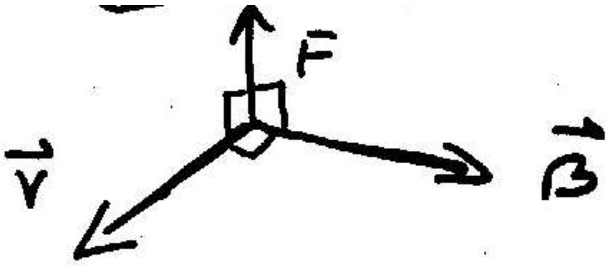
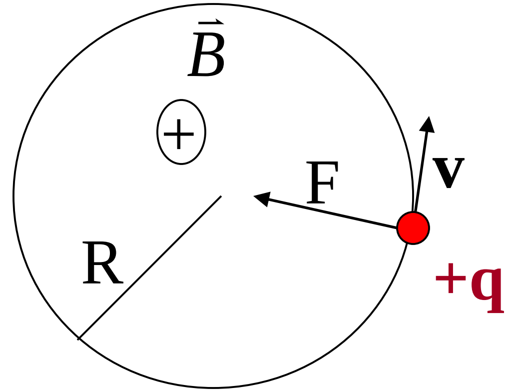


$F = qv_{\perp}\ B = qv\ B_{\perp}$



$$\mathbf{F = I\,\ell\,B_{\perp} = I\,\ell\,B\sin(\theta)}$$

$$\mu_0\ I = \sum_{\text{edge}} B_{\parallel}\ \Delta l$$ **Ampere's Law**

$$\mu_o I = B\ 2\pi R \qquad \Rightarrow B = \frac{\mu_o\ I}{2\pi R}$$

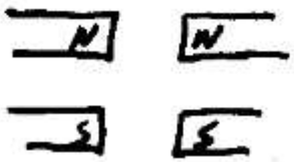
$$B = I\,n\,\mu_0$$

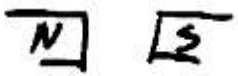
Magnetic Interactions

1.) Force at a distance
2.) Repulsive and attractive
} Like electrostatics!

Permanent magnets

S N —break→ S N   S N


repulsive


attractive!

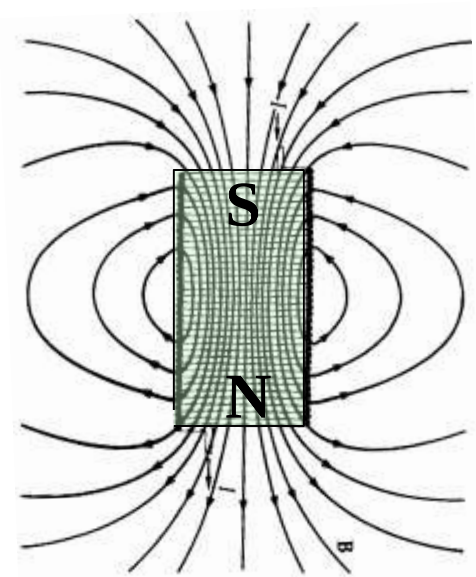
NO MAGNETIC MONOPOLES

S   N

Magnets and Magnetic fields : Dipole Fields

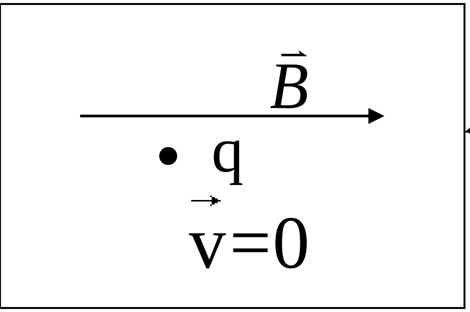
Magnetic field $\vec{B}$ {Like E}

Magnetic field lines

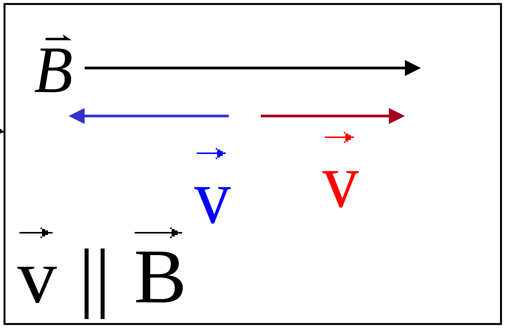


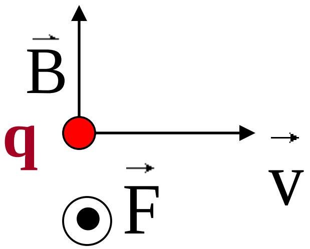
$$B - \text{ units } \text{ Tesla} = \frac{\text{kg}}{\text{CS}}$$

Forces on charge due to $\vec{B}$ (magnetic field)



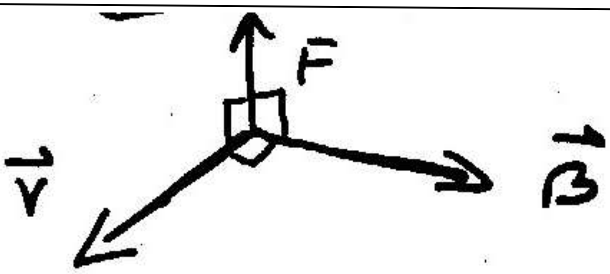
No force





$\vec{v} \perp \vec{B}$ $\exists$ F force

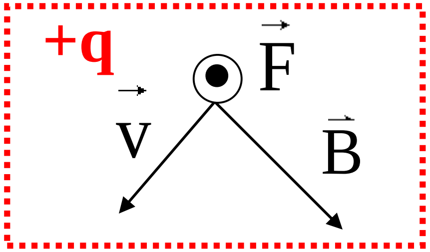
direction by **right hand rule**!

