Chapter 22 Magnetism

22.1 The Magnetic Field

22.2 The Magnetic Force on Moving Charges

22.3 The Motion of Charged particles in a Magnetic Field

22.4 The Magnetic Force Exerted on a Current-Carrying Wire

22.5 Loops of Current and Magnetic Torque

22.6 Electric Current, Magnetic Fields, and Ampere's Law

Magnetism – Is this a new force?

Bar magnets (compass needle) align themselves in a north-south direction.

Poles: Unlike poles attract, like poles repel

Magnet has NO effect on an electroscope and is not influenced by gravity

Magnets attract only some objects (iron, nickel etc)

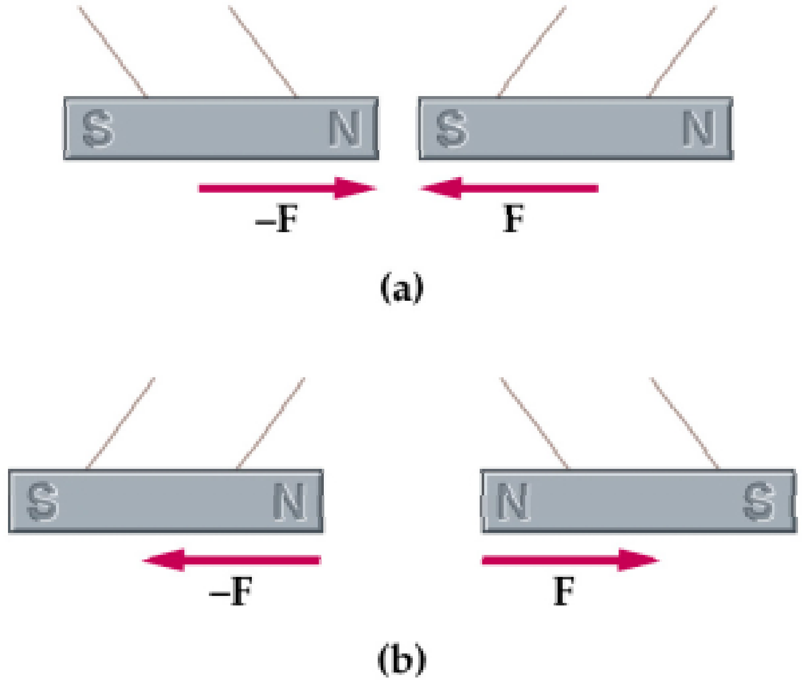
No magnets ever repel non magnets

Magnets have no effect on things like copper or brass

Cut a bar magnet-you get two smaller magnets (no magnetic monopoles)

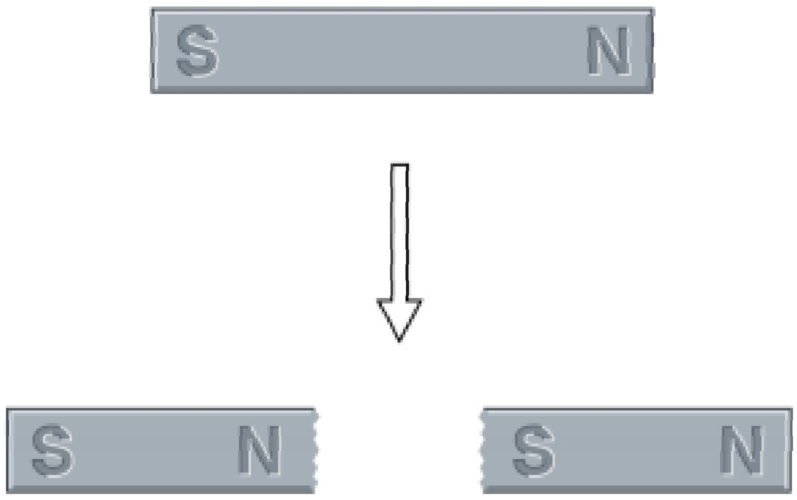
Earth is like a huge bar magnet

Figure 22–1 The force between two bar magnets



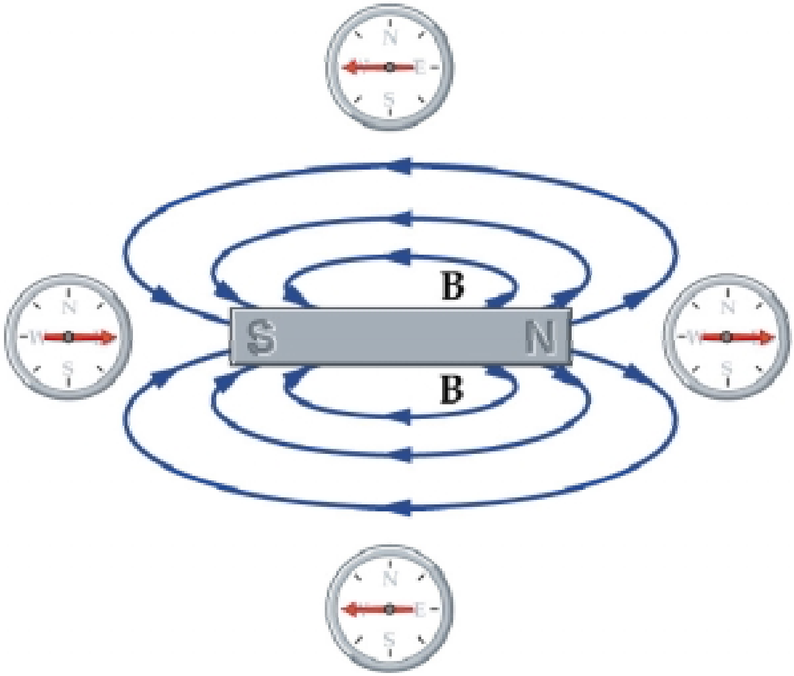
- (a) Opposite poles attract each other. (b) The force between like poles is repulsive.

Figure 22–2 Magnets always have two poles



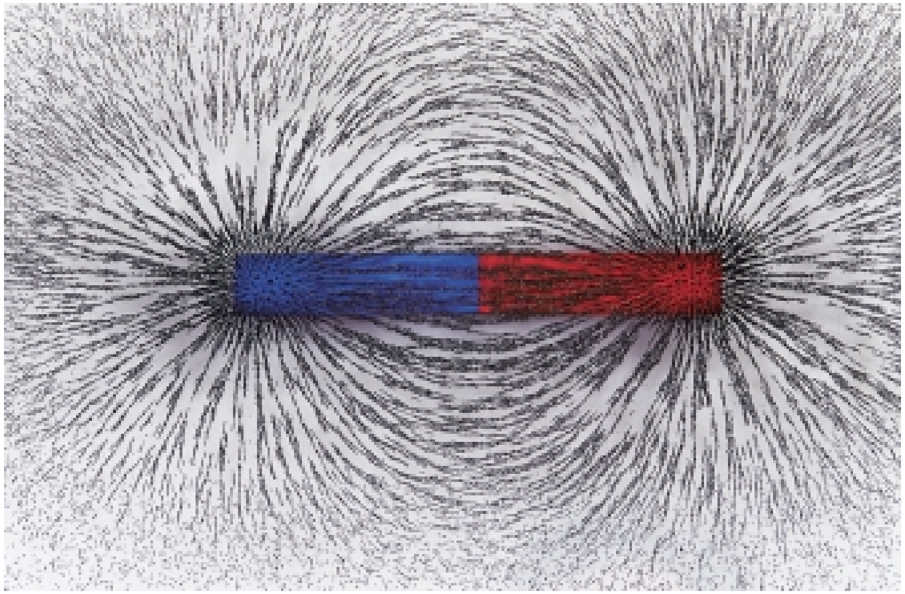
- When a bar magnet is broken in half two new poles appear. Each half has both a north pole and a south pole, just like any other bar magnet.

Figure 22–4 Magnetic field lines for a bar magnet

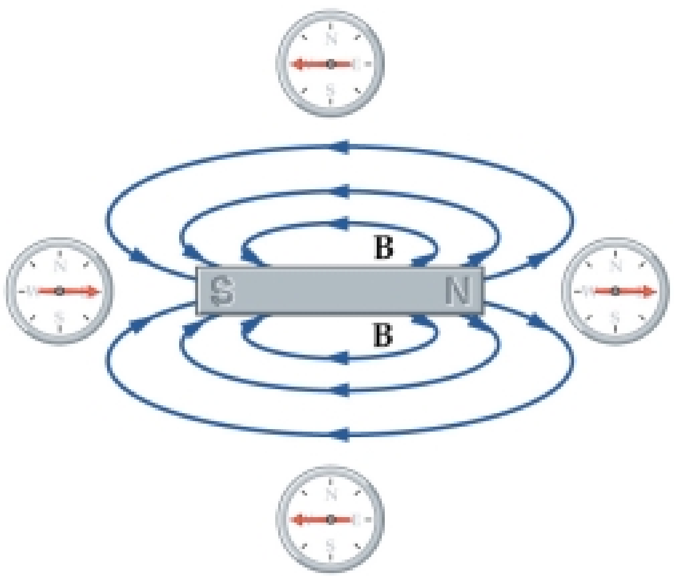


- The field lines are closely spaced near the poles, where the magnetic field B is most intense. In addition, the lines form closed loops that leave at the north pole of the magnet and enter at the south pole.

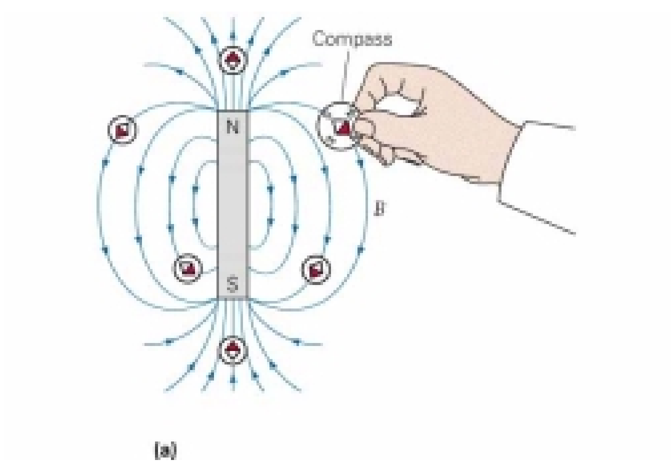
Magnetic Field Lines



If a compass is placed in a magnetic field the needle lines up with the field. The north pole of the compass points in the direction of the field. By noting the direction of the compass needle at various positions we can build up a picture of the magnetic field (B field).

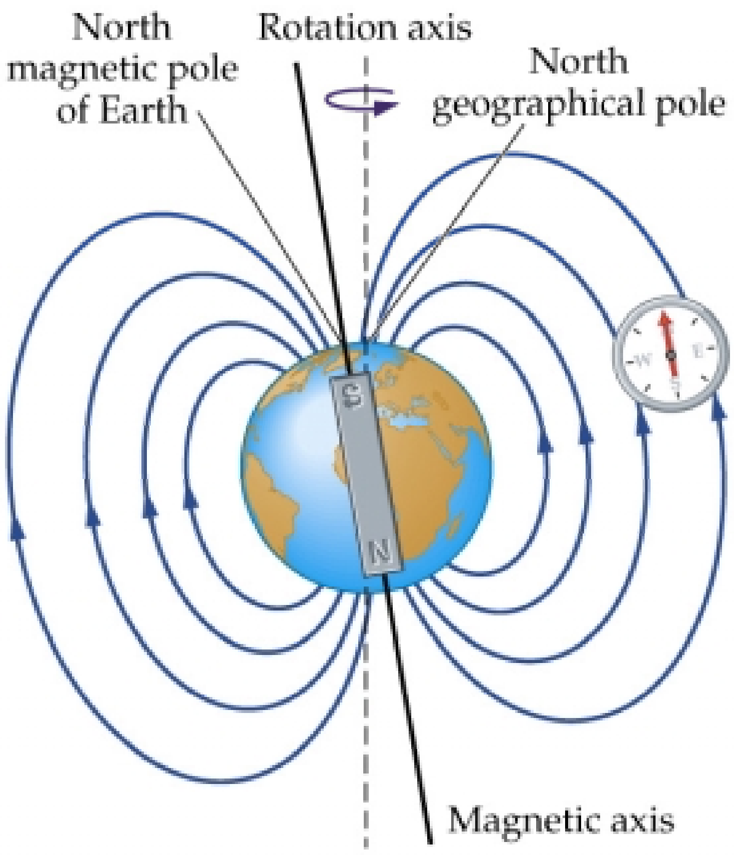


Magnetic fields (B fields) point towards south poles and away from north poles.



Magnetic field from a bar magnet is similar to electric field from an electric dipole.

Figure 22–6 Magnetic field of the Earth



- The Earth's magnetic field is similar to that of a giant bar magnet tilted slightly from the rotational axis. Notice that the north geographic pole is actually near the south pole of the Earth's magnetic field.

Charges experience forces in electric fields.

Do charges experience forces in magnetic fields?

