* Section II

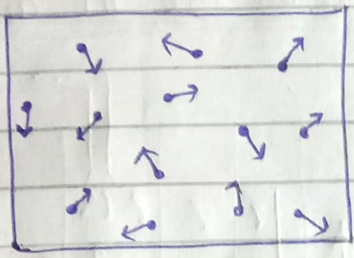
→ Electrodynamics

- "Study of charges in motion."

→ The Electrical Properties of Materials :-

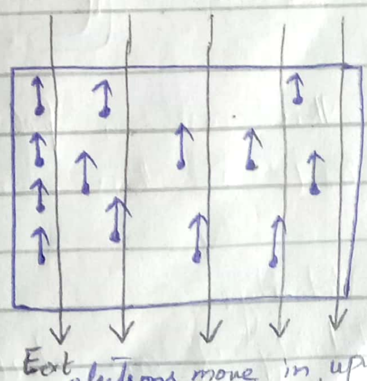
Types of Materials
- i Insulators
- ii Conductors
- iii Semiconductors
- iv Super conductors

→ A conductor in an Electric field :- (Static Condition).



ⓐ A conducting slab with random motion of e⁻s

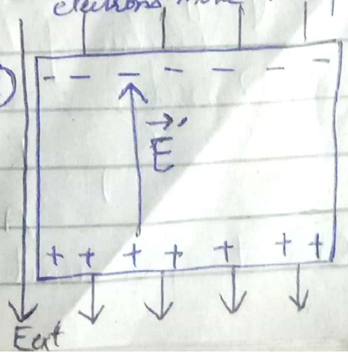
ⓑ



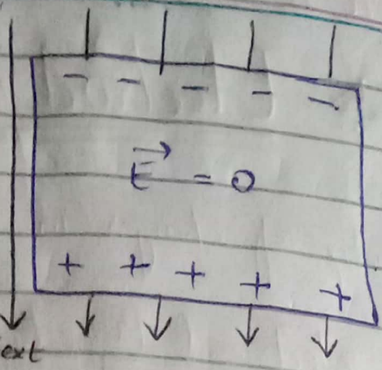
electrons move in upwards direction

E′ is internally established field that is basically established due to polarization

ⓒ



(d)



$E = E_{ext} - E'$

In conductors,

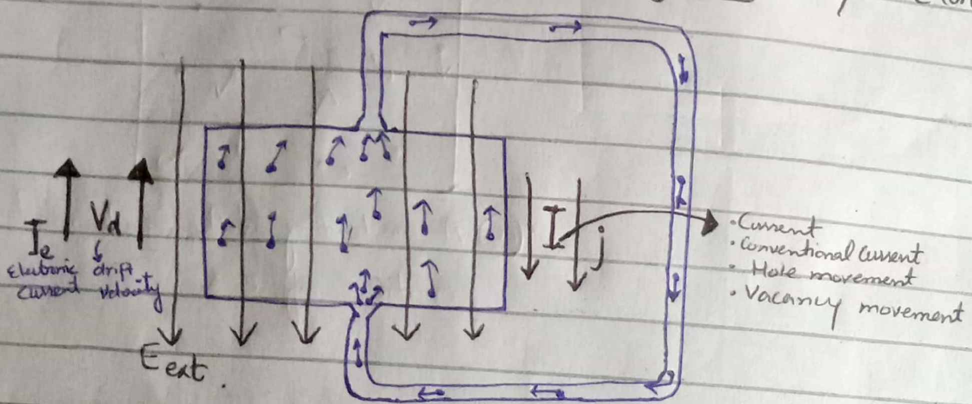
$E' = E_{ext}$

$\boxed{E = 0}$

$\boxed{\vec{E} = 0}$

i.e Field inside a conductor is always zero

* A Conductor in an Electric field:- (Dynamic Condition)



In this case, field inside slab is also equal to Eext as there is no E'

Drift Velocity:-

Velocity of an electron under the influence of applied electric field. when the collision is also present.

Current Density:-

$$J = \frac{I}{A} \qquad \frac{Amp}{m^2}$$

Current per unit area.

