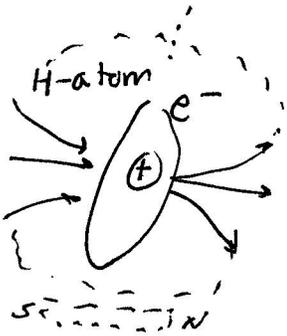
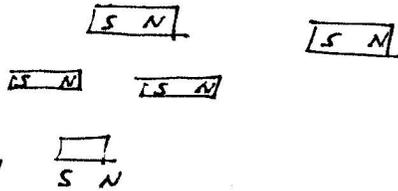
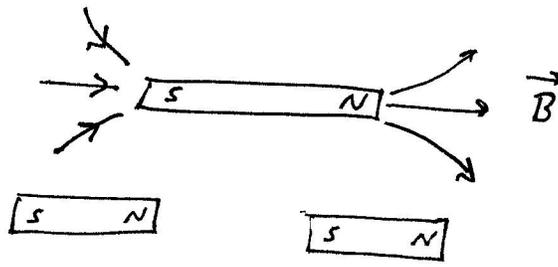


# Ch. 19 Magnetic Forces + Fields

19.1

bar magnet



⇒

where as from Gauss' Law

$$\sum E \cdot A_{ii} = \frac{q_{net}}{\epsilon_0} \Rightarrow \text{electric monopoles exist i.e. } e^-, p^+$$

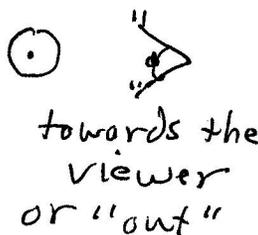
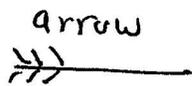
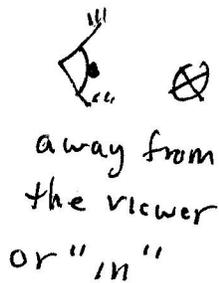
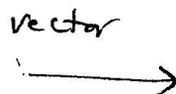
$$\sum B \cdot A_{ii} = \emptyset \Rightarrow \text{no magnetic monopoles exist no } (\otimes) \text{ or } (\odot)$$

every field line closes on itself!

magnetic field  $\vec{B} \rightarrow$  Teslas = T  $\rightarrow$  usually values mT = milli tesla

$$B_{earth} \approx 60 \mu T$$

3-dimensional vector space



# Magnetic force on a charge

$F_m \propto q$  amount of charge (C)

$B$  strength of the field (T)

$v$  speed (m/s)

$\theta$  angle between  $\vec{v}$  and  $\vec{B}$  (placed tail-to-tail)

$\rightarrow \pm 90^\circ$  (or perpendicular)  $\rightarrow$  max

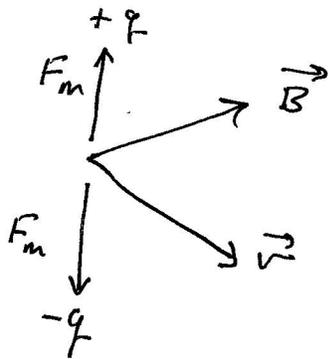
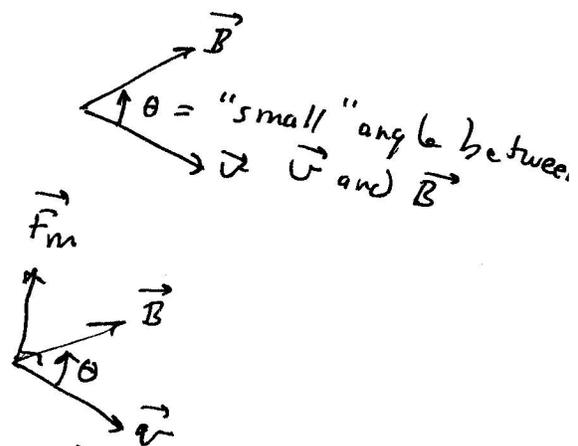
$\rightarrow 0, 180^\circ$  (parallel)  $\rightarrow$  zero  $> \sin \theta$