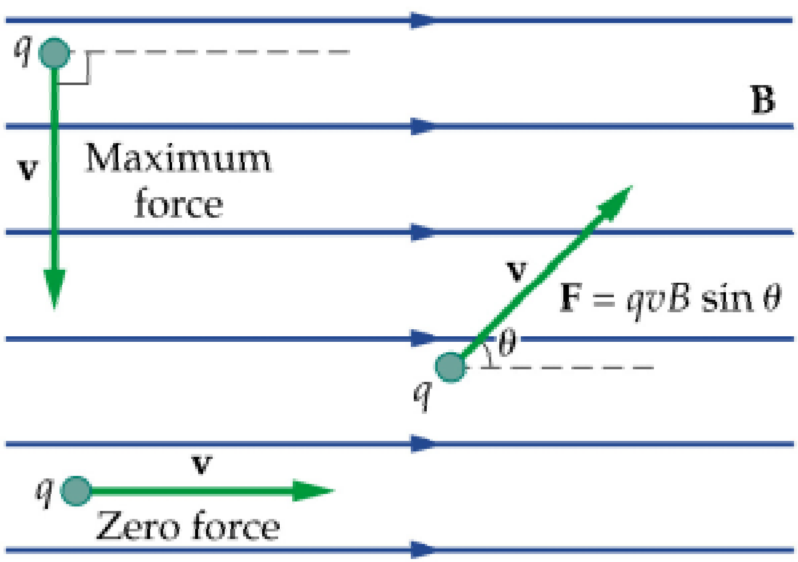
ANSWER

If a charge is stationery, The answer is **NO**

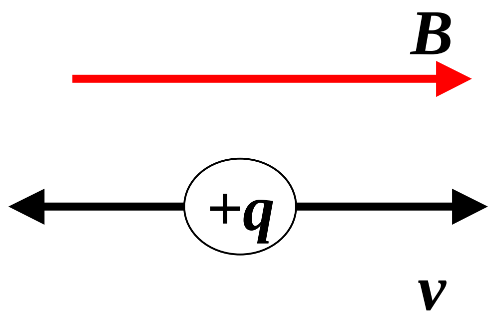
If a charge is moving, The answer is **MAYBE**

If a charge is moving in a direction that has a velocity component that is perpendicular to the magnetic field, The answer is **YES**

Figure 22–7 The magnetic force on a moving charged particle

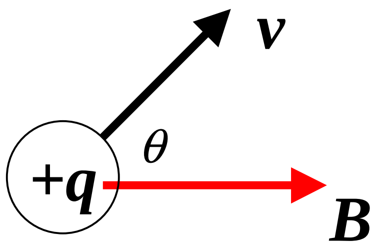


- A particle of charge q moves through a region of magnetic field B with a velocity v. The magnitude of the force experienced by the charge is F = qvB (sin theta). Note that the force is a maximum when the velocity is perpendicular to the field, and is zero when the velocity is parallel to the field.



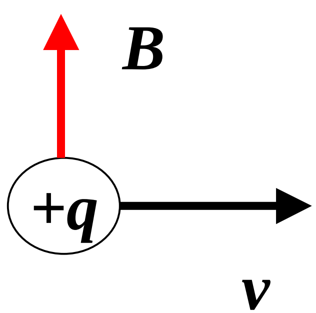
No force

$$\boxed{F = qvB\sin\theta}$$



Some force

Force is **into** the Page, perpendicular to *both* **v** and **B**.



Maximum force

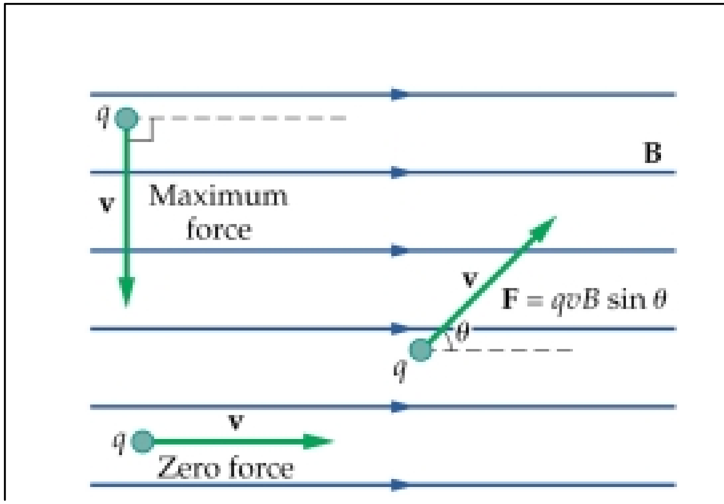
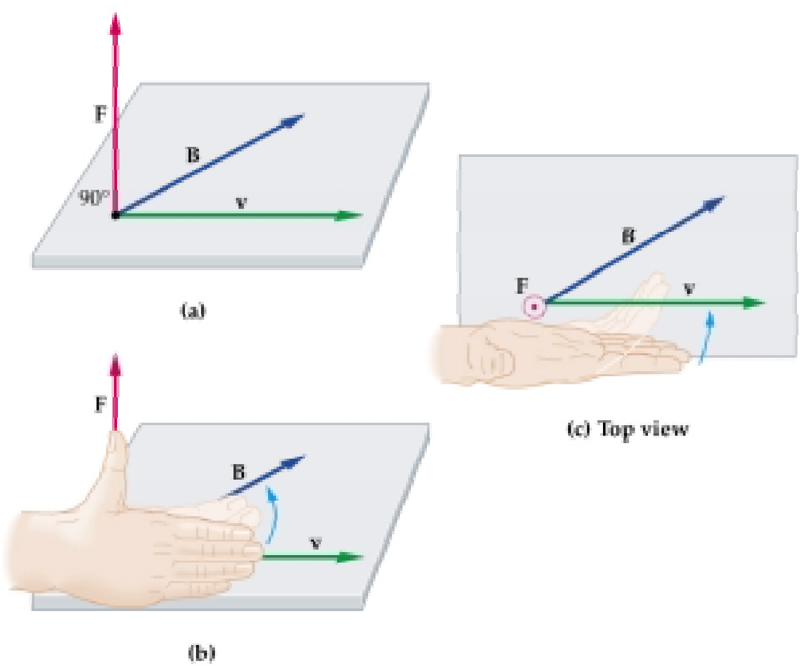
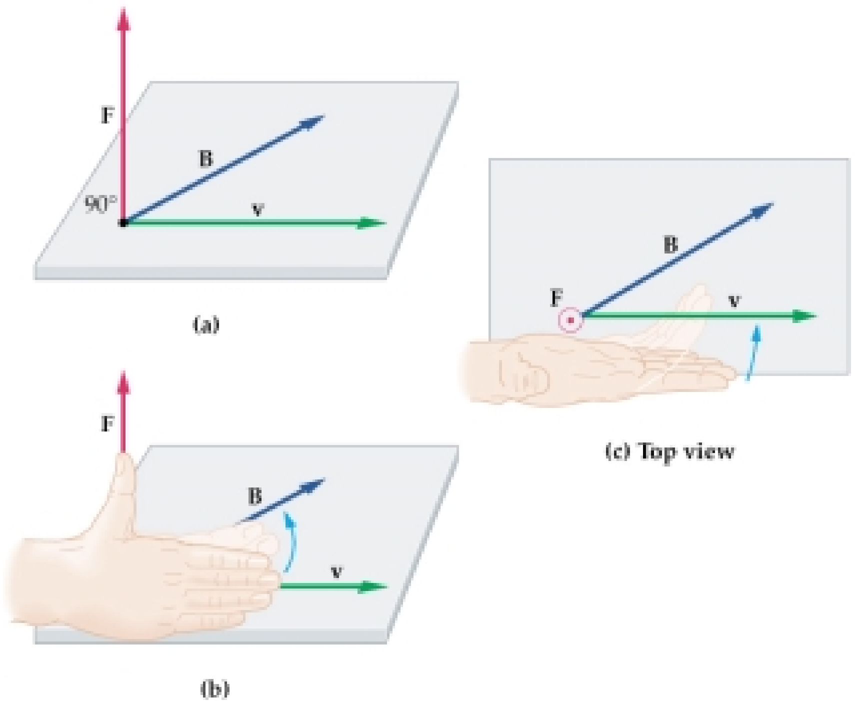


Figure 22–8 The magnetic force right-hand rule

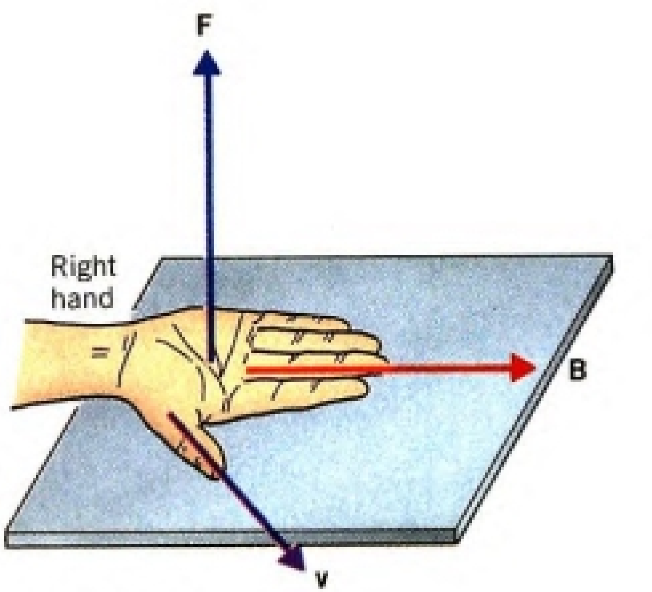


- (a) The magnetic force, F, is perpendicular to both the velocity, v, and the magnetic field, B. (The force vectors shown in this figure are for the case of a positive charge. The force on a negative charge would be in the opposite direction.) (b) As the fingers of the right hand are curled from v to B the thumb points in the direction of F. (c) An overhead view, looking down on the plane defined by the vectors v and B. In this two-dimensional representation, the force vector comes out of the page, and is indicated by a circle with a dot inside. If the charge was negative, the force would point into the page, and the symbol indicating F would be a circle with an X inside.

Right Hand ***FORCE*** *Rule*



Right Hand Palm Rule



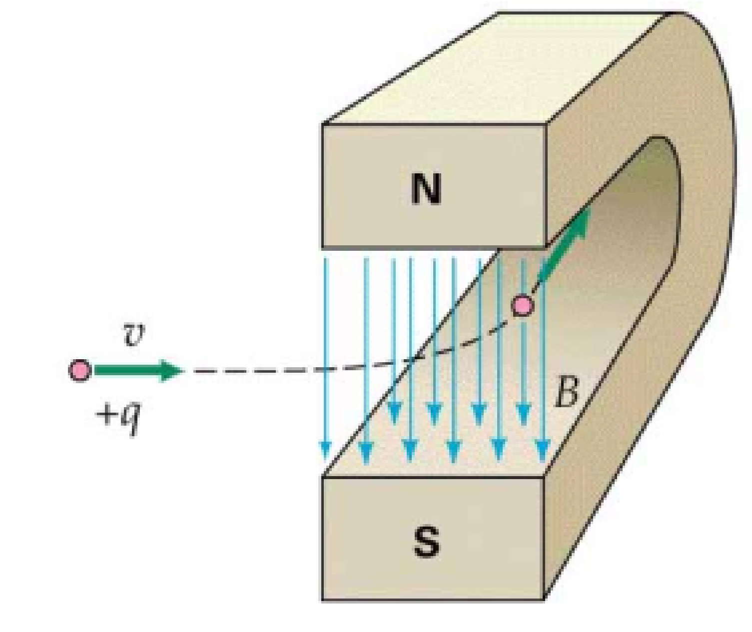
Equivalent

In electrostatics: $\boldsymbol{E}=\boldsymbol{F}/q$

In magnetism: $B=\boldsymbol{F}/q\boldsymbol{v}\sin\theta$

Units of $\boldsymbol{B}$: Tesla (T)

1 Gauss = 10^{-4} T



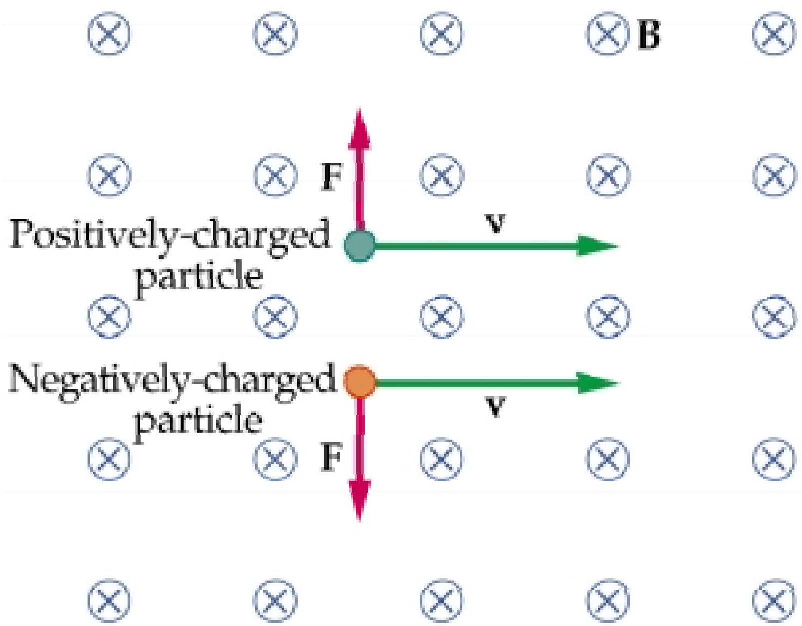
(a)

Magnetic fields (B fields) point towards south poles and away from north poles.

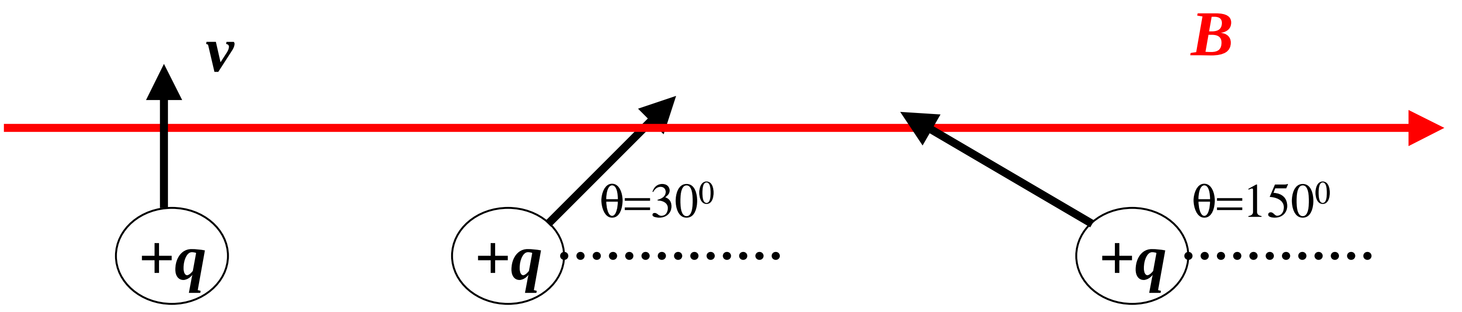
Magnetic field between the poles of a U-magnet is constant. In terms of the field produced, a U-magnet is the magnetic equivalent of a parallel plate capacitor.

Force on a moving charged particle when it enters a magnetic field. The particle experiences a force that is evident because the charge is deflected from its original path.

Figure 22–9 The magnetic force for positive and negative charges



- The direction of the magnetic force depends on the sign of the charge. Specifically, the force exerted on a negatively charged particle is opposite in direction to the force exerted on a positively charged particle.