It is denoted by ~~J~~ j

$\therefore$ j is a vector quantity

$$i = \vec{j} \cdot \vec{A}$$

$$\boxed{j = Amp \cdot m^{-2}}$$

$$i = \int \vec{j} \cdot d\vec{A}$$

- The direction of j is in the direction of conventional current.

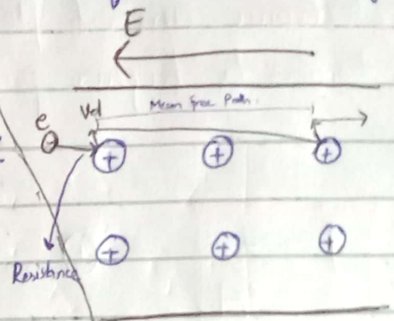
- Resistance :-

Opposition offered to the flow of electrons (charge) is called resistance (R)

- Current :-

$$i = \frac{q}{t} \Rightarrow i = \frac{dq}{dt}$$

$$\frac{C}{sec} = Amp.$$



$$dq = i\,dt$$

$$\boxed{q = \int i\,dt}$$

- Vd is an average velocity

It is the property of material

Mean free Path :-

Path covered between successive collisions is called free path. And their mean is called mean free path

Mean free time :-

Time taken between successive collisions is called free time. And their mean (average) is called mean free time.

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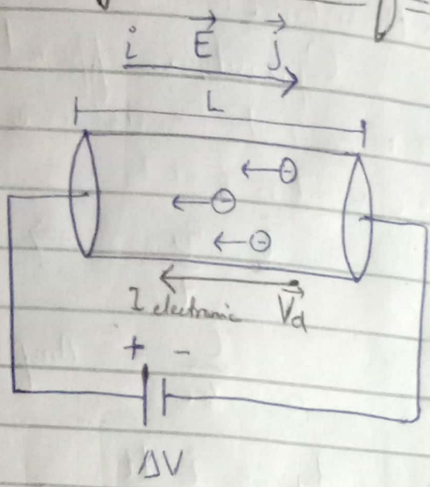
- Mean free Path $\uparrow$ Max $\rightarrow$ then Good Conducting Material
- Mean free time $\uparrow$ Max $\longrightarrow$ then Good Conducting Material
- Conduction reduced due to increase in Temprature as vibration increases.

$V_d \uparrow$ max $\longrightarrow$ Good Conducting Material

→ Relation b/w Current density ($\vec{J}$) & Drift Velocity ($\vec{V_d}$):-



* electronic current flows towards higher potential

$$\boxed{J = \frac{I}{A}} \quad \text{—} (1) \qquad \because I = \frac{q}{t}$$

$$\boxed{J = \frac{q}{At}} \quad (2) \qquad \because q = Ne$$

$$\boxed{J = \frac{Ne}{At}} \quad \text{—} (3)$$

$$\boxed{V_d = \frac{L}{t}}$$

N = total No. of Charge

n = number density

$$\boxed{n = \frac{N}{V}}$$

$$V = AL$$

number density = Total No Per unit Vol.

$$N = nV$$

$$\boxed{N = nAL} \text{—} (4)$$

Putting 4 in 3

$$J = \frac{nALe}{At}$$

$$J = \frac{nLe}{t} \qquad \because V = \frac{L}{t}$$

So

$$\boxed{J = V_d n e}$$

in Vector form

$$\boxed{\vec{J} = -ne\,\vec{V}_d}$$

∴ where the -ve sign shows that the Two vectors are opposite in direction.

