General Physics 2
SCPH 211

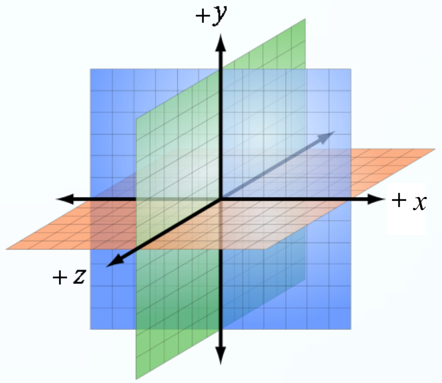
Chapter 28
magnetic Field

What Produces a Magnetic Field?

- Electric field ***E*** is produced by an electric charge
- Magnetic field ***B*** is produced by ? (there is NO magnetic charge)
- Individual (imaginary) magnetic charges is called *magnetic monopoles*
- How then are magnetic fields produced? There are two ways:
  1. Moving electrically charged particles, such as a current in a wire, to make an **electromagnet**
  2. The elementary particles such as electrons have an *intrinsic* magnetic field around them (basic characteristic of each particle)
- For some materials, magnetic fields of the electrons add together to give a net magnetic field around the material → **permanent magnet**
- Other materials, the magnetic fields of the electrons cancel out, giving no net magnetic field surrounding the material. Such cancellation is the reason you do not have a permanent field around your body

The Definition of *B*

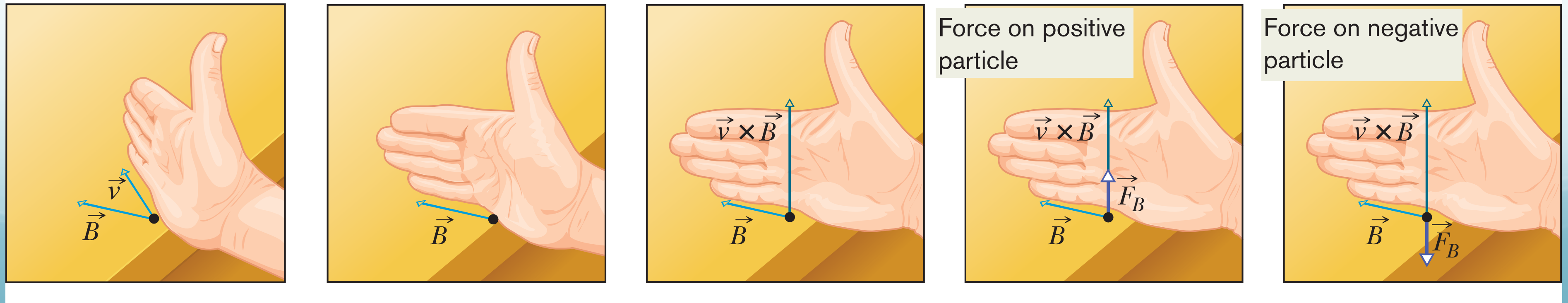
We define $\boldsymbol{B}$ in in terms of the magnetic force $\boldsymbol{F}_B$ exerted on a moving electrically charged test particle by firing a charged particle (of velocity $\boldsymbol{v}$) through the point at which $\boldsymbol{B}$ is to be defined, and determining the force $\boldsymbol{F}_B$ that acts on the particle at th $\vec{F}_B = q\vec{v} \times \vec{B};$



- The magnitude of $F_B = |q|vB \sin\phi,$, where ϕ is the angle between $\boldsymbol{v}$ & $\boldsymbol{B}$
  - $\boldsymbol{F}_B$ *never* has a component parallel to $\boldsymbol{v}$ → cannot change the particle's speed v
    $\boldsymbol{F}_B$ changes only the direction of v → the particle accelerate by $\boldsymbol{F}_B$
  - $\boldsymbol{F}_B = 0$ if $\boldsymbol{v}$ & $\boldsymbol{B}$ are either parallel ($\phi = 0°$) or antiparallel ($\phi = 180°$),
    $\boldsymbol{F}_B$ is maximum when $\boldsymbol{v}$ & $\boldsymbol{B}$ are perpendicular to each other

Finding the Magnetic Force on a Particle

- The direction of $\boldsymbol{F}_B$ is always normal to both velocity and magnetic field, determined by right-hand rule

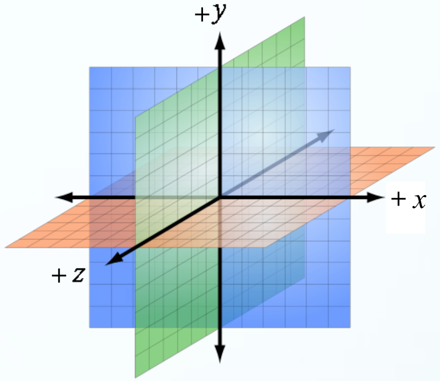


(*a*) (*b*) (*c*) (*d*) (*e*)

