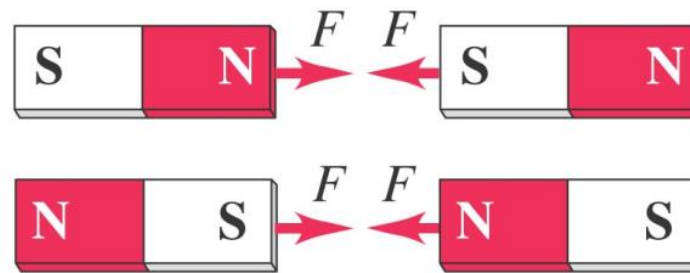
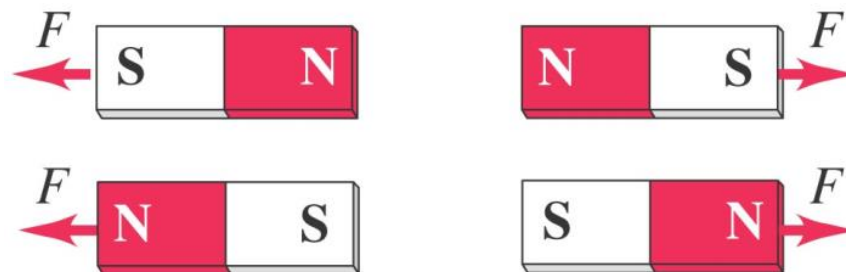


PHYS 122-Lecture 9: Magnetic Field and Magnetic Forces

(a) Opposite poles attract.



(b) Like poles repel.

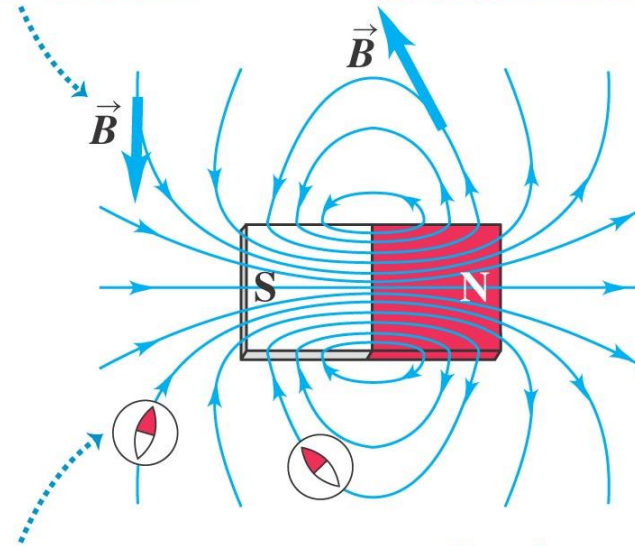


Magnetic field lines

- Figure 27.11 below shows the *magnetic field lines* of a permanent magnet.

At each point, the field line is tangent to the magnetic field vector \vec{B} .

The more densely the field lines are packed, the stronger the field is at that point.

