- Magnetic fields
  - North + south pole
  - Like poles repel
  - unlike poles attract

- B field is defined by the fact that a moving charge in a magnetic field can experience a magnetic force, F_B

$$\vec{F}_B = q\vec{v} \times \vec{B}$$
$$\|F_B\| = qvB\sin\theta$$

$$B = \frac{F_B}{qv\sin\theta} = \frac{N}{C\cdot\frac{m}{s}} = \frac{N}{\frac{C}{s}\cdot m}$$

$$B = \frac{N}{A\cdot m} = \text{Tesla, } T$$

1 Tesla = 10000 gauss, G

- The Right Hand Rule
  - Fingers point w/ velocity
  - Fingers curl w/ B-field ($\approx 90°$)
  - Thumb points w/ magnetic force for $+q$ ($-q$ then $180°$)

    ⊙ out of board

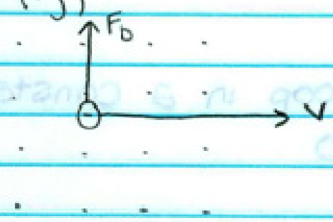
    ⊗ into board

Thank You, Emily Rencsok, for these notes.

Ex e^- @ $v_i = 3.0 \times 10^6$ m/s $\hat{i}$

$\vec{B} = 450\ \mu T\ \hat{k}$

$\vec{F}_b = ?\ (+\hat{j})$



$F_B = qV \times B$

$= (-1.6\times10^{-19})(3\times10^{6}\hat{i}) \times 450\times10^{-6}\hat{k}$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ (-1.6\times10^{-19})\times(3\times10^{6}) & 0 & 0 \\ 0 & 0 & 450\times10^{-6} \end{vmatrix}$$

$= [(0)(450\times10^{-6}) - 0(0)]\hat{i} - [(-1.6\times10^{-19})(3\times10^{6})(450\times10^{-6}) - 0(0)]\hat{j}$

$+ [(-1.6\times10^{-19})(3\times10^{6})(0) - 0(0)]\hat{k}$

$= \boxed{2.2\times10^{-16}\ N\ \hat{j}}$

Derivation of Magnetic Force on a Current Carrying Straight Wire

AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

- Current-carrying wire
  - moving charges

$$I = \frac{\Delta Q}{\Delta t} = \frac{n \mathcal{V} q}{\Delta t} = \frac{n A \Delta x\, q}{\Delta t} = \frac{n A v_d \Delta t\, q}{\Delta t} = n A v_d q$$

$n = \frac{\text{charges}}{\text{volume}}$

$n \mathcal{V} q = \text{charge}$ $\qquad F_B = qv \times B \longrightarrow$ a single charge

$n \mathcal{V} = nAL$ (L ← length of wire) $\qquad F_B = (qv \times B)\,nAL$ on wire

$F_B = qvnAL \times B$

$$\boxed{\vec{F}_B = I\vec{L} \times \vec{B}} \rightarrow \text{wire}$$

- Not straight wire
  - B field is constant

$$F_B = IL \times B$$

$$\int dF_B = \int I\,ds \times B$$

$$F_B = I\int_a^b ds \times B$$

$$F_B = IL' \times B$$

L' is the straight line between A + B

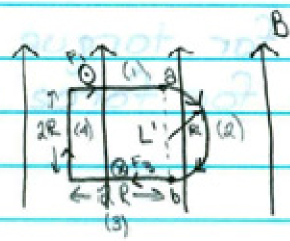
closed loop integral

$$F_B = I\oint ds \times B$$

$$\oint ds = 0$$

F_B on a closed loop in a constant B field is zero

Ex)



$$F_{B1} = IL \times B = ILB\sin\theta$$
$$= I(2R)(B)\sin 90^\circ$$
$$= \boxed{2IRB\ +\hat{k}}$$

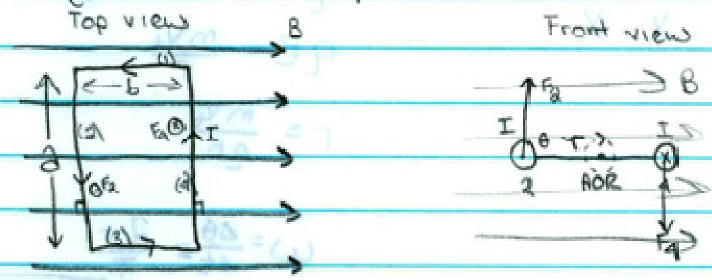
$$\boxed{F_{B3} = 2IRB\ -\hat{k}}$$

$$F_{B4} = ILB\sin\theta$$
$$= ILB\sin 0 = \boxed{0}$$

$$F_2 = \boxed{0}$$
$$= IL' \times B$$
$$= IL'B\sin\theta$$
$$= IL'B\sin 180$$
$$= 0$$