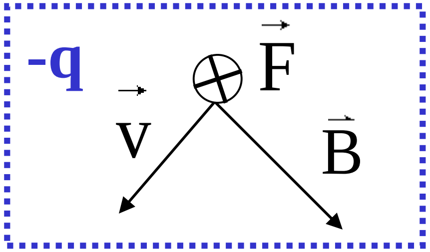


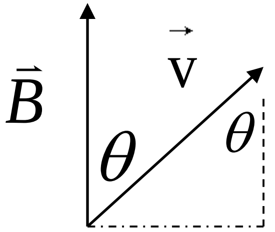
note: ⊙ =vector at you

⊗ = vector into page

+q & -q opposite







$v_{\perp} = v \sin\theta$

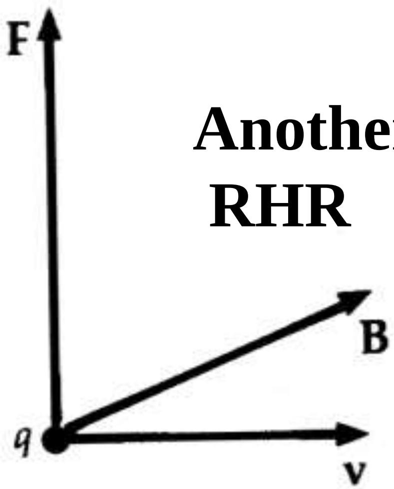
$$F = q v_{\perp} B = q v B_{\perp}$$

$$= q\, v\, B \sin\theta$$

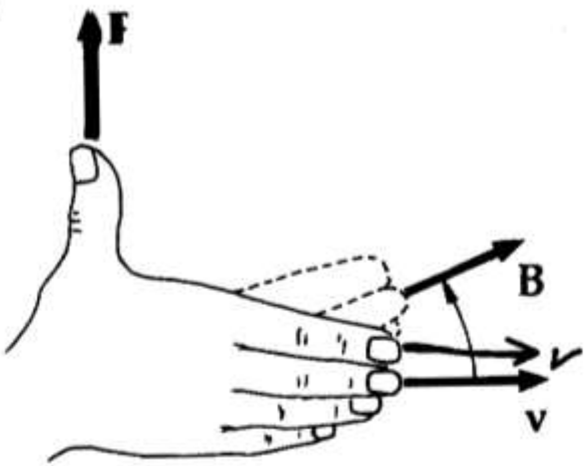
-|q| flip thumb

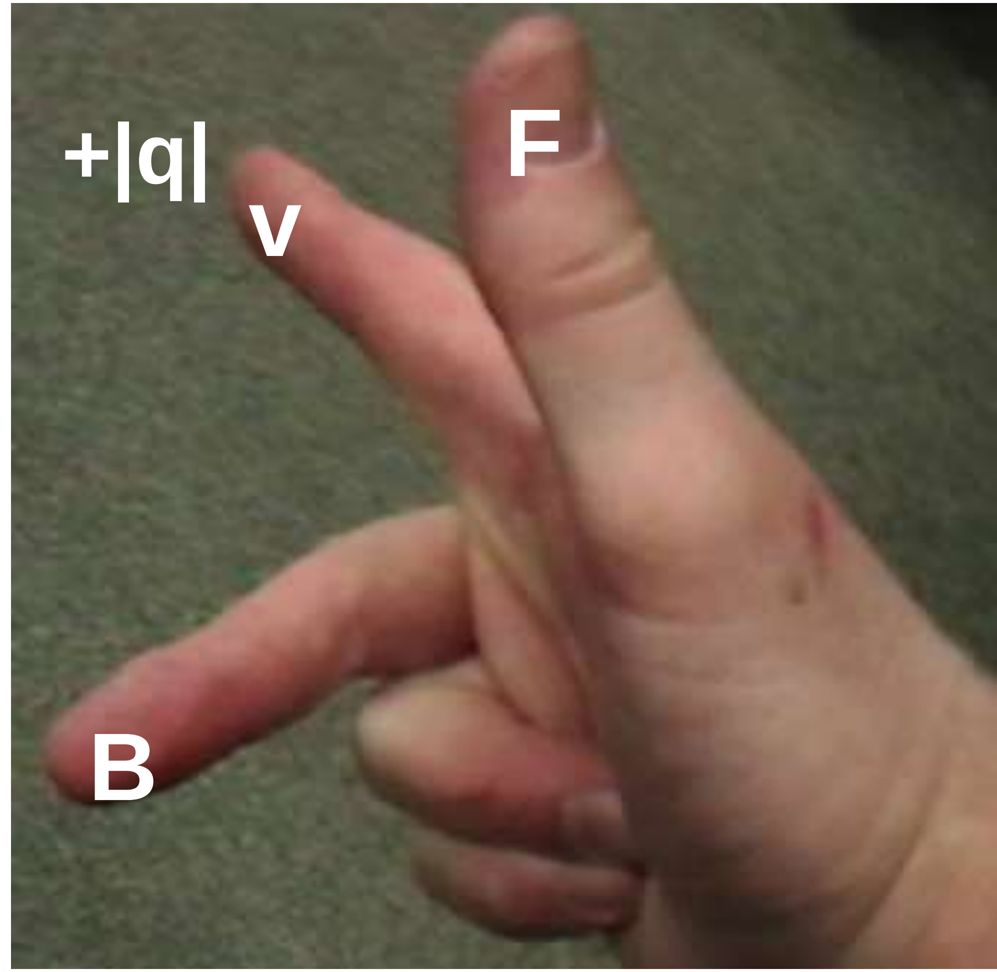
Croft preferred RHR

direction by **right hand rule**!

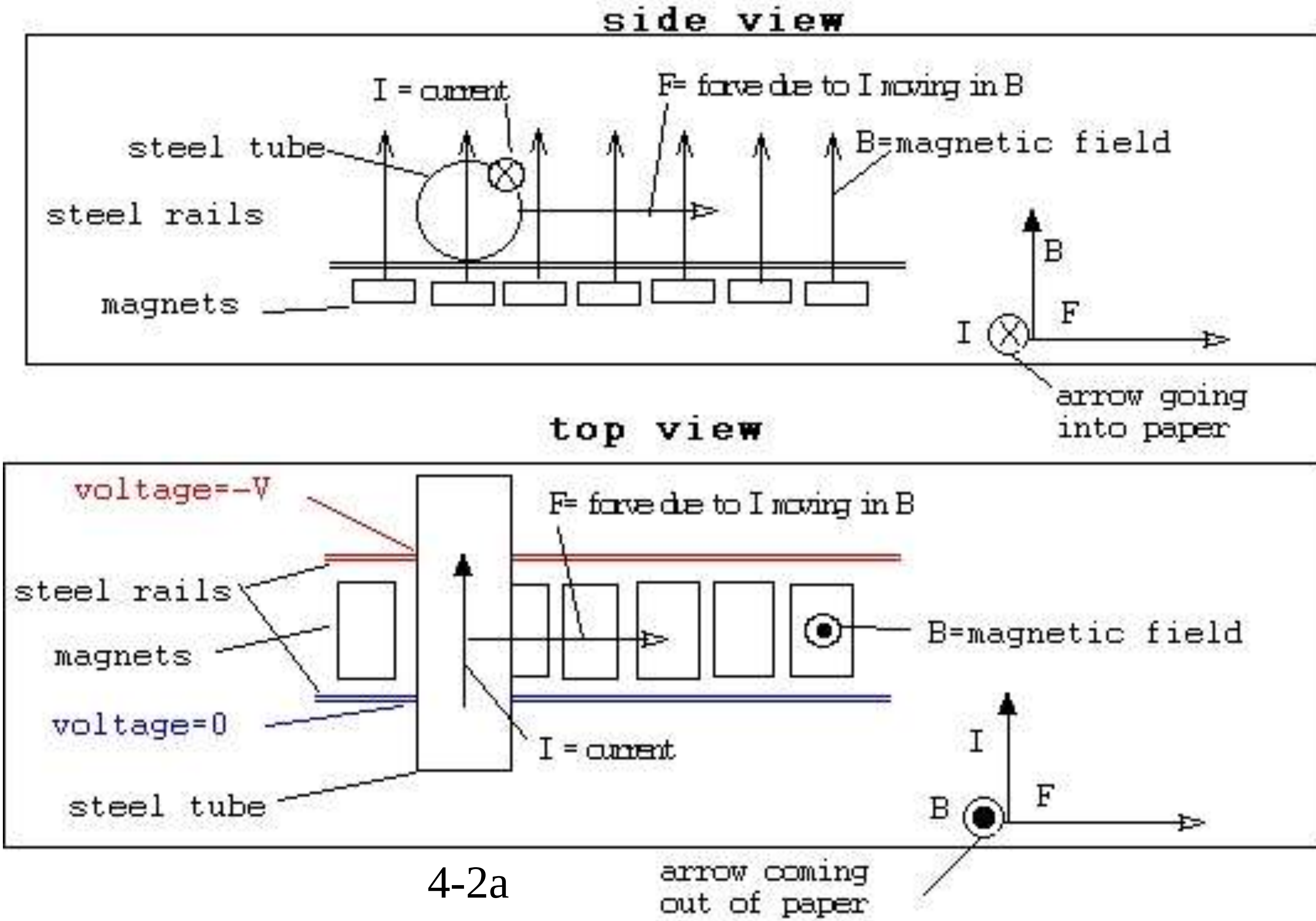


Another equivalent RHR

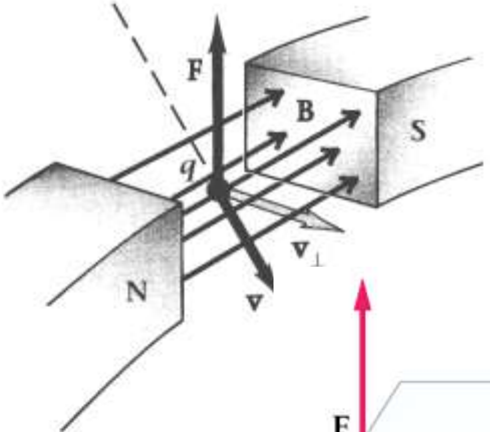




Faraday Motor

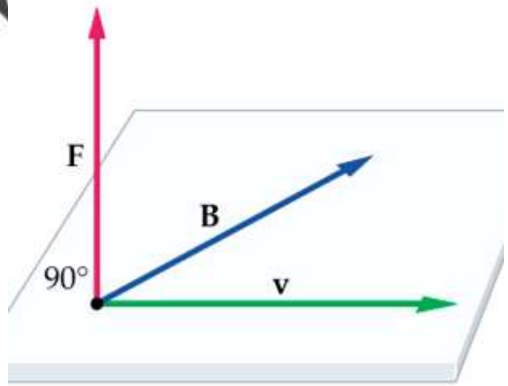


4-2a



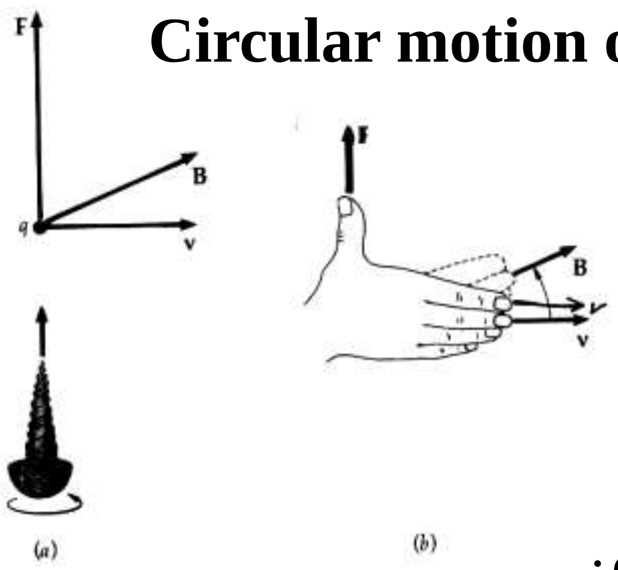
$F = q\, v_\perp B$ Units B field **tesla**

$$\therefore\ N = C\,\frac{m}{s}\,T$$



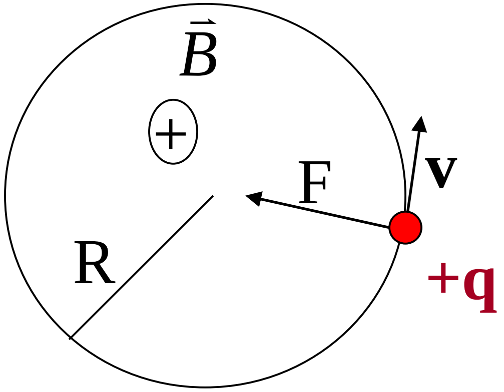
$$\Rightarrow T = \frac{NS}{mC} = kg\,\frac{m}{s^2}\,\frac{s}{mC} = \boxed{\frac{kg}{Cs} = T}$$

Circular motion of charge moving ⊥ to magnetic field



$$F = m\,a = m\,\frac{v^2}{R}$$

$$qvB = \frac{mv^2}{R} \Rightarrow R = \frac{mv}{qB}$$



uniform B field $\rightarrow$ $\vec{v} \perp$ to $\vec{B} \Rightarrow$ circular motion.

