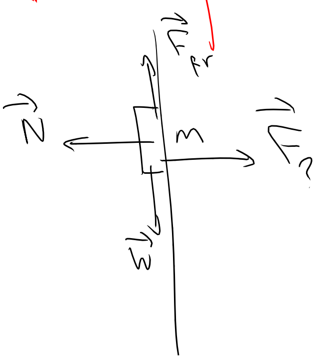
Hand in your HW!



$F_? = N$

$F_{fr} \leq \mu_s N$

$F \propto \frac{1}{d^3}$

electric dipole?

magnetic force

$F_B \propto v$

$F_B \propto q$

region where the charge feels $F_B \neq 0$

$\vec F_B \cdot \vec v = 0$

$F_B \propto q v \sin\theta$

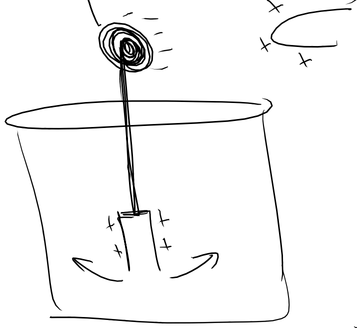
$\vec F_B \neq \vec F_B'$

$$\boxed{\vec F_B = q\vec v \times \vec B}$$

compare with $\vec F_E = q\vec E$

$\vec B$ is called the magnetic field.

$$\vec F = q(\vec E + \vec v \times \vec B)$$

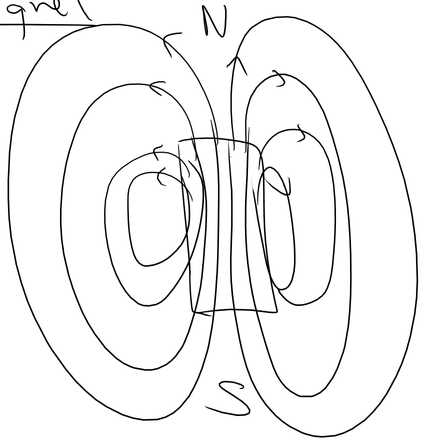


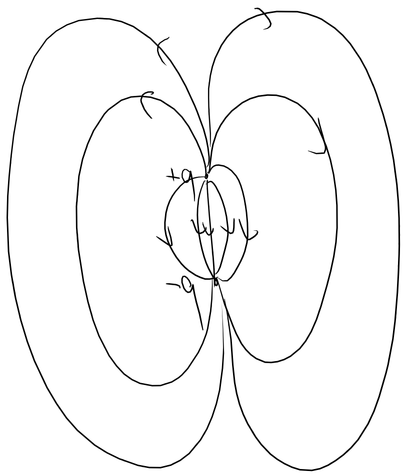
$\vec B$ is created by: - currents

- magnets (spins of electrons)

Magnetic Field Lines

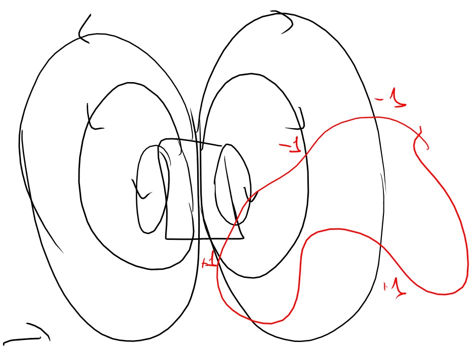
Bar magnet





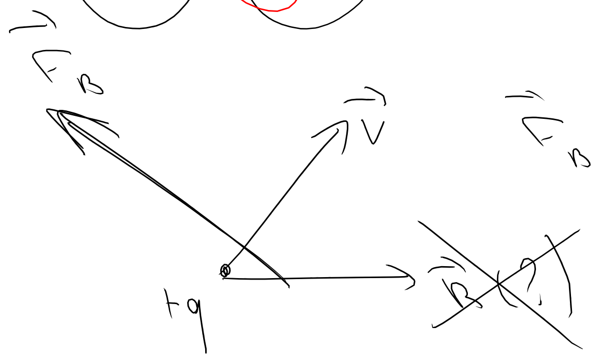
⇑ magnetic dipole

Break in two

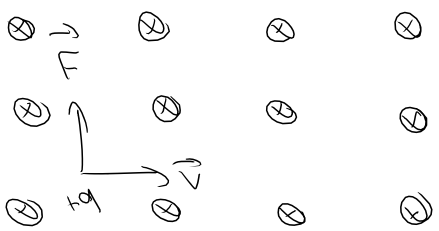


Magnetic Monopole does not exist!