If q=6 μC, v=25 m/s, B=0.15 T
Find the magnitude and direction of the force in the above examples. What if q was –6 μC?

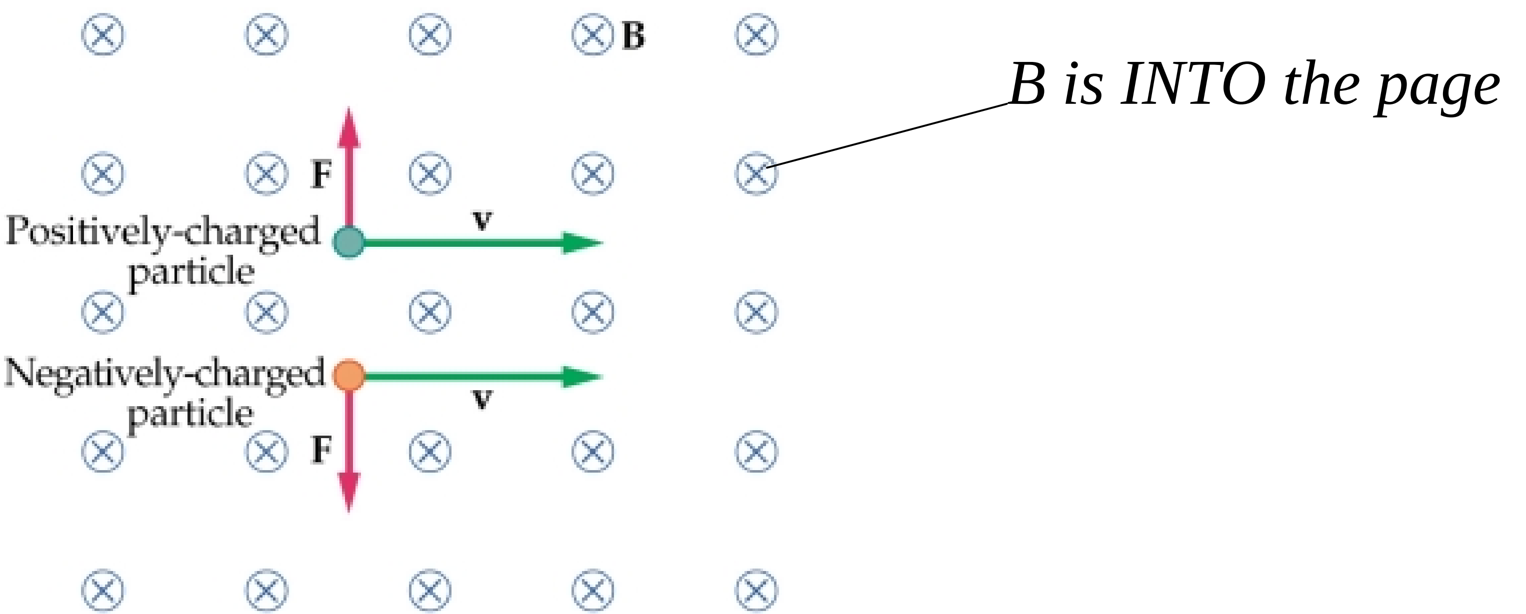
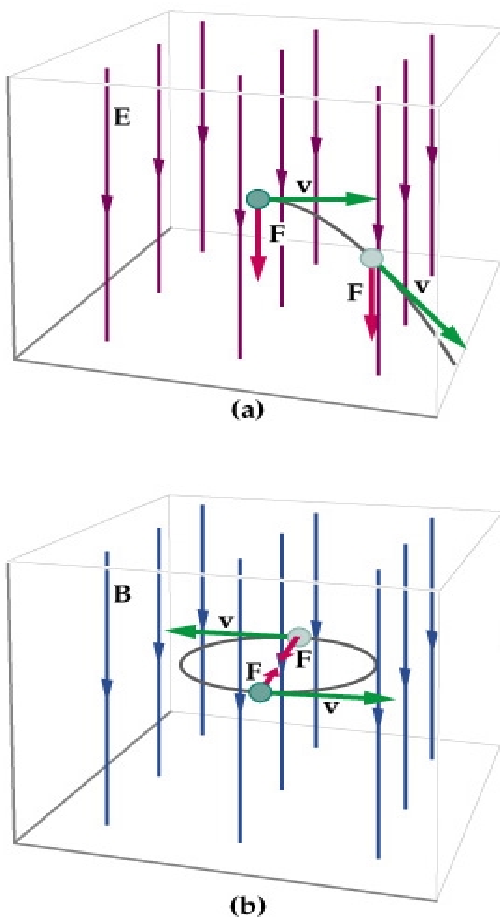


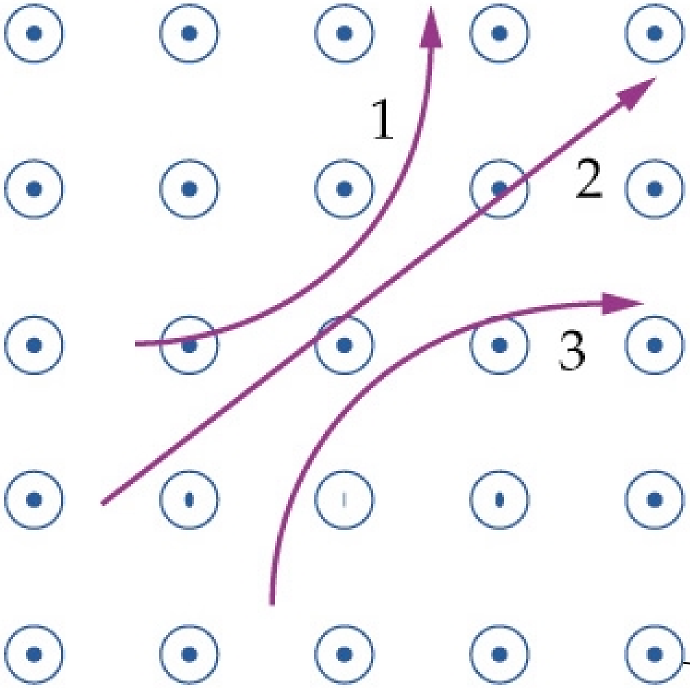
Figure 22–10 Differences between motion in electric and magnetic fields

In an electric field the charges move in the direction of the field lines



In a magnetic field the charges move perpendicular to the direction of the field lines

- (a) A positively charged particle moving into a region with an electric field experiences a downward force which causes it to accelerate. (b) A positively charged particle entering a magnetic field experiences a horizontal force at right angles to its direction of motion. In this case, the speed of the particle remains constant.



Three particles travel through a magnetic field as shown.
State whether the particles are positively charged, negatively charged or neutral.

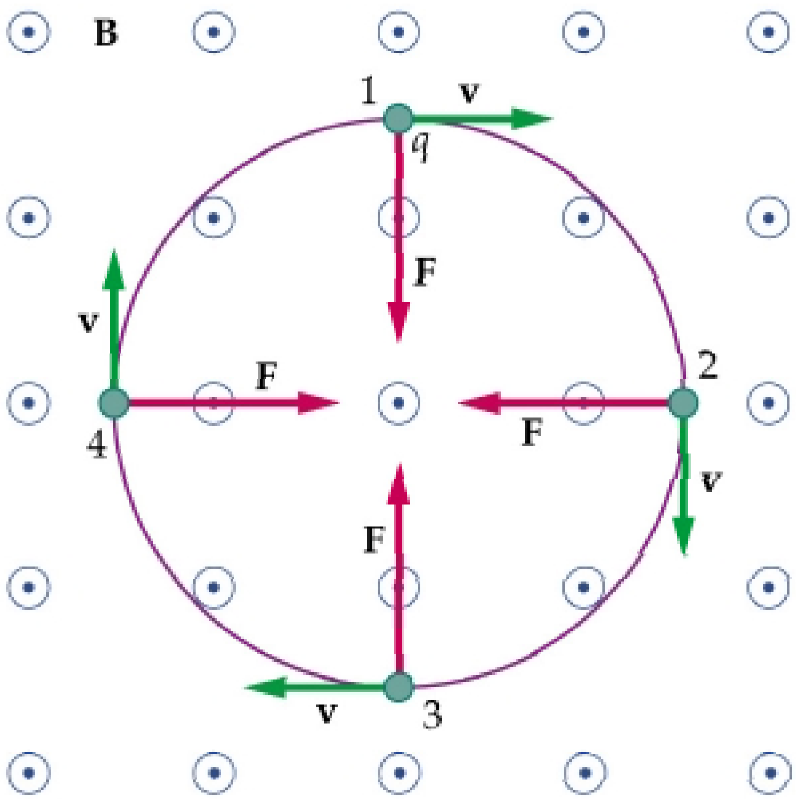
B is OUT OF the page

Notice: The force on the moving charged particle is always at right angles to the magnetic field and the direction of motion.

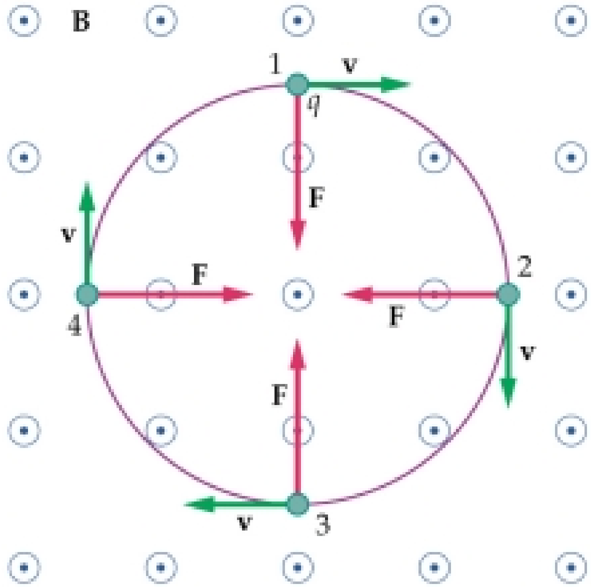
WD=Fd cos(90)=0 NO WORK IS DONE ON A MOVING CHARGE IN A MAGNETIC FIELD.

The KE of the charges is constant. That is, their speed is constant. Only the direction changes.

Figure 22–12 Circular motion in a magnetic field



- A charged particle moves in a direction perpendicular to the magnetic field. At each point on the particle's path the magnetic force is at right angles to the velocity and hence toward the center of a circle.



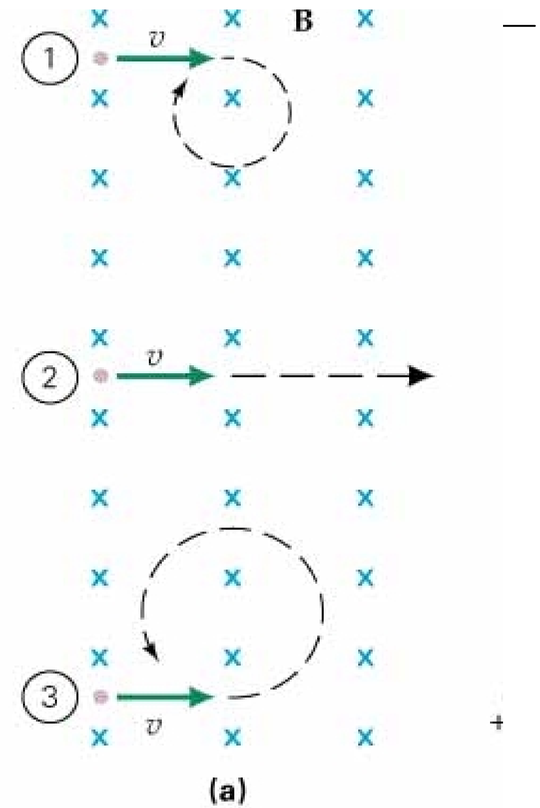
The magnetic field supplies the centripetal force to make the charged particle move in a circle

$$\frac{mv^2}{r} = qvB\sin 90 = qvB$$

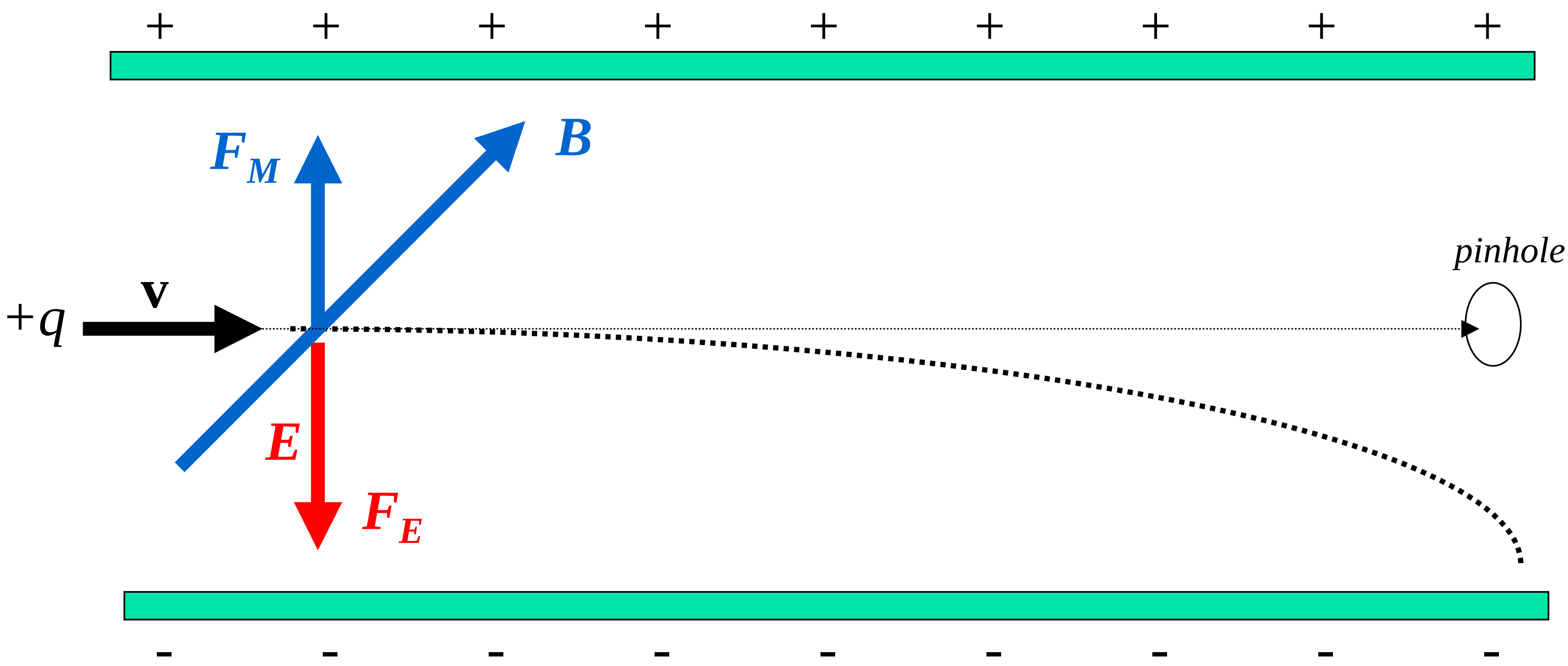
$$\Rightarrow r = \frac{mv}{qB}$$

Three particles enter a uniform magnetic field as shown.