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

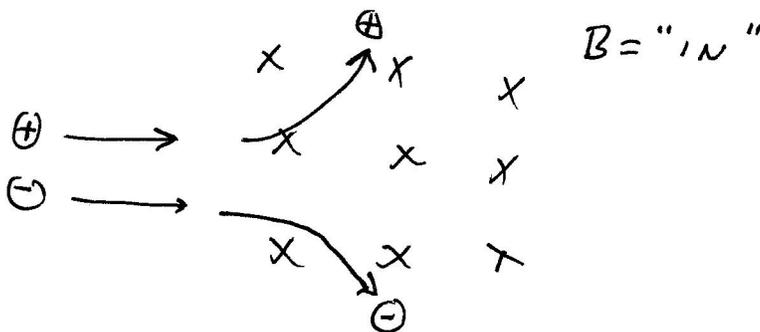
$$\vec{F}_m = q \vec{v} \times \vec{B}$$

cross-product  
(Right Hand Rule) for  $q = \oplus$

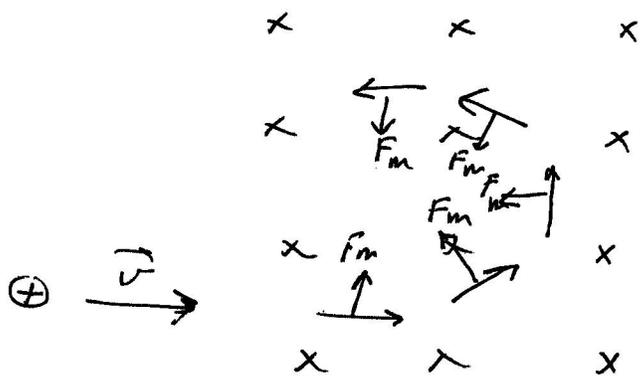
$\vec{F}_m$  is  $\perp$  to plane of  $\vec{v}$  and  $\vec{B}$



i.e.



charge entering a uniform magnetic field will circulate



$F_m$  is  $\perp$  to  $\vec{v}$  so the particle does not speed up or slow down - only change direction  $\Rightarrow$  centripetal force =  $F_c$

$$F_m = F_c = \frac{mv^2}{R} = m\omega^2 R \quad \omega = 2\pi f = \frac{2\pi}{T}$$

assuming  $\vec{B}$  is  $\perp$  to plane of  $\vec{v}$  and  $\vec{B}$ , then

$$F_m = qvB = \frac{mv^2}{R} \rightarrow \boxed{R = \frac{mv}{qB}}$$

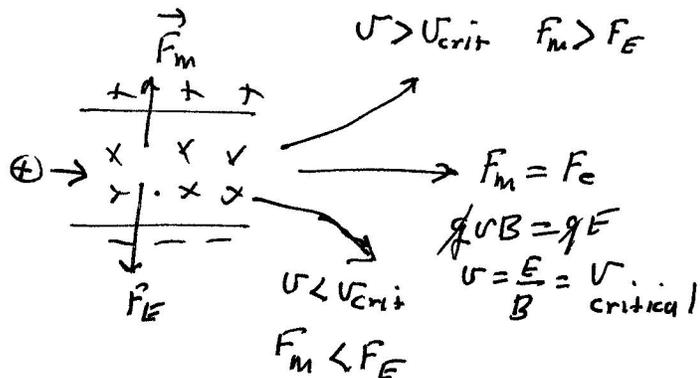
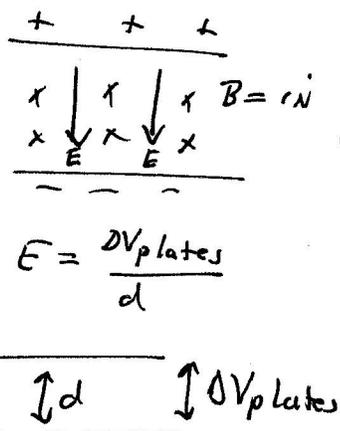
In general a charge "feels" two forces

$$\vec{F}_{net} = \vec{F}_E + \vec{F}_m = q\vec{E} + q\vec{v} \times \vec{B}$$

Velocity selector

$$q\Delta V = \frac{1}{2}mv^2$$

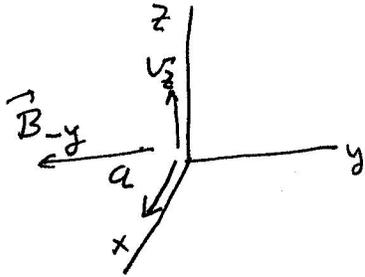
$$v = \sqrt{\frac{2q\Delta V}{m}}$$



19.2.

