Ch 27 Magnetic fields & forces

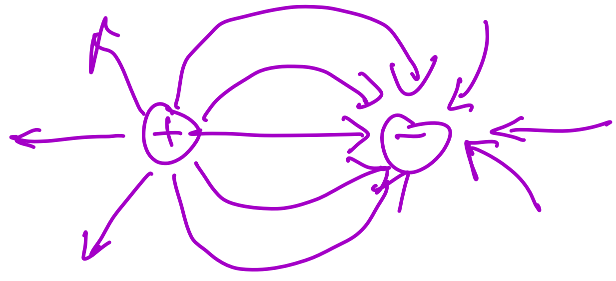
Magnets are ancient discoveries "loadstone"

⇒ compass is earliest use

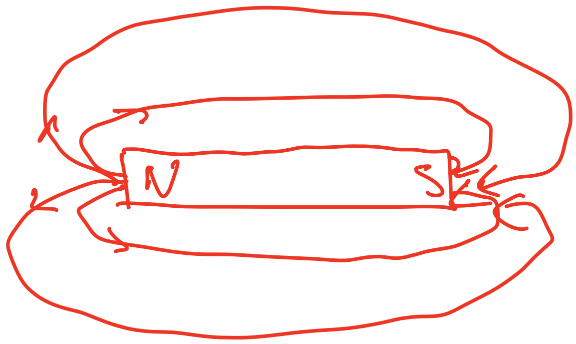
electric charges have + & −
magnets have "poles" N & S
opposites attract
same poles repel
both attract metals like iron ~ why?

- all atoms behave like tiny magnets
- iron has "domains" of large numbers of atoms aligned
- domains are not aligned → no net magnetism
- in presence of external field, domains align

Magnetic field - analogous to electric



electric



units: Tesla T ⇒ 1T = 10^4 gauss

earth ~ 0.25 gauss

refrig magnet ~ 100 gauss

MRI ~ 3T

LHC magnets ~ 8T

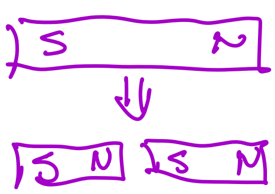
magnetic field lines: never intersect (like electric)

→ field lines are vectors

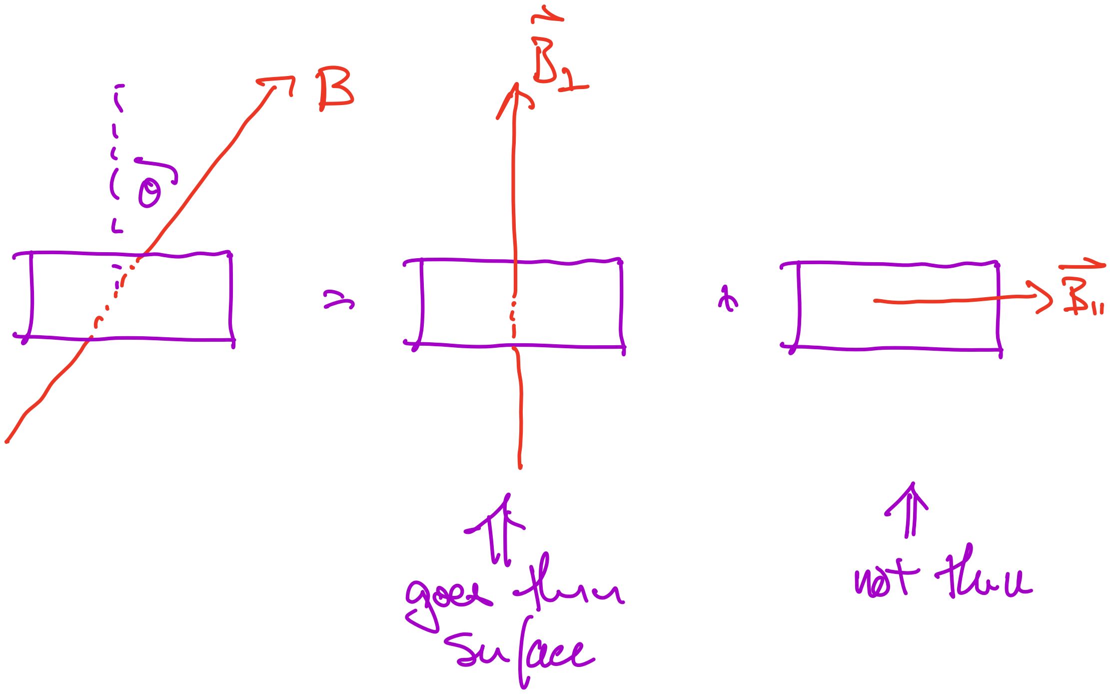
earth's field – see ppt fig

filters out charged particles from sun

poles: can not separate N & S poles!



