Magnetism

Known a longtime

- e.g. stone magnetite attracts pieces of iron
- compass needle directionality

Electric current in a wire

- deflects nearby compass needle
- first hint of close relationship between electrical & magnetic phenomena

Sources of magnetism

- permanent magnet: material hold in a long term magnetic field (eg. ferrite)
- electromagnet: generate magnetic field with electrical current

Magnetic Poles + Fields 18.2

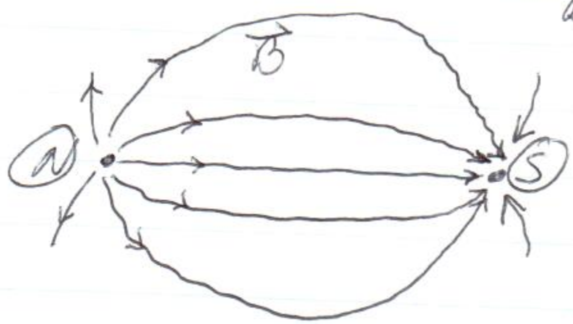
Two types of magnetic "charge" or 'poles':

- North (N) + South (S)
- attract each other, repel same pole
- similar to electrical charge <u>except</u>:

  We've never observed an isolated magnetic pole (a 'monopole')

Magnetic Fields:

noted by "$\vec{B}$"



- lines point away from N and toward S

Magnetic Force:

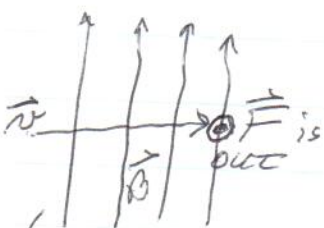
No monopoles means no equivalent to Coulomb's Law.

But magnetic fields do exert force on moving electric charges!!!

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

Lorentz Force Law

$|F_B| \propto q, v,$



leads to Force out of paper

$F_B \perp \vec{v}$ & $\perp \vec{B}$

- when $\vec{v} \parallel \vec{B}$, $F_B = 0$ on particle
- $\boxed{|F_B| = |q| v B \sin\theta}$
- Right-hand screw rule for $\otimes$
  - fingers in $\vec{v}$ direction
  - fold toward $\vec{B}$ direction
  - thumb in $\vec{F}$ direction

$\vec{F}_B$ only present when charge in motion

$\vec{F}_B$ does no work when steady field acts on particle

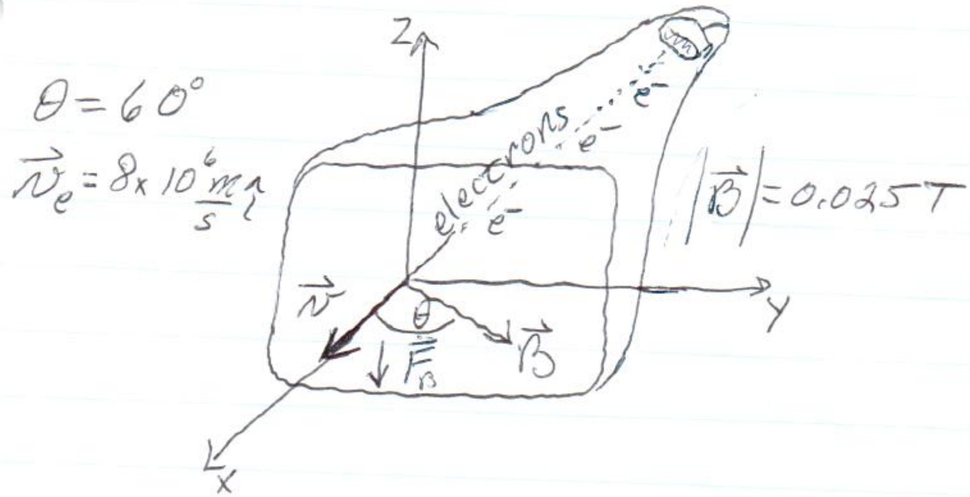
- Since $\vec{F}_B \perp \vec{v}$

∴ can only change direction → not kinetic energy

Magnetic field Units:

$$\boxed{\begin{aligned} 1 \text{ 'Tesla' } (T) &= 1 \frac{N}{C \cdot m/s} \\ &= 1 \frac{N}{A \cdot m} \end{aligned}}$$