17 Circular motion of a charge in a uniform magnetic field

Recall

$$F = ma = \frac{mv^2}{R} = evB$$

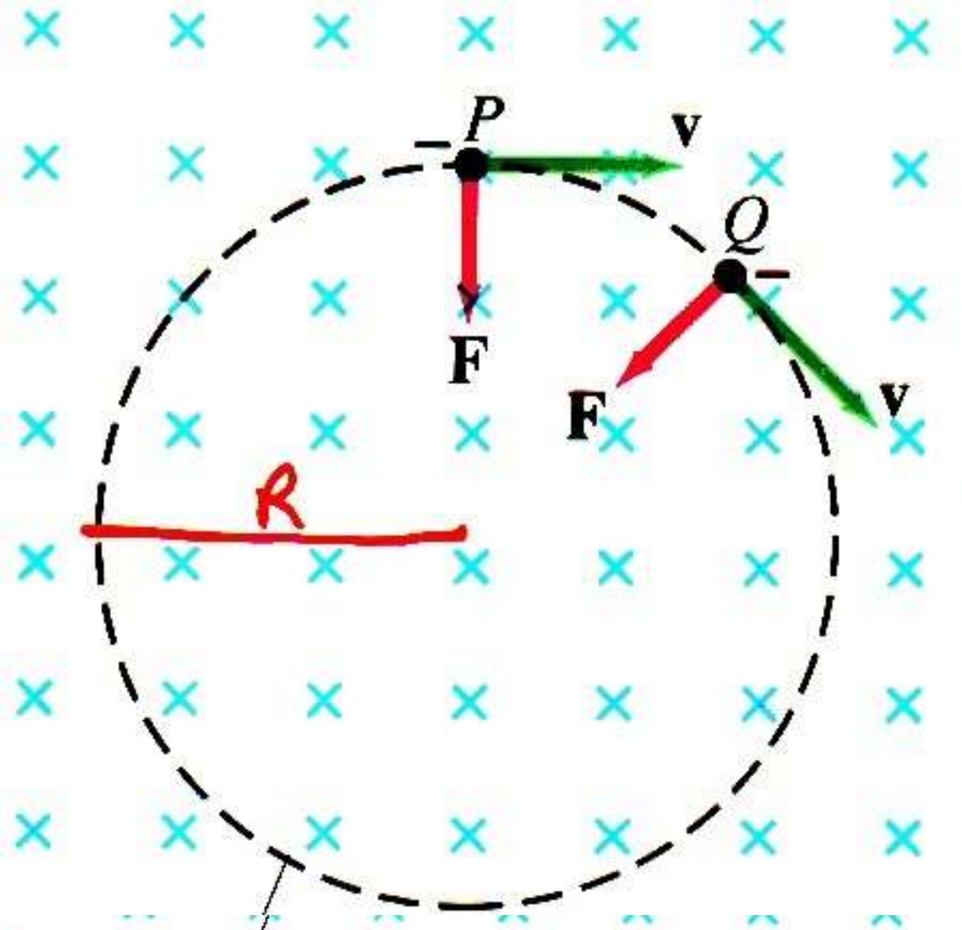
(electron → e)