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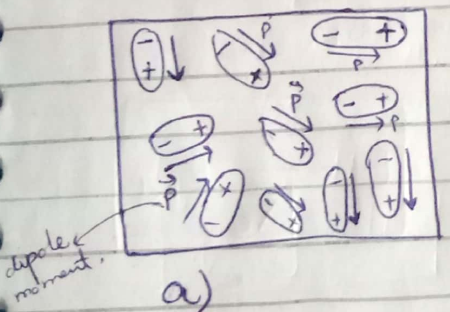
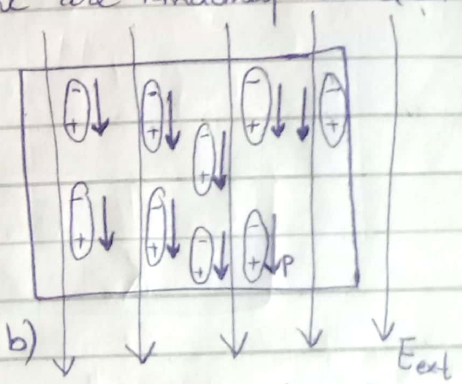
* An Insulator in an Electric field:-

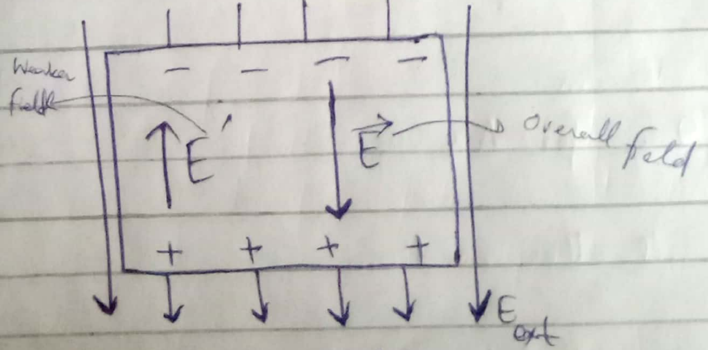
An Insulating slab

∴ In an insulating slab there are randomly oriented dipoles





P vector align itself in the direction of E_{ext}.



In case of insulator only surface charge is participating so E' is always less than E_{ext}

$$\vec{E} = \vec{E}_{ext} \pm \vec{E}'$$

$$E = E_{ext} + (-E') \Rightarrow E = E_{ext} - E'$$

In insulators,

$$E' < E_{ext}.$$

"When an insulator is placed in an electric field induced surface charges appear that tends to weaken the original field with in the material"

so

$$E' < E_{ext}$$

$$E' \propto E_{ext}.$$

$$E \propto E_{ext}$$

E is the field inside the conductor.

$$\boxed{\cancel{E = \frac{1}{K_e} E_{ext}}} \qquad \boxed{\vec{E} = \frac{1}{K_e} \vec{E}_{ext}}$$

where $\frac{1}{K_e}$ is the dielectric constant

$K_e = 1$ for vaccum

$K_e = 1.00059$ for Air

$K_e > 1$ for all other medium

$K_e \uparrow$ means field is reducing.

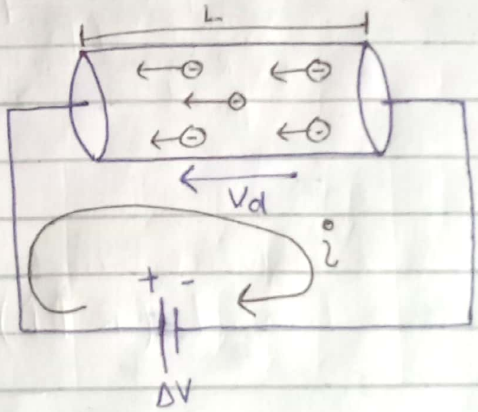
$K_e \uparrow \rightarrow$ means material is more good insulator

In Vector Expression of $E = \frac{1}{K_e} E_{ext}$

which is $\vec{E} = \frac{1}{K_e} E_{ext}$ there is no negative sign as both vectors are in same direction

Ohmic materials:-

let us consider a cylindrical conductor connected with battery provided with potential diffrence ΔV. $\longrightarrow \vec{E}, i, \vec{J}$



• Ohm's law:-

Applied field is the cause of current

$$i \propto \Delta V$$

$$i = \frac{1}{R} \Delta V$$

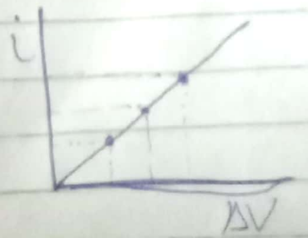
$$\boxed{\Delta V = iR} \text{ — (a)}$$

Macroscopic form of Ohm's law.