Last wire has to be 0 N since it's a closed loop

- Torque on a loop in a uniform B field



$F_1 = F_3 = 0$

$\theta = 0^\circ$ or 180°

$\|F_2\| = \|F_4\| = ILB\sin\theta$

$= IaB\sin 90^\circ$

$= IaB$

θ is still 90° even after it turns

$\Sigma\tau_{AOR} = \vec{r} \times \vec{F}$

$= rF\sin\theta$

$= r(2F_B)\sin\theta$

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

$= IabB\sin\theta$ — area vector

$\tau_{net} = I\vec{A}\vec{B}\sin\theta$

$\tau_{net} = I\vec{A} \times \vec{B}$ for any AOR + for any shape

θ for torque changes

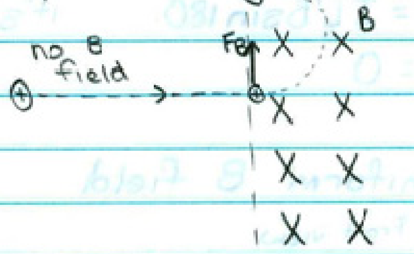
θ for force doesn't

$\tau_{net} = N(I\vec{A} \times \vec{B})$

↑ # of loops ↑ single loop

Thank You, Emily Rencsok, for these notes.

Ex | p^+ entering uniform B field @ 90° to B field



$$\Sigma F_{in} = F_B = m a_c$$

$$= q v B \sin\theta = m \frac{v_t^2}{r} = m r \omega^2$$

$$q B \sin 90 = \frac{m v_t}{r}$$

$$q B = \frac{m v_t}{r}$$

$$r = \frac{m v_t}{qB}$$

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T}$$

$$T = \frac{2\pi}{\omega} = \boxed{\frac{2\pi m}{qB}}$$

$$v_t = \frac{r q B}{m}$$

$$r\omega = \frac{r q B}{m}$$

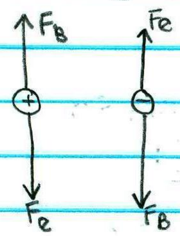
$$\boxed{\omega = \frac{qB}{m}}$$

↑ angular frequency ≠ frequency
(cyclotron)

$$T = \frac{1}{f}$$

- Figure p. 911 mass spectrometer

- Velocity selector



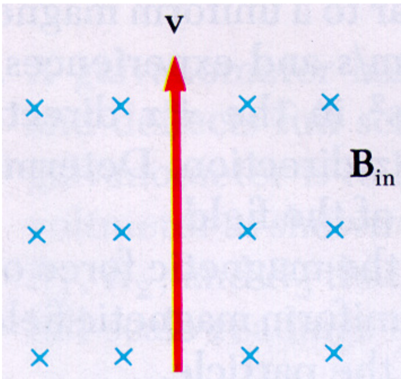
$$\Sigma F_y = F_B - F_e = \cancel{m a_y} = 0$$
$$F_B = F_e$$
$$\cancel{q} V B \sin\theta = \cancel{q} E$$
$$V B \sin 90° = E$$
$$VB = E$$
$$V = \frac{E}{B}$$

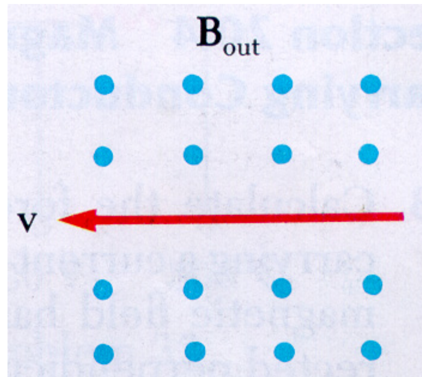
- Detector

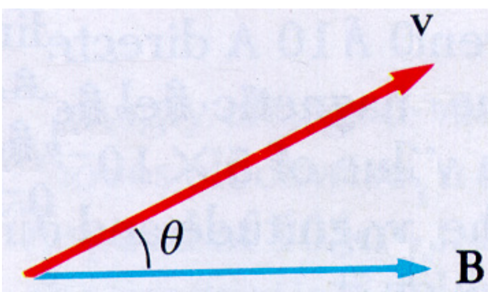
$$\Sigma F_{in} = F_B = m a_c$$
$$q \cancel{V} B \sin\theta = m \frac{V_t^{\cancel{2}}}{R}$$
$$q B \sin 90 = \frac{m V_t}{R}$$
$$q B = \frac{m V_t}{R}$$
$$q B = \frac{m \frac{E}{B}}{R}$$
$$\boxed{\frac{m}{q} = \frac{R B^2}{E}}$$ mass-to-charge ratio

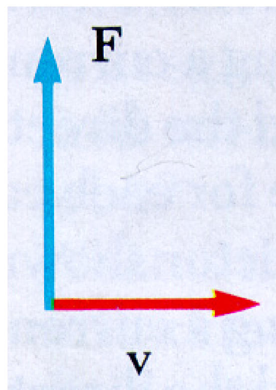
Magnetic Force Right Hand Rule Examples
8
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

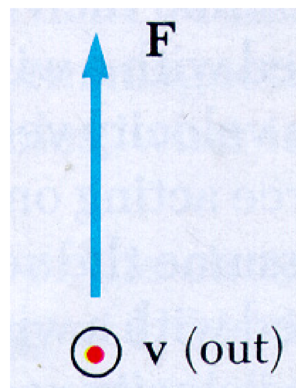
SF3 20-7) Find the direction of the missing component. Unless otherwise stated, Assume Positive Charge.



