Chapter 29 Magnetic Fields

see sections 1-5, 7-9

$\vec{B}$ = magnetic field = a force field created by moving charges:

magnetic force $\vec{F_B} = q\vec{v} \times \vec{B}$

charge

velocity of moving charge

magnetic field

only moving ($\vec{v} \neq 0$) charges feel any magnetic forces.

Note that B has units of $\dfrac{\text{force}}{\text{charge} \cdot \text{velocity}}$

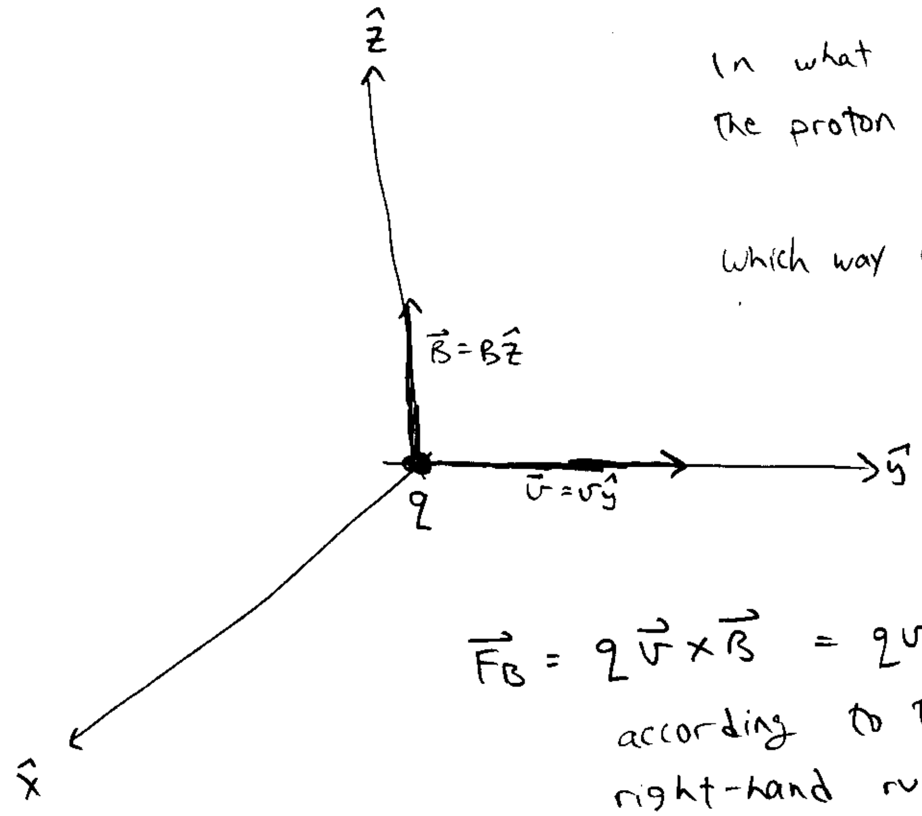
or $\dfrac{N}{C \cdot m/sec} \equiv 1$ Tesla $= 1T$ in SI units

Table 29-1 lists the stregths of various magnetic fields:

at Earth's surface, $B \sim 10^{-4}\,T$

fridge magnet has $B \sim 0.01\,T$

Example: A $q>0$ proton travels thru a $\vec{B}$ = constant magnetic field.



In what direction will the proton be deflected?

Which way would an e^- be deflected?

$\vec{F}_B = q\vec{v}\times\vec{B} = qvB\hat{x}$ = magnetic force on q

according to the right-hand rule.

Note that the magnetic force is always perpendicular to both $\vec{v}, \vec{B}$.