Particles 1 and 3 have equal speeds and charges of the same magnitude. What can you say about the (a) charges and (b) masses of the particles



The *VELOCITY SELECTOR*

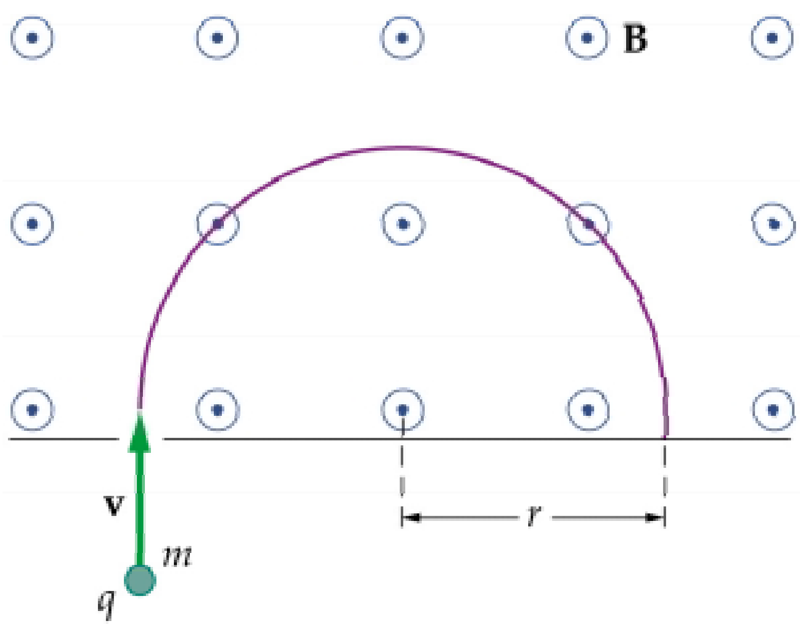


Electric force = *Magnetic Force*

$q\boldsymbol{E} = q\mathbf{v}\boldsymbol{B}$

When $\boxed{v = E/B}$ *particle will travel straight through.*

Figure 22–13 The operating principle of a mass spectrometer



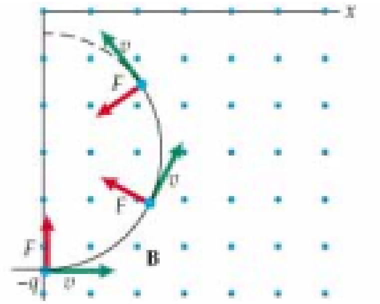
- In a mass spectrometer, a beam of charged particles enters a region with a magnetic field perpendicular to the velocity. The particles then follow a circular orbit of radius r = mv/qB. Particles of different mass will follow different paths.

Problem: In a velocity selector, a uniform magnetic field of 1.5 T is supplied from a large magnet. Two parallel plates with a seperation distance of 1.5 cm produce a perpendicular electric field. What voltage should be applied across the plates so that (a) a singly charged ion traveling at a speed of 8×10^4 m/s will pass through un-deflected or (b) a doubly charged ion traveling at the same speed will pass through un-deflected?

Charged particles in magnetic fields move in circles.
The magnetic force is the source of the required centripetal force.

$$F_C = F_M$$

$$\frac{mv^2}{r} = qvB \qquad \text{or} \qquad r = \frac{mv}{qB}$$



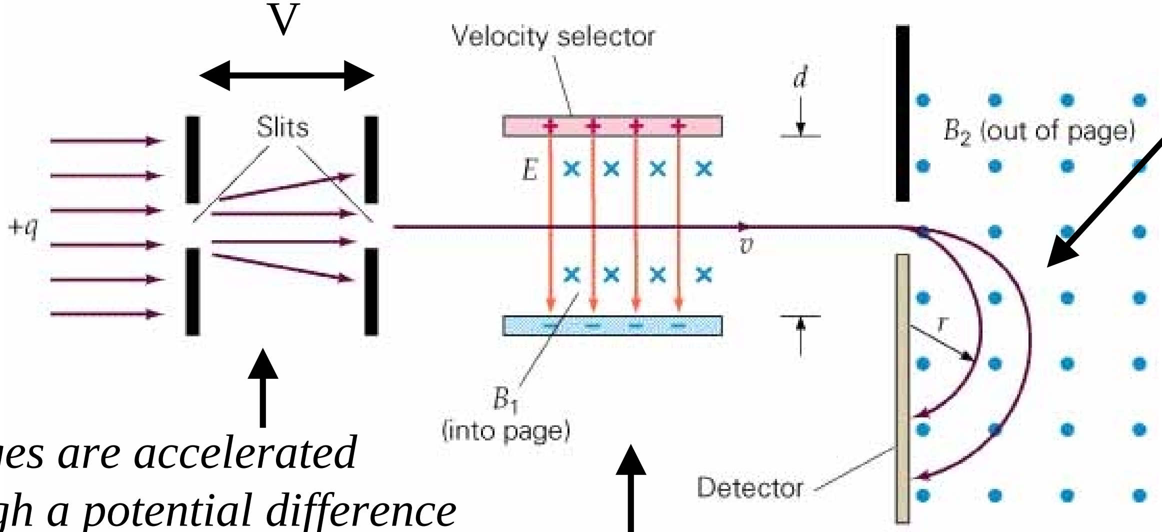
For a given magnetic field and selected charge velocity,
the radius of the circle depends on the mass of the charged particle.
This is the basis for a ***MASS SPECTROMETER****.*

Problem: An electron moves in a circular orbit of radius 1.7 m in a magnetic field of 2.2×10^{-5} T. The electron moves perpendicular to the magnetic field. Determine the kinetic energy of the electron.

The ***MASS SPECTROMETER***

V

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



Charges are accelerated through a potential difference of V volts.

$\frac{1}{2} m v^2 = qV$

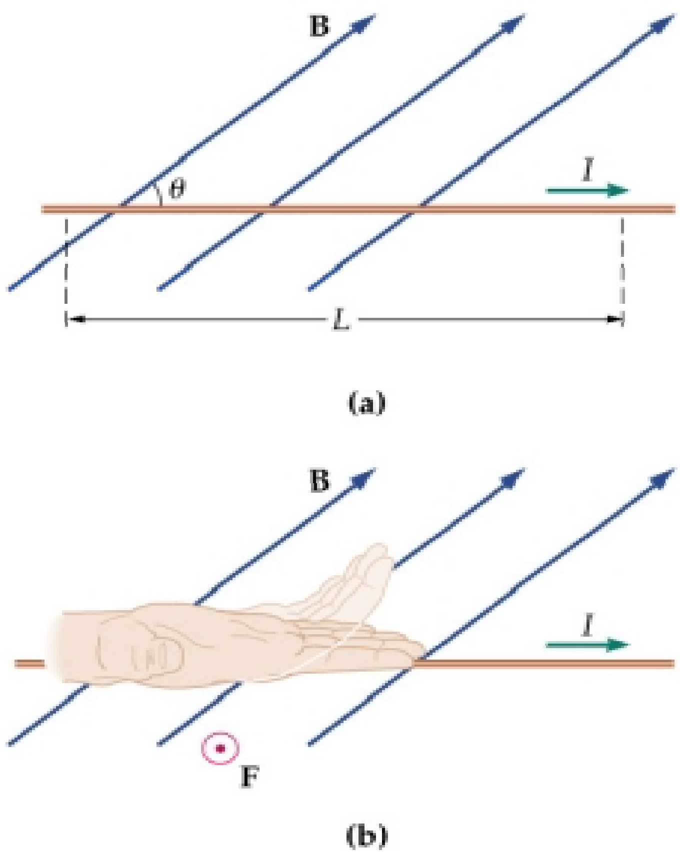
or

$v^2 = 2qV/m$

$v = E/B$

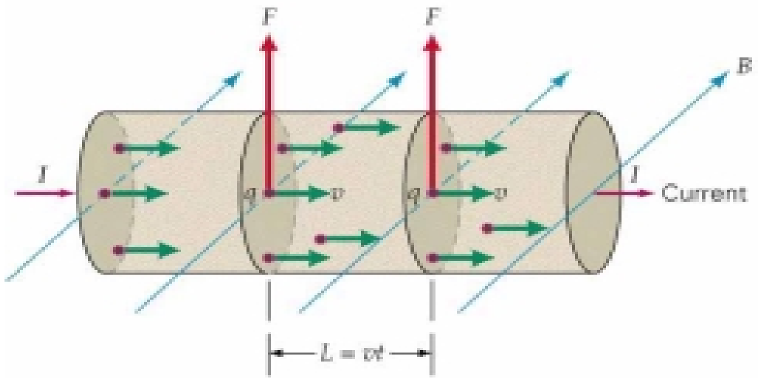
Problem: In a mass spectrometer a singly charged ion having a particular velocity is selected using a magnetic field of 0.1 T perpendicular to an electric field of 1.0×10^3 V/m. The same magnetic field is used to deflect the ion which moves in a circular path of radius 1.2 cm. What is the mass of the ion?

Figure 22–15 The magnetic force on a current-carrying wire



- A current-carrying wire in a magnetic field experiences a force, unless the current is parallel or antiparallel to the field. (a) For a wire segment of length L the magnitude of the force is F = ILB (sin theta). (b) The direction of the force is given by the magnetic force RHR; the only difference is that you start by pointing the fingers of your right hand in the direction of the current I. In this case the force points out of the page.

Wire of length L. Charges have a velocity v.
To move a distance L it takes vt seconds.



Magnetic Force on a Current Carrying Wire

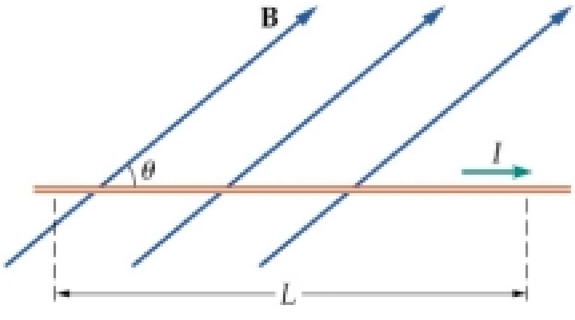
$$I = \frac{q}{t}$$

$$F = qvB\sin\theta = (\frac{q}{t})(vt)B\sin\theta = ILB\sin\theta$$

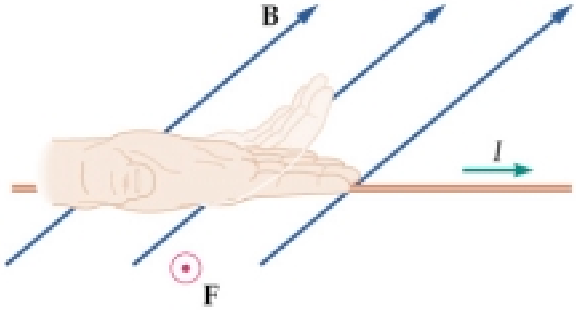
Force on wire: OUT OF PAGE

Magnetic force on a wire of length L

$$F = ILB\sin\theta$$

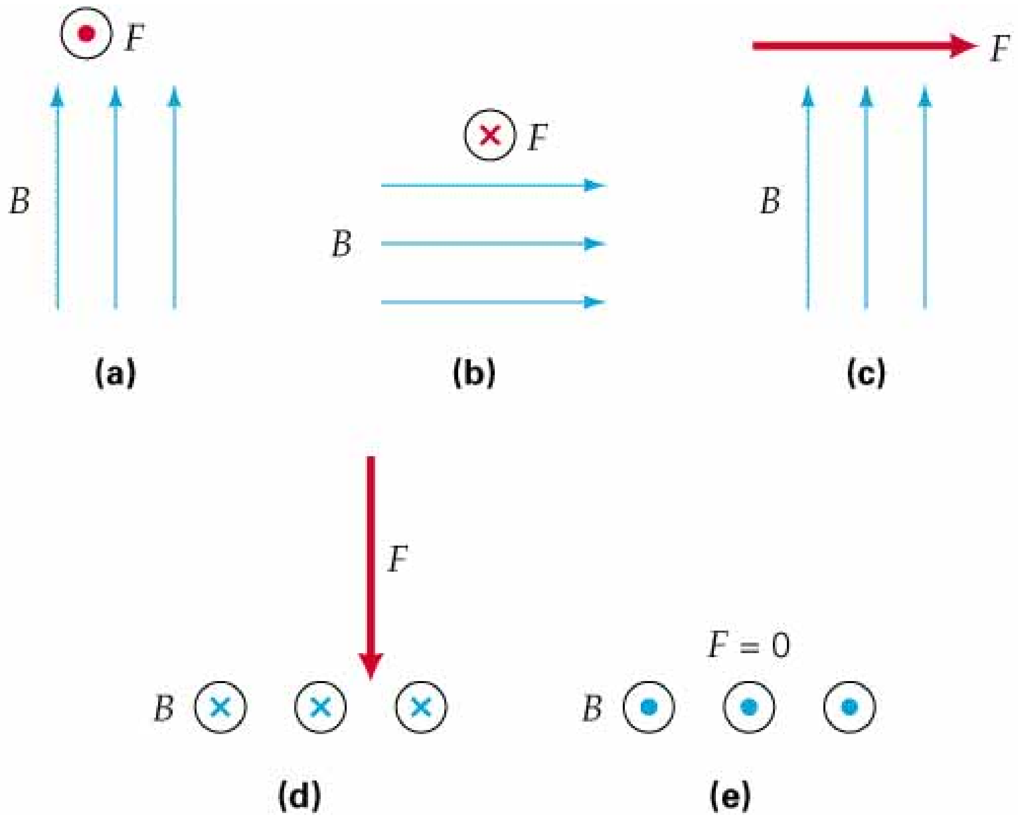


(a)