$$\frac{e}{m} = \frac{v}{RB}$$

or

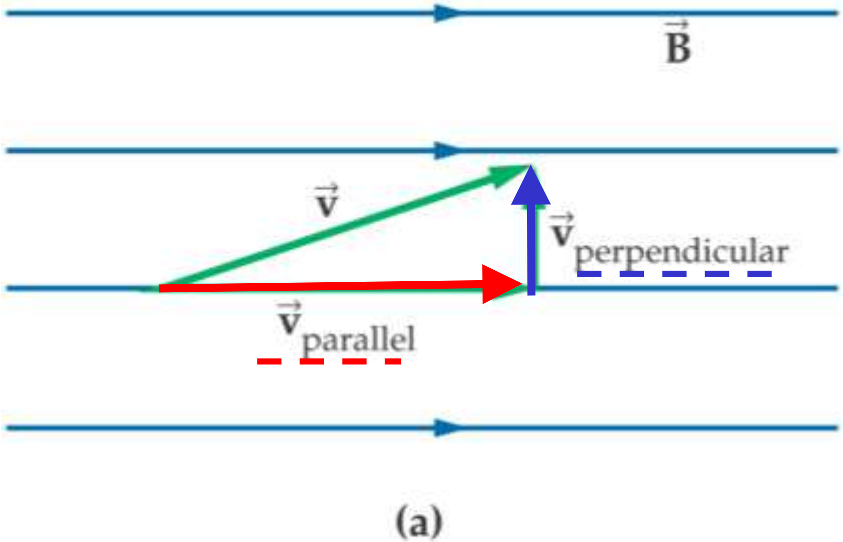
$$v = \left(\frac{e}{m}\right) RB$$

save for later



Path of electron **B** is into the page

General motion of charged particle in a magnetic field



|| direction

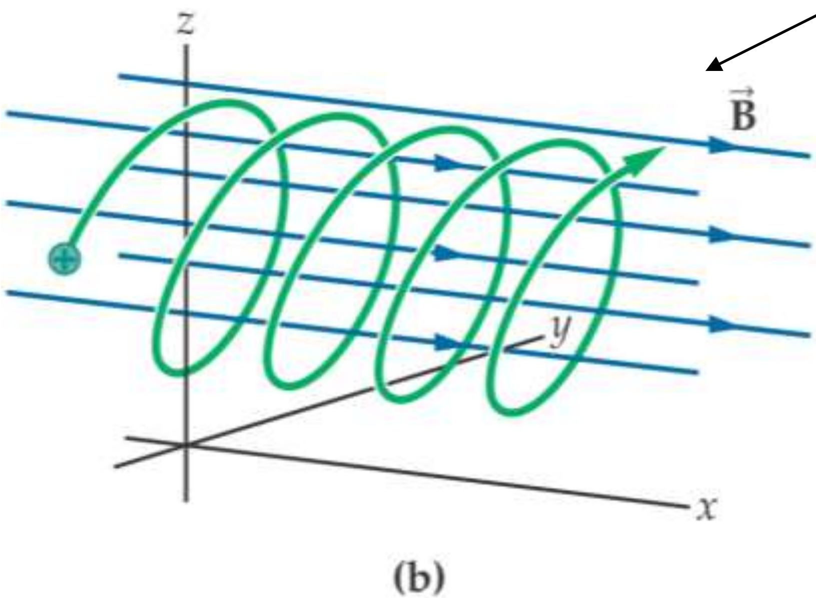
$v_{\parallel} = \text{constant}$

magnitude & direction

⊥ direction

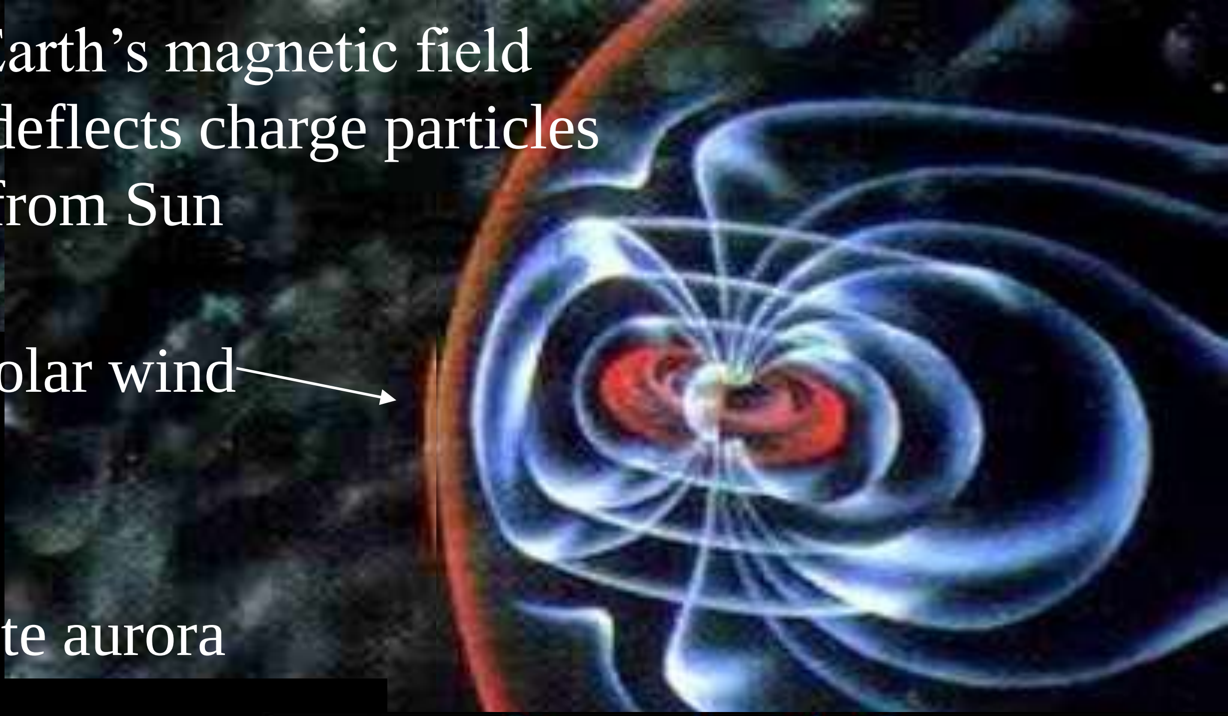
circular motion

speed = $|v_{\perp}|$



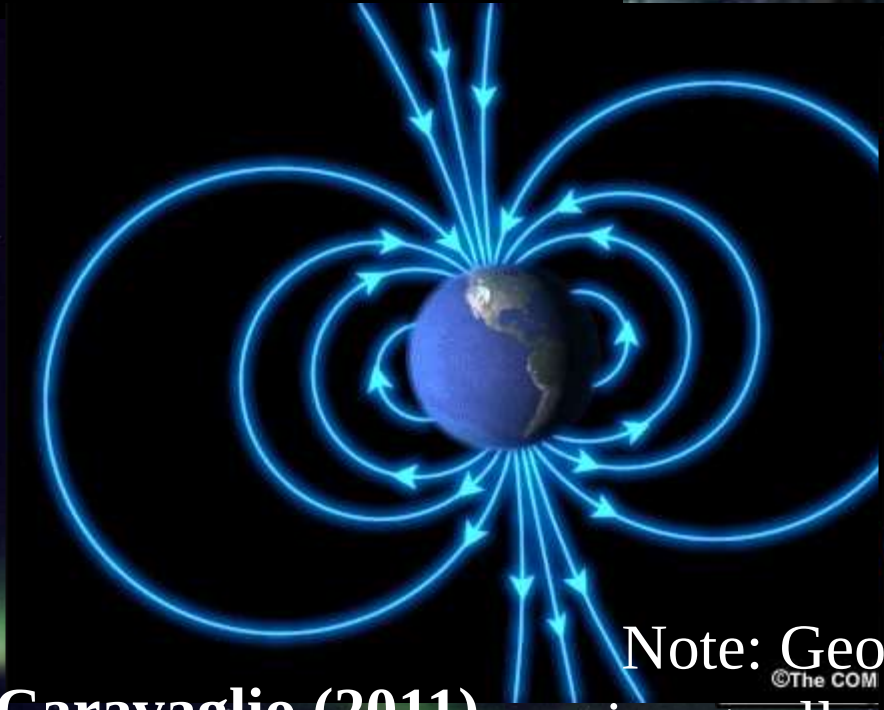
helical-motion

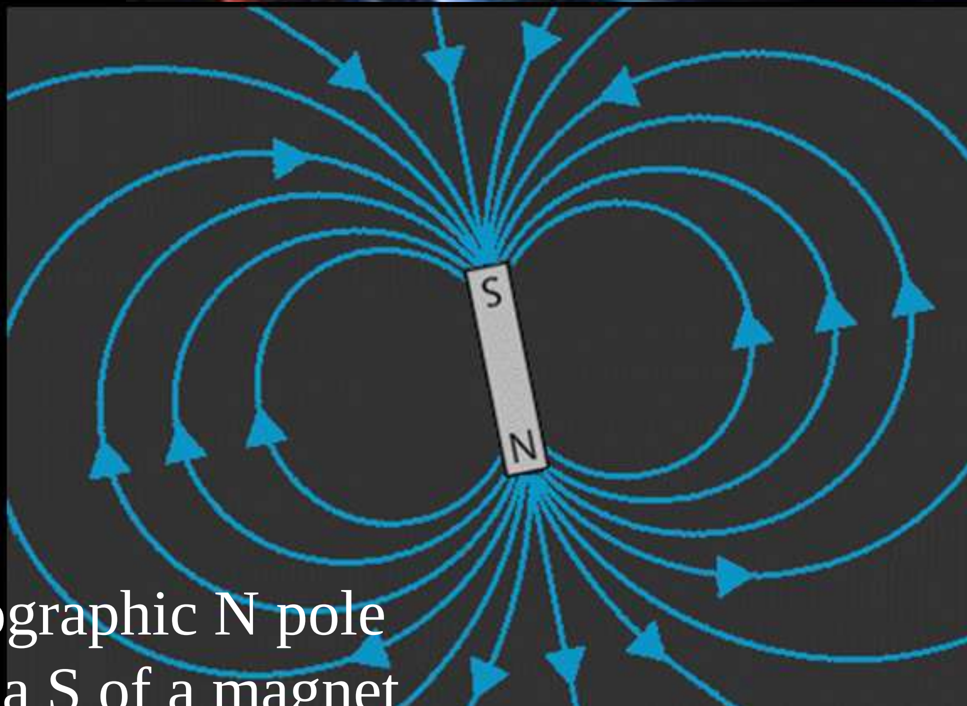
Earth’s magnetic field
deflects charge particles
from Sun



solar wind

charged particles
spiral down
magnetic field lines
near magnetic poles create aurora