- The SI unit for ***B*** is **tesla** (T)

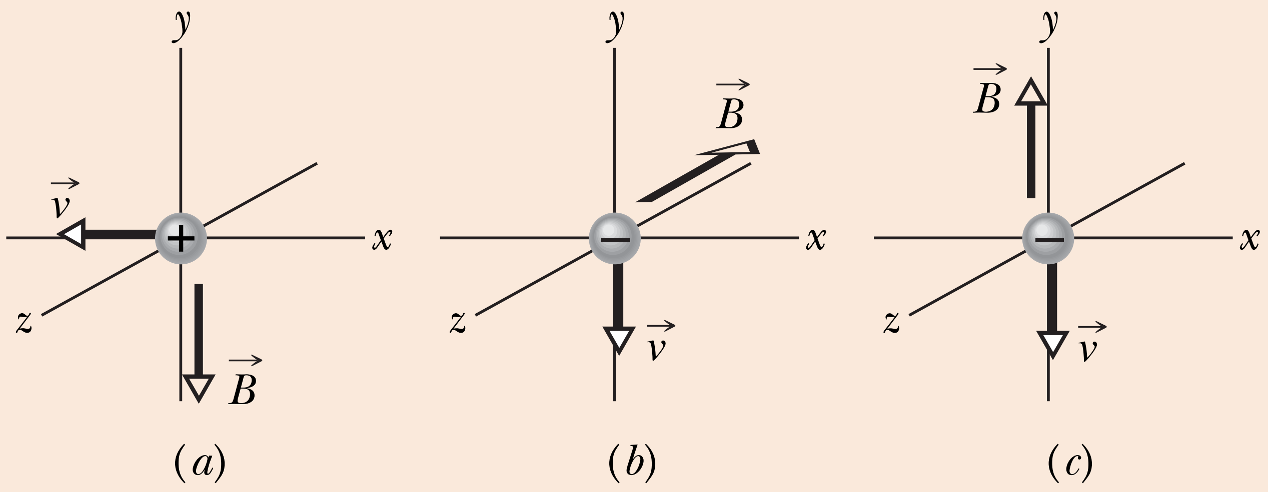
$$1 \text{ tesla} = 1 \text{ T} = 1 \frac{\text{newton}}{(\text{coulomb})(\text{meter/second})} = 1 \frac{\text{newton}}{(\text{coulomb/second})(\text{meter})} = 1 \frac{\text{N}}{\text{A} \cdot \text{m}}.$$

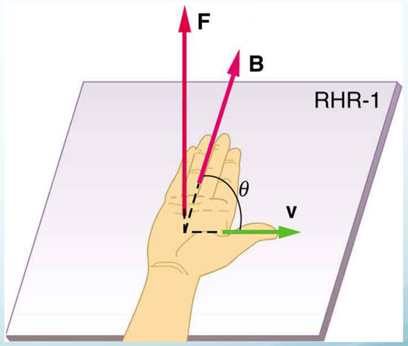
$$1 \text{ tesla} = 10^4 \text{ gauss}.$$



CHECKPOINT 1

The figure shows three situations in which a charged particle with velocity $\vec{v}$ travels through a uniform magnetic field $\vec{B}$. In each situation, what is the direction of the magnetic force $\vec{F}_B$ on the particle?





a) $+z$;
b) $-x$;
c) $\boldsymbol{F} = 0$

Problems:

1. A proton moving with a speed of 4×10^6 m/s through a magnetic field of 4 T experiences a magnetic force of 12.8×10^{-13} N. Find the angle between the proton's velocity and the magnetic field.

Solution

The magnitude of the magnetic force is defined as

$$F = qvB\sin\theta$$

Hence the angle is

$$\sin\theta = \frac{F}{qvB} = \frac{12.8\times10^{-13}}{1.6\times10^{-19}\times4\times10^{6}\times4} = 0.5 \quad \rightarrow \quad \theta = 30^{0}$$

2 . A proton moves with a speed of $4×10^6$ m/s normally to a magnetic field of 2.4 T. Calculate the acceleration of the proton due to the magnetic force.