19.4.

19.6



proton

$$v = 1.0 \times 10^7 \text{ m/s}$$

$$a = 2 \times 10^{13} \text{ m/s}^2$$

$$F_m = qvB \sin \theta^{90^\circ}$$

$$B = \frac{F_m}{qv} = \frac{ma}{qv}$$

$$B = \frac{(1.67 \times 10^{-27} \text{ kg})(2 \times 10^{13})}{(1.6 \times 10^{-19} \text{ C})(1.0 \times 10^7 \text{ m/s})}$$

$$= \boxed{2.09 \times 10^{-2} \text{ T}}$$

-y direction

19.8

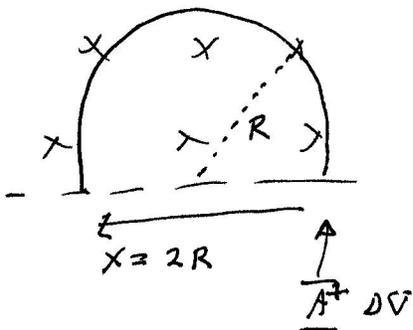
$$\Delta V = 2400 \text{ V} \quad B = 1.70 \text{ T}$$

$$|e^-| \quad eV = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2(1.6 \times 10^{-19})(2400 \text{ V})}{9.11 \times 10^{-31} \text{ kg}}} = 2.90 \times 10^7 \text{ m/s}$$

a)  $F_m(\text{max}, \theta = \pm 90^\circ) = qvB \sin 90^\circ = (1.6 \times 10^{-19})(2.90 \times 10^7)(1.70 \text{ T}) = \boxed{7.90 \times 10^{-12} \text{ N}}$

b)  $F_m(\text{min}, \theta = 0^\circ, 180^\circ) = \boxed{0}$

mass spectrometer



$$q\Delta V = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2q\Delta V}{m}}$$

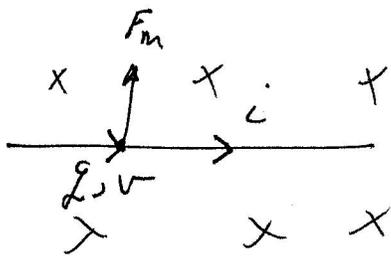
$$R = \frac{mv}{qB} = \frac{m}{qB} \cdot \sqrt{\frac{2q\Delta V}{m}}$$

$$R = \sqrt{\frac{m^2}{q^2 B^2} \cdot \frac{2q\Delta V}{m}} = \boxed{\sqrt{\frac{2m\Delta V}{qB^2}} = R}$$

OR  $R^2 = \frac{2m\Delta V}{qB^2}$

$$\Rightarrow \boxed{m = \frac{qB^2 R^2}{2\Delta V}}$$

## Magnetic force on current carrying conductor



$$F = qvB \sin \theta$$

$$q = it$$

$$l = vt$$

$$= \underbrace{itv}_l B \sin \theta$$

$$F_m = ilB \sin \theta$$

19.14  $F = ilB \sin \theta$

$$F_m = (3.0 \text{ A})(.14 \text{ m})(.2 \text{ T}) \sin 90^\circ$$

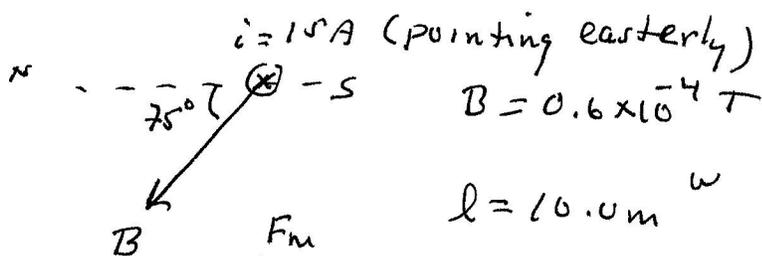
$i = 3.0 \text{ A}$        $B = .2 \text{ T}$   
 $l = 14 \text{ cm}$        $\theta = 90^\circ$

$$= \boxed{.118 \text{ N}}$$

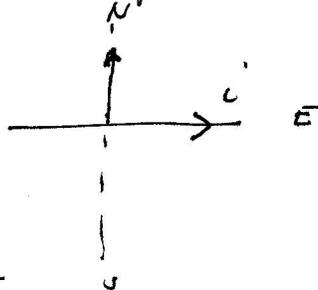
to get direction of force we need to know the direction of  $B$ .