In general, $|\vec{F}_B| = |qvB| \sin\phi$

where ϕ = angle between $\vec{v}$ and $\vec{B}$

See 'electron charge...' demo

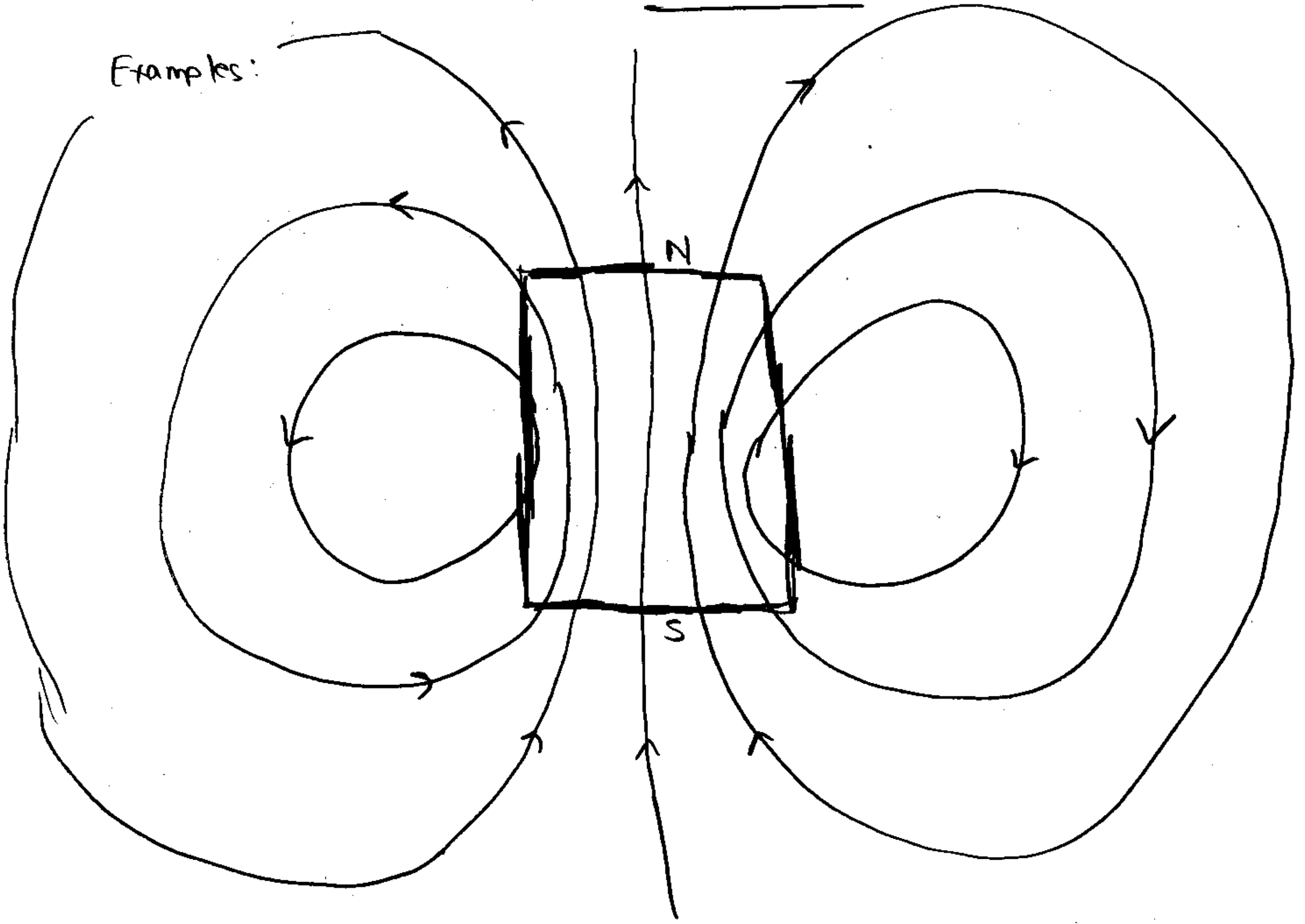
Drawing $\vec{B}$-field lines :

