PHYSICS II

Electricity and Magnetism

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Kaynak: Sears Zemansky Physics
14th.

~Serway; Fundamentals of Phys.

Ders notları; soru

3 vize → 20+20+20
1 final → 40

S R E 13:45 — 1730

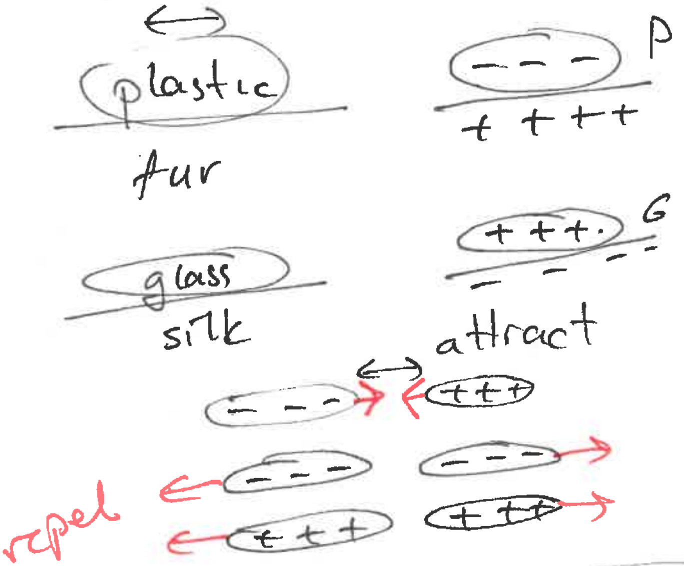
- → electric charge; electric field; force
- → gauss law
- → electric potential
- → capacitance
- → V=IR ; devreler... DC
- → magnetic field forces
sources of mag. field.

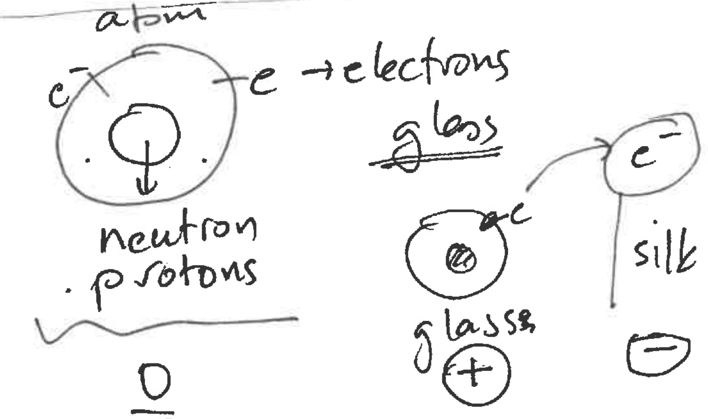
4.7.17
①

Electric Charge

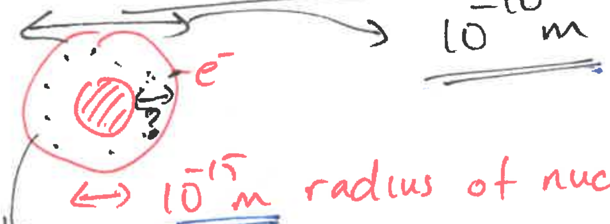
electron ~ amber
kehribar

electro statics





positive + negative = Constant
conserved.

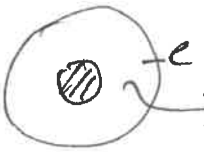


↔ 10^{-15} m radius of nucleus

most of the atom is EMPTY!!

$$\frac{V_{nucleus}}{V_{atom}(e^-)} = \frac{\frac{4}{3}\pi R_n^3}{\frac{4}{3}\pi R_{atom}^3} \sim \frac{10^{-45}}{10^{-30}}$$

$= 10^{-15}$



→ void (empty space) ②

$\sim 10^{-15} = 0.000000000000001$

full

$\% = 99.99999999999999$

empty

Proton $M_p = 1.673\times10^{-27}$ kg

neutron $M_n = 1.675\times10^{-27}$ kg

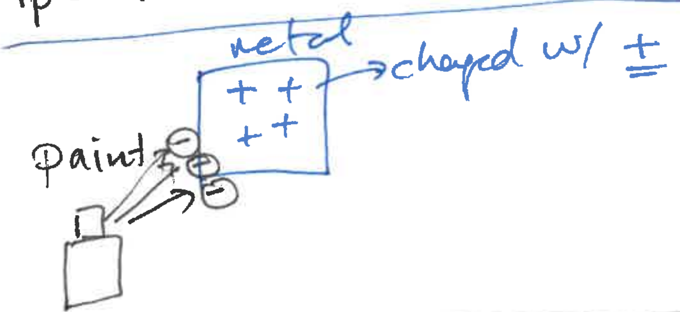
electron $M_e = 9.1\times10^{-31}$ kg

$\frac{M_p}{M_e} \sim \underline{1000}$

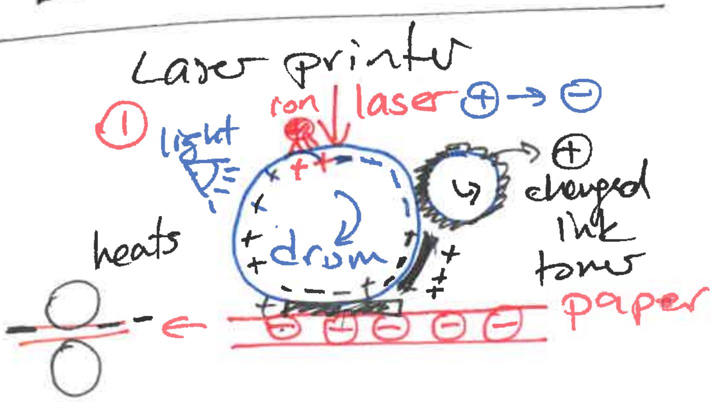
$q_e = -1.6\times10^{-19}$ C

C ↓ coulomb

$q_p = +1.6\times10^{-19}$C



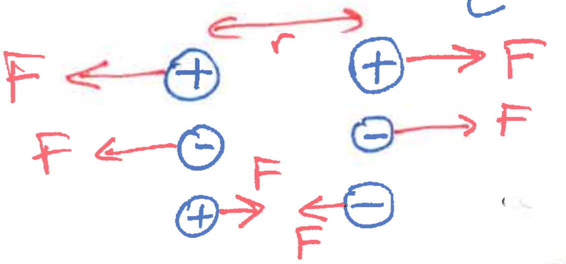
Laser printer



Coulomb's Law

$$|\vec{F}| = k\frac{|q_1||q_2|}{r^2}$$

$k = 8.98\times10^{9}\ \frac{Nm^2}{c^2}$ coulomb const.



$$F = k\frac{qq}{r^2}$$

$$\left[N = \underline{\underline{k}}\ \frac{c^2}{m^2}\right];\left[k = \frac{Nm^2}{C^2}\right]$$

$$F = \frac{1}{4\pi\varepsilon_0}\ \frac{q_1 q_2}{r^2}$$

$k = \frac{1}{4\pi\varepsilon_0}$; $\varepsilon_0 = 8.85\times10^{-12}\frac{C^2}{Nm^2}$

$q_e = -1.6\times10^{-19}$C

ex: $q_1 = +25$ nC (nano Coulomb)

$q_2 = -75$ nC $\ \ \hookrightarrow \underline{\underline{10^{-9}}}$

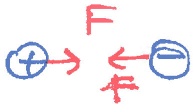
$r = 3$cm

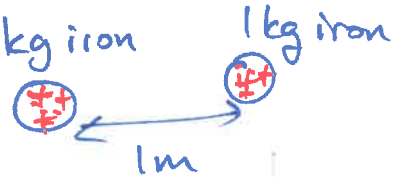
$F = ?$

$10^{-18}C^2 \leftarrow (nC)^2$

$$F = k\frac{q_1q_2}{r^2} = 8.98\times10^{9}\ \frac{25\times75\times}{(0.03m)^2}$$

$\underline{\underline{F = 0.019\,N}}$





what's the force between them if every Fe (iron) atom gives 1e⁻ away

1kg iron has .... atoms

~50gr Fe 6×10^{23} atoms

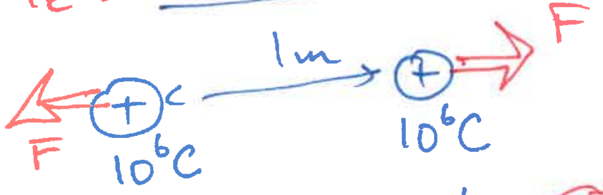
~ 1kg Fe $6\times20\times10^{23}$

$= 1.2\times10^{25}$ atom

⊕

$q_1 = 1.2\times10^{+25} e^- = \overbrace{1.2\times1.6}^{1}\times10^{6} C$

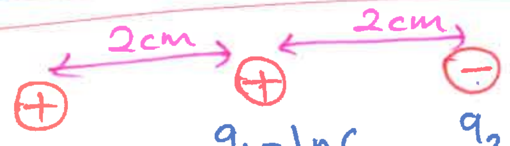
$1e^- = 1.6\times10^{-19} C$



$$F = \underbrace{8.98\times10^9}_{10} \frac{10^6 \ 10^6}{1\cancel{m^2}} \frac{N\cancel{m^2}}{\cancel{C^2}} \cancel{C^2}$$

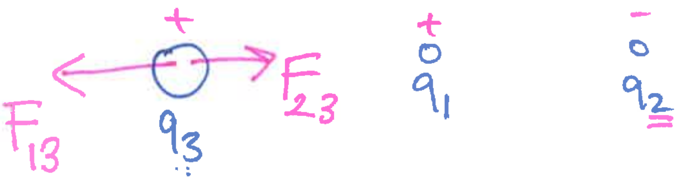
$F = 10^{22} N$

ex:



$q_3 = 5nC$ $q_1 = 1nC$ $q_2 = -3nC$

Total force on q_3 ?



$F_{13} = 1.12\times10^{-4} N$; $F_{23} = 0.84\times10^{-4} N$

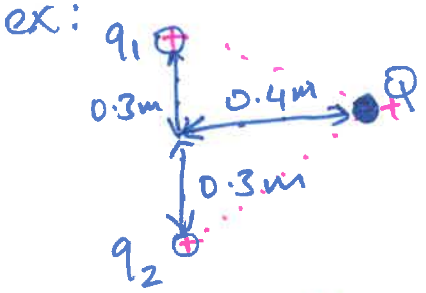
③ $\vec{F}_{13} + \vec{F}_{23}$ → $\hat{i}$

$1.12\times10^{-4}(-\hat{i}) + 0.84\times10^{-4}\hat{i}$

$\Sigma\vec{F} = -0.28\times10^{-4} N \ \hat{i}$

⇐ ③ ΣF

ex:

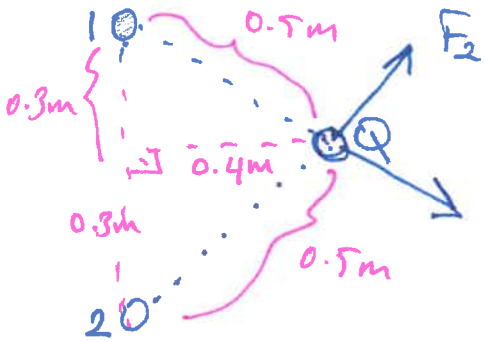


$q_1 = q_2 = 2\mu C$

$Q = 4\mu C$

$\boxed{1\mu C = 10^{-6} C}$

what's the force on Q? magnitude? direction?



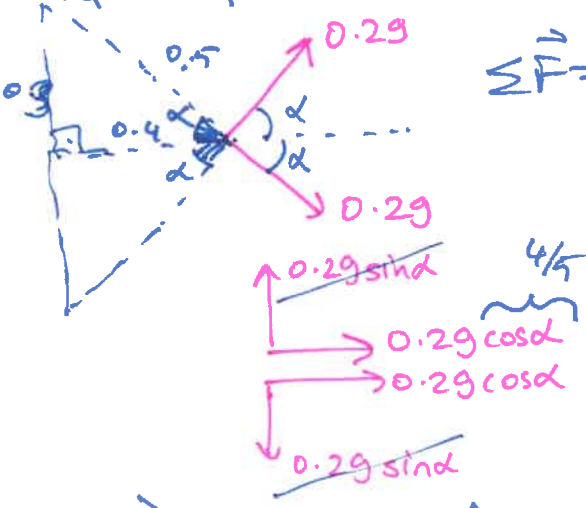
$F_{2Q} = k\frac{Qq_2}{r^2}$

$F_{1Q} = k\frac{Qq_1}{r^2}$

$$F_{1Q} = 9\times\cancel{10^9} \frac{4\times\cancel{10^{-6}}\times2\times10^{-6}}{(0.5)^2} N$$

$F_{1Q} = F_{2Q} = F = 0.29N$

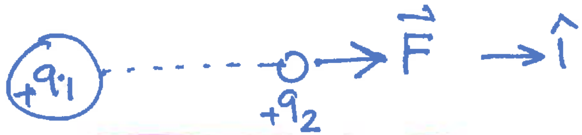
$\Sigma\vec{F} = \vec{F}_{1Q} + \vec{F}_{2Q}$

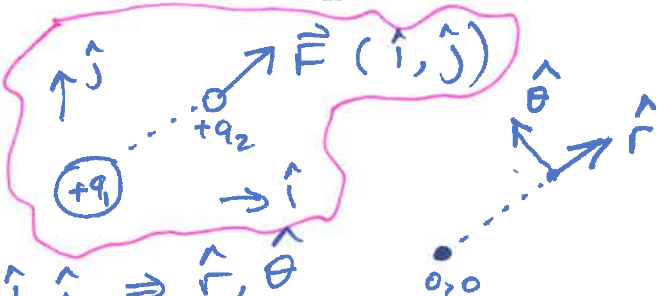


$4/5 = 0.8$

⇒ $\hat{i}$

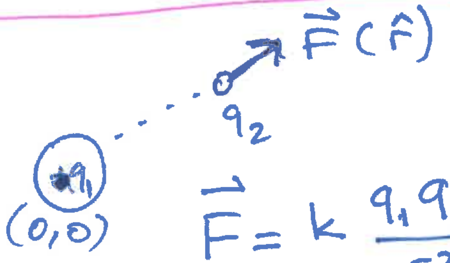
$\Sigma\vec{F} = 0.23N \ \hat{i}$





$\hat{i}, \hat{j} \Rightarrow \hat{r}, \hat{\theta}$

rotational coordinate



$$\vec{F} = k \frac{q_1 q_2}{r^2} \hat{r}$$

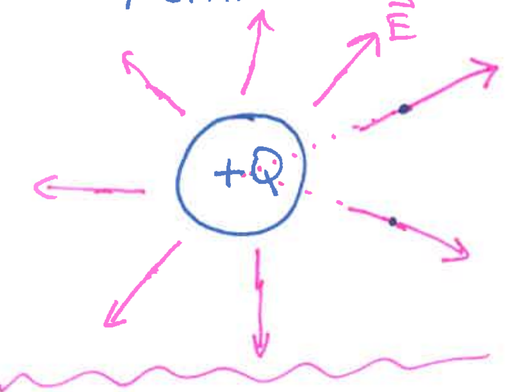
coulomb force

Electric Field $\equiv \vec{E} = \dfrac{\vec{F}}{q_0} = \dfrac{\frac{kQ\cancel{q_0}}{r^2}}{\cancel{q_0}} \hat{r}$

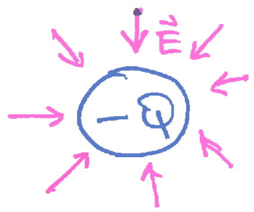
$$\vec{E} = \frac{kQ}{r^2} \hat{r}$$

unit of E ? $\underline{\underline{E}} = \frac{F}{q} = \left[\frac{N}{C}\right]$

$q_0 \Rightarrow$ always positive



$+Q$ E away

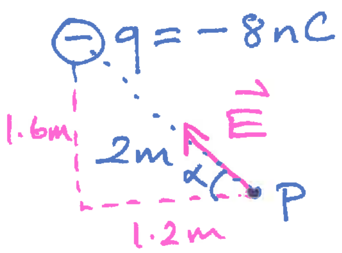


$-Q$ E towards itself.

④

$$E = \frac{kQ}{r^2} = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$$ electric field.

ex:



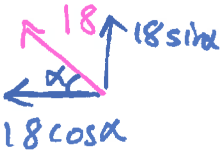
$\vec{E}_p = ?$

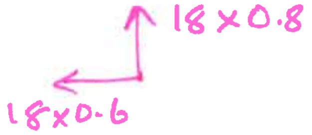
$$\underline{\underline{E}} = \frac{kq}{r^2} = 9\times10^9 \times \frac{8\times10^{-9}}{2^2} \left[\frac{N}{C}\right]$$

$$E = 18 \frac{N}{C}$$

$$= \left[\frac{N\cancel{m^2}}{\cancel{C^2}}\right] \frac{\cancel{C}}{\cancel{m^2}} = \frac{N}{C}$$

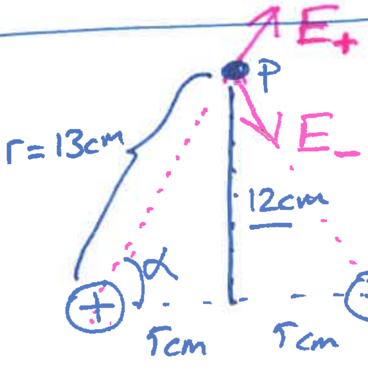
$$\vec{E} = 18 \frac{N}{C} (-\hat{r})$$





$$\vec{E} = -10.8\,\hat{i} + 14.4\,\hat{j} \ \frac{N}{C}$$

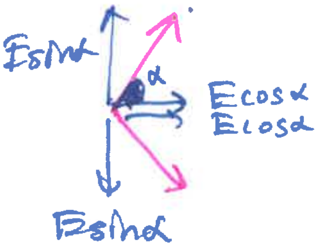
ex:



$E_p = ?$

$$E_+ = \frac{kq_+}{r^2} = \frac{9\times10^9 \times 12\times10^{-9}}{0.13^2} \frac{N}{C}$$

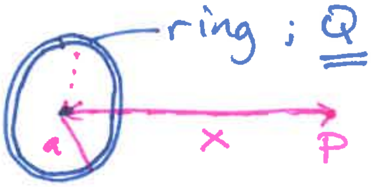
$$E = E_- = \frac{kq_-}{r^2} = E_+ = 6.39\times10^3 \frac{N}{C}$$



} $2E\cos\alpha$

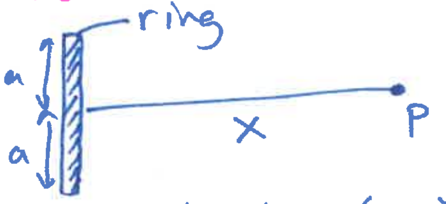
$$\rightarrow E_p = 4.9\times10^3 \frac{N}{C} \uparrow$$

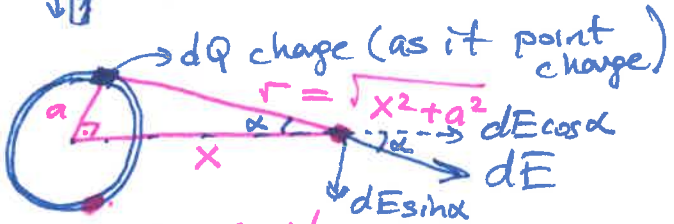
we worked with point charges; other geometrical shape?



$E_p = ?$

side view

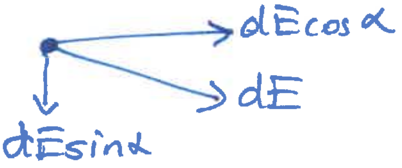




$\underline{dQ} \Rightarrow \underline{dE}$ field

$\cos\alpha = \frac{x}{r}$

$\sin\alpha = \frac{a}{r}$



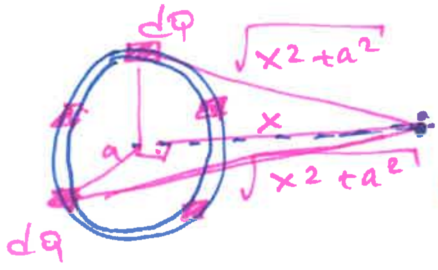
$$\int dE\cos\alpha = \int k\frac{dQ}{r^2}\,\frac{x}{r} = \underline{\underline{E}}$$

$$= \int \frac{k\,dQ\,x}{(x^2+a^2)^{3/2}}$$

; does dQ depend on x ?

if I change location of dQ does $\underline{\underline{x}}$; distance $\underline{r}$ change?

NO!!



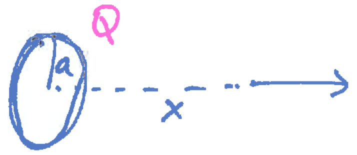
dQ ⇔ r independent

$$\int \frac{k\,dQ\,x}{(x^2+a^2)^{3/2}} = \frac{kx}{(x^2+a^2)^{3/2}} \underbrace{\int dQ}_{}\ Q$$

$$\boxed{E = kxQ \Big/ (x^2+a^2)^{3/2}}$$

ring of a radius; Q charge

x distance from its center



$$E = \frac{kQx}{(x^2+a^2)^{3/2}}$$

⇓

x >> a

very far away

$$E_p = \frac{kQ}{x^2}$$

$$E = \frac{kQx}{\left[x^2\left(1+\frac{a^2}{x^2}\right)\right]^{3/2}} = \frac{kQ\cancel{x}}{x^{\cancel{3}\,2}\left[1+\frac{a^2}{x^2}\right]^{3/2}}$$

$\frac{a^2}{x^2} \to 0$

x>>a ; $\frac{a}{x} \to 0$

$$E = \frac{kQ}{x^2} \checkmark$$

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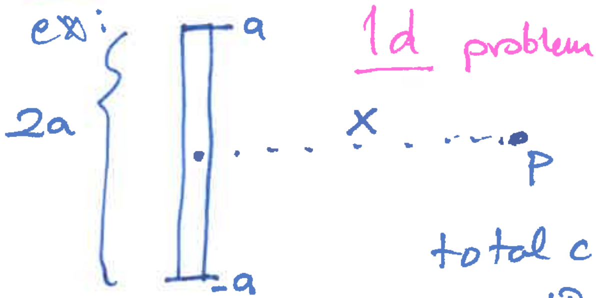
ex:



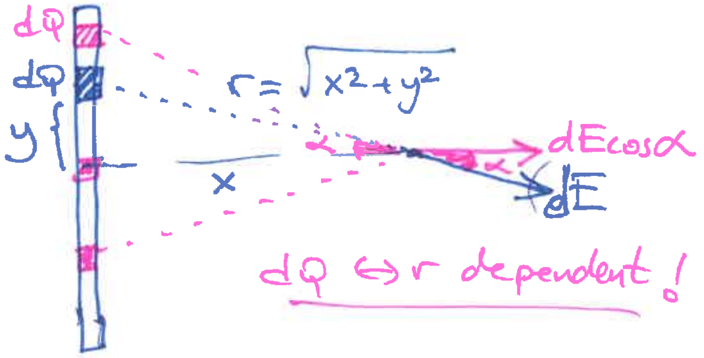
1d problem $E_p = ?$

charged line segment

total charge Q

L = 2a

$$\text{charge density} = \frac{Q}{\text{volume}}\ \underline{3d} = \frac{Q}{\text{area}}\ \underline{2d} = \frac{Q}{\text{length}}\ \underline{1d}$$



dQ ⇔ r dependent!

$\frac{dQ}{r^2}$

$\frac{dQ}{(x^2+y^2)}$

$\int k \frac{dQ}{x^2+y^2} \frac{x}{(x^2+y^2)^{1/2}}$

$\Rightarrow r(x,y)$ related!

nsity $\equiv \lambda \equiv \frac{Q}{\text{length}}$

t

ge

$\boxed{= \frac{dQ}{dy} = \frac{Q}{L}}$

$dQ = \lambda dy$

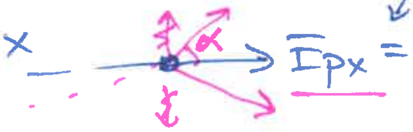
$dQ = \frac{Q}{L} dy$

$\frac{dQ}{dy} \quad x$

$+y^2)^{3/2}$

$\frac{P}{2a} \int_{-a}^{a} \frac{dy}{(x^2+y^2)^{3/2}}$

$^2+a^2 \quad \hat{i} = \vec{E}_p$

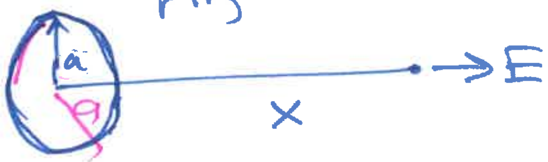


$x \ll a \quad \frac{x}{a} \to 0 \quad \lambda 2\cancel{a}$

$E = \frac{kQ}{x\cancel{a}\left(1+\frac{x^2}{a^2}\right)^{1/2}}$ 0

$\frac{\lambda 2}{x}$

ring



$\vec{E} = \frac{kQx}{(x^2+a^2)^{3/2}} \hat{i}$

Disc

Intgral ≡ add rings ≡ DISC

DISC; Q

ring; r radius

dQ

$a \to r$

$\int dE = \int \frac{k\,dQ\,x}{(x^2+r^2)^{3/2}} \equiv E_{DISC}$

$dQ \Leftrightarrow r$? charge density

charge density $\equiv \frac{Q}{\text{area}} = \frac{Q}{\pi R^2} = \frac{dQ}{dA}$

$\boxed{dA = 2\pi r dr}$

$\sigma = \frac{dQ}{2\pi r dr} \Rightarrow dQ = \sigma 2\pi r dr$

sigma

$\int_0^R \frac{k\, \overset{dQ}{\sigma 2\pi r dr}\, x}{(x^2+r^2)^{3/2}}$

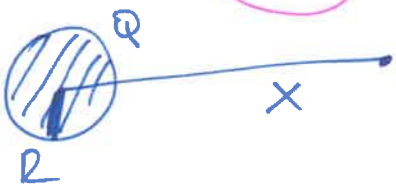
$E_p = k \sigma 2\pi x \int \frac{r dr}{(x^2+r^2)^{3/2}}$

$\frac{1}{4\pi\varepsilon_0}$

derivative $2r dr$

$$E_p = \frac{\sigma x}{2\varepsilon_0}\left[\frac{1}{x} - \frac{1}{\sqrt{x^2+R^2}}\right]$$

$$\sigma = \frac{Q}{A} = \frac{Q}{\pi R^2}$$



$$\sigma = \frac{Q}{\pi R^2}$$

$x << R$ $\quad \frac{x}{R} \to 0$

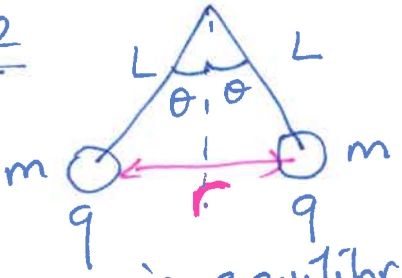
$$E_p = \frac{\sigma x}{2\varepsilon_0 x} - \frac{\sigma x}{2\varepsilon_0}\frac{1}{\sqrt{R^2}\left(1+\frac{x^2}{R^2}\right)^{1/2}}$$

$$= \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0}\frac{x}{R} \to 0$$

$$E_p = \frac{\sigma}{2\varepsilon_0} \qquad x << R$$

very very close to the DISC

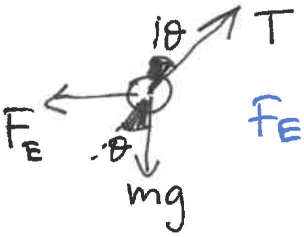
21.62

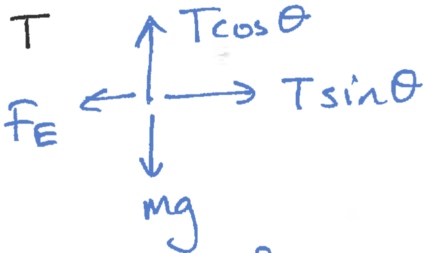


in equilibrium

ⓐ draw free body diagram

ⓑ Felectrostatic force? → mg tanθ



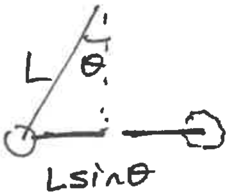


$$T\sin\theta = F_E = k\frac{q^2}{r^2}$$

$$T\cos\theta = mg$$

$$\tan\theta = \frac{kq^2/r^2}{mg} = \frac{F_E}{mg}$$

$$mg\tan\theta = k\frac{q^2}{r^2}$$

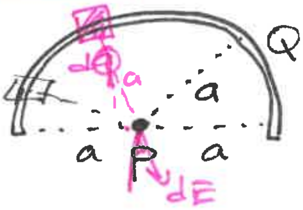


$r = 2L\sin\theta$

$$mg\tan\theta = \frac{kq^2}{4L^2\sin^2\theta}$$

$$\boxed{L^2 = \frac{kq^2}{4mg\tan\theta\sin^2\theta}}$$

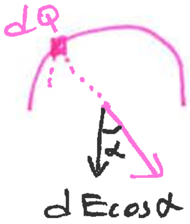
Bridgiy problem



Q arc = half ring

$E_p = ?$

$$dE = \frac{k\,dQ}{r^2} = \frac{k\,dQ}{a^2}$$



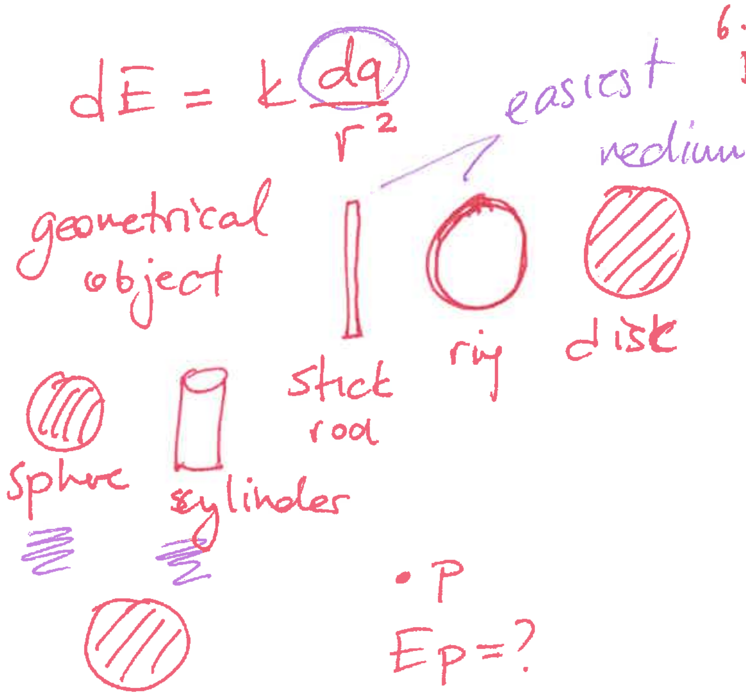
$$\int \frac{k\,dQ}{a^2}\cos\alpha = \int dE$$

$$\frac{dQ}{\text{Length}} = \lambda$$

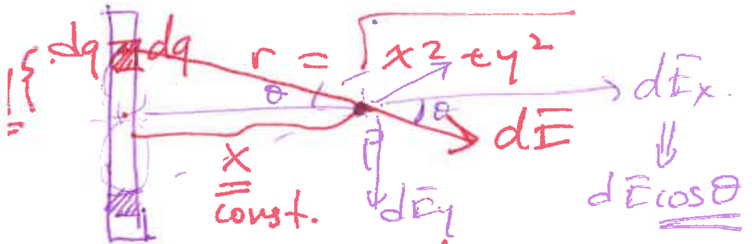
6.6.17
pos ①

$dE = k\frac{dq}{r^2}$

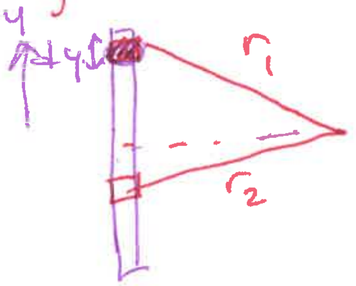
geometrical object



$E_p = ?$



$\int dE = \int k\frac{dq}{r^2}$ dependent



$r_1 \neq r_2$

dq ~ r related

charge density = $\frac{\text{charge}}{L;\ A;\ V}$

1d 2d 3d

lambda

$\lambda = \frac{Q}{L}$ (1d)

(rho)

$\rho = \frac{Q}{V}$ (3d)

$\sigma = \frac{Q}{A}$ (2d)

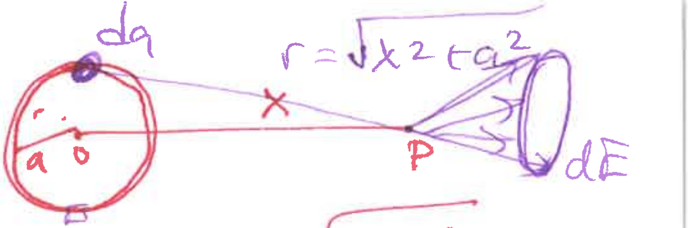
sigma

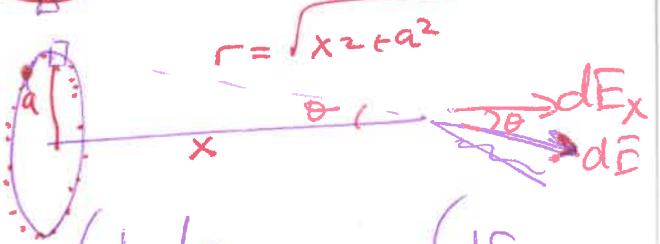
$\lambda = \frac{dq}{dy} = \frac{Q}{L}$

$dq = \lambda dy$

$k\int\frac{dq}{r^2}\cos\theta$

$= k\int\frac{\lambda dy\, x}{(x^2+y^2)^{3/2}}$





$\int\frac{kdq}{r^2}\cos\theta = \int dE_x$

$\int\frac{k\,dq}{r^2}\frac{x}{r}$

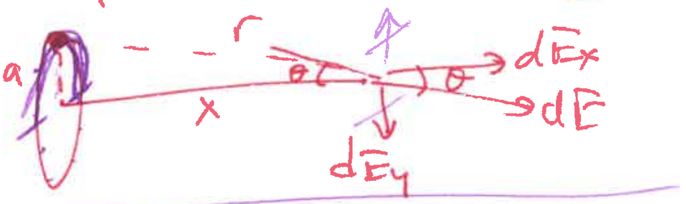
$\int\underbrace{\frac{k\,x}{r^3}}_{const} dq$

$dq \leftrightarrow r$

$\frac{k\,x}{r^3}\int dq = \frac{kQx}{r^3}$

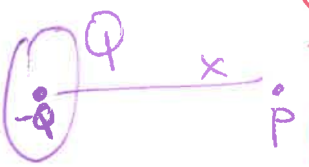
$$\boxed{E_x = \frac{kQx}{(x^2+a^2)^{3/2}}}$$

$\int dE_y = dE\sin\theta$ $= \underline{\underline{0}}$



ex

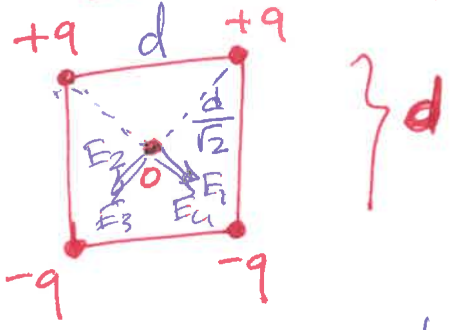
$E_p = ?\ \frac{kxQ}{(x^2+a^2)^{3/2}} + \frac{kq}{x^2}$



$\frac{kxQ}{(x^2+a^2)^{3/2}} - \frac{kQ}{\cancel{x}^2}$

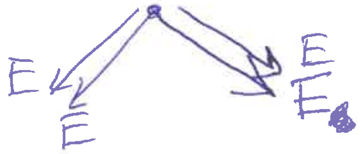
21.42 d

square ②

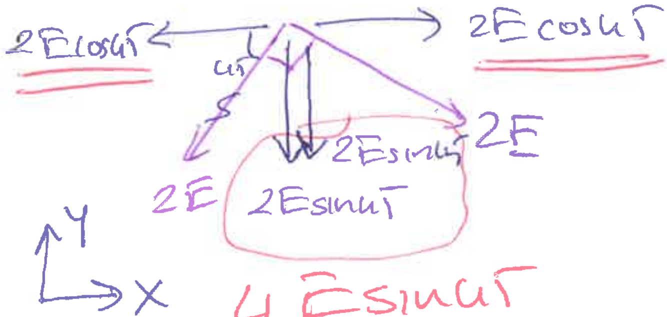


$\vec{E}_0 = ?$

$$E = \frac{kq}{\left(\frac{d}{\sqrt{2}}\right)^2} =$$



$= \frac{2kq}{d^2} = E$



4 Esin45

$$4\,\frac{\cancel{2}kq}{d^2}\,\frac{\sqrt{2}}{\cancel{2}} = \frac{kq\,4\sqrt{2}}{d^2}$$

$$\vec{E} = \frac{kq\,4\sqrt{2}}{d^2}(-\hat{j})$$

Gauss Law

Chapter 22

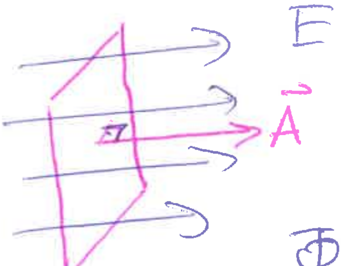
Electric Flux

how many E field lines are there?