19.18

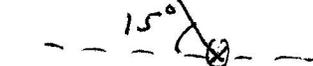
side view



top view



a)

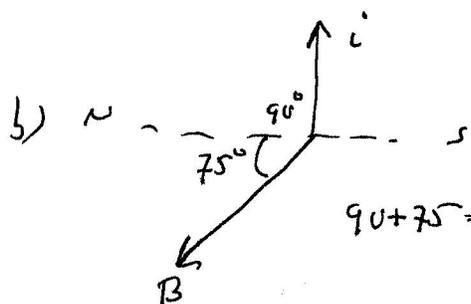


$$F_m = ilB \sin \theta$$

$$= (15 \text{ A})(10 \text{ m})(0.6 \times 10^{-4} \text{ T}) \sin 90^\circ$$

$$= \boxed{9.0 \times 10^{-3} \text{ N}}$$

b)



$$F_m = ilB \sin \theta$$

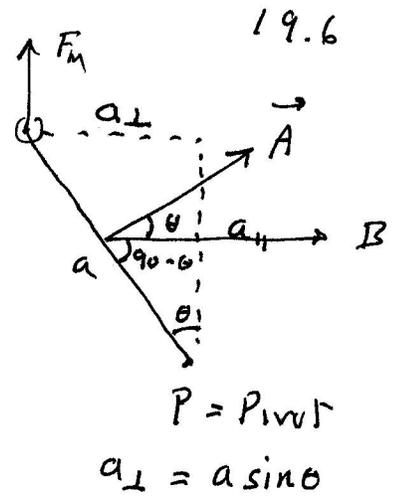
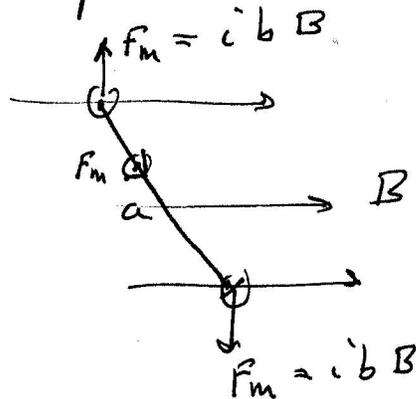
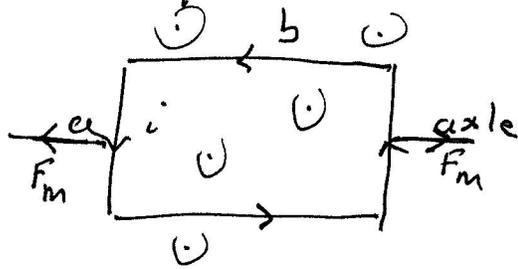
$$= (15 \text{ A})(10 \text{ m})(.6 \times 10^{-4} \text{ T}) \sin (165^\circ)$$

$$90 + 75 = 165^\circ$$

$$= \boxed{2.33 \times 10^{-3} \text{ N}}$$

Horizontal and due west

Torque on current loop.



$$\tau_p = a_{\perp} F_m = a \sin \theta i b B = i (ab) B \sin \theta$$

"  $A = A_{\text{area}}$

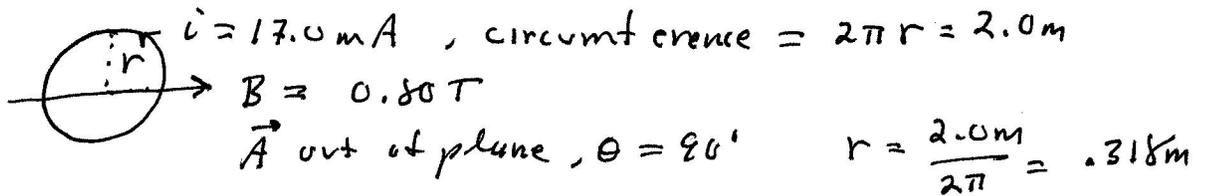
$$\tau_p = i A B \sin \theta$$

for  $N$  turns  $\rightarrow \tau_p = \underbrace{N i A}_{\mu_B} B \sin \theta$

$\mu_B = \text{magnetic dipole moment}$

$$\tau_p = \vec{\mu}_B \times \vec{B}$$

19.26

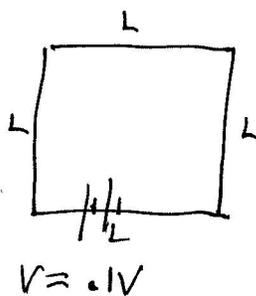


$$\tau = N i A B \sin \theta$$

$$= (1) (i) (\pi r^2) B \sin 90^\circ$$

$$= (17 \times 10^{-3} \text{ A}) \pi (.318 \text{ m})^2 (.8 \text{ T}) = \boxed{4.33 \times 10^{-3} \text{ Nm}}$$