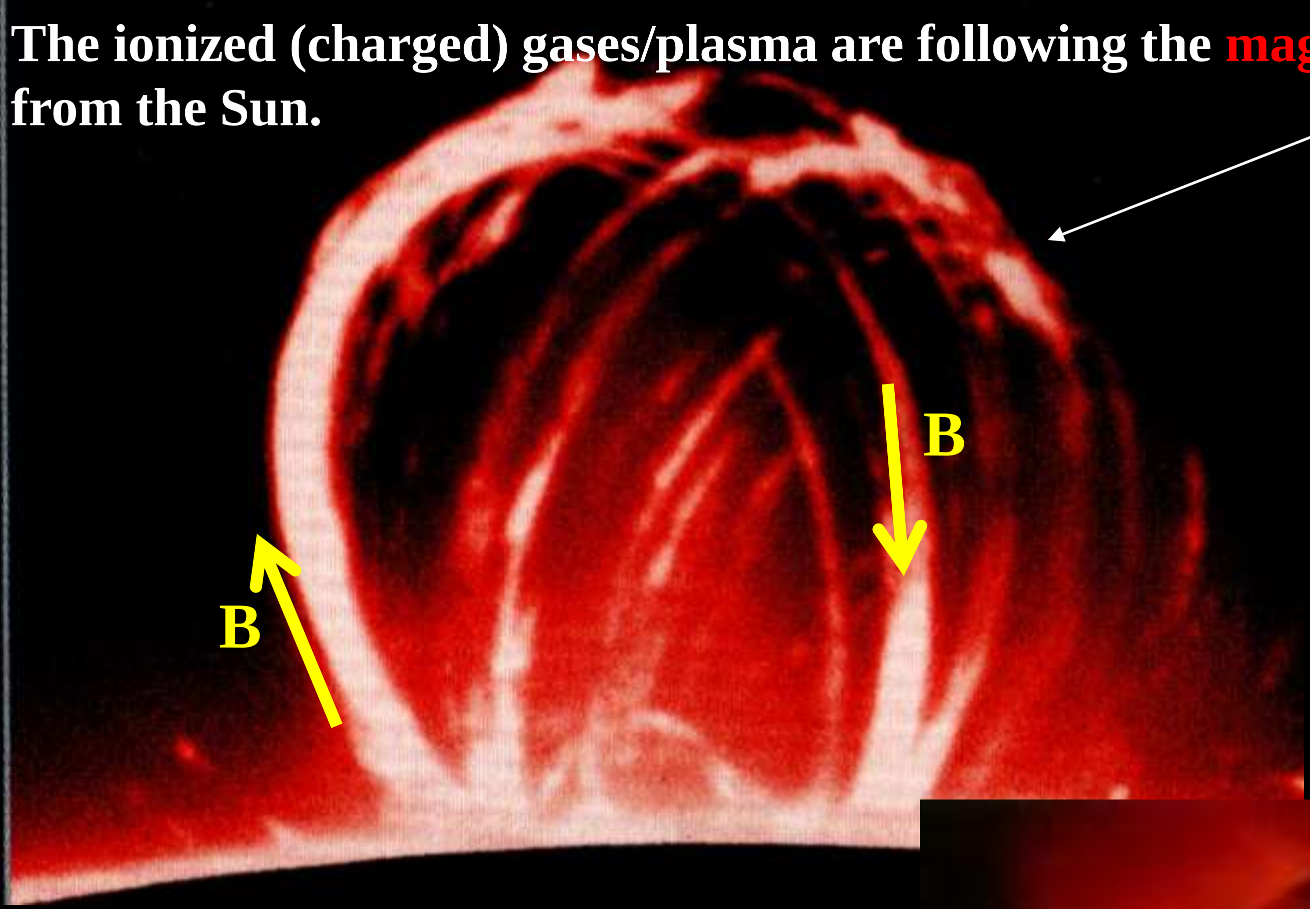




Note: Geographic N pole
is actually a S of a magnet

*** Caravaglio (2011)**

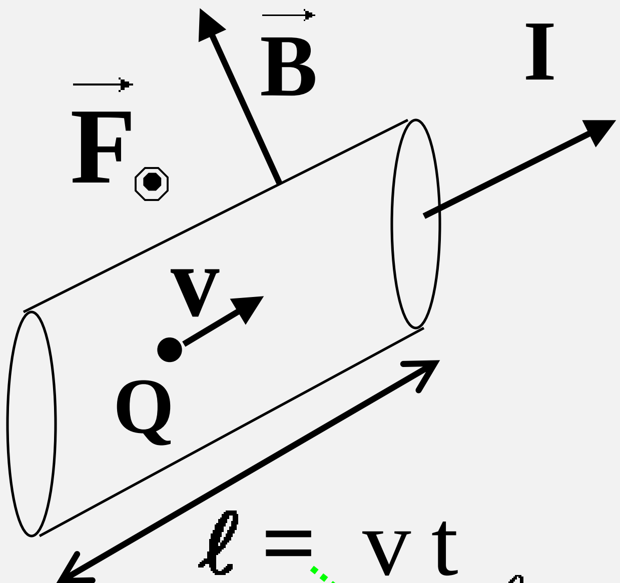
The ionized (charged) gases/plasma are following the magnetic field line protruding from the Sun.



PROMINENCES: Surging clouds of ionized gas are best visible along the limb; loop prominences can tower tens of thousands of miles high.

4-3d

Force on a straight wire with I due to B



$$\ell = v\,t$$

or $t = \dfrac{\ell}{v}$

Note: here $v \perp B \perp F$

$$F = Q\,v\,B$$

but $I = \dfrac{Q}{t}$

so $I = \dfrac{Q}{\ell / v} = \dfrac{Q\,v}{\ell}$

and so $I\,\ell = Q\,v$

$$\Rightarrow F = (Q\,v)\,B = (I\,\ell)\,B$$

$$F = (I\,\ell)\,B$$

units

$N = A\,m\,T$

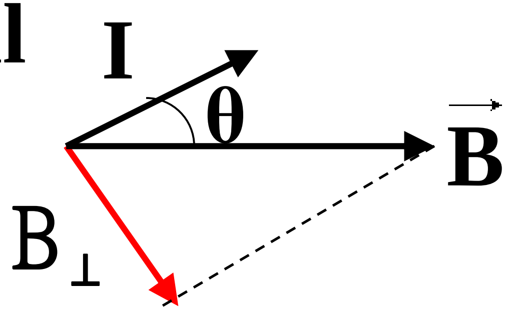
$T = \dfrac{N}{A\,m}$

$T = \dfrac{\frac{kg\,m}{s^2}}{\frac{C}{s}\,m}$

$T = \dfrac{kg}{C\,s}$

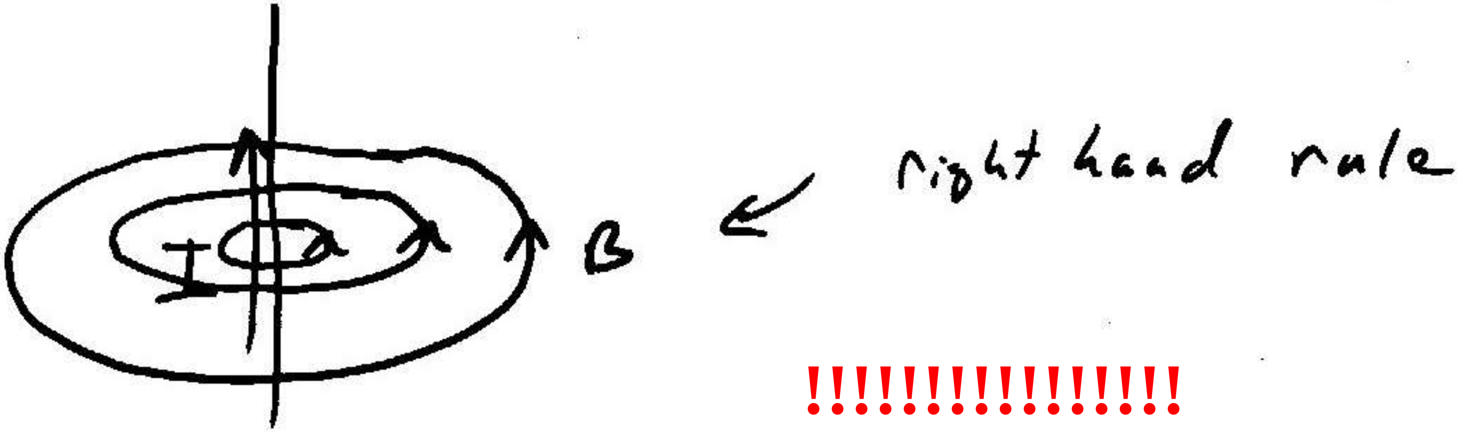
ok

In general



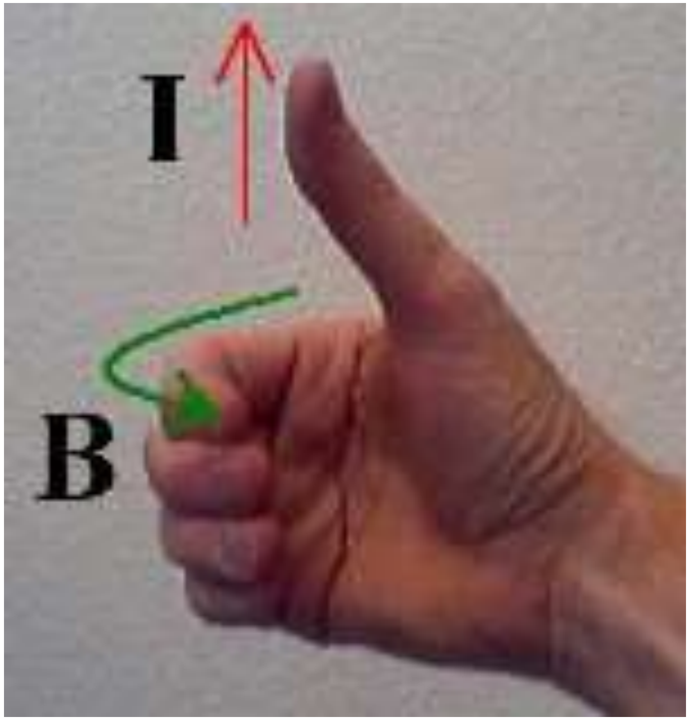
$$F = I\,\ell\,B_{\perp} = I\,\ell\,B\sin(\theta)$$

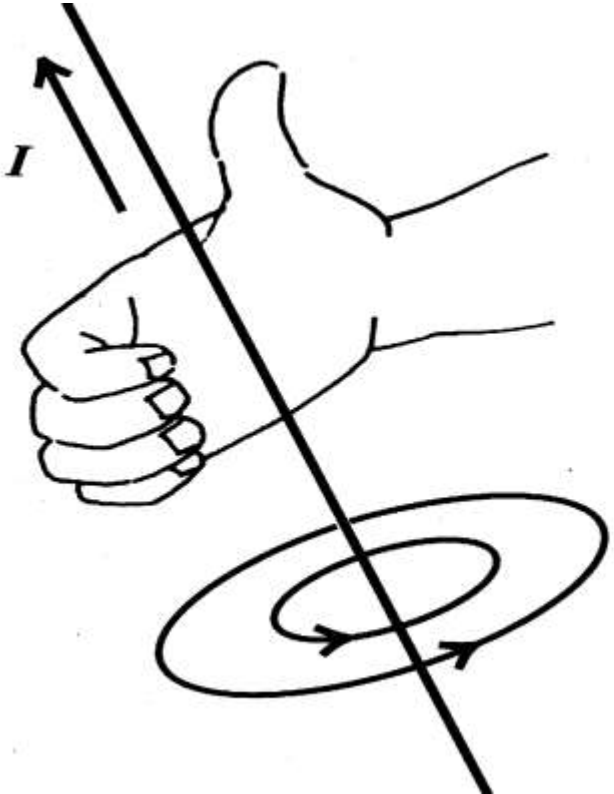
Flowing charge (current) creates magnetic field.



!!!!!!!!!!!!!!!!!