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



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

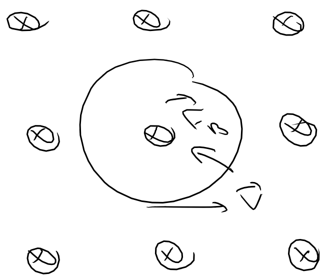


$$\vec{a} = \frac{d\vec{v}}{dt} \neq 0$$

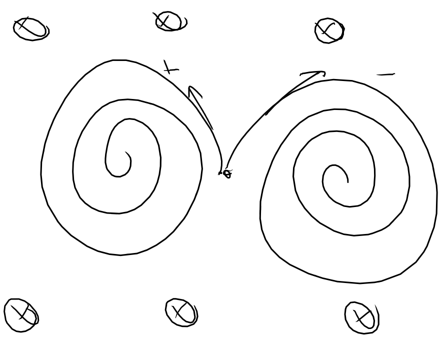
$$\frac{dv}{dt} = \begin{cases} 0 & ? \\ \text{non-zero} & ? \end{cases}$$

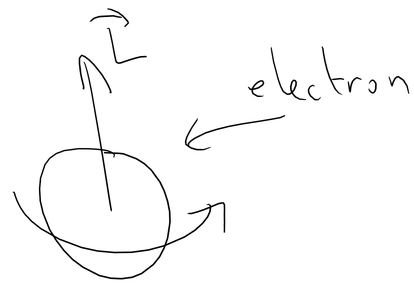
$$v^2 = \vec{v}^2$$

$$\frac{dv^2}{dt} = \frac{d\vec{v}^2}{dt} \longrightarrow 2v\frac{dv}{dt} = 2\vec{v} \cdot \frac{d\vec{v}}{dt} = 0$$

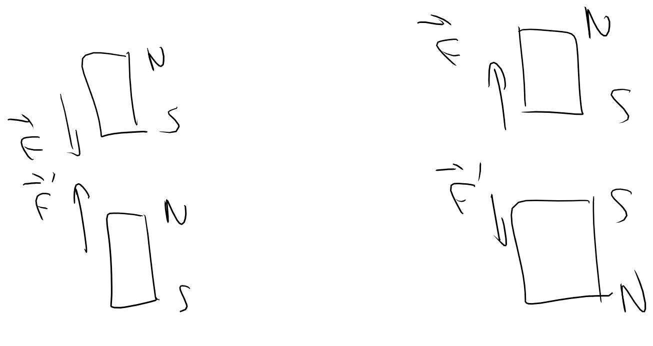


$$F_B = |q\vec{v}\times\vec{B}|$$
$$= qvB\sin 90$$
$$F_B = qvB = m\frac{v^2}{R}$$
$$R = \frac{mv}{qB}$$
$$\Rightarrow \boxed{\frac{q}{m} = \frac{v}{RB}}$$