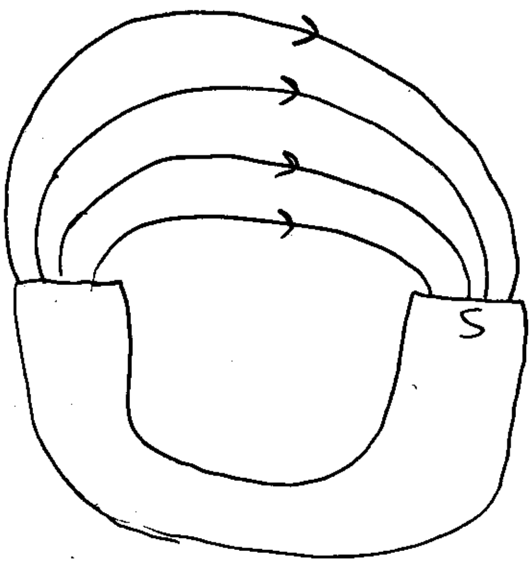
Rules: 1. tangent indicates the direction of $\vec{B}$

2. density of lines indicates the magnitude of $\vec{B}$

Bar magnet

Examples:





lines emerge from N pole, and enter the magnet at the S pole

Horseshoe magnet

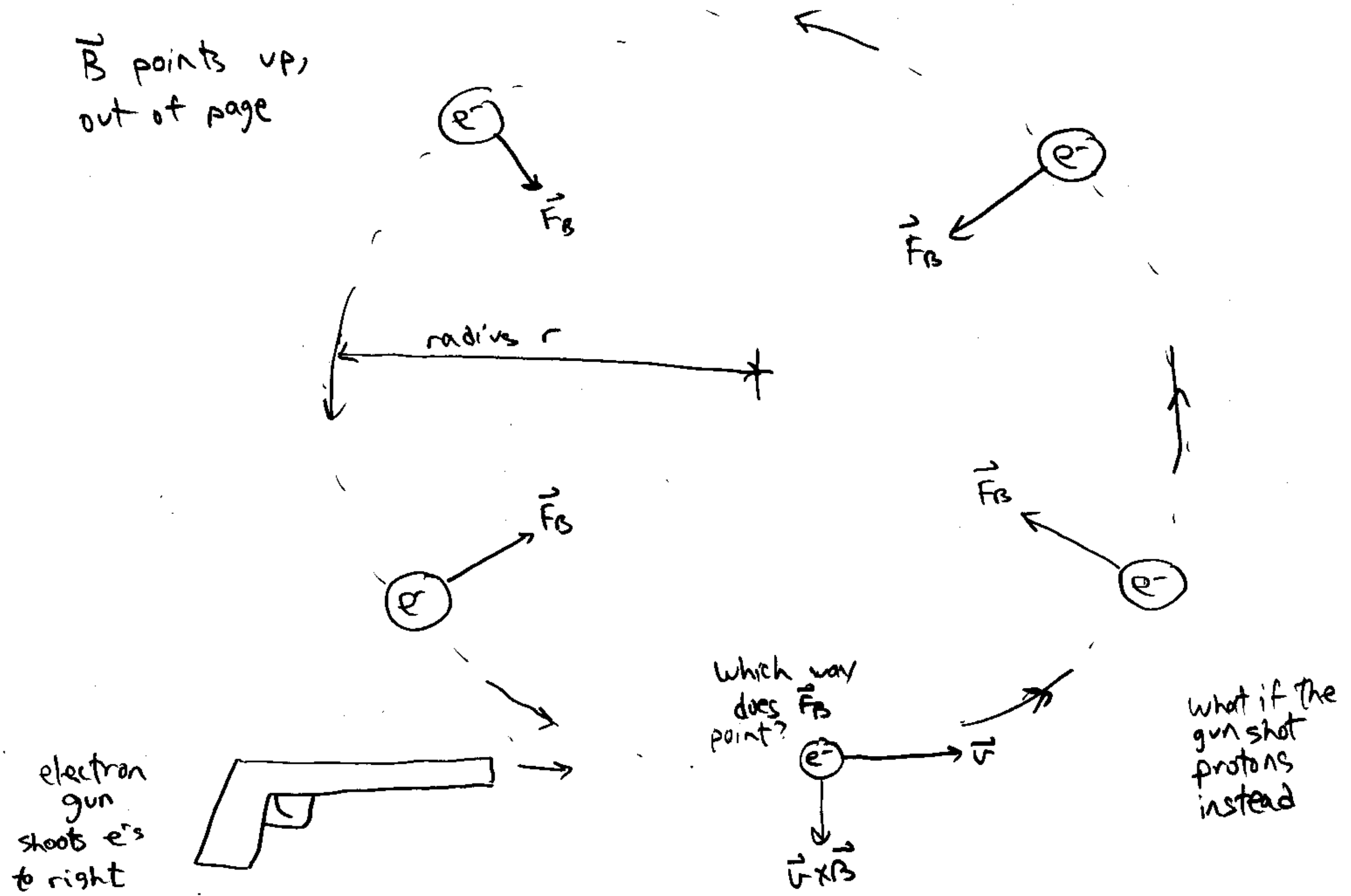
See 'field line demonstrators' demo

Playing with magnets reveals that opposite poles attract, and like poles repel.

Read sections 29-3 (on cathode ray tube, ie, TV picture tube)
29-4 (Hall effect)

Circulating motion in a uniform $\vec{B}$ field:

Use an electron gun to shoot e's with velocity $\vec{v}$ in to a uniform $\vec{B}$-field that is perpendicular to $\vec{v}$.
What is the e⁻'s subsequent motion?



The electron's motion is circular:

$\vec{F}_B = q\vec{v} \times \vec{B}$ so $F_B = qvB$ = magnetic force on e^-; points <u>inwards</u>

Newton's Law: $F_B = ma$