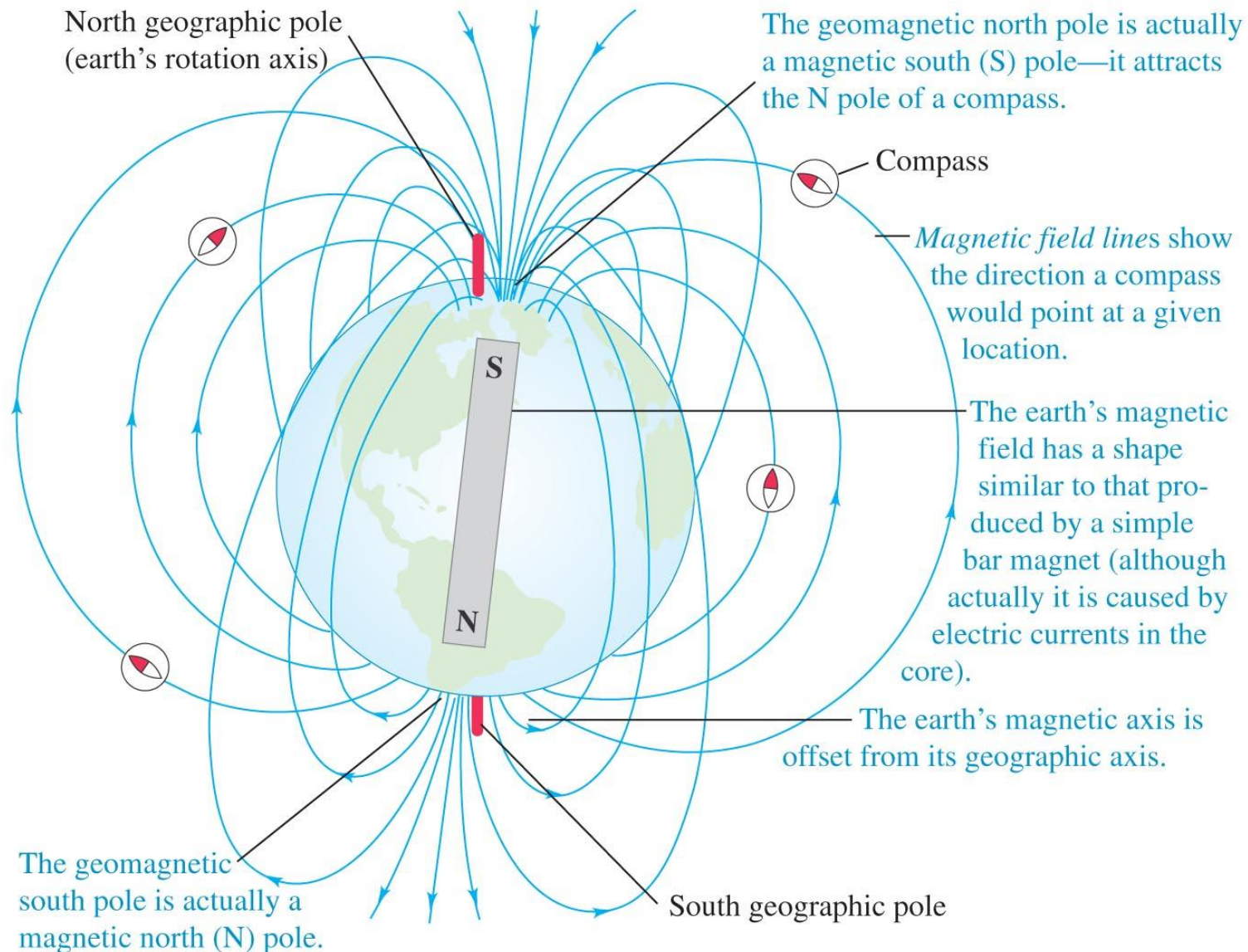


At each point, the field lines point in the same direction a compass would . . .

. . . therefore, magnetic field lines point *away from N poles and toward S poles.*

Magnetic field of the earth

- The earth itself is a magnet. Figure 27.3 shows its magnetic field.

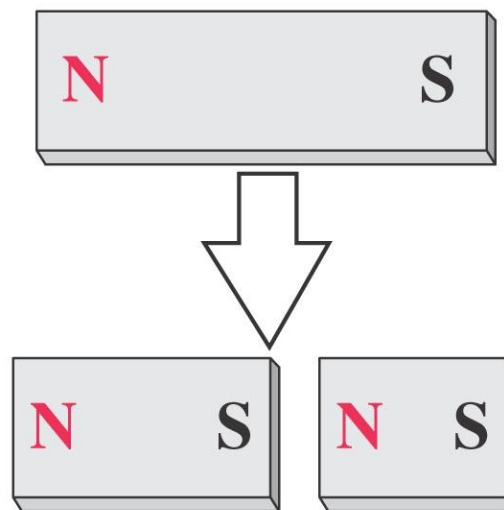


Magnetic monopoles

- Breaking a bar magnet does not separate its poles, as shown in Figure 27.4 at the right.
- There is no experimental evidence for *magnetic monopoles*.

In contrast to electric charges, magnetic poles always come in pairs and can't be isolated.

Breaking a magnet in two ...



... yields two magnets,
not two isolated poles.