$\Phi_E = \vec{E} \cdot \vec{A}$

area

dot product

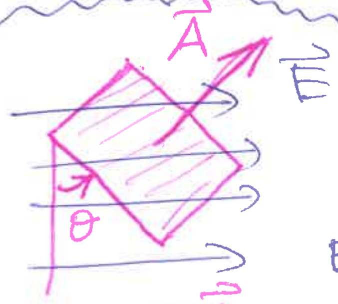


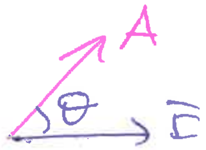
$\Phi = \vec{E} \cdot \vec{A}$

phi

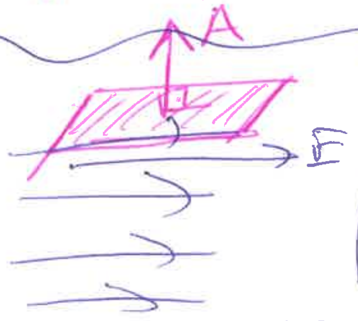
$\Phi = EA\cos\theta$

$\Phi = EA\underbrace{\cos 0}_{1}$





$EA\cos\theta = \Phi$



EAcos90
↓
0

$\Phi = 0$

$\Phi = \vec{E}\cdot\vec{A}$ = flux

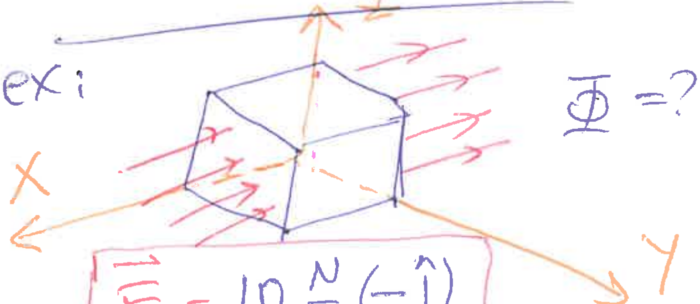
$\Phi = \frac{Q_{enclosed}}{\varepsilon_0} = \frac{Q_{in}}{\varepsilon_0}$

$\Phi = \underbrace{\vec{E}\cdot\vec{A}}_{\text{closed surface}} = \frac{Q_{in}}{\varepsilon_0}$

$\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{Q_{in}}{\varepsilon_0}$

closed surface

ex:



$\Phi = ?$

$\boxed{\vec{E} = 10\,\frac{N}{C}(-\hat{i})}$

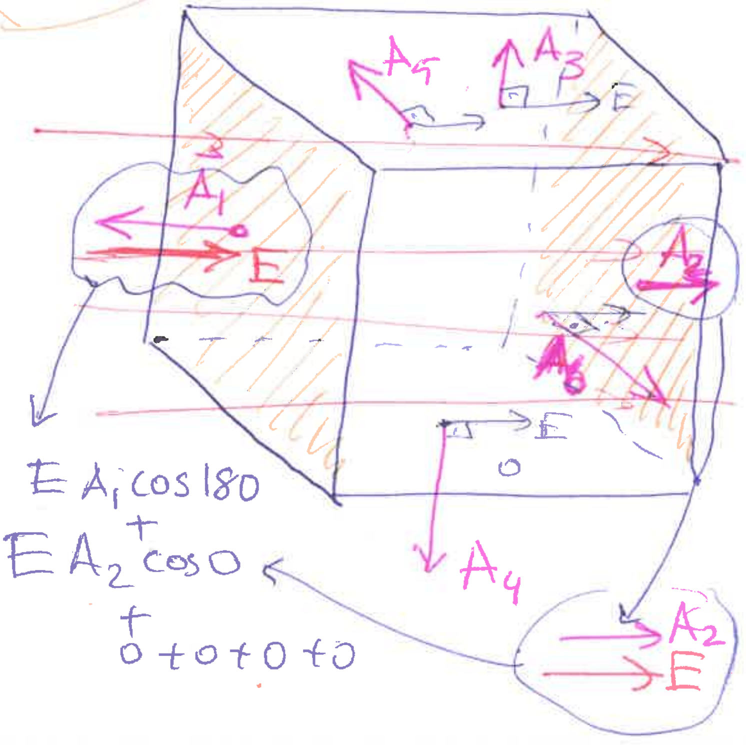
$F = qE$

$[N = C\,\frac{N}{C}]$

side of cube
1m

Area = $1m^2$

$\Phi = ?$ $\oint \vec{E}\cdot d\vec{A} = \sum \vec{E}\cdot\vec{A}$



$E A_1 \cos 180$
$+$
$E A_2 \cos 0$
$+$
$0 + 0 + 0 + 0$

③ $\Phi = EA_1\cos 180 + EA_2\cos 0$

$A_1 = A_2 = 1m^2$; $E = 10\,\frac{N}{C}$

$= 10(1)(-1) + 10(1)(1)$

$= -10 + 10$

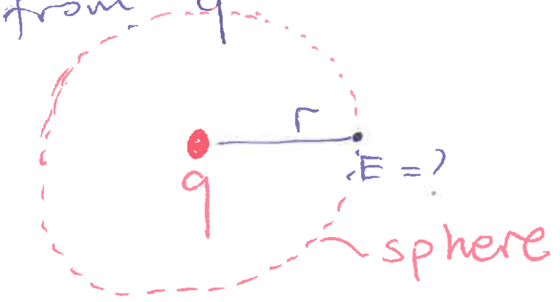
$\Phi = \underline{0}$ total flux ZERO

Ex: $\underset{(\text{akı})}{\Phi} = \int \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

point charge q;

→ what's the flux ? $\Phi = ?$

→ what's $\vec{E}$ at r distance from q?



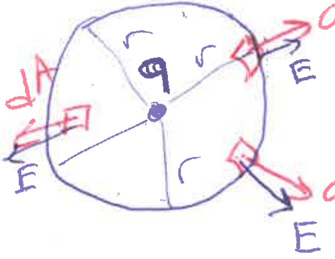
flux ⇒ $\Phi = \frac{q}{\varepsilon_0}$ ✓

previous chapter we know

$E = \frac{kq}{r^2}$

Gauss Law: $\Phi = \oint \underset{?}{\vec{E}}\cdot d\underset{r}{\vec{A}} = \frac{q_{in}}{\varepsilon_0}$

sphere, r



$\int \vec{E}\cdot d\vec{A}$ { $\oint E\,dA\,\underbrace{\cos 0}_{1}$

$\oint \underset{\text{const}}{E}\,dA = \frac{q}{\varepsilon_0} \Rightarrow E\oint dA = \frac{q}{\varepsilon_0}$

$$E \underbrace{\oint dA} = \frac{q}{\varepsilon_0}$$

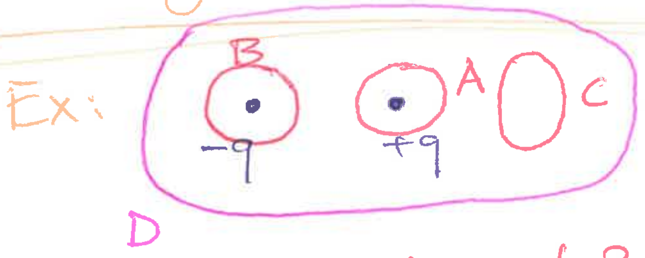
A = area of sphere $= 4\pi r^2$

$$E\, 4\pi r^2 = \frac{q}{\varepsilon_0} \qquad k = \frac{1}{4\pi\varepsilon_0}$$

$$E = \frac{q}{4\pi\varepsilon_0 r^2} = k\,\frac{q}{r^2}$$

gauss

Ex:



A, B, C, D ; surfaces of 3d volume objects.

Flux

$$\Phi_A = ?\ \frac{+q}{\varepsilon_0}$$

$$\Phi_B = -q/\varepsilon_0$$

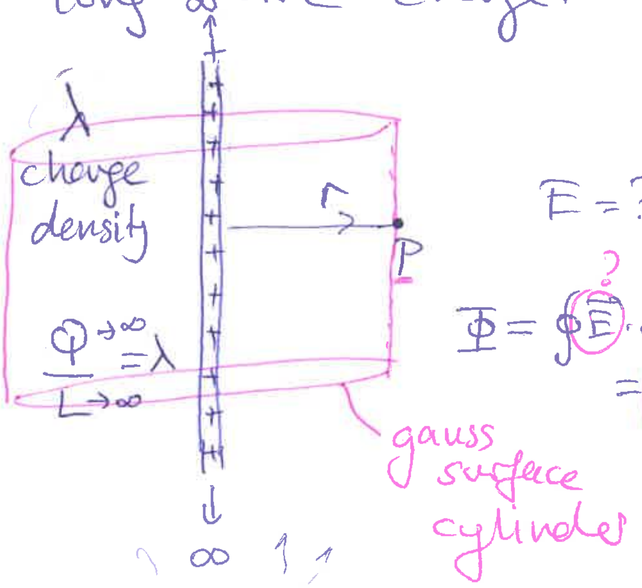
$$\Phi_C = 0$$

$$\Phi_D = \frac{+q-q}{\varepsilon_0} = 0$$

$$\Phi = \frac{q_{in}}{\varepsilon_0}$$

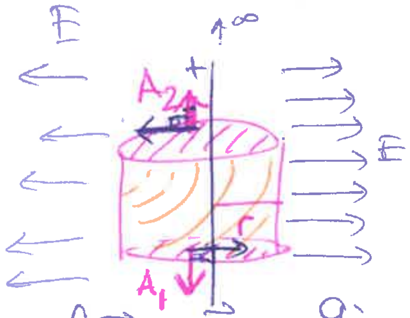
$$\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

④ E field of a infinetly long ∞ line charge.

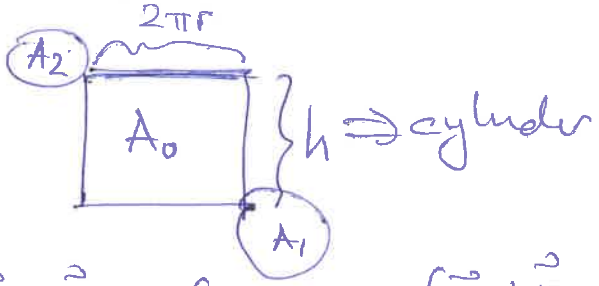


$E = ?$

$$\Phi = \oint \overset{?}{\vec{E}}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$



$$\oint \vec{E}\bullet d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$



$$\oint \vec{E}\cdot d\vec{A} = \int_{A_1} \underbrace{\vec{E}\cdot d\vec{A}}_{0} + \int_{A_2} \underbrace{\vec{E}\cdot d\vec{A}}_{0}$$

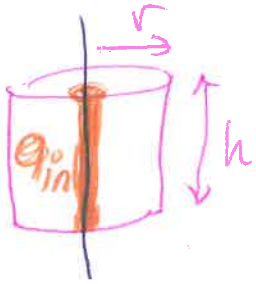
$$+ \boxed{\int_{A_0} \vec{E}\cdot d\vec{A}} = \int \underset{\text{↳const}}{E}\, dA \cos\overset{1}{0}$$

$$\Phi = \int_{A_1} E\,dA \cos\underset{0}{\cancel{90}} + \int_{A_2} E\,dA \cos\underset{0}{\cancel{90}}$$

$$+ E\int_{A_0} dA = E A_0$$

$$\Phi = E\, 2\pi r h = \frac{q_{in}}{\varepsilon_0}$$

⑤



λ = charge density

$\lambda = \frac{q_{in}}{h}$ ← h = length

$$\Phi = E\,2\pi r \cancel{h} = \frac{\lambda \cancel{h}}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

$$E = \frac{2k\lambda}{x}$$

$x \to r$

$$= 2\,\frac{1}{4\pi\varepsilon_0}\,\frac{\lambda}{r}$$

$$\boxed{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

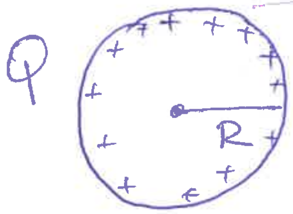
$2\pi r h$

integral

gauss !!

Ex: E field of a metal ~~ch~~ sphere

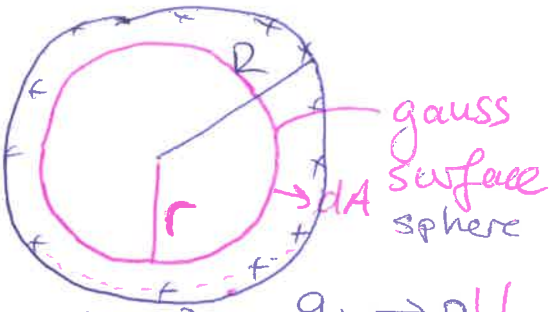
* metal has charges only on its surface.



use gauss

inside sphere outside

E E



$$\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0} \to 0!!$$

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

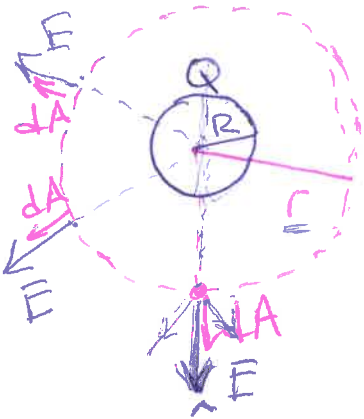
$\Downarrow$ $dA \neq 0$

must be ZERO!

$E(\text{inside}) = 0$

$E(r<R) = \underline{\underline{0}}$

$r > R$ outside Q



$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

$$\oint \vec{E}\cdot d\vec{A} = \oint E\,dA\cos 0 = \frac{Q}{\varepsilon_0}$$

$\cos 0 \to 1$

const

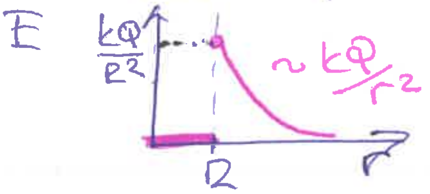
$E \oint dA = Q/\varepsilon_0$

Area of sphere

$E\,4\pi r^2 = Q/\varepsilon_0$

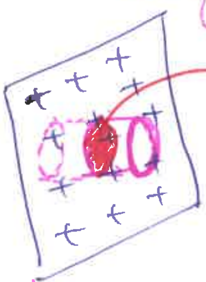
$$E = \frac{Q}{4\pi\varepsilon_0 r^2} \quad (r>R)$$

$\left(r=R \quad E = \frac{Q}{4\pi\varepsilon_0 R^2} \right)$



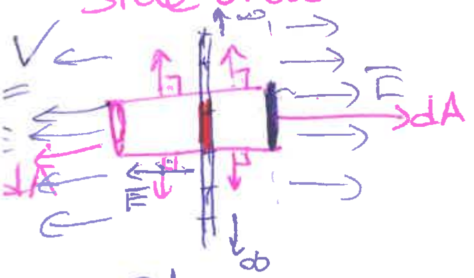
ex Infinite slab (surface) ⑥

of a insulator ~~of charge~~ → ≠metal
charged.

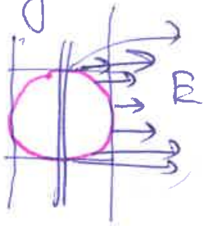


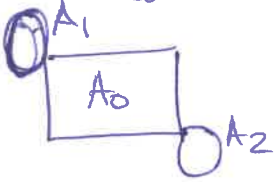
q_{in} $E = ?$

side view



what if spherical gauss shape





$$\oint \vec{E}\cdot d\vec{A} = \underbrace{\int_{A_1} E\,dA}_{\text{const}}\overset{\cos 0}{} + \int_{A_2} E\,dA\overset{\cos 0}{} + \int_{A_0} E\,dA\overset{\cos 90 = 0}{}$$

$$\oint \vec{E}\cdot d\vec{A} = EA + EA + 0 = \frac{q_{in}}{\varepsilon_0}$$

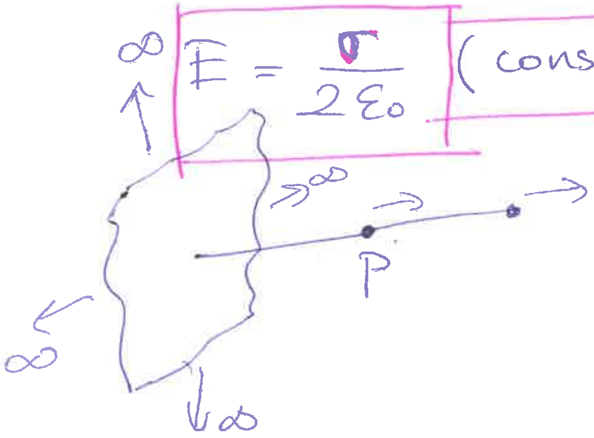
q_{in} = (charge density)(area)

σ sigma

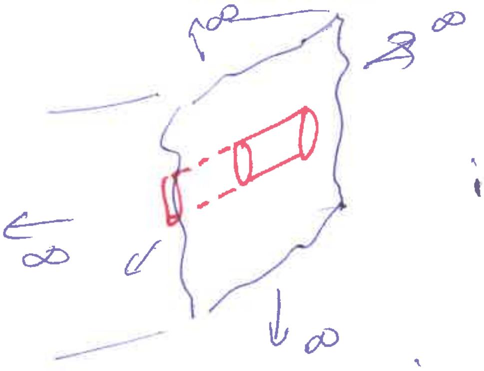
$q_{in} = \sigma A$

$$2E\cancel{A} = \frac{\sigma \cancel{A}}{\varepsilon_0}$$

$$\boxed{E = \frac{\sigma}{2\varepsilon_0}} \quad \boxed{(\text{const})}$$

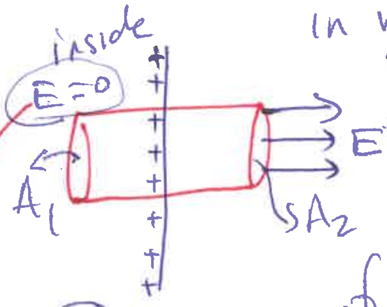


infinitely long wide metal slab (surface)

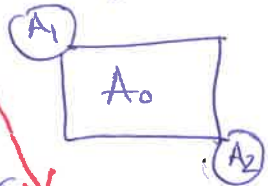


infinitely thick

in metals E inside = 0!



$\oint \vec{E}\cdot d\vec{A}$



$$= \int_{A_1} E\,dA + \int_{A_2} E\,dA\overset{\cos 0}{} + \int_{A_0} \vec{E}\,d\vec{A}\,\overset{\cos 90 = 0}{}$$

$$0 + EA + 0$$

$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0} \quad q_{in} \rightarrow \sigma A$$

$$E\cancel{A} = \frac{\sigma \cancel{A}}{\varepsilon_0}$$

$E = \sigma/\varepsilon_0$ conductor metal

$E = \sigma/2\varepsilon_0$ insulator (plastic glass)

Phys 2

7.7.17 Fiz2

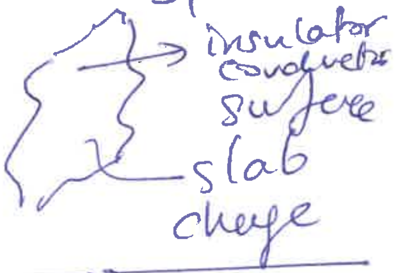
1

Gauss Law cnt'd

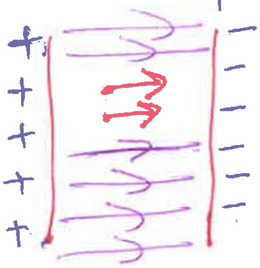
$$\underbrace{\Phi}_{\text{flux}} = \underbrace{\oint \vec{E}\cdot d\vec{A}}_{} = \underbrace{\frac{q_{in}}{\varepsilon_0}}_{Q}$$

- point charge; vetor sphere

line charge;



parallel conducting plates



$E = \frac{\sigma}{\varepsilon_0}$

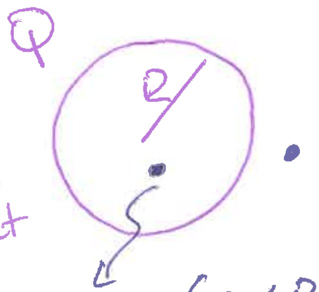
σ: ~~surf~~ charge density

revisit this in condansators / capacity

ex: E field of uniformly charged sphere

insulator [glass, plastic]

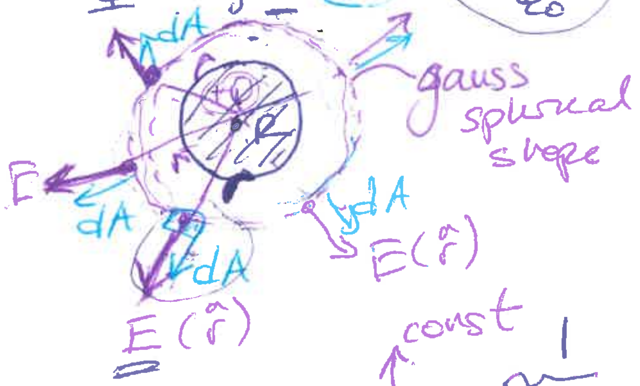
charge density constant



outside $E(r>R)$

$E = (r<R)$

$\Phi = \oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

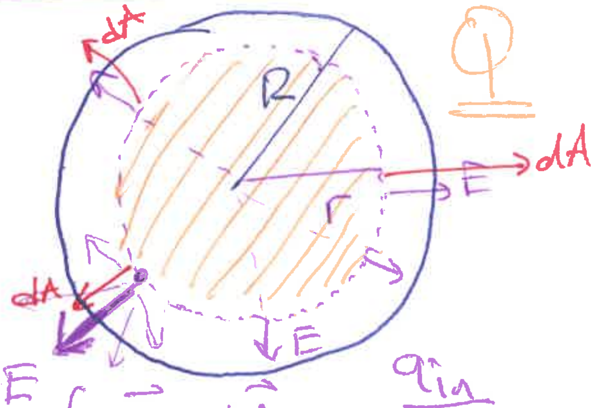


$$\oint \vec{E}\cdot d\vec{A} = \oint \overset{\text{const}}{E}\, dA \underset{}{\overset{1}{\cos 0}}$$

$$E \underbrace{\oint dA}_{\text{area of whole sphere}} = E\, 4\pi r^2 = \frac{Q}{\varepsilon_0}$$

$$\boxed{E = \frac{Q}{4\pi\varepsilon_0 r^2} \quad r>R}$$

✓

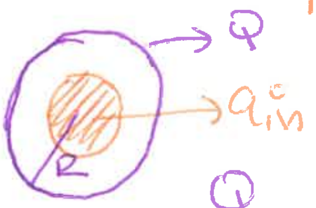


$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

$$\oint E\, dA \cancel{\cos 0}^{1}$$

$$E\oint dA$$

$$E\, 4\pi r^2 = q_{in}/\varepsilon_0$$



charge density $= \rho$ rho

$$\frac{q_{in}}{V_{in}} = \rho = \frac{Q}{V} = \frac{Q}{\frac{4}{3}\pi R^3}$$

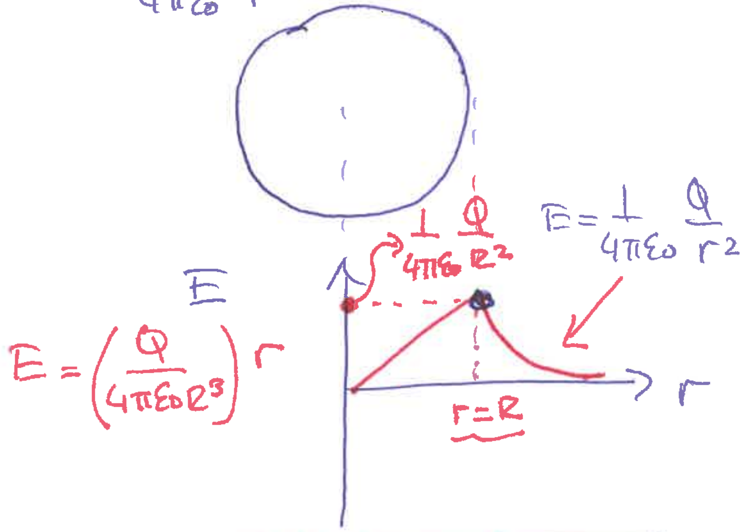
$$\rho = \frac{Q}{\cancel{\frac{4}{3}}\pi R^3} = \frac{q_{in}}{\cancel{\frac{4}{3}}\pi r^3} \Rightarrow q_{in} = \frac{Q\, r^3}{R^3}$$

②

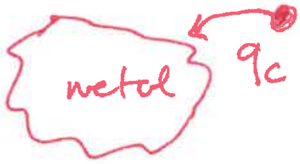
$$E\,4\pi\cancel{r^2} = \frac{Q\,r^{\cancel{3}\,1}}{\varepsilon_0 R^3}$$

$$\boxed{E = \frac{Q}{4\pi\varepsilon_0}\,\frac{r}{R^3} \quad (r<R)}$$

$$E = \frac{1}{4\pi\varepsilon_0}\,\frac{q}{r^2}$$ ✓ unit check ✓

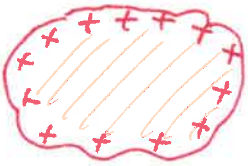


Charges on Conductors

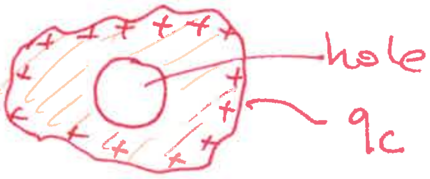


q_c charge on metal

$q=0$

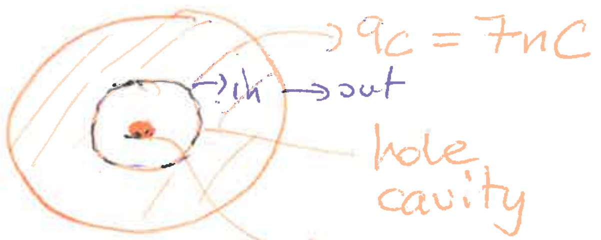


q_c will be on the surface



$q_{in} = +q - q = 0$

$q_{in} = q_c + q$



$q = -5nC$

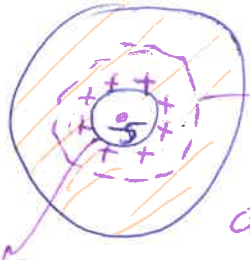
metal had $7nC = q_c$
and $q = -5nC$
was put inside the cavity.

what's the total charge
on the outside of metal
in the inside of metal

$q_{in} = q_c + q$

outer $= 7nC - 5nC$

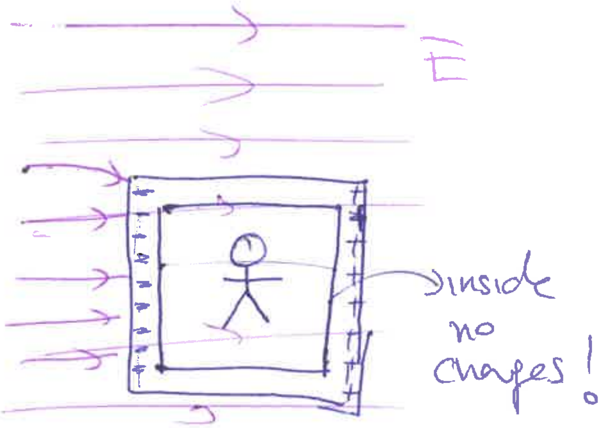
$q_{in} = +2nC$



$q_{in} = \underline{\underline{0}}$

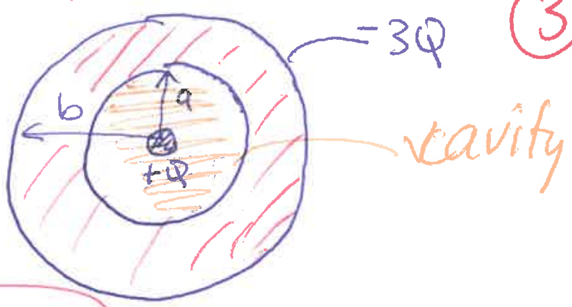
$q_{in} = 0 = -5nC + 5nC$

inner surface $q = +5nC$



Faraday cage

22.44 metal sphere



E; r<a

$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$ r<a

$\oint E\,dA\cos\theta$

$E\,4\pi r^2 = \frac{+Q}{\varepsilon_0}$; $E = \frac{Q}{4\pi\varepsilon_0 r^2}$

a<r<b

$$\begin{array}{r} -q \\ +\ q \\ \hline 0 \end{array}$$

$\oint \vec{E}\,d\vec{A} = \frac{q_{in}}{\varepsilon_0}$

$\oint E\,4\pi r^2 = 0 \Rightarrow E = 0$!

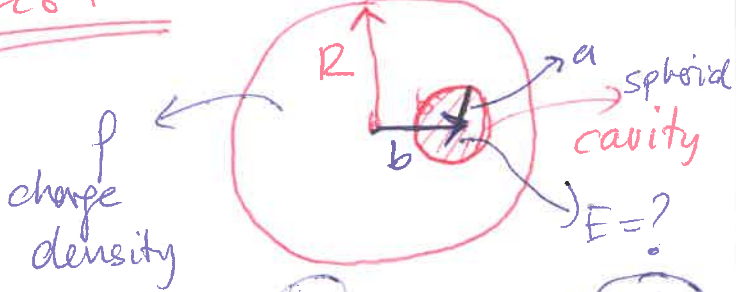
r>b

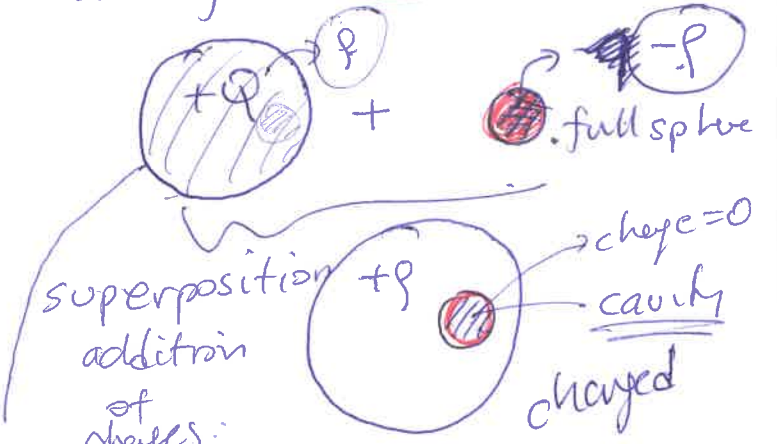
$\oint \vec{E}\cdot d\vec{A} = q_{in}/\varepsilon_0$

$E\,4\pi r^2 = \frac{-3Q+Q-Q}{\varepsilon_0}$

$E = -\frac{3Q}{4\pi\varepsilon_0 r^2}$

③ 22.77 sphere insulator





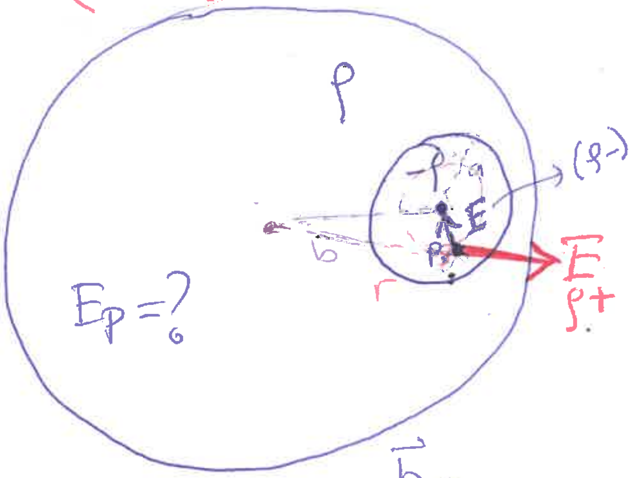
we know inside an insulator

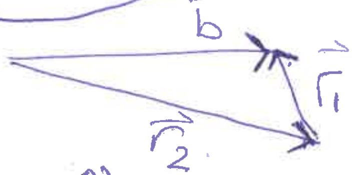
$E = \frac{Q}{4\pi\varepsilon_0 R^3} r$; $\rho = \frac{Q}{\frac{4}{3}\pi R^3}$

$E = \frac{\rho}{3\varepsilon_0} r$

E inside the cavity

$= \vec{E}(+\rho) + E(-\rho)$





$\vec{r}_2 + \vec{r}_1 = \vec{b}$

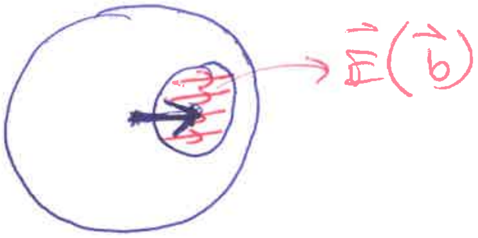
$\vec{E}(\rho-) = \frac{\rho}{3\varepsilon_0} r_1 (\hat{r}_1)$

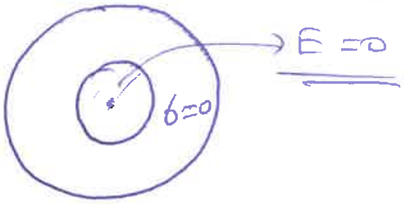
$\vec{E}(\rho+) = \frac{\rho}{3\varepsilon_0} r_2 (\hat{r}_2)$

④ $$\vec{E}(\text{cavity}) = \frac{\rho}{3\varepsilon_0}\left[\overbrace{r_1(\hat{r}_1)}^{\vec{r}_1} + \underbrace{r_2(\hat{r}_2)}_{\vec{r}_2}\right]$$

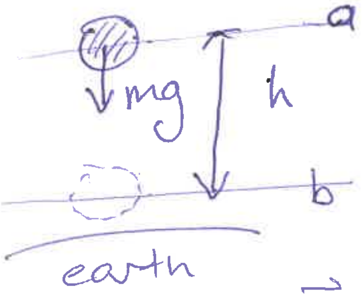
$$\vec{E}(\text{cavity}) = \frac{\rho}{3\varepsilon_0}\left[\underbrace{\vec{r}_1 + \vec{r}_2}_{\vec{b}}\right]$$

$$\vec{B}(\text{cavity}) = \frac{\rho}{3\varepsilon_0}\vec{b}$$





Chapter 23
Electric Potantial ⑤



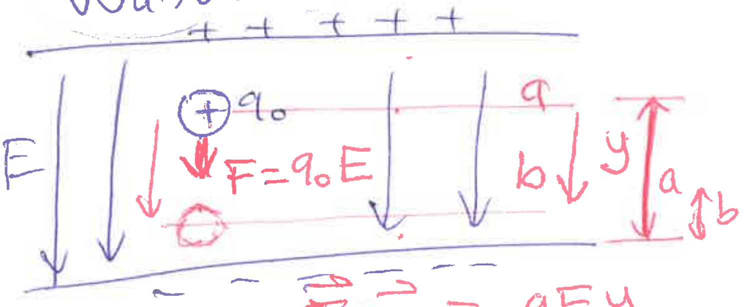
work done on obj.
$a \to b$

$W_{a\to b} = \vec{F}\cdot\vec{h} = \underline{\underline{mgh}}$

$=$ potantial differnce

$= -\Delta U = -(U_b - U_a)$

$W_{a\to b} = U_a - U_b$



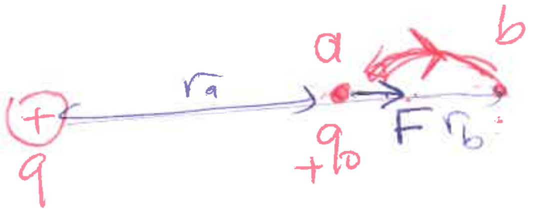
$W_{a\to b} = \vec{F}\cdot\vec{y} = \underline{\underline{qEy}}$

$W_{a\to b} = \underbrace{U_a - U_b}$ potantial energy

~~$U_a =$~~

$U_a = q_0 E a$

$U_b = q_0 E b$



$\vec{F} = k\frac{q_0 q}{r^2}\hat{r}$

$W_{a\to b} = \int_{r_a}^{r_b}\vec{F}\cdot d\vec{r}$

$W = \int_{r_a}^{r_b}\frac{kqq_0}{r^2}dr$

$= kqq_0\int_{r_a}^{r_b}\frac{dr}{r^2} = kqq_0\left[-\frac{1}{r}\right]_{r_a}^{r_b}$

$= kqq_0\left[-\frac{1}{r_b} + \frac{1}{r_a}\right]$

W work done on particle $= kqq_0\left[\frac{1}{r_a} - \frac{1}{r_b}\right]$

$W_{a\to b} = U_a - U_b$

$= \frac{kqq_0}{r_a} - \frac{kqq_0}{r_b}$

potantial energy $\equiv U_a = \frac{kqq_0}{r_a}$

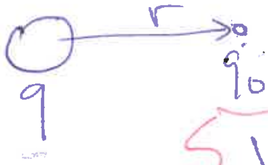
↳ when there are $\underline{\underline{\text{two}}}$ charges.

