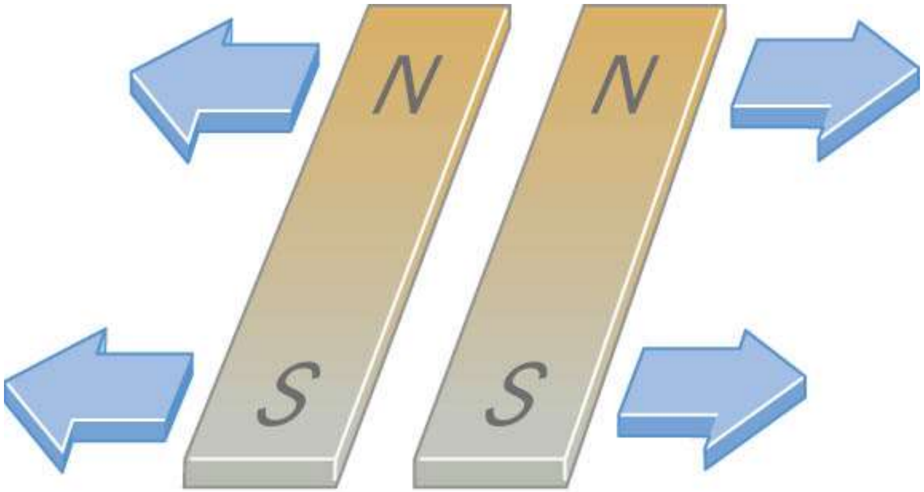
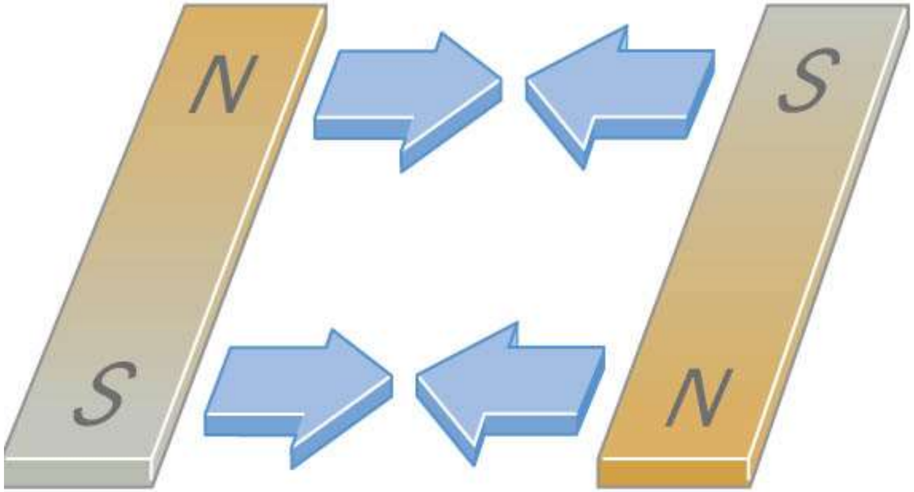
Magnetic Forces and Magnetic Fields

The behavior of magnetic poles is similar to that of like and unlike electric charges.



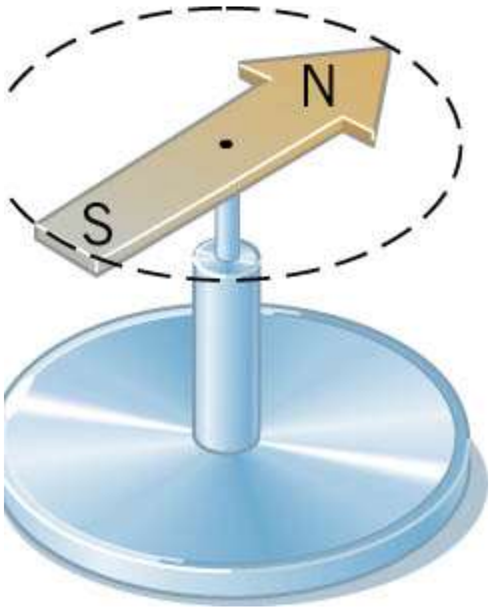
Like poles repel

(a)

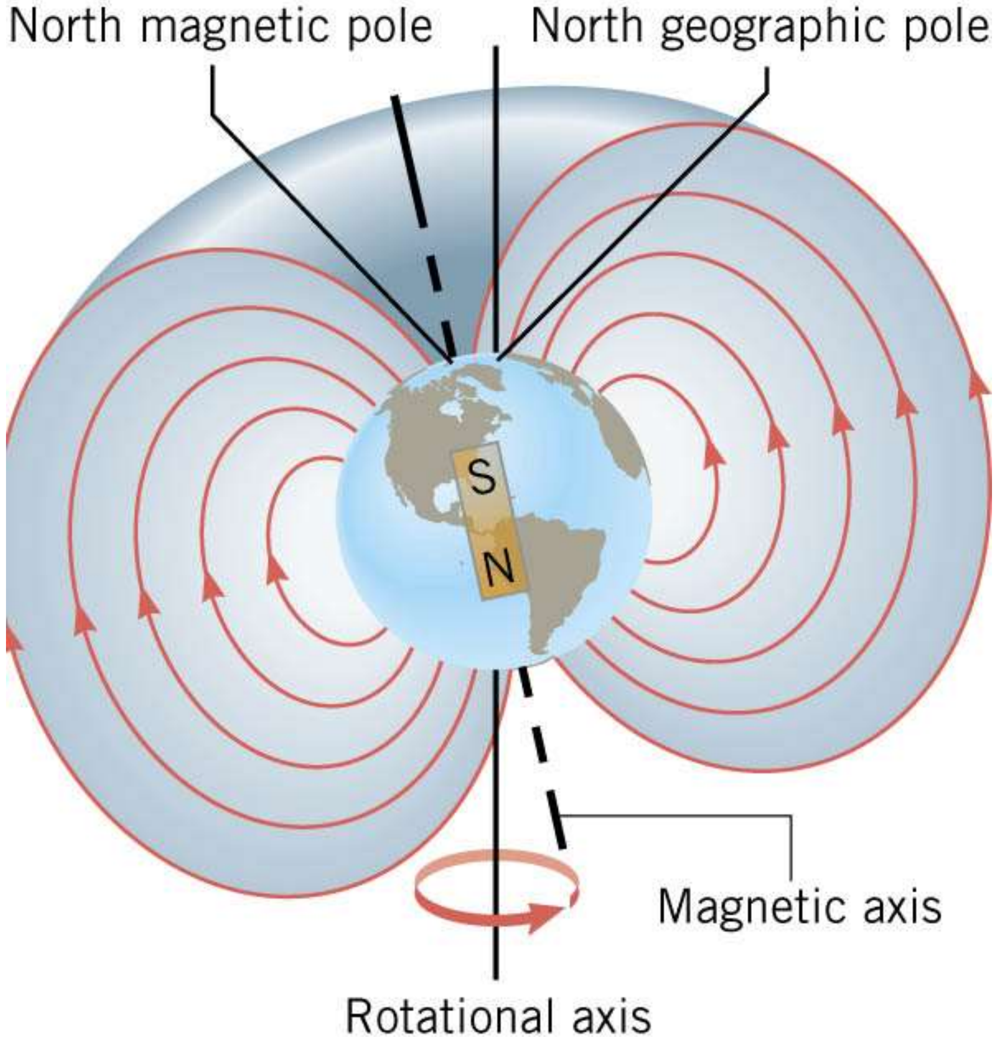


Unlike poles attract

(b)

