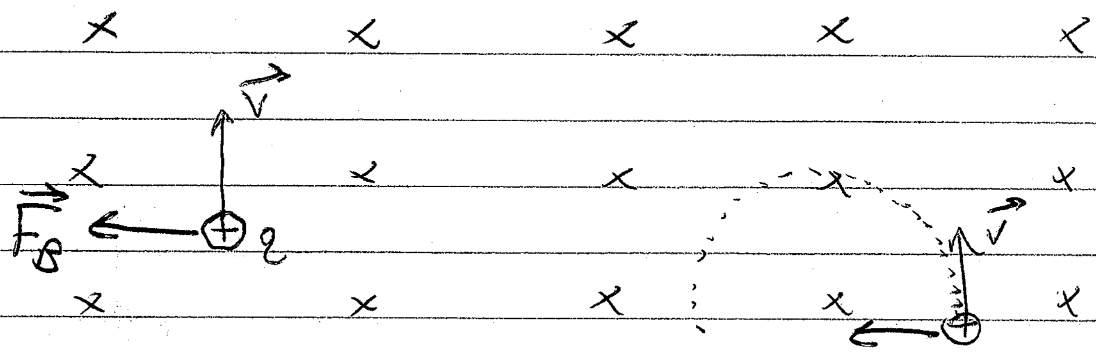
① Phys 2426 2017-10-10 Lec 11

Magnetic Forces and Torques

$\hat{B} = (\text{in})$



Snapshot View Trajectory

Magnetic Force: $\vec{F_B} = q\vec{v} \otimes \vec{B}$

Index = up Middle = Into Page thumb = Left

For positive q, F_B = Thumb.

Since $\vec{F_B} \perp \vec{v} \longrightarrow$ Uniform circular motion

$$F_{net} = ma$$

$$qv_{\perp}B = mv^2/R$$

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

What if $\vec{v}$ isn't perpendicular to $\vec{B}$?

$$\vec{v} = \vec{v_{\parallel}} + \vec{v_{\perp}}$$

Forward progress ↗ $v_{\parallel}$ $v_{\perp}$ ← circular motion

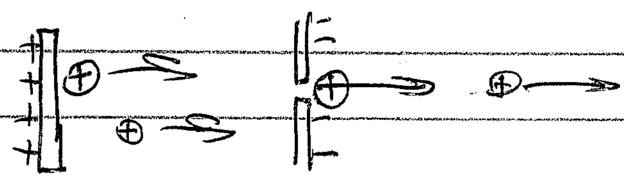
2 $\vec{F}_B = q\,\vec{v} \otimes \vec{B}$

$$|F_B| = |q|\,v\,B\,|\sin\Theta|$$

Θ ↳ Angle between $\vec{v}$ and $\vec{B}$

How do we generate particles with a given $\vec{v}$?

Method 1: Particle Accelerator - i.e. voltage



Ex: Proton beam @ 200 V

$$\underset{\text{Voltage}}{q\,\Delta V} = \text{Energy} = \frac{1}{2} m \underset{\text{velocity}}{v^2}$$

$$v = \sqrt{\frac{2q\,\Delta V}{m}} = \sqrt{\frac{2(1.6\times10^{-19}\,C)(200\,J/C)}{(1.67\times10^{-27}\,kg)}}$$