↳ Ohm's law is valid only if R - Constant

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

$$\text{Ohm} = \frac{\text{Volt}}{\text{Amp}}$$



i.e. slope is same every where.

* "$\Delta V = iR$ is valid on all type of materials weather it is ohmic or not"

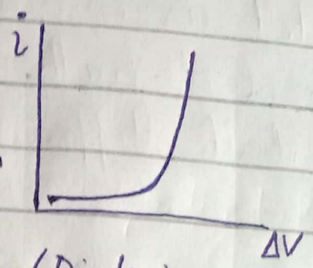
→ <u>Statment of Ohm's law:-</u>

* "Resistance is independent of applied voltage"

~~Resistance of a material~~

i.e Semiconductors are non ohmic but the eq $\Delta V = iR$ is valid (Applicable) on it

slope is not same every point so R varies at every point



(Diodes)
(Non Ohmic)

* Semiconductor diode varies its resistance. if reverse biased ($R\uparrow\uparrow$), if forward ($R\downarrow\downarrow$)

- for ohmic devices ratio of $\frac{V}{I}$ remains same

- for non ohmic devices R is dependent on ΔV
* $R = \frac{\Delta V}{I}$ as here ratio is not same but still R is dependent on ΔV.

→ Microscopic form of Ohm's law:-

$$J = neV_d$$

$$J \propto V_d$$

$$V_d \propto E$$

so $\Rightarrow$ $$j \propto E$$

$$\boxed{J = \sigma E}$$

Vector form ↳ $\boxed{\vec{J} = \sigma \vec{E}}$ — $\beta(i)$

σ = Conductivity of material

↳ it is the property of material does not changes with changing shapes etc. however Resistance varies by changing shapes.

$$\sigma = \frac{1}{\rho}$$

ρ = Resistivity

$$J = \frac{1}{\rho}\vec{E}$$

$$\boxed{\vec{E} = \rho\vec{j}}$$ — $\beta(ii)$

Equation (β) are the microscopic form of Ohm's law.

$$\rho = \frac{E}{J}$$

* Statment of microscopic form of Ohm's law:-

"Resistivity or conductivity of a material is independent of applied field"

Isotropic property:-

Graphite → layered structure.

Conductor in one direction while insulator in other.

* Unit of conductivity

$\cancel{\sigma\ F\ \frac{I}{A}}\ \sigma = J/E$

$\cancel{\boxed{\sigma = Amp/m^2}}$

$J = I/A$
$= \frac{Amp}{m^2}$

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

$$\sigma = \frac{J}{E} = \frac{Amp \cdot \cancel{m}}{m^{\cancel{2}} \cdot V}$$

$$\boxed{Seimens/meter = \frac{Amp}{V}}$$

~~Seimen~~ =

" The diffrence b/w microscopic & macroscopic form of Ohm's law is that
macroscopic ⟶ depends on Geometry. (due to R)
microscopic ⟶ does not depends.. " (due to ρ)

Unit of Resistivity :-

$$\rho = \frac{1}{\sigma}$$

$$= \frac{Volt \cdot m}{Amp} \qquad \boxed{= \Omega m}$$

* "Area ہمیشہ وہی لیا جائے گا جس end پر Battery کا Terminal لگایا گیا ہو
* اور اُن Areas کے درمیان موجود length کو لیا جائے گا۔"

⇒ Dependence of Resistance on Geometry:-

Also

(Proof of $R = \rho \frac{L}{A}$ through Ohm's law)

$$\rho = \frac{E}{J} \qquad \because E = \frac{\Delta V}{L}$$

$$\because J = \frac{i}{A}$$

$$= \frac{\Delta V / L}{i / A}$$

$$\rho = \frac{\Delta V}{i} \cdot \frac{A}{L}$$

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

$$\boxed{\rho = \frac{RA}{L}} \Longrightarrow \boxed{R = \frac{\rho L}{A}}$$

so we conclude that

$$R \propto L$$

$$R \propto \frac{1}{A}$$

$R \uparrow \;\leftarrow$ Collision $\uparrow \;\leftarrow$ Atom sites $\uparrow \;\leftarrow$ زیادہ L.