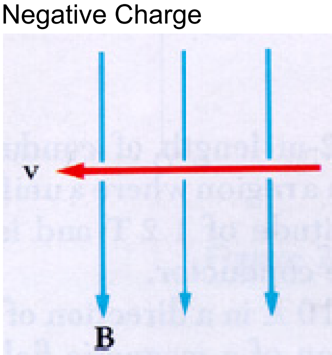




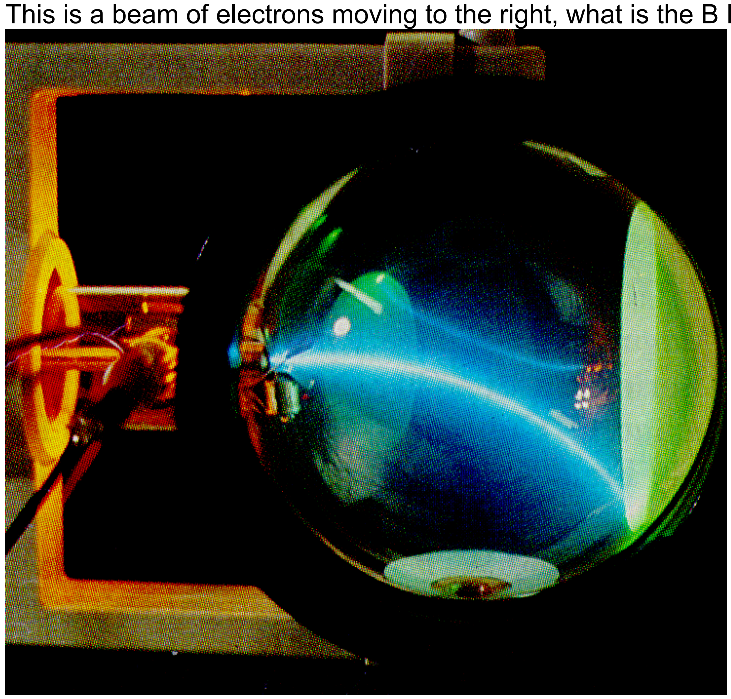




Negative Charge

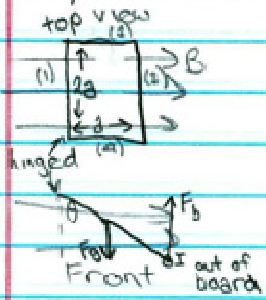


This is a beam of electrons moving to the right, what is the B Field Direction?



Thank You, Emily Rencsok, for these notes.

Ex) $\mu = 20.0 \frac{g}{m}$ $B = 150$ mT $I = ?$ mag + direction



F_1 is irrelevant because $\tau_{F_1} = 0$ since $r = 0$

$\tau_2 + \tau_4$ cancel

I is clockwise

$\vec{F}_{B3} = I\vec{L} \times \vec{B} = ILB\sin\theta$

$F_{B3} = I(2a)(B)\sin 90$

$F_{B3} = 2IaB$

$\Sigma\tau = \tau_{FB_3} - \tau_{Fg} = I\alpha = 0$

AOR @ hinge

$\tau_{FB_3} = \tau_{Fg}$

$r_{B3} F_{B3} \sin\theta_{B3} = r_{g} F_g \sin\theta_{Fg}$

$\mu = \frac{m}{\ell} = \frac{m}{6a}$

$m = 6a\mu$

$a(2IaB)\sin\theta_{B3} = \left(\frac{a}{2}\right) mg \sin\theta_{Fg}$

$2IaB = \frac{mg}{2}$

$I = \frac{mg}{4aB}$

$I = \frac{6a\mu g}{4aB}$

$I = \frac{3\mu g}{2B} = \frac{3(0.02)(9.8)}{2(0.150)}$

I = 1.96 A CW from above

Example - Period of an Electron moving Perpendicular to a Constant Magnetic Field
10
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

Ex| e^- moving $\perp$ to

$B = 755\ nT$

$\frac{\Delta t}{rev} = ? = T$

$\Sigma F_{in} = F_B = m a_c$

$q v B \sin\theta = m \frac{v_t^2}{r}$ ($\theta = 90°$)

$qB = m v_t / r$

$qB = m r \omega / r$

$qB = \frac{m 2\pi}{T}$

$T = \frac{2\pi m}{qB} = \frac{2\pi(9.11\times10^{-31})}{(1.6\times10^{-19})(755\times10^{-9})}$