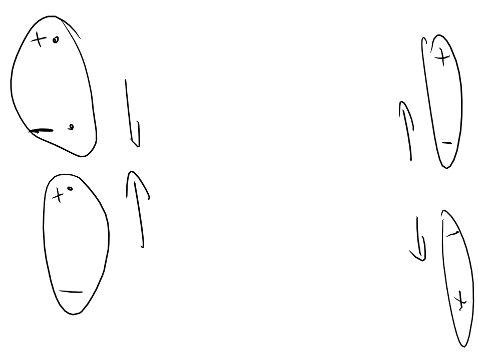




Two magnets



Electric dipole



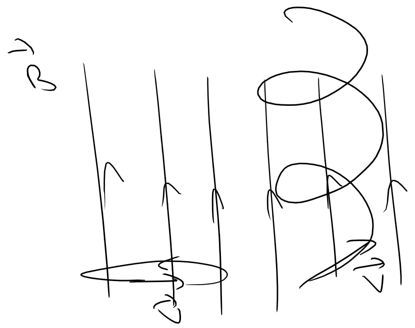
Example

$1 \text{ Gauss} \simeq$ av. magnetic field of earth

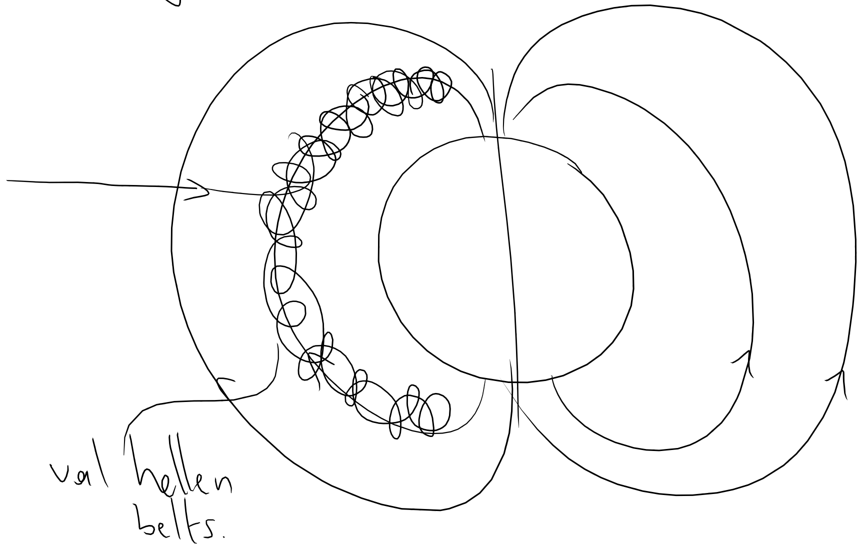
$\vec{F} = q\vec{v} \times \vec{B}$

$$[\vec{B}] = \frac{N}{C\, m/s} = \frac{N}{\left(\frac{C}{s}\right) m} = \frac{N}{Am} = \text{Tesla}$$

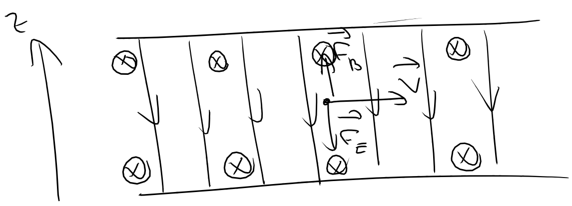
$1 \text{ Tesla} = 10^4 \text{ Gauss}$



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



Example



capacitor

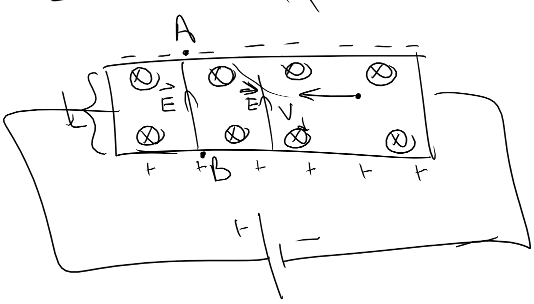
$\vec{F}_E = qE(-\hat{z})$

$\vec{F}_B = qvB\,\hat{z}$

$\vec{F}_{tot} = q(-E + vB)\,\hat{z} = 0$

if $\boxed{v = \frac{E}{B}}$

Hall Effect



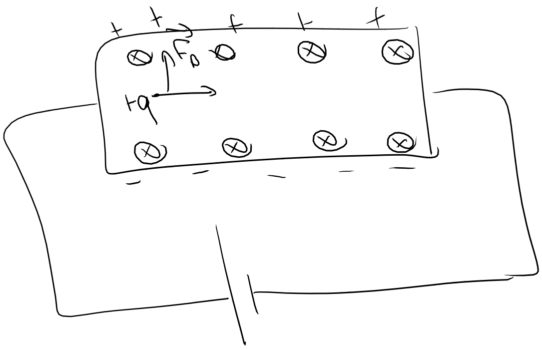
$$\vec{F}_e = (-e)\vec{v}\times\vec{B}$$