what is a for circular motion?

$a = \frac{v^2}{r}$ where v = e^- speed
r = radius of circle
m = e^- mass

so $qvB = \frac{mv^2}{r}$

or $r = \frac{mv}{qB}$ = radius of circular path

Note that stronger B-fields result in smaller-radius loops.

Note that $T = \frac{2\pi r}{v}$ = period = time for e^- to travel about circle

$= \frac{2\pi m}{qB}$ ← depends only on field strength B and the charge/mass ratio q/m

while $f = \frac{1}{T} = \frac{qB}{2\pi m}$ = frequency of e's circular motion.

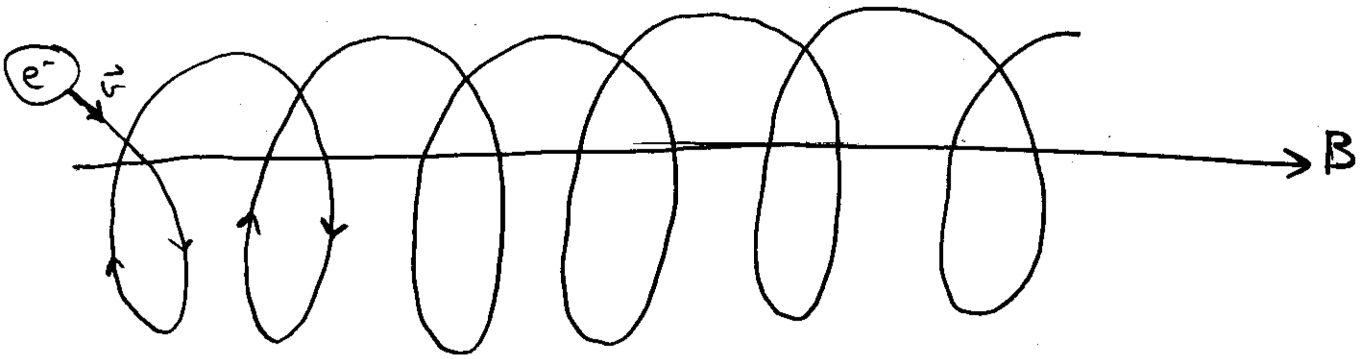
Note that T and f are independant of r.

What if the e-gun was not perfectly $\perp$ to $\vec{B}$, ie, if the velocity $\vec{v}$ had a component parallel $v_{\parallel}$ to $\vec{B}$?

What is the e's motion then?

Recall that $\vec{F}_B = q\vec{v} \times \vec{B}$ so $\vec{F}_B \cdot \vec{B} = 0$,
ie, there is no magnetic force in the direction of $\vec{B}$.