Magnetic flux: net field through surface



flux is $\Phi_B = B_\perp \cdot A$

differential: $d\Phi_B = \vec{B} \cdot d\vec{A}$

so $\Phi_B = \int_{\text{surface}} \vec{B} \cdot d\vec{A}$

note: Φ_B for closed surface $= 0$ always!

because field lines do not stop on any mag charge

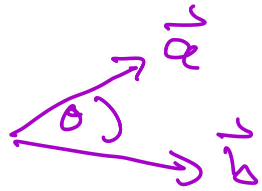
unit of flux: Weber $= 1\ \text{T}\,\text{m}^2$

Forces on moving charge $+q$

Electric: $\vec{F} = q\vec{E}$

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

cross product: $\vec{a} \times \vec{b}$ defines plane



$\perp$ plane either up or down

use "RHR": $\vec{a} \times \vec{b}$ pt fingers along a

"right hand rule" curl into b

that's the direction

$\vec{a} \times \vec{b} \Rightarrow ab\sin\theta$ in direction $\perp$ plane by RHR

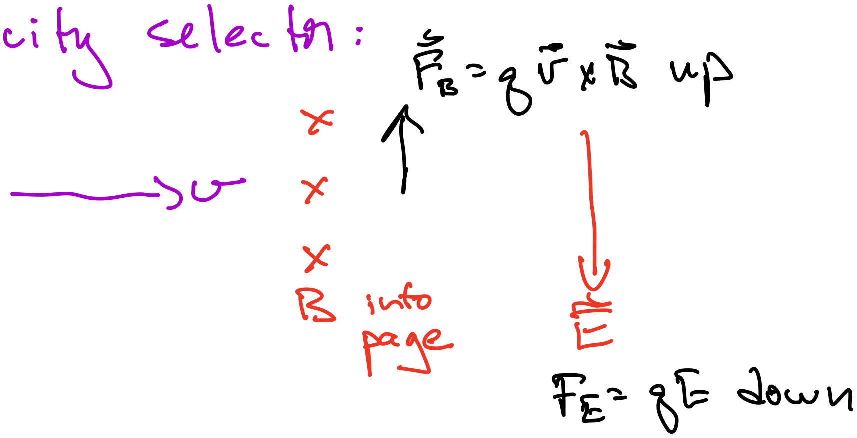
note: 1. force is not along field line for magnets

2. force is zero for particle moving $\parallel$ to field ($\sin\theta = 0$)

3. force for neg charge is opposite to pos charge w/ same velocity

applications

cathode ray tube CRT uses $\vec{B}$ fields to steer beam (see ppt) velocity selector:



for particle to get thru w/no deflection:

$$qvB = qE \quad \text{or} \quad v = E/B$$

Thompson:

electrons go thru voltage V, gain kinetic energy $E = eV$

so $\frac{1}{2}mv^2 = eV$

or $v = \sqrt{\frac{2eV}{m}}$

use velocity selector and adjust E & B on plates so electron hits center of screen

$$v = \frac{E}{B} = \sqrt{\frac{2eV}{m}}$$

$$\therefore \boxed{\frac{e}{m} = \frac{E^2}{2VB^2}}$$ find $\frac{e}{m} = 1.7\times10^{11}$ C/kg

in 1912 Millikan measured $e = 1.6\times10^{-19}$ C

this gives $m = 9.1\times10^{-31}$ kg

Charged particle motion in $\vec{B}$ field

since $\vec{F} \perp \vec{v}$, motion is circular

if particle has $\vec{v}$ that has $\perp$ & $\parallel$ component:

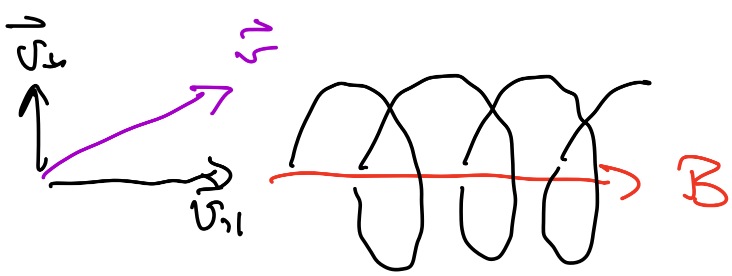
$$\vec{v} = \vec{v}_{\parallel} + \vec{v}_{\perp} \quad \text{to } \vec{B}$$

$$\vec{F} = q\vec{v} \times \vec{B} = q(\vec{v}_{\parallel} + \vec{v}_{\perp}) \times \vec{B}$$

$$= \underbrace{q\vec{v}_{\parallel} \times \vec{B}}_{\text{no force}} + \underbrace{q\vec{v}_{\perp} \times \vec{B}}_{\text{force } \perp \vec{B}}$$