; $U = k\frac{q_1 q_2}{r}$

electric potantial } $\underline{V} \equiv \frac{U}{q_0}$ U = Joules, q_0 Coulomb

Volt

$\left[V = \frac{J}{C}\right]$



$U = k\frac{qq_0}{r}$

$$V = k\frac{q}{r}$$

important

$F = k\frac{q^2}{r^2}$

$N = k\frac{C^2}{m^2}$

$\left[\text{Volt} = \frac{Nm^2}{C^2}\frac{\cancel{C}}{\cancel{m}} = \frac{\overset{\text{Joules}}{Nm}}{C}\right]$

$$W_{a\to b} = U_a - U_b$$

$$U_a = \frac{1}{4\pi\varepsilon_0}\frac{q q_0}{r} \quad \text{potential energy}$$

$$\boxed{V \equiv \frac{U}{q_0} \equiv \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \quad \text{point charge}}$$

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

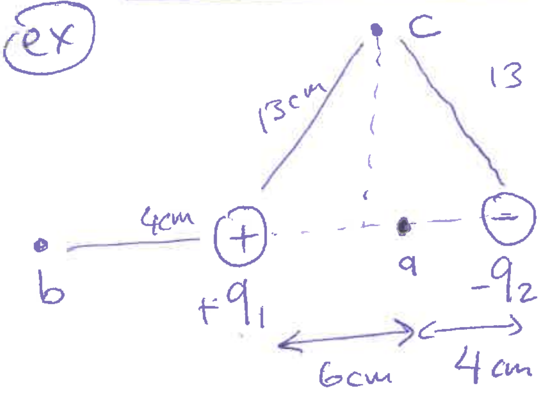
V ≡ electric potential is a scalar ($\overleftrightarrow{}$ ± ; # number)

$$W_{a\to b} = \int \vec{F}\cdot d\vec{r} = U_a - U_b$$

$$\int \cancel{q_0}\vec{E}\cdot d\vec{r} = \cancel{q_0}(V_a - V_b)$$

$$\boxed{V_a - V_b = \int_a^b \vec{E}\cdot d\vec{r}}$$

ex



$q_1 = 12nC$; $q_2 = -12nC$

$V_a = ?$ $V_b = ?$ $V_c = ?$

$$V = k\frac{q}{r} \; ; \; V_a = \frac{kq_1}{6\times10^{-2}} + \frac{k(-q_2)}{4\times10^{-2}}$$

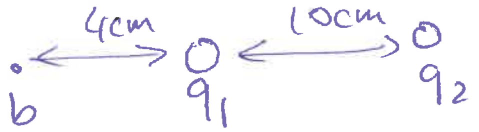
$$V_a = k\left(\frac{12\times10^{-9}}{0.06} - \frac{12\times10^{-9}}{0.04}\right) = k(200-300)$$

$$V_a = k(-100)^{\times10^{-9}} = 9\times10^{9}\times(-100$$

$= -9\times10^{7}$ [illegible]

$V_a =$ [illegible]

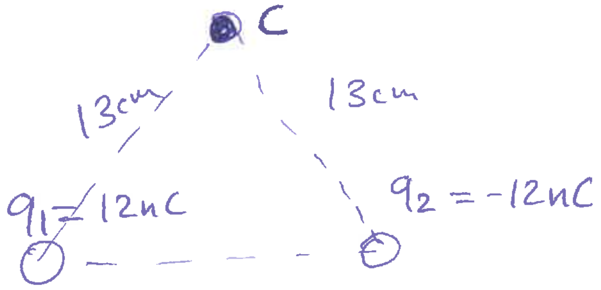
$V_a =$ [illegible] } $-900V$



$$V_b = \frac{kq_1}{0.04} + \frac{kq_2}{0.14}$$

$$= k\left(\frac{12\times10^{-9}}{0.04} - \frac{12\times10^{-9}}{0.14}\right)$$

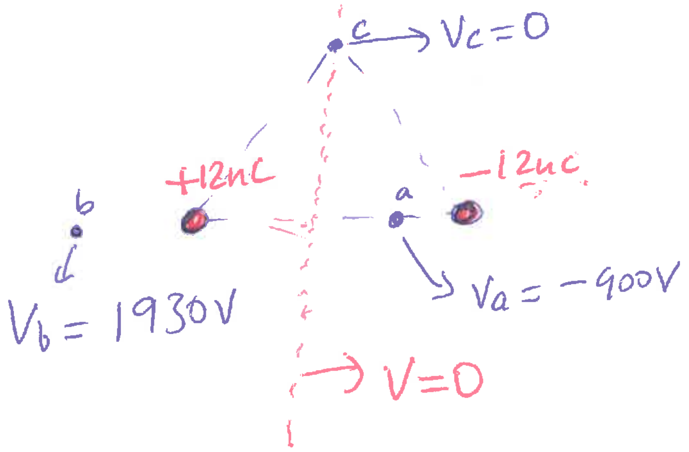
$$V_b = 1930V$$



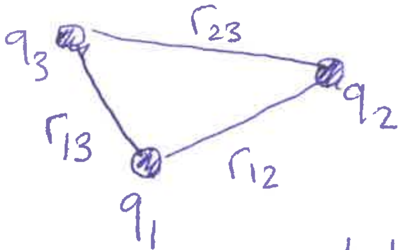
$$V_c = \frac{kq_1}{0.13} + \frac{kq_2}{0.13}$$

$$= \frac{k}{0.13}(12nC - 12nC)$$

$$V_c = 0$$



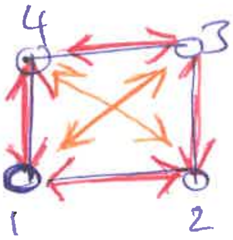
$U = k\frac{q_1 q_2}{r}$ (pot. energy) ⑦



This system has a total pot. energy of

$$\Sigma U = k\frac{q_1 q_2}{r_{12}} + k\frac{q_2 q_3}{r_{23}} + k\frac{q_1 q_3}{r_{13}}$$

$\left.\begin{matrix}q_1\\q_2\\q_3\end{matrix}\right\} \pm$



6 terms !

1st midterm
Tuesday @ 14:00
B201 classroom

2,5 chapters

1st → $\vec{F}, \vec{E}, \int k\frac{dq}{r^2}$

2nd → gauss → %80

3rd → V (electrical potential) → %20

3 or 4 questions

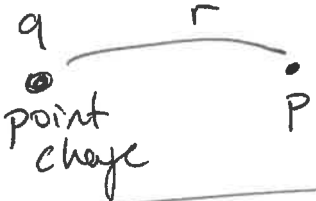
~ 60–80 minutes

CALCULATOR!

Electric Potential - cont'd

Phys 2 11.7.17

①



$V_p = k\frac{q}{r}$

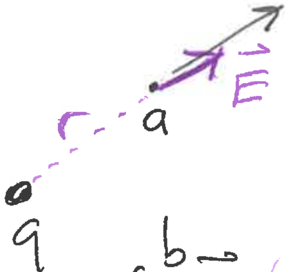
in space.

$$\underbrace{V_a}_{\text{initial}} - \underbrace{V_b}_{\text{final}} = \int_a^b \vec{E}\cdot d\vec{l}$$

$$\left.\underbrace{-(V_b - V_a)}_{\Delta V}\right\} -\Delta V = \int_a^b \vec{E}\cdot d\vec{l} \quad \text{path}$$

$$+\Delta V = +\int_{b(\text{final})}^{a(\text{initial})} \vec{E}\cdot d\vec{l}$$

Ex point charge q $b \to \infty$



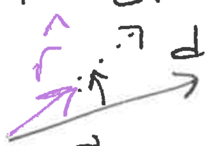
$\vec{E} = k\frac{q}{r^2}\hat{r}$

$$V_a - V_b = \int_a^b \vec{E}\cdot d\vec{l}$$

$$= \int_a^b \frac{kq}{r^2}\underbrace{\hat{r}\cdot d\vec{l}}_{|\hat{r}||d\vec{l}|\cos\theta}$$

$$\underbrace{|\hat{r}|}_{1}\underbrace{|d\vec{l}|\cos\theta}_{dr}$$

$$V_a - V_b = \int_a^b \frac{kq}{r^2}dr$$



$\hat{r}\cdot d\vec{l} = dl\cos\theta$

dr

$$V_a - V_b = kq\int_{r_a}^{r_b}\frac{dr}{r^2} \qquad r_b \to \infty$$

$$V_a - V_b = kq\left[-\frac{1}{r}\right]_{r_a}^{r_b}$$

$$V_a - V_b = kq\left[\frac{1}{r_a} - \frac{1}{r_b}\right]$$

$\Delta V = V_b - V_a$

If $r_b \to \infty$

$$V_a - \overset{0}{V_b} = \frac{kq}{r_a} - \overset{0}{\frac{kq}{r_b}}_{r_b\to\infty}$$

↳ potential at ∞ should be ZERO

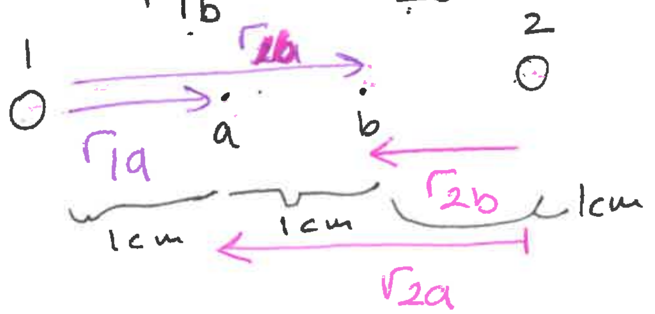
ex:

$q_0 = 2nC$ going from a to b

$V_a - V_b = ?$

$$V_a = \frac{kq_1}{r_{1a}} + \frac{kq_2}{r_{2a}}$$

$$V_b = \frac{kq_1}{r_{1b}} + \frac{kq_2}{r_{2b}}$$



$r_{1a} = 1cm = r_{2b} = r_{ab} = 1cm$

$q_1 = +3nC$ $\quad q_2 = -3nC$

②

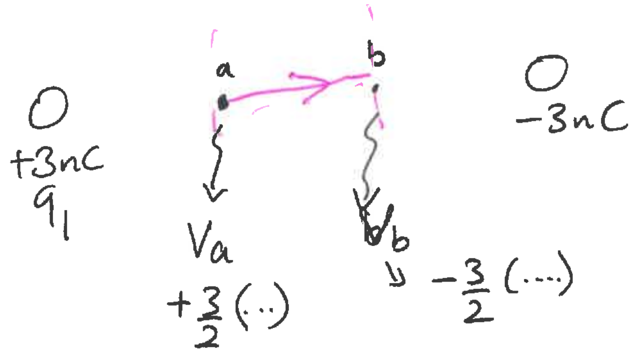
$$V_a = k\frac{3nC}{1cm} + \frac{k(-3nC)}{2cm}$$

$$= \frac{3}{2}k\frac{nC}{1cm} = \frac{3}{2}k\frac{10^{-9}C}{10^{-2}m}$$

$$V_a = \frac{3}{2}k\,10^{-7}\,\frac{C}{m}$$

$$V_b = k\frac{3nC}{2cm} + \frac{k(-3nC)}{1cm}$$

$$V_b = -\frac{3}{2}k10^{-7}\frac{C}{m}$$



$$\Delta V = V_b - V_a = \left[-\frac{3}{2} - \left(\frac{3}{2}\right)\right](\ldots)$$

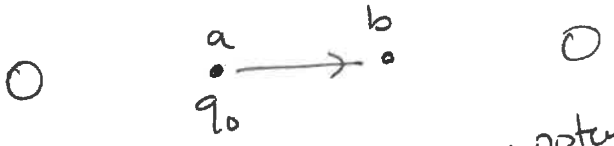
$$\underline{\Delta V} = -3(\ldots) = -3k10^{-7}\frac{C}{m}$$

$$-\Delta V = +3k10^{-7}\frac{C}{m}$$

$$= 3\times 9\times10^{9}\times10^{-7}\ \text{Volt}$$

$$-\Delta V = 27\times10^{2}\ \text{Volts}$$

$= 2700V$



$q_0(V_a - V_b) = \Delta U$ (potential energy)

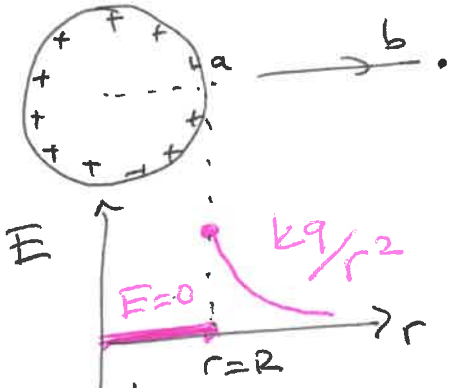
↳ 2nC

$$\Delta U = (2\times10^{-9}C)(2700V)$$

$$\Delta U = 5.4\times10^{-6}\ \text{Joules}$$

point charge $V = k\frac{q}{r}$

metal/conducting sphere



$$V_a - V_b = +\int_a^b \vec{E}\cdot d\vec{l}$$

r<R

E = 0

$$V_a - V_b = \int 0\cdot d\vec{l}$$

$$\underline{V_a = V_b \neq 0}$$

r=R $\quad$ r>R

a=R $\quad$ b→∞

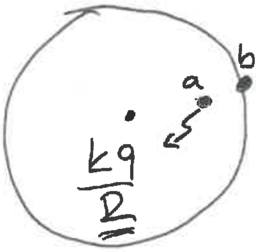
$$V_a - \underset{0}{\cancel{V_b}} = \int_R^{r} \underset{\frac{kq}{r^2}\hat{r}\cdot d\vec{l}}{\vec{E}}\cdot \underset{dr}{d\vec{l}}$$

b→∞

$$V_a(r=R) = kq\left[-\frac{1}{r}\right]_R^{\infty}$$

$$= kq\left[-\underset{0}{\frac{1}{\infty}} - \left(-\frac{1}{R}\right)\right]$$

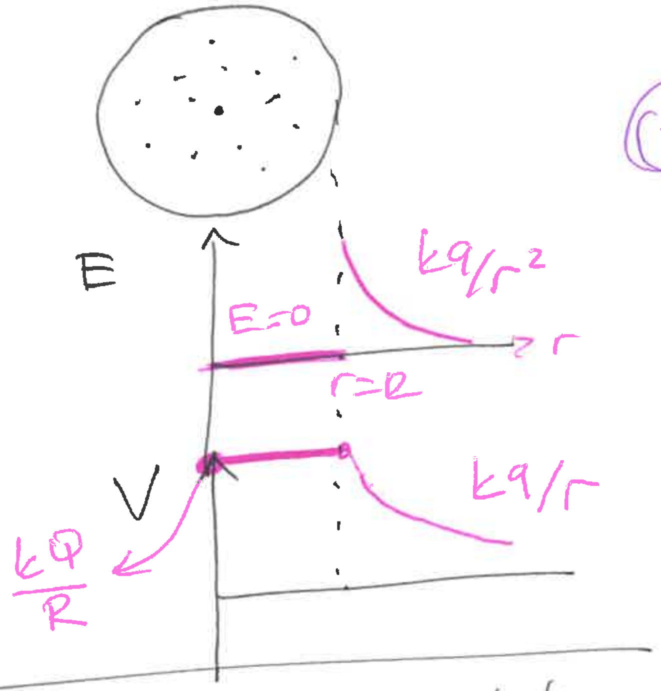
$$\underline{V = kq/R \quad (r=R)}$$



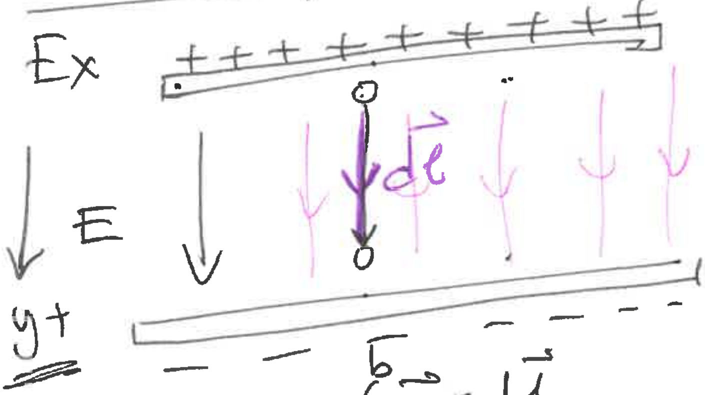
$\frac{kq}{R}$

inside

$V_a = V_b$



Ex



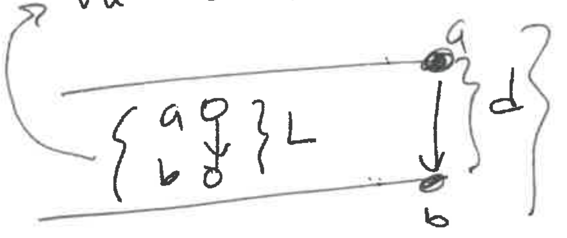
$$V_a - V_b = \int_a^b \underset{\text{const}}{\vec{E}}\cdot d\vec{l}$$

$$= \int_b E\hat{j}\cdot dl\,\hat{j}$$

$$= \int_a \underline{E}\,dl \quad \xrightarrow{} \text{const}$$

$$V_a - V_b = E\underbrace{\int_a^b dl}_{\underline{L}\ (\text{total displacement})}$$

$$V_a - V_b = EL$$



$$V_a - V_b = Ed$$

13.7.17

Phys II

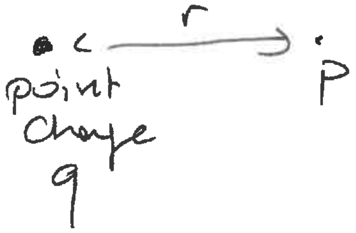
Electric Potential Contd.

E1

$\Delta U \sim$ Work done $= q\,\Delta V$

pot. energy difference

V: electric potential

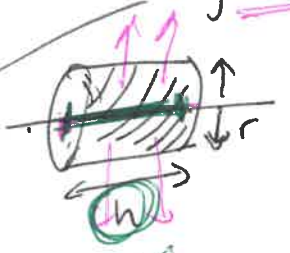


$V_p = k\frac{q}{r}$

Ex: V of infinitely long charged line/rod.

$V_a - V_b = \int_a^b \vec{E}\cdot d\vec{\ell}$

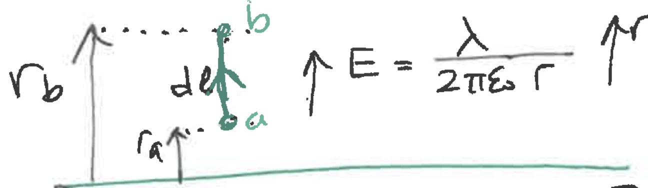
Gauss Law $\oint \vec{E}\cdot d\vec{A} = q_{in}/\varepsilon_0$



λ charge density

$$E\,2\pi r\cancel{h} = \frac{\lambda\cancel{h}}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$



$$\int_{r_a}^{b} \vec{E}\cdot d\vec{\ell} = \int \underbrace{E\,d\ell}_{dr}\,\underbrace{\cos 0}_{1}$$

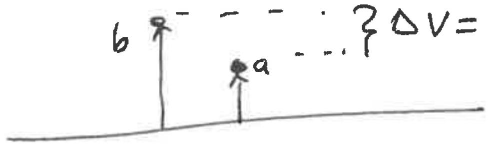
$$\int E\,d\ell = \int_{r_a}^{r_b} \underset{\substack{\downarrow \\ \frac{\lambda}{2\pi\varepsilon_0}\frac{1}{r}}}{E}\,dr$$

const.

$$\frac{\lambda}{2\pi\varepsilon_0}\int\frac{dr}{r} = \frac{\lambda}{2\pi\varepsilon_0}\left[\ln r\right]_{r_a}^{r_b}$$

$$\frac{\lambda}{2\pi\varepsilon_0}\left[\ln r_b - \ln r_a\right]$$

$$\frac{\lambda}{2\pi\varepsilon_0}\ln\left(\frac{r_b}{r_a}\right) = V_a - V_b$$



$? \Delta V = V_b - V_a$

V ⇒ potential values can be set as differently in some situations.

ΔV ⇒ does not change

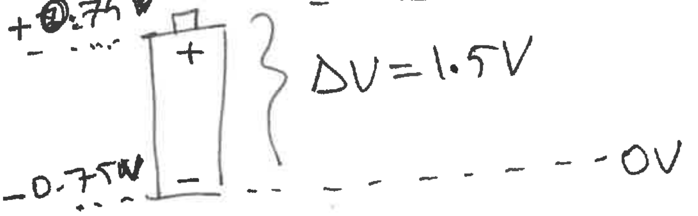
U = pot. energy = mgh

$U \equiv 0$ → arbitrary

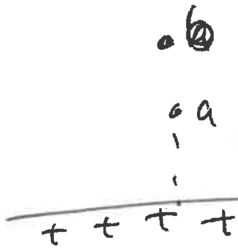
ΔV = Va

V = 0V arbitrary

battery (pil)



ΔV = 1.5V



$(\cdot\cdot) \ln \frac{r_b}{r_a}$ if $r_b \to \infty$ ②

line charge

$$\Delta V = \frac{\lambda}{2\pi\varepsilon_0} \ln\left(\frac{\infty}{r_a}\right) \to \infty$$

$r_b \to \infty$

assume $V_b\ (r_b \to \infty) = 0$

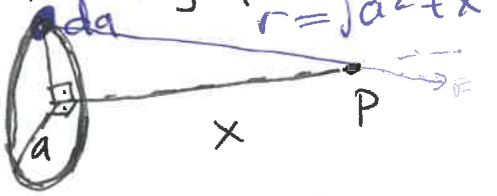
$r_b \to r_0$

$$\Delta V = V_a - V_b = \frac{\lambda}{2\pi\varepsilon_0} \ln\left(\frac{r_0}{r_a}\right)$$

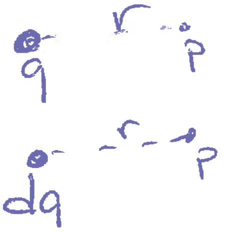
$\Downarrow$

$V - 0$

Ex: charged Ring Q



$r = \sqrt{a^2+x^2}$



$V_p = k\frac{q}{r}$

$dV = k\frac{dq}{r}$

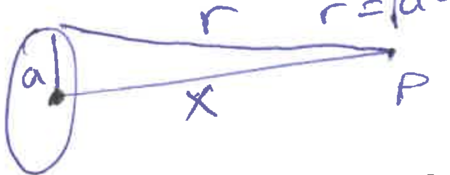
$$V = \int k\frac{dq}{r}$$

$dq \Leftrightarrow r$ independant

$r \Rightarrow$ same

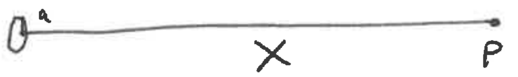
$$V = \frac{k}{r}\int dq = \frac{kQ}{r}$$

$r = \sqrt{a^2+x^2}$



$$V = \frac{kQ}{\sqrt{a^2+x^2}}$$

potantial of q charged ring. at P



$x \gg a$ very far away from ring ; ring should look like a point

$\Downarrow$

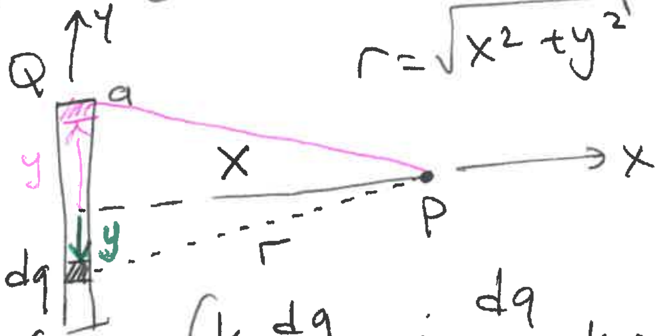
check if $V = kQ/X$

$$V = \frac{kQ}{\sqrt{a^2+x^2}} = \frac{kQ}{\sqrt{x^2\left(\frac{a^2}{x^2}+1\right)}}$$

$\frac{a}{X} \simeq 0$

$$= \frac{kQ}{\sqrt{x^2(0+1)}} = \frac{kQ}{X}$$

✓



$r = \sqrt{x^2+y^2}$

$\int k\frac{dq}{r}$; dq depends on r.

$$\lambda = \frac{Q}{L} = \frac{Q}{2a} = \frac{dq}{dy}$$

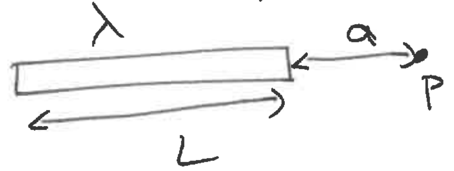
$$V = \int k\frac{dq}{r} = \int_{-a}^{a} \frac{k\lambda dy}{(x^2+y^2)^{1/2}}$$

integral table

$$V = k\lambda \ln\left(\frac{\sqrt{a^2+x^2}+a}{\sqrt{a^2+x^2}-a}\right)$$

$$V = k\frac{Q}{2a} \ln\left(\frac{\sqrt{a^2+x^2}+a}{\sqrt{a^2+x^2}-a}\right)$$

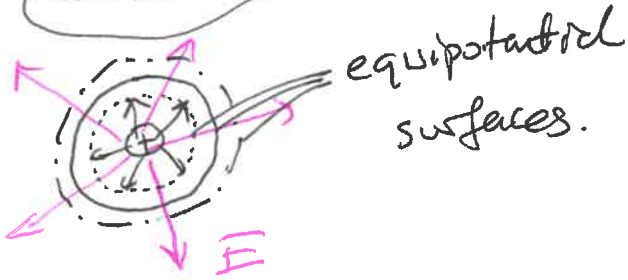
Try: $V_p = ?$

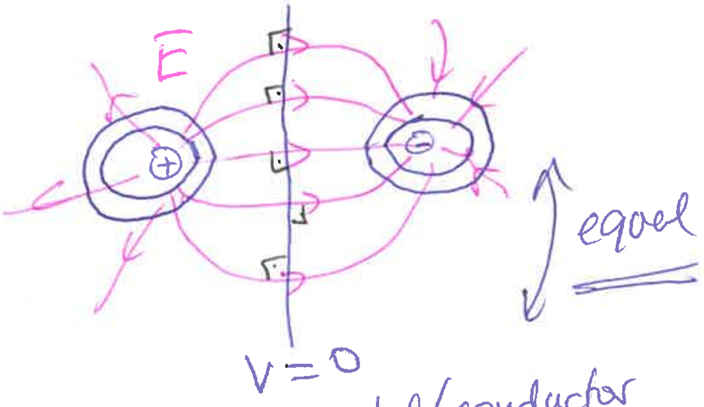


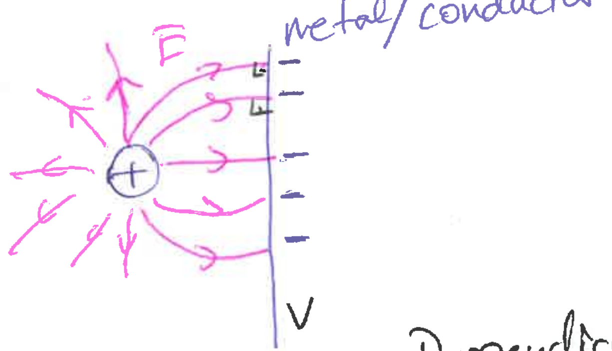
EQUIPOTENTIAL SURFACES:

equal

~~Blagba~~ Topographic map

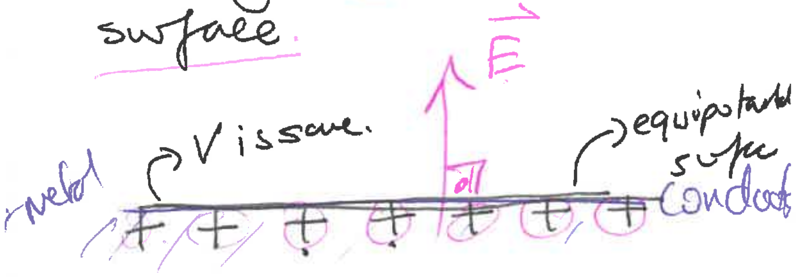




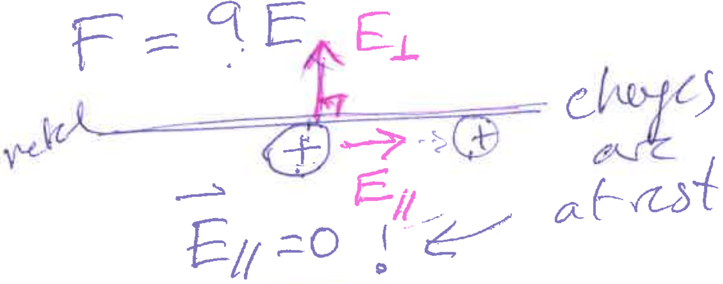


$\vec{E}$ field lines are Perpendicular to equipotential lines.

When all charges are at REST the surface of a conductor is always a equipotential surface.



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

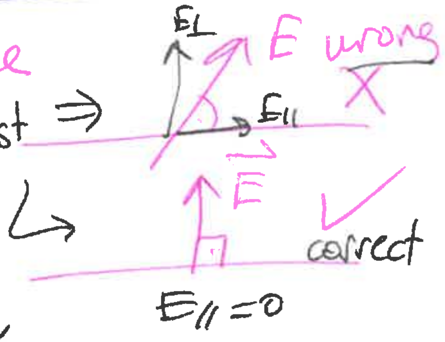


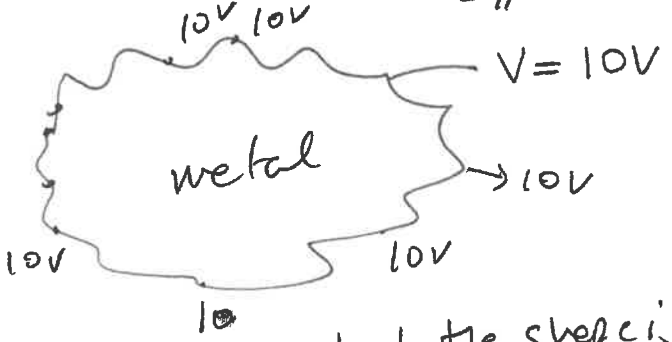
$\vec{E}_{//} = 0$!

~~apply a $\vec{E}$~~ there is a current I then $\vec{E}_{//} \neq 0$

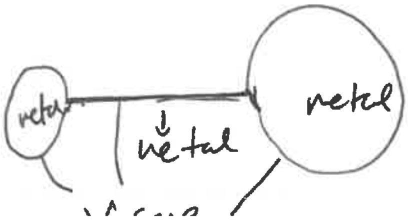
metal surface

charges at Rest ⇒





no matter what the shape is the metal surfaces have the same potential value!!!



$$V_a - V_b = \int_a^b \vec{E}\cdot d\vec{l}$$

$-\Delta V$ $\quad a \to b$, $\quad i \quad f$

→ final - initial

$$\Delta V = -\int_a^b \vec{E}\cdot d\vec{l}$$

$$\vec{E} = E_x\hat{i} + E_y\hat{j} + E_z\hat{k}$$

$$d\vec{l} = dx\,\hat{i} + dy\,\hat{j} + dz\,\hat{k}$$

$$\int_a^b dV = -\int_a^b \vec{E}\cdot d\vec{l}$$

$$dV = -\vec{E}\cdot d\vec{l}$$

$$dV = -(E_x dx + E_y dy + E_z dz)$$

$E_x = -\frac{\partial V}{\partial x}$ (partial derivative)

$E_y = -\frac{\partial V}{\partial y}$ $\quad E_z = -\frac{\partial V}{\partial z}$

***

$V(x,y,z)$;

$$\vec{E} = -\frac{\partial V}{\partial x}\hat{i} - \frac{\partial V}{\partial y}\hat{j} - \frac{\partial V}{\partial z}\hat{k}$$

$\vec{\nabla}$: gradient

$$\vec{\nabla} f = \hat{i}\frac{\partial f}{\partial x} + \hat{j}\frac{\partial f}{\partial y} + \hat{k}\frac{\partial f}{\partial z}$$

$$\boxed{\vec{E} = -\vec{\nabla} V}$$ *

④ $(x,y,z) \to (r,\theta,\phi)$

cartesian → spherical

$$E_r = -\frac{\partial V}{\partial r}$$

Ex: $V = k\frac{q}{r}$ is given

$E = ?$

$$E = -\frac{\partial}{\partial r}\left(\frac{kq}{r}\right)$$

$$= -kq\frac{\partial}{\partial r}\left(\frac{1}{r}\right)$$

$$\frac{d}{dr}(Ar^n) = A\,n\,r^{n-1}$$

$n = -1$

$$E = -kq\left(-\frac{1}{r^2}\right)$$

$$E = \frac{kq}{r^2}$$

Ex:

$$V = \frac{kQ}{(x^2+a^2)^{1/2}}$$

$E = ?$ $\quad E_x = -\frac{\partial V}{\partial x}$

$$-kQ\frac{\partial}{\partial x}(x^2+a^2)^{-1/2}$$

$$-kQ\left(-\frac{1}{2}\right)(x^2+a^2)^{-3/2}(2x)$$

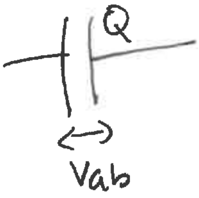
$$E = \frac{kQx}{(x^2+a^2)^{3/2}}$$

end of chapter 23

Ch 24 capacitance and dielectrics

Th

capacitor :



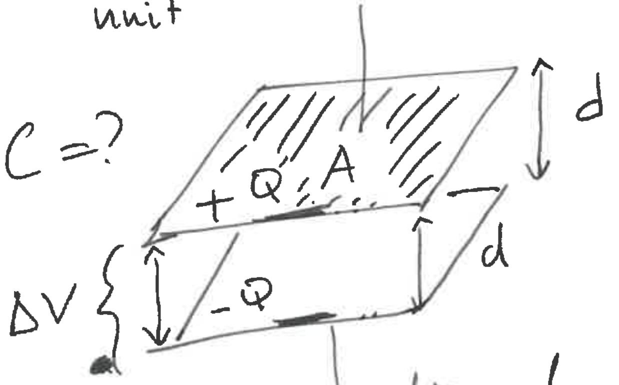
capacitance

$$\hookrightarrow C \equiv \frac{Q}{V_{ab}} = \underbrace{\left[\frac{C}{V}\right]}_{\text{Farad units}}$$

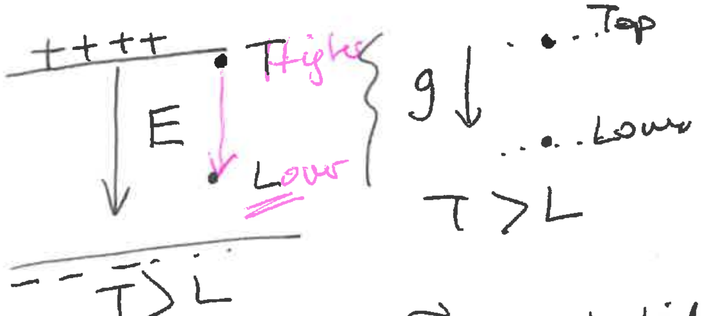
$$\left[F = \frac{C}{V}\right]$$

unit

$C = ?$



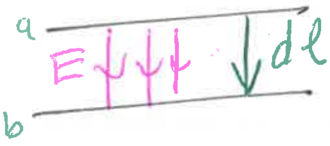
Area A; seperation d.



if you go along $\vec{E}$; potential V decreases

$$\underbrace{V_a - V_b}_{-\Delta V} = \int_a^b \vec{E} \cdot d\vec{l}$$

?

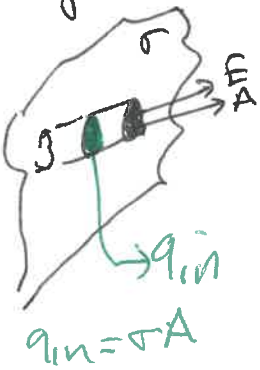


What's $\vec{E}$ of a charged metal surface

remember Gauss:

$$\oint \vec{E} \cdot d\vec{A} = q_{in}/\varepsilon_0$$

$$E\cancel{A} = \frac{\sigma \cancel{A}}{\varepsilon_0}$$

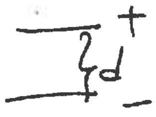


$$E = \frac{\sigma}{\varepsilon_0}$$

E↓ ↓dl

$$V_a - V_b = \int \vec{E} \cdot d\vec{l}$$

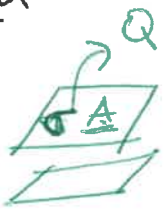
↳ const.



$$\boxed{V_a - V_b} = E \underbrace{\int dl}_{d}$$

Vab

$$V_{ab} = Ed \Rightarrow \frac{\sigma d}{\varepsilon_0}$$



$$C = \frac{Q}{V_{ab}} = \frac{Q}{\sigma d/\varepsilon_0}$$

$$C = \frac{\sigma A}{\sigma d/\varepsilon_0} = \varepsilon_0 \frac{A}{d}$$

capacitance of two metal parallel plates is

$$C = \varepsilon_0 \frac{A}{d}$$

unit analysis.

