Due to a Long Straight Wire

Force between Two Parallel Wires

Solenoids and Electromagnets

Magnets and Magnetic Fields

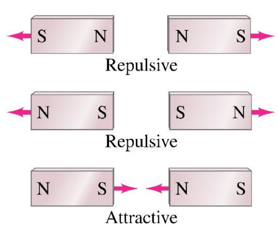
Magnetic fields can be visualized using magnetic field lines, which are always closed loops.



Magnets and Magnetic Fields

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

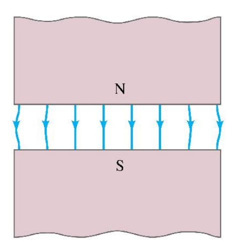
Like poles repel; unlike poles attract.



Magnets and Magnetic Fields

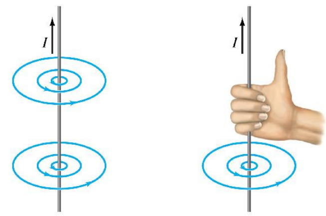
A uniform magnetic field is constant in magnitude and direction.

The field between these two wide poles is nearly uniform.



Electric Currents Produce Magnetic Fields

Experiment shows that an electric current produces a magnetic field.



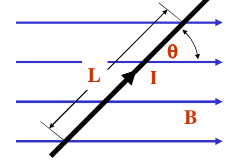
(b) (c)

Force on an Electric Current in a Magnetic Field

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

$$F = ILB\sin\theta$$

The force is directed into the screen.



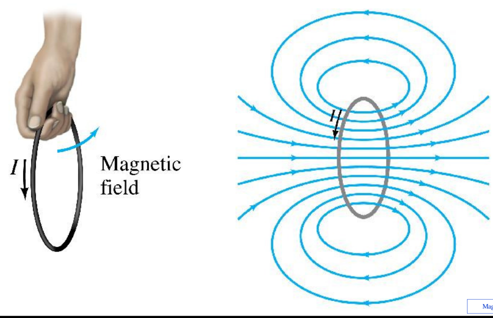
This equation defines the magnetic field B.

Unit of B: the tesla, T.

$$1\,T = 1\,\frac{N}{A \cdot m}$$

Electric Currents Produce Magnetic Fields

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



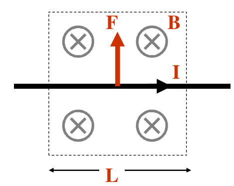
Force on an Electric Current in a Magnetic Field

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

$$F = ILB\sin\theta$$

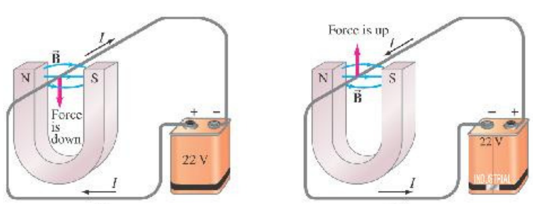
When the current is perpendicular to the magnetic field.

$$F = ILB$$



Force on an Electric Current in a Magnetic Field

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



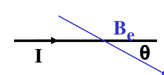
(a) (b)

Force on an Electric Current in a Magnetic Field

Problem 20-04

A 1.5-m length of wire carrying 4.5 A of current is oriented horizontally. At that point on the Earth's surface, the dip angle of the Earth's magnetic field (5.5×10^{-5} T) makes an angle of 38° to the wire. Estimate the magnitude of the magnetic force on the wire due to the Earth's magnetic field of at this point.

$$F = ILB\sin\theta$$



$$F = (4.5\,A)(1.5\,m)(5.5 \times 10^{-5}\,T)\sin 38$$

$$\boxed{F = 2.3 \times 10^{-4}\,N}$$

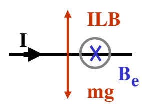
Force on an Electric Current in a Magnetic Field

Problem 20-08

Suppose a straight 1.00-mm-diameter copper wire could just "float" horizontally in air because of the force due to the Earth's magnetic field which is horizontal, perpendicular to the wire, and of magnitude What current would the wire carry?