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$$



$$\nabla \cdot \vec{D} = \rho$$

$$\vec{D} = \epsilon \vec{E}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$$



$$\nabla \cdot \vec{D} = \rho$$

$$\vec{D} = \epsilon \vec{E}$$

$$\oint \vec{B} \cdot d\vec{A} = 0$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$$



$$\nabla \cdot \vec{D} = \rho$$

$$\vec{D} = \epsilon \vec{E}$$

$$\oint \vec{B} \cdot d\vec{A} = 0$$

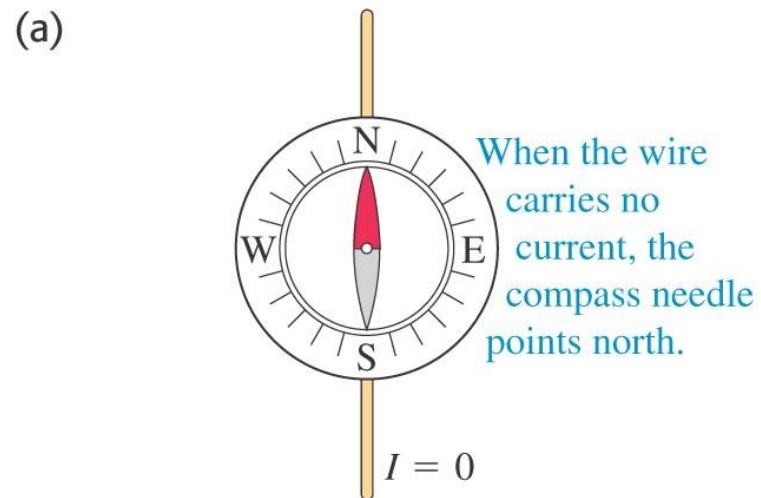


$$\nabla \cdot \vec{B} = 0$$

“The No-Name Law”
No Magnetic Monopoles

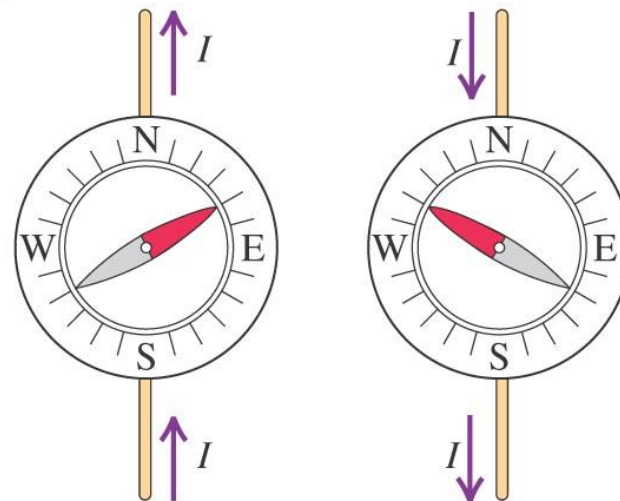
Electric current and magnets

- In 1820, Hans Oersted discovered that a current-carrying wire causes a compass to deflect. (See Figure 27.5 at the right.)
- This discovery revealed a connection between moving charge and magnetism.



(b)

When the wire carries a current, the compass needle deflects. The direction of deflection depends on the direction of the current.



The magnetic field

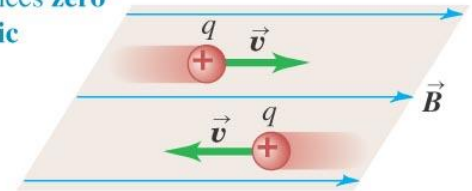
- A moving charge (or current) creates a *magnetic field* in the surrounding space.
- The magnetic field exerts a force on any other moving charge (or current) that is present in the field.

The magnetic force on a moving charge

- The magnetic force on q is perpendicular to *both* the velocity of q and the magnetic field. (See Figure 27.6 at the right.)
- The magnitude of the magnetic force is $F = |q|vB \sin\phi$.