$$= 2\times10^{5}\ m/s$$

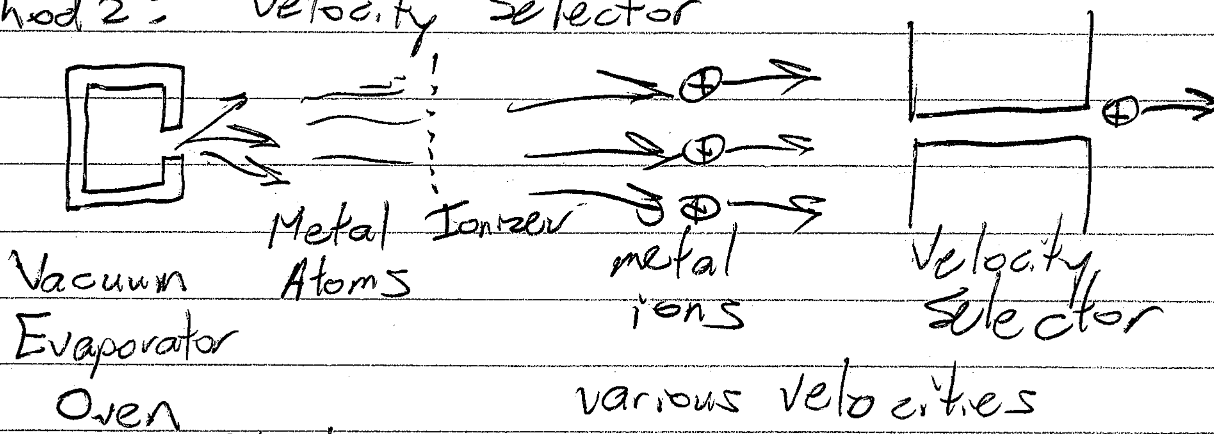
How strong is B to make $r = 5$ cm?

$$r = \frac{mv}{qB} \rightarrow B = \frac{mv}{qr} = \frac{(1.67\times10^{-27})(2\times10^{5})}{(1.6\times10^{-19})(0.05)}$$

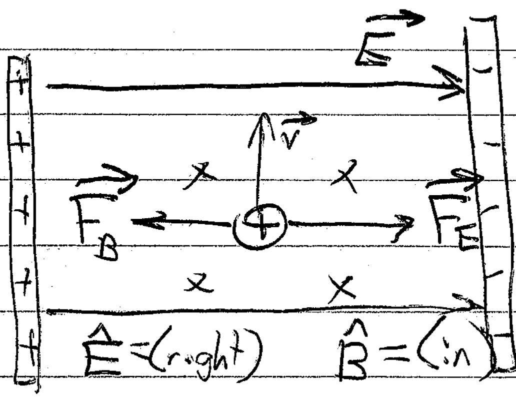
$$B = 0.042\ T = 42\ mT$$

③

Method 2: Velocity Selector



Velocity Selector



- Want $F_{net} = 0$
- $\vec{F}_B = -\vec{F}_E$
- $\vec{E}$ points $\perp$ $\vec{B}$

Magnitudes:

$$|F_B| = |F_E|$$

$$\cancel{q}vB = \cancel{q}E$$

$$v = E/B$$

- What if $v =$ too slow? F_E wins, bends right.
- What if $v =$ too fast? F_B wins, bends left.

- What if $q = \ominus$? Both forces reverse. $F_{net} = 0$ for same velocity.

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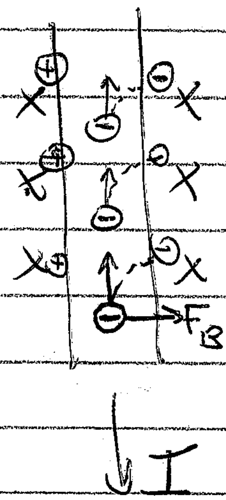
Hall Effect: A wire in a magnetic field becomes its own velocity selector.



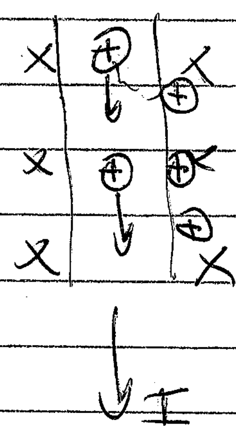
External $\vec{B} = (\text{in})$

The moving electrons generate their own E in the wire.

$\vec{E} = \vec{J} \otimes \vec{B}$

So the Left side gets a ⊕ voltage.