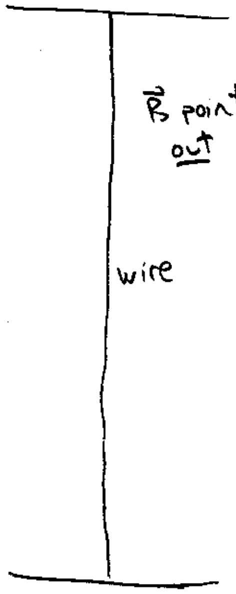
$\Rightarrow$ the resulting motion will be helical:



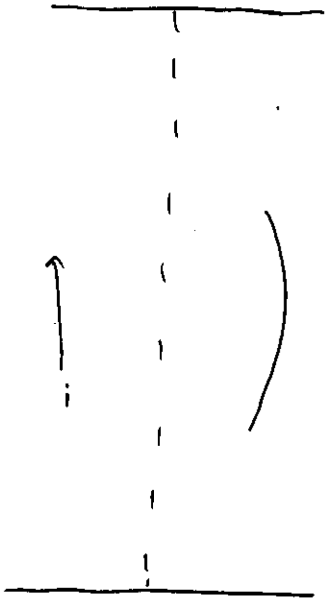
horizontal distance travelled $= v_{\parallel} t$

$\vec{B}$-Force on a current-carrying wire

Run a wire perpendicular to a uniform $\vec{B}$-field
That points <u>out of page</u>:



no current,
$i=0$



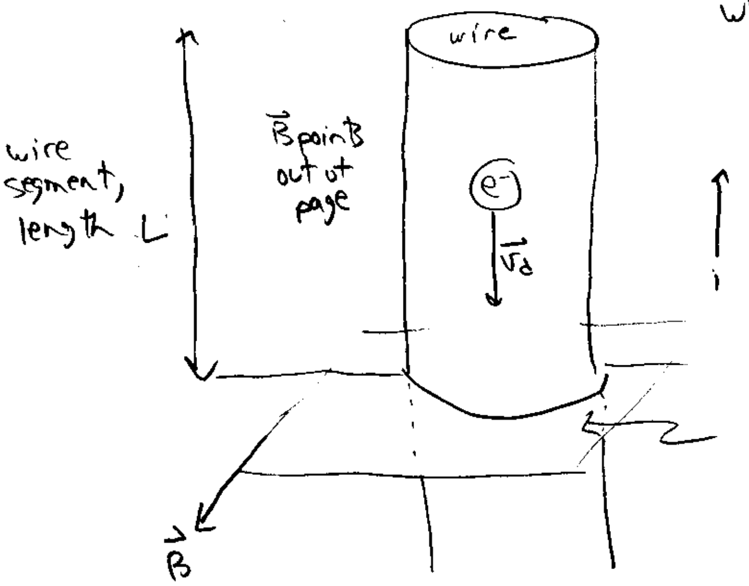
turn on an
upward current

Which way does
the $\vec{B}$-force
bend the wire?

what if the
current runs
downwards?

calculate the force on a wire-segment.
The conduction e's travel down wire at
the drift-velocity $\vec{v}_d$ (see section 27-3).

which way is the current i flowing?



after time Δt,
all e's in segment $\Delta L = v_d \Delta t$
will have passed down thru
this plane

The amount of charge in segment L is

$$q = i\,\Delta t = \frac{iL}{v_d}$$

The total magnetic force on those charges is

$$F_B = |q\,\vec{v}_d \times \vec{B}\,|$$

where $|\vec{v}_d \times \vec{B}| = v_d B \sin\phi$
what is ϕ = angle between $\vec{v}_d$ & $\vec{B}$?

which way is $\vec{F}_B$ pointed? Up/down or left/right?

$$F_B = \left(\frac{iL}{v_d}\right) v_d B = iLB =$$

magnetic force on wire of length L due to field B.

