Magnetism

15.1

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 15.2

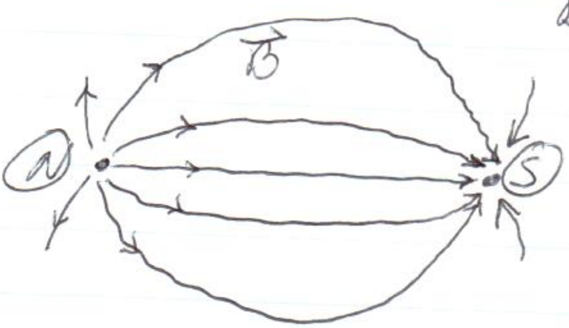
two types of magnetic "charge" or 'poles':

- 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')

<u>Magnetic Fields</u>:

noted by "$\vec{B}$"



- lines point away from Ⓝ and toward Ⓢ

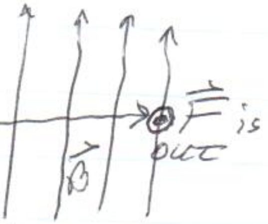
Magnetic Force: 15.3

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 ⊗
  - 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

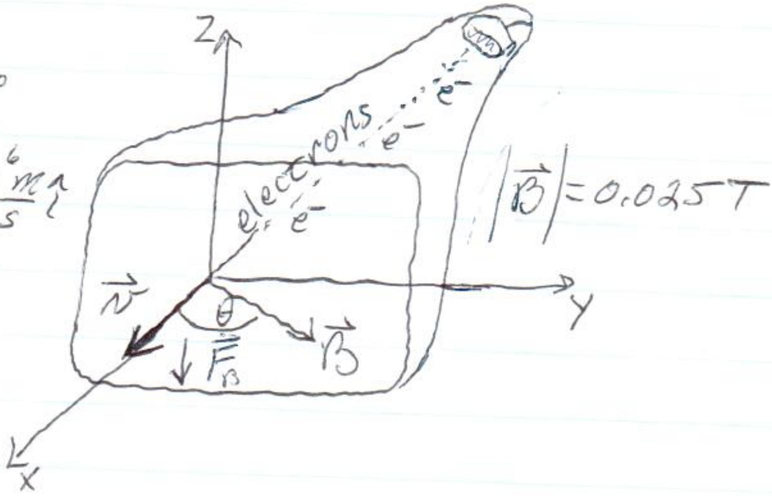
<u>Magnetic field Units</u>:

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

Example

$\theta = 60°$

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



Consider CRT monitor with an electron gun as shown.

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

$$F_B = |q| v B \sin\theta$$
$$= 1.6 \times 10^{-19} C \left(8 \times 10^6 \frac{m}{s}\right)(0.025 T) \times \sin 60°$$
$$= \underline{\underline{2.8 \times 10^{-14} N}}$$

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

Example (cont.)

b) what is the vector expression of this force?

$$\vec{v} = 8\times10^{6}\,\tfrac{m}{s}\,\hat{i}$$

$$\vec{B} = (0.025T\cos60^\circ\,\hat{i} + 0.025T\sin60^\circ\,\hat{j})$$

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

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

$$= (-1.6\times10^{-19}C)\Big[(8\times10^{6}\tfrac{m}{s})(0.013\,T)\overset{0}{\cancel{\hat{i}\times\hat{i}}}$$

$$+(8\times10^{6}\tfrac{m}{s})(0.022T)\underset{\hat{k}}{\cancel{(\hat{i}\times\hat{j})}}\Big]$$

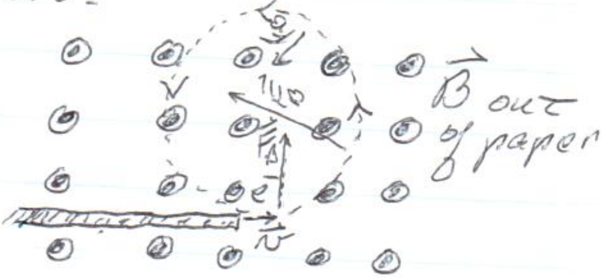
$$= -1.6\times10^{-19}C\Big[(8\times10^{6}\tfrac{m}{s})(0.022T)\hat{k}\Big]$$

$$= -2.8\times10^{-14}\Big(\cancel{C}\cdot\cancel{\tfrac{m}{s}}\cdot\Big(\frac{N}{\cancel{C}\cdot\cancel{\tfrac{m}{s}}}\Big)\Big)\hat{k}$$

$$= \boxed{-2.8\times10^{-14}N\hat{k}}$$

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

∴ particle moves in a circular motion

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

$$r = \frac{m v^{\cancel{2}}}{|q| \cancel{v} B} = \boxed{\frac{mv}{|q|B}}$$ 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 $\vec{B}$, what is the radius of curvature of it's path?

$$v = 0.99(c) \qquad (c = \text{speed of light} = 3\times10^{8}\,m/s)$$
$$= 2.97\times10^{8}\,m/s$$

$$r = \frac{mv}{|q|B} = \frac{(9.1\times10^{-31}\,kg)(2.97\times10^{8}\,m/s)}{|-1.6\times10^{-19}\,C|(2\,T)}$$

$$= \frac{3.26\times10^{-22}\,kg\,m^2/s^2}{3.2\times10^{-19}\,\cancel{C}\cdot\cancel{T}\,\frac{N}{\cancel{C}\cdot\cancel{m}/\cancel{s}}}$$

$$= 1.0\times10^{-3}\,\cancel{N}m/\cancel{N}$$

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