$\vec{E}$: a "force field" made by charge
a map of the force some other charge would feel $\vec{F}_E = q\vec{E}$

$\vec{B}$: another force field made by moving charges
(we have never found a stationary "magnetic charge")

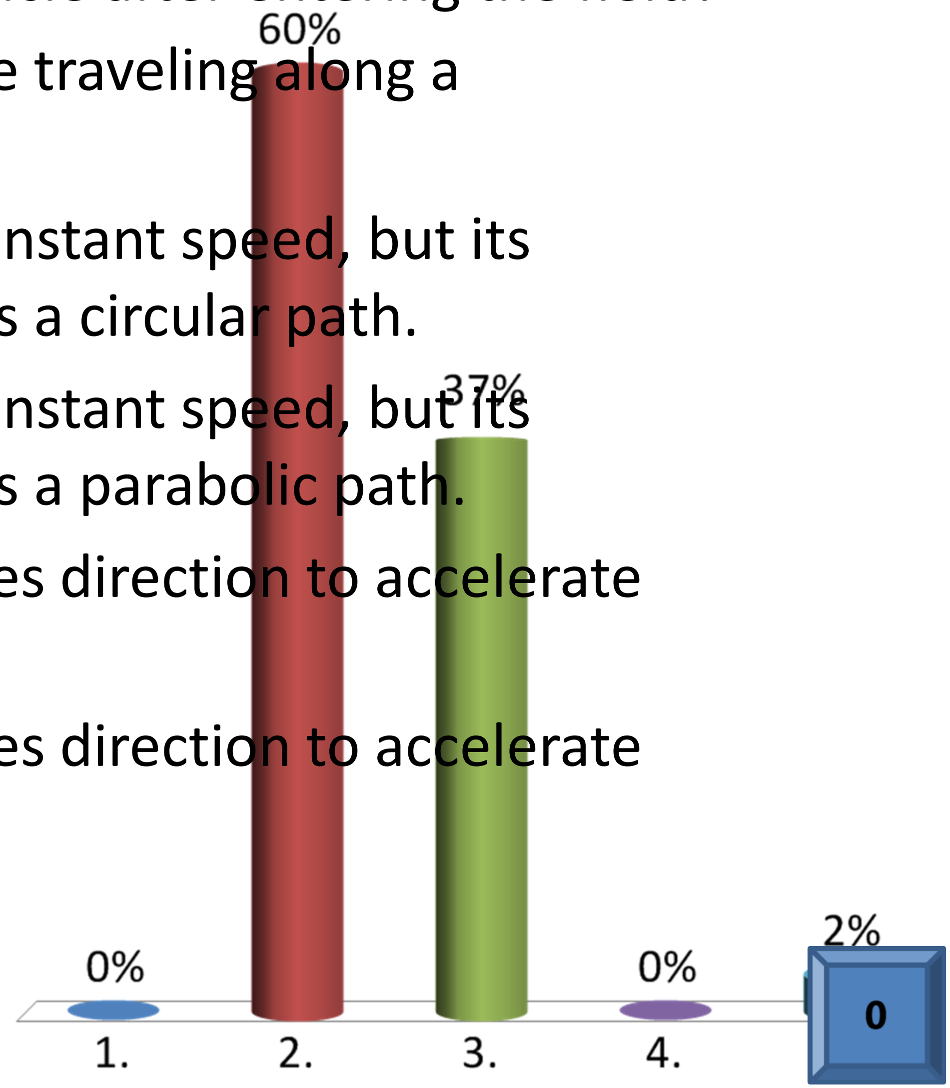
charges moving through $\vec{B}$ feel a force

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

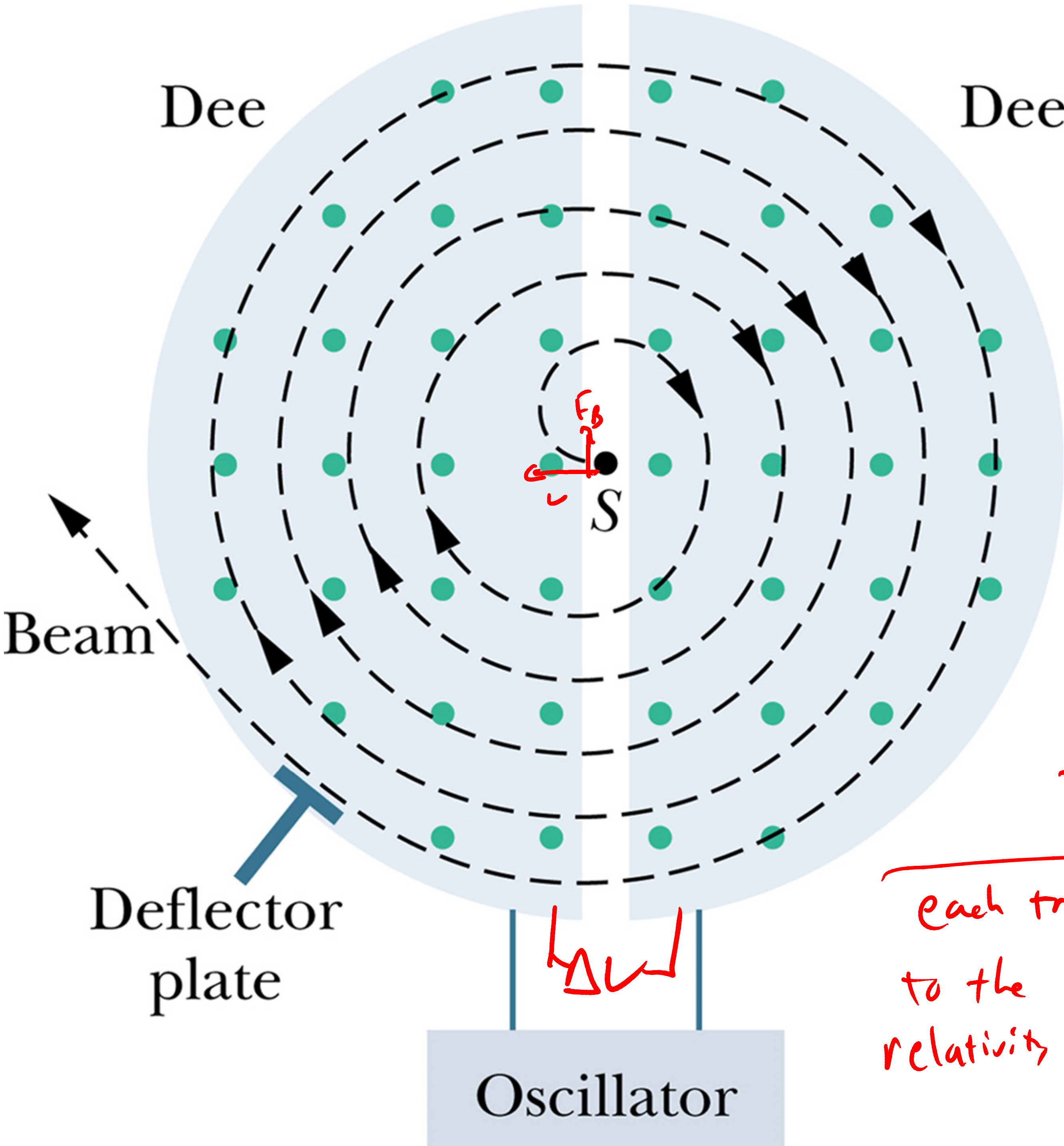
$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

An alpha particle (an He^{++} ion) is moving east when it enters a magnetic field that is directed north. Which happens to the motion of the alpha particle after entering the field?

1. The particle decelerates while traveling along a straight line until it stops.
2. The particle continues at a constant speed, but its direction changes as it follows a circular path.
3. The particle continues at a constant speed, but its direction changes as it follows a parabolic path.
4. The particle slows and changes direction to accelerate to move due north.
5. The particle slows and changes direction to accelerate to move directly upward.



43 of 52



Cyclotron

flip ΔV between sides, boost again - repeat.