Or in general,

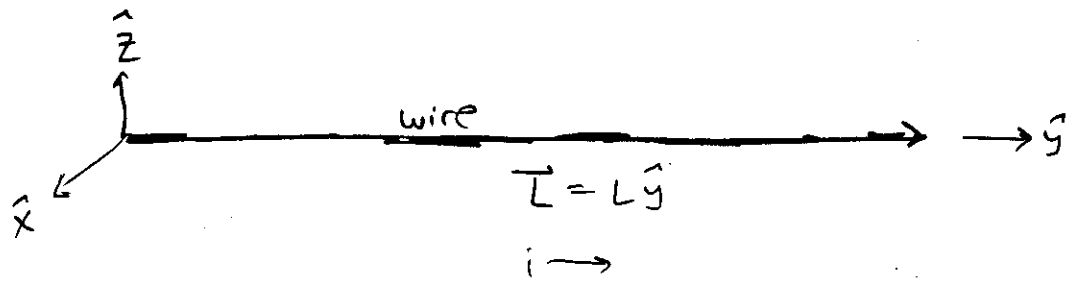
$\vec{F}_B = i\vec{L}\times\vec{B}$ = force on wire due to external $\vec{B}$-field,
where $\vec{L}$ = wire's <u>length vector</u>, pointing along current flow.

<u>Sample Problem 29-6</u>

a horizontal wire carries a current $i = 28$ amps, and has a linear density $\lambda = 0.047$ kg/m

What $\vec{B}$ field is needed to suspent the wire againts gravity?

Which way does $\vec{B}$ point?



Recall $\vec{F}_B = i\vec{L}\times\vec{B}$. Orient $\vec{B}$ so that F_B points up.

Try $\vec{B}$ pointing into page: $\vec{B} = -B\hat{x}$ where $B > 0$

so $\vec{F}_B = -iLB\underbrace{(\hat{y}\times\hat{x})}_{-\hat{z}} = +iLB\,\hat{z}$ which points in the correct direction

