Phys 1402 2017-07-18 Lec 9

How do we create a nice uniform magnetic field?

- Permanent Magnets - compact, no energy needed
  - But, field strongest near magnet.

- Electromagnets - require electricity.

  - Straight Wire $B = \dfrac{\mu_0 I}{2\pi r}$

    r = our dist. from wire

Ex: $I = 2.0$ A

$r = 2$ cm

$\mu_0 = 4\pi \times 10^{-7}$ T·m/A

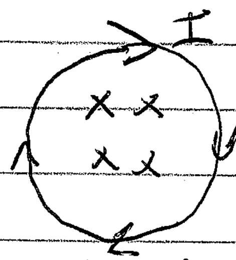
$$B = \frac{(4\pi \times 10^{-7})(2.0)}{2\pi(0.02)} = 2E{-5} = 2\times10^{-5}\ \text{T}$$

$$= 20\ \mu\text{T}$$

$$= 0.02\ \text{mT}$$

(0.02) ← was in cm

- Loop or Coil



B = "into page" in the loop

N = # loops

R = rad of loop

$$B = \frac{\mu_0 N I}{2R}$$

Still not uniform.

Strongest @ center.

Ex: $I = 2$A

$R = 2$ cm

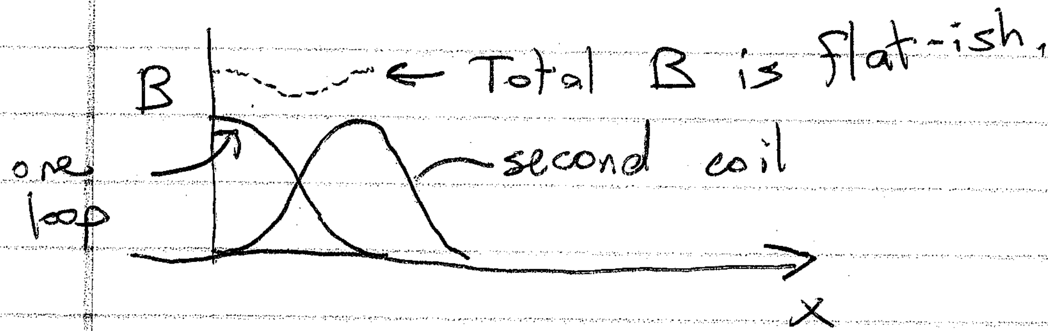
$N = 100$

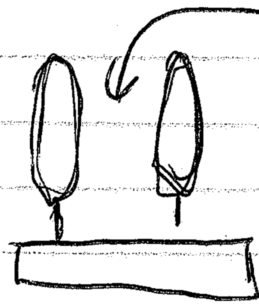
$$B = \frac{\mu_0(100)(2.0)}{2(0.02)} = 0.006\ \text{T}$$

$$= 6\ \text{mT}$$

(2)

- Helmholtz Coils



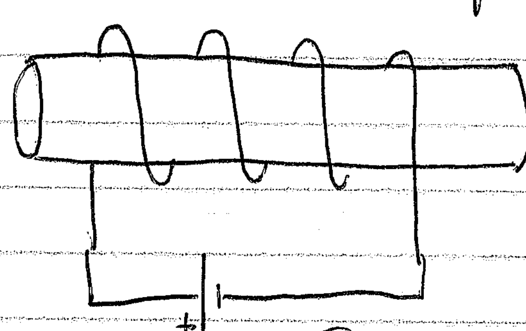


Big empty area.

Fairly uniform $\vec{B}$

Access from all sides.

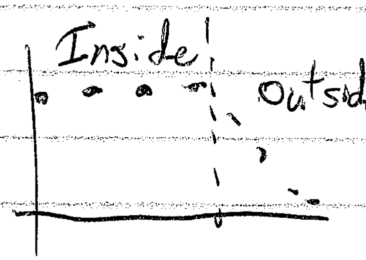
- Solenoid Coil



$$B = \frac{\mu_0 N I}{l}$$

l = length of coil

- ~~Fairly B~~
- Very uniform inside.
- Hollow
- Access from ends.
- Can have <u>many</u> loops.



Ex: $I = 2.0$ A

$l = 0.1$ cm $\quad B = 0.025\ T = 25$ mT

$N = 1000$

(3)

Magnetic Effects

- Force on moving Charge

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

↑ vector cross product

Magnitude: $F_B = q v_\perp B$

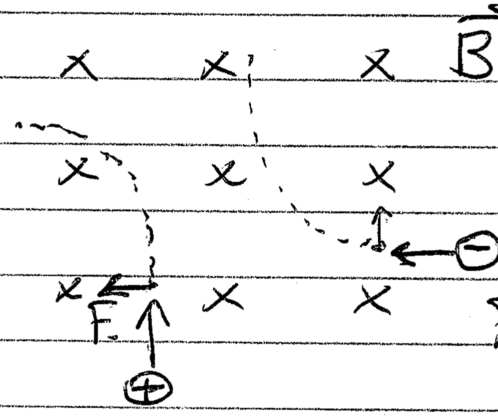
↑ perpendicular component

Direction: Right-hand-rule

- Index Finger - <u>extended</u> to match $\vec{v}$
- Middle Finger - <u>bent inward</u> to match $\vec{B}$
- Thumb - <u>extended</u> to match $\vec{F}$ on ⊕

(If q is ⊖, Force is <u>opposite</u> to thumb.)

Ex: $\vec{B}$ = into page



For this ⊖ ...

For this ⊕: $v = +\hat{y} = $ Up

$B = -\hat{z} = $ In

$\vec{F} = -\hat{x} = $ Left

$\vec{F}_B$ provides <u>centripetal force</u>.