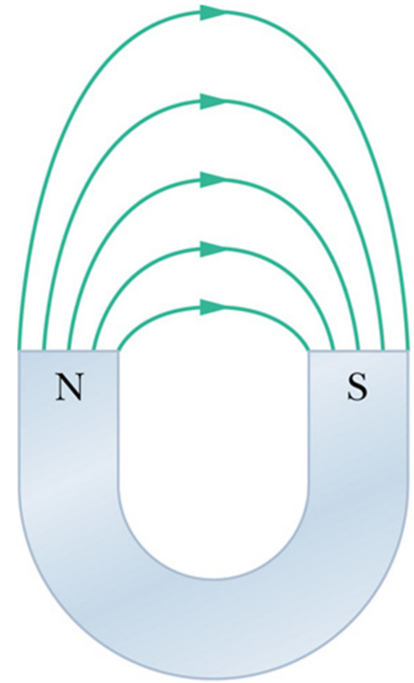
T spent in ½ loop

$$\frac{2\pi m}{qB} = T_{full}$$

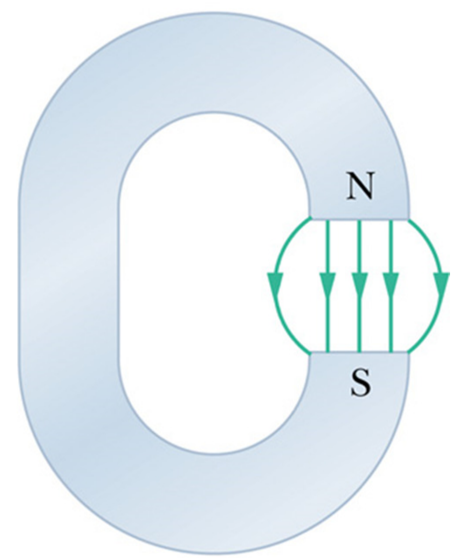
$f = 1/T$ = frequency

each trip you add $U = qV$ to the $\frac{1}{2}mv^2$

relativity caps this out ~ 50 MeV

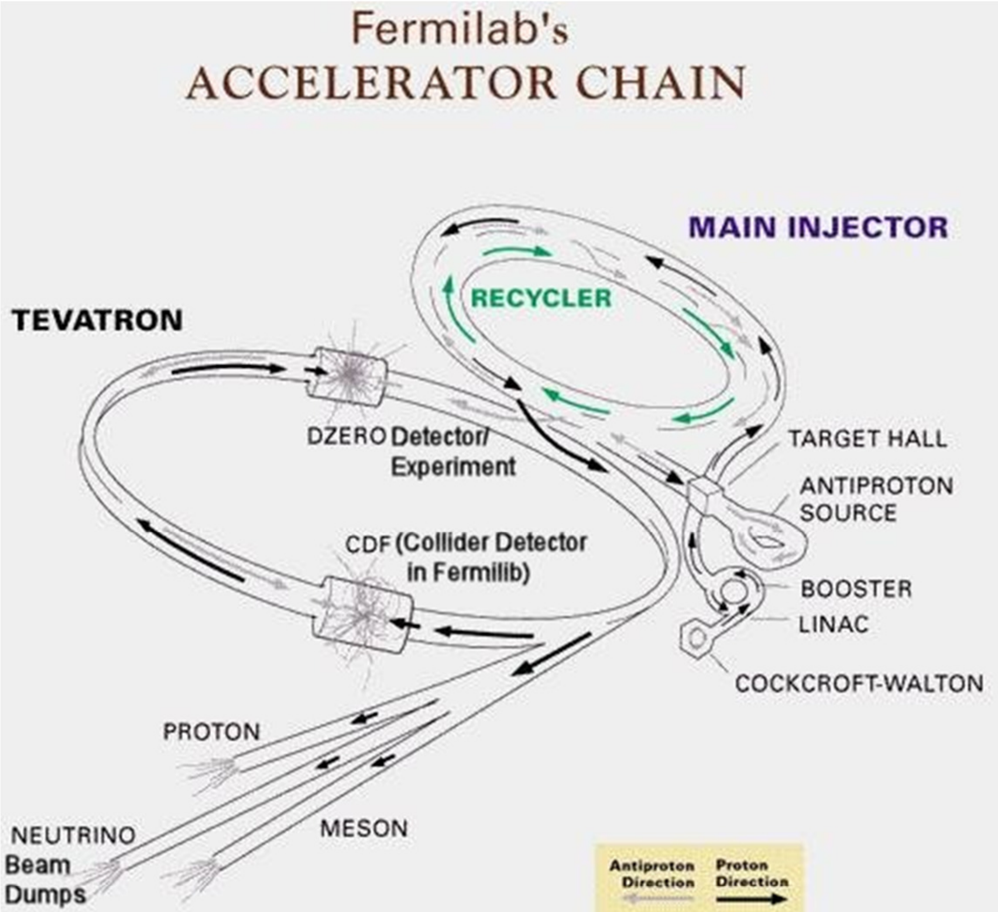


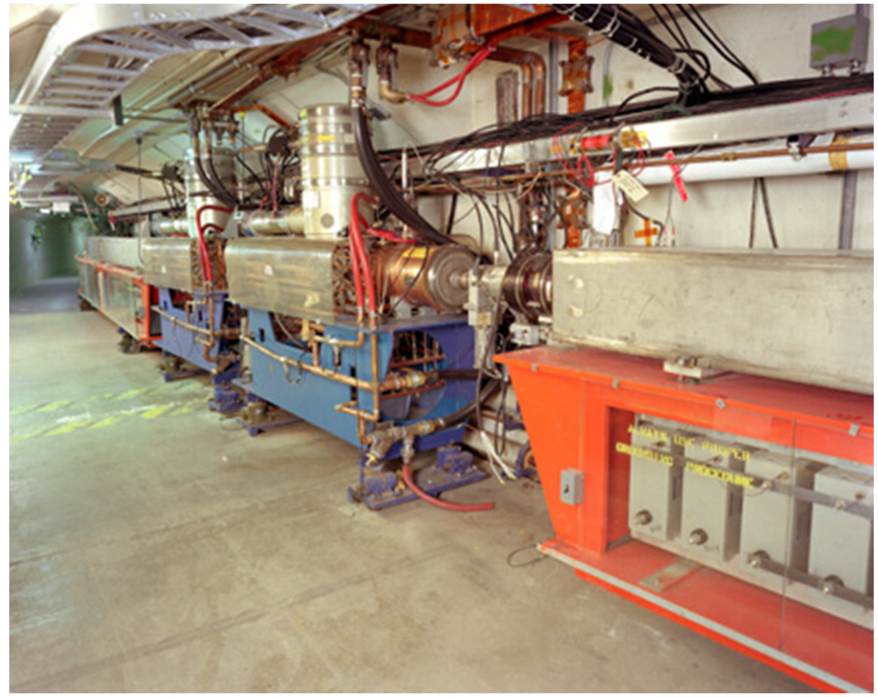
(*a*)



(*b*)