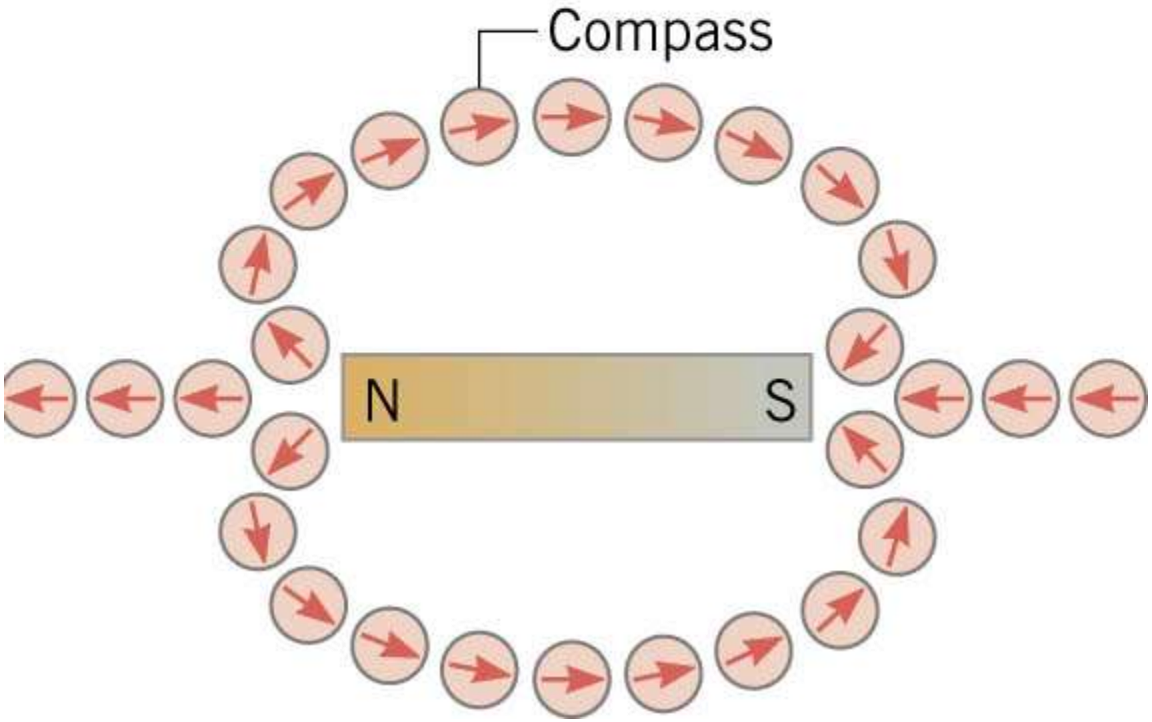


The needle of a compass is permanent magnet that has a north magnetic pole (N) at one end and a south magnetic pole (S) at the other.



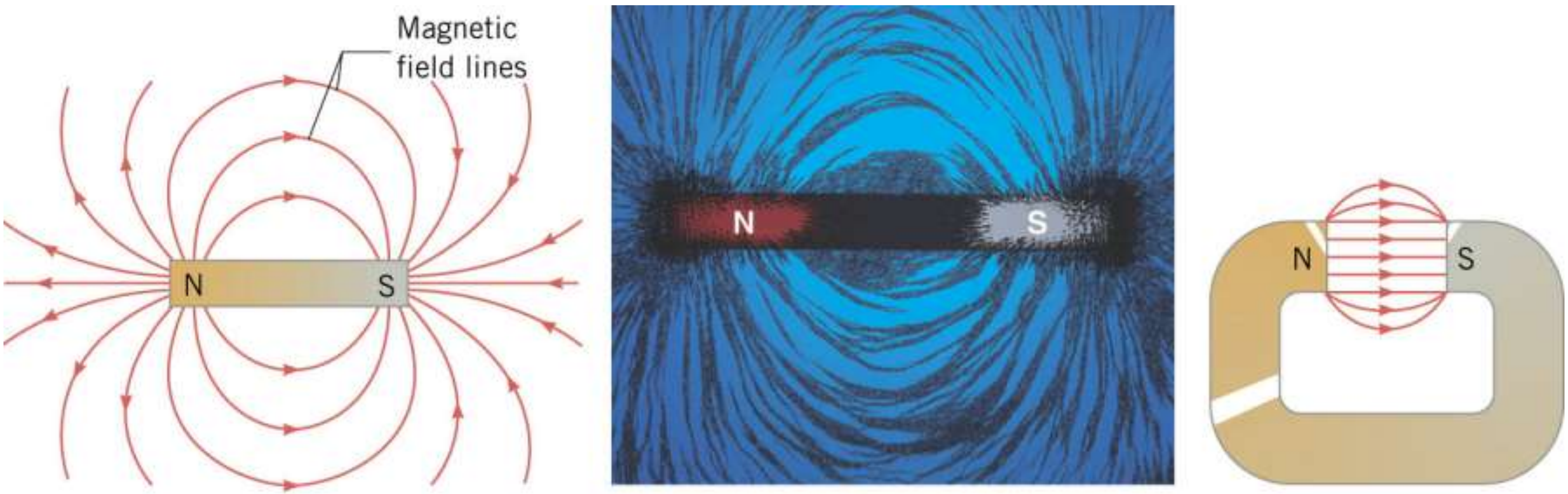
Earth acts like a huge bar magnet. North magnetic pole (actually has south polarity) is near north geographic pole. That why north pole on compass points North. Poles wander and sometimes flip!

Surrounding a magnet there is a ***magnetic field***. The direction of the magnetic field at any point in space is the direction indicated by the north pole of a small compass needle placed at that point.



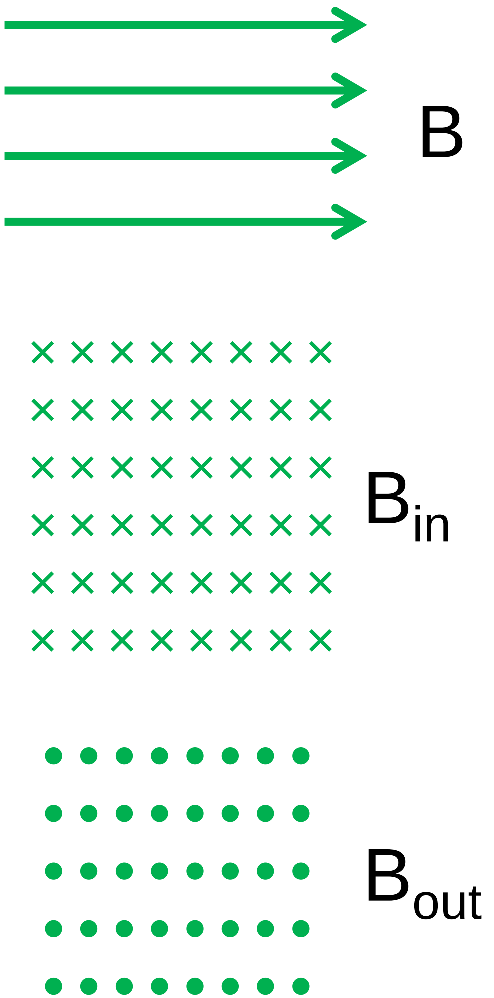
21.1 **Magnetic Fields**

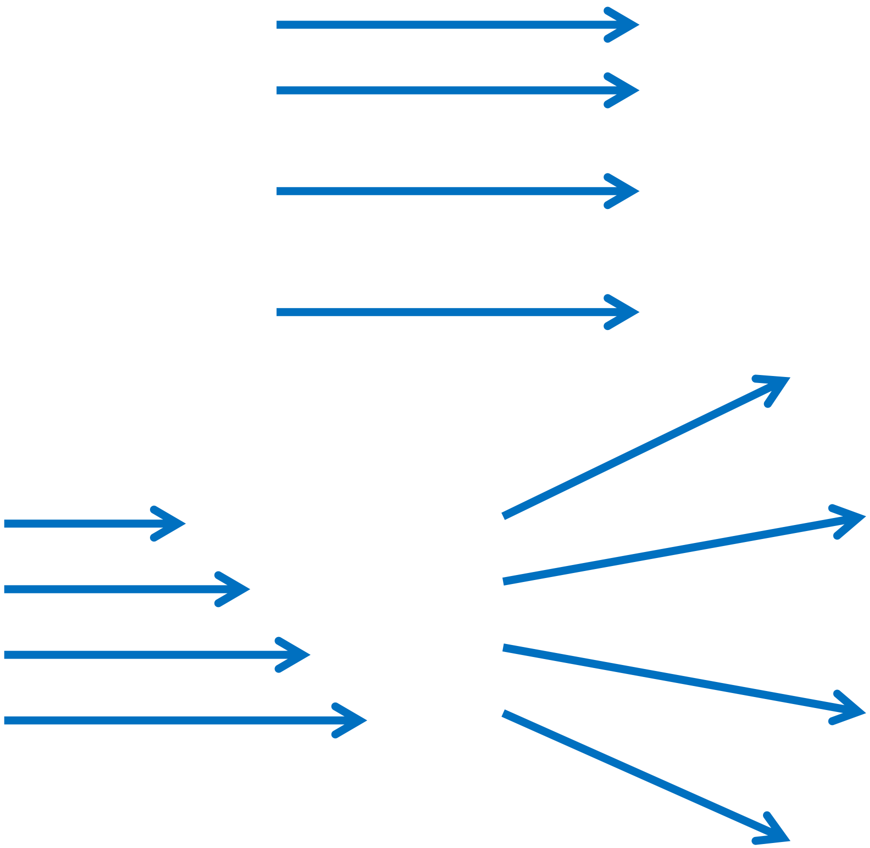
The magnetic field lines and pattern of iron filings in the vicinity of a bar magnet and the magnetic field lines in the gap of a horseshoe magnet.