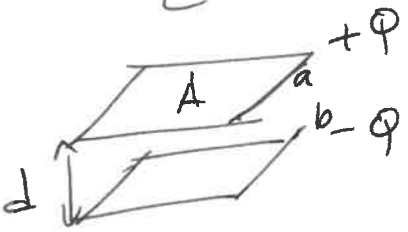
$$\left[F = \frac{C}{V}\right] = \varepsilon_0 \frac{m^{\cancel{2}}}{\cancel{m}}$$

$$\text{Force} = \frac{1}{4\pi\varepsilon_0} \frac{q^2}{r^2}$$

$$\varepsilon_0 = \frac{q^2}{Fr^2} = \frac{C^2}{Nm^2}$$

$$\boxed{F = \frac{C}{V} = \frac{C^2}{Nm^{\cancel{2}}}\cancel{m}}$$

$$\boxed{F = \frac{C^2}{Nm}}$$



$$C = \varepsilon_0 \frac{A}{d} = \frac{Q}{V_{ab}}$$

check $C = \varepsilon_0 (\text{Length})$

always true.

$$\varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{m}$$

$$\varepsilon_0 = 8.85 \times 10^{-12} \frac{C}{V}$$

$$\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$$

Ex: want to make capacitor 1F value with parallel plates separation 1mm. What should be the area of the plates?

$$C = \varepsilon_0 \frac{A}{d} \qquad A = \frac{Cd}{\varepsilon_0}$$

$$\text{Area} = \frac{(1\cancel{F})(10^{-3}m)}{8.85 \times 10^{-12} \cancel{F}/m}$$

$$= 1.1 \times 10^8 m^2 \simeq 10^8 m^2$$

$\boxed{\text{HUGE!!!}}$ 10km

10km

Ex: Area = 2 m²

d = ~~2~~ 5mm

$\Delta V = 10kV = 10000V$

a) capacitance?

b) $\underline{Q}$ =? on each plate?

c) $|\vec{E}|$ =? ~~on~~ between plates.

$$C = \varepsilon_0 \frac{A}{d} = \frac{Q}{V_{ab}}$$

a) $C = 8.85 \times 10^{-12} \frac{2}{5 \times 10^{-3}} = 3.5 \times 10^{-9} F$

$= 3.5 nF$

b) $Q = C\Delta V = C V_{ab}$

$= 3.5 \times 10^{-9} \times 10000 \; C$

$= 3.5 \times 10^{-5} C$

$= 35 \times 10^{-6} C = 35 \mu C$

+ + + + + +35μC

- - - - - -35μC

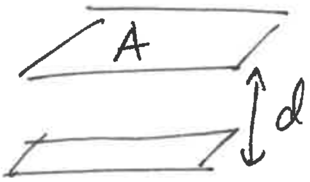
c) $E = \sigma/\varepsilon_0 = \frac{Q}{A\varepsilon_0}$ $\qquad \Delta V = Ed$, $\overset{N}{F} = q\overset{C}{E}$

$$E = \frac{35 \times 10^{-6}}{2 \times 8.85 \times 10^{-12}} \left[\frac{N}{C} \text{ or } \frac{V}{m}\right]$$

$$E = 2 \times 10^6 \, N/C$$

also

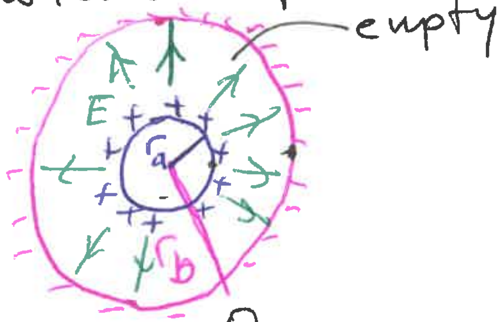
$$\underset{\substack{\downarrow \\ 5mm}}{E d} = \underset{\substack{\downarrow \\ 10000V}}{\Delta V} \Bigg\} E = 2 \times 10^6 \frac{N}{C}$$



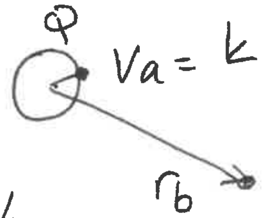
$C = \varepsilon_0 \frac{A}{d}$

7

spherical capacitor



$C = ? = \frac{Q}{V_{ab}}$



$V_a = k\frac{Q}{r_a}$

$V_b = k\frac{Q}{r_b}$

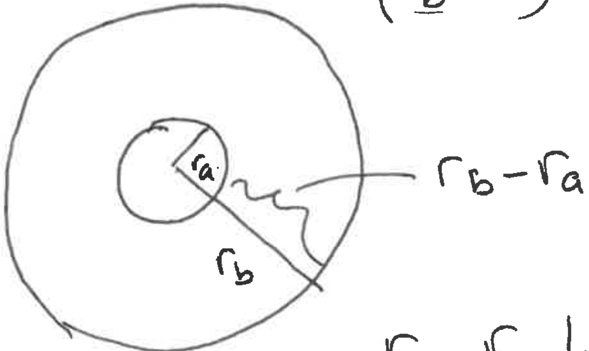
$V_{ab} = V_a - V_b$

$= kQ\left[\frac{1}{r_a} - \frac{1}{r_b}\right]$

$k = \frac{1}{4\pi\varepsilon_0}$

$C = \frac{\cancel{Q}}{k\cancel{Q}\left[\frac{r_b - r_a}{r_a r_b}\right]}$

$C = 4\pi\varepsilon_0 \frac{r_a r_b}{(r_b - r_a)} \sim \varepsilon_0(\text{Length})$ ✓

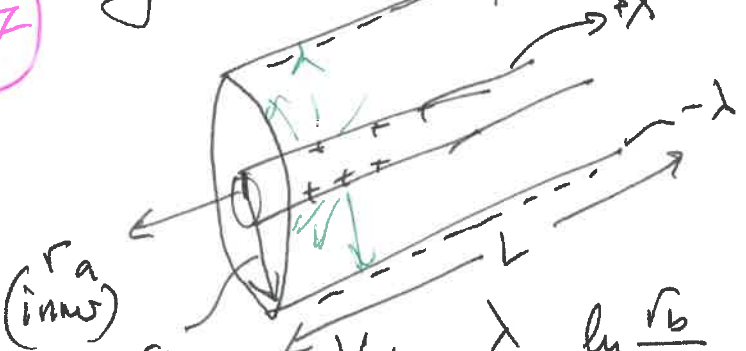


$C\uparrow;\quad r_b - r_a \downarrow$

$r_a r_b \uparrow$

spherical capacitor.

Cylindrical Capacitor



$V_{ab} = \frac{\lambda}{2\pi\varepsilon_0}\ln\frac{r_b}{r_a}$

previous chapter

$C = \frac{Q}{V_{ab}} = \frac{\cancel{\lambda} L}{\frac{\cancel{\lambda}}{2\pi\varepsilon_0}\ln\frac{r_b}{r_a}} = 2\pi\varepsilon_0 \frac{L}{\ln\left(\frac{r_b}{r_a}\right)}$

$C\uparrow;\quad L\uparrow,\ \ln\left(\frac{r_b}{r_a}\right)\downarrow$

$r_b - r_a$ small

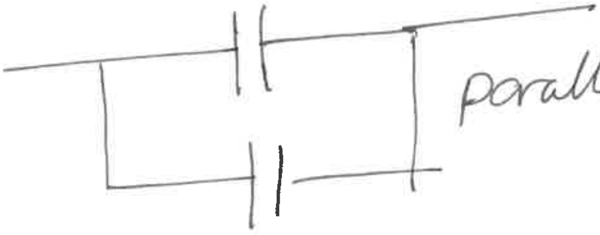
$C = 2\pi\varepsilon_0 \frac{L}{\ln\left(\frac{r_b}{r_a}\right)}$

unit analysis.

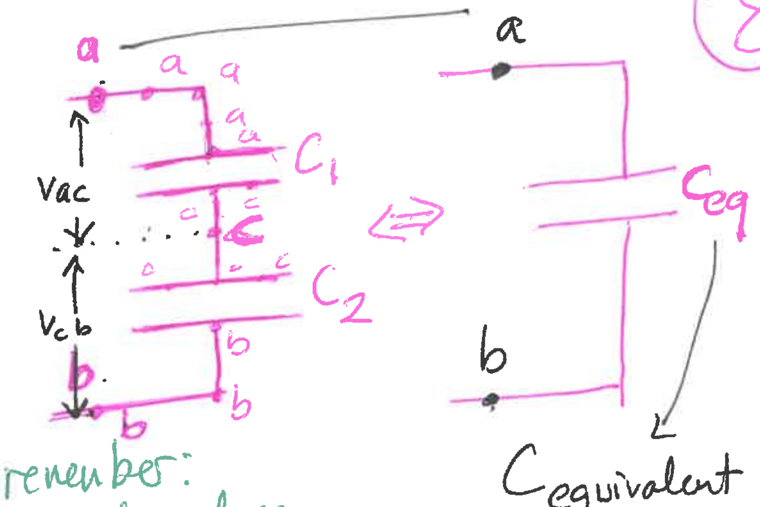
$C \sim \varepsilon_0(\text{Length})$ ✓

Capacitors in SERIES & PARALLEL


series


parallel

SERIES

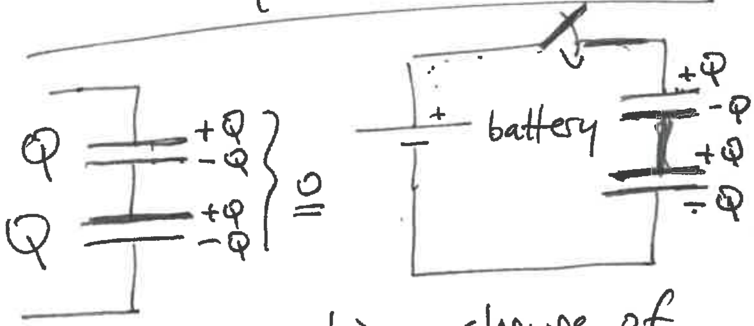


remember: metal surface should have the same Voltage.

$C = Q/\Delta V$

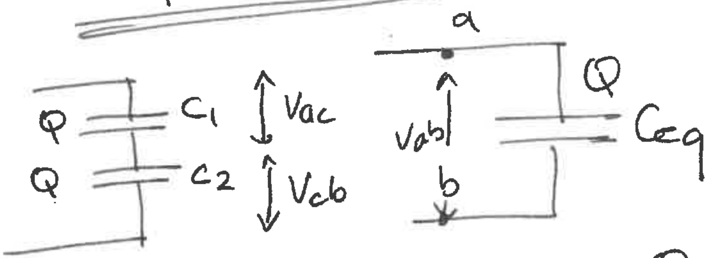
$V_{ab} = V_{ac} + V_{cb}$

$C_{eq} \overset{?}{\Leftarrow} C_1 \cancel{+} ; C_2$



series connection charge of C_1 and C_2 are Q SAME!!

$Q_1 = Q_2 = Q$

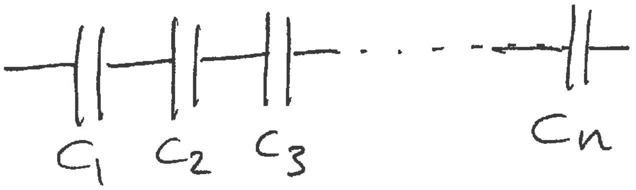


$V_{ab} = V_{ac} + V_{cb}$; $\Delta V = \frac{Q}{C}$

$$\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

series $$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

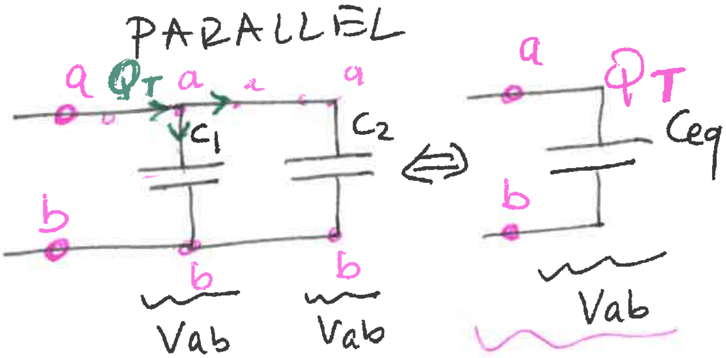
8

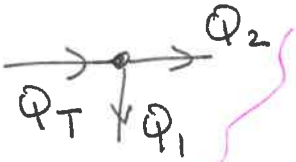


$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n}$$

SERIES connected capacitors!!!

PARALLEL



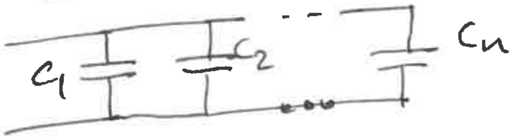


$Q_T = Q_1 + Q_2$

$C = \frac{Q}{\Delta V}$

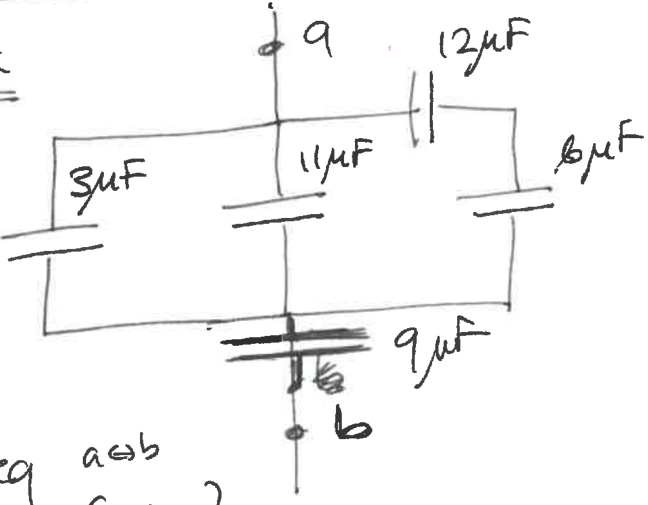
$C_{eq} V_{ab} = C_1 V_{ab} + C_2 V_{ab}$

$C_{eq} = C_1 + C_2$ parallel



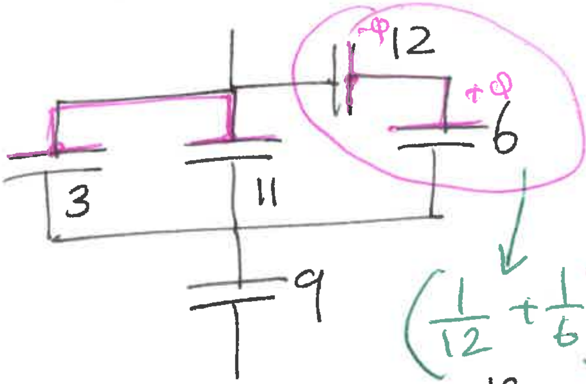
$C_{eq} = C_1 + C_2 + \dots + C_n$

Ex



Ceq a⟷b

$C_{ab} = ?$

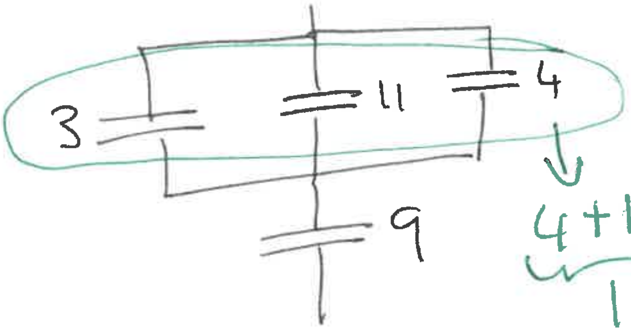


Series

$\bigcirc 9$

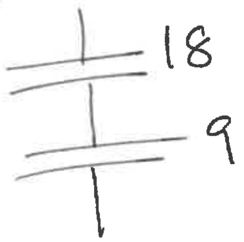
$\left(\frac{1}{12}+\frac{1}{6}\right)^{-1}$

$\frac{12}{3} = \underline{4}$



parallel

$\underbrace{4+11+3}_{18}$

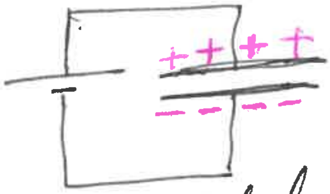


$\left(\frac{1}{18}+\frac{1}{9}\right)^{-1}$

$\frac{18}{3} = \underline{6\mu F}$

$C_{eq} = 6\mu F$

Energy Stored in Capacitors



can be calculated via integral

$\boxed{C = \frac{Q}{\Delta V}} = \frac{Q}{V}$

work done

$\int dq\, V = \int dW$

related

$\int dq \frac{q}{C} = \frac{1}{C}\int q\,dq = \frac{q^2}{2C}$

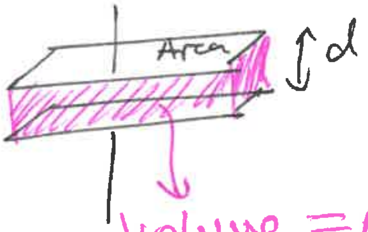
energy stored by the battery

$U = \underline{\frac{Q^2}{2C}} = \frac{(CV)^2}{2C} = \underline{\frac{CV^2}{2}}$

potential energy stored in capacitor

$C = \frac{Q}{\Delta V} = \frac{Q}{V}$

$U = \frac{Q^2}{2C} = \frac{Q^2}{2\frac{Q}{V}} = \underline{\frac{QV}{2}}$



store the energy in a volume.

Volume = Ad

$\text{Energy density} \equiv \frac{\text{Energy}}{\text{Volume}} = \frac{\frac{1}{2}CV^2}{Ad}$

$C = \varepsilon_0 \frac{A}{d}$; $V = Ed$

$U = \frac{\frac{1}{2}\varepsilon_0 \frac{\cancel{A}}{\cancel{d}} E^2 d^{\cancel{2}}}{\cancel{A}\cancel{d}}$

$U = \frac{1}{2}\varepsilon_0 E^2$

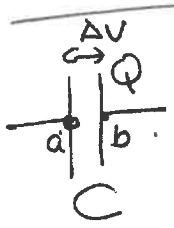
energy density

$E = \sigma/\varepsilon_0$

$U = \frac{1}{2}\varepsilon_0 \frac{\sigma^2}{\varepsilon_0^2} = \underline{\frac{\sigma^2}{2\varepsilon_0}}$

Capacitors Contd PHYS ②

14.7.17 ①

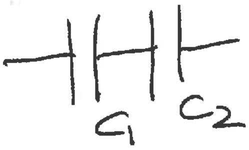


$\Delta V = V_{ab}$

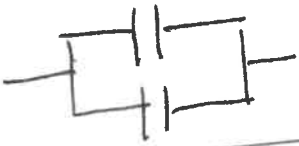
$$C = \frac{Q}{V_{ab}} = \frac{Q}{\Delta V}$$

energy of a capacitor.

$$U = \frac{Q^2}{2C} = \frac{QV}{2} = \frac{CV^2}{2}$$



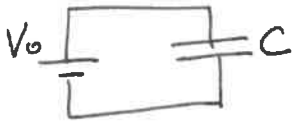
$$C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$



$$C_{eq} = C_1 + C_2$$

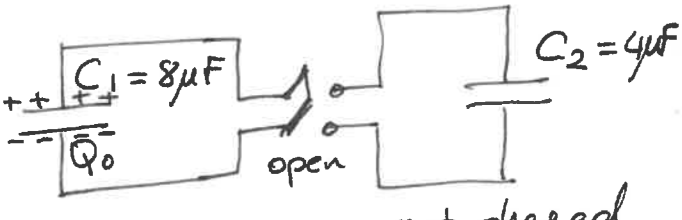
Ex: charged capacitor $C_1 = 8\mu F$ under $V_0 = 120V$.; disconnected from battery; ~~&~~

ⓐ what's the charge?



$$Q_0 = CV$$
$$= 8\mu F \; 120V$$
$$= 960 \, \mu FV$$
10^{-6} Coulom
$$= 0.96 \times 10^{-3} C$$
$$Q_0 = 0.96 \, mC$$

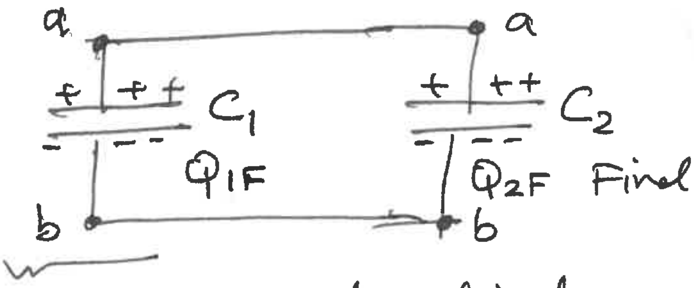
ⓑ



not charged

switch is closed
what's the charge on each capacitor?

Total charge before Q_0
after should be Q_0



~~be~~ initial final

$$Q_0 = Q_{1F} + Q_{2F}$$

$$V_{ab} = \frac{Q_{1F}}{C_1} = \frac{Q_{2F}}{C_2} = V_{ab}$$

$$Q_{1F} = \frac{C_1}{C_2} Q_{2F} = \frac{8}{4} Q_{2F}$$

$$Q_0 = 2 Q_{2F} + Q_{2F}$$

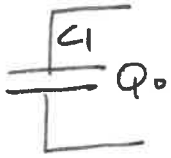
80V

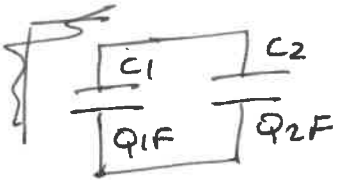
$$Q_{2F} = \frac{Q_0}{3} = \frac{0.96 \, mC}{3}$$

$$Q_{2F} = 0.32 \, mC$$

$$Q_{1F} = 2 Q_{2F} = 0.64 \, mC$$

ⓒ what's the ratio of initial energy over final energy?





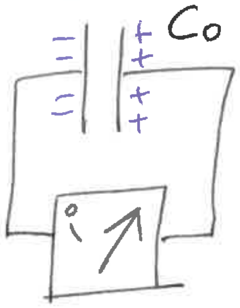
U_{1i} U_{1F} U_{2F}

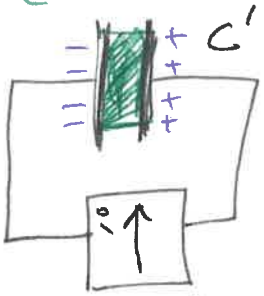
$$\frac{U_{1i}}{U_{1F} + U_{2F}} = ? \qquad \frac{\cancel{\frac{1}{2}} \frac{Q_0^2}{C_1}}{\cancel{\frac{1}{2}} \frac{Q_{1F}^2}{C_1} + \cancel{\frac{1}{2}} \frac{Q_{2F}^2}{C_2}}$$

$$= \frac{\frac{(0.96 \, mC)^2}{8\mu F}}{\frac{(0.64 \, mC)^2}{8\mu F} + \frac{(0.32)^2 (mC)^2}{4\mu F}}$$

$$= \frac{0.106 \, J}{0.076 \, J} = 1.4$$

Dielectrics in capacitors





voltage

Voltage difference decreases when dielectric are put between plates.

Q ⇒ const.

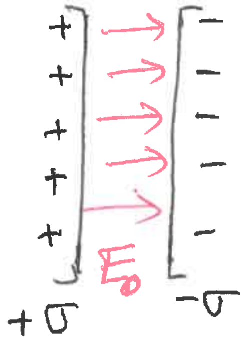
$C_0 = \frac{Q}{V_0}$ $\quad \uparrow C' = \frac{Q}{V'\downarrow}$

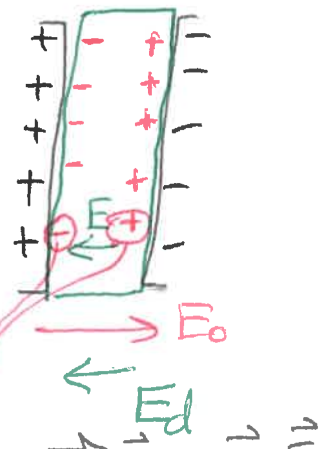
$C' > C_0$

$$\boxed{\begin{array}{l} C' = K C_0 \quad \llcorner \text{kappa} > 1 \\ V' = \frac{V_0}{K} \end{array}}$$

putting dielectrics is GOOD; you increase C; you can store more charges, Q.

materials	K
vacuum	→ 1.
air	→ 1.0006
teflon	→ 2.1
glass	→ 5-10
glycerin	→ 42.5
strontium titanate	→ 310





$\Rightarrow \vec{E} = \vec{E_0} + \vec{E_d}$

$$E = \frac{E_0}{K}$$

$E_0 = \frac{\sigma}{\varepsilon_0}$ (metal) from Gauss

$$E = \frac{\sigma - \sigma_i}{\varepsilon_0}$$; σ_i ⇒ induced charges in dielectric

$$E = \frac{\sigma / \cancel{\varepsilon_0}}{K} = \frac{\sigma - \sigma_i}{\cancel{\varepsilon_0}}$$

$$\Rightarrow \frac{\sigma}{K} = \sigma - \sigma_i \Rightarrow \sigma_i = \sigma\left(1 - \frac{1}{K}\right)$$

How much of a charge will be induced depends on σ, K

$$\sigma_i = \sigma\left(\frac{K-1}{K}\right)$$

if $K = 2.5 \Rightarrow \sigma_i = \sigma \overset{0.6}{\boxed{\frac{1.5}{2.5}}}$

66% of charges ~~of~~ induced in the dielectric material.

ε_0 ⇒ electric permittivity of vacuum

$K\varepsilon_0 \equiv \in$; el. permittivity of dielectric material.

permittivity (geçirgenlik)

$C = K C_0$; $C_0 = \varepsilon_0 \frac{A}{d}$ ③

$C = K \varepsilon_0 \frac{A}{d}$ parallel plate

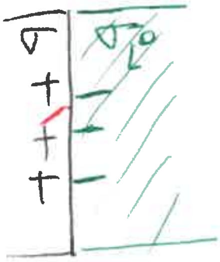
$K \varepsilon_0 \equiv \epsilon$

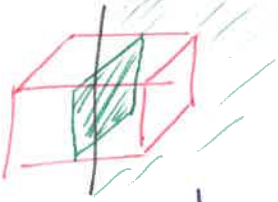
$C = \epsilon \frac{A}{d}$;

energy density $u = \frac{1}{2} \varepsilon_0 E^2$

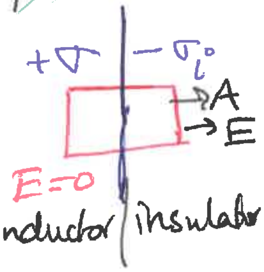
$u = \frac{1}{2} \varepsilon_0 K E^2$

Gauss' Law in Dielectrics





$\Phi = \oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$



$E A = \frac{(\sigma - \sigma_i) A}{\varepsilon_0}$

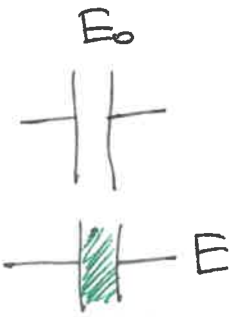
$E = \frac{\sigma - \sigma_i}{\varepsilon_0} = \frac{\sigma - \sigma_i}{\varepsilon_0}$

$\sigma - \sigma_i = \boxed{\frac{\sigma}{K}}$

$E = \frac{\sigma}{K \varepsilon_0}$; $K E = \underbrace{\frac{\sigma}{\varepsilon_0}}_{E_0}$

E field with dielectrics

E_0 no dielectric

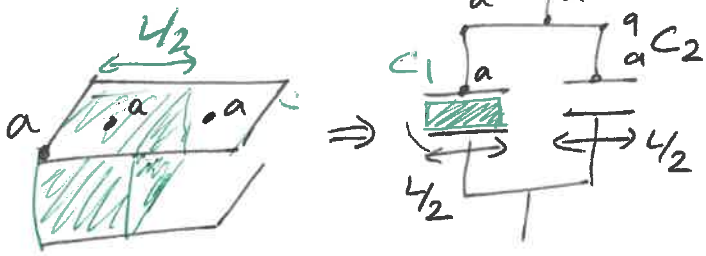


$E = \frac{E_0}{K} \Rightarrow V = \frac{V_0}{K}$ potential

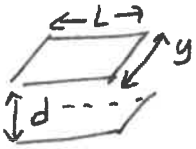
24.66

C_0

Cnew ?



$\boxed{C_0} = \varepsilon_0 \frac{A}{d}$

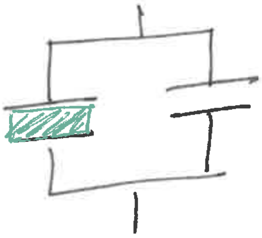


$C_0 = \varepsilon_0 \frac{L y}{d}$

$C_2 = \frac{\varepsilon_0 \frac{L}{2} y}{d} = \frac{1}{2} \boxed{\varepsilon_0 \frac{A}{d}}$ C_0

$C_1 = K \frac{\varepsilon_0 \frac{L}{2} y}{d} = \frac{K}{2} \boxed{\varepsilon_0 \frac{A}{d}}$ C_0

$\frac{K C_0}{2}$

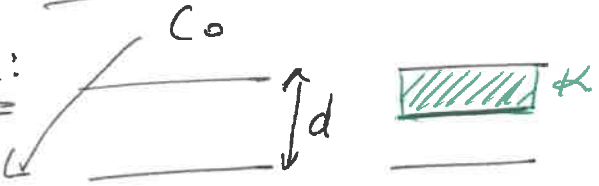


$\frac{C_0}{2}$

parallel ⇒ $C_{eq} = \frac{C_0}{2} + \frac{K}{2} C_0$

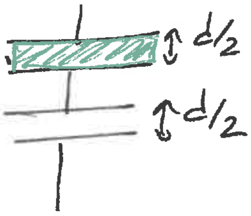
$C_{new} = C_{eq} = \frac{C_0}{2}(1+K)$

Ex:



$\varepsilon_0 \frac{A}{d}$

⇓

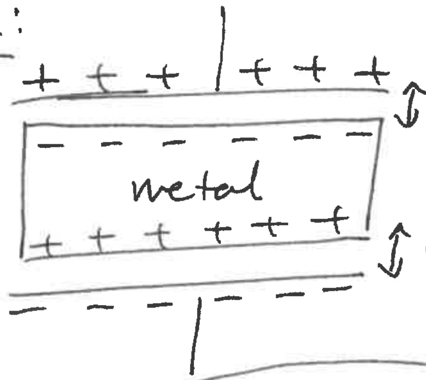


$2 K C_0 \Leftarrow \frac{K \varepsilon_0 A}{d/2}$

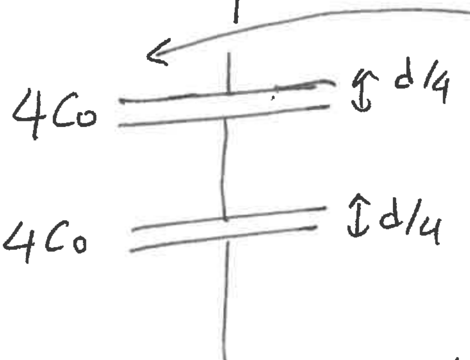
$\left(\frac{1}{2C_0} + \frac{1}{2KC_0}\right)^{-1}$

$2 C_0 \Leftarrow \frac{\varepsilon_0 A}{d/2}$

Ex:



$C_0 = \varepsilon_0 \frac{A}{d}$ ④



$C_1 = \varepsilon_0 \frac{A}{d/4}$

$C_2 = \varepsilon_0 \frac{A}{d/4}$

$$\left(\frac{1}{4C_0} + \frac{1}{4C_0}\right)^{-1} = \left(\frac{2}{4C_0}\right)^{-1} \Rightarrow C_{eq} = 2C_0$$

Chapter 25

current; resistence Electromotive Force

metal excess of charge

metal atoms

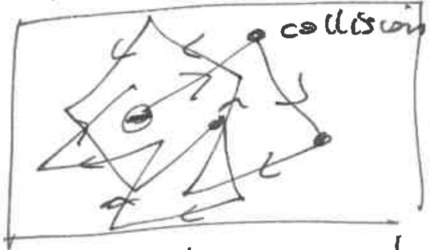
$Al \rightarrow 2e^-$ gives out

metals; sea of electrons

travel $\sim 10^6$ m/s speed

they collide (çarpışmak) with other ions frequently

~~E≠0~~



E = 0

happens at room temperature

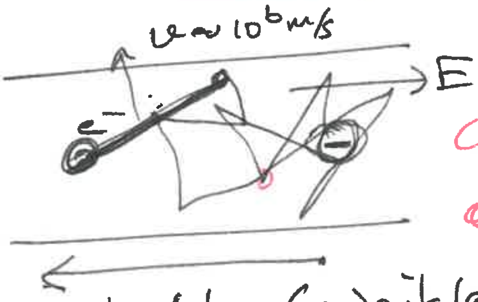
on average e⁻ will ~~[illegible]~~ move 0 distance.

E = 0

if we want to direct/move e⁻ towards a direction, apply $\vec{E}$

$\vec{F} = -q_e \vec{E}$

qE = F

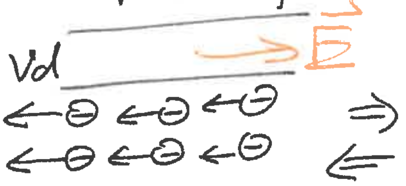


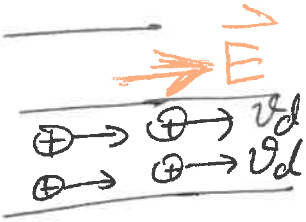
collisions + qE

drifts (sürüklenmek)

V_{drift} speed ~ mm/s

reality



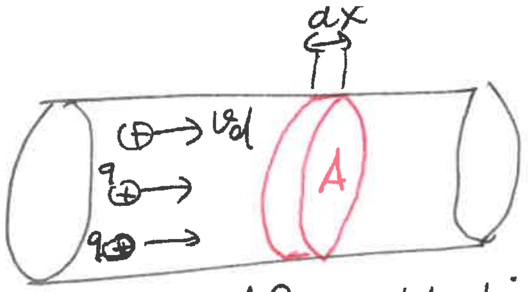


⊖ moves → I (current)

⊕ moves → I (current)

$$I = \frac{dQ}{dt} \quad \left[\text{Ampere} = \frac{C}{s}\right]$$

$$\left[A = \frac{C}{s}\right]$$



current $I = \frac{dQ}{dt}$ dt time

dx distance $\Rightarrow dx = v_d dt$

dQ ⇒ how many charges are there in certain volume at certain dt time.

Al, Cu, Au

$n = \frac{\#\text{ of charges}}{\text{Volume}}$ = charge concentration

$dQ \equiv q(dV)\underline{n}$

$= q(dx\ A)\underline{\underline{n}}$

$v_d dt$

$dQ = q v_d dt A n$

q = charge of $1e^-$ = -1.6×10^{-19}C

$$I \equiv \frac{dQ}{dt} = q v_d A n$$

$$\frac{I}{A} \equiv J = q v_d n \equiv \text{current density}$$

$$\vec{J} = q \vec{v}_d n$$ vector form

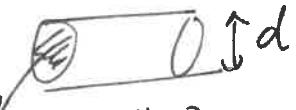
Ex: copper wire diameter of 1.02mm; $I = 1.67A$

free e^- density $n = 8.5 \times 10^{28} / m^3$

a) $J = ?$ b) $v_d = ?$

⑤

a) $J = \frac{I}{A}$



$A = \pi\left(\frac{d}{2}\right)^2$

d = 1.02mm

$$J = \frac{1.67A}{3.14\frac{(1.02\times10^{-3})^2}{4}}$$ $A = \pi \frac{d^2}{4}$

$J = 2\times10^6\ A/m^2$

ⓑ $v_d = ?$ $J = n q v_d$

$$\underline{\underline{J}} = \left(\frac{8.5\times10^{28}}{m^3}\right)(1.6\times10^{-19}C)\, v_d$$

$$v_d = \frac{J}{nq} = \left[\frac{A/m^2}{\frac{1}{m^3}C}\right] = \left[\frac{A\,m}{C}\right]$$

$$v_d \Rightarrow \left[A = \frac{C}{s} \Rightarrow \frac{\cancel{C}}{s}\frac{m}{\cancel{C}} = \frac{m}{s}\right]$$

$v_d = 1.5\times10^{-4}$ m/s = 0.15mm/s

v_d is very very small #

1s ⇒ 0.2mm

Resistivity (Direnç)

ρ Resistivity

$$\rho = \frac{E}{J} = \frac{\text{El. field}}{\text{cur. density}}$$

ohm

$$= \left[\frac{V/m}{A/m^2}\right] = \boxed{\frac{V}{A}}\, m$$

$= [\Omega m]$

ρ materials	ρ (Ωm)
Silver	1.47×10^{-8}
Copper	1.72×10^{-8}
Gold	2.44×10^{-8}
Alumunum	2.75×10^{-8}

Alloys (alasum) ⇝ $50-100\times10^{-8}$

semiconductors ⇝ $(10^{5} - 2300)$

insulator → $10^{10} - 10^{14}$

glass $10^{8} - 10^{11}$

wood

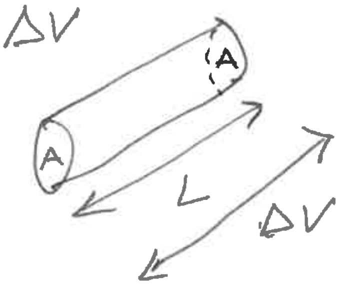
$$\frac{E}{J} = \rho \quad ; \quad \vec{E} = \rho\vec{J}$$

OHM'S LAW

$$\int \vec{E}\cdot\vec{d} = \Delta V$$

$$E = \frac{\Delta V}{L}$$

$$J = \frac{I}{A}$$



$$\frac{\Delta V}{L} = \rho\,\frac{I}{A}$$

$$\Delta V = \rho\,\frac{L}{A}\,I$$

$$\Delta V = I\,\boxed{\frac{\rho L}{A}}$$

R resistance

ohm's law $\Delta V = I R$

$$\downarrow R = \rho\,\frac{L\downarrow}{A\uparrow}$$

⑥ Ex: area of wire $= 8.2\times10^{-7}\,m^2$

$I = 1.67\,A$

ⓐ $E = ?$ $\quad \rho = 1.72\times10^{-8}\,\Omega m$ (Copper)

$$J = \frac{I}{A} \quad ; \quad E = \rho J$$

$$E = \rho\,\frac{I}{A} = (1.7\times10^{-8})\,\frac{1.67}{8.2\times10^{-7}}$$

$$E = 0.035\,\frac{V}{m}$$

ⓑ $\Delta V = ?$ $\quad L = 50\,m$

$$EL = \Delta V$$

$$\Delta V = 1.75\,V$$

ⓒ Resistance of 50m long copper wire?

$$R = \rho\,\frac{L}{A} =$$

$$= 1.7\times10^{-8}\,\frac{50}{8.2\times10^{-7}}$$

$$R = 1.05\,\Omega$$

$$R = \left[\Omega\,\cancel{m}\,\frac{\cancel{m}}{\cancel{m^2}}\right] = [\Omega]$$

Resistance increases with increase of Temperature

$$R = R_0\left[1 + \alpha\,(T - T_0)\right]$$

const

Ex: $\alpha = 0.00393 \frac{1}{C^\circ}$ for Copper

$R = 1.05\Omega$ at $20°C$

R (at $T = 0°C$) =?