$\therefore \vec{v}_{\parallel}$ constant

motion will be helical



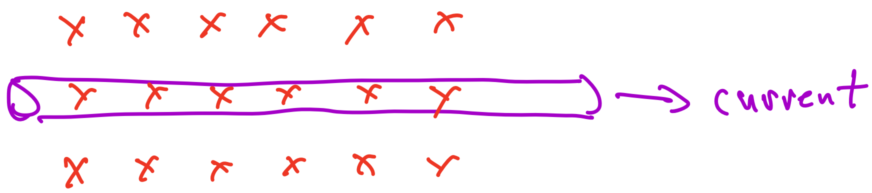
for circular part: centripetal $a = v_{\perp}^2/R$

so $ma = \frac{mv_{\perp}^2}{R} = qv_{\perp}B \Rightarrow R = \frac{mv_{\perp}}{qB}$ radius of circle

angular freq $\omega = \frac{v_{\perp}}{R} = \frac{v_{\perp}}{mv_{\perp}/qB} = \frac{qB}{m}$ "cyclotron frequency"

(see ppt)

Force on wire due to external field:



current of + charges flowing

$\vec{B} \perp$ wire into page

Force on single charge: $F = qvB$ $\quad v =$ "drift velocity"

total # charges: n = # per volume

V = volume

$N = nV$ $\quad$ total charge $Q = qnV$

$V = AL$ $\quad A$ = cross sectional area

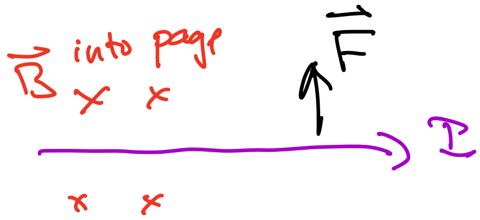
L = length

$$F_{tot} = QvB = qnVvB = \underbrace{qnAv}_{I \text{ (last semester!)}} \cdot BL$$

so $F = ILB$

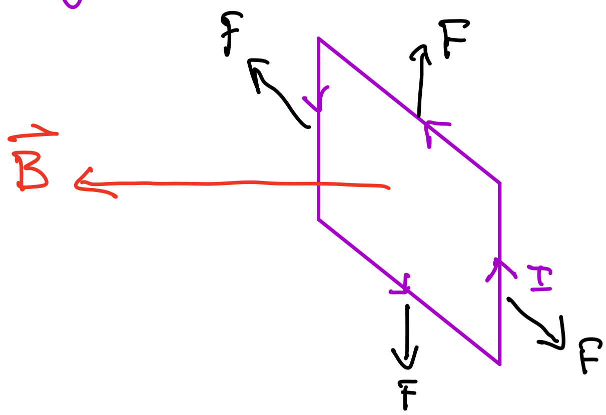
must be direction: $\vec{F} = I\vec{L} \times \vec{B}$ $\quad \vec{L}$ pts in dir of I

ex:

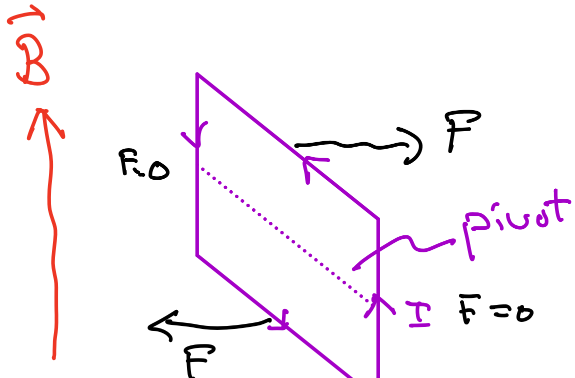


$\vec{F} = I\vec{L} \times \vec{B}$ up

loop of current

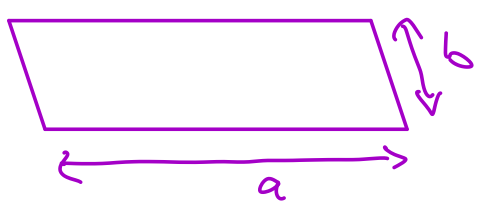


total force is zero



if allowed to pivot, loop will rotate so that the plane $\perp \vec{B}$

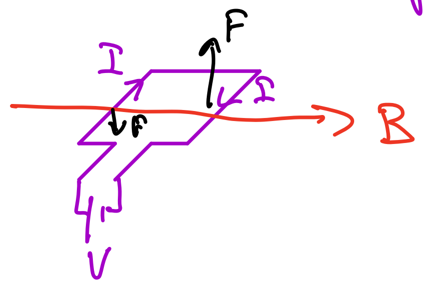
Magnetic moment:



Area $A = ab$

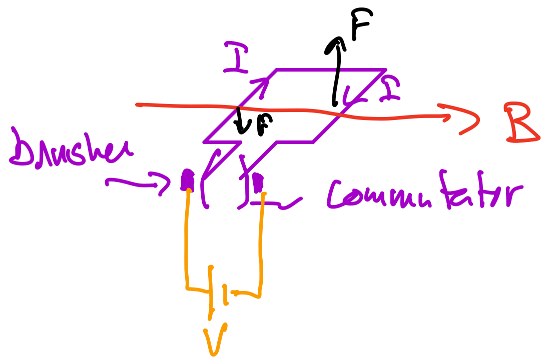
magnetic moment: $\mu = IA = Iab$

$\vec{\mu} = I\vec{A}$ where $\vec{A} \perp$ plane ab



loop will rotate

add "commutator" to switch dir of I



when loop flips then current switches dir
in time to keep F up on right & down on left

DC motor!

series DC motor: has internal resistance R_i
usually small, $R_i \sim 2\Omega$

let $V = 120V$ DC across motor

power supplied $P = IV$

Power dissipated by R_i: $P_i = I^2 R_i$

" used by motor: $P_{used} = I\mathcal{E}$

where $\mathcal{E} \equiv$ electromotive force total Power: $IV = I^2R + I\mathcal{E}$

$\mathcal{E} = V - IR$ as expected

what happens when motor "siezes"?

$\mathcal{E} \to 0 \ \therefore \ 0 = V - IR$

$I = V/R = 60A$! trips circuit breaker!

$$\text{efficiency} = \frac{P_{used}}{P_{delivered}} = \frac{I\mathcal{E}}{I\mathcal{E} + I^2R} = \frac{\mathcal{E}}{\mathcal{E} + IR}$$

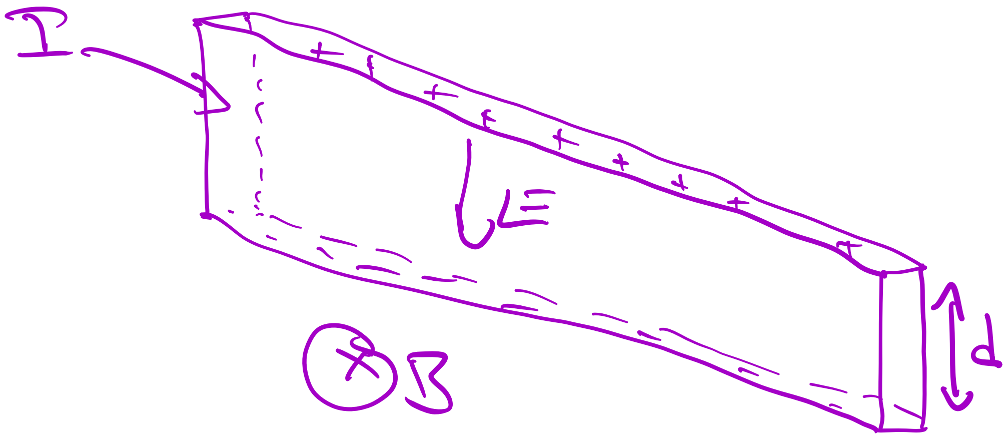
let $I = 4A$, $V = 120V$ $\therefore P_{del} = 4 \cdot 120 = 480W$

$\mathcal{E} = V - IR = 120 - 4 \cdot 2 = 118$

$$\text{eff } e = \frac{118}{118+8} = \frac{118}{126} = 94\%$$

$P_{used} = \mathcal{E} \cdot I = 118 \cdot 4 = 472\,W$

Hall Effect



$q v_d B = q E$ here $E = \Delta V / d$ volt diff top-bot

so $v_d = E/B = \dfrac{\Delta V}{dB}$

can use this to measure v_d in materials!

also: $I = nq v_d = nq\,\Delta V / dB$

so if you know I, can solve for

$nq = \dfrac{dIB}{\Delta V}$ charge density in metal conductor

if you have a very well defined material so you know nq, v_d, can use this to measure B fields (Hall probe)

$B = \dfrac{\Delta V}{d \cdot v_d}$ or $\dfrac{nq\,\Delta V}{dI}$