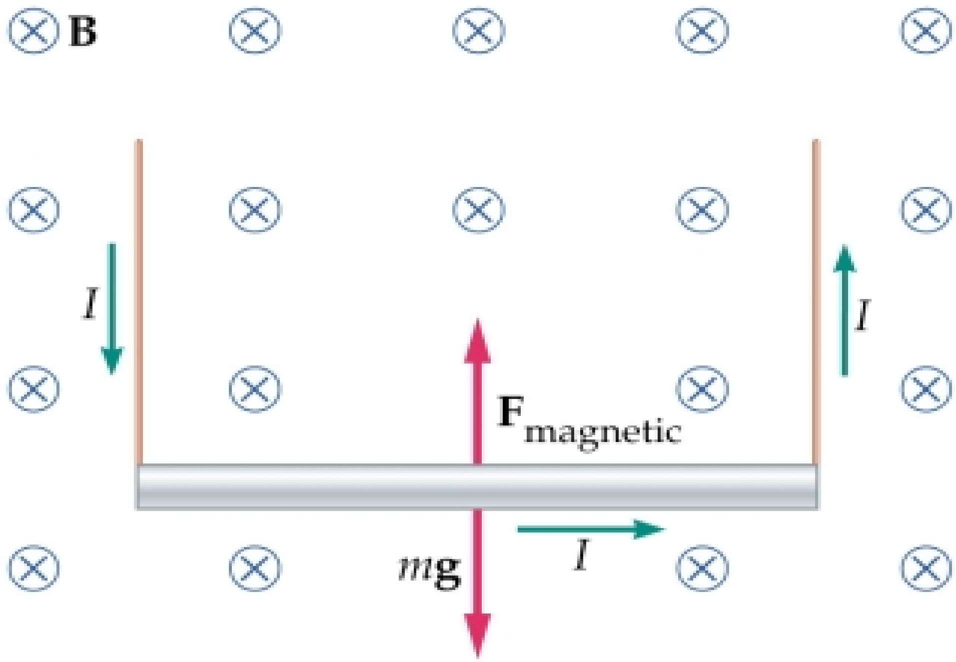


(b)

Problem: A current carrying wire is in a magnetic field. Find the direction of the current so that it gives rise to a force on the wire in the directions shown in the figures.

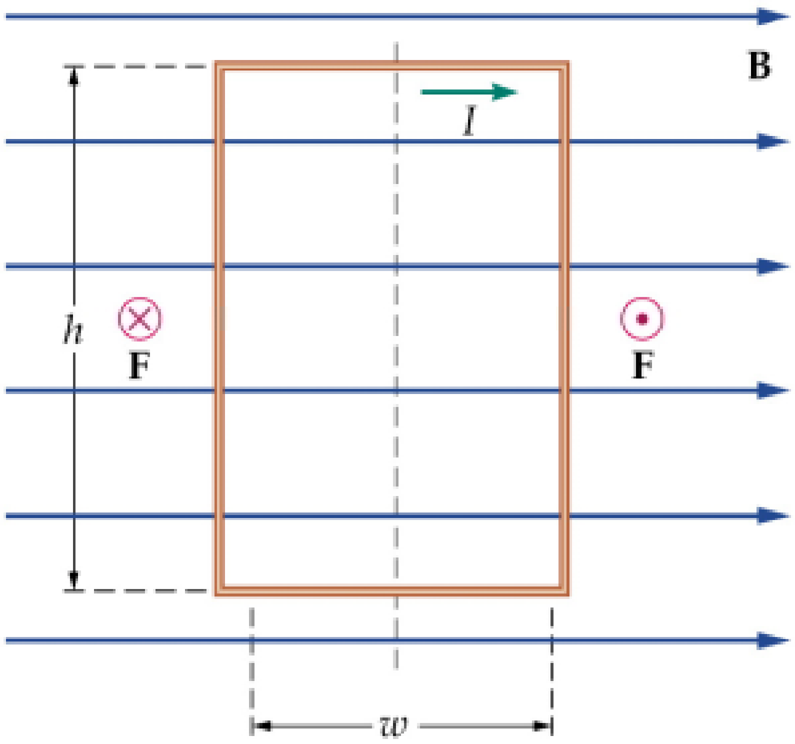


Magnetic Levitation



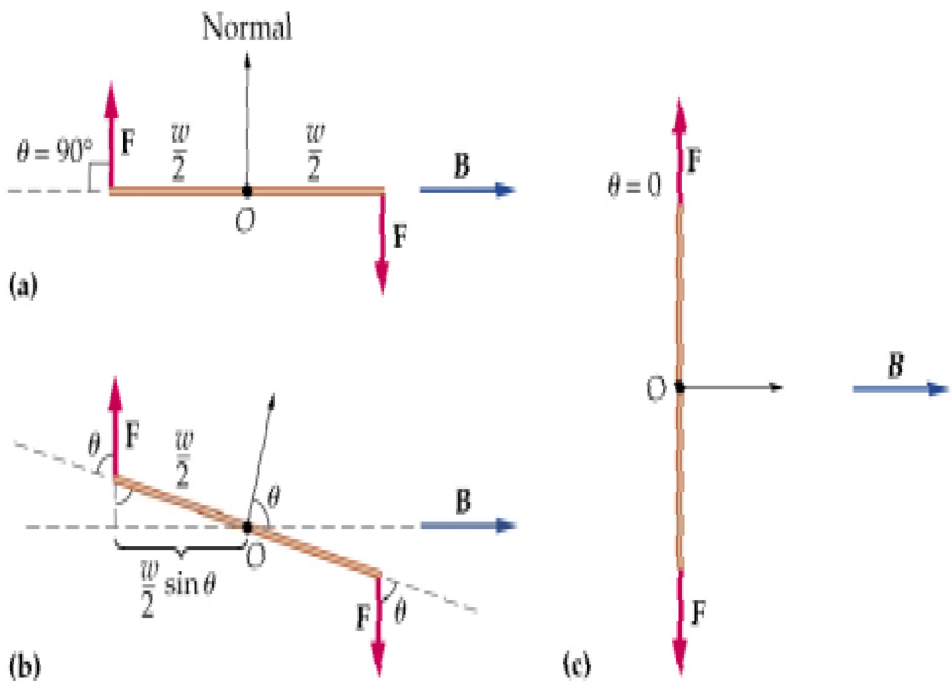
Example 22.4, p726.
m=0.05 kg
B=0.550 T into page
Find: Current. Magnitude and Direction required to make wire “float”

Figure 22–16 Magnetic forces on a current loop

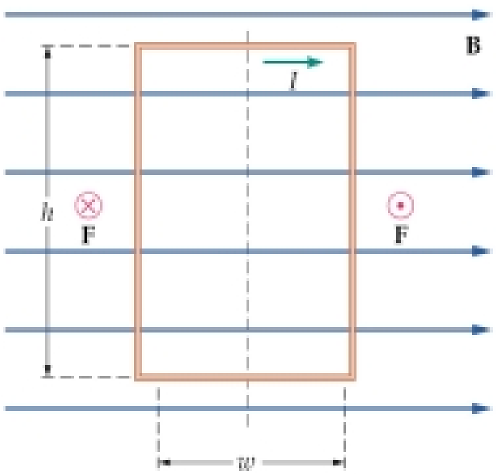


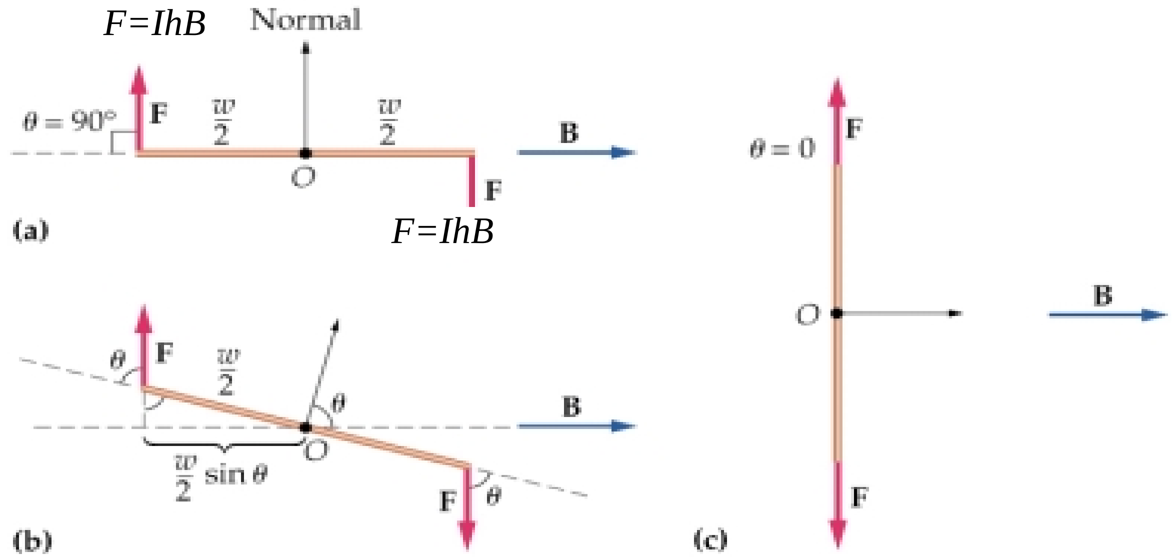
- A rectangular current loop in a magnetic field. Only the vertical segments of the loop experience forces, and they tend to rotate the loop about a vertical axis.

Figure 22–17 Magnetic torque on a current loop



- A current loop placed in a magnetic field produces a torque. (a) The torque is greatest when the plane of the loop is parallel to the magnetic field. (that is, when the normal to the loop is perpendicular to the magnetic field) (b) As the loop rotates, the torque decreases by a factor of sin theta. (c) The torque vanishes when the plane of the loop is perpendicular to the magnetic field.

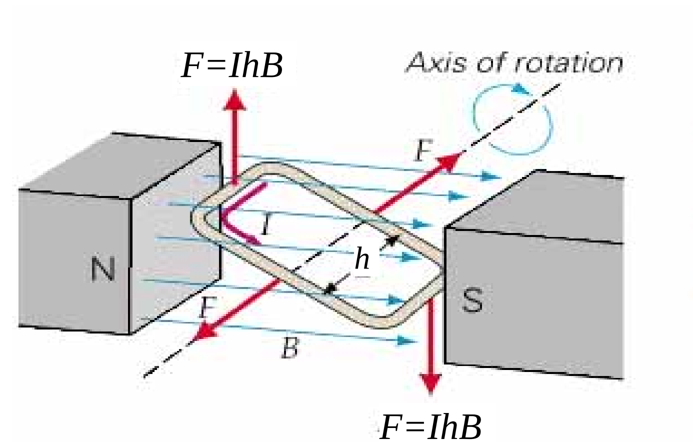


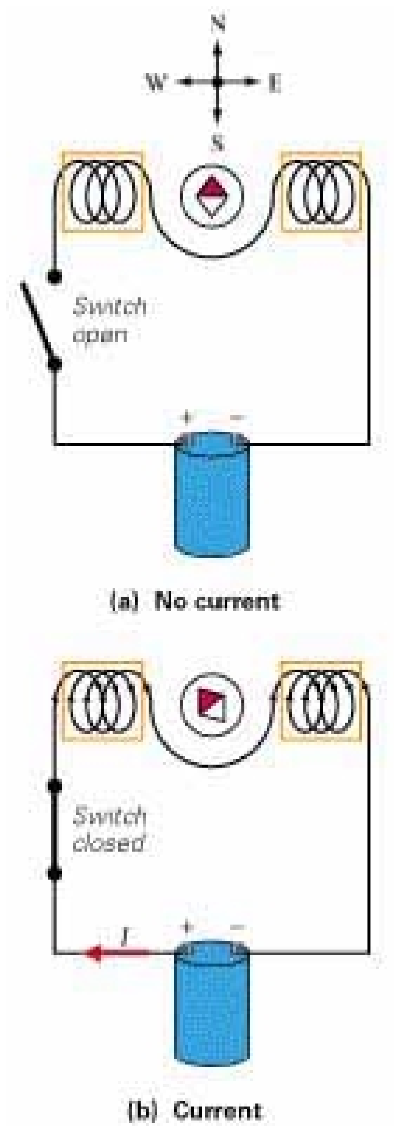


Area of loop, A=hw

Total Torque, $\tau=2(Ih(w/2)B\sin\theta)= Ihw/2B\sin\theta=IAB\sin\theta$

Note the angle θ *carefully. When* $\theta=0$, $\tau=0$.
No torque, no rotation





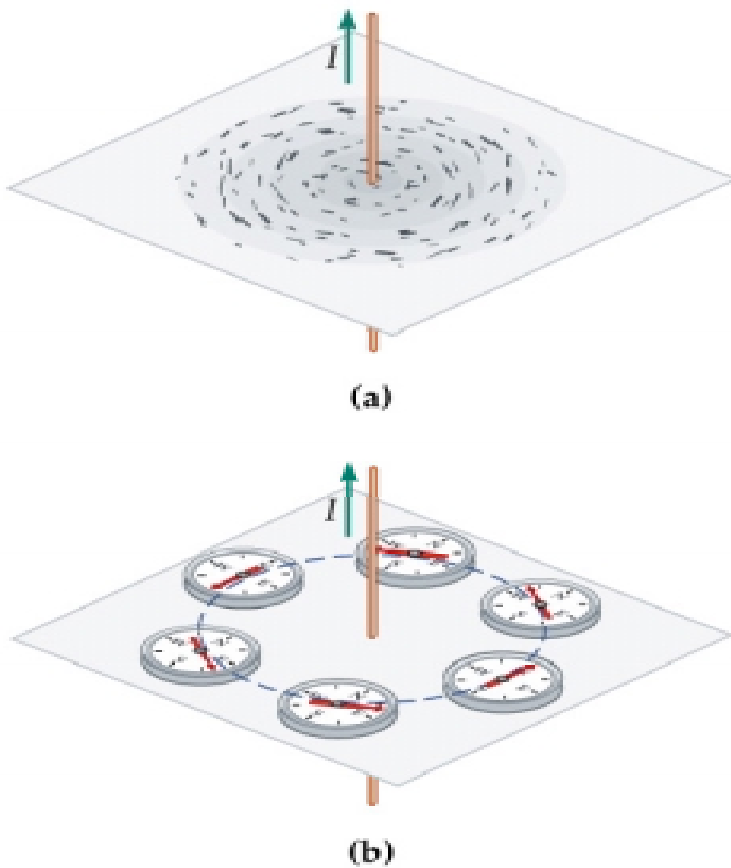
Currents in wires produce magnetic fields.