$ILB_e = mg$

$ILB_e = \left[\rho\pi\left(\frac{d}{2}\right)^2 L\right]g$



$I = \frac{\rho\pi d^2 g}{4B_e}$

$= \frac{\left(8.9 \text{ x } 10^3 \frac{kg}{m^2}\right)\pi\left(1.0 \text{ x } 10^{-3} m\right)2}{4\left(5.0 \text{ x } 10^{-5} T\right)} g$

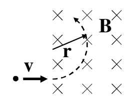
$I = 1400 \text{ A}$

Force on Electric Charge Moving in a Magnetic Field

Problem 20-09

Alpha particles of charge +2e and mass of $6.6 \text{ x } 10^{-27}$ kg are emitted from a radioactive source at a speed of $6.6 \text{ x } 10^7$ m/s. What magnetic field strength would be required to bend them into a circular path of radius of 0.25 m?

$F_M = qvB = \frac{mv^2}{r}$



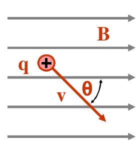
$B = \frac{mv}{qr}$

$= \frac{\left(6.6 \text{ x } 10^{-27} \text{ kg}\right)\left(6.6 \text{ x } 10^7 \text{ m/s}\right)}{2\left(1.6 \text{ x } 10^{-19} \text{ C}\right)\left(0.25 \text{ m}\right)} = \quad 5.4T$

Force on Electric Charge Moving in a Magnetic Field

The force on a moving charge in a magnetic field is related related to its charge and velocity.

$F = qvB\sin\theta$



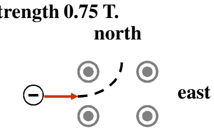
The force is directed out of the screen.

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

Force on Electric Charge Moving in a Magnetic Field

Problem 20-10

Determine the magnitude and direction of the force on an electron traveling horizontally v= 8750 m/s, to the east in a vertically upward magnetic field of strength 0.75 T.



Direction?

$F_M = qvB$

$F_M = \left(1.6 \text{ x } 10^{-19} \text{ C}\right)\left(8.75 \text{ x } 10^3 \text{ m/s}\right)\left(0.75\text{T}\right)$

$F_M = 1.05 \text{ x } 10^{-15} \text{ N}$

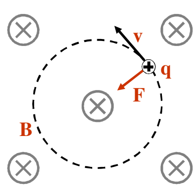
Force on Electric Charge Moving in a Magnetic Field

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

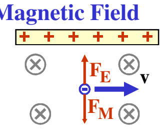
$F = qvB$

$qvB = \frac{mv^2}{r}$

$qrB = mv$ — Momentum



Force on Electric Charge Moving in a Magnetic Field



Problem 20-16

What is the velocity of a beam of electrons that go undeflected when passing through perpendicular electric and magnetic fields of magnitude 8.8 x 10^3 V/m and 3.5 x 10^{-3} T, respectively? What is the radius of the electron orbit if the electric field is turned off?

$F_E = F_M$

$qE = qvB$

$v = \frac{E}{B} = \frac{8.8 \text{ x } 10^3 \text{ V/m}}{3.5 \text{ x } 10^{-3} \text{ T}}$

$v = 2.5 \text{ x } 10^6 \text{ m/s}$

$F_M = qvB = \frac{mv^2}{r}$

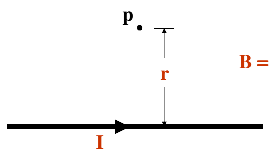
$r = \frac{mv}{qB}$

$= \frac{\left(9.11 \text{ x } 10^{-31} \text{ kg}\right)\left(2.5 \text{ x } 10^6 \text{ m/s}\right)}{\left(1.6 \text{ x } 10^{-19} \text{ C}\right)\left(3.5 \text{ x } 10^{-3} \text{ T}\right)}$

$r = 4.1 \text{ x } 10^{-3} \text{ m}$

Magnetic Field Due to a Long Straight Wire

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



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

The constant μ_0 is called the permeability of free space, and has the value:

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

Magnetism 20

Force between Two Parallel Wires

The magnetic field produced at the position of wire 2 due to the current in wire 1 is:

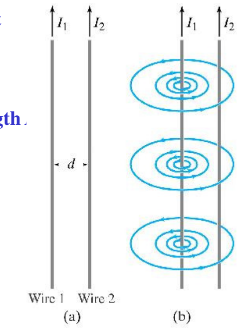
$$B_1 = \frac{\mu_0}{2\pi}\frac{I_1}{d}$$

The force this field exerts on a length of wire 2 is:

$$F = I_2 L B_1$$

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

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



Magnetism 20

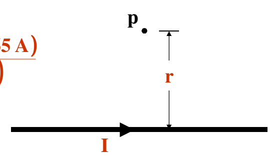
Magnetic Field Due to a Long Straight Wire

Problem 20-26

A jumper cable used to start a stalled vehicle carries a 65-A current. How strong is the magnetic field 6.0 cm away from it?