$\Rightarrow \vec{B}$ must point in $-\hat{x}$ direction to 'float' the wire

The upward magnetic force

$|\vec{F}_B| = iLB$ must counter balance gravity

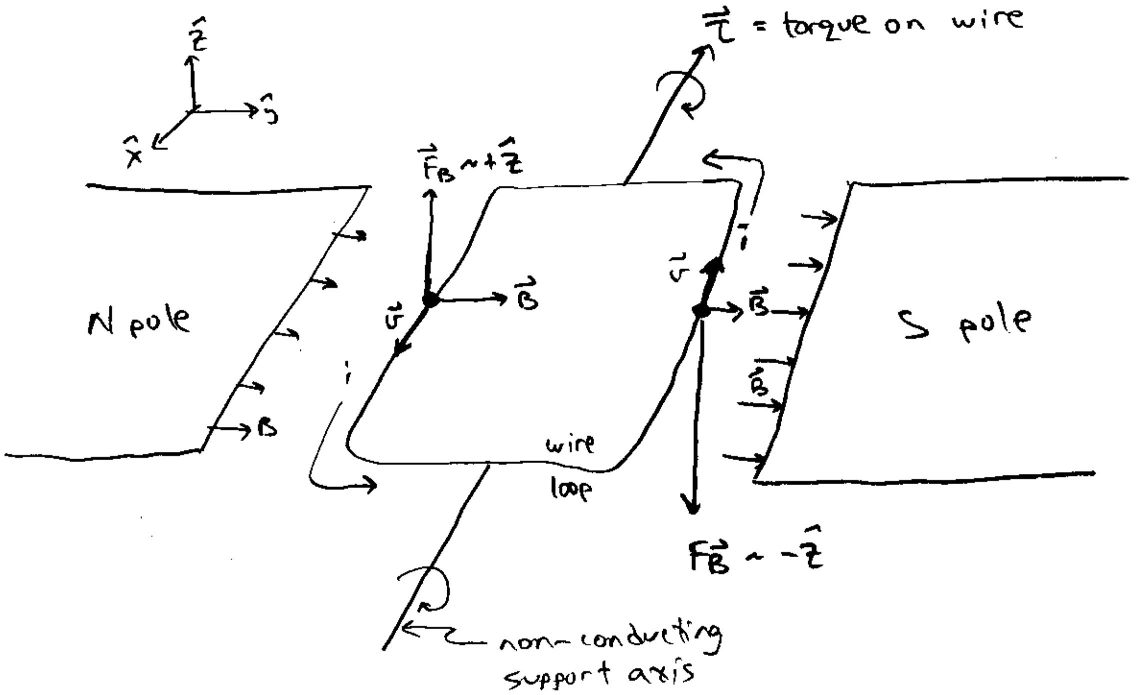
$= m_{wire}\, g = \lambda L g$

$$\Rightarrow B = \frac{\lambda L g}{iL} = \frac{\lambda g}{i} = 0.016\ \text{T}$$

~100× Earth's B-field

Current-carrying loops & Motors (section 29-8)

Consider a wire loop carrying current i while embedded between the poles of a magnet

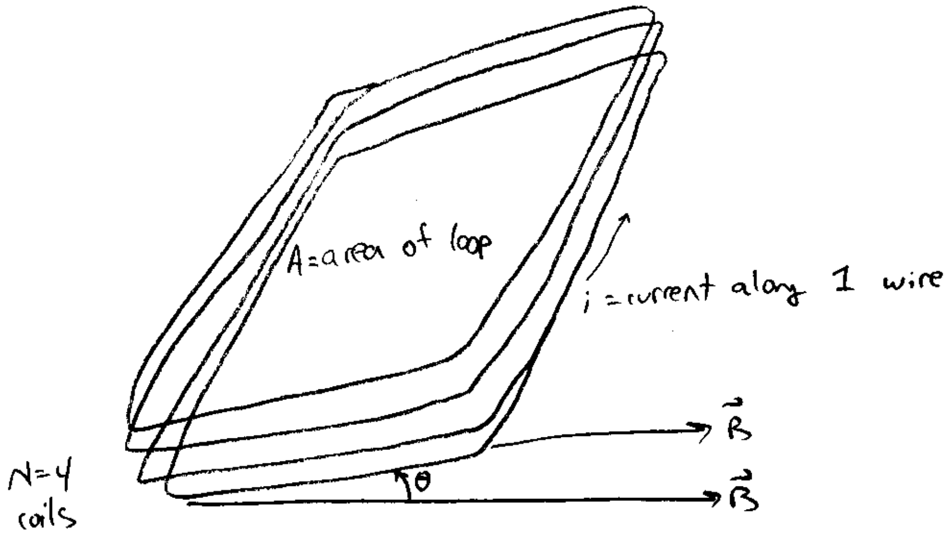


This figure illustrates the principal behind an <u>electric motor</u>:

- current flows thru wire loop that is embedded in a $\vec{B}$-field
- magnetic forces cause loop to <u>rotate</u>; ie, $\vec{B}$ <u>torques</u> the loop
- reversing the current every half-turn sustains the torque

the text shows that the torque τ is

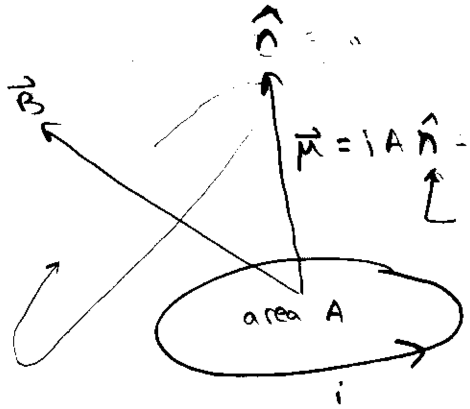
$|\vec{\tau}| = NiAB\sin\theta$ = torque on loop composed of $\underline{\underline{N}}$ coils (or turns).



we often let $\mu = NiA$ = magnetic moment of this loop.

Magnetic Dipole Moment

consider a current-carrying loop



$\vec{\mu} = iA\hat{n}$ - magnetic dipole moment of this loop

dipole is oriented perpindicular to loop

$\vec{\tau} = \mu \times \vec{B}$ = torque that $\vec{B}$ exerts on this magnetic dipole

what does this torque due to the orientation of the dipole?

Causes the dipole direction to <u>precess</u> about $\vec{B}$.