That is, moving charges generate magnetic fields. This is Oersted’s Discovery

Currents in wires behave like magnets.

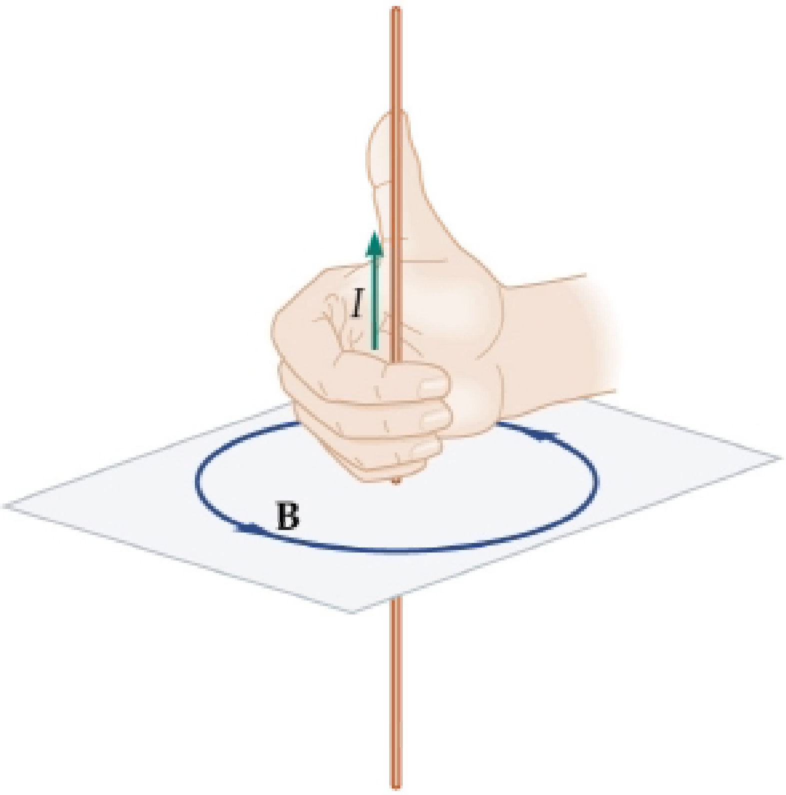
Connection between
Electricity and magnetism-**Electromagnetism**

Figure 22–19 The magnetic field of a current-carrying wire



- (a) An electric current flowing through a wire produces a magnetic field. In the case of a long, straight wire, the field circulates around the wire. (b) Compass needles point along the circumference of a circle centered on the wire.

Figure 22–20 The magnetic-field right-hand rule

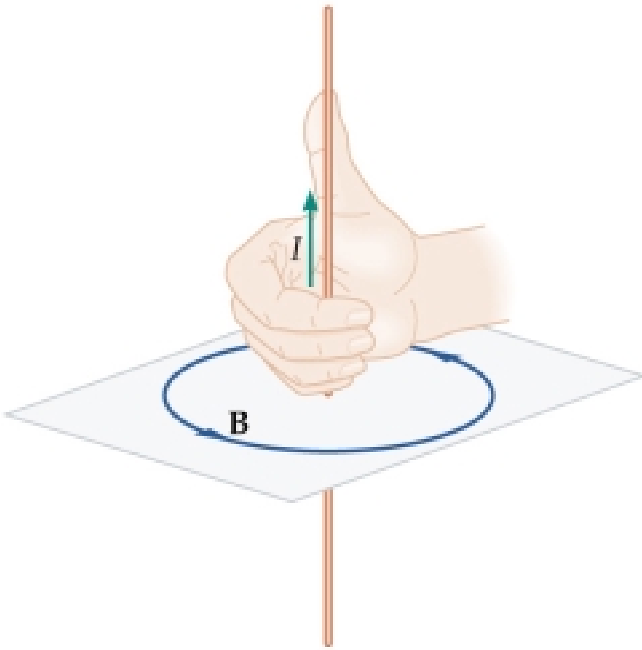


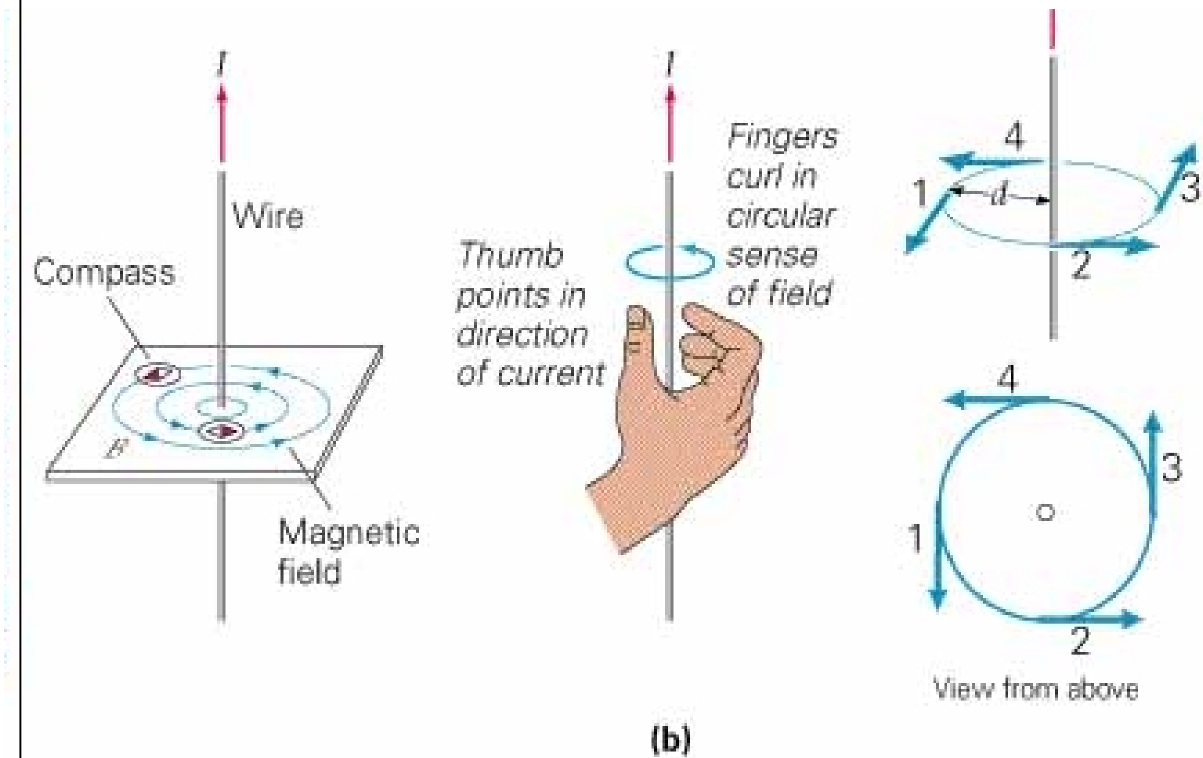
- The magnetic field right-hand rule determines the direction of the magnetic field produced by a current-carrying wire. With the thumb of the right hand pointing in the direction of the current, the fingers curl in the direction of the field.

Right hand ***SOURCE*** *rule or RHR-2,*

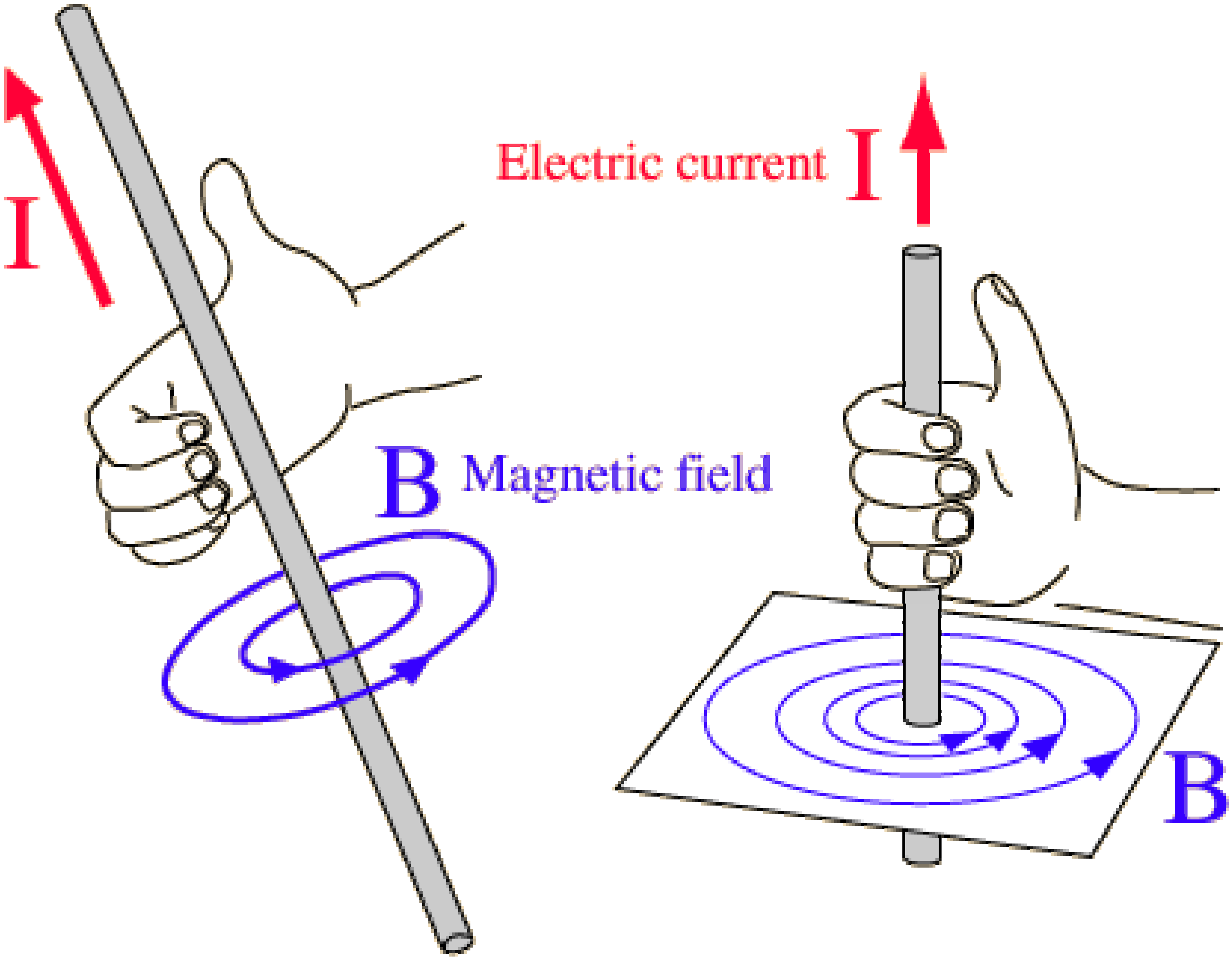
It is called a source rule because the current is the source of the magnetic field.

Also called the magnetic field right hand rule.



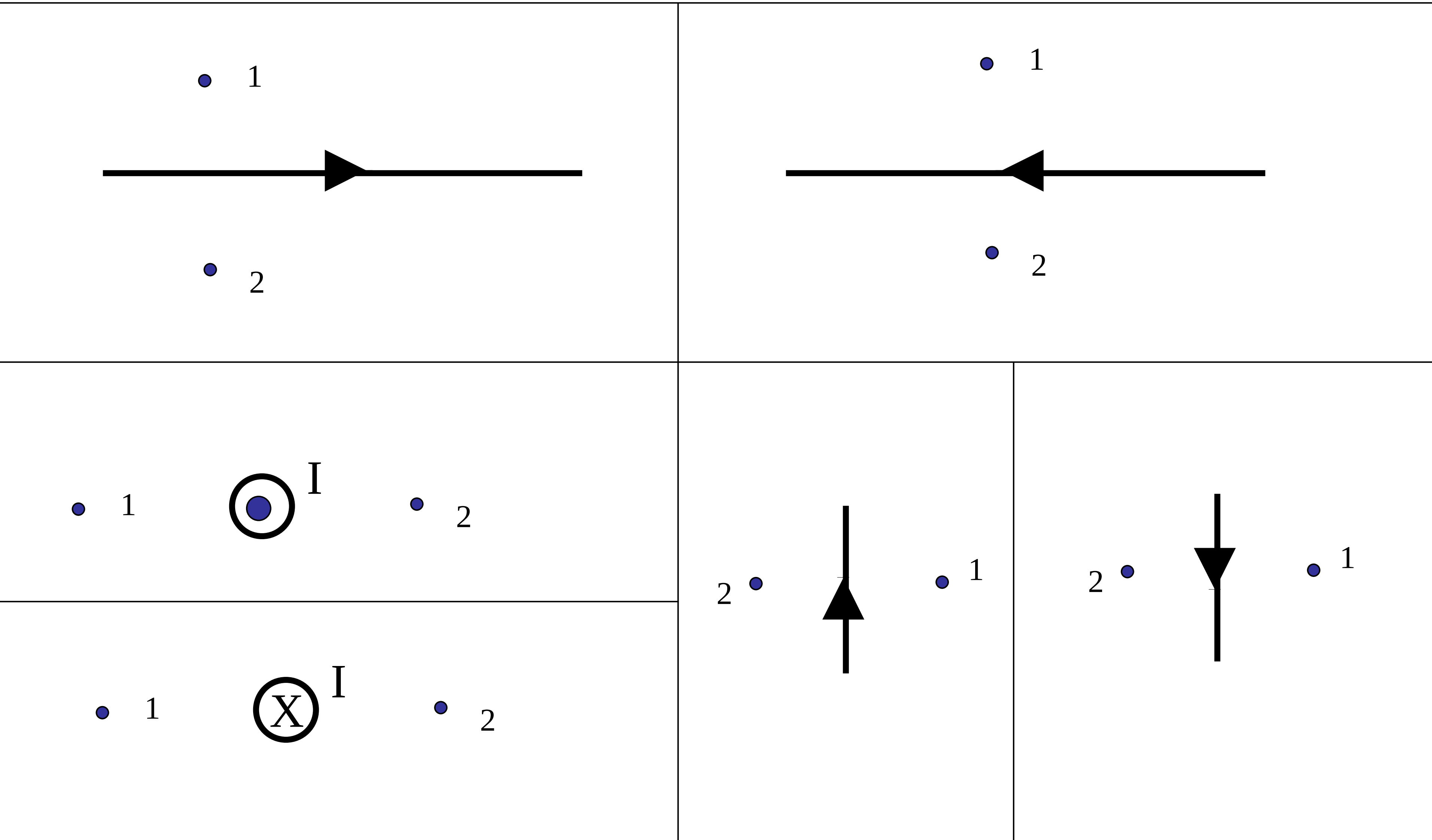


Magnetic field right hand rule.