$T = 4.74\times10^{-5} = \boxed{47\,\mu s}$

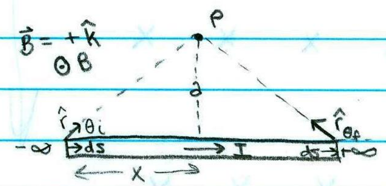
$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T}$

- Biot-Savart Law

$\mu_0 = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$ (permeability of free space)

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{s} \times \hat{r}}{r^2}$$

$$\vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{ds \times \hat{r}}{r^2}$$



$$\sin\theta = \frac{O}{H} = \frac{a}{r}$$

$$r = a/\sin\theta$$

$$r = a\csc\theta$$

$$\tan\theta = \frac{O}{A} = \frac{a}{-x}$$

$$x = -a/\tan\theta$$

$$x = -a\cot\theta$$

$$dx = -a(-\csc^2\theta)\,d\theta$$

$$dx = a\csc^2\theta\,d\theta$$

$$d\vec{s} \times \hat{r} = (dx\, r \sin\theta)\hat{k}$$ (with $r = 1$)

$$= dx\sin\theta\,\hat{k}$$

$$B = \frac{\mu_0 I}{4\pi} \int \frac{dx \sin\theta}{r^2}$$

$$B = \frac{\mu_0 I}{4\pi} \int \frac{a\csc^2\theta\, d\theta\, \sin\theta}{(a\csc\theta)^2}$$

$$B = \frac{\mu_0 I}{4\pi} \int \frac{a\csc^2\theta \sin\theta\, d\theta}{a^2\csc^2\theta}$$

$$B = \frac{\mu_0 I}{4\pi} \int \frac{\sin\theta\, d\theta}{a}$$

$$B = \frac{\mu_0 I}{4\pi a} \int_{\theta_i}^{\theta_f} \sin\theta\, d\theta$$

$$B = \frac{\mu_0 I}{4\pi a} \left[-\cos\theta\right]_{\theta_i}^{\theta_f}$$

$$B = \frac{\mu_0 I}{4\pi a} \left(-\cos\theta_f - (-\cos\theta_i)\right)$$

$$B = \frac{\mu_0 I}{4\pi a} \left(\cos\theta_i - \cos\theta_f\right)$$

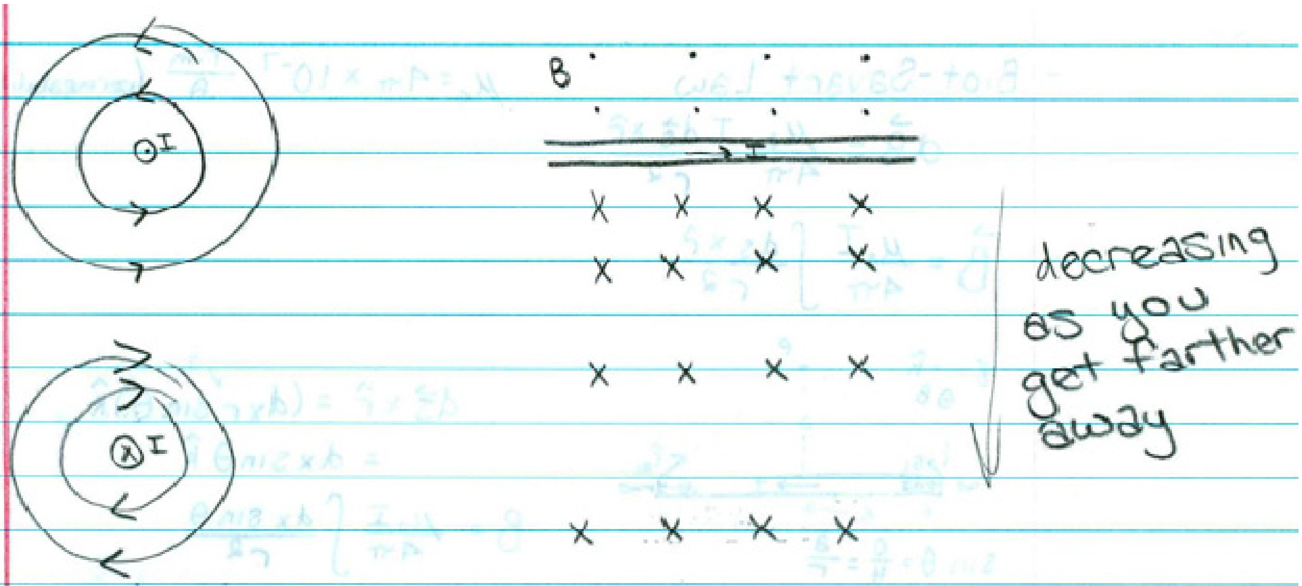
$$B = \frac{\mu_0 I}{4\pi a} \left(\cos 0 - \cos 180\right)$$

$$B = \frac{\mu_0 I}{4\pi a} \left(1 - (-1)\right)$$

$$B = \frac{\mu_0 I}{4\pi a} (2)$$

$$\boxed{B = \frac{\mu_0 I}{2\pi a}}\ \hat{k}$$

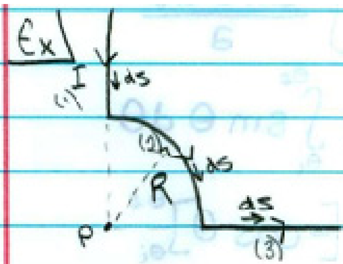
Magnetic Field Lines around Straight Current Carrying Wires
12
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.