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A})(65\ \mathrm{A})}{2\pi\,(6.0 \times 10^{-2}\ \mathrm{m})}$$

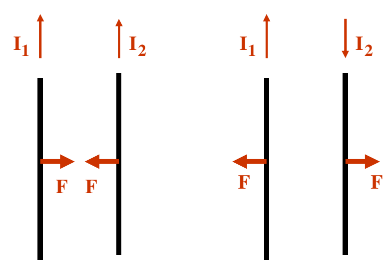
$$\boxed{B = 2.2 \times 10^{-4}\ \mathrm{T}}$$



Magnetism 20

Force between Two Parallel Wires

Parallel currents attract; anti-parallel currents repel.

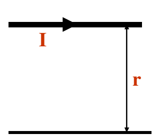


Magnetism 20

Magnetic Field Due to a Long Straight Wire

Problem 20-32

A power line carries a current of 95 A along the tops of 8.5 m-high poles. What is the magnitude of the magnetic field produced by this wire at the ground?



$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A})(95\ \mathrm{A})}{2\pi\,(8.5\ \mathrm{m})}$$

$$\boxed{B = 2.2 \times 10^{-6}\ \mathrm{T}}$$

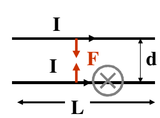
Magnetism 20

Force between Two Parallel Wires

Problem 20-30

Determine the magnitude and direction of the force between two parallel wires 35 m long and 6.0 cm apart, each carrying 25 A in the same direction.

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



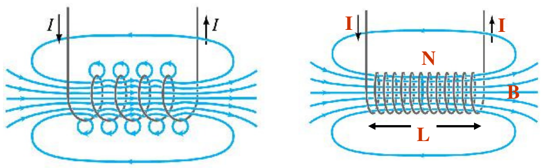
$$F = \frac{(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A})(25\ \mathrm{A})^2}{2\pi\,(6.0 \times 10^{-2}\ \mathrm{m})}(35\ \mathrm{m}) \quad \boxed{= 7.3 \times 10^{-2}\ \mathrm{N}}$$

Magnetism 20

Solenoids and Electromagnets

A solenoid is a long coil of wire. If it is tightly wrapped, the magnetic field in its interior is almost uniform:

$$B = \frac{\mu_o IN}{L}$$



Summary

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: $F = ILB\sin\theta$

A magnetic field exerts a force on a moving charge $F = qvB\sin\theta$

Solenoids and Electromagnets

Problem 20-48

A thin 12-cm-long solenoid has a total of 420 turns of wire and carries a current of 2.0 A. Calculate the field inside near the center.

$$B = \frac{\mu_o IN}{L}$$

$$= \frac{(4\pi\,x10^{-7}\ T\cdot m/A)(2.0\ A)(420)}{(0.12\ m)}$$

$$B = 8.8\,x10^{-3}\ T$$

Summary

Magnitude of the field of a long, straight current-carrying wire $B = \frac{\mu_o}{2\pi}\frac{I}{r}$

Parallel currents attract; anti-parallel currents repel

Magnetic field inside a solenoid $B = \frac{\mu_o IN}{L}$

Force between to long straight currents. $F = \frac{\mu_o}{2\pi}\frac{I_1 I_2}{d}L$

Solenoids and Electromagnets

Problem 20-49

A 30.0-cm-long solenoid 1.25 cm in diameter is to produce a field of 0.385 T at its center. How much current should the solenoid carry if it has 975 turns of the wire?

$$B = \frac{\mu_o IN}{L} \quad \Rightarrow \quad I = \frac{BL}{\mu_o N}$$

$$I = \frac{(0.385\ T)(0.300\ m)}{(4\pi\,x10^{-7}\ T\cdot m/A)(975)}$$

$$B = 94.3\ A$$