$$\cancel{q}E = \cancel{q}vB \qquad q = -e$$

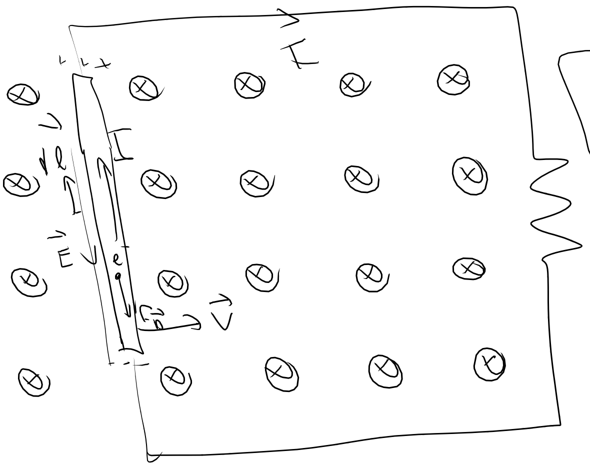
$$\boxed{E = v_d B}$$

$$V_{AB} = EL = v_d BL$$

$$\boxed{v_d = \frac{V_{AB}}{BL}} \Longrightarrow B = \frac{V_{AB}}{v_d L}$$



Example Conductor Moving in a Magnetic Field



$$\boxed{E = vB}$$

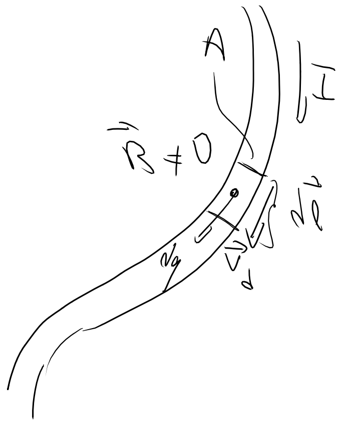
$$d\vec{F} = I\, d\vec{l}\times\vec{B}$$

$$\vec{F}_B\cdot d\vec{l} = 0$$

$$\underbrace{\vec{F}_B\cdot \underbrace{(\vec{v}\,dt)}_{d\vec{l}} = 0}_{dW = 0}$$

Force acting on a wire

$d\vec{F} = (dq)\,\vec{v}_d \times \vec{B}$



n: # density of charges

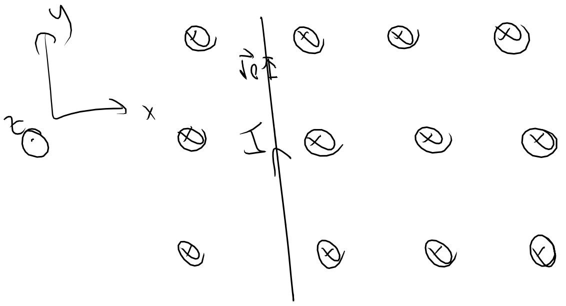
$\vec{v}_d\, dt = d\vec{l}$

$I = \frac{dq}{dt}$

$d\vec{F} = \underbrace{\left(\frac{dq}{dt}\right)}_{I} \underbrace{(\vec{v}_d\, dt)}_{d\vec{l}} \times \vec{B}$

$$\boxed{d\vec{F} = I\, d\vec{l} \times \vec{B}}$$

Example Force on a straight wire segment in a uniform magnetic field:



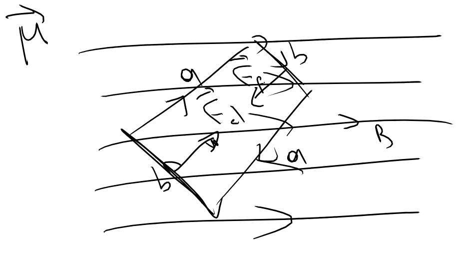
$d\vec{F} = I\, d\vec{l} \times \vec{B}$

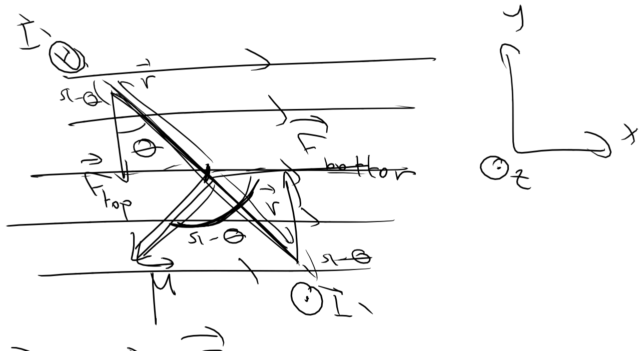
$= I\, dl\, B\, (-\hat{x})$

$\frac{d\vec{F}}{dl} = I B (-\hat{x}) = \vec{I} \times \vec{B}$

$\vec{I} = I\hat{y}$

Example





$F_{top} = IBa$

$F_{bottom} = IBa$

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\tau} = \hat{z}(\tau_{top} + \tau_{bottom})$

$\tau_{top} = \left(\frac{b}{2}\right)(IBa)\sin(\pi - \theta)$

$|\vec{\mu}| = I(ab)$

$\tau_{bottom} = \left(\frac{b}{2}\right)(IBa)\sin(\pi - \theta)$

$$\boxed{\vec{\tau} = I(ab)\, B \sin\theta\, \hat{z}}$$

$$|\vec{\mu} \times \vec{B}| = |\vec{\mu}| B \sin(\pi - \theta)$$

$$\vec{\mu} \times \vec{B} = I(ab) B \sin\theta \, \hat{z} = \vec{\tau}$$

$$\boxed{\vec{\tau} = \vec{\mu} \times \vec{B}}$$

$\vec{\mu}$: magnetic dipole moment