$R \downarrow \;\leftarrow$ free Spaces $\uparrow \;\leftarrow$ But $\leftarrow$ Atomic Sites $\uparrow \;\leftarrow A \uparrow$.

Area $\uparrow$, free path $\uparrow$, $R \downarrow$

Magnetism

"The study of magnetic field and magnetic interactions established due to naturally occuring ~~moth~~ magnets".

* magnetic interactions ⟶ Magnetic forces.

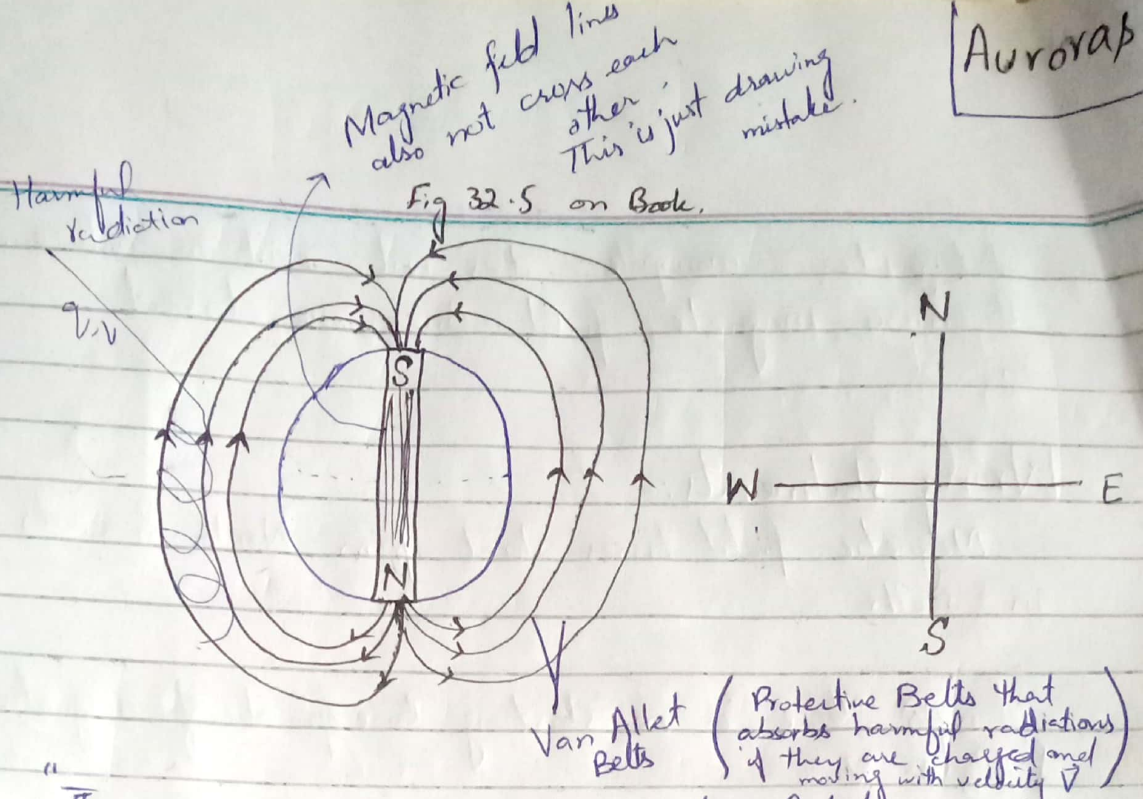
* magnetism produced due to moving charges is called electromagnetism.
* While magnetic interaction produced due to natural magnets is called magnetism

⇒ Magnetic interaction & Magnetic poles:-

"like poles repel each other while unlike poles attract each other"

• "Earth's geographical north is its magnetic south"

Auroras



* "The cause of Earth's magnetic field is its spin motion"

In electrostatics,

Static Electric Charge $\rightleftharpoons \vec{E} \rightleftharpoons$ Static Electric Charge

~~Magt.~~ Magnetic Charge $\rightleftharpoons \vec{B} \rightleftharpoons$ Magnetic Charge

As magnetic charge does not Exists in nature.