2'nd right hand rule: RHR for B direction created by current

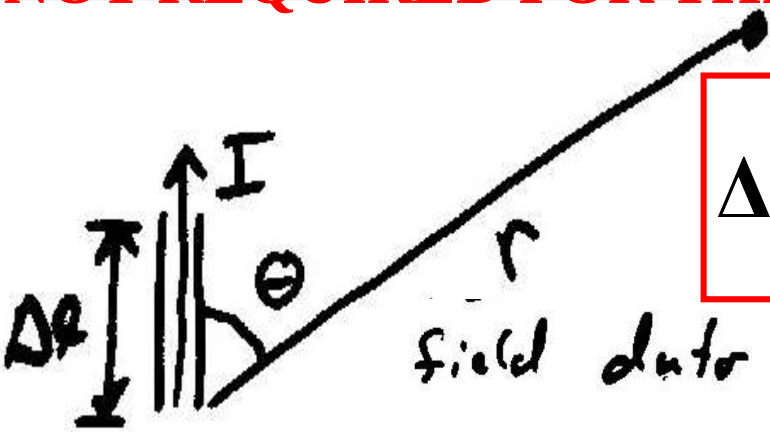




Magnitude of field (Biot & Savart Law)

{Like point charge electric field law but for current}

{**NOT REQUIRED FOR THIS COURSE : BUT GOOD TO KNOW**}



$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\,\Delta\ell}{r^2}\sin(\theta)$$

field due to I in length Δℓ

To calculate tot field add (*as vectors) up all ΔB from each $\Delta\ell$

[B&S Law- magnetic field equivalent of electric field point charge]

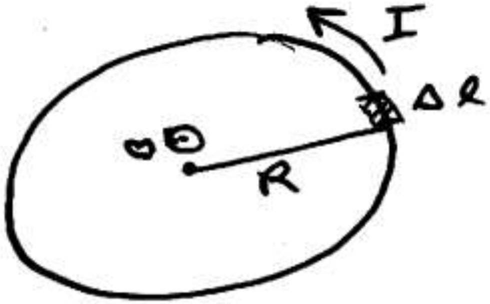
$$\Delta B = k'\frac{I\,\Delta\ell}{r^2}\sin(\theta)$$

$k' = (10)^{-7}\frac{N}{A^2}$ also $k' = \frac{\mu_0}{4\pi}$

4-6a

$\vec{B}$ field – simple example **(using Biot & Savart Law)**

circular loop – field at center



$$\Delta B = \frac{kI}{R^2}\,\Delta \ell$$

divide circle into N parts of $\Delta \ell$ each

$$\Delta \ell = \frac{2\pi R}{N} \Longrightarrow N\Delta \ell = 2\pi R$$

note every ΔB same ∴

$$B = N\,\Delta B = Nk\frac{I}{R^2}\,\Delta \ell$$

$$= \frac{kI}{R^2}(N\Delta \ell)$$

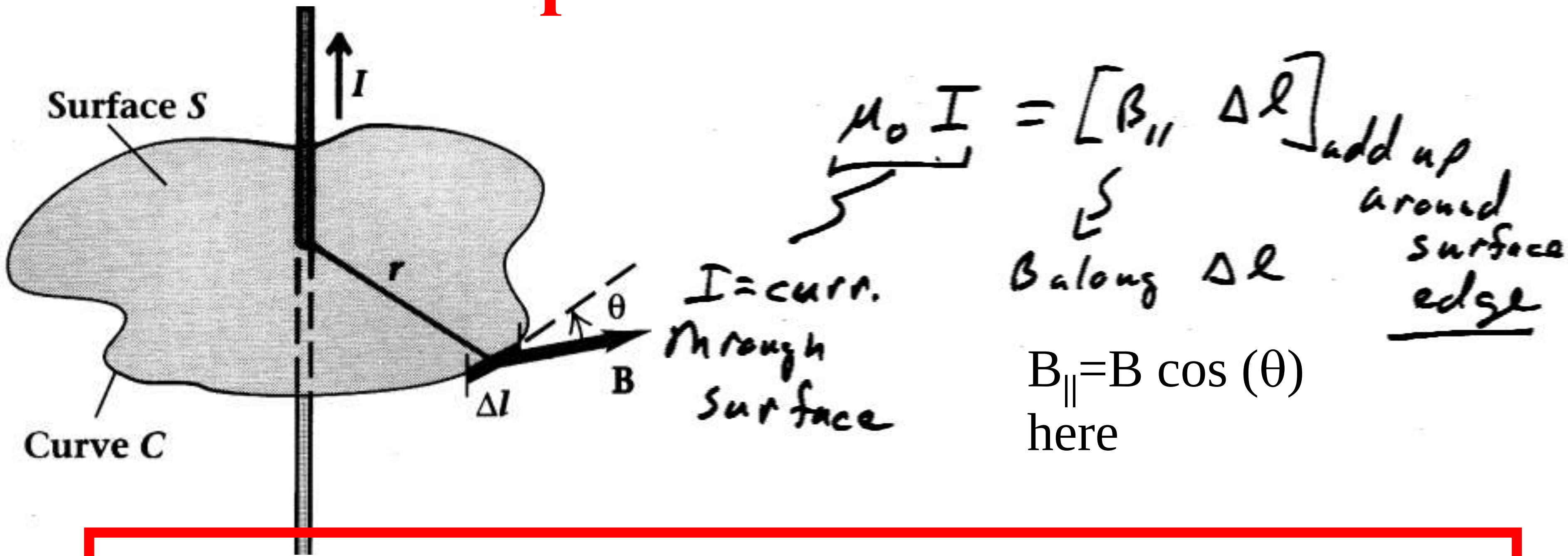
$$= \frac{kI}{R^2}\,2\pi R$$

$$B = \frac{2\pi \mu_0}{4\pi}\frac{I}{R}$$

$$\boxed{B = \frac{2\pi k I}{R}} \quad \text{or} \quad \boxed{B = \frac{\mu_0 I}{2R}}$$

{**NOT REQUIRED FOR THIS COURSE : BUT GOOD TO KNOW**}

Ampere's Law



$B_{\parallel} = B\cos(\theta)$ here

closed edge- line integral form.

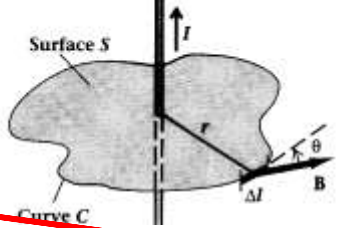
$$\mu_0\ I = \sum_{\text{edge}} B_{\parallel}\ \Delta l \qquad \mu_0\ I = \oint_{\text{edge}} B_{\parallel}\ dl$$

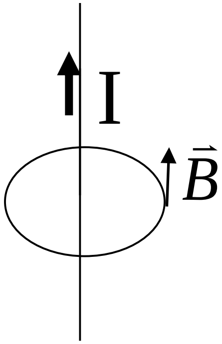
I= current through surface

B along Δl

Add up around surface edge.

recall Ampere's Law $\mu_0 I = \sum_{\text{edge}} [B_{\parallel} \Delta l]$





B field around an ∞ wire with I

$\vec{B}$ along circle & B always constant on circle.
[circumference]

$\mu_o I = B\,[2\pi R]$

From Ampere's Law $k' = \frac{\mu_0}{4\pi}$

$\Rightarrow$ $B = \frac{\mu_o\ I}{2\pi R}$ ← For a wire **or** $B = \frac{2k'I}{R}$

example

Suppose I = 1A : R = 1m : B=?

$$B = \frac{[4\pi(10)^{-7}\frac{N}{A^2}]\ 1A}{2\pi\quad 1m}$$

$$= 2(10)^{-7}\frac{NA}{A^2 m} \qquad B = 2(10)^{-7}\frac{N}{A\ m}$$

$B = 2(10)^{-7}$ T very small!

Units check

Recall: F=qVB F=IℓB

$B = \frac{F}{I\ell} \Rightarrow T = \frac{N}{Am}$

– Two long magnetic wires carry currents of 2.0 A and 6.0 A. The wires are 1.0 m apart and the currents flow in opposite directions. Determine the magnetic field strength and its direction at a point (P) 2.0 m away from the right long straight wire.