Solution

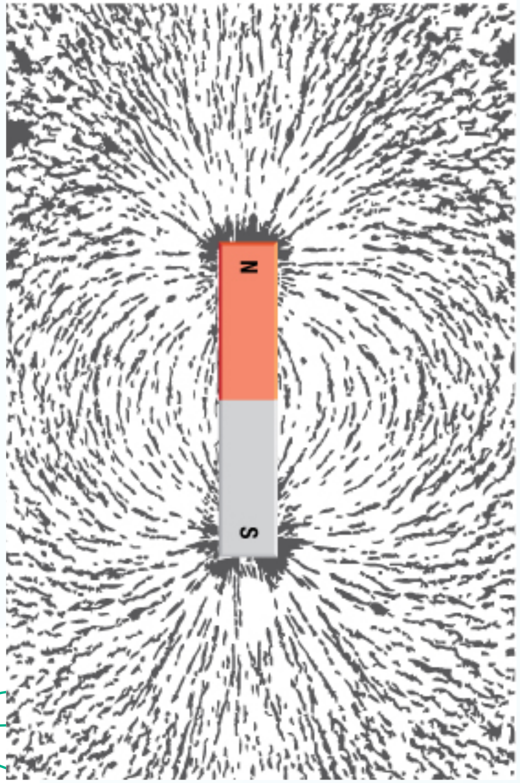
The magnitude of the magnetic force is

$$F = qvB = 1.6\times10^{-19}\times4\times10^{6}\times2.4 = 1.54\times10^{-12}\,N$$

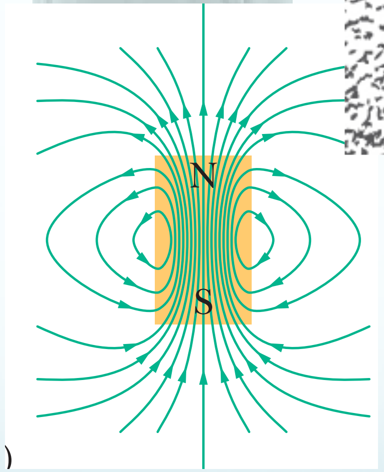
Hence the magnitude of its acceleration (from Newton's second law) is

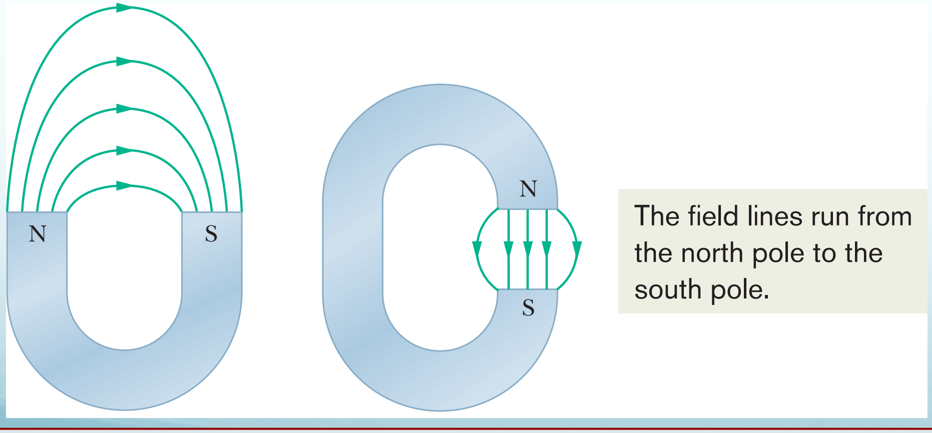
$$F = ma \quad \rightarrow \quad a = \frac{F}{m} = \frac{1.54\times10^{-12}}{1.67\times10^{-27}} = 9.2\times10^{14}\,m/s^{2}$$

- **Magnetic fields lines:**
  (1) the direction of the tangent to a magnetic field line at any point gives the direction of ***B***
  (2) the spacing of the lines represents the magnitude of ***B*** (stronger where the lines are closer together)



- Magnetic field lines of *bar magnet:*
  - The lines all pass through the magnet, and they all form closed loops
  - The external magnetic effects of a bar magnet are strongest near its ends, where the field lines are most closely spaced
  - *B* lines goes from the *north pole* N of the the *south pole* S
  - Because a magnet has two poles, it is said to be a **magnetic dipole**





Opposite magnetic poles attract each other, and like magnetic poles repel each other.

A Circulating Charged Particle

- If a charged particle q of mass m and speed v enters a uniform $\boldsymbol{B}$
  → the particle will move in a circular path of radius r given by

$$r = \frac{mv}{|q|B} \quad \text{(radius)}.$$

The period T (the time for one full revolution) is equal to the circumference divided by the speed:

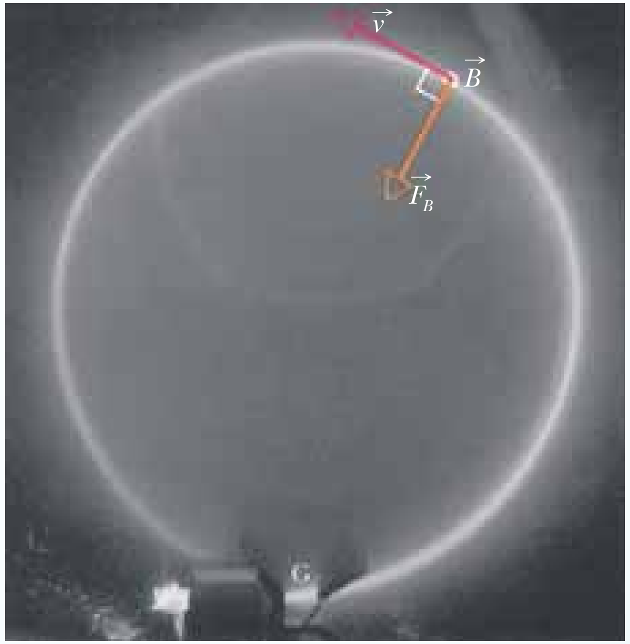
$$T = \frac{2\pi r}{v} = \frac{2\pi}{v}\frac{mv}{|q|B} = \frac{2\pi m}{|q|B} \quad \text{(period)}.$$

The frequency f (the number of revolutions per unit time) is

$$f = \frac{1}{T} = \frac{|q|B}{2\pi m} \quad \text{(frequency)}.$$

The angular frequency ω of the motion is then

$$\omega = 2\pi f = \frac{|q|B}{m} \quad \text{(angular frequency)}.$$



Problems:

3. An electron of a speed of 2×10^5 m/s perpendicularly enters a uniform magnetic field of 4 mT. Calculate (i) the magnetic force and (ii) the radius of its path.

Solution

(i) The magnitude of the magnetic force, since the velocity is normal to magnetic field, is

$$F = qvB = 1.6\times10^{-19}\times2\times10^{5}\times4\times10^{-3} = 1.28\times10^{-16}\,N$$

(ii) The radius of its circular path is

$$R = \frac{mv}{qB} = \frac{9.11\times10^{-31}\times2\times10^{5}}{1.6\times10^{-19}\times4\times10^{-3}} = 2.85\times10^{-4}\,m$$

Magnetic Force on a Current-Carrying Wire

- Consider a wire of length L carrying current i in a magnetic field $\boldsymbol{B}$ All conduction electrons will drift past plane xx in a time $t = L/v_d$

  → a charge q given by

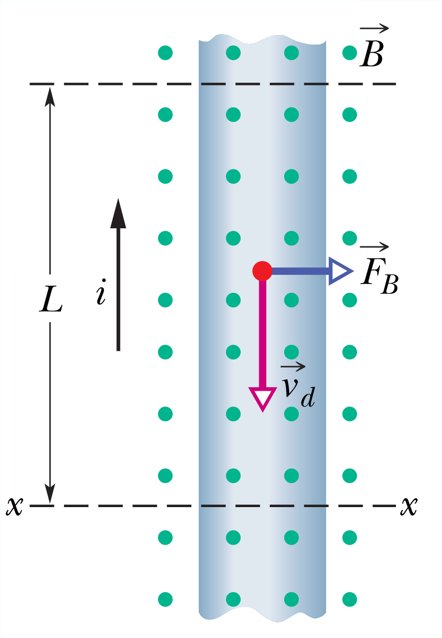
$$q = it = i\frac{L}{v_d}$$

$$F_B = qv_dB\sin\phi = \frac{iL}{v_d}v_dB\sin 90^\circ$$

$$F_B = iLB.$$

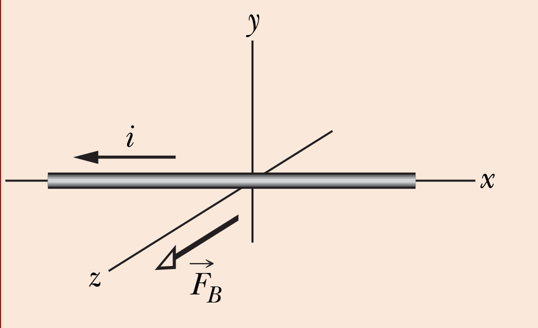
- The magnetic force due to a current passing through a wire of length L is

$$\vec{F}_B = i\vec{L} \times \vec{B} \qquad \text{(force on a current)}$$



CHECKPOINT 4

The figure shows a current i through a wire in a uniform magnetic field $\vec{B}$, as well as the magnetic force $\vec{F}_B$ acting on the wire. The field is oriented so that the force is maximum. In what direction is the field?



Answer: *-y*

4. In a certain electric motor wires that carry a current of 8 A are perpendicular to a magnetic field of 50 mT. Calculate the magnetic force on each centimeter of these wires.

Solution

The magnitude of the magnetic force, since the magnetic field is normal to the wire, is

$$F = iLB = 8 \times 0.01 \times 50 \times 10^{-3} = 0.004N$$