R (at $T = 100°C$) =?

$$R = R_o[1 + \alpha(T - T_o)]$$

$R_o = 1.05\Omega$ $T_o = 20°C$

$R = 1.05[1 + 0.00393(0-20)]$

$R = 0.97\Omega$ at $T = 0°C$

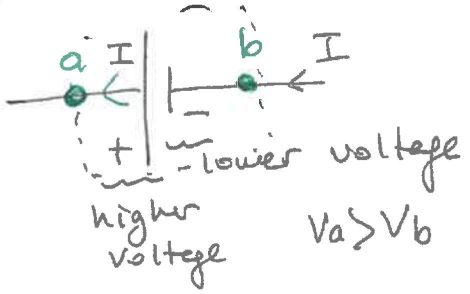
$R = 1.05[1 + 0.00393(100-20)]$

$R = 1.38\Omega$ at $T = 100°C$

Electroomotor Force

EMF makes the current flow from lower to higher potantial:

Batteries (pillar) have EMF

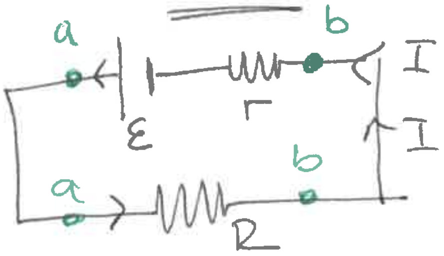


$V_{ab} = \mathcal{E} - Ir$ → internal resistance of battery

↙ EMF voltage

$V_{ab} = \mathcal{E}$ (ideal battery)

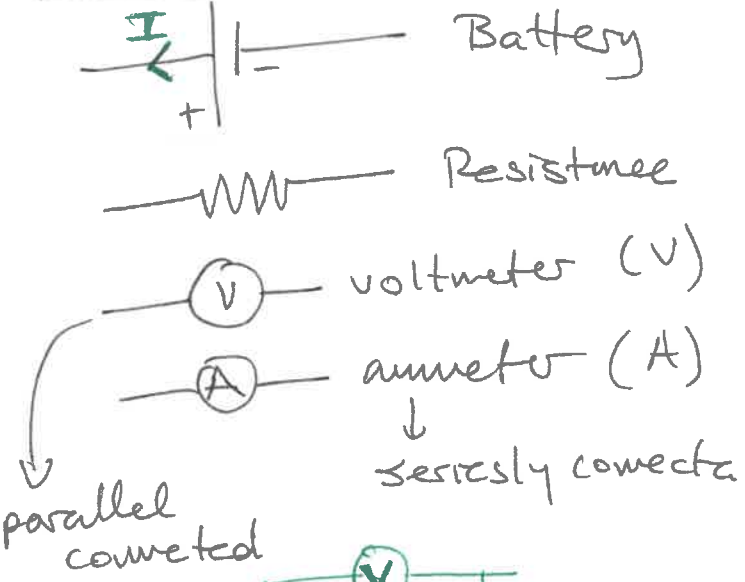
$r = 0$



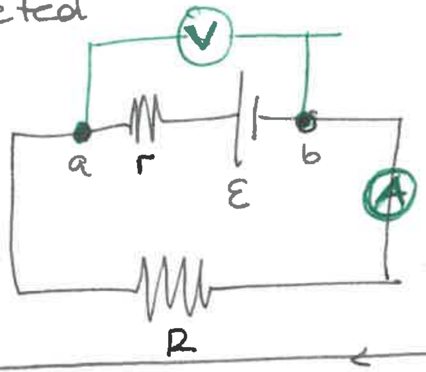
$\mathcal{E} - Ir = V_{ab} = IR$

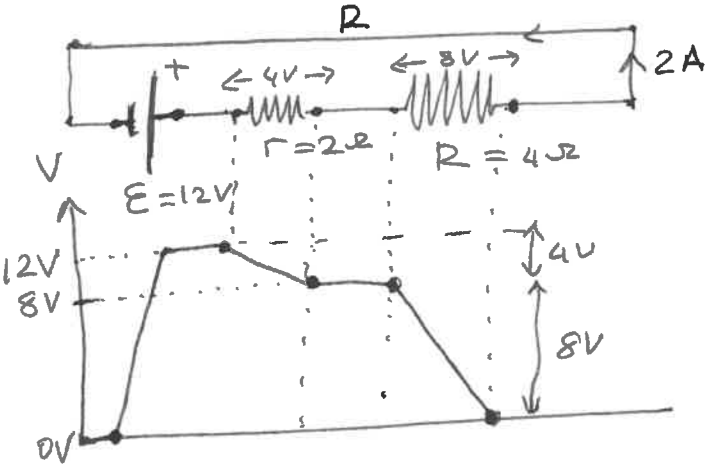
$I = \frac{\mathcal{E}}{(R+r)}$; if $r = 0$ ideal $I = \frac{\mathcal{E}}{R}$

r = internal resistance



$I = \frac{\mathcal{E}}{r+R}$





Power & Energy in circuits

$\text{Power} = \frac{\text{Energy}}{\text{Time}}$

$\left[\text{Watt} = \frac{\text{Joule}}{\text{sec}}\right]$ $W = \frac{J}{S}$

Enrgy of achage

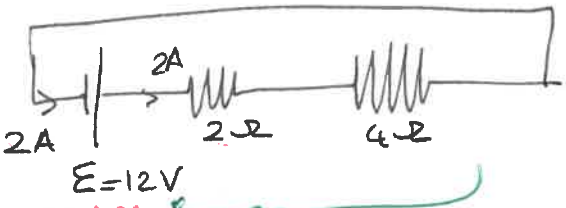
$\underline{\underline{\Delta U}} = q \underline{\underline{\Delta V}}$ $I \equiv$ current

$W = \frac{J}{s};\ \frac{\Delta U}{\Delta t} \equiv P \equiv \frac{q}{\Delta t} \Delta V$

$P = I \Delta V = \underline{\underline{I V_{ab}}}$

$\Delta V = IR$

$P = I(IR) = I^2 R = \frac{\Delta V^2}{R}$



$P = 2^2(2) + 2^2(4)$

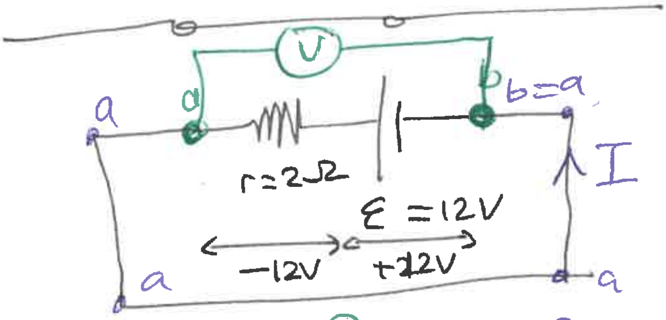
P = 24 Watts power is consumed by resistors.

$P = I \Delta V$
$= 2(12) = 24$ watts

power given by the battery

Battery creates energy!

resistors consumes energy!



$V_{ab} = ?$ $V_{aa} = 0$

$I = \frac{\mathcal{E}}{r} = \frac{12}{2} = 6A$

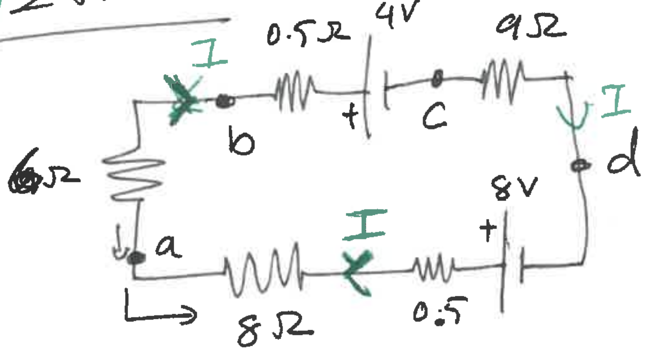
$\mathcal{E} = Ir \Rightarrow \mathcal{E} - Ir = 0$

$\underbrace{12}\ \underbrace{-12} = 0$

$I(\mathcal{E} - Ir) = 0$

$\underbrace{\mathcal{E} I}_{\text{power}} - \underbrace{I^2 r}_{\text{power}} = 0 \rightarrow \underbrace{+72W}_{\text{battery}} - \underbrace{72W}_{\text{resistor}} = 0$

⑧ 25-62



$V_{ad} = ?$

$V_{ad} + V_{dc} + V_{cb} + V_{ba} = 0$

$\Sigma \mathcal{E} = (8-4)V = I(9+8+6+0.5+0.5)$

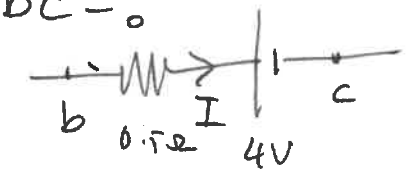
$4V = I\,24$

$I = \frac{4}{24} = \underline{\underline{\frac{1}{6} A}}$

$8V - I(8.5\Omega) = V_{ad}$

$\left(8 - \frac{8.5}{6}\right) V = V_{ad}$

$V_{bc} = ?$



$-0.5 \boxed{I}\frac{1}{6} - 4V$

$\left(-\frac{0.5}{6} - 4\right) V$

Phys 2   18.7.17   ①

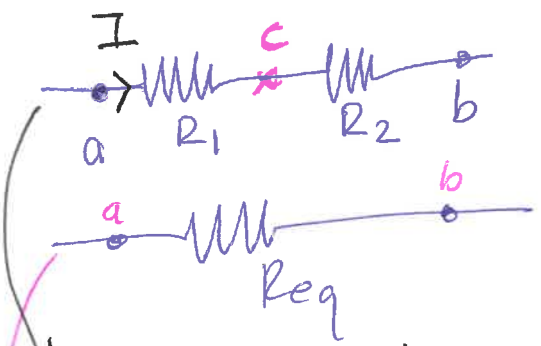
Ch 26

Direct Current Circuits

ohm's law: $V_{ab} = I R_{ab}$

R_{eq}

Resistors Series

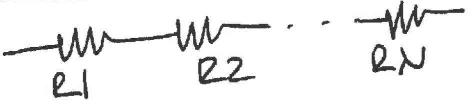


$V = IR$

$V_{ab} = V_{ac} + V_{cb}$

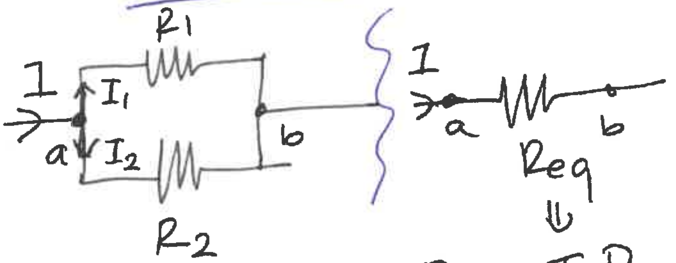
$I R_{eq} = I R_1 + I R_2$

SERIES: $R_{eq} = R_1 + R_2$ //



$R_{eq} = R_1 + R_2 + \dots + R_N$ //

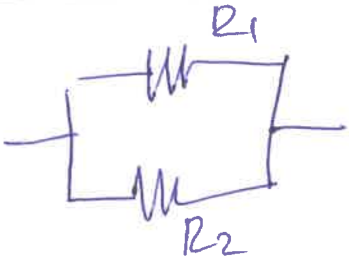
Resistors Parallel



$V_{ab} = I_1 R_1 = I_2 R_2 = I R_{eq}$

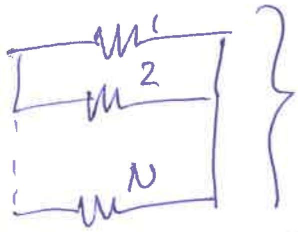
$I_1 + I_2 = I$

$\frac{\cancel{V_{ab}}}{R_1} + \frac{\cancel{V_{ab}}}{R_2} = \frac{\cancel{V_{ab}}}{R_{eq}}$



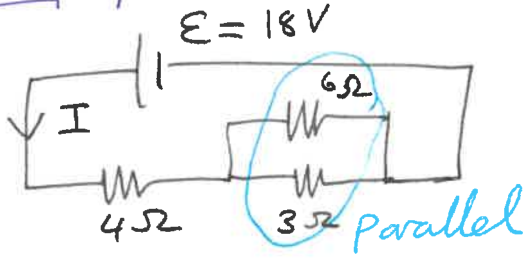
$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

PARALLEL Resistors



$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_N}$

Ex:

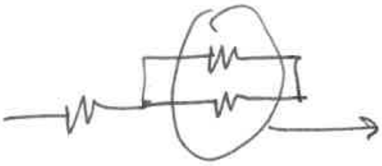


find Req = ?

I = ?

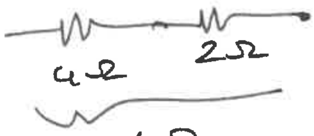
current on 6Ω ?

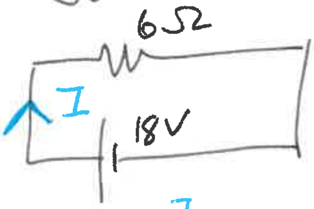
Power of 3Ω?



$\left(\frac{1}{R}\right)^{-1} = \left(\frac{1}{3} + \frac{1}{6}\right)^{-1}$ (2)

$2\Omega = \left(3/6\right)^{-1}$

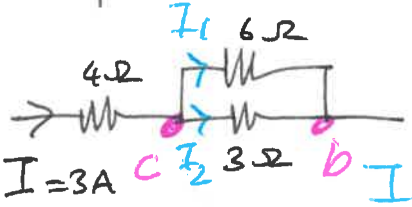




$V = I R$

$18 = I\,6$

$I = 3A$



I = 3A

$I_1 = ?$ $I_2 = ?$

$V_{cb} = I_1 6 = I_2 3 \Rightarrow I_2 = 2 I_1$

$I_1 + I_2 = I = 3A$

$3 I_1 = 3A$ $I_1 = 1A$

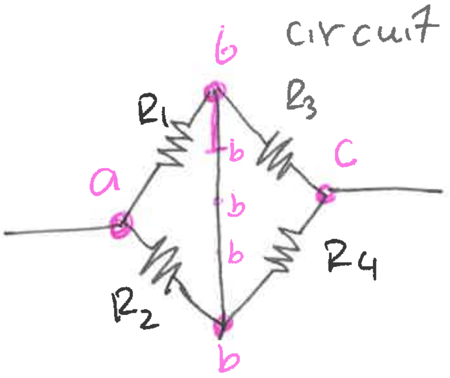
$I_2 = 2A$ ✓

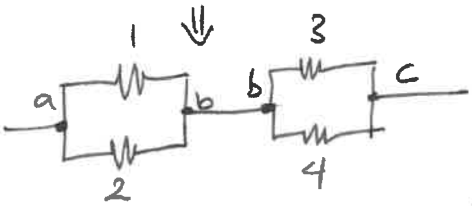
Power of

3Ω $P = I^2 R = IV = (2^2)3$

$= 12$ Watts

Remember potantial value of a metal is same unless there is a circuit element.



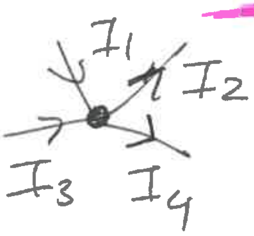


$$\left(\frac{1}{R_1}+\frac{1}{R_2}\right)^{-1}+\left(\frac{1}{R_3}+\frac{1}{R_4}\right)^{-1}=R_{eq}$$

Kirchoff's Rules

$$\Sigma I = 0 \Rightarrow \Sigma I_{in} = \Sigma I_{out}$$

at a junction



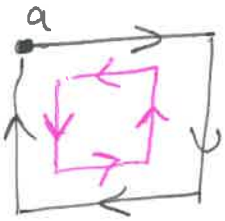
$$\underbrace{I_1 + I_3}_{in} - \underbrace{(I_2) - I_4}_{out} = 0$$

$$I_1 + I_3 = I_2 + I_4$$

* incoming currents are equal outgoing currents.

$$\Sigma I_{in} = \Sigma I_{out}$$

loop (döngü)



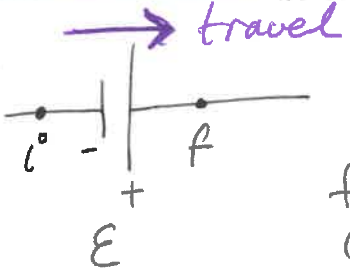
$V_{aa} = 0$

$\Delta V_{a\to a} = 0$

Clockwise or counter-clockwise } $V_{aa} = 0$

The sum of potantial differences around any loop should BE ZERO!

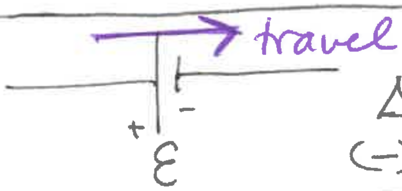
ΔV? (depend on direction of the current; also direction of loop)



$\Delta V = +\varepsilon$

final - initial

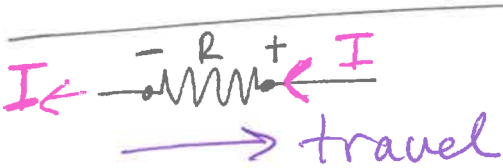
$(+) - (-) > 0$



$\Delta V = -\varepsilon$

$(-) - (+) < 0$!

$0 - (1.5V) = -1.5V$



$\Delta V = +IR$

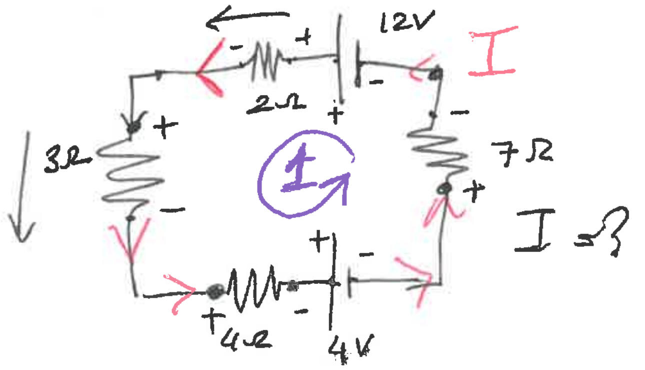
* current flows from HIGH potential to LOW potential

$\Delta = \text{final} - \text{initial}$

$\Delta V = (+) - (-) > 0$

$\Delta V = -IR$

$\Delta V = \text{final} - \text{initial} = (-) - (+) < 0$



③

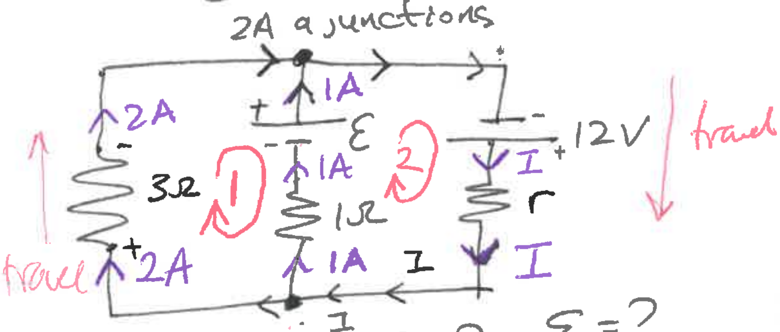
travel counterclockwise (CCW) direction

$\Delta V = 0$

$+12V - I(2\Omega) - I(3\Omega) - I(4\Omega) - 4V - I(7\Omega) = 0$

$8V - I(16\Omega) = 0$

$I = \frac{8}{16}\frac{V}{\Omega} = 0.5A$



$r = ?$ $I = ?$ $\varepsilon = ?$

@ junctions $\Sigma I_{in} = \Sigma I_{out}$

$(2+1) = I = 3A$

loop 1 (CW) $\Delta V_{a\to a} = 0$

$-\varepsilon + (1A)(1\Omega) - (2A)(3\Omega) = 0$

$-\varepsilon + 1 - 6 = 0$

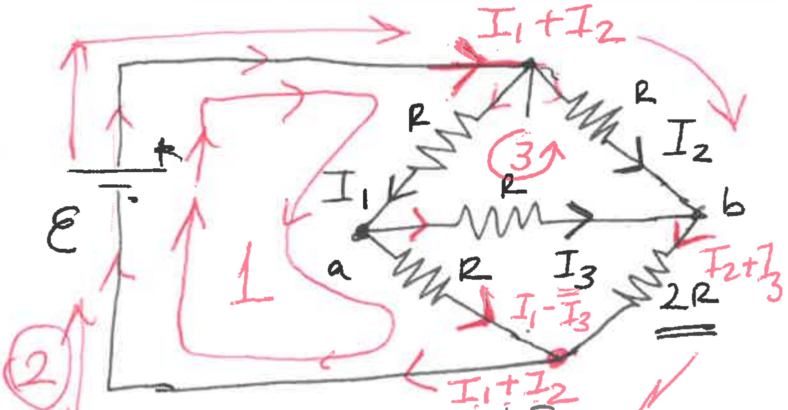
$\varepsilon = -5V$

loop2 $\Delta V_{a\to a} = 0$

$+12V - Ir - (1A)(1\Omega) + \varepsilon = 0$

$I = 3A$; $\varepsilon = -5V$

$12 - 3r - 1 - 5 = 0$ $r = \frac{6}{3}\Omega$



$\varepsilon = 13V$; $R = 1\Omega$

$I_1, I_2, I_3 = ?$ $R_{eq} = ?$

$\Sigma I_{in} = \Sigma I_{out}$

① Loop

$-I_1R - (I_1 - I_3)R + \varepsilon = 0$

2nd Loop out

$-I_2R - (I_2 + I_3)2R + \varepsilon = 0$

3rd loop

$-I_1R + I_2R - I_3R = 0$

$I_2\cancel{R} = (I_1 + I_3)\cancel{R}$

$I_2 = I_1 + I_3$

2nd eqn

$-(I_1+I_3)R - (I_1+I_3+I_3)2R + \varepsilon = 0$

~~I_1+I_3~~

② $-3I_1R - 5I_3R + \varepsilon = 0$

① ×5 $-2I_1R + I_3R + \varepsilon = 0$

+

$(-3I_1 - 10I_1)R + 6\varepsilon = 0$

$-13I_1R = -6\varepsilon$

$R = 1\Omega$ $\varepsilon = 13V$

$+\cancel{13}I_1 = +6(\cancel{13})$

$I_1 = 6A$

into eqn ②

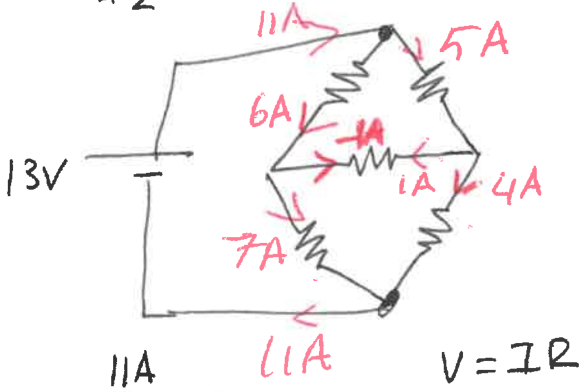
$-3(6)1 - 5I_3(1) + 13 = 0$

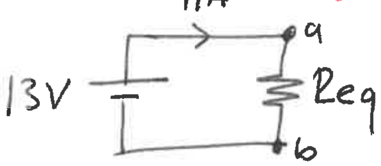
$-5I_3 - 5 = 0$

$\underline{I_3 = -1A}$

$I_2 = I_1 + I_3$

$I_2 = 6 + (-1) = 5A$





$V = IR$

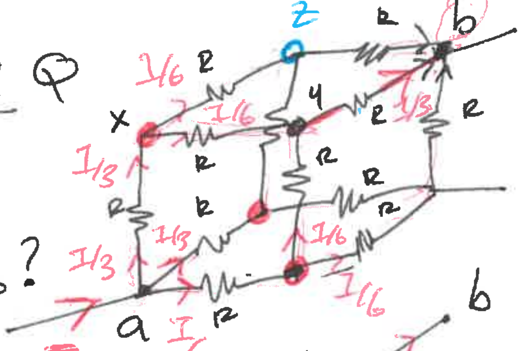
$R_{eq} = \frac{13V}{11A}$

$R_{eq} = 1.2\Omega$

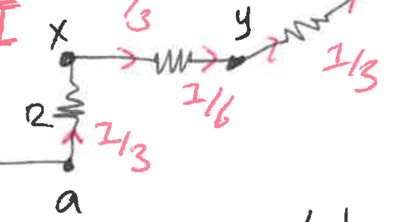
26.84 Q

R all

$R_{eq} = R_{ab}$?



a→x→y→b



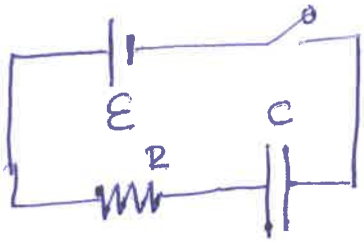
$V_{ab} = V_{ax} + V_{xy} + V_{yb}$

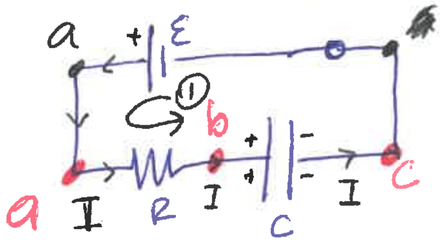
$$\underline{IR_{ab}} = R\underset{(2)}{\frac{I}{3}} + R\underset{(1)}{\frac{I}{6}} + R\underset{(2)}{\frac{I}{3}}$$

$$\cancel{I}R_{ab} = \frac{5\cancel{I}R}{6} \qquad R_{ab} = \frac{5}{6}R$$

R-C circuits

Charging a Capacitor





very ~~too~~ earliest steps of chagiy

$\Delta V_{a \to a} = 0$; $C = \frac{q}{\Delta V}$

1 loop

$-IR - \frac{q}{C} + \varepsilon = 0$ $\Delta V = q/C$

I, q are chagiy with time.

$\varepsilon - IR - \frac{q}{C} = 0$

when switch is closed.

$t = 0^+ = 0.000000001$sec.

~~[illegible]~~ $\underline{q = 0}$ no charge on capacitor.

$\varepsilon - I_0R - 0 = 0$

$\boxed{I_0 = \varepsilon/R \quad \text{current @ } t = 0^+}$

as $q\uparrow$; $I\downarrow$

when capacitor is charged fully

then there is NO CURRENT

$t \to$ very large $\underline{I = 0}$

$t \to \infty$

$\varepsilon - \underset{0}{\cancel{I}}R - \frac{Q_f}{C} = 0$

$\varepsilon = \frac{Q_f}{C} \Rightarrow$ fully charged

$\boxed{\varepsilon = \frac{Q_f}{C}}$

$t = 0^+ \quad I_0 = \varepsilon/R$

$t \to \infty \quad \varepsilon = \frac{Q_f}{c} \Rightarrow \underline{\underline{Q_f = C\varepsilon}}$ ⑤

$$\underline{\underline{t}} \begin{cases} \to 0^+ \\ \to ? \\ \to \infty \end{cases}$$

$I \leftrightarrow q$

$I = \frac{\Delta q}{\Delta t}$

$$\varepsilon - IR - \frac{q}{c} = 0$$

$$\frac{dq}{dt} = I = \frac{\varepsilon - q/c}{R} = \frac{\varepsilon}{\underset{(C)}{R}} - \frac{q}{RC}$$

$$\frac{dq}{dt} = \frac{\varepsilon c - q}{RC} = -\frac{1}{RC}(q - \varepsilon c)$$

$$\int_0^q \frac{dq}{(q - \varepsilon c)} = \int_0^t -\frac{dt}{RC}$$

$q - \varepsilon c = u$

$dq = du$

$$\int_{-\varepsilon c}^{q-\varepsilon c} \frac{du}{u} = \ln u$$

$$\ln\left(\frac{q - C\varepsilon}{-C\varepsilon}\right) = -\frac{t}{RC}$$

$$\frac{q - C\varepsilon}{-C\varepsilon} = e^{-t/RC}$$

$$q = \left(-C\varepsilon e^{-t/RC} + C\varepsilon\right)$$

$$\boxed{q(t) = C\varepsilon\left(1 - e^{-t/RC}\right)}$$

$t = 0 \quad q(t=0) = C\varepsilon(1 - \cancel{e^{0}}^{\,1})$

$\underline{\underline{q = 0}}$

$t \to \infty \quad q(t \to \infty) = C\varepsilon(1 - \underbrace{e^{-\infty}}_{0})$

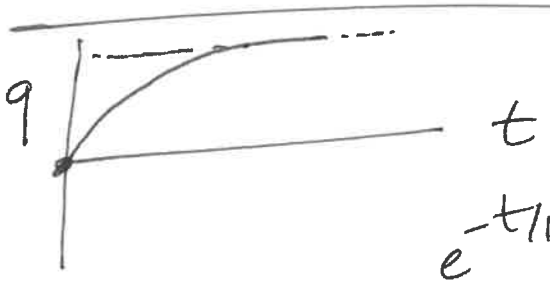
$\underline{\underline{q(t \to \infty) = C\varepsilon}}$

⑤ $I = \frac{dq}{dt}$; $q = C\varepsilon(1 - e^{-t/RC})$
$= C\varepsilon - C\varepsilon e^{-t/RC}$

$$I(t) = +\cancel{C}\varepsilon\left(+\frac{1}{R\cancel{C}}\right)e^{-t/RC}$$

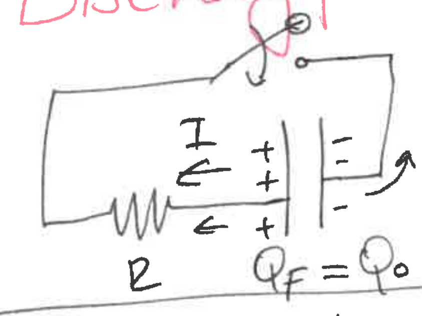
$$\boxed{I(t) = \frac{\varepsilon}{R} e^{-t/RC}}$$

$t = 0$; $I_0 = \frac{\varepsilon}{R}\underbrace{e^{-0}}_{1} = \frac{\varepsilon}{R}$ ✓



$e^{-t/RC}$

Discharging the capacitor

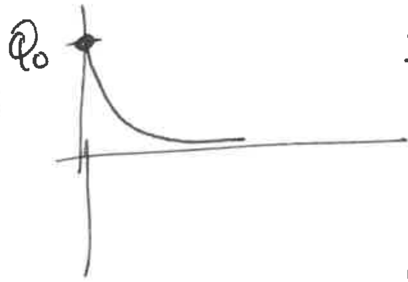


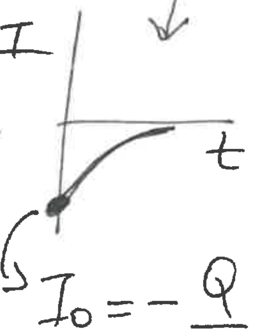
switch closed

discharge

$$q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$





$I_0 = -\frac{Q}{RC}$

opposite direction

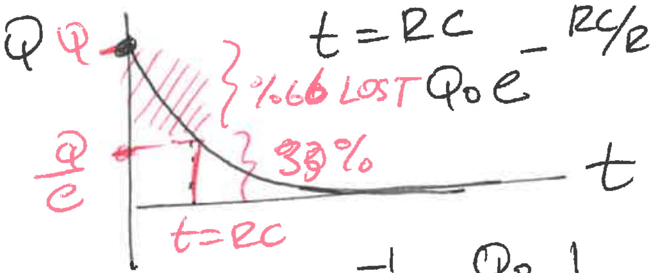
charging or discharging ⑥

$e^{-t/RC}$ $\qquad e^{-\frac{sec}{sec}}$

unit of RC? [RC = sec]

$R = \frac{\Delta V}{I} = \frac{\Delta V}{\frac{\Delta Q}{\Delta t}}$; $C = \frac{\Delta Q}{\Delta V}$

$\frac{\cancel{\Delta V}}{\frac{\cancel{\Delta Q}}{\Delta t}} \cdot \frac{\cancel{\Delta Q}}{\cancel{\Delta V}} = \underline{\underline{\Delta t}}$ (sec) ✓



t = RC $\qquad Q_0 e^{-RC/RC}$

$q(t=RC) = Q_0 e^{-1} = Q_0 \frac{1}{2.74}$

$= \sim \frac{Q_0}{3} \Rightarrow$

t = RC ~ 66 % of charge is LOST

33 % of is remaining

Ex: R = 18 MΩ

C = 1 μF $\qquad \mathcal{E} = 12V$

charging the capacitor.

ⓐ time constant? $e^{-t/\underline{\underline{RC}}}$

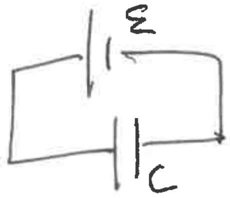
RC =?

$RC = (18 \times 10^{6} \Omega)(1 \times 10^{-6} F)$

$= \underline{\underline{18 s}}$

ⓑ at t = 46s what is the charge on the capacitor

$q(t) = \underset{?}{\underline{\underline{Q_F}}}(1 - e^{-\underset{46s}{t}/\underset{18s}{\underline{\underline{RC}}}})$



$Q_F = C\mathcal{E}$

$Q_0 = (1\mu F)(12V)$

$= \underline{\underline{12 \mu C}}$

$q(t=46s) = 12 \times 10^{-6}(\underbrace{1 - e^{-46/18}}_{0.92})$

$= 11.1 \mu C$

$q(t=46s) = 11.1 \times 10^{-6} C$

I(t=46s)

$I = I_0 e^{-t/RC}$

$I_0 = \frac{\mathcal{E}}{R} = \frac{12 V}{18 \times 10^{6} \Omega} = \frac{2}{3} \times 10^{-6} A$

$I(t=46s) = \frac{2}{3} \times 10^{-6} e^{-46/18}$

$= \frac{2}{3} \times 10^{-6} \times 0.08$

$= 0.05 \times 10^{-6} A$

$= \underline{0.05 \mu A}$

Power

what's the current in 100W bulb? V = 220 Volts

$P = I^2 R = IV$

$100 W = I(220) V$

$0.45 = I = \frac{100}{220} A$

$488 \Omega \Leftarrow R = ? = \frac{V}{I} = \frac{220V}{0.45A}$

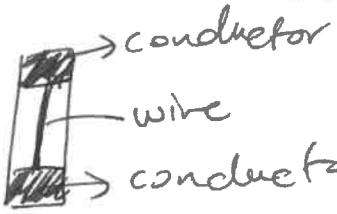
Circuit Breaker

Sigorta (Fuse)

allows a max current

Fuse

old



when a high current flow wire heats up / breaks!

Ex: in US outlet V 120V.

1800W of toaster
+
1.3kW of frying pan
+
100W of bulb

plugged into the same 20A, 120V circuit.

a) what current is drawn by each device?

b) resistance of each device?

c) will this combination trip the circuit breaker? (sigorta atar mı?)