B field lines don't have to start + end on magnetic poles. They are "always" closed loops. No magnetic monopole.

Example - Magnetic Field at the Center of a Quarter Circle Wire
13
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

Ex



$$B = \frac{\mu_0 I}{4\pi} \int \frac{d\vec{s} \times \hat{r}}{r^2}$$

$$B_2 = \frac{\mu_0 I}{4\pi} \int \frac{ds}{r^2}$$

$$B_2 = \frac{\mu_0 I}{4\pi R^2} \int ds$$

$$B_2 = \frac{\mu_0 I s}{4\pi R^2}$$

$S = R\theta$ ↑ θ in radians

$$B_2 = \frac{\mu_0 I R \theta}{4\pi R^2}$$

$$B_2 = \frac{\mu_0 I \theta}{4\pi R}$$

(1) $d\vec{s} \times \hat{r} = ds\,\hat{r} \sin\theta$

(1) $\theta_1 = 0^\circ$ so $B_1 = 0$

(3) $\theta_3 = 0^\circ$ so $B_3 = 0$

(2) $d\vec{s} \times \hat{r} = ds\,\hat{r} \sin\theta$

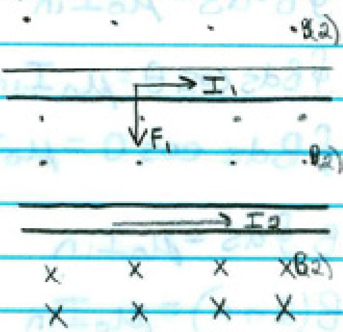
$= ds(1)\sin 90$

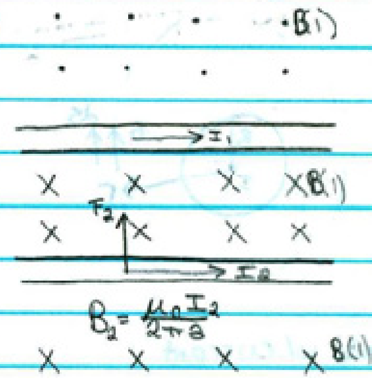
(2) $d\vec{s} \times \hat{r} = ds$

$\theta = \frac{\pi}{2}$ rad $\rightarrow B_Q = \frac{\mu_0 I \frac{\pi}{2}}{4\pi R} = \boxed{\frac{\mu_0 I}{8R}}$

$\theta = 2\pi$ rad $\rightarrow B = \frac{\mu_0 I 2\pi}{4\pi R} = \frac{\mu_0 I}{2R}$

- 2 parallel wires





I same dir = attract

I opp dir = repel

$F_1 = I \ell B \sin\theta$

$F_1 = I_1 \ell B_2 \sin 90$

$F_1 = I_1 \ell B_2$

$F_1 = I_1 \ell \left(\frac{\mu_0 I_2}{2\pi a}\right)$

$$\boxed{F_1 = \frac{\mu_0 \ell I_1 I_2}{2\pi a}}$$ On either wire

$$\boxed{\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi a}}$$

Derivation of Ampere's Law and Magnetic Field Outside a Current Carrying Wire
15
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

- Ampere's Law
  - B field // to Gauss' Law

$$\oint B \cdot ds = \oint B\,ds\cos\theta$$
$$= \oint B\,ds\cos 0$$
$$= \oint B\,ds$$
$$= B\oint ds$$
$$= \frac{\mu_0 I}{2\pi r}2\pi r$$
$$= \mu_0 I$$

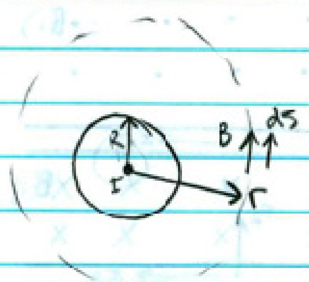
$$\boxed{\oint B \cdot ds = \mu_0 I_{in}}$$

inside Amperian loop

true for any shape

Ex)

$r \geq R$

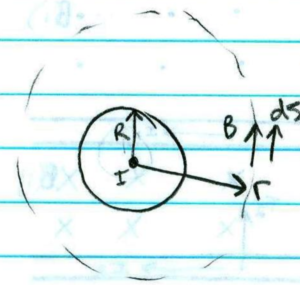


Thumb w/ current
Fingers curl w/ B

$$\oint B \cdot ds = \mu_0 I_{in}$$
$$\oint B\,ds\cos\theta = \mu_0 I_{in}$$
$$\oint B\,ds\cos 0 = \mu_0 I_{in}$$
$$B\oint ds = \mu_0 I_{in}$$
$$B(2\pi r) = \mu_0 I_{in}$$
$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