19.30



length of wire  $= 8.0 \text{ m}$ ,  $4L = 8 \text{ m}$ ,  $L = 2.0 \text{ m}$

Area  $= 2^2 = 4 \text{ m}^2$

$A_w = 1.0 \times 10^{-4} \text{ m}^2$

$B = .4 \text{ T}$        $\tau = N i A B \sin \theta$

$$\tau = (1) (73.5 \text{ A}) (4 \text{ m}^2) (.4 \text{ T}) \sin 90^\circ$$

$$= \boxed{118 \text{ Nm}}$$

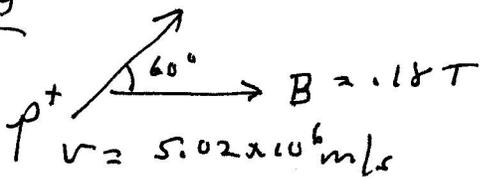
$i = \frac{V}{R}$

$$R = \frac{\rho L}{A} = \frac{(1.7 \times 10^{-8}) (8 \text{ m})}{1.0 \times 10^{-4} \text{ m}^2}$$

$$= 1.36 \times 10^{-3} \Omega$$

$$i = \frac{1 \text{ V}}{1.36 \times 10^{-3} \Omega} = 73.5 \text{ A}$$

19.34



$$F = qvB \sin \theta$$

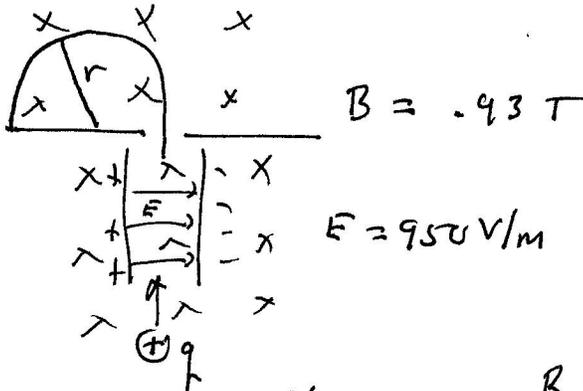
$$F = (1.6 \times 10^{-19} \text{ C})(5.02 \times 10^6 \text{ m/s})(0.18 \text{ T}) \sin 60^\circ$$

$$= 1.25 \times 10^{-13} \text{ N}$$

$$F = ma, \quad a = \frac{F}{m} = \frac{1.25 \times 10^{-13} \text{ N}}{1.67 \times 10^{-27} \text{ kg}} = 7.50 \times 10^{13} \text{ m/s}^2$$

19.7

19.36



to pass straight through the velocity selector

$$F_m = F_E \rightarrow qvB = qE$$

$$v = \frac{E}{B} = \frac{950}{0.93} = 1.02 \times 10^3 \text{ m/s}$$

$$m = 2.18 \times 10^{-26} \text{ kg}$$

singly charged = 1 e removed  
 $\therefore q = +e$

$$R = \frac{mv}{qB} = \frac{(2.18 \times 10^{-26})(1.02 \times 10^3)}{(1.6 \times 10^{-19})(0.93 \text{ T})}$$

$$R = 1.49 \times 10^{-4} \text{ m} = 0.15 \text{ mm}$$

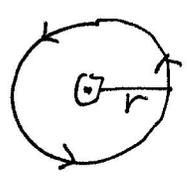
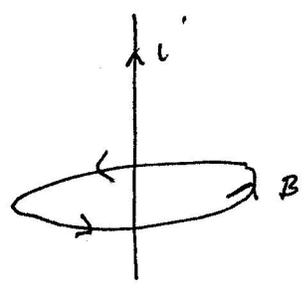
$$19.40 \quad R = \frac{mv}{qB}, \quad K = \frac{1}{2}mv^2, \quad v = \sqrt{\frac{2K}{m}}$$

$$v = \frac{qBR}{m} = \sqrt{\frac{2K}{m}} \rightarrow \frac{q^2 B^2 R^2}{m^2} = \frac{2K}{m} \rightarrow m = \frac{q^2 B^2 R^2}{2K}$$

$$v = \sqrt{\frac{2K \cdot 2K}{q^2 B^2 R^2}} = \sqrt{\frac{4K^2}{q^2 B^2 R^2}} = \frac{2K}{qBR} = v$$