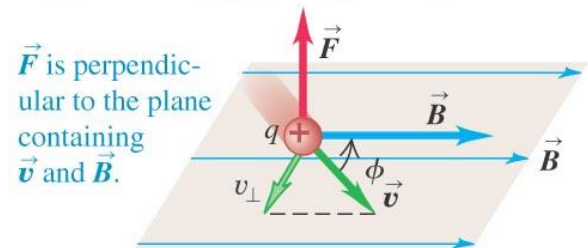
(a)

A charge moving **parallel** to a magnetic field experiences **zero magnetic force**.



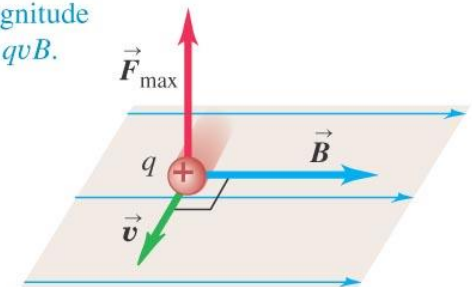
(b)

A charge moving at an angle ϕ to a magnetic field experiences a magnetic force with magnitude $F = |q|v_{\perp}B = |q|vB \sin\phi$.



(c)

A charge moving **perpendicular** to a magnetic field experiences a maximal magnetic force with magnitude $F_{\max} = qvB$.



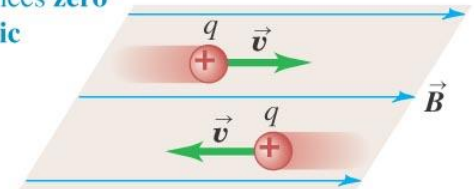
The magnetic force on a moving charge

- The magnetic force on q is perpendicular to *both* the velocity of q and the magnetic field. (See Figure 27.6 at the right.)
- The magnitude of the magnetic force is $F = |q|vB \sin\phi$.

$$\vec{F}_B = q(\vec{v} \times \vec{B})$$

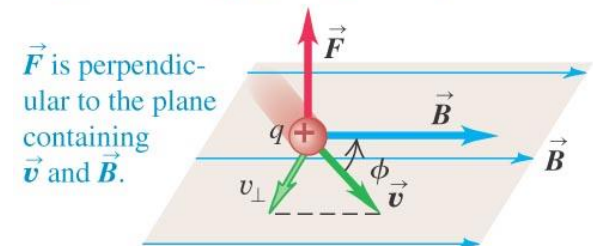
(a)

A charge moving **parallel** to a magnetic field experiences **zero magnetic force**.



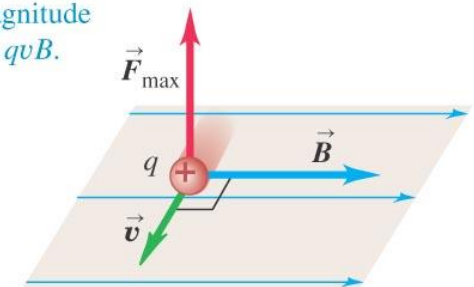
(b)

A charge moving at an angle ϕ to a magnetic field experiences a magnetic force with magnitude $F = |q|v_{\perp}B = |q|vB \sin\phi$.



(c)

A charge moving **perpendicular** to a magnetic field experiences a maximal magnetic force with magnitude $F_{\max} = qvB$.



Magnetic force as a vector product

- We can write the magnetic force as a vector product (see Figure 27.7 below).
- The right-hand rule gives the direction of the force on a *positive* charge.

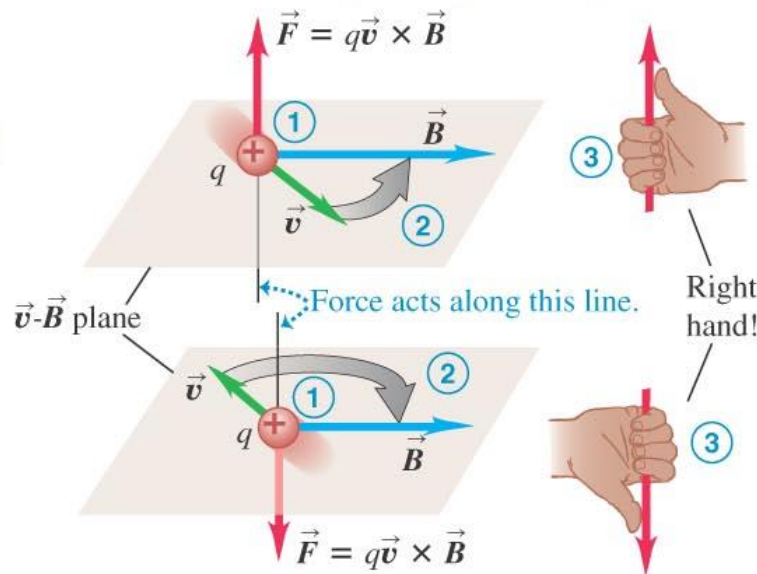
(a)