If the current was from ⊕ charges



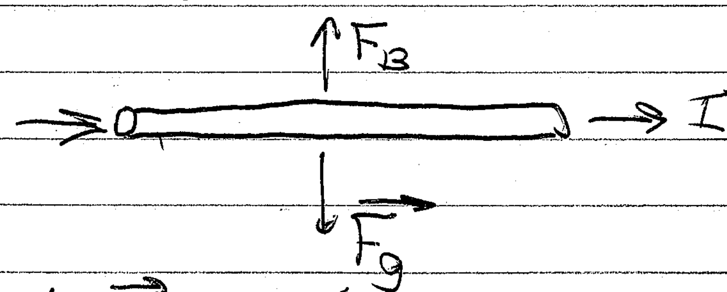
Here, right side gets ⊕ voltage.

Hall effect confirms wires have moving electrons (⊖).

Forces on Currents

$$\vec{F}_B = q\vec{v} \otimes \vec{B} \longrightarrow \vec{F}_B = I\vec{l} \otimes \vec{B}$$

How to Levitate a wire:



Need $\vec{B} = B_0$ (in)

Ex: wire is $0.05\ kg/m = \lambda$

$I = 0.5\ A$

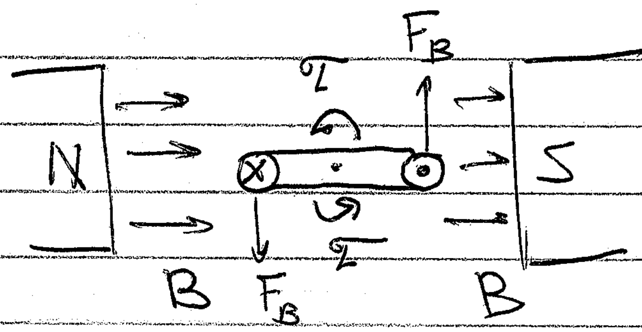
$$F_B = F_g$$

$$I l B = \lambda l g$$

$$(0.5\ A) \cancel{l}\, B = (0.05\ kg/m) \cancel{l}\, (9.8\ N/kg)$$

$$B = \frac{(0.05)\, 9.8}{0.5} = 0.98\ T$$

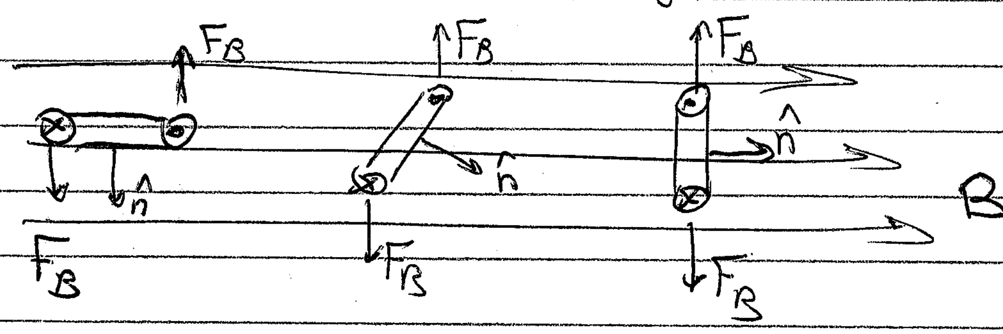
Torque on a Coil



Net torque as drawn: $\tau = NBA\,I$

Area of loop

What if the orientation changes?



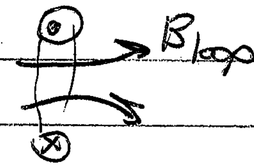
$\tau = NBAI$ $\qquad\qquad\qquad\qquad$ $\tau = 0$

$$\tau = NBAI \sin\theta$$

$\hat{n}$ = normal vector for loop by RHR

θ = angle between $\hat{n}$ and $\vec{B}$

What does the loop do to B?



Looks like