Toaster ⇒ 1800W ; V=120V

$$I_T = \frac{P}{V} = \frac{1800}{120} = 15A$$

$$R_T = \frac{V}{I_T} = \frac{120}{15} = 8\Omega$$

⑦ Frying pan $P = 1.3kW = 1300W$

$$I_F = \frac{P}{V} = \frac{1300}{120} = 11A$$

~~$R = \frac{P}{I^2}$~~ $= \quad P = (I)V, \quad I \rightarrow \frac{V}{R}$

$$P = V^2/R$$

$$R_F = \frac{V^2}{P} = \frac{(120)^2}{1300} = 11\Omega$$

Lamp $I_L = \frac{100W}{120} = 0.83A$

$R_L = 144\Omega$

$\boxed{\text{toaster}} + \boxed{\text{frying pan}} + \boxed{\text{lamb}}$

15A 11A 0.83A

27A > 20A Fuse

sigorta atar!

Ex: Heater 3000 Watt each day use for 5 hrs what's the electric bill after a month?

$P = \frac{\text{energy}}{\text{time}}$ ⇒ energy sold!

energy = (Power)(time)
= kW hr (kWsa)

each day ⇒ 3kW ~~x5~~ 5 hr = 15 kWhr

month ⇒ 450 kWhr 50ks

20.7.17

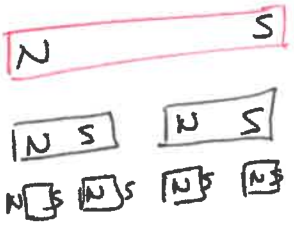
Phys 2

Chapter 27

magnetic fields & magnetic forces

magnets

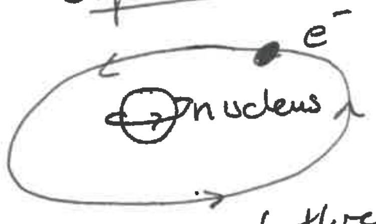
2 poles
North
South



single atom

magnetism is due to
- e⁻ motion
- e⁻ spin
- nucleus spin

addition of three vectors!



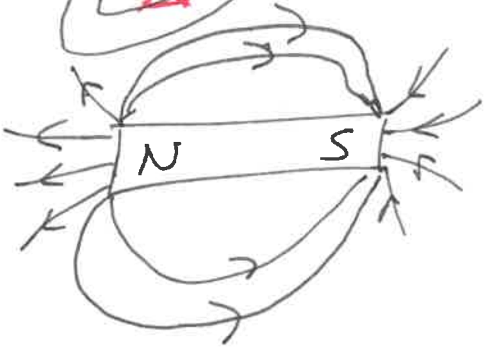
→ Quantum mechanics
spin of nucleus & electron.....

If a charge is moving it creates a magnetic field !!

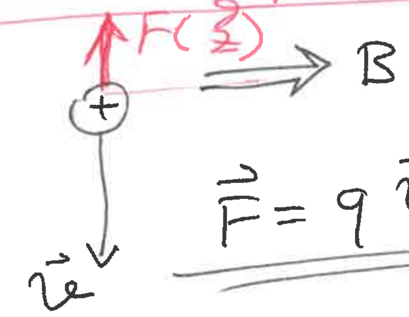
→ current ⇒ magnetic field.

$\vec{B}$

⇒ compass (pusula)

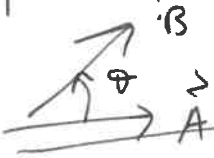


① Magnetic Forces on Moving charges



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

$|\vec{A} \times \vec{B}| = \underbrace{AB\sin\theta}_{\text{magnitude}}$ $\quad \underbrace{\hat{A} \times \hat{B}}_{\text{right hand rule}}$



$$\boxed{\vec{F} = q\,\vec{v} \times \vec{B}}$$

F = 0 when θ = 0
sin θ = 0

$\vec{v}$, $\vec{B}$ parallel ⇒ $\vec{F} = 0$

unit? (birim)

$$\left[N = C \, \frac{m}{s} \, \underline{\underline{B}} \right]$$

$$\left[\underline{\underline{B}} = \frac{N\,s}{C\,m} \equiv \text{Tesla} \right]$$

C/s = Amper

$$\left[T = \frac{N}{A\,m} \right]$$

Earth's magnetic field is

$10^{-4}\,T = 1$ gauss $= 1G$

$10^{-2}\,T$ ⇒ fridge magnets

45 T ⇒ research labs

1 - 1.5 T ⇒ NMR; MRI

Electrostatics $\vec{F} = q\vec{E}$ ②

$$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$$

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

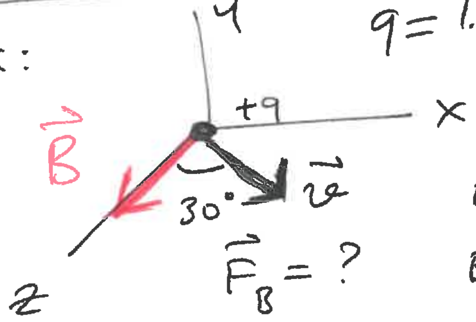
$\vec{B}$ ↳ pointing (isaret)

$\vec{v}$ ↓ thumb (baş)

$\vec{F}_B$ ↓ middle finger (orta)

right hand rule

Ex:



$q = 1.6\times10^{-19}$ C

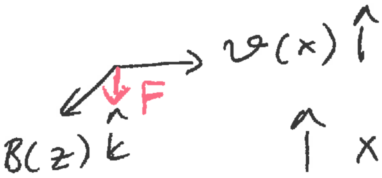
$v = 3\times10^{5}$ m/s

$B = 2$ T

$\vec{F}_B = ?$

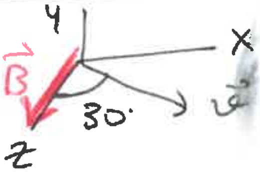
$$F = qvB\sin\theta$$
$$= (1.6\times10^{-19})(3\times10^{5})(2)\sin30$$
$$F = 4.8\times10^{-14}\ \text{N}$$ magnitude

direction ⇒ Right hand Rule

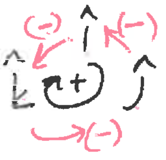


$$\hat{i}\times\hat{k} = -\hat{j}$$

2nd way



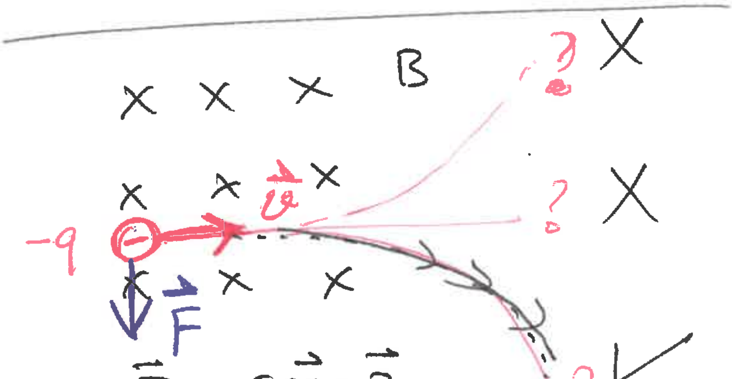
$$\vec{v} = v_x\hat{i} + v_z\hat{k}$$
$$\vec{v} = v\sin30\,\hat{i} + v\cos30\,\hat{k}$$
$$\vec{B} = 2T(\hat{k}) = B_0\hat{k}$$
$$(\vec{v}\times\vec{B}) = (v\sin30\,\hat{i} + v\cos30\,\hat{k}) \times B_0\hat{k}$$



$$= vB\sin30\,(\hat{i}\times\hat{k}) \Rightarrow -\hat{j}$$
$$+ vB\cos30\,(\hat{k}\times\hat{k}) \Rightarrow 0$$

⊗ ⇒ into the page

⊙ ⇒ out of the page



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

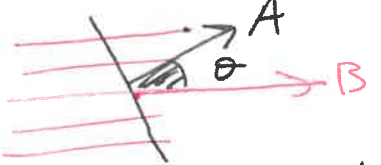
Magnetic Flux

(like electric flux)

$$\Phi_B = \vec{B}\cdot\vec{A}$$

$\vec{B}$ ↓ mag. field

$\vec{A}$ ↓ area



$$\Phi_B = BA\cos\theta$$

$\vec{B}$ is not constant

$$d\Phi_B = B\,dA\cos\theta$$
$$= \vec{B}\cdot d\vec{A}$$

$$\Phi_B = \int \vec{B}\cdot d\vec{A}$$

[Weber = T m²] = Φ_B

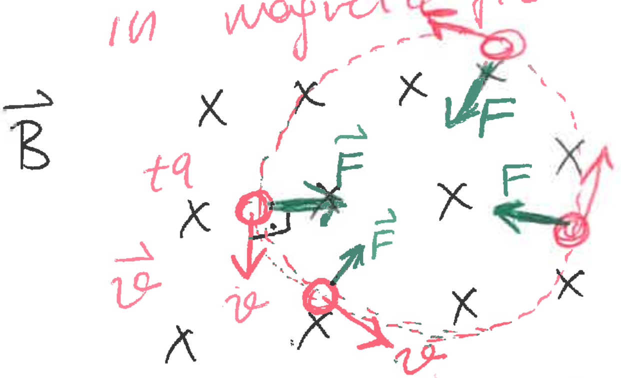
[1 Wb = 1 Tm²]

Gauss Law for magnetism

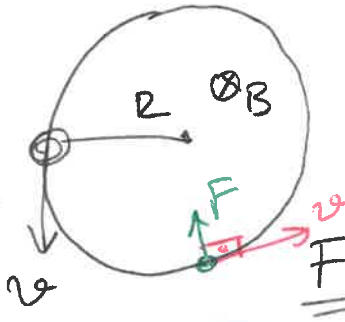
$$\Phi_B = \oint_{\text{closed surface}} \vec{B}\cdot d\vec{A} = \underline{\underline{0}}$$

total magnetic flux through any closed surface is ZERO.

motion of charged particles in magnetic field.



uniform circular motion



$$a_r = \frac{v^2}{R}$$

$$\underline{F = qvB\sin 90}$$

$$\Sigma F = ma$$

$$q\cancel{v}B\,\overset{1}{\sin 90} = m\frac{v^{\cancel{2}}}{R}$$

$$qBR = mv$$

5 parameter; if 4 of them find 5th

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

$$\underline{\underline{v = \omega R}}$$

ω: angular speed

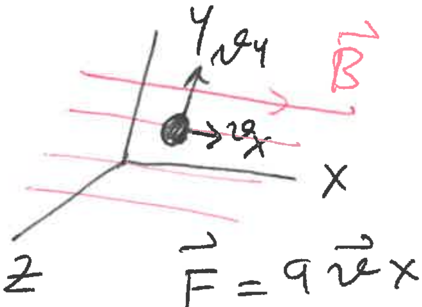
$$R = \frac{mv}{qB} = \frac{m\omega R}{qB} = R$$

angular speed $\Leftarrow \omega = \frac{qB}{m}$

angular frequency $f = \frac{\omega}{2\pi}$

cyclotron frequency

particle accelerators!



$\vec{B} = B_0\hat{i}\,(x)$

$\vec{v} = v_y\hat{j} + v_x\hat{i}$

$\hat{k}$

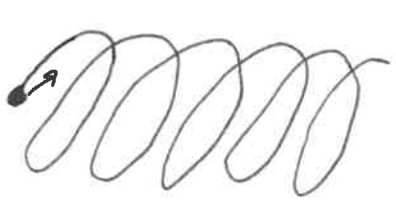
$-\hat{k}$

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

$$= q(v_x\hat{i} + v_y\hat{j})\times B\hat{i}$$

0

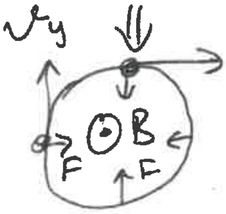
$$\vec{F} = -qv_yB\hat{k}$$

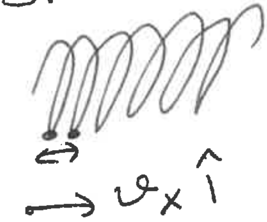


spiral motion

from front view (UCM)

side view





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

$\vec{v}_\parallel \to$ parallel to B

$\vec{v}_\perp$ ⇓ perpendicular to $\vec{B}$

spiral ≡ helical motion

Ex: A magnetron in a microwave oven emits EM waves at $f = 2450\text{MHz}$

$|\vec{B}| = ?$ for electrons to move in circular motion.

$f = 2450\text{MHz} = 2450\times10^{6}\text{ Hz}$

$\frac{1}{s} = \text{Hz}$

$\Sigma F = ma$

$qvB = m\frac{v^2}{R} \Rightarrow qBR = mv$

$v = \omega R \; ; \; \omega = \boxed{2\pi f}$

$qB\cancel{R} = m(2\pi f)\cancel{R}$

$qB = m\, 2\pi f$ ✓

$(1.6\times10^{-19})\, B = (9\times10^{-31})(2\times3.14) \times 2450\times10^{6}$

$B = 0.087$ Tesla

Ex: Helical motion

$q = 1.6\times10^{-19}\text{C}$

$m = 1.67\times10^{-27}\text{ kg}$

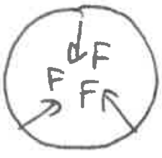
$B_x = 0.5\text{ T}$ $(\hat{x})$ direction

$v_x = 1.5\times10^{5}\text{ m/s}$

$v_y = 0$

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

ⓐ $F = ?$ $a = ?$



$F = qv_\perp B = m\boxed{\frac{v^2}{R}}$ a

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

④

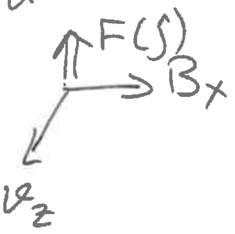
$F = qvB$

$= (1.6\times10^{-19})(2\times10^{5})(0.5)$

$F = 1.6\times10^{-14}\text{ N}$

$a = \frac{v^2}{R} = \frac{F}{m} = \frac{1.6\times10^{-14}\text{ N}}{1.67\times10^{-27}\text{ kg}}$

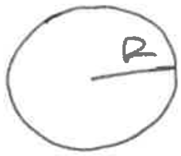
$(a = 9.6\times10^{12}\text{ m/s}^2)$



$\vec{a} = a\hat{j}$

$\vec{F} = F\hat{j}$

ⓑ Radius of helical path?



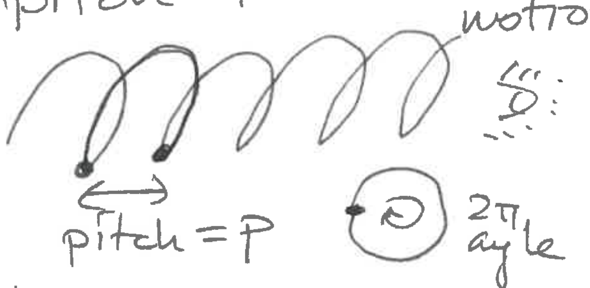
$qv_\perp B = m\frac{v_\perp^2}{R}$

$R = \frac{mv_\perp}{qB}$

$R = \frac{(1.67\times10^{-27})(2\times10^{5})}{(1.6\times10^{-19})(0.5)}$

$R = 4.2\times10^{-3}\text{ m} = 4.2\text{mm}$

ⓒ pitch of helical motion



1 turn $P = v_x \underset{\text{period}}{T}$

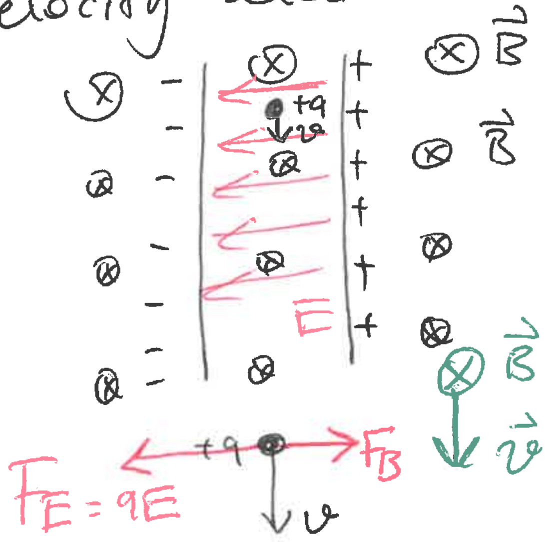
$T = \frac{\text{distance}}{\text{speed}} = \frac{2\pi R}{v_\perp}$

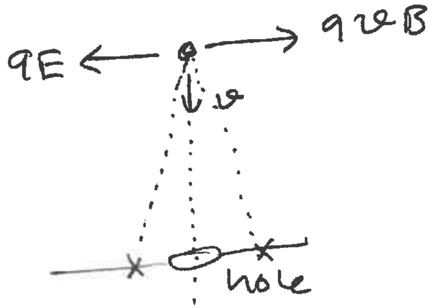
$P = v_x \frac{2\pi R}{v_\perp} = 19.7\text{mm}$

Applications of motion of charged particles

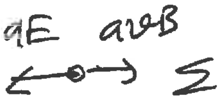
$$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$$

velocity selector





velocity selector. { only charges with certain v can pass through the hole



$$\sum\vec{F} = m\cancel{\vec{a}}^{\,0} \quad \rightarrow x$$

$$qE - qvB = 0$$

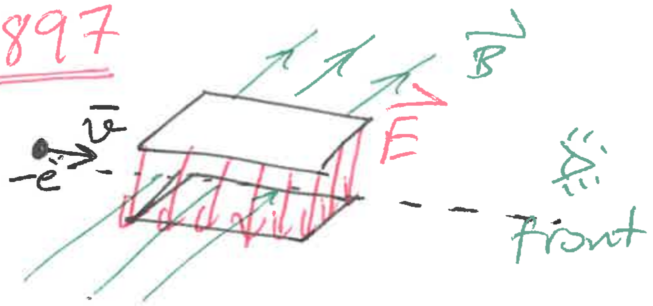
$$\cancel{q}E = \cancel{q}vB$$

$$\boxed{v = \frac{E}{B}}$$

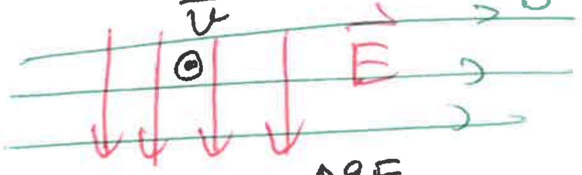
velocity selector.

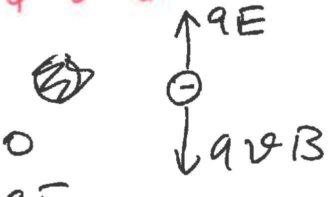
⑤ Thomson's e/m experiment

1897



FRONT VIEW





$$\sum F = 0$$

$$qvB = qE$$

$$\boxed{\underline{v} = \frac{E}{B}}$$

$$K = \frac{1}{2}mv^2$$

e⁻ has gained KE through electric potential $\underline{\underline{V}}$

$$\underline{\underline{\Delta K}} = W_{done} = \underline{\underline{eV}}$$

$$\frac{1}{2}mv^2 = eV$$

$$\frac{1}{2}m\frac{E^2}{B^2} = eV$$

1897

e = ?

m = ?

$$\frac{e}{m} = \frac{\cancel{2}E^2}{2B^2V}$$

$$\checkmark \quad \frac{e}{m} = \frac{E^2}{2B^2V}$$

; E, B, V experimentally measured!

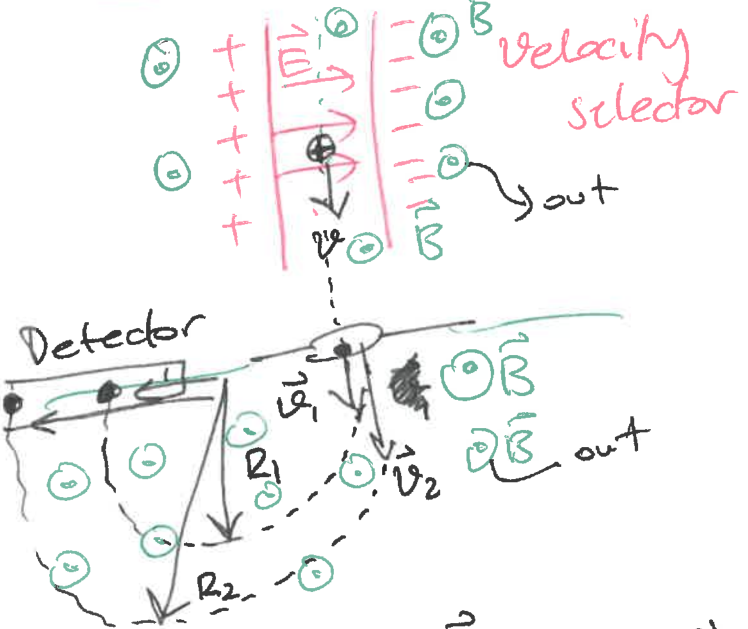
$$\frac{e}{m} = 1.7588 \times 10^{11}\,\frac{C}{kg}$$

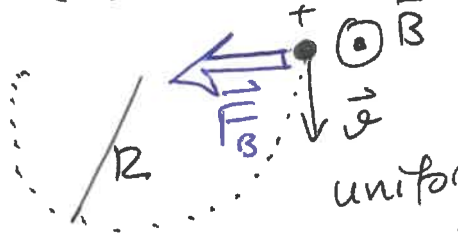
1897 Thomson

~1912 Robert Millikan measured $\underline{e}$

$\underline{\underline{m}}$ found

Mass Spectrometers





$\vec F_B = q\vec v \times \vec B$

uniform circ. motion.

$$F_B = qvB = m\frac{v^2}{R} = ma$$

$$R = \frac{mv}{qB}$$ $m_1, v_1\ R_1$

$$R_1 = \frac{m_1 v_1}{qB} \Leftrightarrow R_2 = \frac{m_2 v_2}{qB}$$

$$v_1 = v_2 = v$$

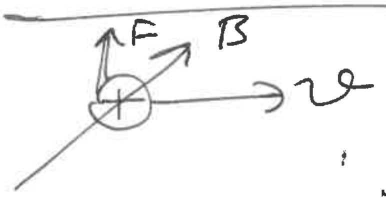
$$\frac{R_1}{R_2} = \frac{m_1}{m_2}$$ } mass ratio

CH_3^+ CH_4^+

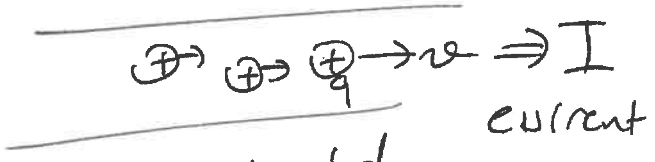
12+3 12+4

$m_1 = 15\ g/mol$ $m_2 = 16\ g/mol$

⑥ Next Lecture



in wire



wire should experience a force

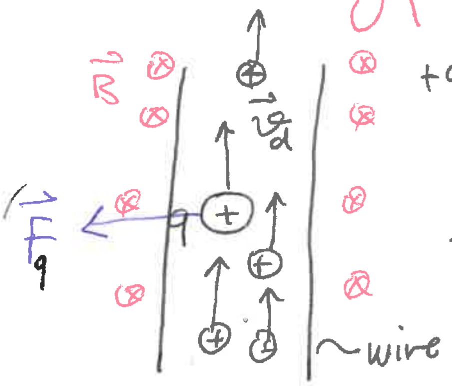
$$\sum F = \sum q\,\vec v \times \vec B \Rightarrow$$

force acting on the current carrying wire.!

$$\vec F = I\,\vec l \times \vec B$$

Phys II 21-7.17 ©

Magnetic Force on a current carrying conductor.



+q charges going with speed of v_d: drift velocity

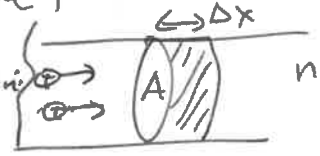
$$\Sigma F_q = \Sigma F_{\text{current carrying wire}}$$

$$\underbrace{\text{\# of charges}}\ F_q = q v_d B$$

force on a single charge

Total force on the wire.

current description prev. chapter



n: no of charges per volume.

$$n\Delta V = \underbrace{nA\Delta x}_{\text{\# of charges.}}$$

$\Delta x = \underline{\ell}$ length of the wire

$$(nA\underline{\ell})(q v_d B) = \text{total force on wire.}$$

$$\underbrace{(nAqv_d)}_{I}\,\ell B = F$$

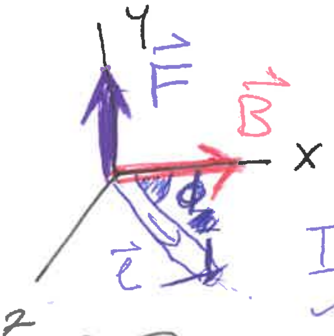
$$F = I\ell B$$

$$\boxed{\vec F = I\vec\ell\times\vec B}$$

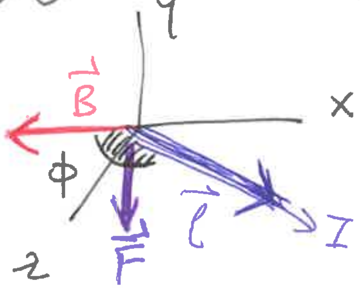
magnetic force acting on current carrying wire

$$d\vec F = I\,d\vec\ell\times\vec B$$

↳ use it for different geometry (circle, etc.)



$$I\vec\ell\times\vec B \Rightarrow \underbrace{I\ell B\sin\phi\,\hat j}_{\vec F}$$



$\hat B(-\hat i) = \vec B$

$\vec\ell\ (\hat i, \hat k)$

$$\vec F = I\vec\ell\times\vec B = |I\ell B\sin\phi|(-\hat j)$$

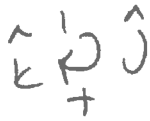
$$\vec B = B(-\hat i) \qquad \vec\ell = (\ell_x\hat i + \ell_z\hat k)$$

~~IℓB~~ $\vec F = I\,\underline{\ell_x\hat i\times(B-\hat i)}$

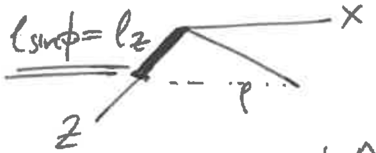
$+ I\ell_z\hat k\times(B-\hat i)$

$\hat i\times\hat i = 0$

$\underline{-(\hat k\times\hat i)} = \underline{-\hat j}$ $\qquad \vec F = I\underline{\ell_z}B(-\hat j)$



$\underline{\ell\sin\phi = \ell_z}$



$$\underline{\vec F = -I\ell B\sin\phi\,\hat j}$$

$$\vec F = q\vec v\times\vec B \Rightarrow \left[N = C\frac{mT}{s}\right]$$

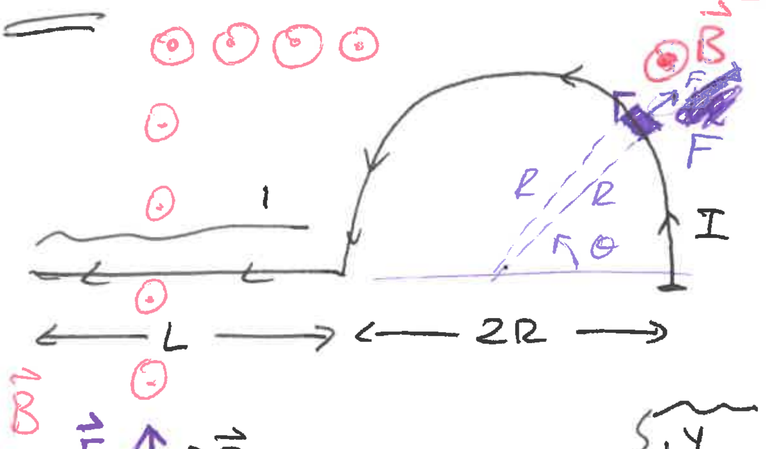
$$\vec F = I\vec\ell\times\vec B$$

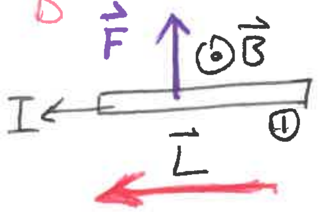
$$\Leftarrow C/s = A$$

$$[N = A\,m\,T]$$

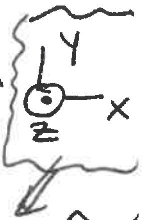
EX:

②



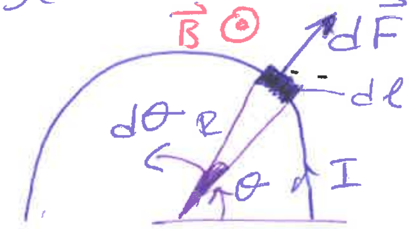


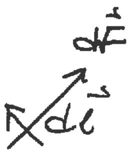
$$\vec{F}_1 = ILB\,\hat{j}$$



$$\hat{x}\times\hat{y} = \hat{z}\ ✓$$

2nd part ; semi circle wire



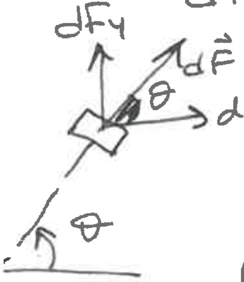


$$dl = R\,d\theta$$? why ?

$$d\vec{F} = I\,d\vec{l}\times\vec{B}$$
$$= I\,dl\,B\,\hat{r}$$

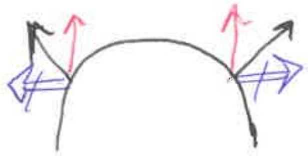
angle between $d\vec{l}$ and $\vec{B}$ ⇒ 90°

$$d\vec{F} = dF_x\,\hat{i} + dF_y\,\hat{j}$$



$$dF_x = dF\cos\theta$$
$$dF_y = dF\sin\theta$$

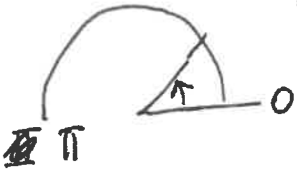
$$\int d\vec{F} = \int dF_x\,\hat{i} + \int dF_y\,\hat{j}$$



$$dF = IB\,dl$$
$$dF = IBR\,d\theta$$

$$\int d\vec{F} = \int dF_x\,\hat{i} + \int dF_y\,\hat{j}$$
$$= \int dF\cos\theta\,\hat{i} + \int dF\sin\theta\,\hat{j}$$

$$\vec{F}_x = \int_0^{\pi} IBR\cos\theta\,d\theta\,\hat{i}$$

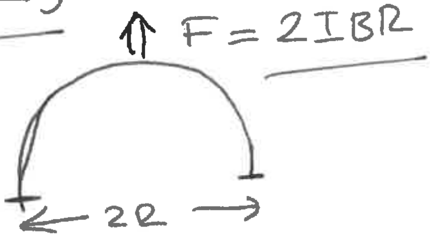


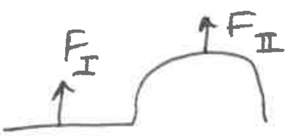
$$\vec{F}_x = IBR\int\cos\theta$$
$$= IBR\left[\sin\theta\right]_0^{\pi}$$
$$\vec{F}_x = 0$$

$$\vec{F}_y = \int_0^{\pi} IBR\sin\theta\,d\theta$$
$$= IBR\int\sin\theta\,d\theta$$
$$= IBR\left[-\cos\theta\right]_0^{\pi}$$
$$\vec{F}_y = IBR\underbrace{\left[-\underbrace{\cos\pi}_{(-1)} - (-\cos 0)\right]}_{2}\hat{j}$$

$$\vec{F}_y = IBR2\,\hat{j}$$

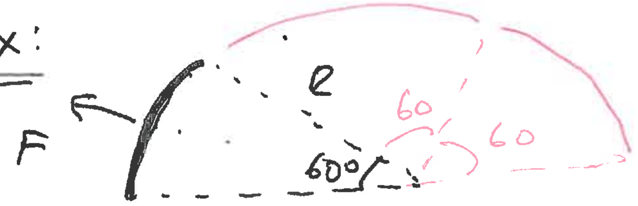
$$F = 2IBR$$

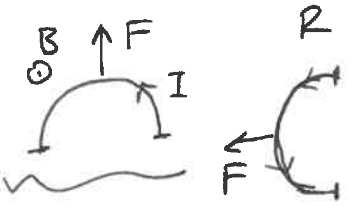




$$\Sigma\vec{F} = \left[ILB + I(2R)B\right]\hat{j}$$
$$= BI(2R+L)\,\hat{j}$$

Ex:



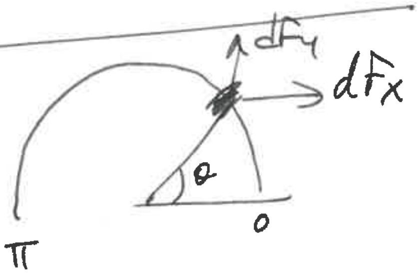


1st way

$F = IB(2R) \Rightarrow 180°$

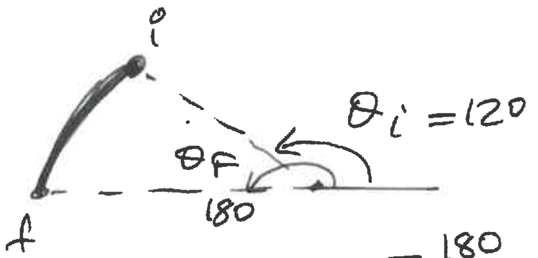
$\frac{F}{3} = IB\left(\frac{2R}{3}\right) \Rightarrow 60°$

2nd way



$dF_y = IBR\int \sin\theta\, d\theta$

$dF_x = IBR\int \cos\theta\, d\theta$



$\int dF_y = IBR\left[\cos\theta\right]_{120}^{180}$

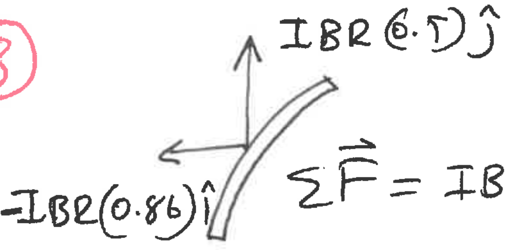
$\int dF_x = IBR\left[\sin\theta\right]_{120}^{180} \neq 0$

$\vec{F}_y = \hat{j}\left[IBR\left[\underbrace{-\cos 180}_{+1} - \underbrace{(-\cos 120)}_{+(-0.5)}\right]\right]$ $\underbrace{\quad\quad}_{0.5}$

$$\boxed{\vec{F}_y = \hat{j}\, IBR\,\frac{1}{2}}$$

$F_x = \hat{i}\left[IBR(\underbrace{\sin 180}_{0} - \underbrace{\sin 120}_{0.86})\right]$

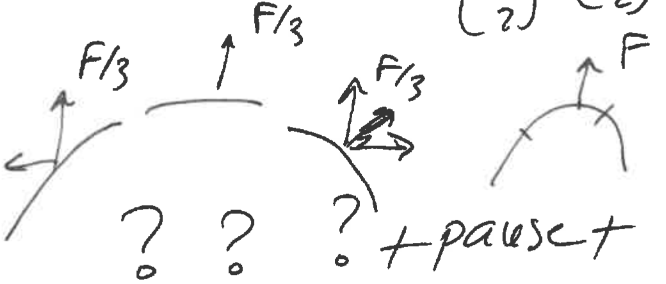
$\vec{F}_x = -0.86\, IBR\,\hat{i}$

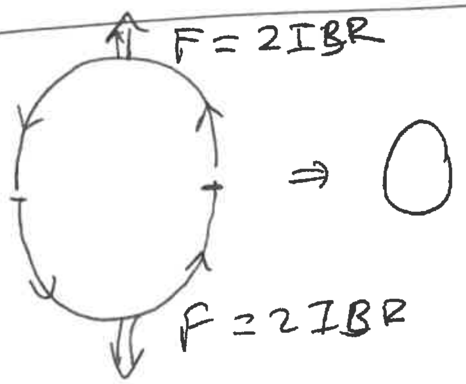


$\hat{j}\uparrow\rightarrow\hat{i}$

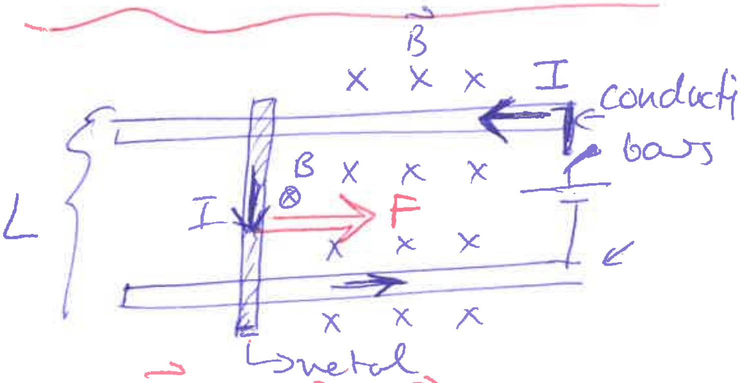
$\sum\vec{F} = IBR\sqrt{0.5^2 + 0.86^2}$

$\left(-\frac{1}{2}\right)^2 + \left(\frac{\sqrt{3}}{2}\right)^2$





always do the integration with circular wire questions!!!