Right-hand rule for the direction of magnetic force on a **positive** charge moving in a magnetic field:

① Place the \vec{v} and \vec{B} vectors tail to tail.

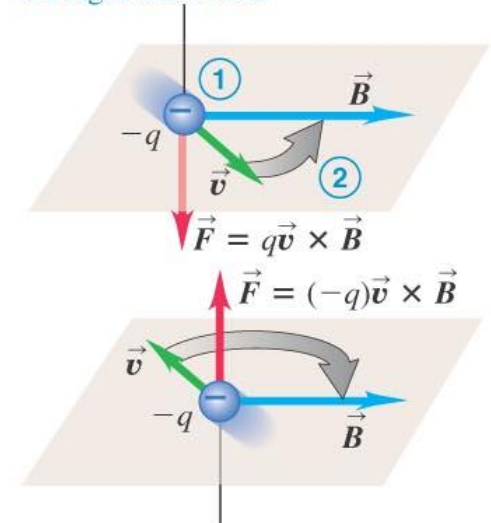
② Imagine turning \vec{v} toward \vec{B} in the \vec{v} - \vec{B} plane (through the smaller angle).

③ The force acts along a line perpendicular to the \vec{v} - \vec{B} plane. Curl the fingers of your *right hand* around this line in the same direction you rotated \vec{v} . Your thumb now points in the direction the force acts.



(b)

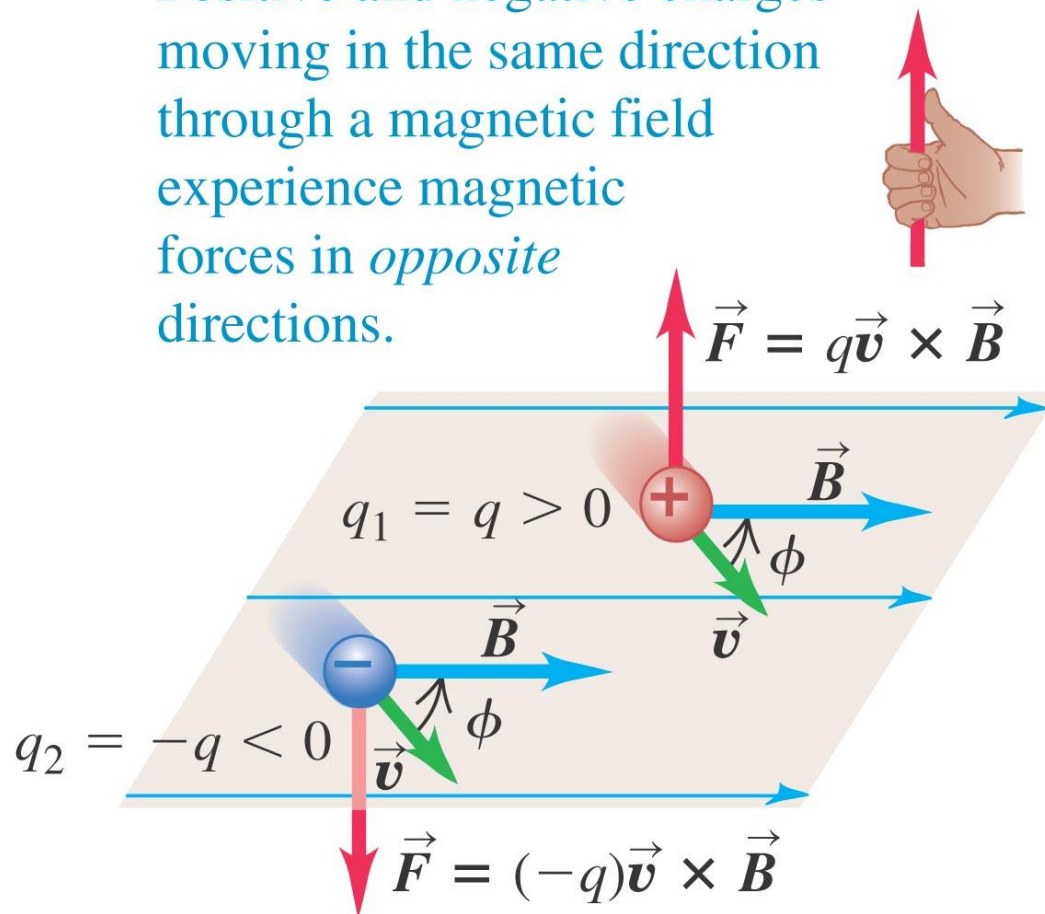
If the charge is negative, the direction of the force is *opposite* to that given by the right-hand rule.