Synchrotron

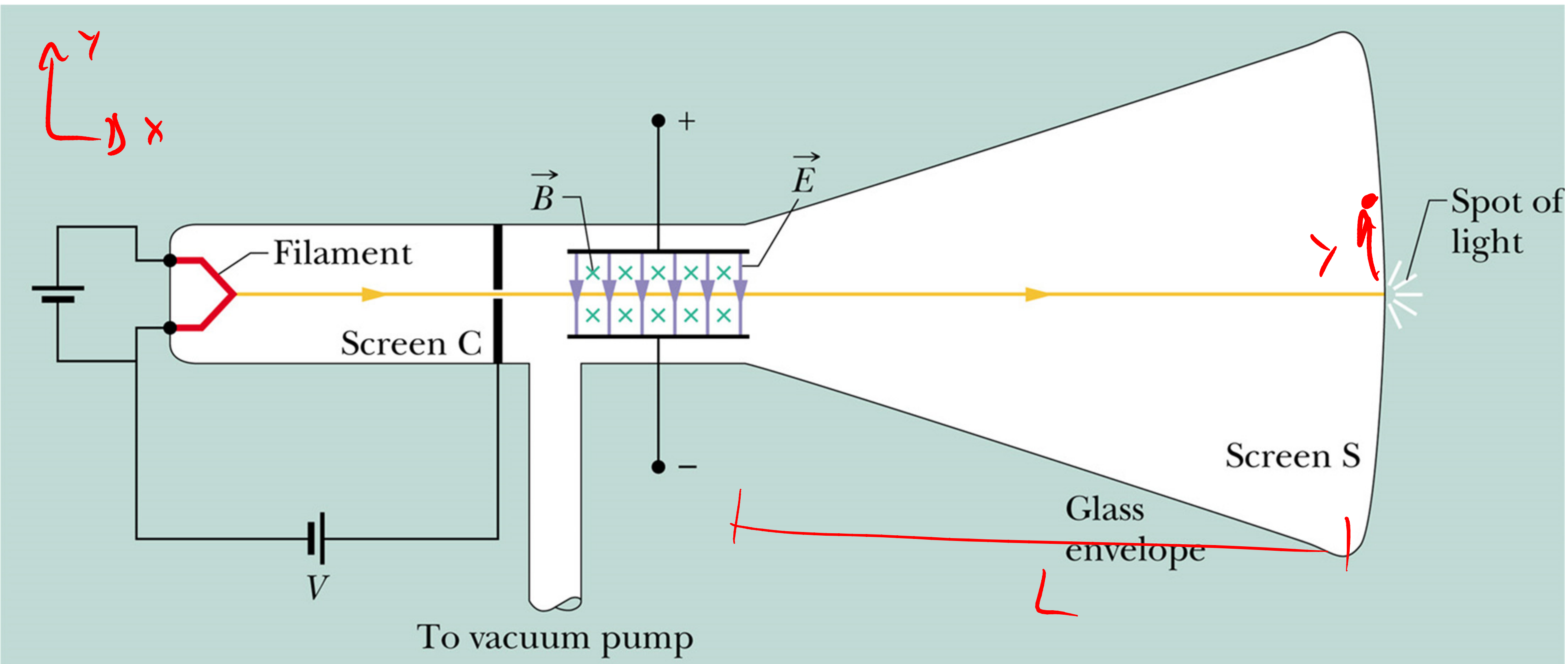




Start with E deflecting
a beam of electrons
JJ Thomsen, 1897

$$\vec{F}_E = q\vec{E} = ma$$

$$y = \frac{qEL^2}{2mv^2}$$



Now add a B

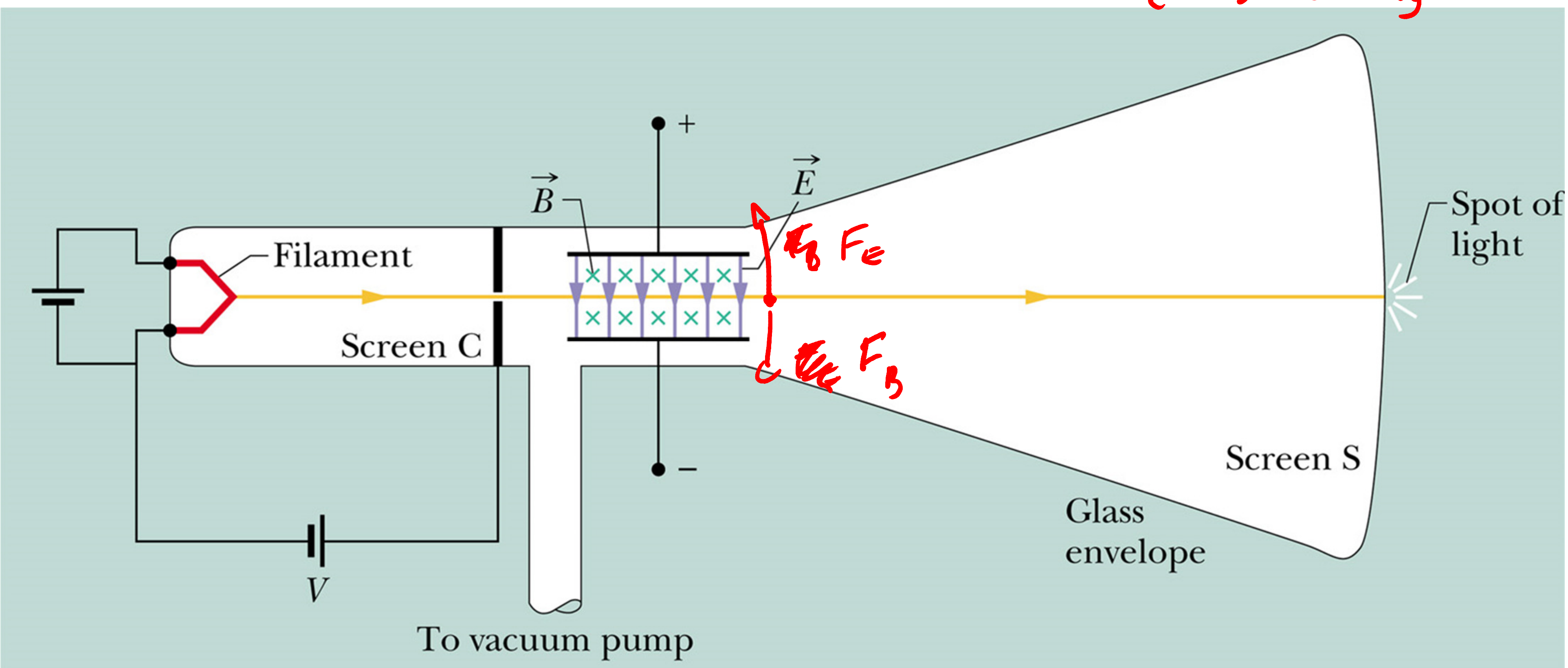
$$qE = q|v||B|\sin\cancel{\theta} \rightarrow 1$$

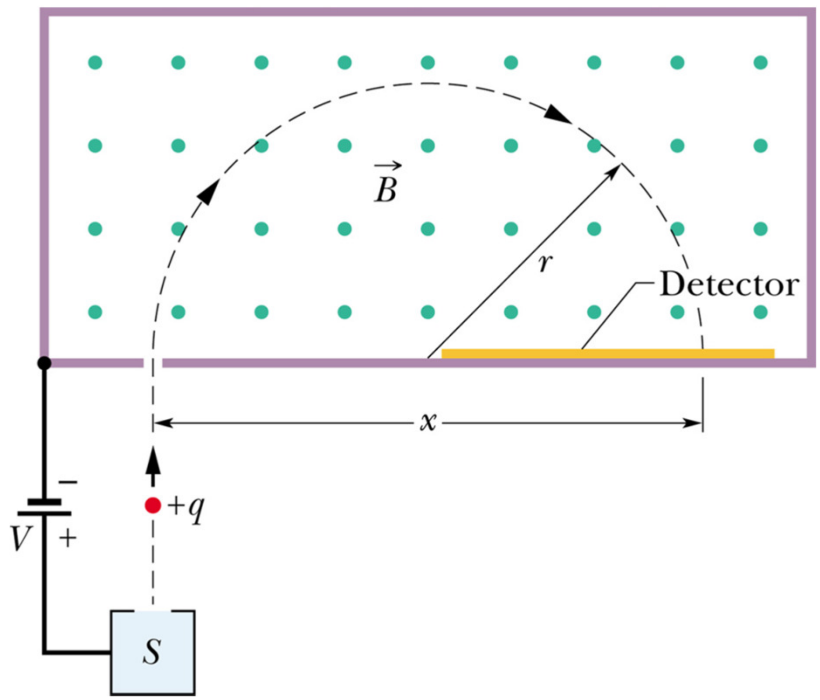
$$v = E/B \longleftrightarrow v = \sqrt{\frac{2eV}{m}}$$

$$U = eV \rightarrow \tfrac{1}{2}mv^2$$

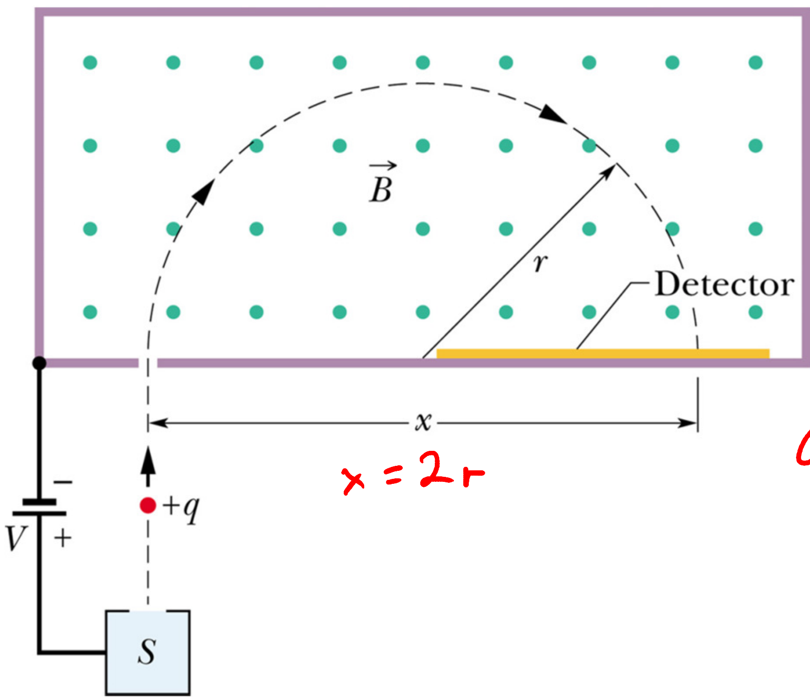
$$E/B = \sqrt{\frac{2eV}{m}} \quad \text{or} \quad \frac{q}{m} = \frac{E^2}{2VB^2} = 1.75882015\times10^{11}\ \text{C/kg}$$

$$m_e = 9.31\times10^{-31}\ \text{kg}$$





Mass spectrometer



$x = 2r$

Mass spectrometer

What mass thing hits at x

What happens when a q cruises around in a B? goes in a circle.

gyroradius $r = \dfrac{mv}{qB}$

What do you know there

conserve energy

pot $\longrightarrow$ kinetic

$U = qV = \frac{1}{2} m v^2$

$v = \sqrt{\dfrac{2qV}{m}}$

so $r = \dfrac{mv}{qB} = \dfrac{m}{qB}\sqrt{\dfrac{2qV}{m}} = \dfrac{1}{B}\sqrt{\dfrac{2mV}{q}}$