Example - Magnetic Field Inside a Current Carrying Wire
16
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

Ex|



Thumb w/ current
Fingers curl w/ B

$r \geq R$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{in}$$

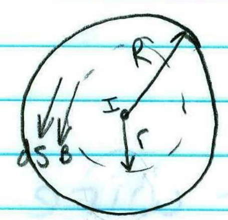
$$\oint B\,ds \cos\theta = \mu_0 I_{in}$$

$$\oint B\,ds \cos 0 = \mu_0 I_{in}$$

$$B \oint ds = \mu_0 I_{in}$$

$$B(2\pi r) = \mu_0 I_{in}$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$



$r < R$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{in}$$

$$\oint B\,ds \cos\theta = \mu_0 I_{in}$$

$$\oint B\,ds \cos 0 = \mu_0 I_{in}$$

$$B \oint ds = \mu_0 \frac{I r^2}{R^2}$$

$$B(2\pi r) = \frac{\mu_0 I r^2}{R^2}$$

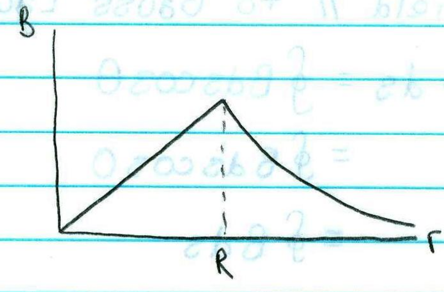
$$\boxed{B = \frac{\mu_0 I r}{2\pi R^2}}$$

$$J_t = J_{in}$$

$$\frac{I_t}{A_t} = \frac{I_{in}}{A_{in}}$$

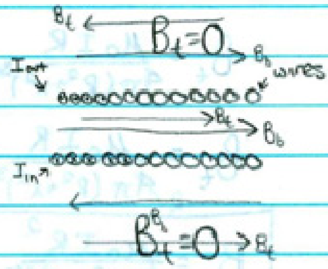
$$\frac{I}{\pi R^2} = \frac{I_{in}}{\pi r^2}$$

$$I_{in} = \frac{I r^2}{R^2}$$



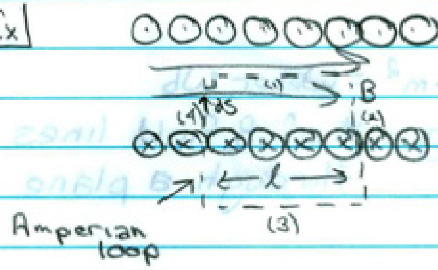
Thank You, Emily Rencsok, for these notes.

- Solenoid



Ideal solenoid → $B_{outside} = 0$

Ex



$$\oint B \cdot ds = \mu_0 I_{in}$$

$$\int_1 B \cdot ds + \int_2 B \cdot ds + \int_3 B \cdot ds + \int_4 B \cdot ds = \mu_0 I_{in}$$

(2: $\theta = 90°$; 3: $B = 0$; 4: $\theta = 90°$)

$$\int_{\text{side } 1} B \cdot ds = \mu_0 I_{in}$$

$$B \int ds \cos 0 = \mu_0 I_{in}$$

$$B\ell = \mu_0 I_{in}$$

$$B\ell = \mu_0 N I$$

(N = # of turns)

$$\boxed{B = \frac{\mu_0 N I}{\ell}}$$

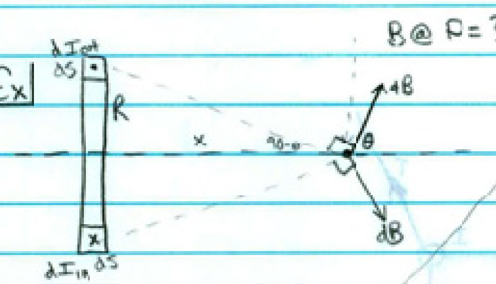
$B_s = \mu_0 n I$

n: turn density $= \frac{\text{\# loops}}{\text{length}}$

Example - Magnetic Field along the Axis of a Current Carrying Circle
18
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

Current carrying loop

Ex



$dB_x = dB\cos\theta$

$dB = \frac{\mu_0 I}{4\pi}\frac{ds}{R^2+x^2}$

$dB_x = \frac{\mu_0 I}{4\pi}\frac{ds}{R^2+x^2}\cos\theta$

$\cos\theta = \frac{A}{H} = \frac{R}{\sqrt{R^2+x^2}}$ $\quad dB = \frac{\mu_0 I}{4\pi}\frac{ds \times \hat{r}}{r^2}$