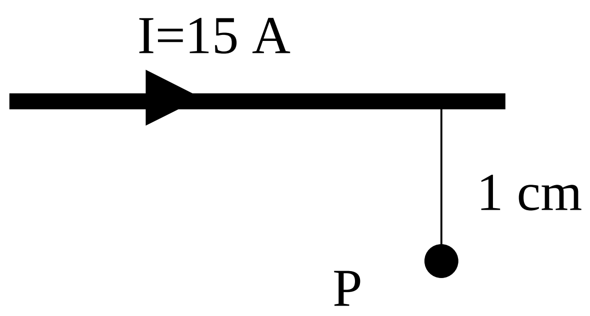
Using the RH-SOURCE rule

Find the direction of the fields produced by the following current carrying wires At the positions shown.



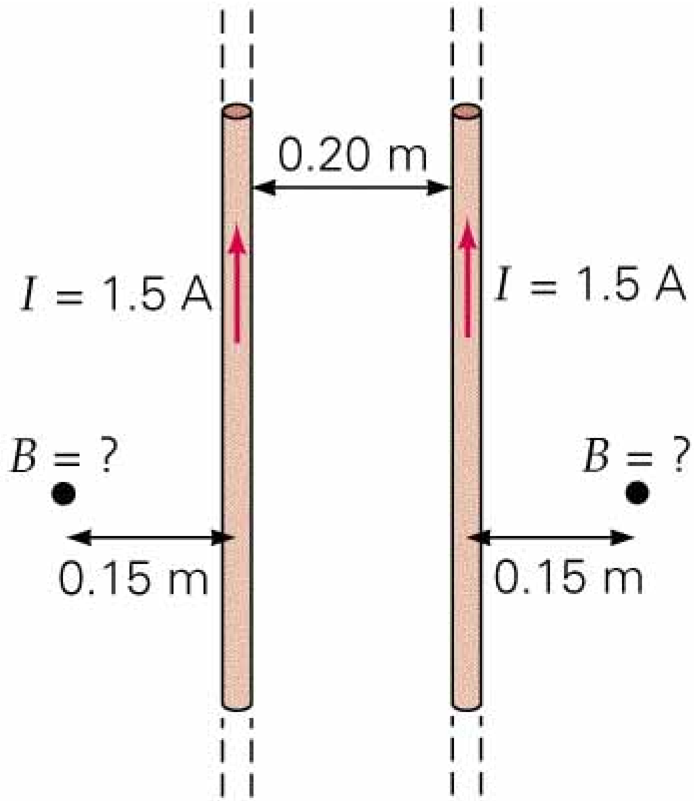
What is the magnitude and direction of the magnetic field at point P?

See exercise 22.2, p731



$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \text{x} 10^{-7}\, Tm/A)(15\text{ A})}{2\pi(0.01m)} = 30\text{x}10^{-5}\text{T} = 3\text{x}10^{-4}\text{T} = 0.3\text{ mT}$$

Problem: Two long parallel wires separated by 0.2 m carry equal currents of 1.5 A in the same direction. Find the magnitude of the magnetic field 0.15 m away from each wire on the side opposite the other wire.

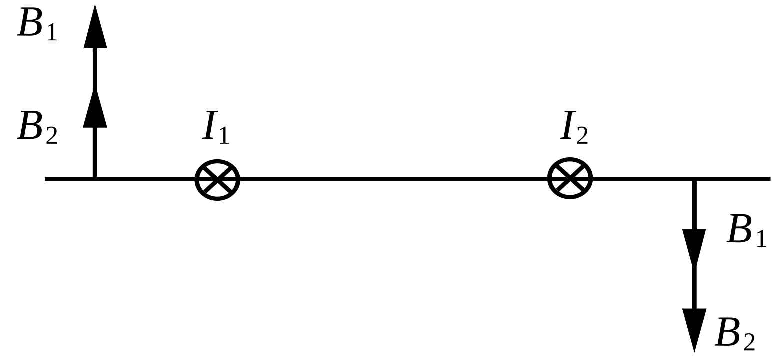


Problem Solution

The magnitudes at both locations are the same.

Calculate for the location to the right of I_2.

There are two fields,both point downwards:



$$B_1 = \frac{\mu_0 I_1}{2\pi d_1} = \frac{(4\pi \text{x} 10^{-7}\, Tm/A)(1.5\text{ A})}{2\pi(0.2m + 0.15m)} = 8.57\text{x}10^{-7}\text{ T}$$

$$B_2 = \frac{\mu_0 I_2}{2\pi d_2} = \frac{(4\pi \text{x} 10^{-7}\, Tm/A)(1.5\text{ A})}{2\pi(0.15m)} = 2\text{x}10^{-6}\text{ T}$$

So the net field is

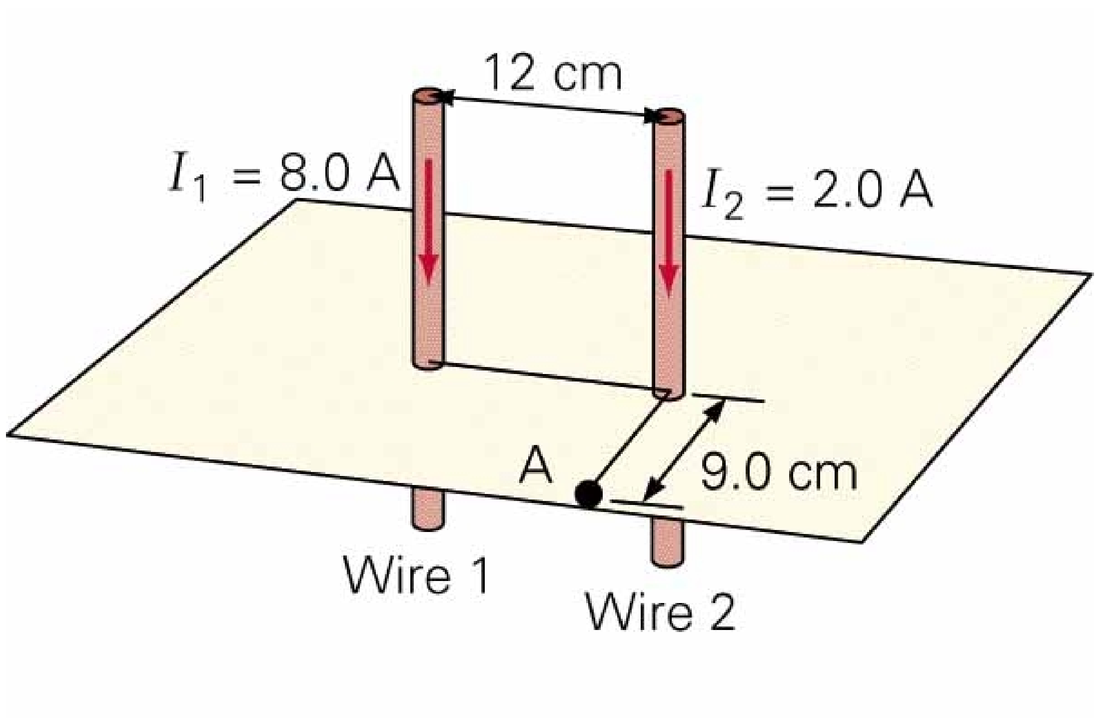
$$B = B_1 + B_2 = 8.57 \times 10^{-7}\text{ T} + 2.0 \times 10^{-6}\text{ T} = \mathbf{2.9 \times 10^{-6}\text{ T}}\,.$$

Problem : Two long parallel wires carry currents of 8 A and 2A as shown.

(A) What is the magnitude of the magnetic field midway between the wires?

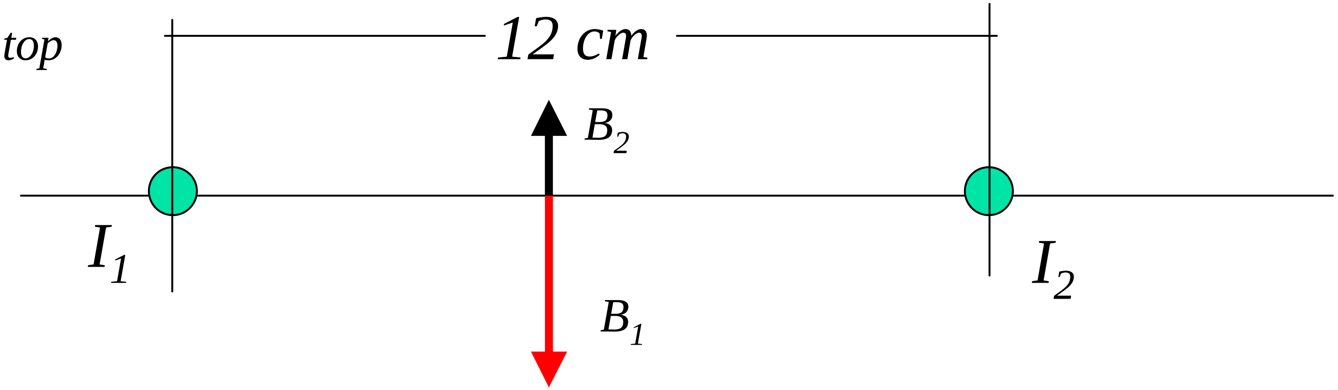
(B) Where on a line perpendicular to and joining the two wires is the magnetic field zero?

Repeat problem 30 if the current in wire 1 is reversed.



Chapter 19
Figure 36

View from the top looking down



30.(a) The directions of the fields from the two wires are opposite.

$$B_1 = \frac{\mu_0 I_1}{2\pi d} = \frac{(4\pi x10^{7})(8\,A)}{2\pi(0.06\text{ m})} \qquad \text{or} \qquad B_1 = 2.67\text{x}10^{-5}\text{ T downwards}$$

$$B_2 = \frac{\mu_0 I_2}{2\pi d} = \frac{(4\pi x10^{7})(2\,A)}{2\pi(0.06\text{ m})} \qquad \text{or} \qquad B_1 = 6.67\text{x}10^{-6}\text{ T upwards}$$

So the net field is : So the net field is $\text{B} = \text{B}_1 - \text{B}_2 = 2\text{x}10^{-5}$ T downwards

(b) The field can only be zero somewhere between the wires.
Assume the net field is zero at a distance x from wire 1.
You know beforehand that the point MUST be closer to wire 2 than wire 1 by almost a factor of 4.

$$B_1 = \frac{\mu_0 I_1}{2\pi x} = \frac{\mu_0 I_2}{2\pi(0.12 - x)}$$

or

$$\frac{(8A)}{x} = \frac{(2A)}{(0.12 - x)}$$

or

$x = 4(0.12\ m - x)$.

$x = 9.6 \times 10^{-2}$ m or 9.6 cm from wire 1

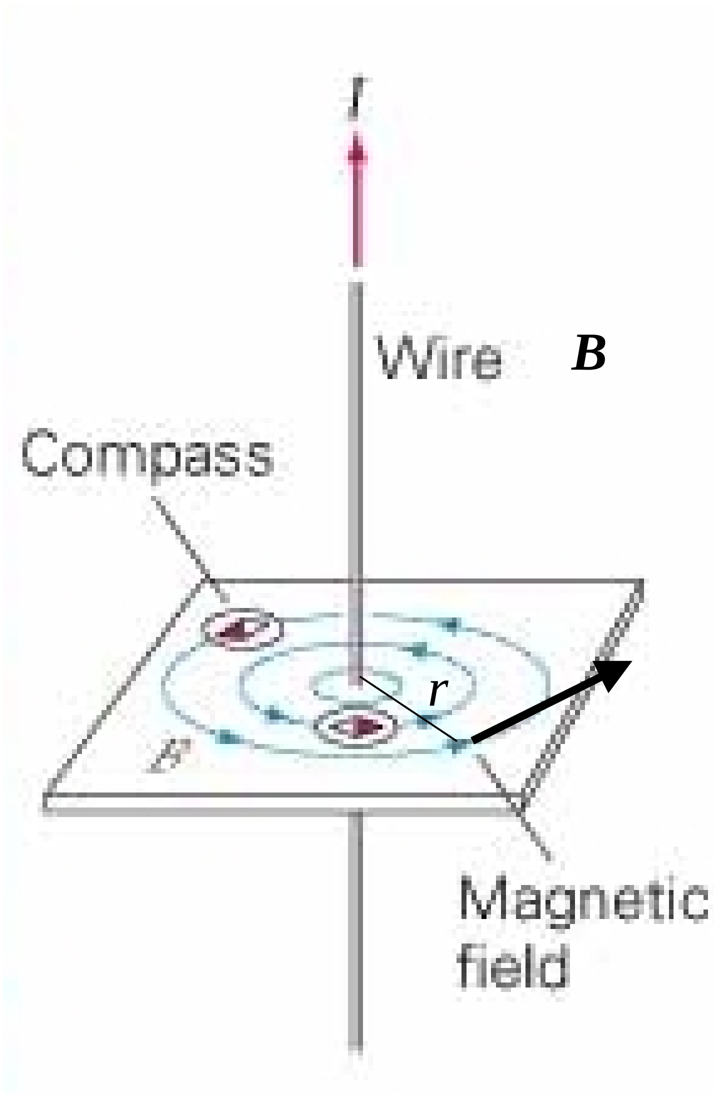
(a) The fields by the two wires are in the same direction.
$B_1 = 2.67 \times 10^{-5}$ T,
$B_2 = 6.67 \times 10^{-6}$ T.