(a) (b) (c)

Uniform Fields





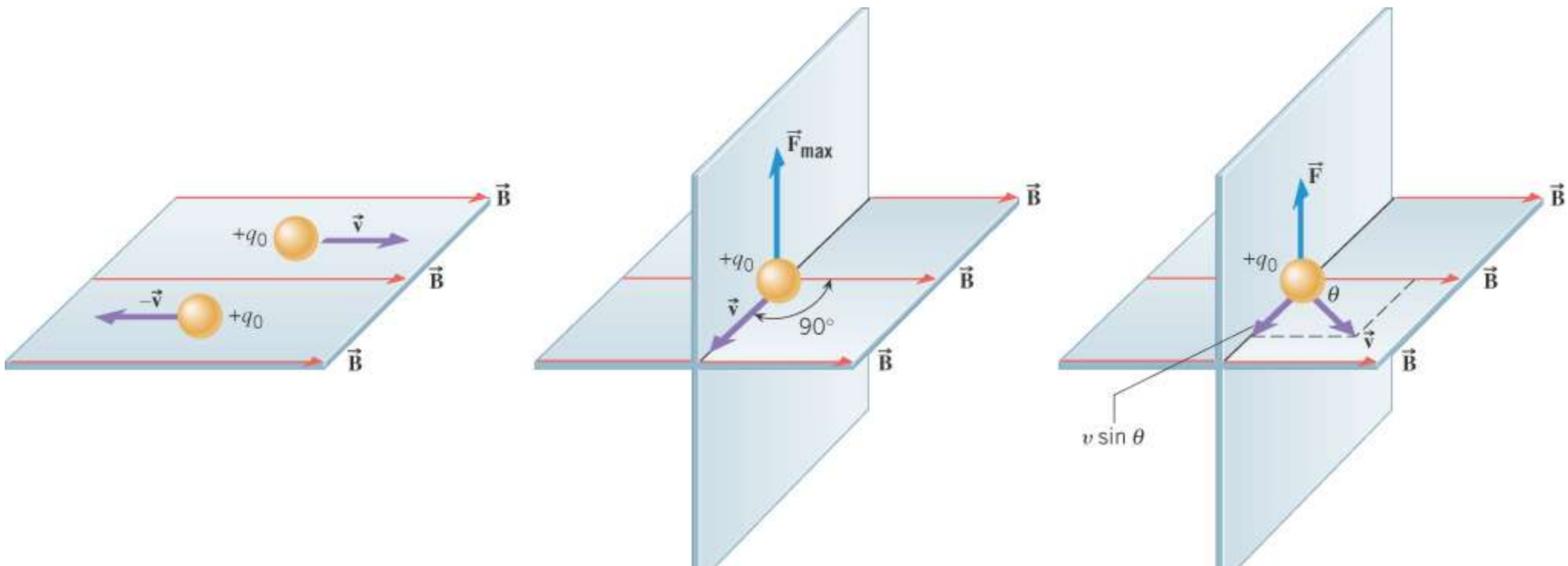
Uniform

Non-uniform

21.2 The Force That a Magnetic Field Exerts on a Charge

The following conditions must be met for a charge to experience a magnetic force when placed in a magnetic field:

1. The charge must be moving.
2. The velocity of the charge must have a component that is perpendicular to the direction of the magnetic field.

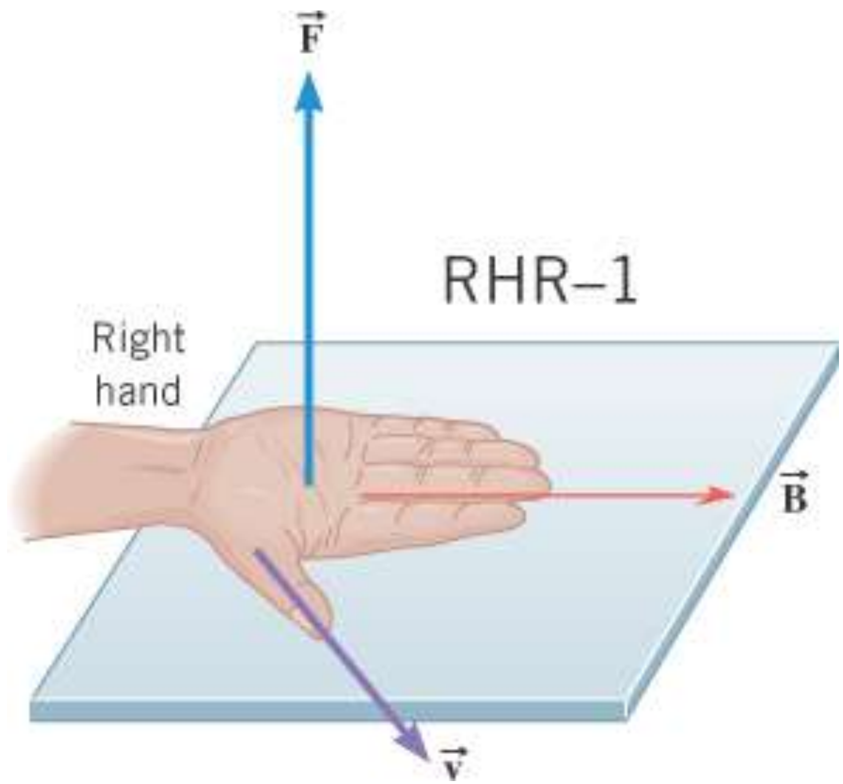


(a) (b) (c)

$$F_M = qvB\sin\theta$$

Right Hand Rule No. 1. Extend the right hand so the fingers point along the direction of the magnetic field and the thumb points along the velocity of the charge. The palm of the hand then faces in the direction of the magnetic force that acts on a positive charge.

If the moving charge is negative, the direction of the force is opposite to that predicted by RHR-1.



Note: F is perpendicular to the plane formed by v and B

DEFINITION OF THE MAGNETIC FIELD

The magnitude of the magnetic field at any point in space is defined as

$$B = \frac{F}{|q_o|(v\sin\theta)}$$

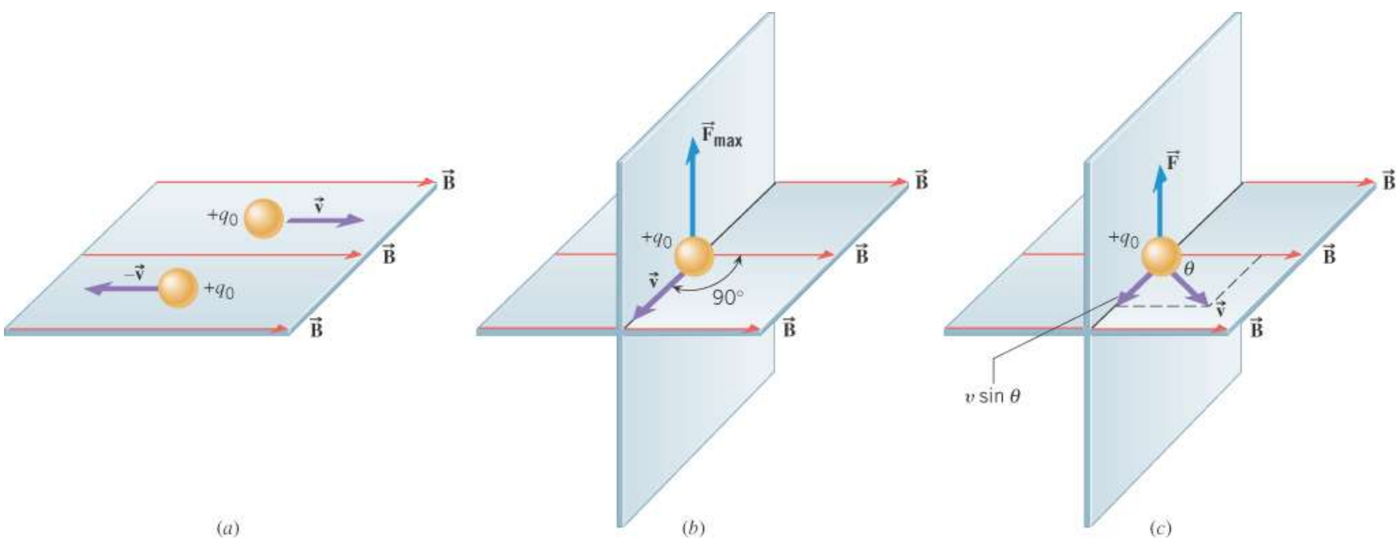
where the angle (0<θ<180º) is the angle between the velocity of the charge and the direction of the magnetic field.