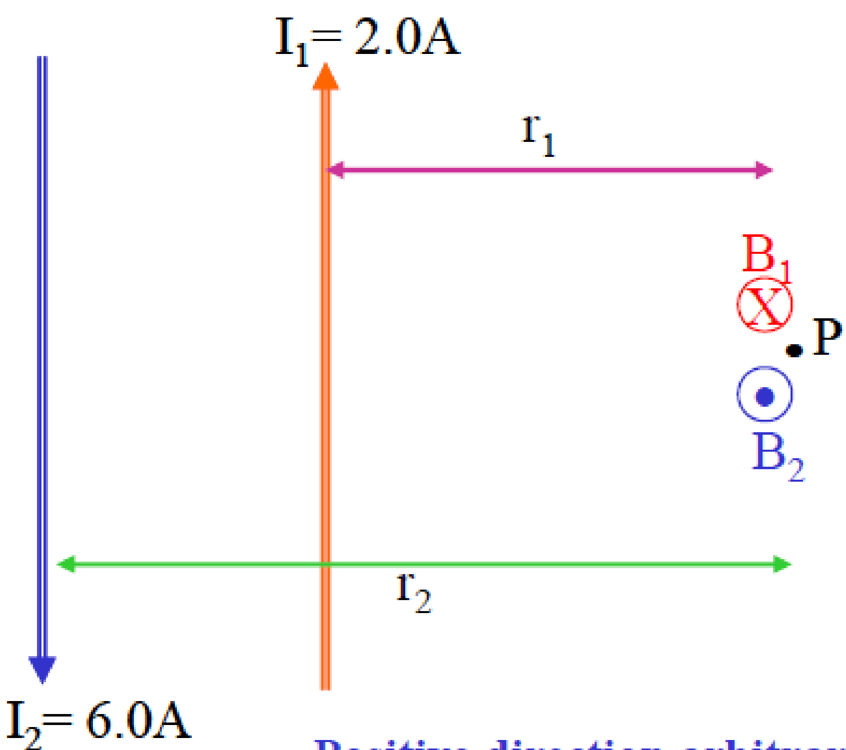
$$\mathbf{B}_1 = \frac{\mu_0 \mathbf{I}_1}{2\pi \mathbf{r}_1} = 2.0\ (10^{-7})\ \mathbf{T}$$

$$\mathbf{B}_2 = \frac{\mu_0 \mathbf{I}_2}{2\pi \mathbf{r}_2} = 4.0\ (10^{-7})\ \mathbf{T}$$

$$\vec{\mathbf{B}} = \vec{\mathbf{B}}_1 + \vec{\mathbf{B}}_2$$

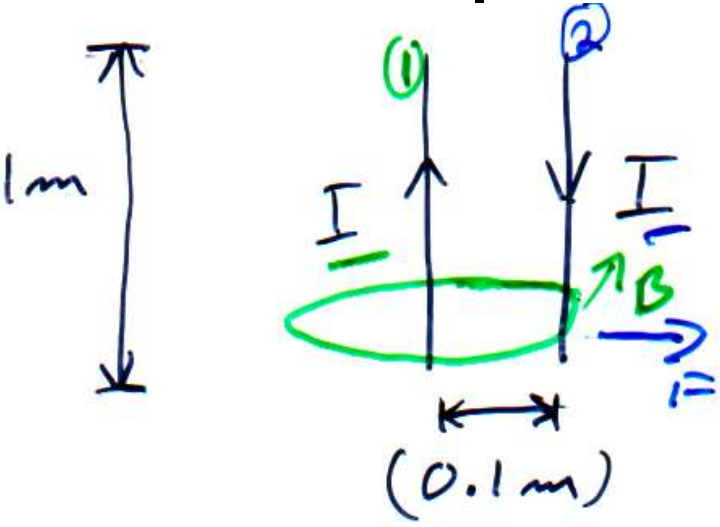
Out of the page

$$\mathbf{B} = +\mathbf{B}_1 - \mathbf{B}_2 = -2.0\ (10^{-7})\ \mathbf{T}$$



Positive direction arbitrary chosen to be into the page(+)

Force between 2 parallel wires L=1 m, at 0.1m, I = ±50 A



B due to 1

$$B = \frac{k 2 I}{R}$$

$$F_{on\,2} = l I B = l I \frac{2kI}{R}$$

$$F = \frac{l}{R} I^2 2k$$

$$F = \frac{1\,m}{(0.1\,m)} (50)^2 A^2 \, 2 \, 10^{-7} \frac{N}{A^2}$$

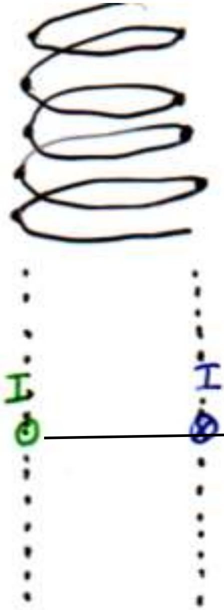
$$= (10) \cdot 2500 \cdot 2 (10)^{-7} \; N$$