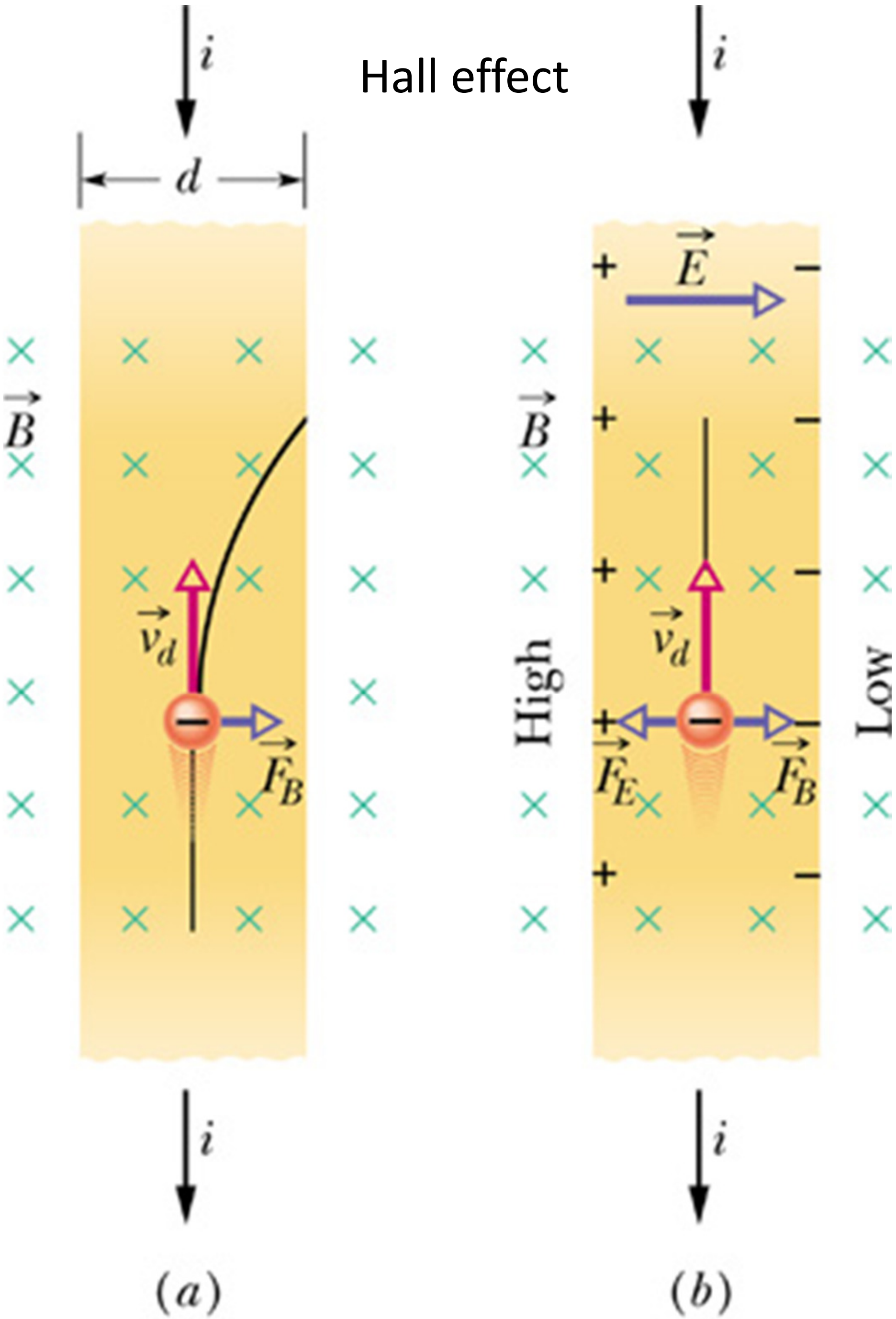
$r = 2x$, so $x = \dfrac{2}{B}\sqrt{\dfrac{2mV}{q}}$

Solve for $m = \dfrac{B^2 q x^2}{8V}$

$V_{235} = 90{,}415$ m/s | 1.32 m

$V_{238} = 90{,}351$ m/s | 1.33 m

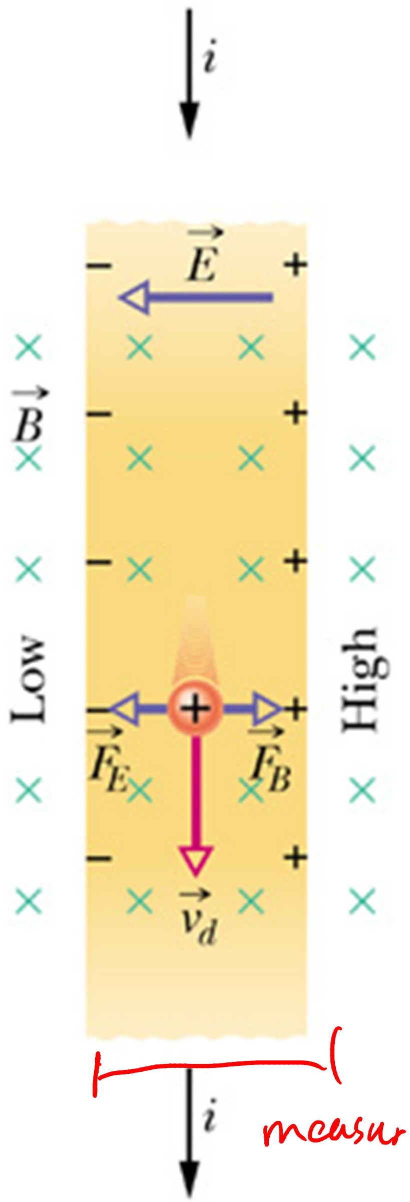
Hall effect



$F_B = q(\vec{v}_d \times \vec{B})$

pushes e to right.

$\vec{F}_E = q\vec{E}$



(c)