* "Here magnetic pole can also be not written as magnetic monopole does not exist in nature"

* No source and sink exists in magnetic field.

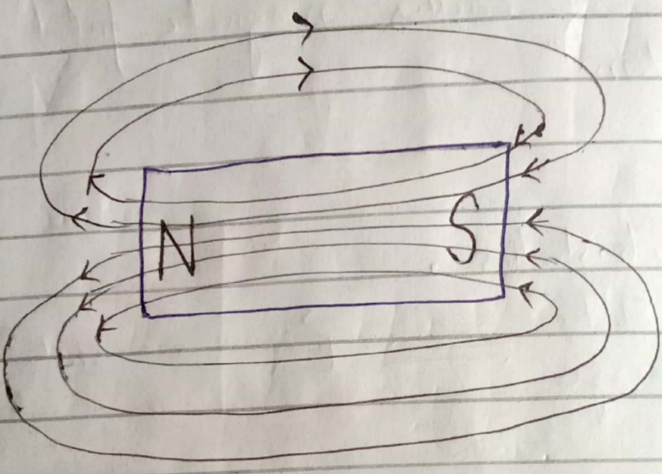
* Effect of Earth's magnetic field is strong at poles as compared to equator.

Magnetic monopole does not exist in nature.
Because magnetic field lines are closed in it

Wrong Statments:-

Magnetic field lines start from North & ends in south

As there is no starting line/point of magnetic fields



Correct Statment

Moving Electric Charge $\rightleftharpoons \vec{B} \rightleftharpoons$ Moving Electric Charge

$\vec{B} \to q, \vec{V}$ $\qquad$ $\vec{F}_B \to q, \vec{V}$

World's smallest Magnet:-

A moving electron.

We cannot associate a magnetic P.E with a moving electric charge in a magnetic field.

$\Delta U = -W$

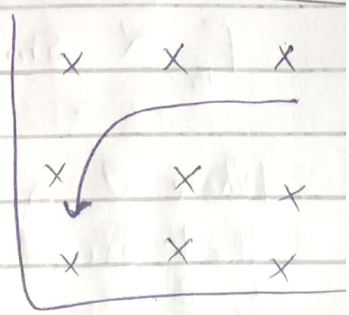
$= -\vec{F}_B \cdot \vec{S}$ from figure

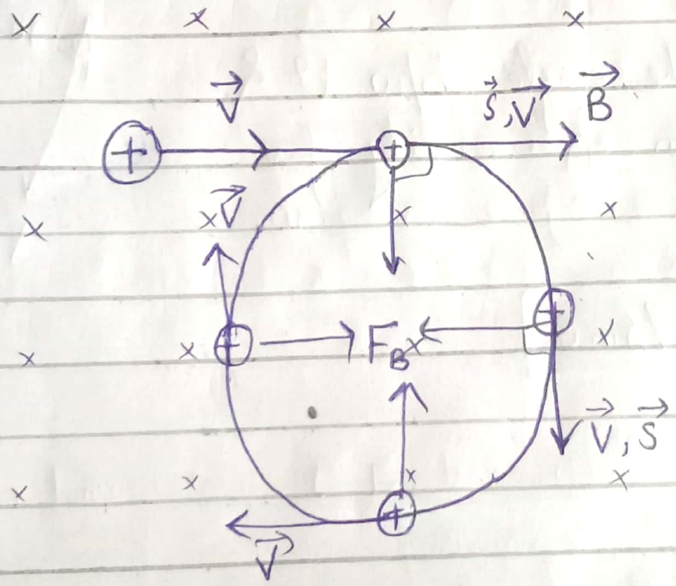
$= -F_B S \cos\theta = \cos 90 = 0$

"Any force which is velocity dependent is always non conservative force"

* As Magnetic force is velocity dependent force so it is non conservative force

"Magnetic force is a side ways deflected force"
~~always acts at the angle of 90°~~





No work done by the magnetic field as the angle b/w them is 90°.