Summary: If B points away from us

⊕ makes "Left Turns" ⇒ CCW circles

④

Force on Current

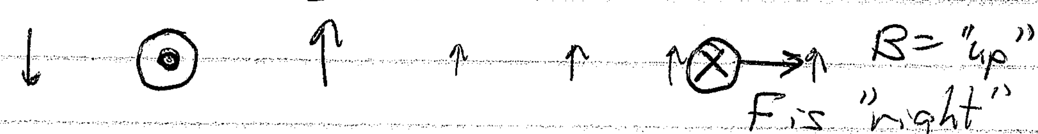
(This actually defines the ampere)

Direction: same RHR

Magnitude: $F_B = I \ell B$

Ex: Two nearby currents

$\vec{B}$ as if I_2 doesn't exist.



$I_1 = 2.0A$
out of page
"Source"

$I_2 = 3.0A$ into page
"Target"

$r = 5$ cm center-to-center.

- I_1 causes $B = CCW$
- At location of I_2: $B = \frac{\mu_0 I_1}{2\pi r} = 8 \times 10^{-6}$ T

Dir of $\vec{B}$ =

- Force on I_2: Is $I_2 \perp \vec{B}$? Yes

$$F_B = I_2 \ell B = \ell(3.0A)(8\times10^{-6}T)$$

$$\frac{F}{\ell} = 24\times10^{-6} \text{ N/m}$$

Dir of Force: $I = -\hat{z}$ $\quad F_B = +\hat{x}$

$B = +\hat{y}$

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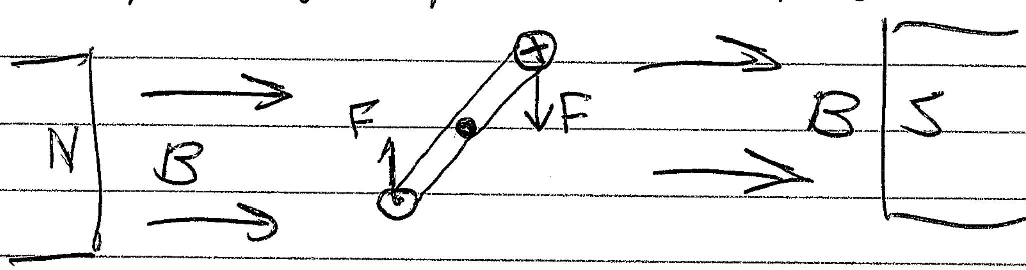
Torque on a coil

- Similar to a compass turning to match $\vec{B}$

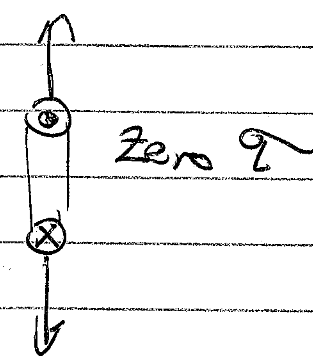
Top View, Coil pivot is into page



Force on ⊗: I = "in"
B = "right"
F_B = "Bot of page"

Force on ⊙: I = "out"
B = "right"
F_B = "Top of page"

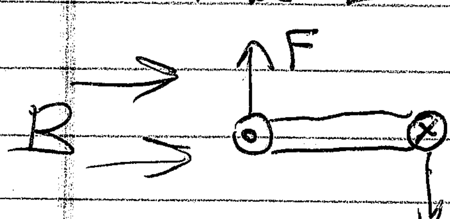
Net result: coil Twisted until:



Twisting Force is a torque:

Area of loop

$$\text{Max } \tau = NBAI$$



Max τ

In a Mass Spec, how do we create a beam with a known speed?

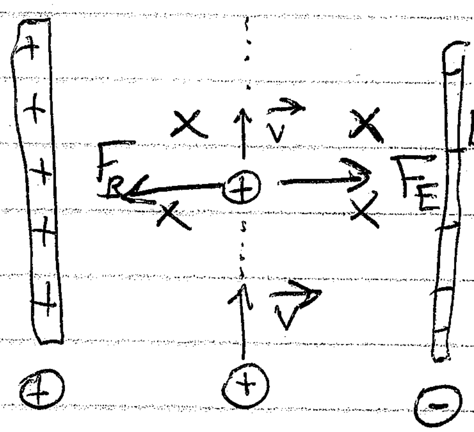
- Accelerating Voltage

$$\text{Energy} = q\,\underbrace{\Delta V}_{\text{voltage}} = \frac{1}{2} m \underbrace{v}_{\text{speed}}^2$$

But, in a mass spec, m's aren't all the same.

- Thermal Energy - Heat it until it evaporates.
  But, lots of different v's.

Then - Velocity Selector



B = ~~Right~~ into page

F_B = "Left"

Cancel with F_E = "right"

So make $\vec{E}$ = "right"

$$\cancel{q}E = \cancel{q}vB \Rightarrow v = \frac{E}{B}$$

Ex: $v = 2\times10^{6}$ m/s

$B = ~~A~~\ 3$ mT

$$E = (2\times10^{6})(3\times10^{-3}) = 6\times10^{3}\ \text{V/m}$$

Actual Mass Spectrometer

$$F_B = qvB = ma = \frac{mv^2}{r}$$

$$rqB = mV$$

$$r = \frac{mv}{qB}$$

- Each has same $q = +1.6 \times 10^{-19}\,C$
  - same B (given)
  - same v (vel. selector)

Conclusion: Bigger $m \rightarrow$ Bigger r