So the net field is $B = B_1 + B_2 = 2.67 \times 10^{-5}\ \text{T} + 6.67 \times 10^{-6}\ \text{T} =$

(b) Since the fields by the two wires in between the line perpendicular to and joining the wires are in the same direction, there is NO PLACE where the magnetic field is zero. However, outside the two wires on the same line there is a location (closer to I_2) where the magnetic field is zero.

Ampere's Law

$$B \ \alpha \ (C)\frac{1}{r} \quad \text{or} \quad B = \frac{\mu_0 I}{2\pi r}$$

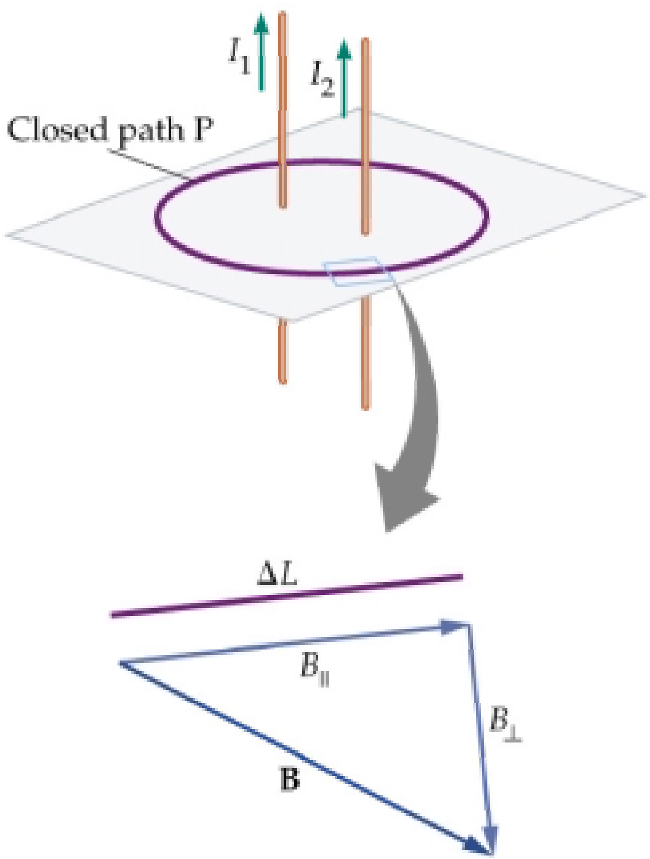


μ_0 - permeability of free space.

$\mu_0 = 4\pi x 10^{-7}$ *Tm/A*

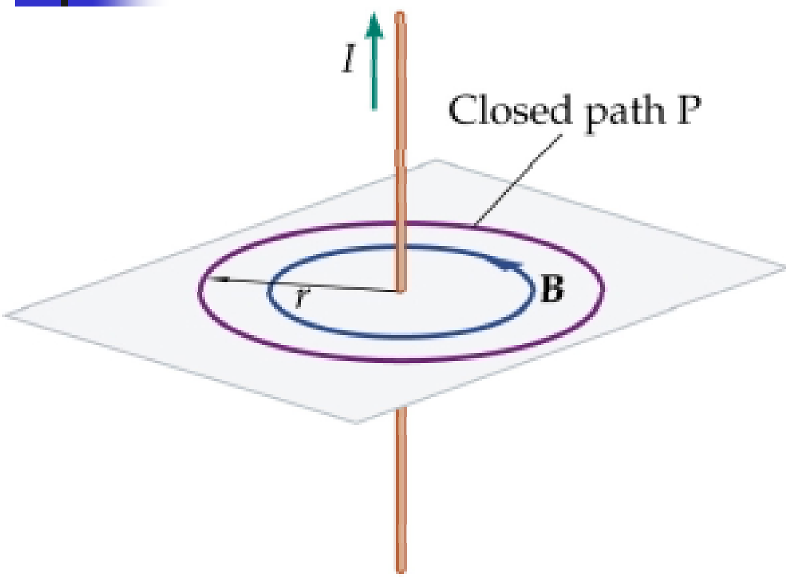
$= 4x3.14x10^{-7} = 12.56x10^{-7}$

Figure 22–21 Illustrating Ampère's law



- A closed path P encloses the currents I_1 and I_2. According to Ampère's law, the sum of B||DL around the path P is equal to m0Ienclosed. In this case, I(enclosed) = $I_1 + I_2$.

Figure 22–22 Applying Ampère’s law

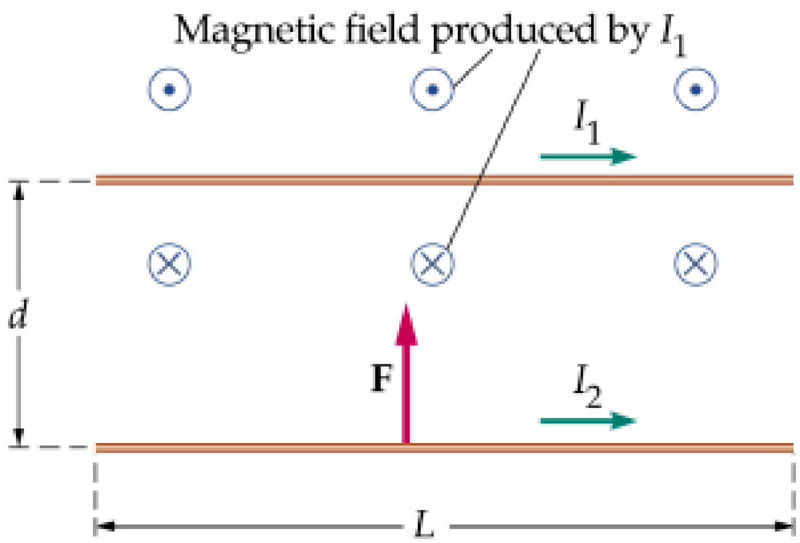


$$\sum B_{\|}\Delta L = B_{\|}\sum \Delta L = B2\pi r = \mu_{\circ} I_{enclosed}$$

$$B = \frac{\mu_{\circ} I_{enclosed}}{2\pi r}$$

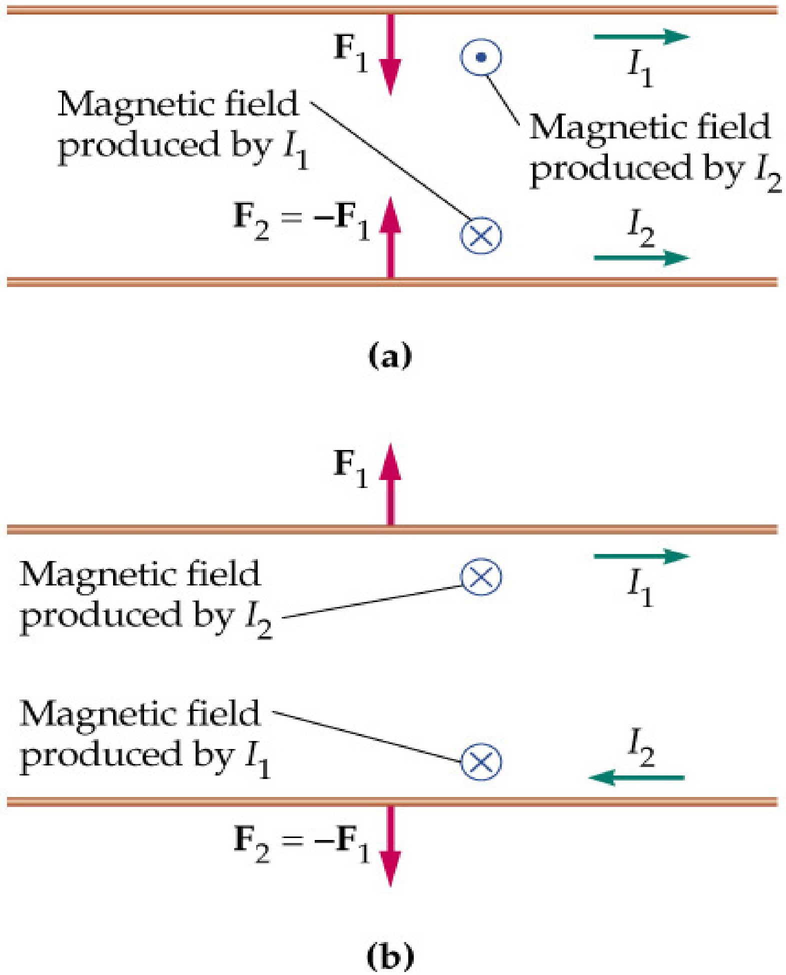
- To apply Ampère’s law to a long, straight wire we consider a circular path centered on the wire. Since the magnetic field is everywhere parallel to this path, and has constant magnitude B at all points on it, the sum of $B_{\|}\Delta L$ over the path is $B(2\pi r)$. Setting this equal to $\mu_0 I$ yields the magnetic field of the wire: $B = \mu_0 I / 2\pi r$.

Figure 22–23 The magnetic force between current-carrying wires



- A current in wire 1 produces a magnetic field, $B1 = \mu_0 I_1 / 2\pi d$, at the location of wire 2. The result is a force exerted on a length L of wire 2 of magnitude $F = \mu_0 I_1 I_2 L / 2\pi d$.

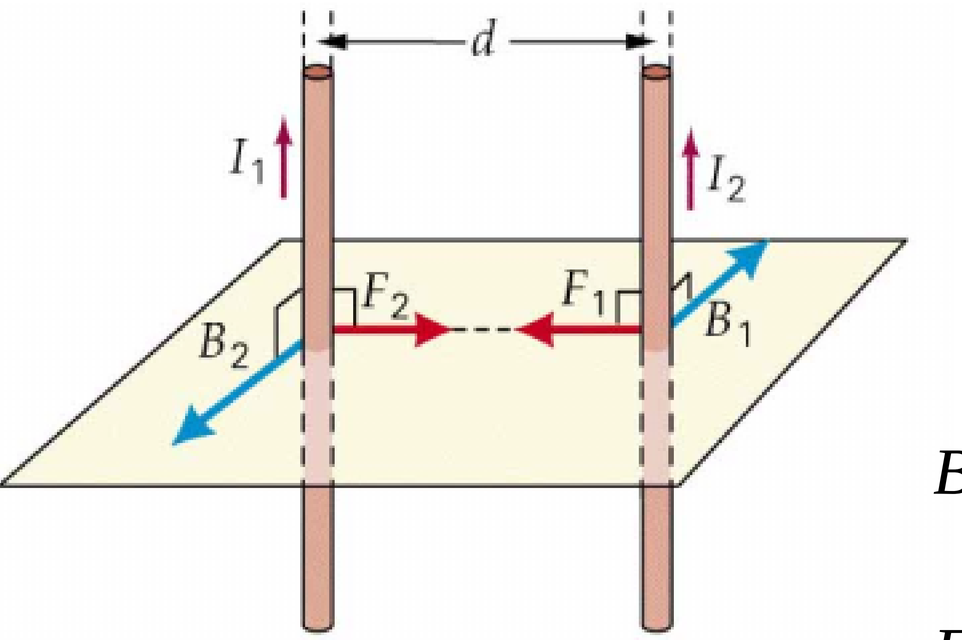
Figure 22–24 The direction of the magnetic force between current-carrying wires



- The forces between current-carrying wires depend on the relative direction of their currents. (a) If the currents are in the same direction, the force is attractive. (b) Wires with oppositely directed currents experience repulsive forces.

Two current carrying wires will interact. They will attract if the currents are in the same direction but repel if currents are opposite.

The unit of current (the Amp) is defined in terms of the strength of this mutual interaction.

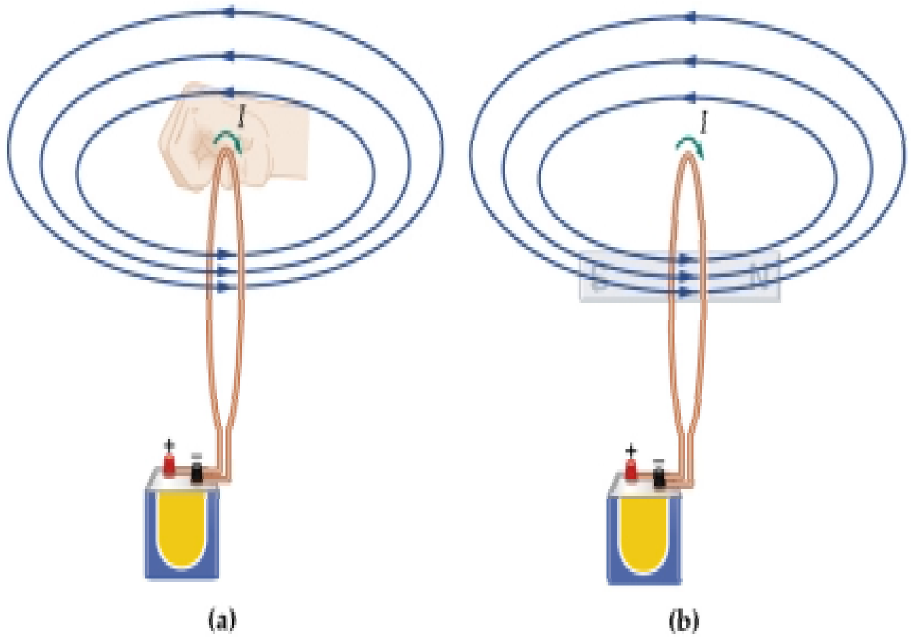


Current I_1 produces a field B_1 at wire 2. Thus we have a current carrying wire (wire 2) in a field. Wire 2 will therefore experience a force.

$$B_1 = \frac{\mu_\circ I_1}{2\pi d}$$

$$F = I_2 B_1 L = I_2 \left(\frac{\mu_\circ I_1}{2\pi d}\right) L = \frac{\mu_\circ I_2 I_1}{2\pi d} L$$

Figure 22–25 The magnetic field of a current loop



- (a) The magnetic field produced by a current loop is relatively intense within the loop and falls off rapidly outside the loop. (b) A permanent magnet produces a field that is very similar to the field of a current loop.