measure V

Balance when $F_E = F_B$

$$qE = q|v_d||B|\cancel{\sin\theta}$$

$$v_d = \frac{J}{ne} = \frac{I}{neA}$$

$$E = \frac{V}{d}$$

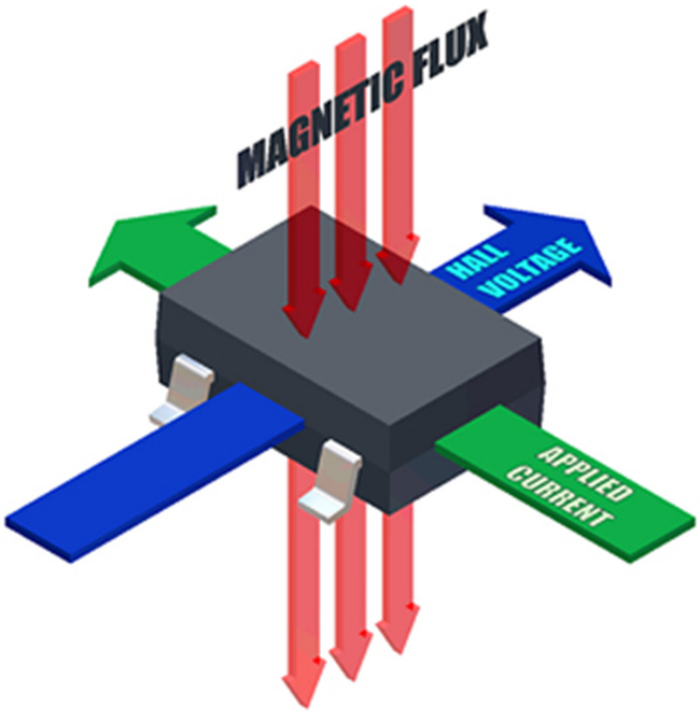
$$\frac{V}{d} = \frac{BI}{neA}$$

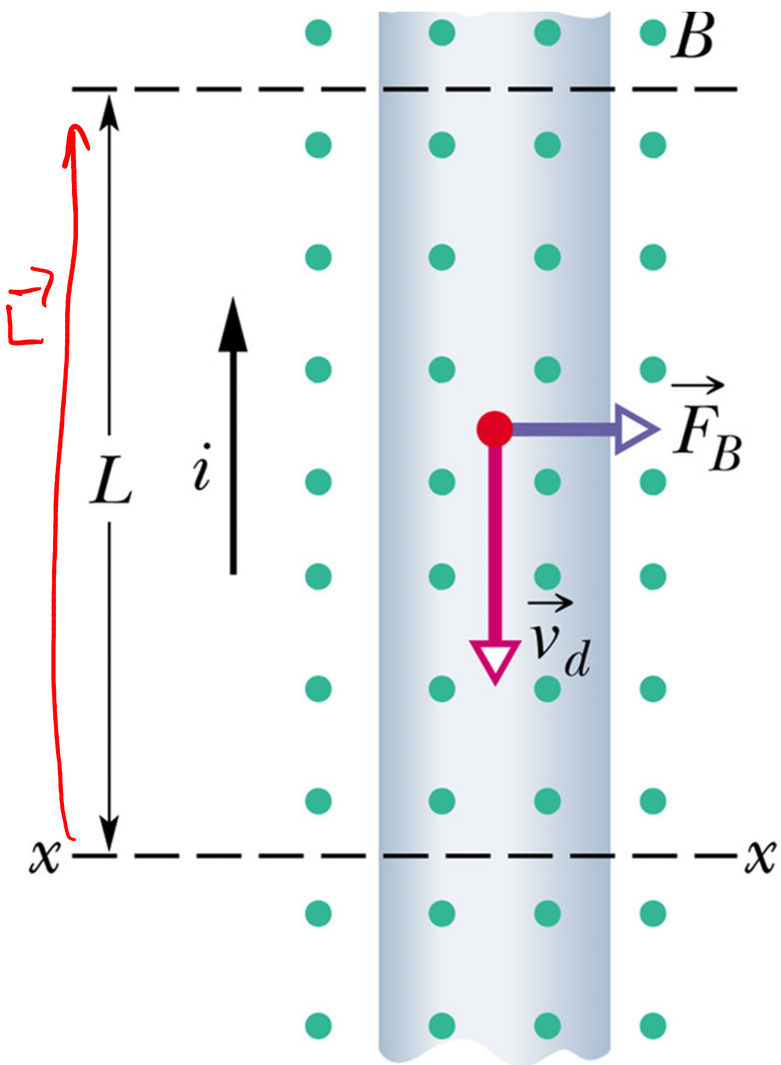
$A/d = \ell$ (depth

$$n = \frac{dIB}{VeA}$$

Or, solve for B

Get all 3 components with three chips





$$I = \frac{q}{t} \qquad q = It = I\,{}^{L}/_{v_d}$$

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

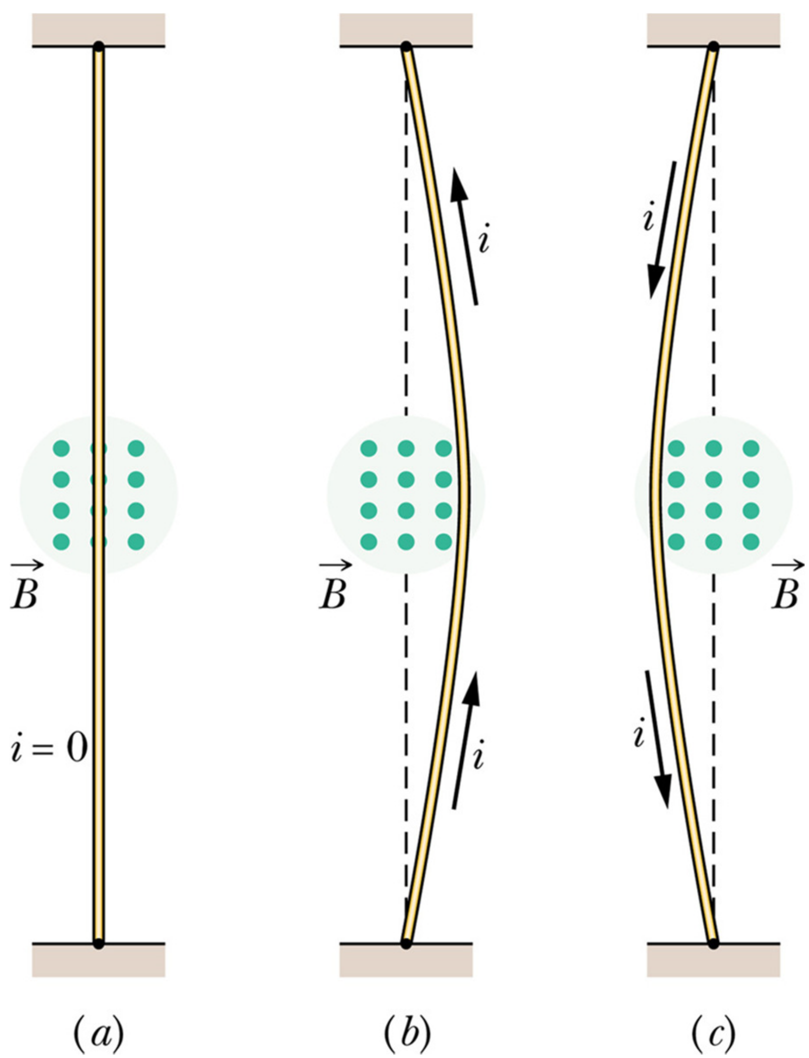
$$= \left(\frac{IL}{v_d}\right)\vec{v} \times \vec{B}$$

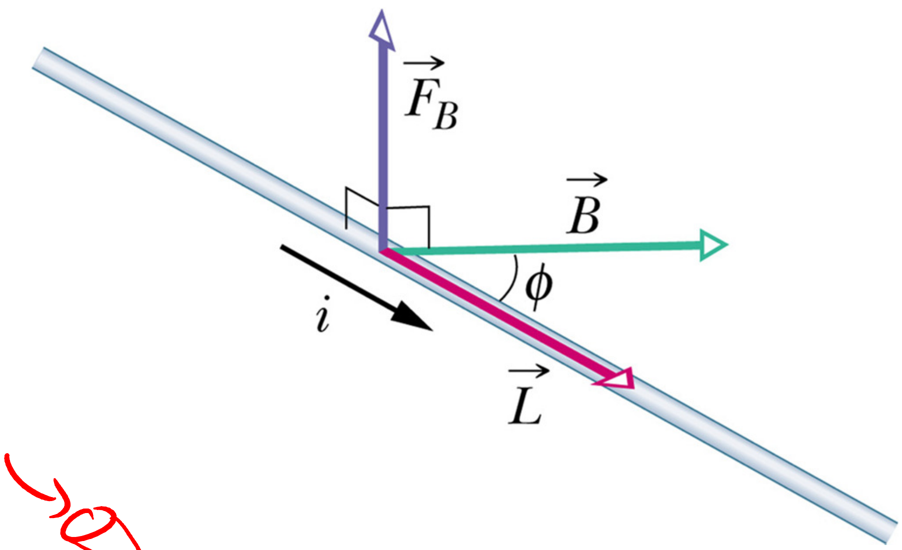
if $\perp$, $\frac{\vec{v}}{v_d} = 1$

$$\vec{F}_B = I\vec{L}\vec{B}$$

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

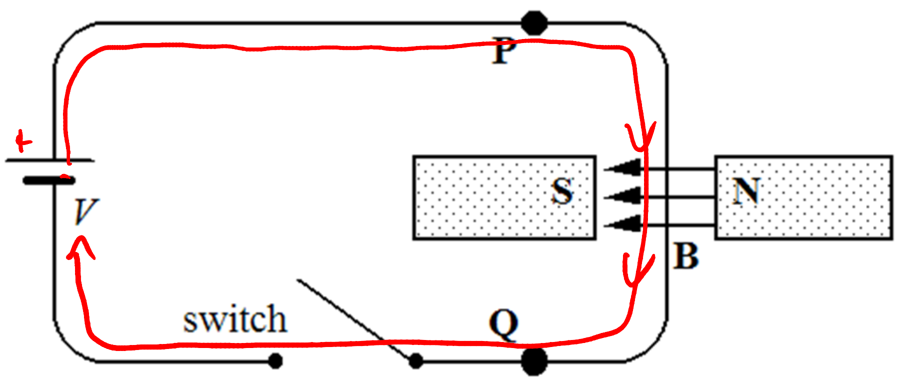
$\vec{F}_B = I\vec{L}\times\vec{B}$

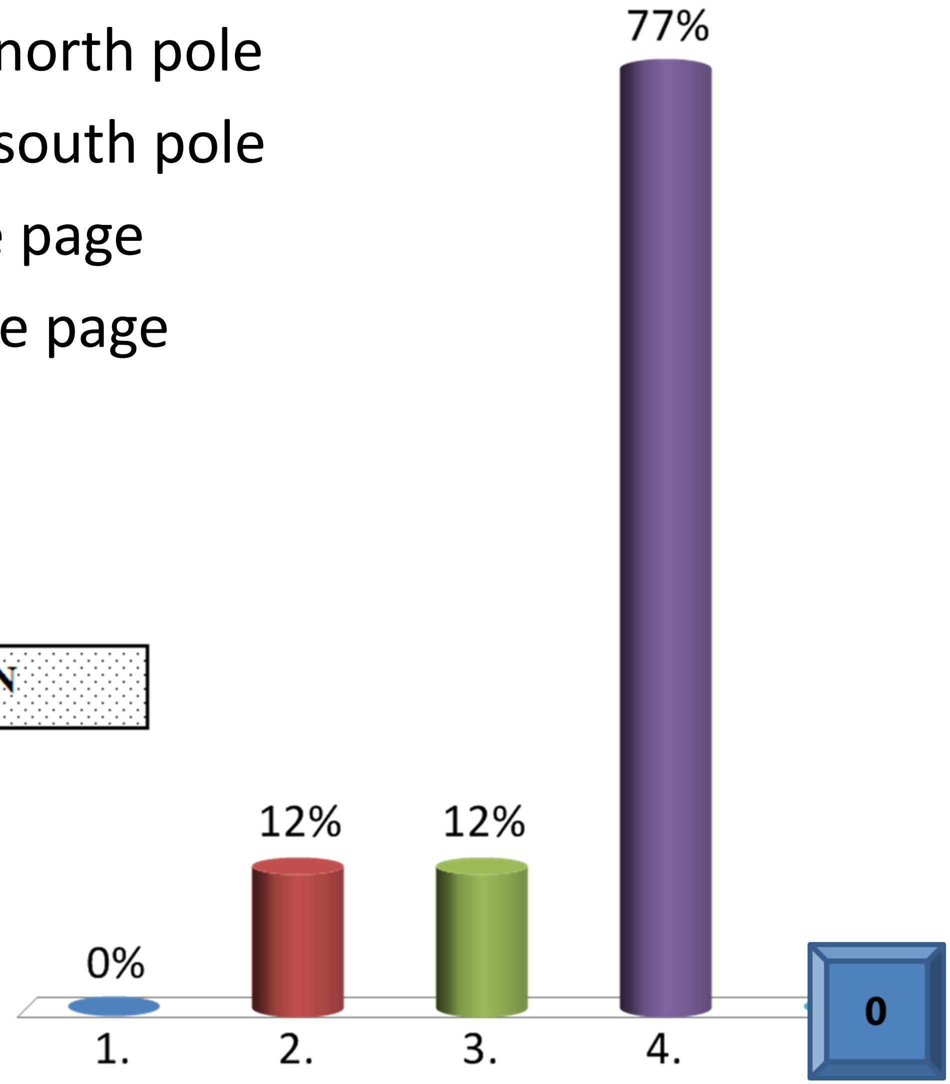




Part of a loop of wire passes between the poles of a magnet. When the switch is closed and a current flows, what is the movement of the wire between the poles of the magnet?