Equal velocities but opposite signs

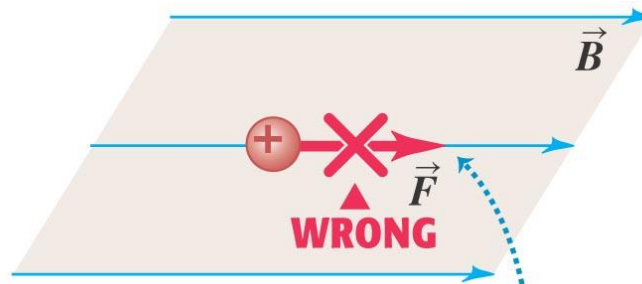
- Two charges of equal magnitude but opposite signs moving in the same direction in the same field will experience magnetic forces in opposite directions. (See Figure 27.8 below.)

Positive and negative charges moving in the same direction through a magnetic field experience magnetic forces in *opposite* directions.

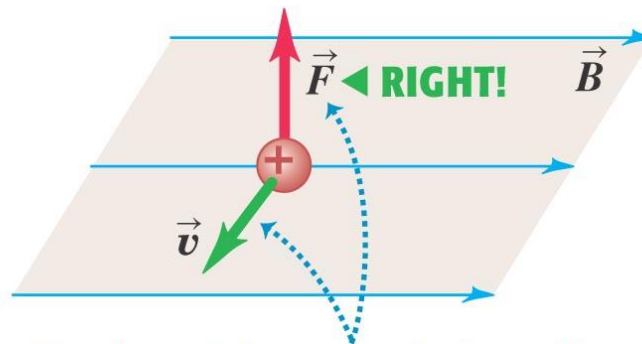


Magnetic field lines are *not* lines of force

- It is important to remember that magnetic field lines are *not* lines of magnetic force. (See Figure 27.12 below.)



Magnetic field lines are *not* “lines of force.”
The force on a charged particle is not along the direction of a field line.



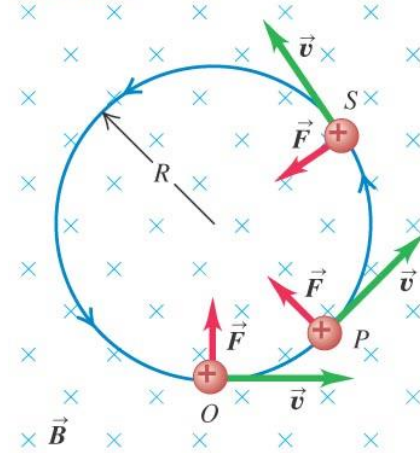
The direction of the magnetic force depends on the velocity \vec{v} , as expressed by the magnetic force law $\vec{F} = q\vec{v} \times \vec{B}$.