SI Unit of Magnetic Field: $\frac{\text{newton}\cdot\text{second}}{\text{coulomb}\cdot\text{meter}} = 1\,\text{tesla}\,(\text{T})$

$$1\,\text{gauss} = 10^{-4}\,\text{tesla}$$

Example 1 Magnetic Forces on Charged Particles

A proton in a particle accelerator has a speed of 5.0×10^6 m/s. The proton encounters a magnetic field whose magnitude is 0.40 T and whose direction makes and angle of 30.0 degrees with respect to the proton's velocity (see part (c) of the figure). Find (a) the magnitude and direction of the force on the proton and (b) the acceleration of the proton. (c) What would be the force and acceleration of the particle were an electron?



21.2 The Force That a Magnetic Field Exerts on a Charge

(a) $$F = |q_o| vB\sin\theta = \left(1.60\times10^{-19}\,\mathrm{C}\right)\left(5.0\times10^{6}\,\mathrm{m/s}\right)\left(0.40\mathrm{T}\right)\sin\left(30.0^\circ\right)$$
$$= 1.6\times10^{-13}\,\mathrm{N}$$

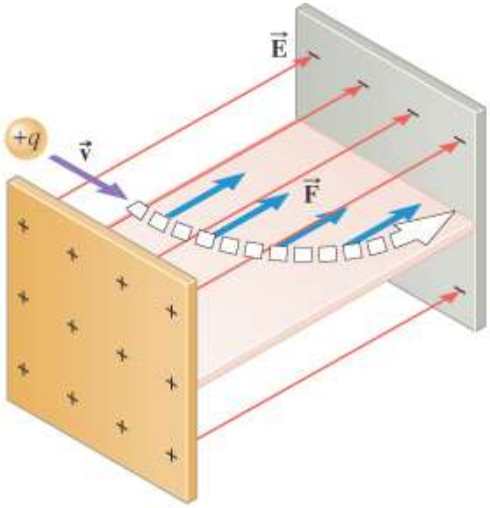
(b) $$a = \frac{F}{m_\mathrm{p}} = \frac{1.6\times10^{-13}\,\mathrm{N}}{1.67\times10^{-27}\,\mathrm{kg}} = 9.6\times10^{13}\,\mathrm{m/s^2}$$

(c) Magnitude is the same, but direction is opposite.

$$a = \frac{F}{m_\mathrm{e}} = \frac{1.6\times10^{-13}\,\mathrm{N}}{9.11\times10^{-31}\,\mathrm{kg}} = 1.8\times10^{17}\,\mathrm{m/s^2}$$

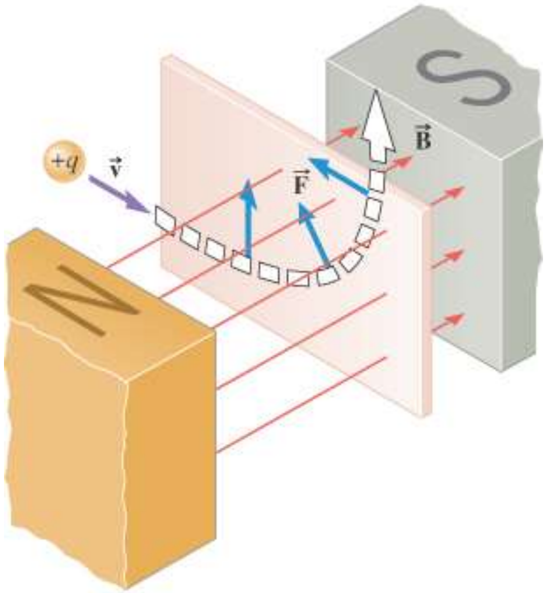
21.3 The Motion of a Charged Particle in a Magnetic Field

The electrical force *can* do work on a charged particle.



(*a*)

The magnetic force *cannot* do work on a charged particle since F is always perpendicular to direction of motion.

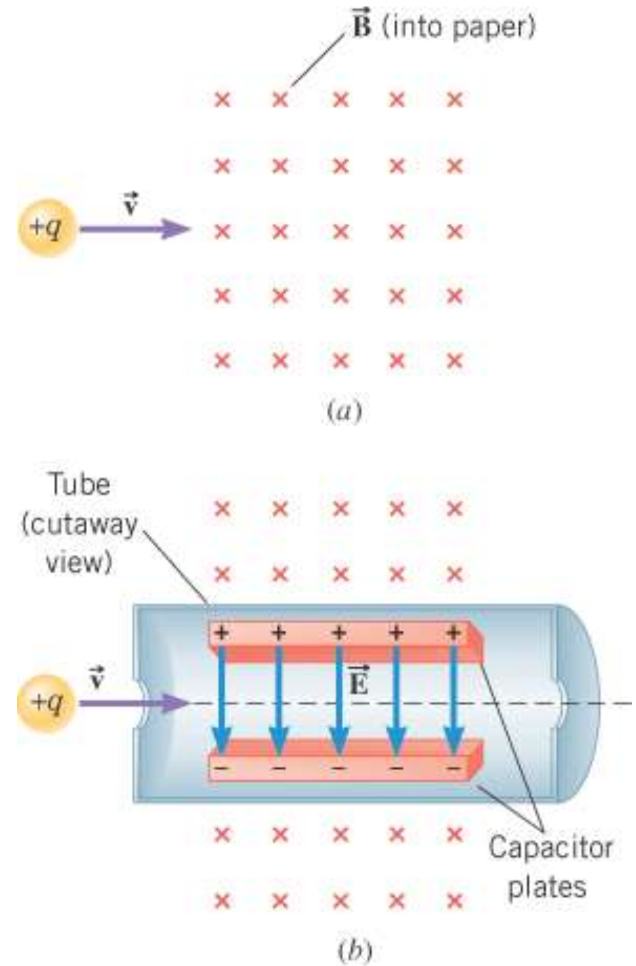


(*b*)

Conceptual Example 2 A Velocity Selector

A velocity selector is a device for measuring the velocity of a charged particle. The device operates by applying electric and magnetic forces to the particle in such a way that these forces balance.

How should an electric field be applied so that the force it applies to the particle can balance the magnetic force?



21.3 The Motion of a Charged Particle in a Magnetic Field

The magnetic force always remains perpendicular to the velocity and is directed toward the center of the circular path.