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

(orta) (baş) (işaret)

no friction

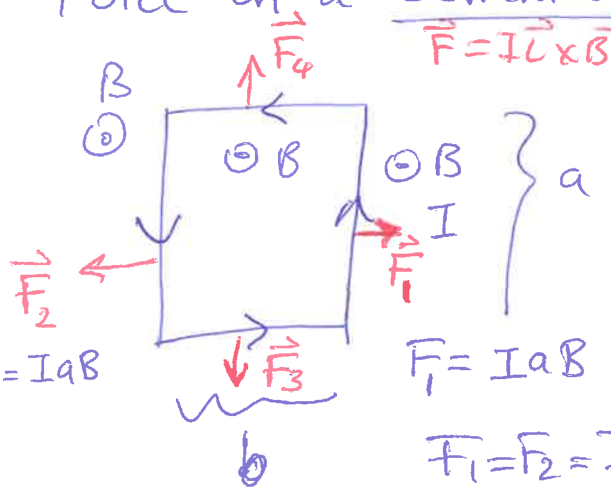
$|\sum\vec{F}| = ILB = ma$

mass of the metal bar.

ΣWork = ΔK [Physics I]

Force on a Current Loop ④

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



$F_2 = IaB$

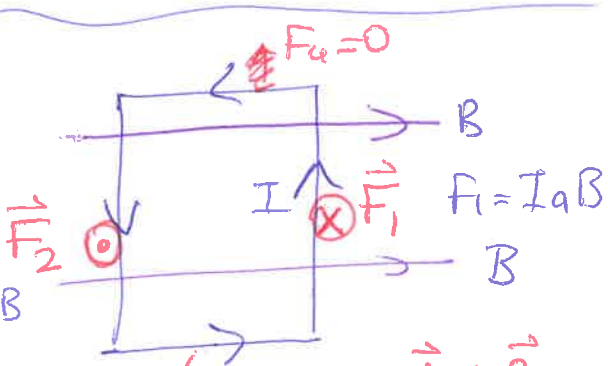
$F_1 = IaB$

$F_1 = F_2 = IaB$

$F_3 = IbB = F_4$

$\sum\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4$

$\sum\vec{F} = \underline{0}$



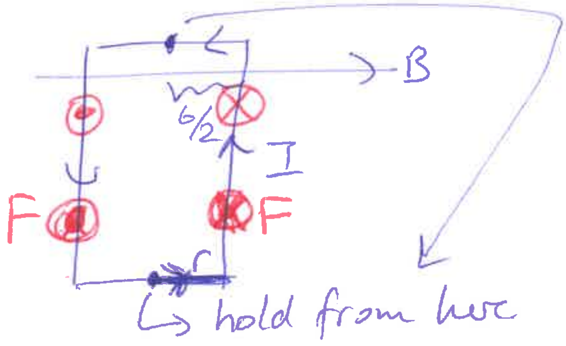
$F_1 = IaB$

$F_2 = IaB$

$F_3 = 0$ $\vec{I} \parallel \vec{B}$

$\sin\theta = 0$

$\sum\vec{F} = \vec{F}_1 + \vec{F}_2$
$= 0$



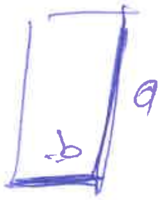
↳ hold from here

Rotate Tork 70

$\vec{\text{Tork}} = \vec{r}\times\vec{F}$

$|\vec{\tau}| = 2\,\frac{b}{2}F \rightarrow IaB$

$|\vec{\tau}| = I\,(ab)\,B$
area



$\tau = (IA)\,B$
current area

$\mu \Leftarrow$ magnetic dipole moment

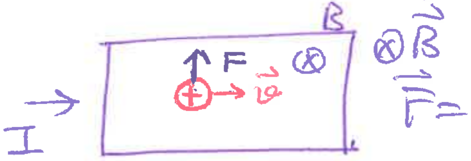
$\mu = IA$

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

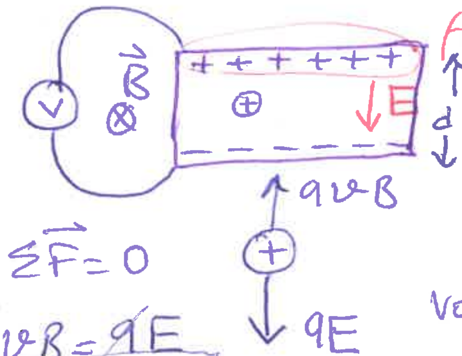
$U = -\vec{\mu}\cdot\vec{B}$
potential energy

Hall Effect

like velocity selector



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



from accumulation (toplama) of + charges on top

↓E

$\sum\vec{F} = 0$

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

$\boxed{v\,B = \frac{\Delta V}{d}}$ → voltage

speed

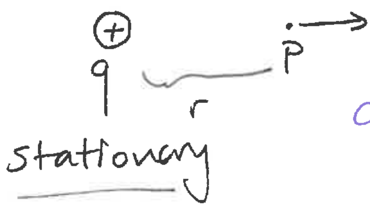
Hall probe

voltage difference between top bottom.

$\Delta V = Ed$

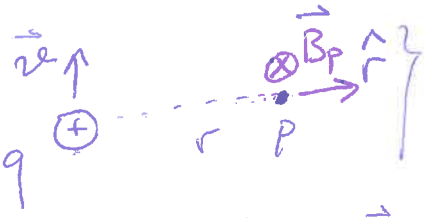
Phys II 27.7.17 ①

Ch 28
Sources of Magnetic Field



$\vec{E} = k\frac{q}{r^2}\hat{r}$

charge is a source of Electric Field

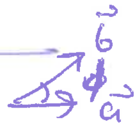


moving charge will create magnetic field

$$\vec{B}_p = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$$

$$|\vec{B}_p| = \frac{\mu_0}{4\pi}\frac{qv\sin\phi}{r^2} \quad \text{(magnitude)}$$

$$|\vec{a}\times\vec{b}| = ab\sin\phi$$



μ_0 = magnetic constant = magnetic permibility (geçirgenlik)

$$\mu_0 = 4\pi\times10^{-7}\frac{N\,s^2}{C^2}$$

$$\mu_0 = \frac{4\pi r^2 B_p}{qv\sin\phi} = \left[\frac{m^2\;T}{C\;m/s}\right]$$

$$\mu_0 = \left[\frac{m\,T\,s}{C}\right] \quad ; \quad \vec{F} = q\vec{v}\times\vec{B} \quad \left[T = \frac{N}{C\,m/s}\right]$$

$$= \left[\frac{\cancel{m}\,\frac{Ns}{C\cancel{m}}\,s}{C}\right]$$

$$\underline{\mu_0} = \left[\frac{N s^2}{C^2}\right]$$

↳ **

ε_0 = Electric permibility

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} \; ; \; \varepsilon_0 = \cancel{\left[\frac{N\,m^2}{C^2}\right]^{-1}}$$

$$\varepsilon_0 = \left[\frac{C^2}{N m^2}\right] \; ; \; \mu_0 = \left[\frac{N s^2}{C^2}\right]$$

$$\varepsilon_0\mu_0 = \frac{\cancel{C^2}}{\cancel{N} m^2}\,\frac{\cancel{N} s^2}{\cancel{C^2}} = \frac{s^2}{m^2}$$

$$\mu_0\varepsilon_0 = \frac{1}{(\text{speed})^2}$$

$$\boxed{\frac{1}{\mu_0\varepsilon_0} = c^2 \quad \text{↳ speed of light}} \quad ***$$

moving charge creates magnetic field.

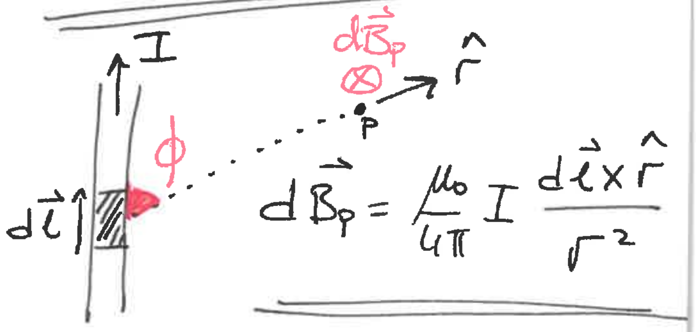
$$\vec{B}_p = \frac{\mu_0}{4\pi}\,q\,\frac{\vec{v}\times\hat{r}}{r^2}$$

$$\boxed{\hat{r} = \frac{\vec{r}}{r}}$$

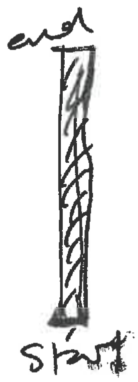
---

put charges in a wire;
↳ move them ⇒ current

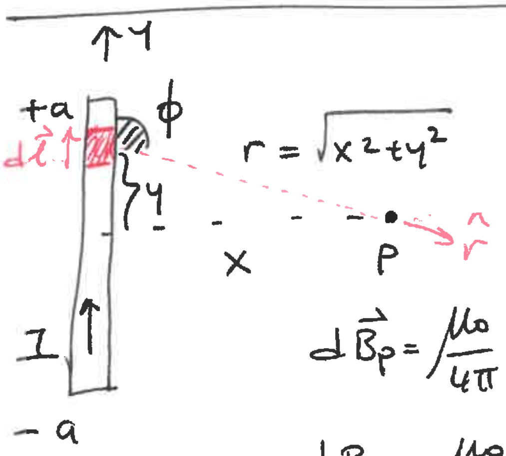
current carrying wires create magnetic fields!



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



$$\bullet p \qquad B_p = \frac{\mu_0}{4\pi} I \int_{start}^{end} \frac{d\vec{l} \times \hat{r}}{r^2}$$

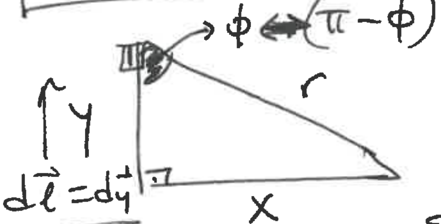


$$r = \sqrt{x^2+y^2}$$

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

$$dB_p = \frac{\mu_0}{4\pi} I \frac{dl \sin\phi}{x^2+y^2}$$

$$\boxed{\sin\phi = \sin(\pi-\phi)}$$



$$\underline{d\vec{l} = d\vec{y}}$$

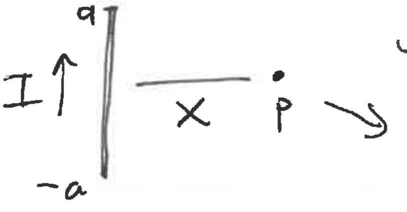
$$\sin\phi = \frac{x}{\sqrt{x^2+y^2}}$$

$$dB_p = \frac{\mu_0}{4\pi} I \overset{dy}{(dl)} \frac{x}{(x^2+y^2)^{3/2}}$$

$$\int dB_p = \int_{-a}^{+a} \frac{\mu_0 I}{4\pi} \frac{x\,dy}{(x^2+y^2)^{3/2}}$$

x: const

$$\boxed{B_p = \frac{\mu_0 I}{4\pi} \frac{2a}{x\sqrt{x^2+a^2}}}$$



$$\underset{\sim\sim\sim}{x \ll a}$$

$$\frac{x}{a} \to 0$$

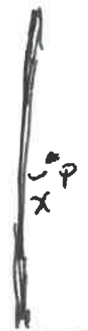
②

$$x \ll a \quad ; \quad \frac{x}{a} \to 0$$

$$B_p = \frac{\mu_0 I}{4\pi} \frac{2a}{x\sqrt{x^2+a^2}}$$

$$= \frac{\mu_0 I}{\underset{2}{\cancel{4}}\pi} \frac{\cancel{2}\cancel{a}}{x\sqrt{\cancel{a^2}\left(\underset{\downarrow 0}{\frac{x^2}{a^2}}+1\right)}}$$

$$B_p = \frac{\mu_0 I}{2\pi x \sqrt{1}} = \underline{\frac{\mu_0 I}{2\pi x}}$$



⇒ as if the wire is infinite

Ex: A long wire carries 1A at what distance from the wire; the magnetic field is 0.5×10^{-4} T (Earth's magnetic field)

ass x

$$B_p = \frac{\mu_0 I}{2\pi x}$$

$$0.5\times10^{-4} = \frac{4\pi\times10^{-7}\ 1A}{2\pi\ x}$$

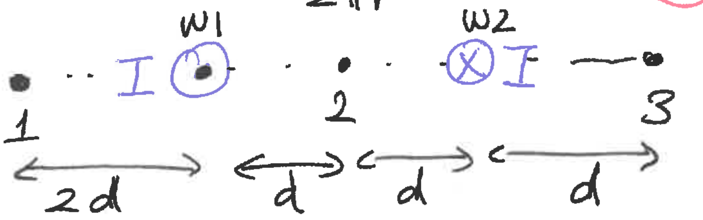
$$x = 4\times10^{-3}\,m$$

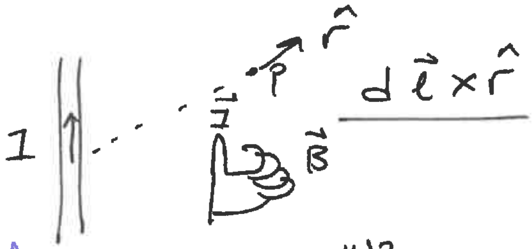
$$\boxed{x = 4\,mm}$$

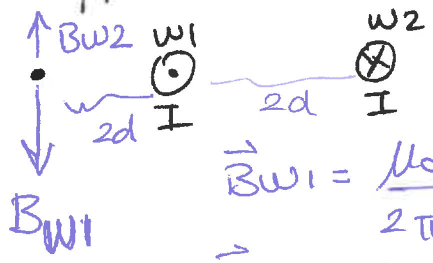
Ex: Two long parallel wires carrying current

③

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







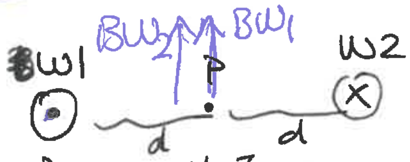
$$\vec{B}_{W1} = \frac{\mu_0 I}{2\pi\, 2d}(-\hat{j})$$

$$\vec{B}_{W2} = \frac{\mu_0 I}{2\pi\, 4d}(\hat{j})$$

① $\Sigma\vec{B} = \vec{B}_{W1} + \vec{B}_{W2}$

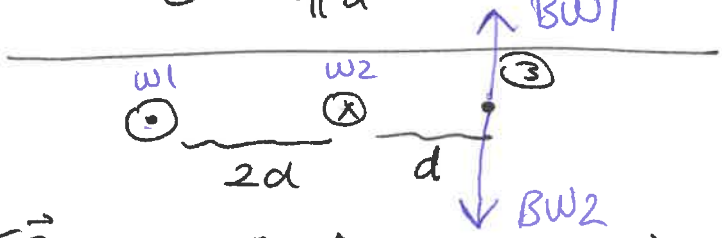
$$\Sigma\vec{B}_{①} = -\frac{\mu_0 I}{8\pi d}\hat{j} \qquad \downarrow \Sigma\vec{B}$$

②



$$\Sigma\vec{B}_{②} = \frac{\mu_0 I}{2\pi d}\hat{j} + \frac{\mu_0 I}{2\pi d}\hat{j}$$

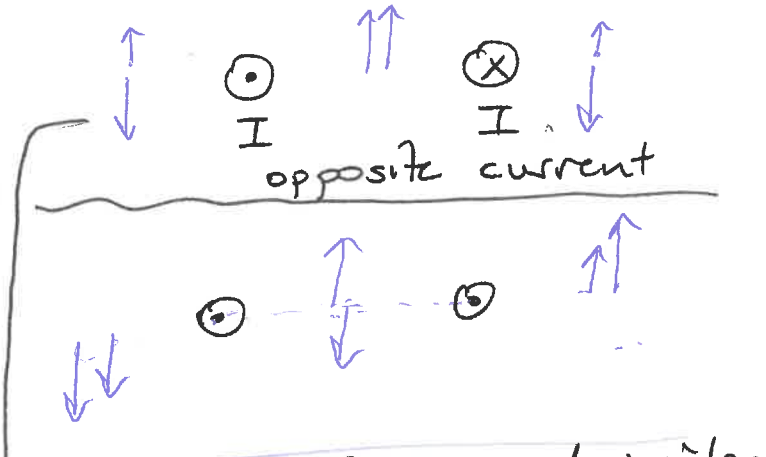
$$\Sigma\vec{B}_{②} = \frac{\mu_0 I}{\pi d}\hat{j}$$



$$\Sigma\vec{B}_{③} = \frac{\mu_0 I}{2\pi\, 3d}\hat{j} + \frac{\mu_0 I}{2\pi d}(-\hat{j})$$

$$\Sigma\vec{B}_{③} = -\frac{\mu_0 I}{3\pi d}\hat{j}$$

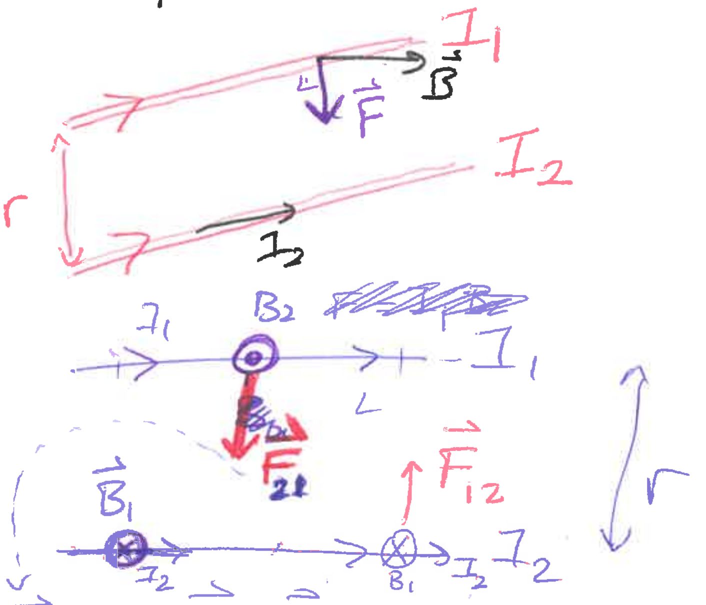
Summarize of two parallel long wire



computer wires; audio; video currents are in opposite direction wires are very close to each other; so that the magnetic field outside is minimum

Force between parallel wires

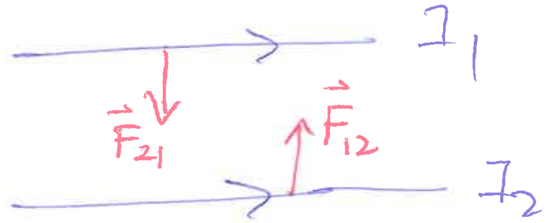
$$\vec{F} = I\vec{L}\times\vec{B}$$



$$\vec{F}_{21} = I_1\vec{L}\times\vec{B}_2 = I_1 L B_2(-\hat{j})$$

$$\vec{F}_{12} = I_2\vec{L}\times\vec{B}_1 = I_2 L B_1(\hat{j})$$

$$\boxed{B_1 = \frac{\mu_0 I_1}{2\pi r}} \; ; \; \boxed{B_2 = \frac{\mu_0 I_2}{2\pi r}}$$



$$\vec{F}_{21} = I_1 L B_2^{(-\hat{j})} = \frac{I_1 L \mu_0 I_2}{2\pi r}(-\hat{j})$$

$$\vec{F}_{12} = I_2 L B_1 = \frac{I_1 I_2 L \mu_0}{2\pi r}(\hat{j})$$

$$\vec{F}_{21} = -\vec{F}_{12}$$

action-reaction pairs!

$$|\vec{F}_{21}| = |\vec{F}_{12}| = \frac{\mu_0 I_1 I_2 L}{2\pi r} = F$$

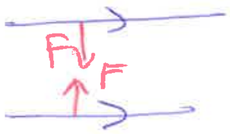
$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

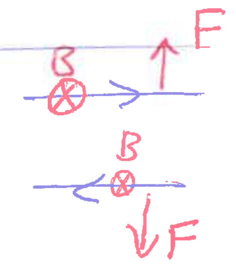
force per length

if $r = 1m$; $I_1 = I_2 = 1A$

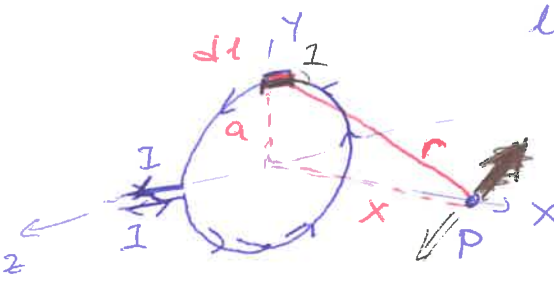
$$\frac{F}{L} = \frac{4\cancel{\pi}\times10^{-7}(1)(1)}{2\cancel{\pi}(1)}$$

$$= \cancel{3}2\times10^{-7}\ N/m$$





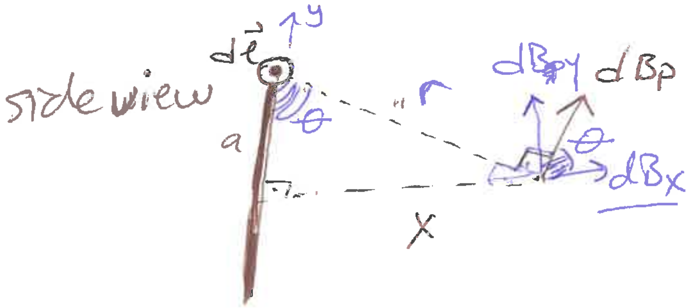
④ Magnetic field of a circular current loop



loop is in yz plane

$B_p = ?$

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



$$dB_p = \frac{\mu_0 I\, dl}{4\pi r^2} \quad ; r^2 = x^2 + a^2$$

dB_y cancels out!

dB_x survives!

$$dB_x = dB_p \cos\theta = dB_p \frac{a}{r}$$

$$\int dB_x = \int \frac{\mu_0 I\, dl}{4\pi(x^2+a^2)}\frac{a}{\sqrt{x^2+a^2}}$$

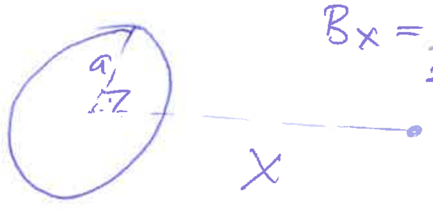
$dl \Leftrightarrow x, a$?

related. a, x const

$$\int dB_x = \frac{\mu_0 I a}{4\pi(x^2+a^2)^{3/2}}\underbrace{\int dl}_{2\pi a}$$

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

$$B_x = \frac{\mu_0 I a^2}{2(x^2+a^2)^{3/2}}$$



$$B_x = \frac{\mu_0 I a^2}{2(x^2+a^2)^{3/2}}$$

$X = 0$?

$x = 0$

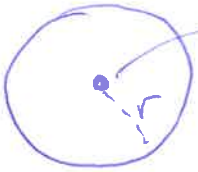
$$B_x(x=0) = \frac{\mu_0 I a^2}{2(a^2)^{3/2}}$$

$$B(x=0) = \frac{\mu_0 I}{2a}$$

LONG straight wire

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

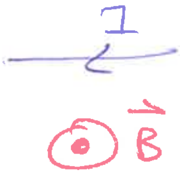
LOOP wire
circular



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

PUT $\underline{N}$ of circular wire

$$B = \frac{N \mu_0 I}{2r} +$$



$\vec{B}$ direction !!

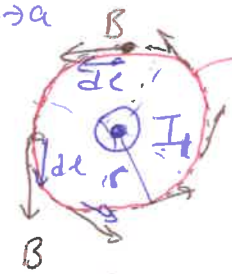
Ampere's Law

like Gauss Law
you can use for certain
problems; avoid integrals

→ for finding $\vec{B}$ field from
a wire!!

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enclosed}$$

a→a



→ dl (circle)

$$\vec{B} \cdot d\vec{l} = B\,dl \underbrace{\cos\theta}_{\underbrace{\cos 0}_{1}}$$

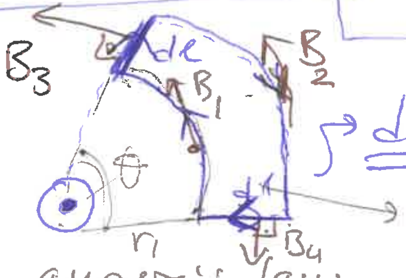
$$\oint \underbrace{B}_{const}\,dl \underbrace{\cos 0}_{1} = \mu_0 I_1$$

$$B \underline{\oint dl} = \mu_0 I_1$$

$$B\,2\pi r = \mu_0 I_1$$

$$B = \frac{\mu_0 I_1}{2\pi r}$$

(we calculated this via integral before!)



∫dl path

$I_{enc} = 0$

ampere's law

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

$$\int_1 \vec{B}_1 \cdot \underset{\cos 0}{d\vec{l}} + \int_2 \vec{B}_2\, \underset{\cos 180}{d\vec{l}} + \int_3 \vec{B}\,d\vec{l} + \int_4 \vec{B} \cdot d\vec{l}$$

$$B_1 \oint dl + B_2 \int dl(-1) \qquad \underbrace{B \cdot dl \cos 90}_{0}$$

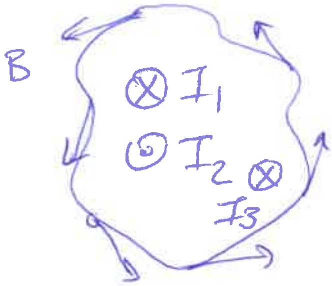
$$B_1 \int dl + B_2 \int - dl$$

1 $r_1\theta$ 2 $r_2\theta$

$$\frac{\mu_0 I}{2\pi r_1} r_1\theta - \frac{\mu_0 I}{2\pi r_2} r_2\theta = 0 \checkmark$$

ampere's law

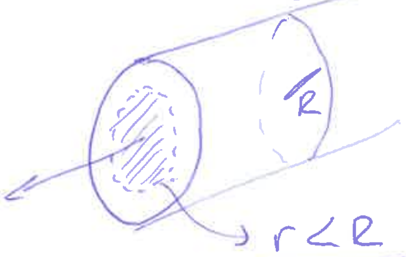
$$\oint \vec{B}\cdot d\vec{l} = 0 \Rightarrow \underbrace{\sum I_{enclosed}}_{ZERO}$$



$$I_{enc} = I_2 - I_1 - I_3$$

If $I_{enc} = 0 \Rightarrow \oint \vec{B}\cdot d\vec{l} = 0$

Ex: what's the B magnetic field inside and outside of a long wire?



$r < R$ (inside)

$I_{enc}(r<R)$

current density $J = \frac{I}{area} = \frac{I}{\pi R^2} = \frac{I_{enc}}{\pi r^2}$

ⓑ $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$

Const

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

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

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

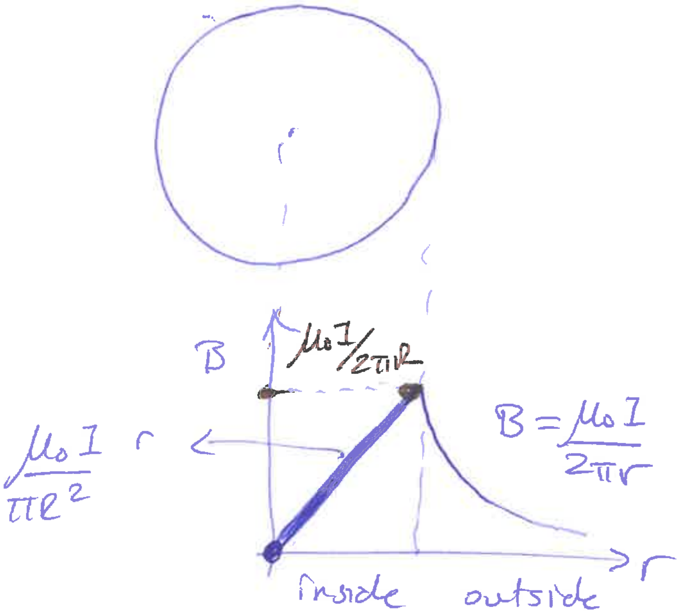
$$\boxed{B = \mu_0 \frac{I}{2\pi R^2} r}$$

$r < R$

B outside

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

$r > R$

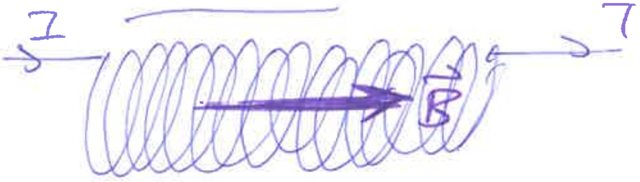


Ampere's Law

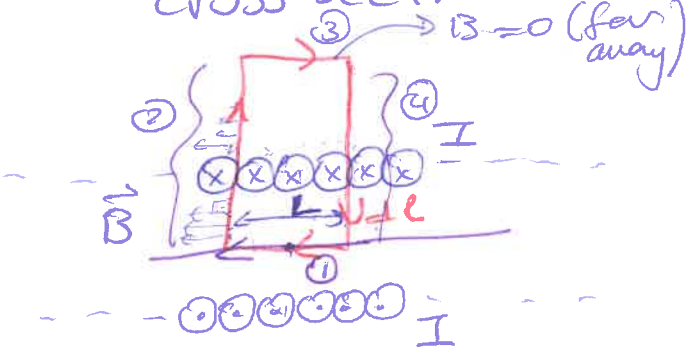
↳ B of Selonoid

↳ B of Toroid

Selonoid



cross section



$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$$

$$\underbrace{\int_1 \vec{B} d\vec{l}} + \underbrace{\int_2 \vec{B}\cdot d\vec{l}} + \int_3 \vec{B} d\vec{l} + \underbrace{\int_4 \vec{B}\cdot d\vec{l}}$$

$\int_1 B\,dl\cos 0$

const

$B\,L$ +

$B\,dl\cos 90 = 0$

B is zero wy far away

0

$$BL + 0 + 0 + 0 = \mu_0 I_{enc}$$

$$B\,L = \mu_0 \underset{\substack{\downarrow \\ \#\text{of wires}}}{N} I$$

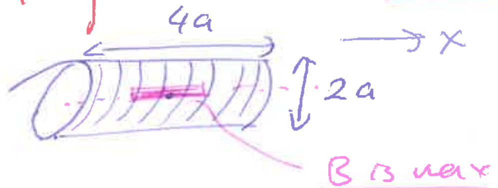
$$B = \mu_0 I \underbrace{\frac{N}{L}}_{n} \rightarrow \frac{\#\text{of wires}}{\text{Length}}$$

$$B = \mu_0 I \vec{n}$$

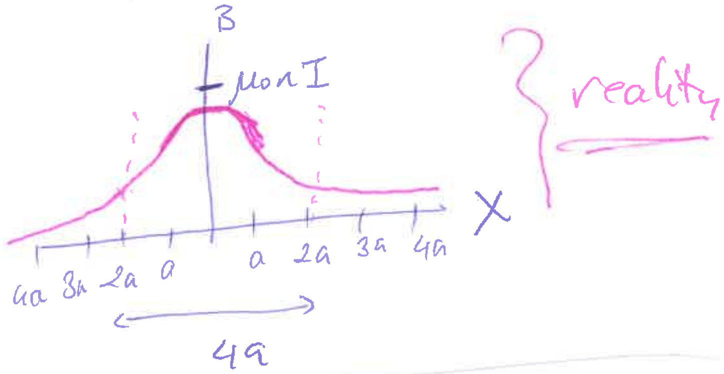
Phys 2

28.7.17

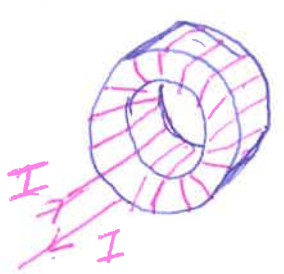
①

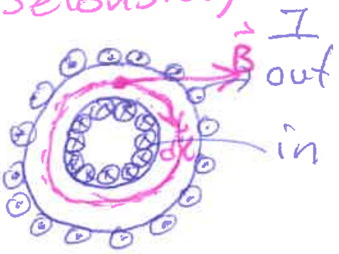


$B = \mu_0 n I$



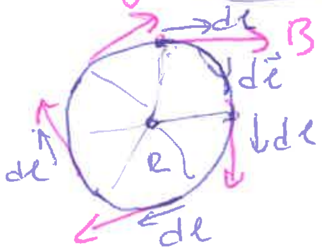
TOROID
(Toroidal Selonoid)





Ampere's Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc.}$$



$B\,dl\cos 0$

$\downarrow$ const ?

$\cos 0 = 1$

$$\underbrace{B}\oint \underbrace{dl} = \mu_0 I_{enc.}$$

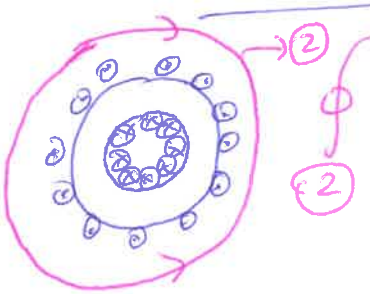
$$B\, 2\pi R = \mu_0 N I$$

↳ # of wires.

$$B = \frac{\mu_0 N I}{2\pi R}$$

$\left(R\downarrow\ I\uparrow,\ N\uparrow \quad B\uparrow \right)$

TOROID



$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

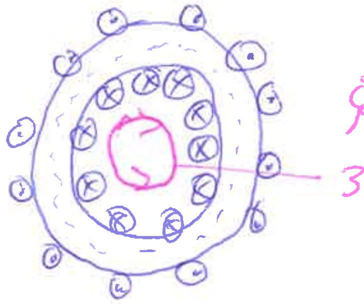
$$I_{enc} = 0 = (NI - NI)$$

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

$d\vec{l} \neq 0$

$$\underline{B = 0}$$

no $\vec{B}$ field outside of a toroid



$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

$d\vec{l} \neq 0$, $I_{enc} = 0$

$$\underline{B = 0}$$

no $\vec{B}$ inside as well!

Bohr magneton

$$\frac{\Delta q}{\Delta t} = \frac{e}{T}$$

T ↙ period

$$\mu = I(\text{area})$$

magnetic moment

$$\mu = \frac{e}{T}\pi r^2 = \frac{e}{\frac{2\pi r}{v}} \cdot \pi r^2$$

$$\Delta x = v\Delta t$$

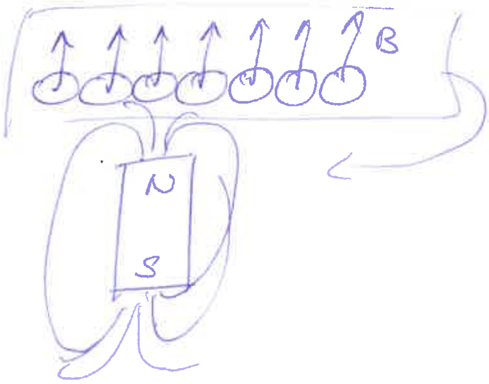
$$2\pi r = vT$$

angular momentum $L = mvr$

$$\mu = \frac{evr}{2}$$

$$\mu = \frac{eL}{2m}$$

e^- ⇒ rotate ⇒ spin ⇒ create $\vec{B}$ field ②



Magnetism

$\vec{M} \equiv$ magnetization

$\vec{M} = \frac{\sum \vec{\mu}}{\text{Volume}}$ ⇒ magnetic field of the material

~~Diag~~

Diamagnetism: are materials that opposes external magnetic field.
they cancel the magnetic field.
Cu ⇒ Copper (Bakır)

Ferromagnetism: Iron, Nickel cobalt

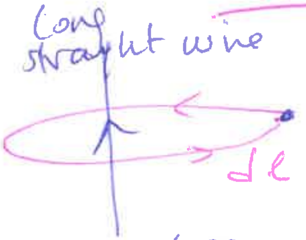
~~they~~ ~~line up~~ the magnetic domains line up with external $\vec{B}$ so that they can have a permenant magnetization.