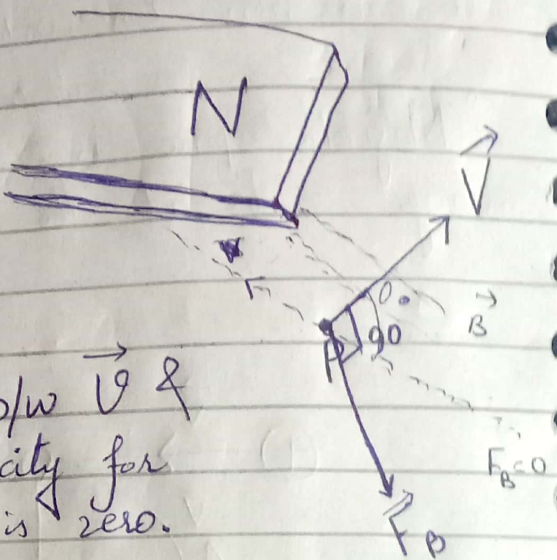
from $\Delta U = -W$

As Work is zero then their is no P.E.

⇒ Applications
1) Protective (Van Allen Belts)
2) Auroras.
↳(

$F_B \propto q$
$F_B \propto V$
$\vec{F_B} \perp \vec{V}$

$F_B \propto \sin\theta$
$F_B \propto qV\sin\theta$



Where θ is the angle b/w $\vec{V}$ & that orientation of velocity for which magnetic force is zero.

$$\boxed{F_B = qV\sin\theta}$$

At point P "$\vec{B}$" is constant so we cannot write here $\boxed{F = qVB\sin\theta}$
But if point varies then $\boxed{F = qVB\sin\theta}$

In vector form:-
$$\boxed{\vec{F_B} = q(\vec{V} \times \vec{B})}$$

★ For Max. Force

$\boxed{F = qvB}$ As $\theta = 90$

$$\boxed{B = \frac{F_{B\,max}}{qV}}$$

Units $= \frac{N}{\frac{C}{s} m} = \frac{N}{Amp \cdot m} =$ Tesla

$\boxed{1 \text{ Tesla} = 10^4 \text{ Gauss}}$

For Cross Product "Use this R Hand Rule

Finger towards V
Palm towards B
thumb $\longrightarrow$ gives you F_B

i.e Only Right hand finger towards first vector and palm towards second vector then thumb will point F_B

"V & F are always perpendicular
F & B are also always perpendicular"

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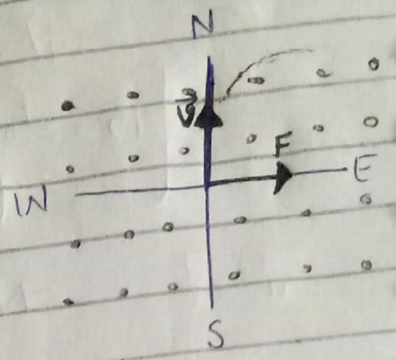
Sample Problem 32.1

$B = 1.2\,mT$

$K.E = 5.3\,MeV$

$F = ?$



$E = \frac{1}{2} m v^2$

$v^2 = \frac{2E}{m}$ $\quad V = \sqrt{\frac{2K.E}{m}}$ $\quad = \cancel{7.96 \times 10^{16}}$

$= 31867991$

$= 3.1 \times 10^{6}$

$\cancel{= 31\,M}$

$$\boxed{F = q\left(\sqrt{\frac{2K.E}{m}} \times B\right)}$$

$\theta = 90$

$$F = q\sqrt{\frac{2K.E}{m}}\, B \sin\theta$$

$$F = q\sqrt{\frac{2K.E}{m}}\, B$$

$$= 1.6 \times 10^{-19} \times 3.1 \times 10^{7} \times 1.2 \times 10^{-3}$$

* for a negative charge:-

$$\vec{F}_B = q(\vec{V} \times \vec{B})$$

for -ve charge $q = -e$

$\cancel{\vec{F}_B = q}$ $\boxed{\vec{F}_B = -e(\vec{V}_d \times \vec{B})}$ — (1)

* Magnetic force is velocity dependent, there is no magnetic force on static charge.