Magnetic Field

1820 Hans Oersted



infinitely (very) long straight wire:

$$B = \frac{\mu_0 i}{2\pi r}$$

$\mu_0 =$  permeability of free space  
 $= 4\pi \times 10^{-7} \text{ Tm/A}$

right hand rule:  
 thumb of right hand in direction of current, fingers curl in direction of magnetic field.

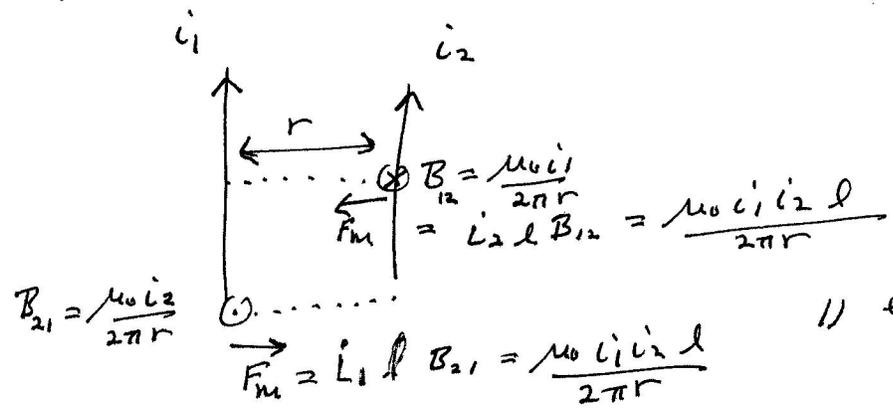
Ampere's Law: from  $B = \frac{\mu_0 i}{2\pi r}$

re-write:  $B(2\pi r) = \mu_0 i$

$$\sum (B_{||} dl) = \mu_0 i_{\text{inside enclosed Amperian Loop.}}$$

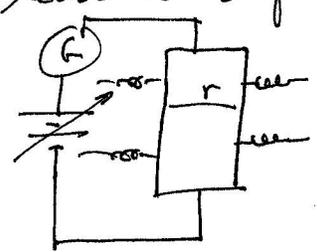


Magnetic force between parallel wires



// equal and opposite

this leads to defining current



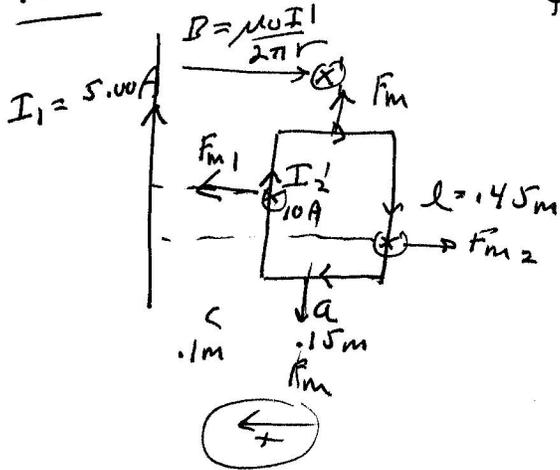
$$F/l = \frac{\mu_0 i_1 i_2}{2\pi r}$$

let  $i_1 = i_2 = 1\text{A}$   
 $r = 1\text{m}$

$$= \frac{\mu_0 (1)(1)}{2\pi (1)} = \frac{4\pi \times 10^{-7}}{2\pi} = 2 \times 10^{-7} \text{ N/m}$$

a number

19.58



the "y" components add to zero



$$F_{net} = F_{m1} - F_{m2}$$

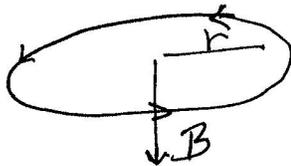
$$= I_2 l \frac{\mu_0 I_1}{2\pi c} - I_2 l \frac{\mu_0 I_1}{2\pi (a+c)}$$

$$F_{net} = \frac{(10A)(1.45)(4\pi \times 10^{-7})(5A)}{2\pi (0.1)} - \frac{(10)(1.45)(4\pi \times 10^{-7})(5A)}{2\pi (0.25)}$$

$$= 4.50 \times 10^{-5} - 1.80 \times 10^{-5}$$

$$= 2.70 \times 10^{-5} \text{ N to the left}$$

current loop!