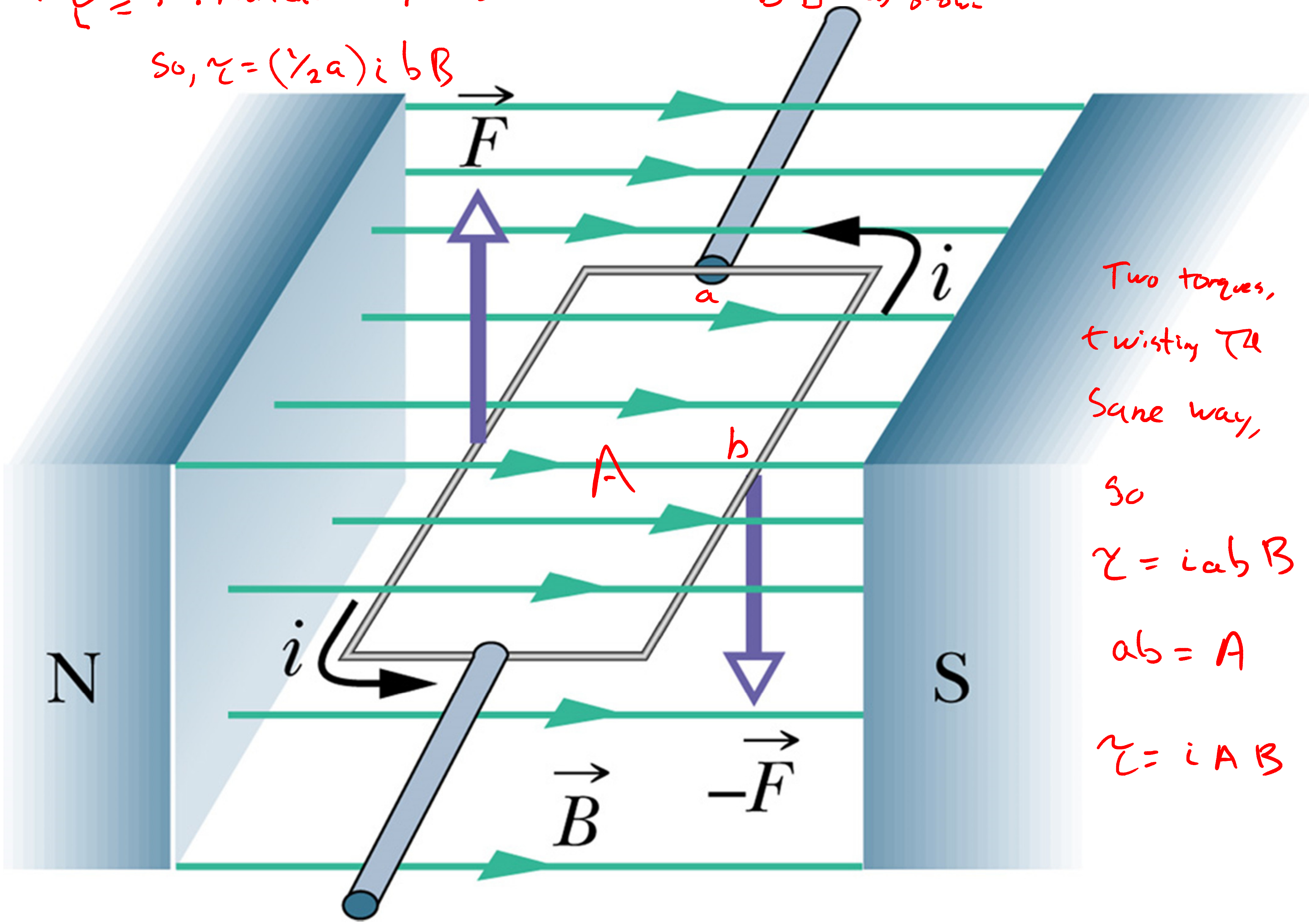
1. The wire moves towards the north pole
2. The wire moves towards the south pole
3. The wire moves up out of the page
4. The wire moves down into the page
5. No movement happens





$\tau = F \cdot \text{moment} \qquad F = I\vec{L} \times \vec{B} = i\,b\,B$ as shown