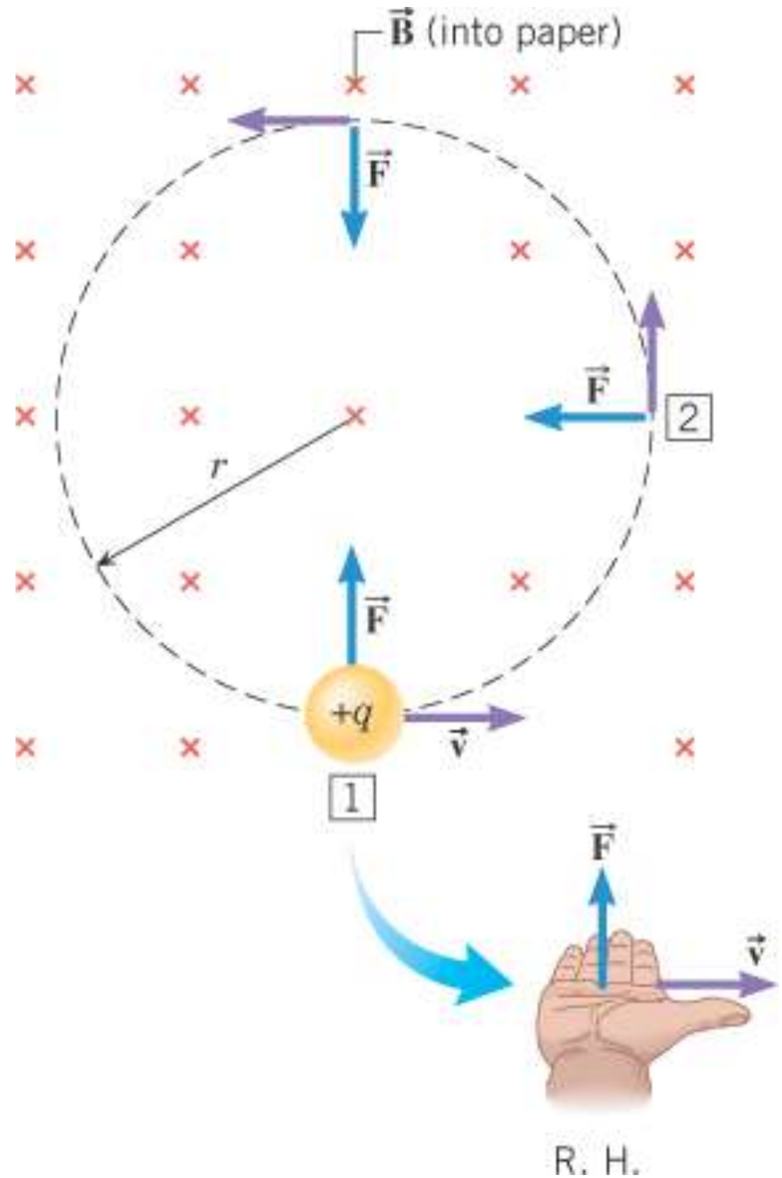
$$F_{net} = m\frac{v^2}{r}$$

$$\Downarrow$$

$$qvB = m\frac{v^2}{r}$$

$$\Downarrow$$

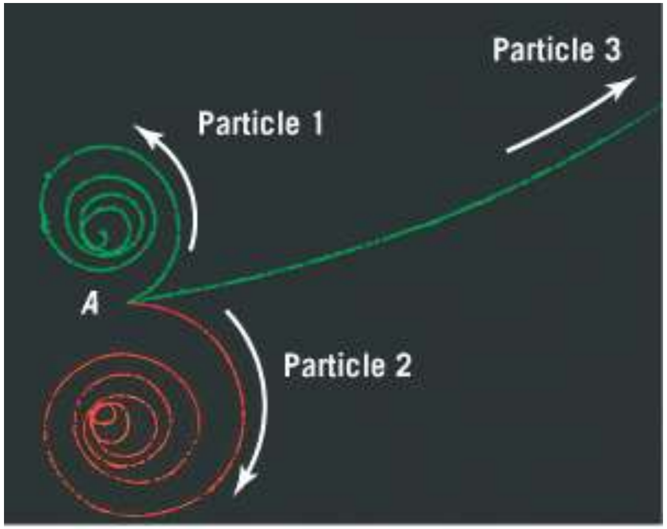
$$r = \frac{mv}{qB}$$



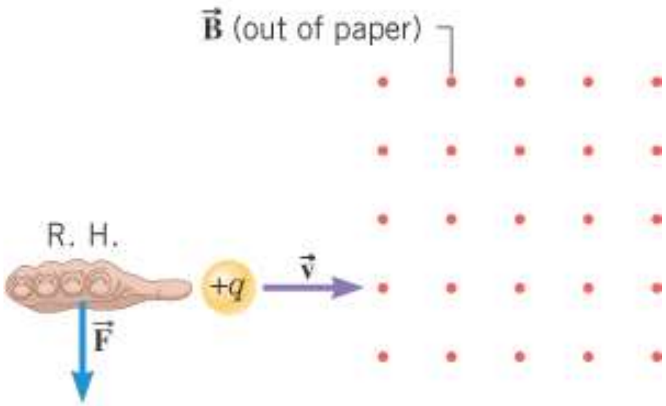
Conceptual Example 4 Particle Tracks in a Bubble Chamber

The figure shows the bubble-chamber tracks from an event that begins at point A. At this point a gamma ray travels in from the left, spontaneously transforms into two charged particles. The particles move away from point A, producing two spiral tracks. A third charged particle is knocked out of a hydrogen atom and moves forward, producing the long track.

The magnetic field is directed out of the paper. Determine the sign of each particle and which particle is moving most rapidly.



(*a*)



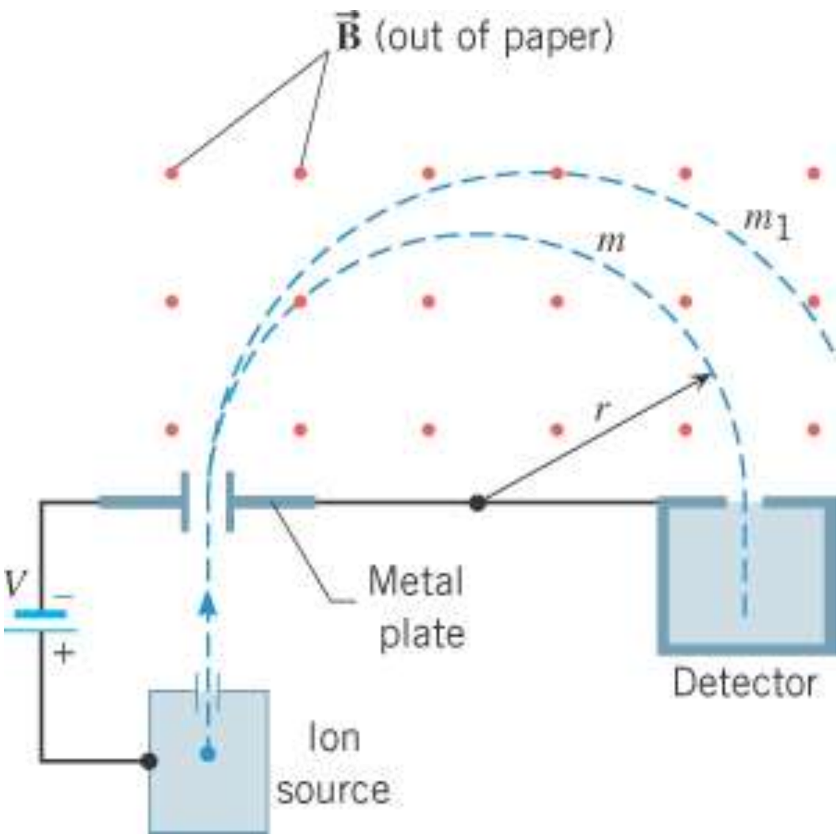
(*b*)

$$r = \frac{mv}{qB} = \frac{mv}{(ne)B}$$

$$\tfrac{1}{2}mv^2 = qV$$

Ion charge in multiples of electron charge

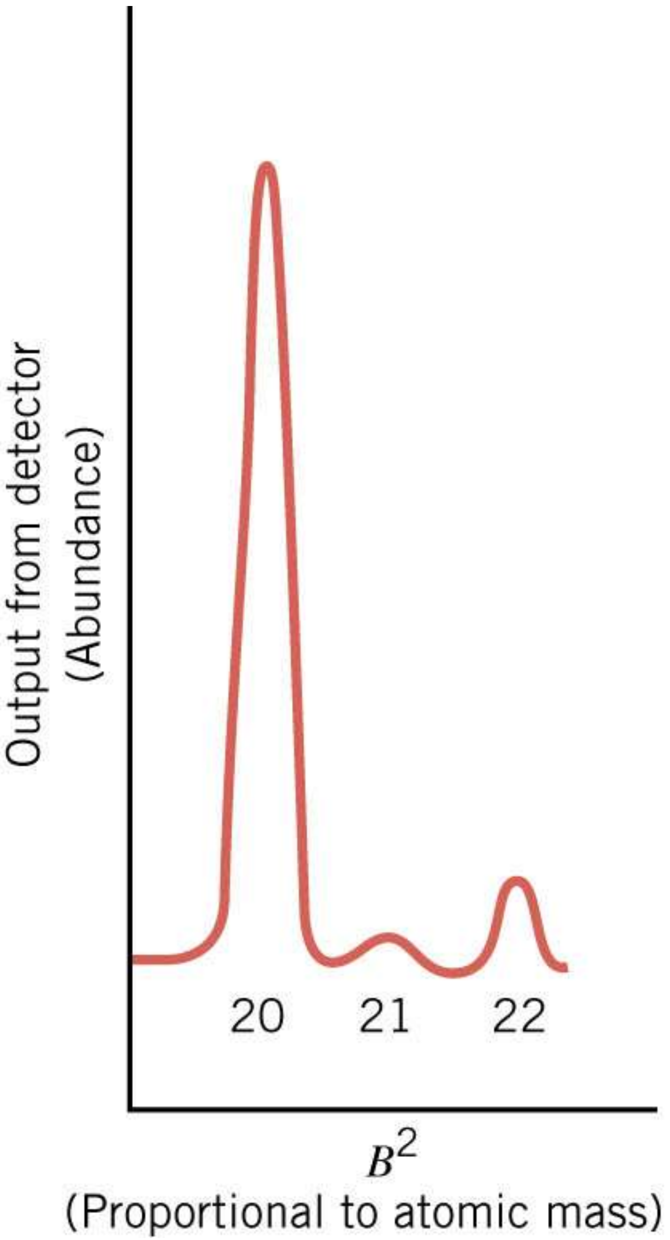
KE=PE



$$m = \left(\frac{qr^2}{2V}\right)B^2$$

N.B. $e = 1.602 \times 10^{-19}$ C

The mass spectrum of naturally occurring neon, showing three isotopes.