$$= 50{,}000 (10)^{-7} \; N$$

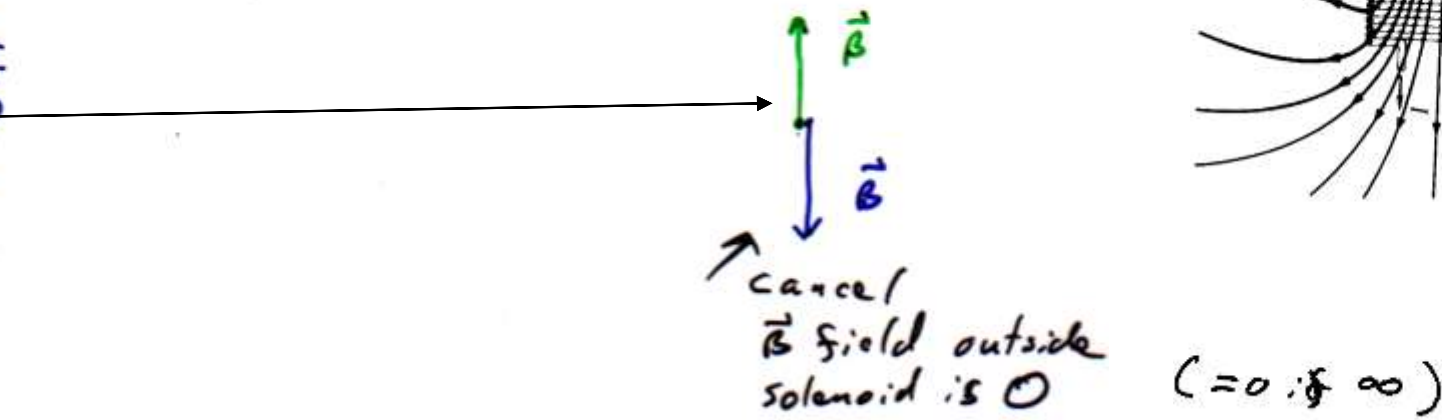
$$F = .005\,N$$

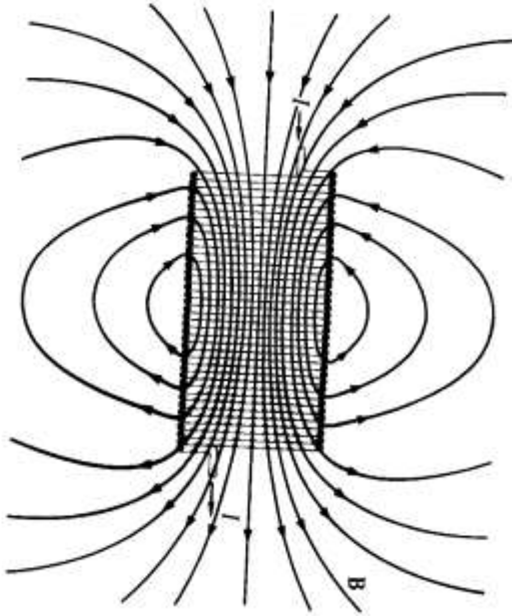
.01 m ⇒ .05 N
.001 m ⇒ .5 N

Magnetic field of long solenoid



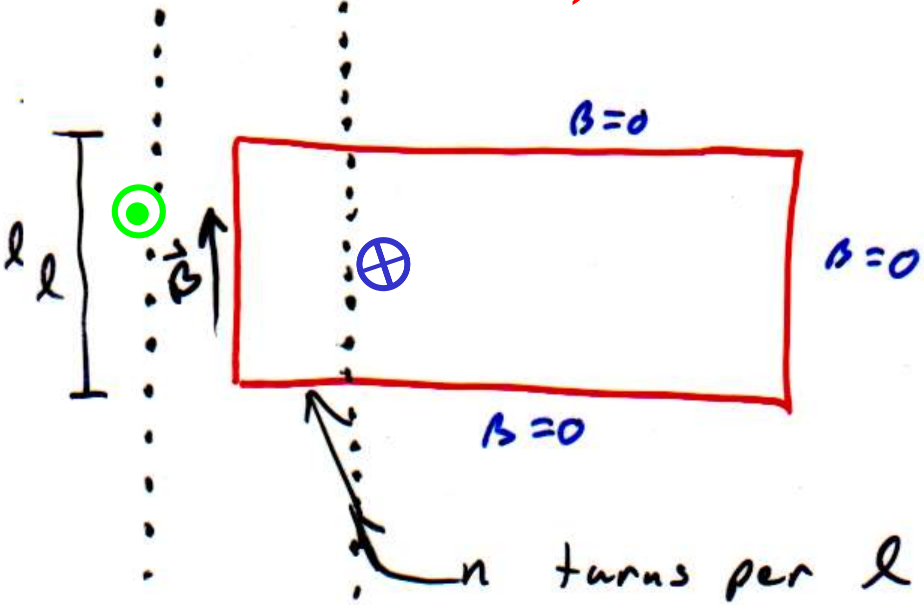
1.) B field outside goes to 0

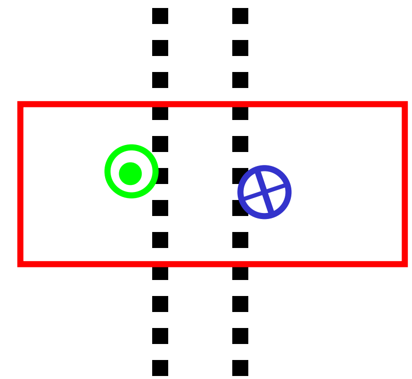




Magnetic field of long solenoid

2.) B field inside





$0 = +I\,n\,L - I\,n\,L$

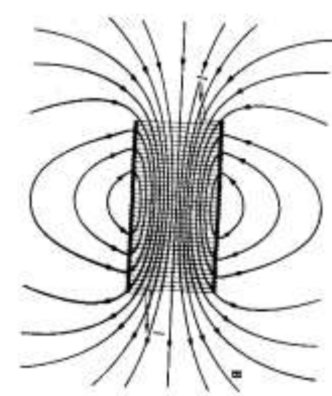
$B_{out} = 0$

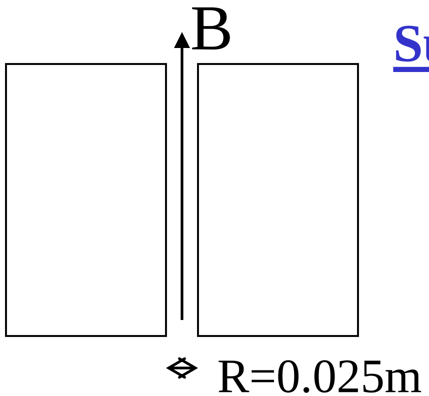
$I \cdot n\ell$ = tot curr through surface

B around loop

$$B \cdot \ell + 0 = I n \ell \mu_0$$

$$\therefore \boxed{B = I n \mu_0} \quad \infty \text{ solenoid}$$





Superconducting solenoid

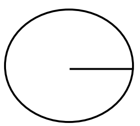
Q: What is outward force on inside of such a solenoid?

$$B = I\, n\, \mu_0$$

$$= 100\text{A}\ [100{,}000\ \frac{\text{turns}}{\text{m}}]\ [\,4\pi(10)^{-7}]\frac{\text{N}}{\text{A}^2}$$

$$=(10)^2\ 10^5\ 4\pi\ (10)^{-7}\ \frac{\text{NA}}{\text{mA}^2} = 4\ [3.14]\ \ \text{T}$$

B = 12T



l= 2 π R= 2 π 0.025m

$$F = I\, l\, B = (100\text{A})\ (.025\text{m}\ \ 2\pi)\ 12\text{T}$$

$$= (100)\ (.025)\ (6.28) 12\ \frac{\text{ANm}}{\text{Am}}$$

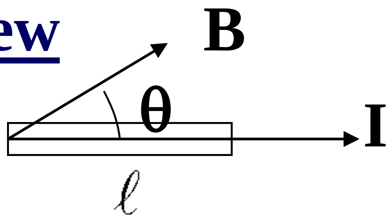
$$=(2.5)(6.28)\ 12\text{N}$$

$$=150\text{N}$$

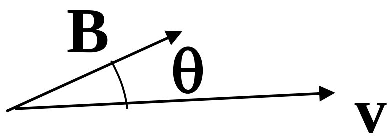
~33.7 lbs.

Magnetic Field Review

$F = qv_{\perp}B$ or $F = qvB\sin\theta$



Right Hand Rule



$F = I\ell B_{\perp}$ or $F = I\ell B\sin\theta$

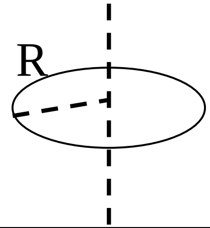
$$\Delta B = k'\frac{I\Delta l}{r^2}\sin\theta$$

Not required:

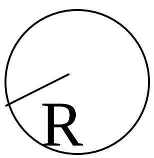
$$k' = \frac{\mu_0}{4\pi}$$

Long wire:

$$B = k'\frac{2I}{R} \quad \text{or} \quad B = \frac{\mu_0 I}{2\pi R}$$

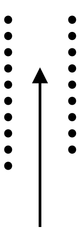


Center of Loop (circular):



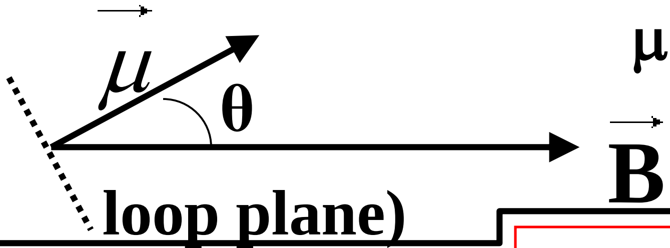
$$B_{center} = \frac{2\pi k' I}{R} = \frac{\mu_0 I}{2R}$$

Solenoid:



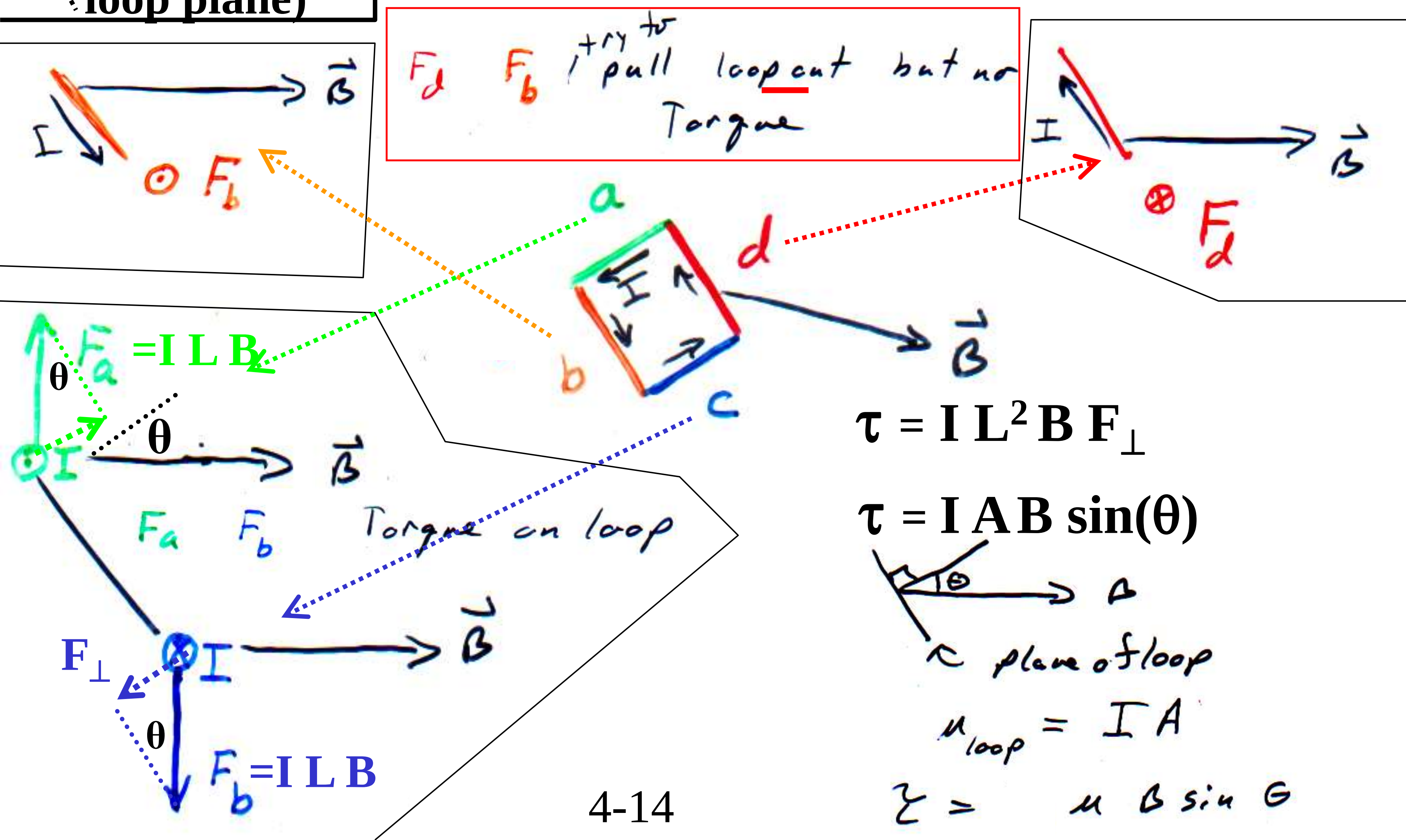
$$B = \mu_0 nI = 4\pi k' nI$$

Torque, τ, on current loop (assume square) in B field



$\vec{\mu}$ = magnetic moment (like electric dipole)

$$\tau = \mu\, B \sin(\theta)$$



$$\tau = I\, L^2\, B\, F_\perp$$

$$\tau = I\, A\, B \sin(\theta)$$