$dB_x = \frac{\mu_0 I}{4\pi}\frac{ds}{R^2+x^2}\frac{R}{\sqrt{R^2+x^2}}$

$|ds \times \hat{r}| = ds(r)\sin\theta$

$= ds(1)\sin 90$

$|ds \times \hat{r}| = ds$

$dB_x = \frac{\mu_0 I R\, ds}{4\pi(R^2+x^2)^{3/2}}$

$B_t = B_x = \oint \frac{\mu_0 I R}{4\pi(R^2+x^2)^{3/2}}\, ds$

$B_t = \frac{\mu_0 I R}{4\pi(R^2+x^2)^{3/2}}\oint ds$

$B_t = \frac{\mu_0 I R}{4\pi(R^2+x^2)^{3/2}}(2\pi R)$

$$\boxed{B_t = \frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}}\hat{i}}$$

if $x = 0$, $B_t = \frac{\mu_0 I R^2}{2(R^2)^{3/2}} = \boxed{\frac{\mu_0 I}{2R}}$

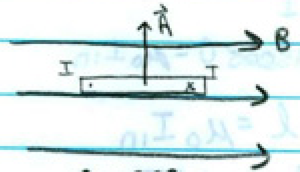
Thank You, Emily Rencsok, for these notes.

- Magnetic Flux

$T \cdot m^2$ = Weber, Wb

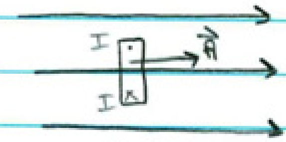
$\Phi_B = \int B \cdot dA = BA\cos\theta$ — # of B field lines through a plane

$\Phi_E = \int E \cdot dA$



$\theta = 90°$

$\Phi_B = 0$

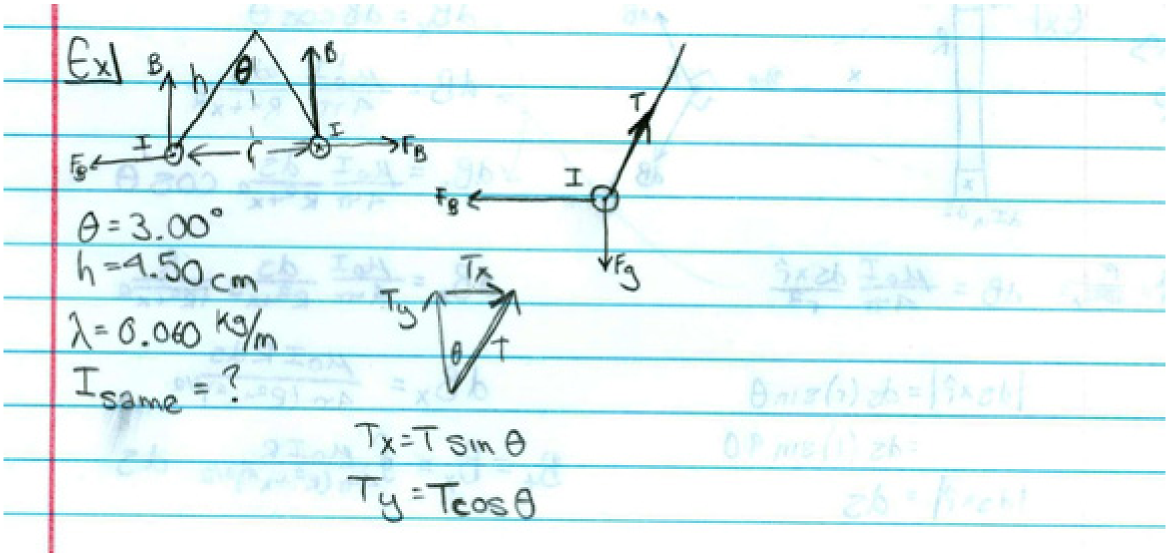


$\theta = 0°$

Φ_B = max

- Gauss' Law in Magnetism

$\oint \vec{B} \cdot d\vec{A} = 0$


Ex
B
h
θ
B
I
I
F_B
r
F_B
$\theta = 3.00°$
$h = 4.50$ cm
$\lambda = 0.060$ kg/m
$I_{same} = ?$
T_x
T_y
θ
T
$T_x = T \sin\theta$
$T_y = T\cos\theta$
T
I
F_B
F_g

$$\Sigma F_y = T_y - F_g = m\cancel{a_y} = 0$$
$$T_y = F_g$$
$$T\cos\theta = mg$$
$$T = \frac{mg}{\cos\theta}$$

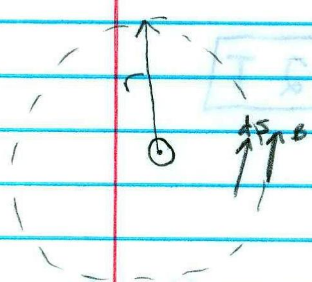
$$\Sigma F_x = T_x - F_B = m\cancel{a_x} = 0$$
$$T_x = F_B$$