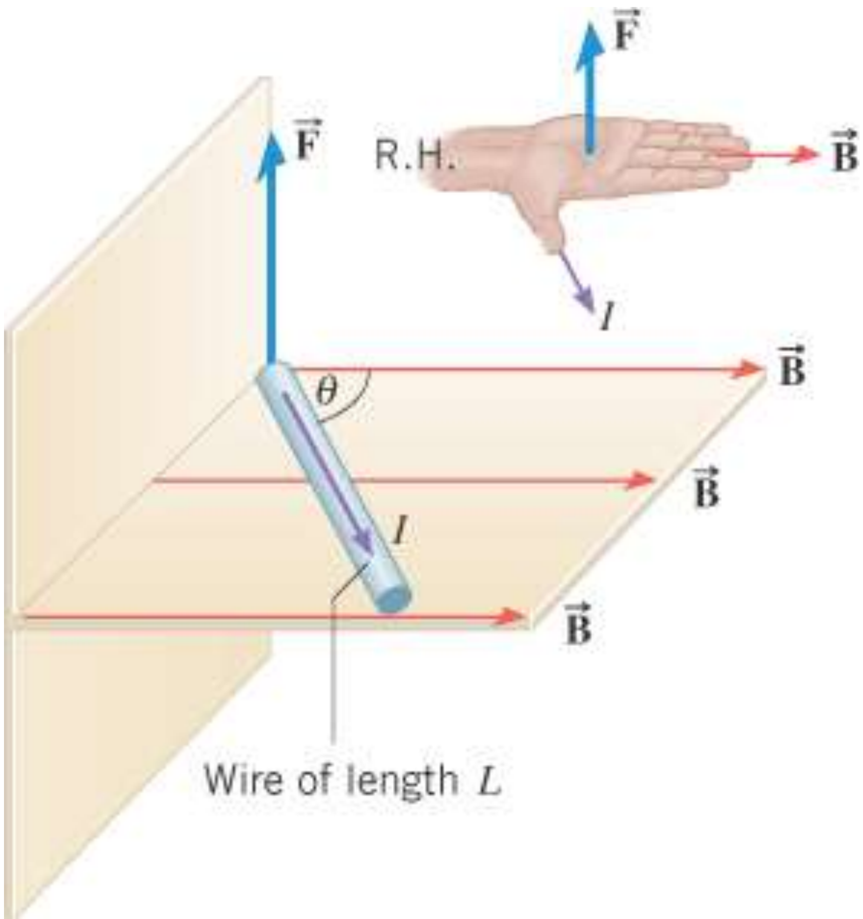
$$F = qvB\sin\theta$$

$$\Downarrow$$

$$F = \underbrace{\left(\frac{\Delta q}{\Delta t}\right)}_{I}\underbrace{(v\Delta t)}_{L}B\sin\theta$$