Example



Consider CRT monitor with an electron gun as shown.

a) what is the magnitude of the magnetic force on the electron.

$$F_B = |q| v B \sin\theta$$
$$= 1.6\times10^{-19} C \left(8\times10^6 \frac{m}{s}\right)(0.025T) \times \sin 60°$$
$$= \underline{\underline{2.8\times10^{-14} N}}$$

$\vec{v}\times\vec{B}$ means $\vec{F}_B$ in negative z direction (since $q<0$)

Example (cont.)

b) What is the vector expression of this force?

$$\vec{v} = 8 \times 10^6 \tfrac{m}{s}\,\hat{i}$$

$$\vec{B} = (0.025T\cos 60^\circ\,\hat{i} + 0.025T\sin 60^\circ\,\hat{j})$$

$$= 0.013T\,\hat{i} + 0.022T\,\hat{j}$$

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

$$= (-1.6 \times 10^{-19} C)\Big[(8 \times 10^6 \tfrac{m}{s})(0.013\,T)\underbrace{\cancel{\hat{i} \times \hat{i}}}_{0} + (8 \times 10^6 \tfrac{m}{s})(0.022T)(\underbrace{\hat{i} \times \hat{j}}_{\hat{k}})\Big]$$

$$= -1.6 \times 10^{-19} C\Big[(8 \times 10^6 \tfrac{m}{s})(0.022T)\,\hat{k}\Big]$$

$$= -2.8 \times 10^{-14}\left(\cancel{C} \cdot \cancel{\tfrac{m}{s}} \cdot \left(\tfrac{N}{\cancel{C} \cdot \cancel{\frac{m}{s}}}\right)\right)\hat{k}$$

$$= \boxed{-2.8 \times 10^{-14} N\,\hat{k}}$$

Circulating Electric Charge

Consider prior example, but where a charged particle, q, enters into a larger volume having a uniform $\vec{B}$ field.

At each point: $\vec{v} \perp \vec{B}$

- $\vec{F}_B$ toward 'left' if looking along direction of motion

$\therefore$ particle moves in a circular motion

$$F = m\frac{v^2}{r} \ (= |q| v B)$$

$$r = \frac{m v^{\cancel{2}}}{|q| \cancel{v} B} = \boxed{\frac{mv}{|q| B}}$$ radius of curvature of circular path

We know period, T, is therefore:

$$T = \frac{2\pi r}{v} = \frac{2\pi}{\cancel{v}}\left(\frac{m\cancel{v}}{|q| B}\right) = \boxed{\frac{2\pi m}{|q| B}}$$

and the frequency is

$$f = \frac{1}{T} = \boxed{\frac{|q| B}{2\pi m}}$$

Example

An electron travels into a region of uniform magnetic field at the Large Hadron Collider. The Field is 2 T. If the electron velocity is 99% the speed of light, and ⊥ to B, what is the radius of curvature of it's path?

$$v = 0.99(c) \qquad (c = \text{speed of light} = 3\times 10^{8}\, m/s)$$
$$= 2.97\times 10^{8}\, m/s$$

$$r = \frac{mv}{|q|B} = \frac{(9.1\times 10^{-31}\,kg)(2.97\times 10^{8}\, m/s)}{|-1.6\times 10^{-19}\,C|(2\,T)}$$

$$= \frac{3.26\times 10^{-22}\,kg\,m^2/s^2}{3.2\times 10^{-19}\,C\cdot T\,\frac{N}{\frac{C}{s}\cdot m}}$$

$$= 1.0\times 10^{-3}\,\cancel{N}m/\cancel{N}$$

$$r = \boxed{1mm}$$