So, $\tau = (\tfrac{1}{2}a)\,i\,b\,B$



Two torques, twisting the same way, so

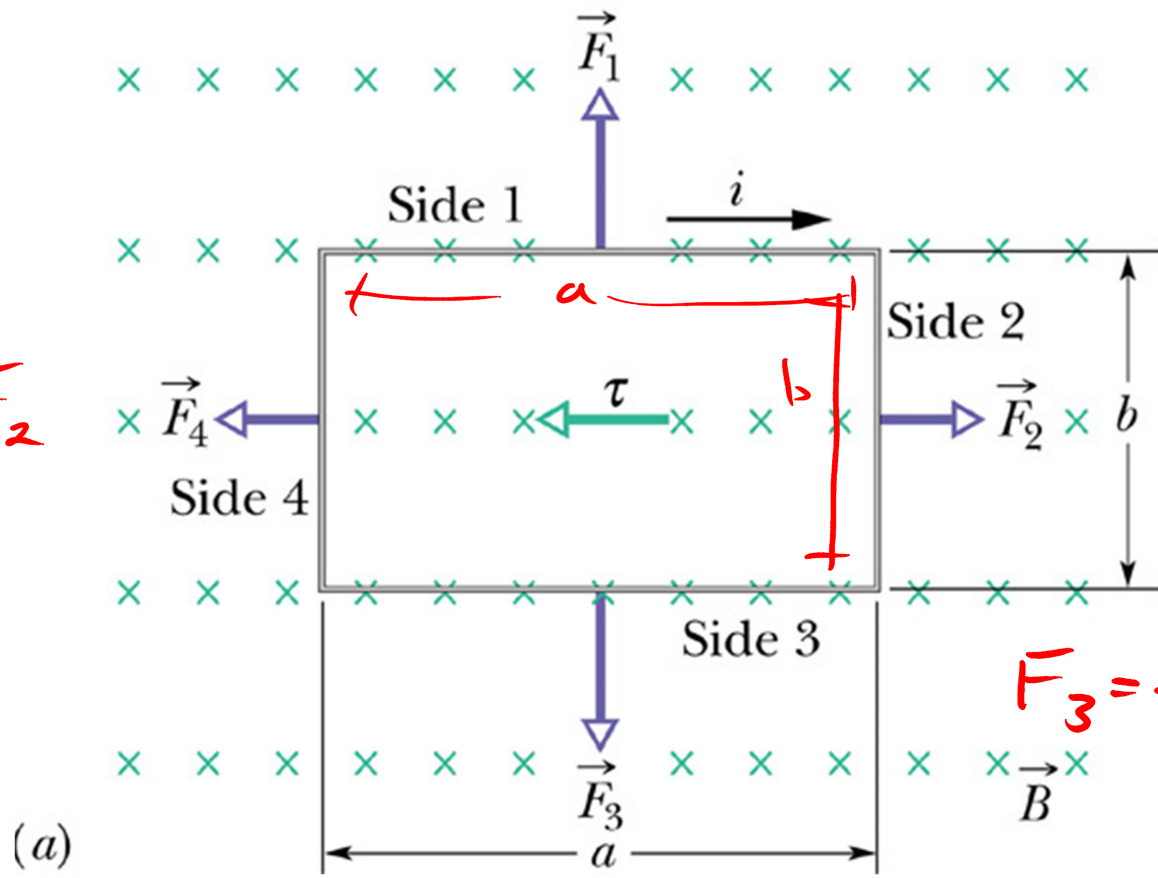
$\tau = i\,a\,b\,B$

$ab = A$

$\tau = i\,A\,B$

$F_1 = I \vec{L} \times \vec{B} = I a \sin 90°$

$F_4 = -F_2$

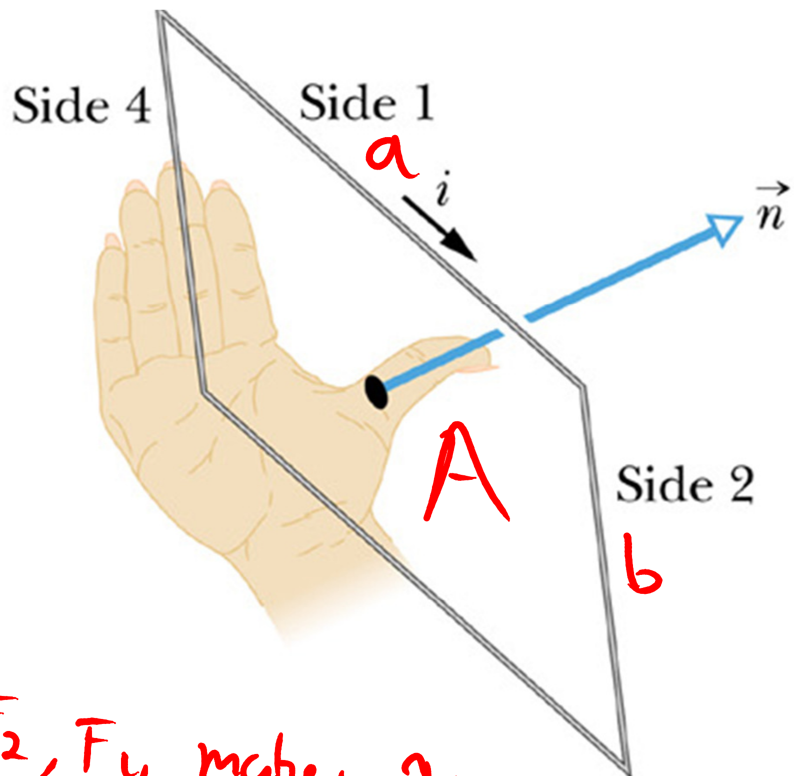


$F_2 = I b \sin 90°$

$F_3 = -F_1$

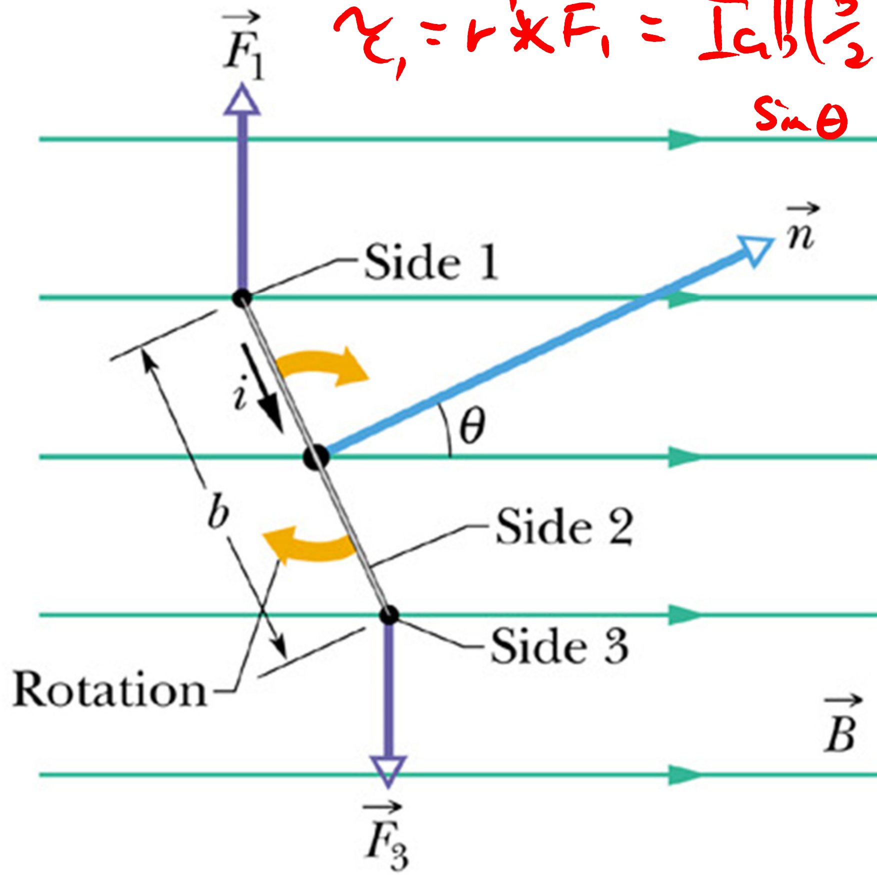
$F_1 = ILB = IaB$

$\vec{\tau}_1 = \vec{r} \times \vec{F}_1 = IaB\left(\frac{b}{2}\right)\sin\theta$



F_2, F_4 make no τ

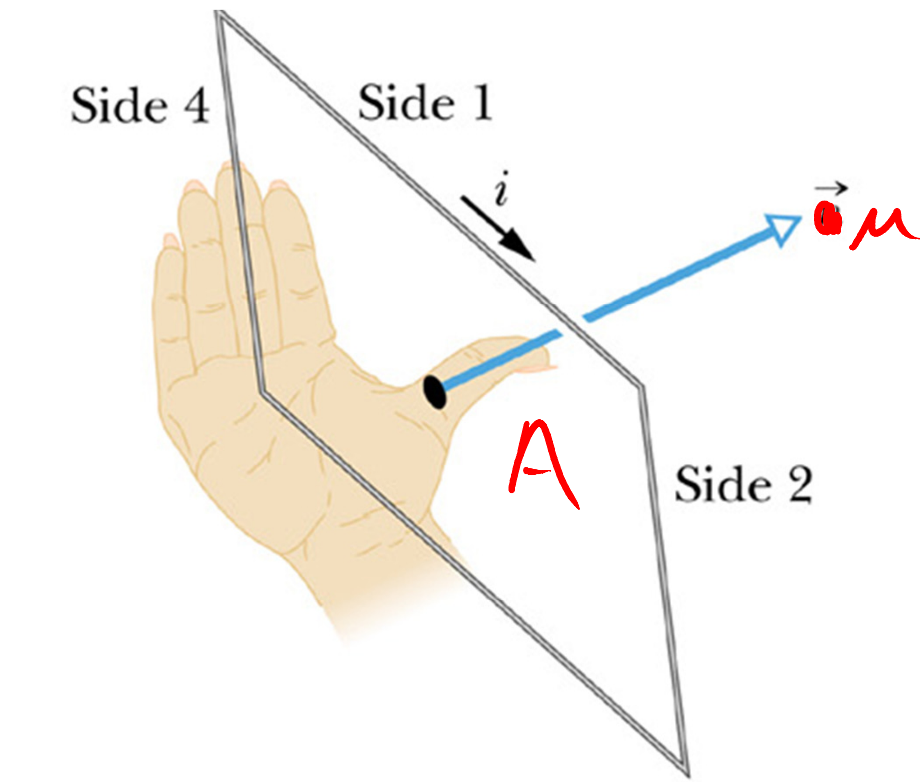
(b)



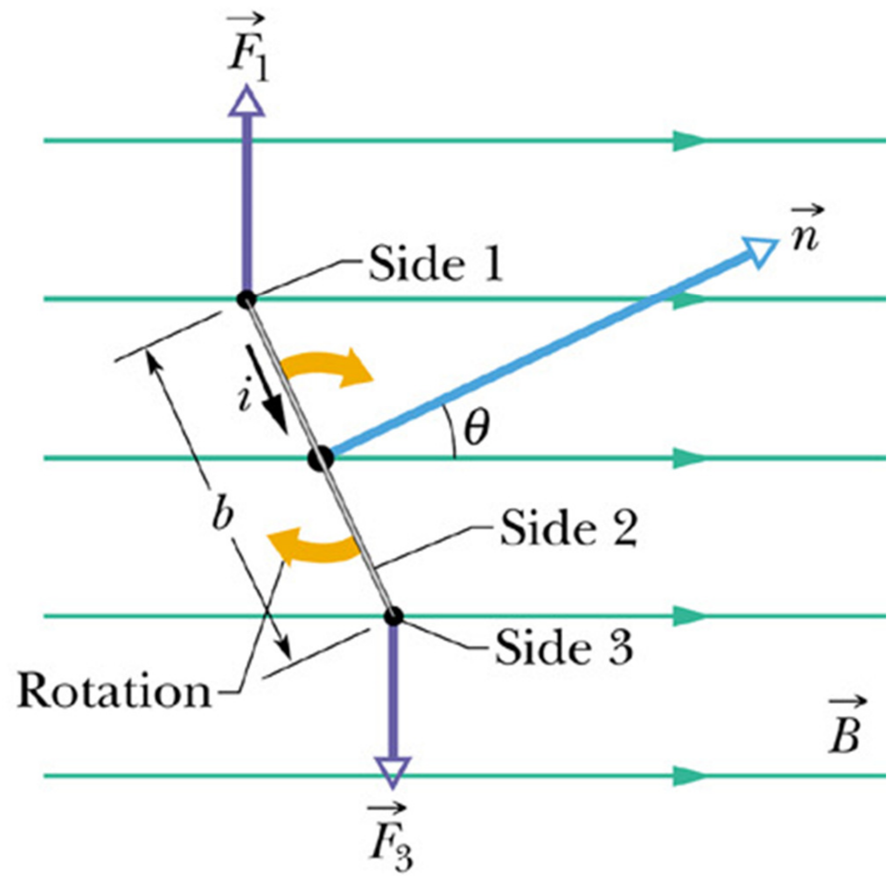
(c)

$$\tau_{TOT} = \tau_1 + \tau_2$$
$$= IaBb\sin\theta$$
$$\tau = IAB\sin\theta$$

$$F_3 = ILB = IaB$$
$$\tau_3 = F_3\left(\frac{b}{2}\right)\sin\theta$$
$$= IaB\left(\frac{b}{2}\right)\sin\theta$$



(b)



(c)