$$\Downarrow$$

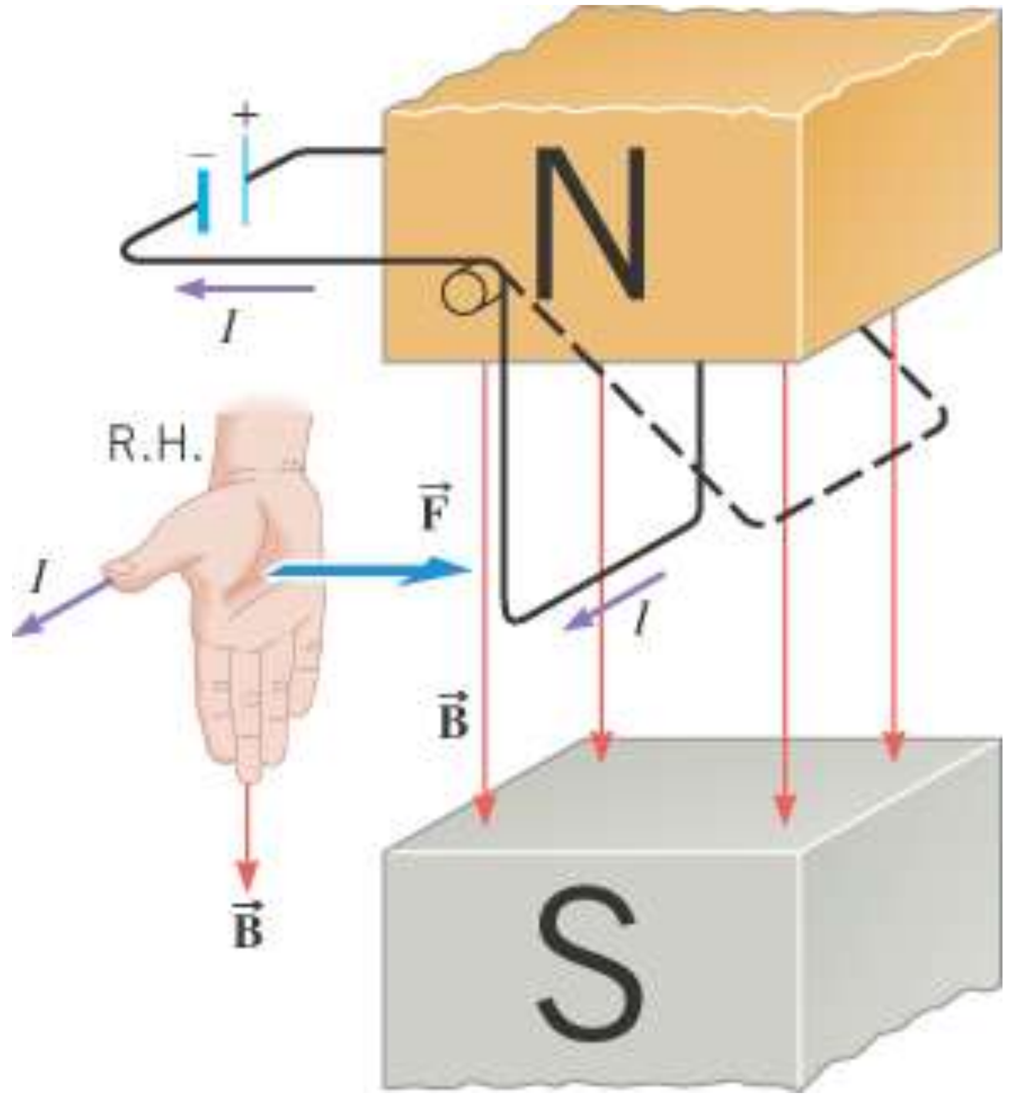
$$F = ILB\sin\theta$$



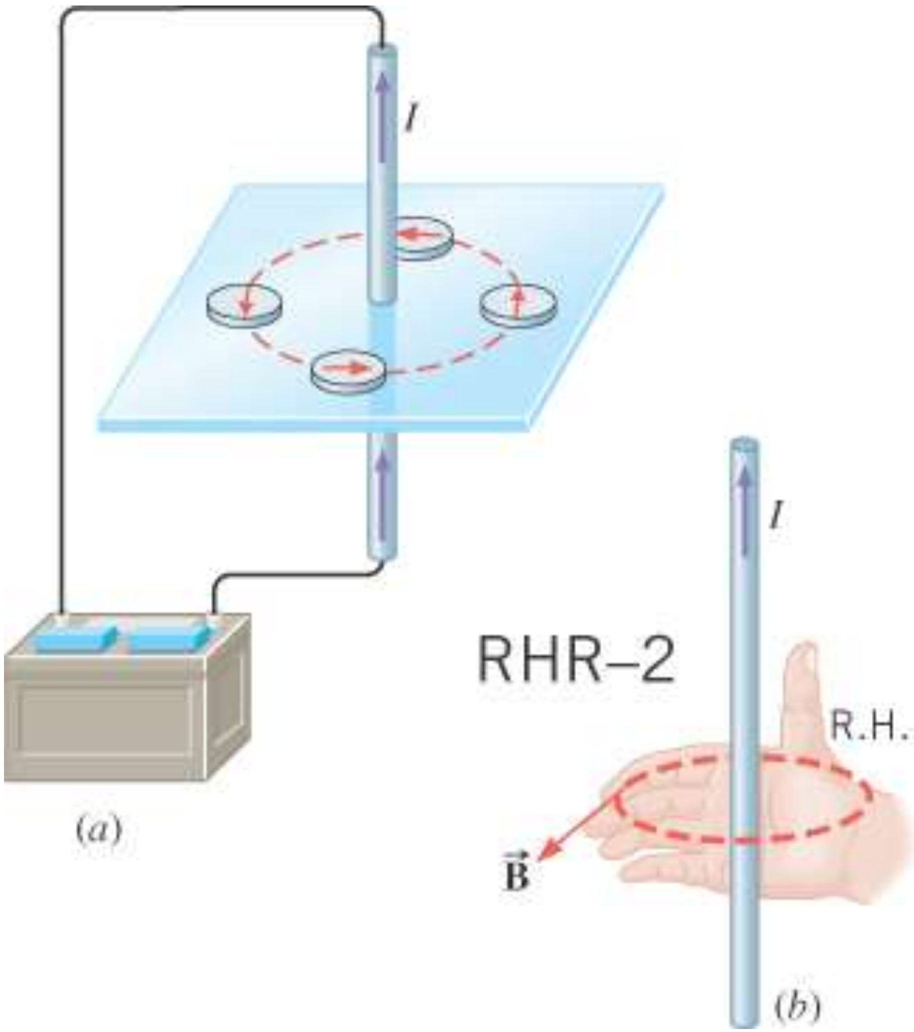
Only the portion of the wire that is immersed in the B field experiences the force.

The magnetic force on the moving charges pushes the wire to the right.

Motors work on this principle.

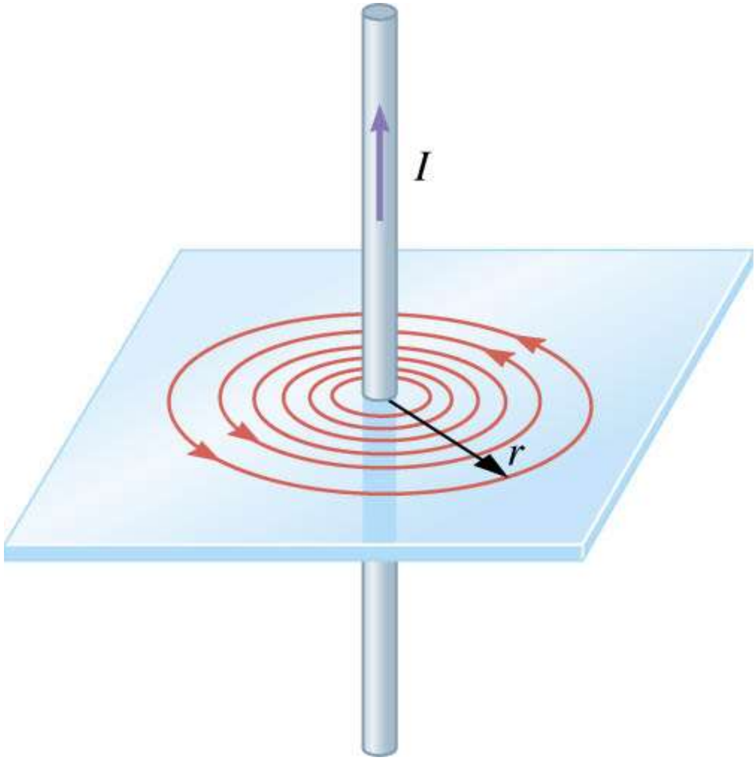


Currents can produce magnetic fields!



Right-Hand Rule No. 2.
Curl the fingers of the right hand into the shape of a half-circle. Point the thumb in the direction of the conventional current, and the tips of the fingers will point in the direction of the magnetic field.