Motion of charged particles in a magnetic field

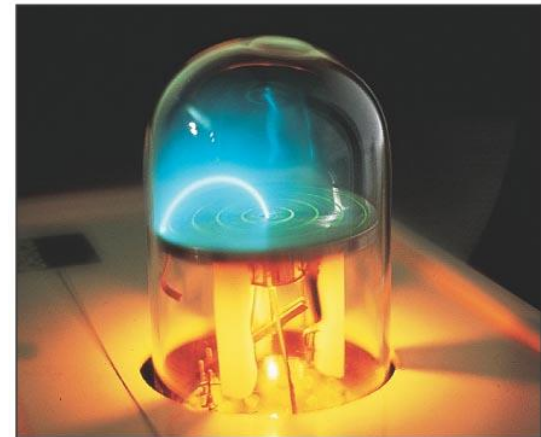
- A charged particle in a magnetic field always moves with constant speed.
- Figure 27.17 at the right illustrates the forces and shows an experimental example.
- If the velocity of the particle is perpendicular to the magnetic field, the particle moves in a circle of radius $R = mv/|q|B$.
- The number of revolutions of the particle per unit time is the *cyclotron frequency*.

(a) The orbit of a charged particle in a uniform magnetic field

A charge moving at right angles to a uniform \vec{B} field moves in a circle at constant speed because \vec{F} and \vec{v} are always perpendicular to each other.



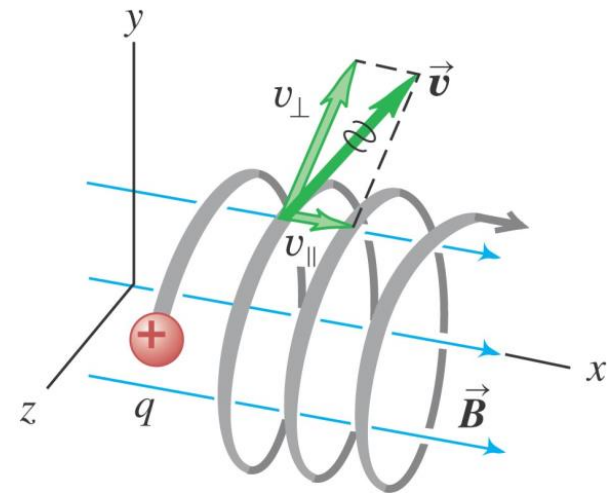
(b) An electron beam (seen as a blue arc) curving in a magnetic field



Helical motion

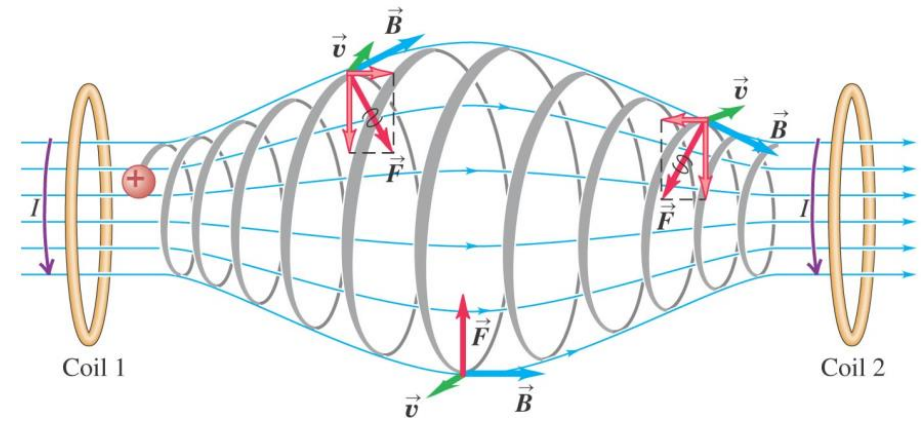
- If the particle has velocity components parallel to and perpendicular to the field, its path is a *helix*. (See Figure 27.18 at the right.)
- The speed and kinetic energy of the particle remain constant.

This particle's motion has components both parallel (v_{\parallel}) and perpendicular (v_{\perp}) to the magnetic field, so it moves in a helical path.



A nonuniform magnetic field

- Figure 27.19 at the right shows charges trapped in a *magnetic bottle*, which results from a nonuniform magnetic field.
- Figure 27.20 below shows the Van Allen radiation belts and the resulting aurora. These belts are due to the earth's nonuniform field.



(a)

(b)