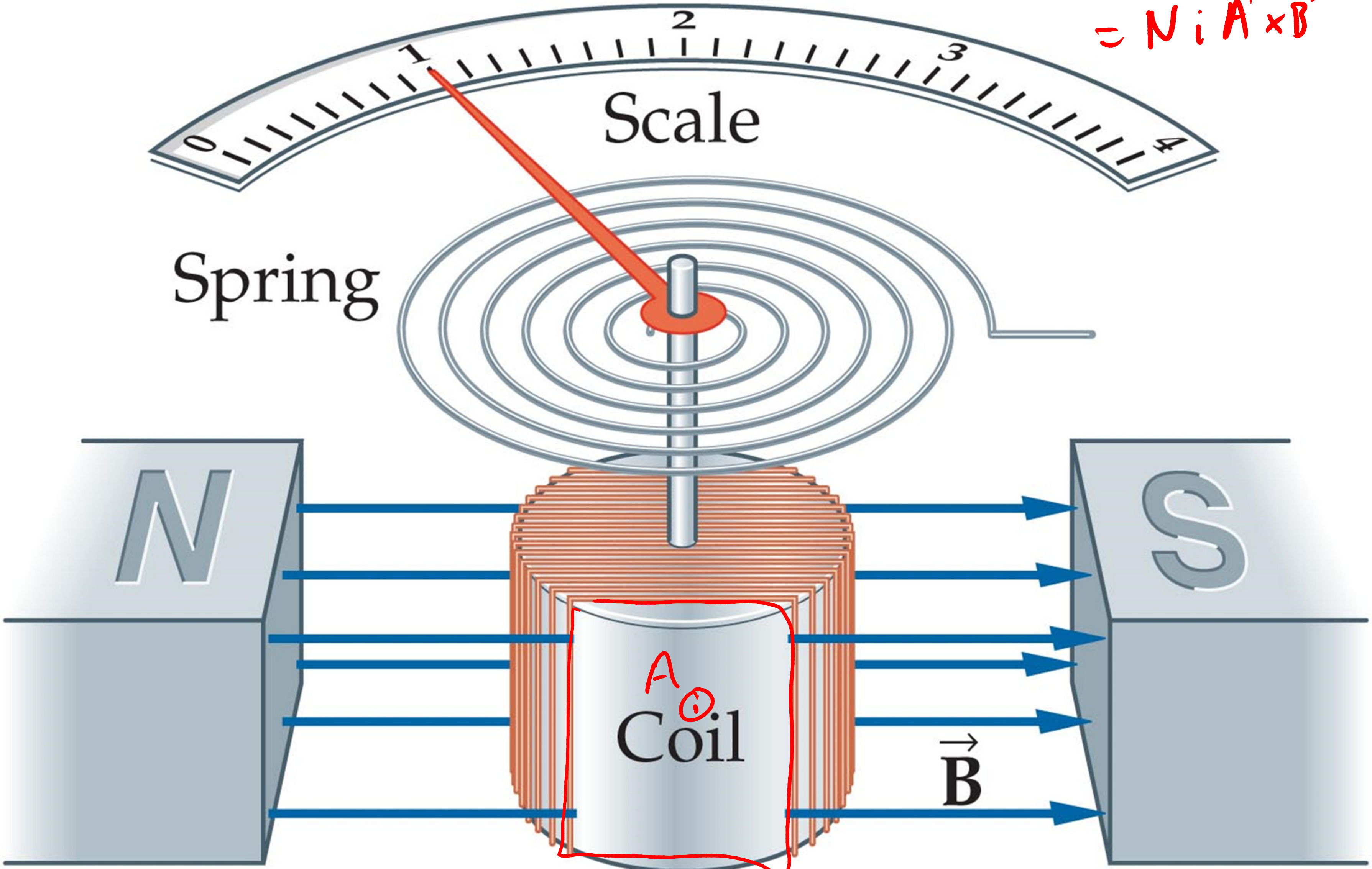
let $\mu = NIA$ $N = \#$ loops

$$\tau = \mu B \sin\theta$$

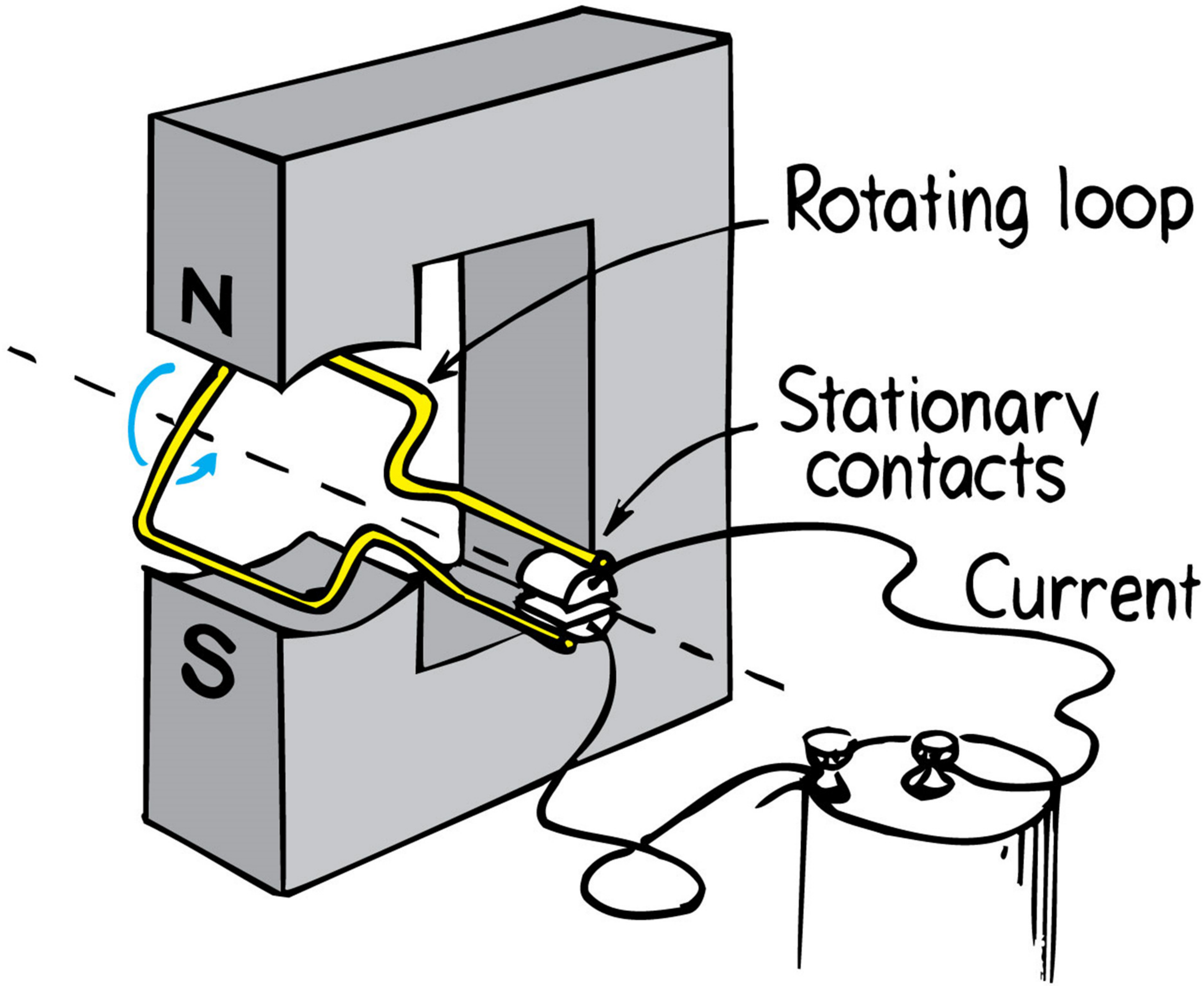
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

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

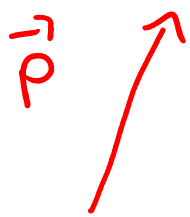
$= N i \vec{A} \times \vec{B}$

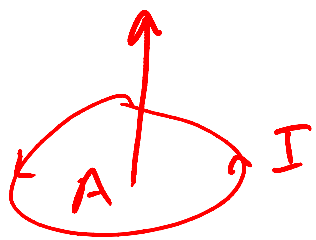


$\vec{\mu} = N \cdot I \cdot \vec{A}$ $\qquad$ $\vec{\tau} = \vec{\mu} \times \vec{B}$


N
S
Rotating loop
Stationary contacts
Current

Dipole worksheet
(*not to do now, but keep it as a study aid*)





$$\vec{p} = q\vec{d}$$

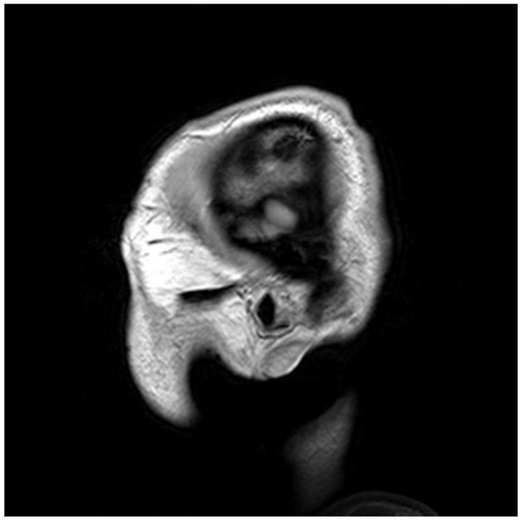
$$\vec{\mu} = NI\vec{A}$$

$$\vec{\tau} = \vec{p} \times \vec{E}$$

$$U = -\vec{p} \cdot \vec{E}$$

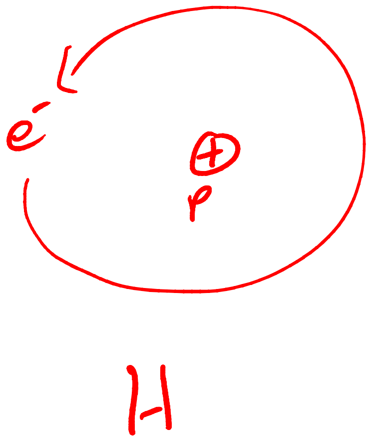
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

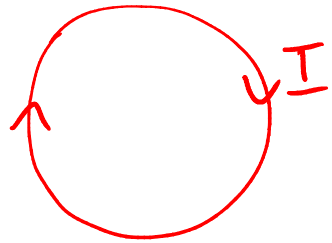
$$U = -\vec{\mu} \cdot \vec{B}$$



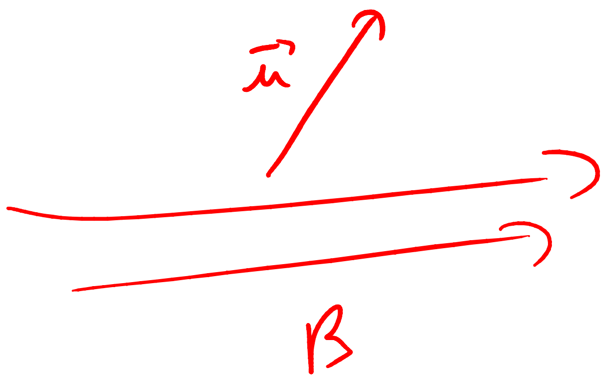
Images swiped from Wikipedia's MRI article

How that MRI makes images by getting H atoms to flip dipoles and change U





$\vec{\mu}$



Two Long Parallel Wires

and on the other side,

Forces between parallel wires