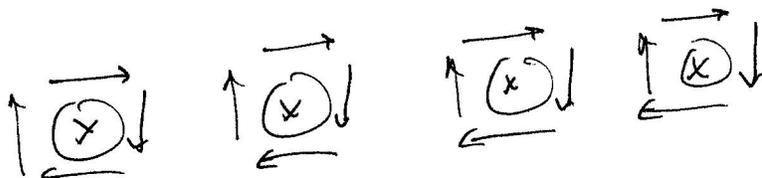
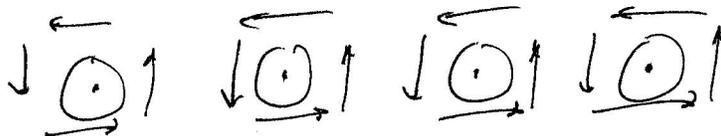
$$B = \frac{\mu_0 i}{2r}$$

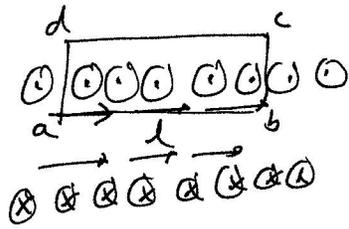
or for N turns

$$B = N \frac{\mu_0 i}{2r}$$

= "loosely wound coil"

solenoid! long narrow, tightly wound coil





$$\sum B_{||} dl = \mu_0 i$$

$$\sum ab + bc + cd + da = \mu_0 i$$

$$Bl + 0 + 0 + 0 = \mu_0 N i$$

$$B = \mu_0 \frac{N}{l} i = \boxed{\mu_0 n i = B}$$

$N = \# \text{ loops}$

$n = \# \text{ loops/meter}$

19.60 superconducting solenoid  
 $l = .50 \text{ m}$

$$B = 9.0 \text{ T}$$

$$i = 75 \text{ A}$$

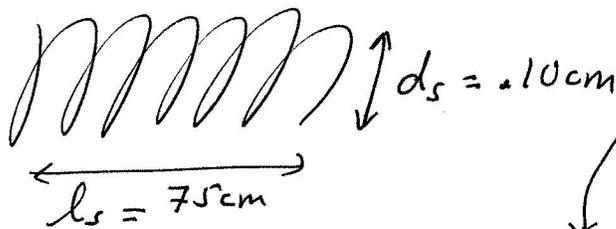
solenoid

$$B = \mu_0 n i = \mu_0 \frac{N}{l} i$$

$$N = \frac{Bl}{\mu_0 i} = \frac{(9 \text{ T})(.50 \text{ m})}{(4\pi \times 10^{-7})(75 \text{ A})}$$

$$\boxed{N = 4.78 \times 10^4 \text{ turns}}$$

19.62



copper:  $d_w = 1.0 \text{ cm}$

? Power  $\rightarrow B = 8.0 \text{ mT}$

$$B = \mu_0 n i = \mu_0 \frac{N}{l_s} i$$

$$N = \frac{l_s}{d_w} = \frac{.75 \text{ m}}{(.1 \times 10^{-2} \text{ m})} = 750 \text{ turns}$$

$$i = \frac{B l_s}{\mu_0 N} = \frac{(0.008 \text{ T})(.75 \text{ m})}{(4\pi \times 10^{-7})(750 \text{ turns})} = 6.37 \text{ A}$$

$$R = \frac{\rho L_w}{A_w}, \quad L_w = N(\pi d_s) = (750 \text{ turns})\pi(.1 \times 10^{-2}) = 236 \text{ m}$$

$$R = \frac{\rho L_w}{\frac{\pi d_w^2}{4}} = \frac{4 \rho L_w}{\pi d_w^2} = \frac{4(1.7 \times 10^{-8})(236 \text{ m})}{\pi(.1 \times 10^{-2} \text{ m})^2} = 5.11 \Omega$$

$$P = i^2 R = (6.37 \text{ A})^2 (5.11 \Omega) = \boxed{207 \text{ Watts}}$$