$\lambda = \frac{m}{\ell}$

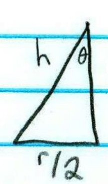
$m = \lambda \ell$

$$T\sin\theta = I\ell B\sin\theta$$
$$\frac{mg}{\cos\theta}\sin\theta = I\ell B\sin\theta$$

$$mg\tan\theta = I\ell B\cancel{\sin 90}$$
$$mg\tan\theta = I\ell B$$
$$\lambda \cancel{\ell} g\tan\theta = I\cancel{\ell}B$$
$$I = \frac{\lambda g\tan\theta}{B}$$



$$\oint B \cdot ds = \mu_0 I_{in}$$
$$\oint B\,ds\cancel{\cos\theta} = \mu_0 I_{in} \quad \theta = 0°$$
$$B\oint ds = \mu_0 I_{in}$$
$$B\,2\pi r = \mu_0 I$$
$$B = \frac{\mu_0 I}{2\pi r}$$



$$I = \frac{\lambda g\tan\theta}{\mu_0 I/2\pi r}$$

$\sin\theta = \frac{o}{H} = \frac{r/2}{h}$

$r = 2h\sin\theta$

$$I = \frac{\lambda g\tan\theta\,2\pi\,2h\sin\theta}{\mu_0 I}$$
$$I^2 = \frac{4\pi h\lambda g\tan\theta\sin\theta}{\mu_0}$$
$$\boxed{I = \sqrt{\frac{4\pi\lambda g h\sin\theta\tan\theta}{\mu_0}}}$$

$$\boxed{I = 27\text{ A}}$$

Thank You, Emily Rencsok, for these notes.

29-54)

$m = 0.200\ kg$

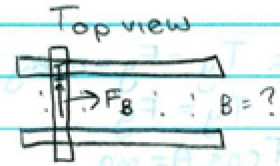
$I = 10.0\ A$

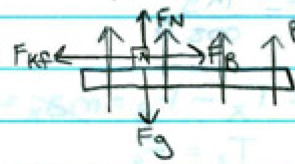
$\ell = 0.500\ m$

$B = ?$

C.V.

$\mu_K = 0.100\ m$



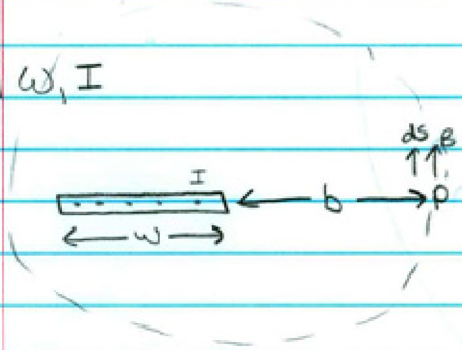


$$\Sigma F_y = F_N - F_g = ma_y = 0$$
$$F_N = F_g = mg$$

$$\Sigma F_x = F_B - F_{Kf} = ma_x = 0$$
$$F_B = F_{Kf}$$
$$I \ell B \sin\theta = \mu_K F_N$$
$$I \ell B \sin 90^\circ = \mu_K mg$$
$$B = \frac{\mu_K mg}{I\ell} = \boxed{0.0392\ T}$$

Problem 30-49 - Magnetic Field around a Flat Wire
22
AP Physics C – Video Lecture Notes
Chapter 29-30
Thank You, Emily Rencsok, for these notes.

30-49) ω, I



$$\oint \vec{B}\cdot d\vec{s} = \mu_0 I_{in}$$

$$\oint B\,ds\cos\theta = \mu_0 I_{in} \quad \theta = 0^\circ$$

B isn't constant

$$B\,2\pi\left(b+\frac{w}{2}\right) = \mu_0 I$$

← r isn't constant

$$B = \frac{\mu_0 I}{2\pi\left(b+\frac{w}{2}\right)}$$

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

$$dB = \frac{\mu_0\,dI}{2\pi r}$$

$$\frac{I}{w} = \frac{dI}{dr}$$

$$B = \int \frac{\mu_0\,dI}{2\pi r} = \int \frac{\mu_0}{2\pi r}\,\frac{I}{w}\,dr$$

$$dI = \frac{I}{w}\,dr$$

$$B = \frac{\mu_0 I}{2\pi w}\int_b^{b+w} \frac{1}{r}\,dr = \frac{\mu_0 I}{2\pi w}\left[\ln r\right]_b^{b+w}$$

$$B = \frac{\mu_0 I}{2\pi w}\left(\ln(b+w) - \ln b\right)$$

$$\boxed{B = \frac{\mu_0 I \ln\left(\frac{b+w}{b}\right)}{2\pi w}} \text{ up}$$

$\tau_{loop} = N(IA \times B)$ *memorize + prove

q => ⊥ B field moves in a circle

$\Sigma F_{in} = F_B = ma_c$

$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T}$

Biot-Savart

$dB = \frac{\mu_0 I}{4\pi} \frac{ds \times \hat{r}}{r^2}$ B field @ center of circle/ part of circle/ on axis of circle

$B = \frac{\mu_0 I}{2\pi a}$ ∞ long I wire

Ampere's Law

$\oint B \cdot ds = \mu_0 I_{in}$

RHR

1) Thumb => I
Curl => B

2) Fingers => V or I
Curl => B
Thumb => F_B (+charge)
(-q 180°)

$\oint B \cdot dA = 0$

2 parallel wires