A LONG, STRAIGHT WIRE

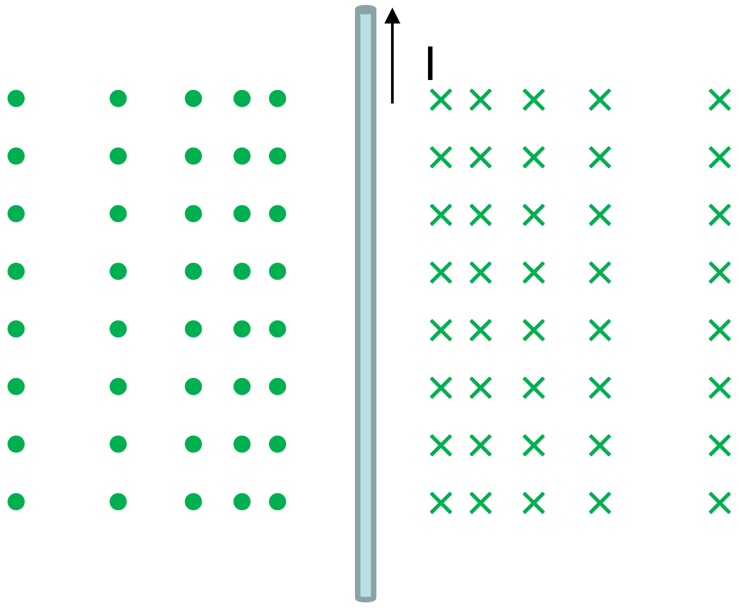


$$B = \frac{\mu_o I}{2\pi r}$$

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

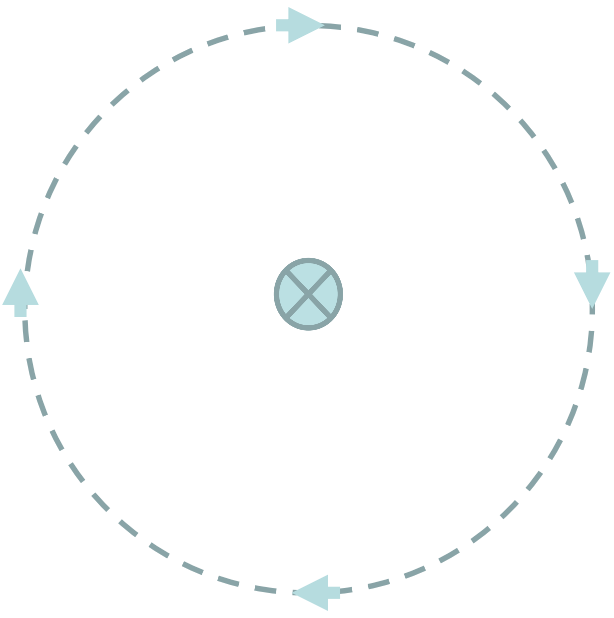
permeability of free space

Direction of B



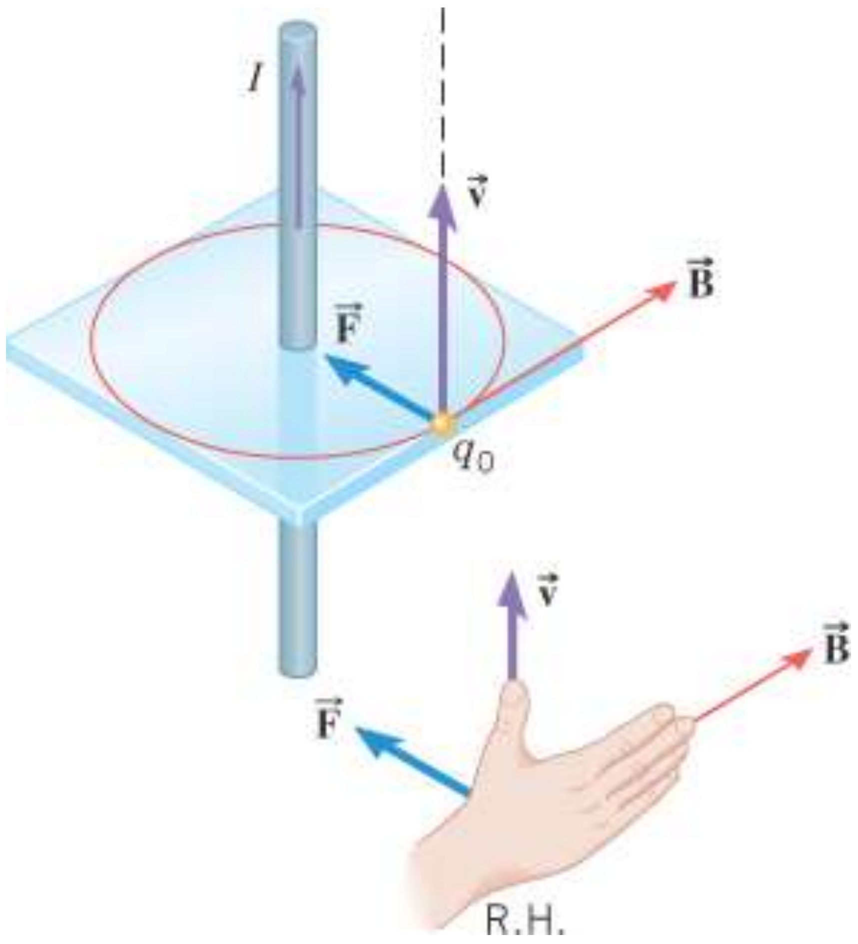
Looking from above

Looking head on



Example 7 A Current Exerts a Magnetic Force on a Moving Charge

The long straight wire carries a current of 3.0 A. A particle has a charge of $+6.5\text{x}10^{-6}$ C and is moving parallel to the wire at a distance of 0.050 m. The speed of the particle is 280 m/s.

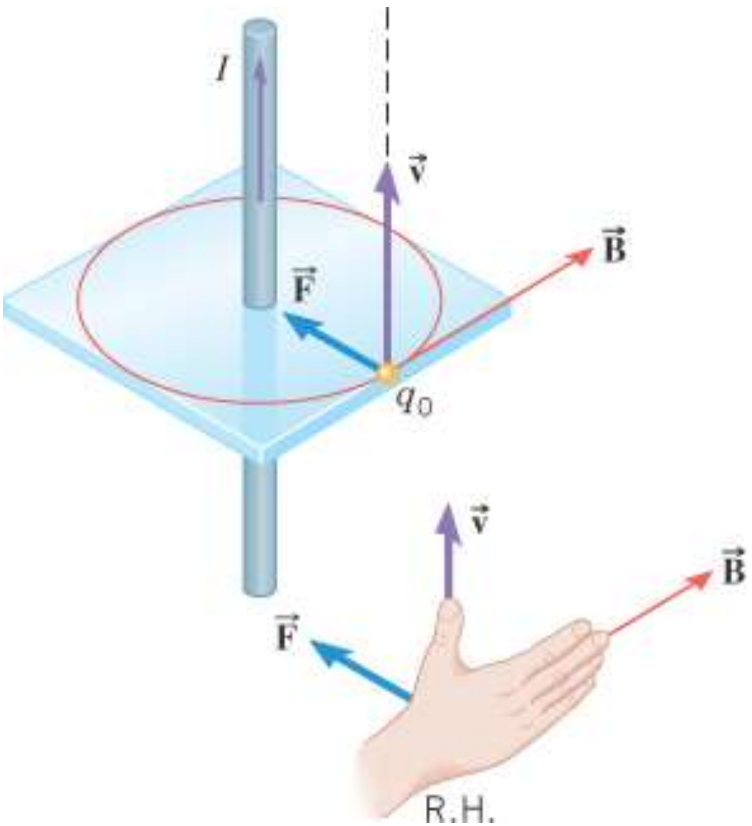


Determine the magnitude and direction of the magnetic force on the particle.

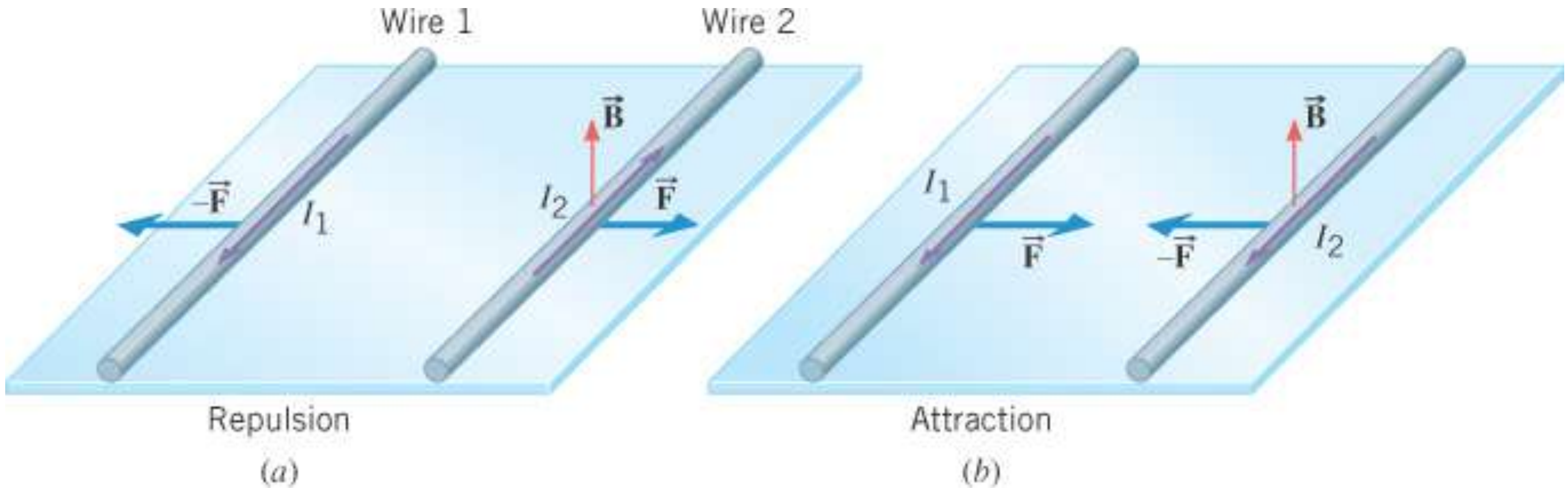
21.7 Magnetic Fields Produced by Currents

$$F = qvB\sin\theta = qv\left(\frac{\mu_o I}{2\pi r}\right)\sin\theta$$

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



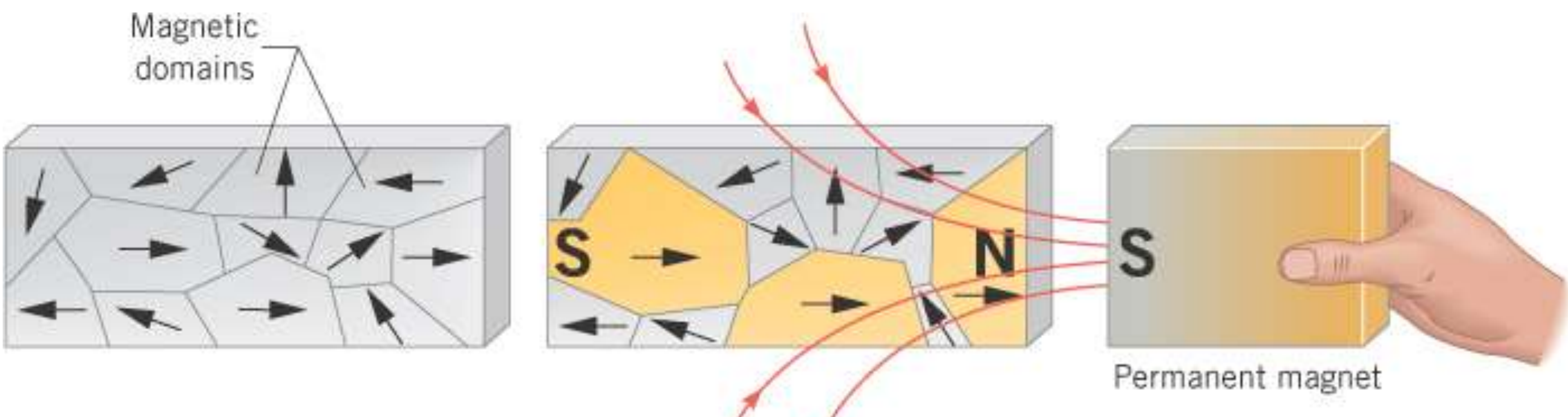
Current carrying wires can exert forces on each other.



21.9 Magnetic Materials

The intrinsic "spin" and orbital motion of electrons gives rise to the magnetic properties of materials.

In ***ferromagnetic materials*** groups of neighboring atoms, forming ***magnetic domains,*** the spins of electrons are naturally aligned with each other.



(*a*) Unmagnetized iron (*b*) Induced magnetism