End of Ch28

Ch28: Sources of magnetic field

Summary

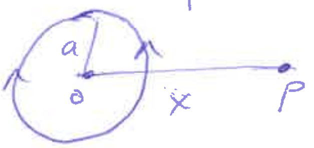
Long straight wire



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

integral

loop



$B_p = \frac{\mu_0 I a^2}{2(x^2+a^2)^{3/2}}$

$B_0 = (x=0) = \frac{\mu_0 I a^2}{2a^3} = \frac{\mu_0 I}{2a}$

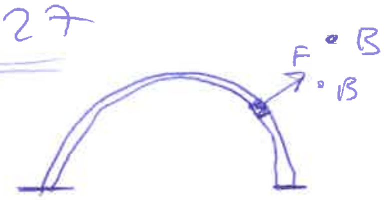
N Loop $B_0 = \frac{N \mu_0 I}{2a}$

~~Bo~~ $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$

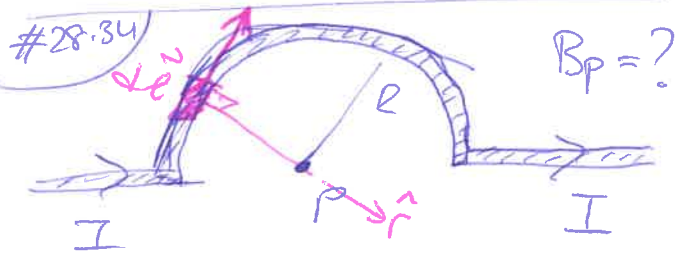
↳ selonoid

→ toroid

Ch27



#28.34



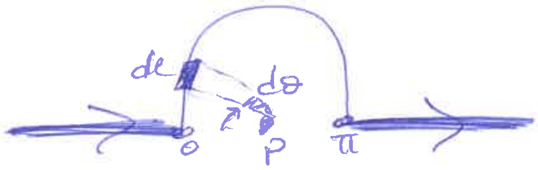
$B_p = ?$

$dB = \frac{\mu_0 I}{4\pi} \frac{d\vec{l} \times \hat{r}}{r^2}$

$= \int \frac{\mu_0 I dl}{4\pi} \frac{\sin 90}{R^2}$

$\frac{\mu_0 I}{4\pi R^2} \underbrace{\int dl}_{\pi R} = \frac{\mu_0 I}{4R}$

③

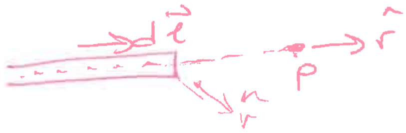


$$\underbrace{\frac{\mu_0 I}{4\pi R^2}}_{(\cdots)} \int \underbrace{dl}_{R\,d\theta} = (\cdots) R \underbrace{\int_0^{\pi} d\theta}_{\pi}$$

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

semi circle

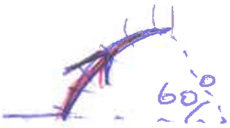
$$d\vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{d\vec{l} \times \hat{r}}{r^2} \rightarrow \underbrace{dl|\hat{r}|\sin 0}_{0}$$



full circle

Remember

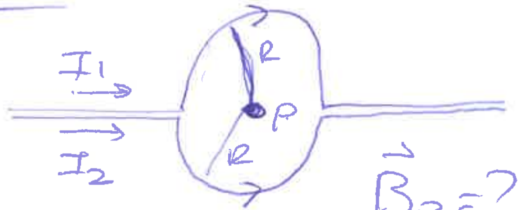
$$B = \frac{\mu_0 I}{2R}$$



$$\frac{\mu_0 I}{4\pi R^2} R \int_0^{\pi/3} d\theta = \frac{\text{full circle}}{6}$$

$$= \frac{\mu_0 I}{12R}$$

28-35



$$\vec{B}_p = ?$$

$$\frac{\mu_0 I_1}{4R} \otimes (-\hat{k}) \qquad \frac{\mu_0 I_2}{4R} \odot \hat{k}$$

$$\vec{B}_p = \frac{\mu_0 (I_1 - I_2)}{4R} (-\hat{k})$$

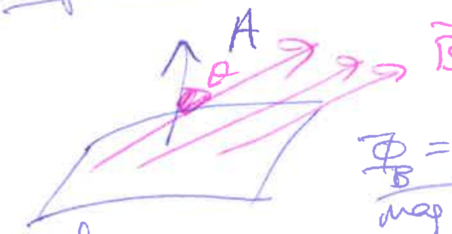
Chapter 29

Electromagnetic Induction

" If the magnetic flux through a circuit changes; an EMF (electromotor force) and a current are induced in the circuit"

FARADAY'S LAW

magnetic flux: $\Phi_B = \vec{B} \cdot \vec{A}$



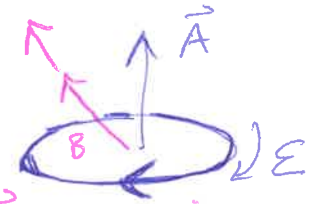
$\Phi_B = BA\cos\theta$

magnetic flux:

emf ↑

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

induced emf in a closed loop.



$\vec{B}$ increasing

$\vec{B}$ decreasing

$$\frac{\Delta\Phi}{\Delta t} = \frac{[T m^2]}{[s]} \qquad \left[T = \frac{N}{Am}\right]$$

$$V = \frac{N}{Am} \frac{m^2}{s} = \frac{Nm}{As} \quad V \quad \cancel{\overline{As}}$$

phys II

phys I

$\frac{1}{2}mv^2 = \text{joule} = qV$

$kg\frac{m^2}{s^2} = \text{joule} = C.\ Volt$

$N.m = CV.$

$I = \frac{Q}{\Delta t}$

$A = \frac{C}{s}$

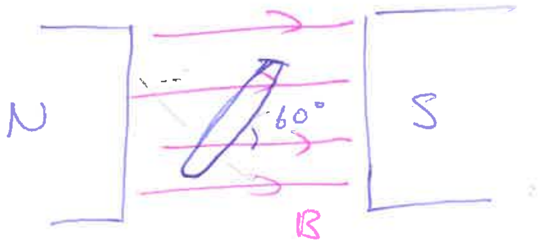
④

<u>for 1 loop</u> $\Phi_B = \vec{B}\cdot\vec{A}$

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

for N loop = $\mathcal{E} = -N\frac{d\Phi_B}{dt}$

<u>Ex:</u> 700 loop R = 4 cm
circular wire coil

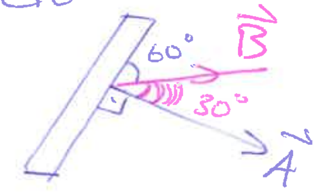


$\vec{B}$ decreases at 0.2 T/s.
what are the magnitude and
the direction of emf?

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}$$

$\Phi_B = \vec{B}\cdot\vec{A}$

$= BA\cos 30$



$A = \pi R^2 = 3.14(0.04)^2 m^2 =$

$$\mathcal{E} = -N\frac{d\Phi_B}{dt} = -N\frac{d(BA\cos 30)}{dt}$$

A = const

$$= -\underset{700}{N}\,\underset{\downarrow}{A}\,\underbrace{\cos 30}_{\frac{\sqrt{3}}{2}}\,\underbrace{\frac{dB}{dt}}_{(\pm 0.2\,T/s\ \text{which one})}$$

B is decreasing with -ve

$$\frac{dB}{dt} = -0.2\ T/s$$

$$\underline{\underline{\mathcal{E} = 0.435V}}$$

Phys II 6.8.17

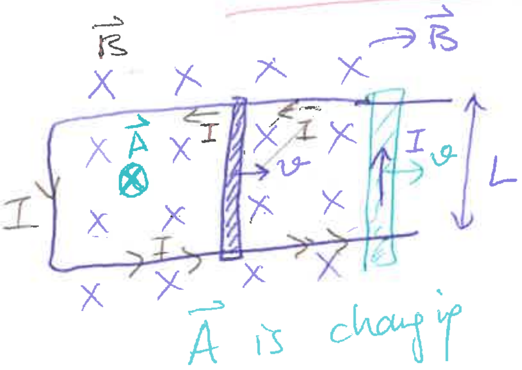
①

Faraday's Law of Induction

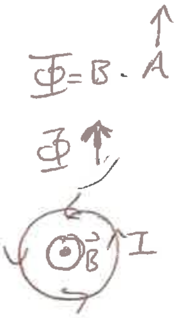
$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

$$\Phi_B = \vec{B}\cdot\vec{A} = \int \vec{B}\cdot d\vec{A}$$

The slidewire Generator



$\vec{A}$ is changing

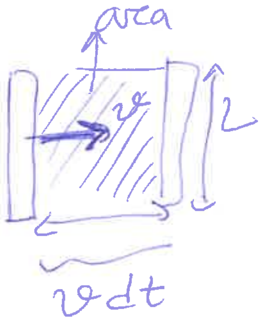


$$\mathcal{E} = -\frac{d(BA)}{dt} \leftarrow \vec{B}\cdot\vec{A} = BA\cos 0$$

const

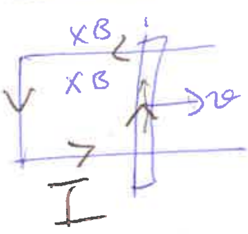
$$= -B\frac{d(\text{Area})}{dt}$$

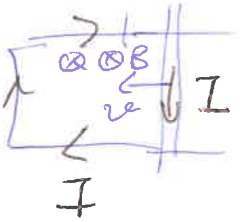
area $= (v\,dt)\,L$



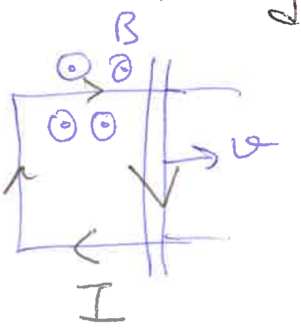
$$\mathcal{E} = -B\frac{vL\,dt}{dt}$$

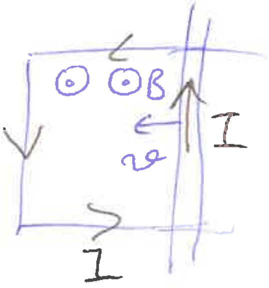
$$\boxed{\mathcal{E} = -BLv}$$

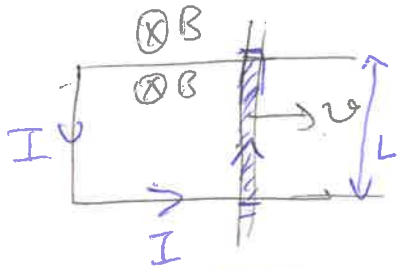




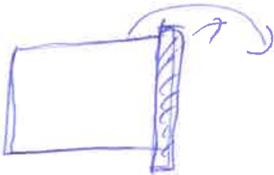
$$\mathcal{E} = -\frac{d(BA)}{dt}$$







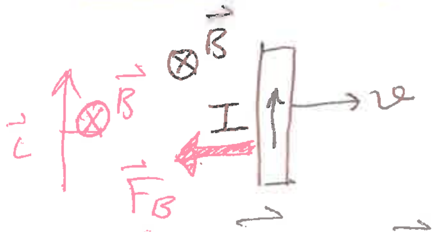
$$\mathcal{E} = -BLv$$



resistance

$$R_{TOTAL} = R$$

magnitude $\mathcal{E} = IR = BLv$



$\vec{F}_B = ?$ force

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

$$I = \frac{BLv}{R}$$

$$\text{Power} = P = I^2R = I\mathcal{E} = \frac{\mathcal{E}^2}{R}$$

$$P = \left(\frac{BLv}{R}\right)^2 R = \frac{B^2L^2v^2}{R}$$

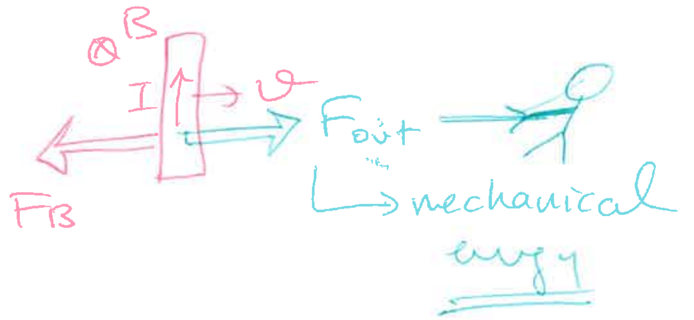
power

Physics I

$$P = \vec{F}\cdot\vec{v} \to ILBv \to \frac{BLv}{R}$$

equal

$$P = \frac{B^2L^2v^2}{R}$$



$\hookrightarrow$ mechanical energy

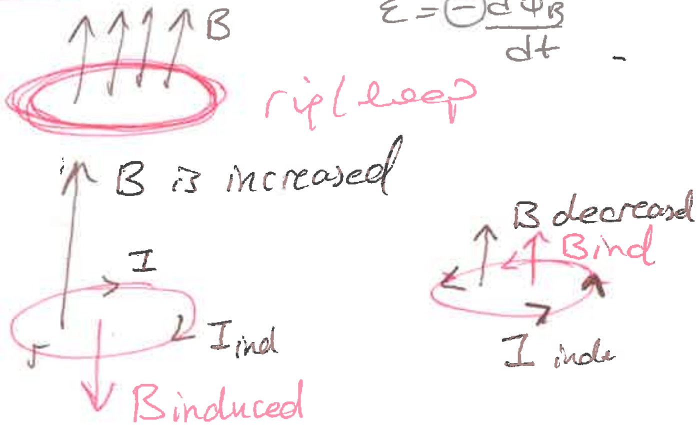
Lenz Law

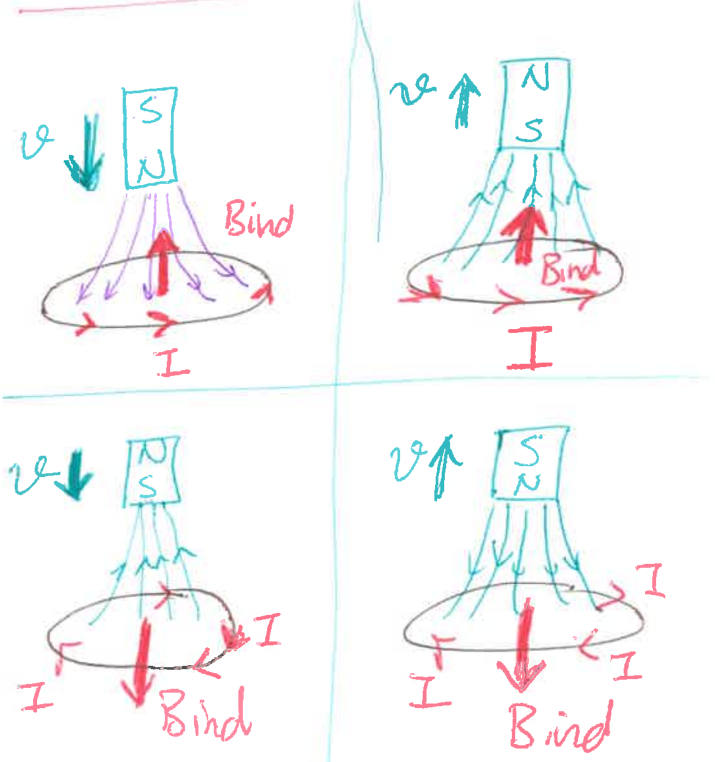
a

The direction of any magnetic induction effect is such ~~that~~ as to oppose the cause of the effect

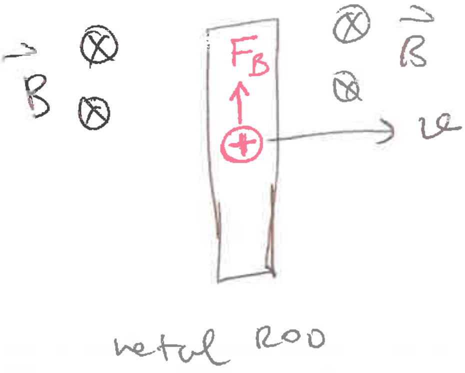
lenz law

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

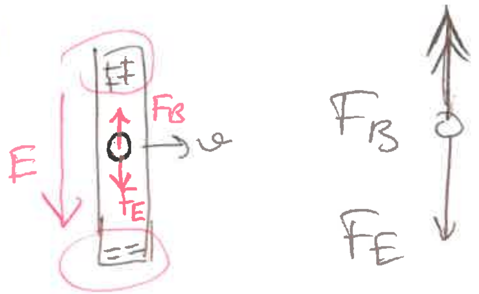




Motional Emf



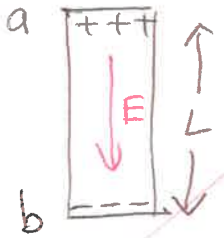
$$\vec{F}_B = q\vec{v}\times\vec{B}$$



$F_B = F_E$

$qvB = qE$

$$\boxed{vB = E}$$



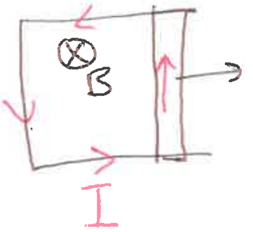
$\Delta V = V_{ab} = V_a - V_b$

$V_{ab} = EL$

$= -\int_a^b \vec{E}\,d\vec{l}$

$vB = \frac{V_{ab}}{L}$

$V_{ab} = \Delta V = \varepsilon = BLv$ ✓



$\varepsilon = -\frac{\partial\Phi_B}{\partial t}$

$\varepsilon = BvL$

magnitude of E

ε is also called as motional electromotor force

$\varepsilon = BLv$

$$V = Tm\frac{m}{s}$$

$$V = Tm^2/s \Rightarrow T = \frac{Vs}{m^2}$$

$\boxed{\varepsilon = vBL}$ $\varepsilon = \oint(\vec{v}\times\vec{B})\cdot d\vec{l}$

$$\mathcal{E} = \oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$$ ③

must be perpendicular

$\vec{B} \otimes \longrightarrow \vec{v}$

$\downarrow \downarrow d\vec{l} \quad \oint (\vec{E}) \cdot d\vec{l}$

must be parallel

$\vec{E}$

max ΔV

$\Phi_B = \vec{B} \cdot \vec{A}$

$$\mathcal{E} = -\frac{d\Phi_B}{dt} \Rightarrow \mathcal{E} = BLv$$

$\swarrow$

$$\oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$$

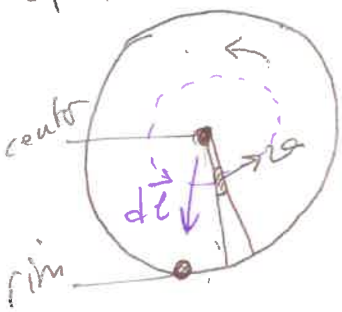
***

Ex:

rotating metal/conductor disc with radius R.

$\vec{B}$ = is in $\hat{z}$ direction

Find the induced emf between the center and the rim (edge) of the disc.



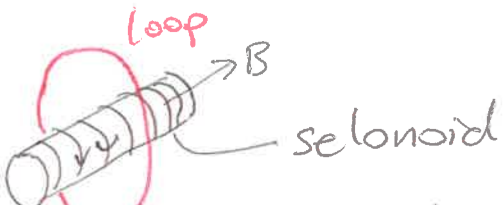
$$\oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$$

(vB)

$$\Delta V_{center-rim} = \mathcal{E} = \int E \, dl$$

$$\mathcal{E} = \int_0^R \underset{\hookrightarrow \omega r}{v} B \, \boxed{dl} \rightarrow dr$$

$$\int_0^R \omega B \, r dr = \omega B \frac{R^2}{2}$$



$\Phi = BA$ ↪ selonoid current

↳ $\mu_0 I n$

\# loops

⚠

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

if the I (selonoid current) is changing with the time

$$\mathcal{E} = -\frac{d}{dt}(\overbrace{\mu_0 n I A}^{\Phi_B})$$

$$\mathcal{E} = -\mu_0 n A \frac{dI}{dt}$$

↳ Loop

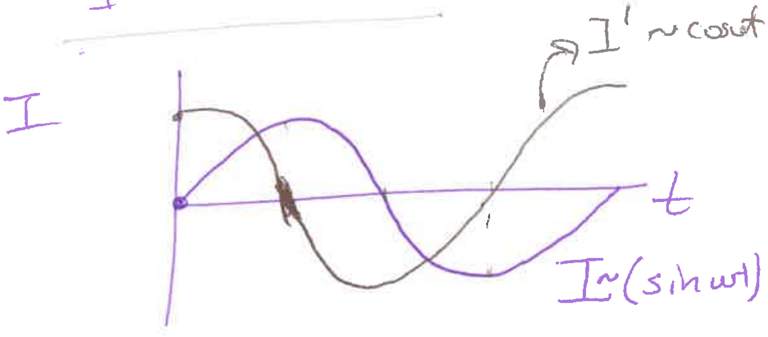
$$I = \sin(\omega t) \rightarrow \frac{dI}{dt} = \cos\omega t$$

if

$\mathcal{E} = I'R$

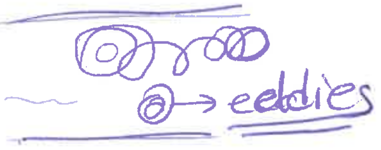
↳ resistance of the loop.

$I' \sim \cos \omega t$



EDDY CURRENTS

River



eddy

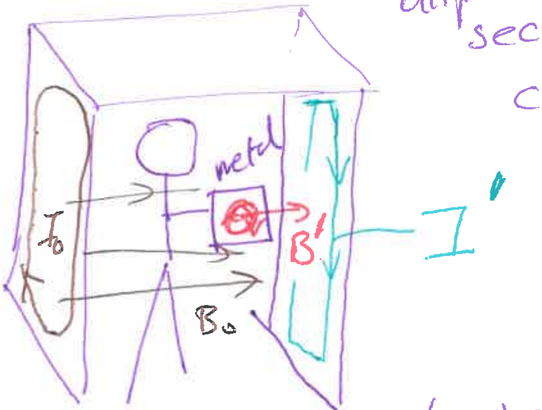
When a conductor is moved under a magnetic field; it opposes to that field and creates magnetic field and creates its own $\vec{B}'$; and ⇒ currents

Eddy currents

Loop currents ≡ Eddy currents

How metal detectors work!

airport security check



metal object is going to induce $\vec{B}'$ field; that will be detected by I'

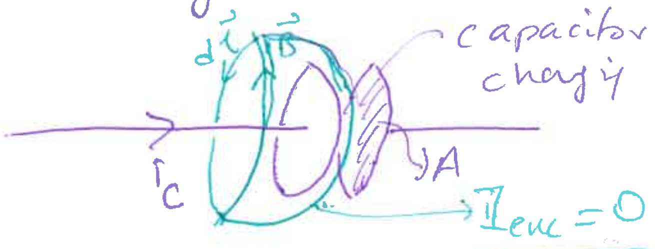
---

* Displacement current and Maxwell Equations

Displacement Current

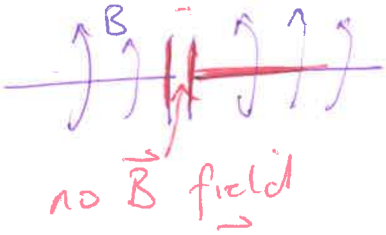
(yerdeğiştiren akım)

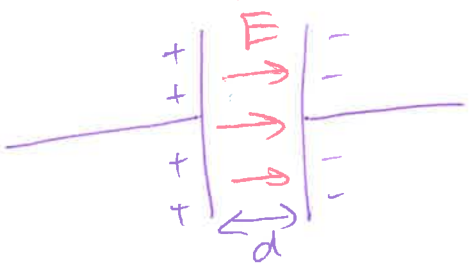
hayali bir terim aslında



$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

$$I_{enc} \rightarrow I_C$$





$$q = CV$$

$$C \rightarrow \varepsilon_0 \frac{A}{d} \qquad V \rightarrow Ed$$

$$= \varepsilon_0 \frac{A}{\cancel{d}} E\cancel{d}$$

$$q = \varepsilon_0 A E \rightarrow \Phi_E = \vec{E} \cdot \vec{A}$$

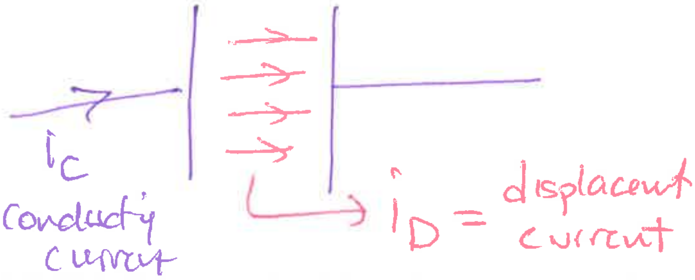
Electric flux

$$i = \frac{dq}{dt}$$

$$= \frac{d}{dt}(\varepsilon_0 \Phi_E)$$

$$i_D = \varepsilon_0 \frac{d\Phi_E}{dt}$$

(displacement current)



$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \left(\underset{\text{wire}}{i_c} + \underset{\text{empty space}}{i_D}\right)_{enc}$$

$i_D = \varepsilon_0 \frac{d\Phi_E}{dt}$ (empty space)

$i_D = \varepsilon \frac{d\Phi_E}{dt}$

↳ some dielectric

$$\oint \vec{B}\cdot d\vec{l} = \underbrace{\mu_0 i_c}_{\text{conduction (wire) current}} + \underbrace{\mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}}_{\text{displacement current}}$$

when $I_c = 0$ no wires!

$\frac{d\Phi_E}{dt} > 0 \Rightarrow$ will create $\vec{B}$

$\vec{E} \rightarrow \vec{B}$

Electro Magnetic Waves!!

Maxwell Equations

① Gauss Law

$$\oint \vec{E}\cdot d\vec{A} = \cancel{\varepsilon_0} \frac{Q_{enc}}{\varepsilon_0}$$

monopole

② $\oint \vec{B}\cdot d\vec{A} = 0$

↳ no monopole of magnetic fields.

③ $\mathcal{E} = -\frac{d\Phi_B}{dt}$

↓

$\oint \vec{E}\cdot d\vec{l} = \frac{-d\Phi_B}{dt}$

④ $\oint \vec{B}\cdot d\vec{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$

Symetry in Maxwell equations

one side ⇓ E

other side ⇓ B

E ⟷ B

$$\underbrace{\oint \vec{E}\cdot d\vec{l}}_{} = -\frac{d\Phi_B}{dt} = \frac{-d}{dt}\underbrace{\int \vec{B}\cdot d\vec{A}}_{}$$

$I_c = 0$

$$\underbrace{\oint \vec{B}\cdot d\vec{l}}_{B} = \mu_0 \varepsilon_0 \frac{d}{dt}\underbrace{\int \vec{E}\cdot d\vec{A}}_{E}$$

B ⟷ E

$\frac{1}{c^2} = \mu_0 \varepsilon_0$

↳ speed of light

Superconductor

$T_c \sim 180K$

179K ↙ superconductor.

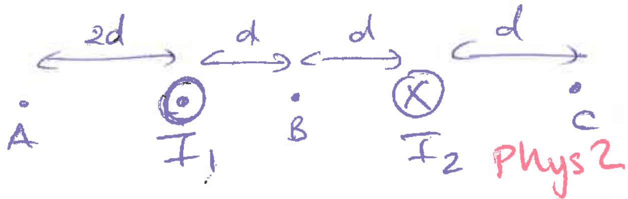
Resistance = 0

MRI machines have superconductors! ~ look

END

3.cusmauq 21.7.17 dahil olmak üzere sonuna kadar dahil

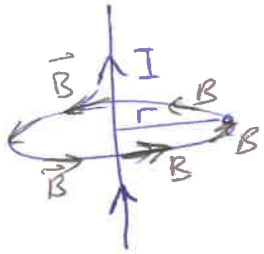
LONG WIRE's carry curr



①

Phys 2
3.8.17

$B_A = ?$



Top view

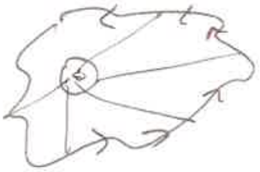
$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

$$\oint B\, dl \cos\theta$$

B

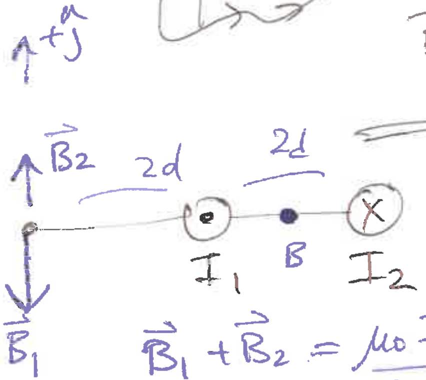
const

$$B \underbrace{\oint dl}_{2\pi r} = \mu_0 I$$



$B \neq const$

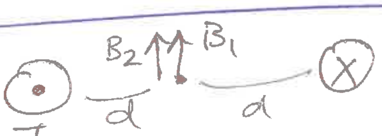
$$B = \frac{\mu_0 I}{2\pi r}$$



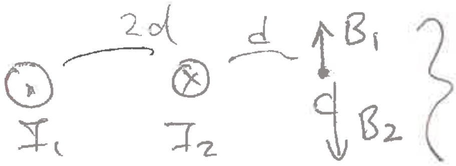
$$\vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I_1}{2\pi\, 2d} - \frac{\mu_0 I_2}{2\pi\, 4d}$$

$$B_A = \frac{\mu_0}{4\pi d}\left(I_1 - \frac{I_2}{2}\right)(-\hat{j})$$

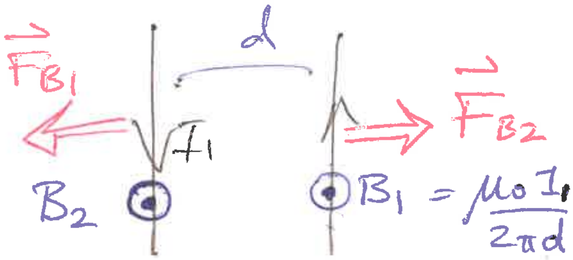
$\vec{B}_B = ?$



$$\vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I_1}{2\pi d} + \frac{\mu_0 I_2}{2\pi d}$$



$$\left(\frac{\mu_0 I_1}{3d} - \frac{\mu_0 I_2}{d}\right)\hat{j} = B_{B_1}$$



$$= \frac{\mu_0 I_1}{2\pi d}$$

I_1 I_2

$$\vec{F}_{B1} = I_1 \vec{L} \times \vec{B}_2$$

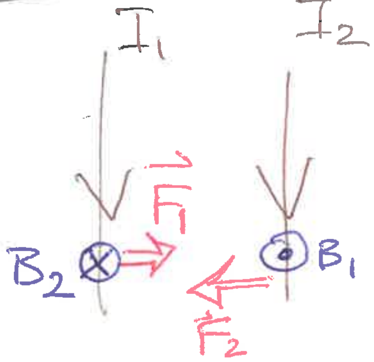
$$F_{B1} = I_1 L \frac{\mu_0 I_2}{2\pi d}$$

$$(\vec{F}_B)_2 = I_2 \vec{L} \times \vec{B}_1$$

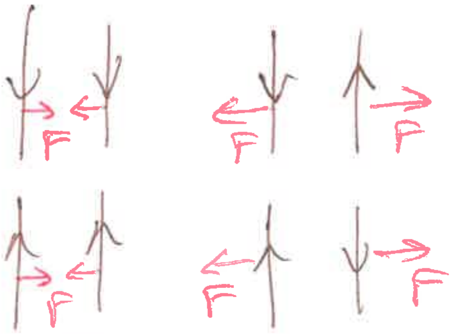
$$= I_2 L \frac{\mu_0 I_1}{2\pi d}$$

$$F_{B_2} = \mu_0 \frac{I_1 I_2}{2\pi d} L$$

$F_{B1} = F_{B2}$; $\vec{F}_{B1} = -\vec{F}_{B2}$

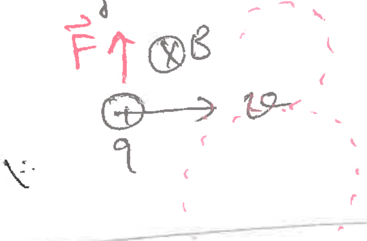


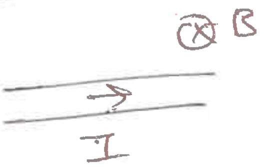
$$\vec{F}_2 = I_2 \vec{L} \times \vec{B}_1$$



Ch 27

Magnetic Field & Magnetic Forces



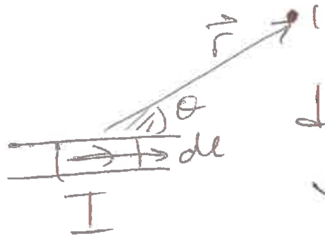


$\vec F = I \vec L \times \vec B$

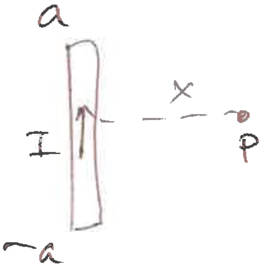
Hall effect; $\vec B$, $\vec E$

Ch 28

Sources of magnetic field



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



$$B_P = \int d\vec B$$

$$= \frac{\mu_0 I}{4\pi} \frac{2a}{x\sqrt{x^2+a^2}}$$

$X \to 0$

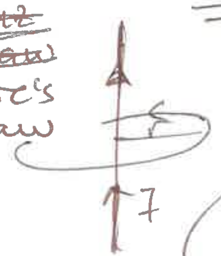
infinetly long wire

$$\Downarrow$$

$$\frac{\mu_0 I}{2\pi X} \; //$$

~~Lenz Law~~

Ampere's Law

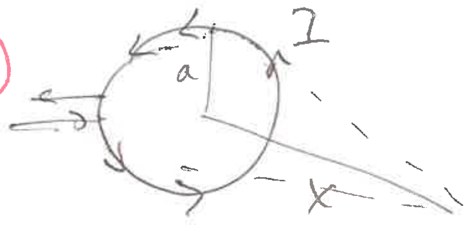


$$\oint \vec B d\vec l = \mu_0 I_{en}$$

$$\boxed{\frac{\mu_0 I}{2\pi r}} \checkmark$$

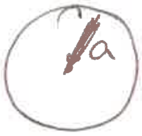
F = ? $\vec F = I \vec L \times \vec B$

②



$$B = \frac{\mu_0 I a^2}{2(x^2+a^2)^{3/2}}$$

$X \Rightarrow 0$



$$B = \frac{\mu_0 I a^2}{2(a^2)^{3/2}} = \frac{\mu_0 I}{2a}$$

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

↓ straight wire

↓ circular loop wire

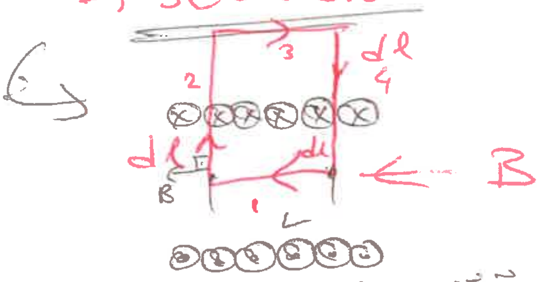
Ampere's Law

$$\oint \vec B \cdot d\vec l = \mu_0 I_{enc}$$

↳ straight wire

→ toroid

→ selenoid



$$\oint \vec B d\vec l = \int_1 \vec B d\vec l + \int_2 \vec B d\vec l + \int_3 \vec B d\vec l + \int_4 \vec B d\vec l$$

2 and 4

$\} = 0$

0 0

$B_3 = 0$ $\oint_3 \vec B d\vec l$ 0

$\int_1 B dl$

$BL = \mu_0 I_{enc}$

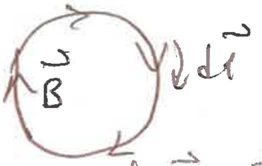
↳ (# of wire) × I_0

$BL = \mu_0 N I_0$

$B = \mu_0 I_0 \frac{N}{L} \rightarrow n$

$B = \mu_0 n I_0$ Selenoid

TOROID.



$\mu_0 I_{enc} = \oint \underset{\text{sbt}}{\vec{B}} \cdot d\vec{l}$ y cosθ

$\mu_0 N I = B \underbrace{\oint dl}_{2\pi r}$

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

TOROID

selenoid $B = \mu_0 I \frac{N}{L}$

Ch 29 EM induction

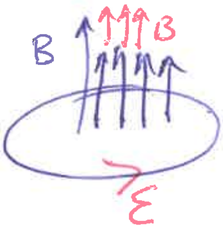
$\mathcal{E} = -\frac{d\Phi_B}{dt}$ Faraday's Law

$\Phi_B = \vec{B} \cdot \vec{A}$

Volt

$\int \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$

increasiŋ $\vec{B}$



decreasiŋ B

$\Phi_B \uparrow\downarrow$

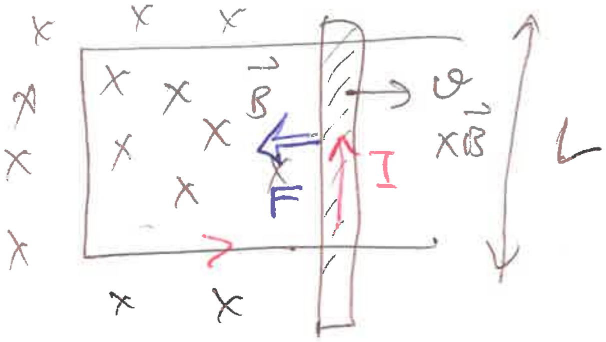
$\vec{B} \cdot \vec{A}$
$\updownarrow \quad \updownarrow$

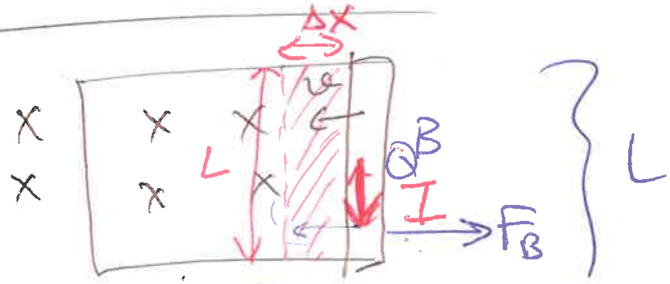
③ Ampere's Law

$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_C + \varepsilon_0 \mu_0 \frac{d\Phi_E}{dt}$

$I_{enc} = \left(I_C + \varepsilon_0 \frac{d\Phi_E}{dt}\right)$

I Displacement current





$F = I L B = ma$

$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d(\vec{B} \cdot \vec{A})}{dt}$

$= B \frac{dA}{dt}$ $A \rightarrow L\,dx$

$\mathcal{E} = BL \frac{dx}{dt}$ $\frac{dx}{dt} \rightarrow v$

$\mathcal{E}$

L

$I = \frac{\mathcal{E}}{R} =$