As cross product is Anti commute property
i.e

$$\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$$

equation 1 can also be written as

$$\boxed{F_B = e\,(B \times V)}$$

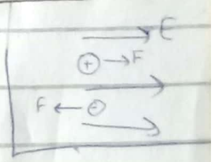
* "For -ve charge i.e electron the direction of force is reversed"

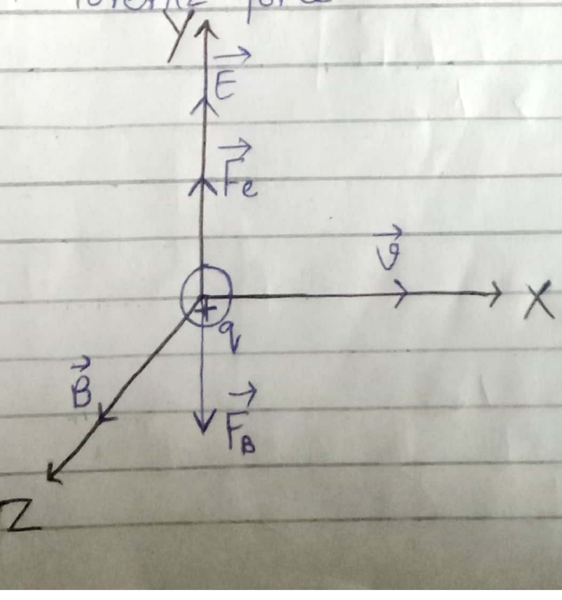
"There will be no force on particle that is parallel & antiparallel to field as angle b/w ~~the~~ V & B is ($\sin\theta$) is 0° & 180° respectively".

* "Sign of Charge must be noted in this topic"

→ Combined Electric & Magnetic fields:-

↳ lorentz force





$$\vec{F} = \vec{F_e} + \vec{F_B}$$

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

In scaler form

$$F = qE - qvB \sin 90^\circ$$

it means that two vectors are in opposite direction

if lorentz force is zero then

$$0 = \cancel{q}E - \cancel{q}vB$$

$$E = vB$$

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

Velocity Selector

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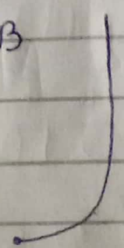
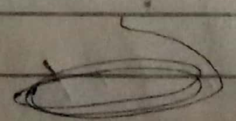
* "Electric force is translatory force while magnetic force is rotatory"

* $F_e > F_B$



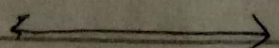
straight up

* $F_B > F_e$



spiral motion downwards

* $F_B = F_e$



moves straight undeflected.

⇒ The Magnetic force on a current carrying wire:

$$\boxed{\vec{F}_B = q(\vec{V} \times \vec{B})} \text{ — } ①$$

↳ magnetic force on a single charge

Let us consider electron to be the charge carrier.

$$\boxed{F_B = -e(\vec{V}_d \times \vec{B})} \text{ — } ②$$

N = total number of e^-

$$\boxed{F_B = -Ne(\vec{V}_d \times \vec{B})} \text{ — } ②$$

$$\therefore n = \frac{N}{V} = \frac{N}{AL}$$

$$\boxed{N = nAL} \text{ — } ③$$

Put 3 in 2

$$F_B = -(nAL)e(\vec{V}_d \times \vec{B})$$

$$F_B = -nALe(\vec{V}_d \times \vec{B})$$

$$\boxed{F_B = i\,\vec{L} \times \vec{B}}$$

$j = -neV_d$

As $J = \frac{i}{A}$

$$\boxed{i = JA}$$

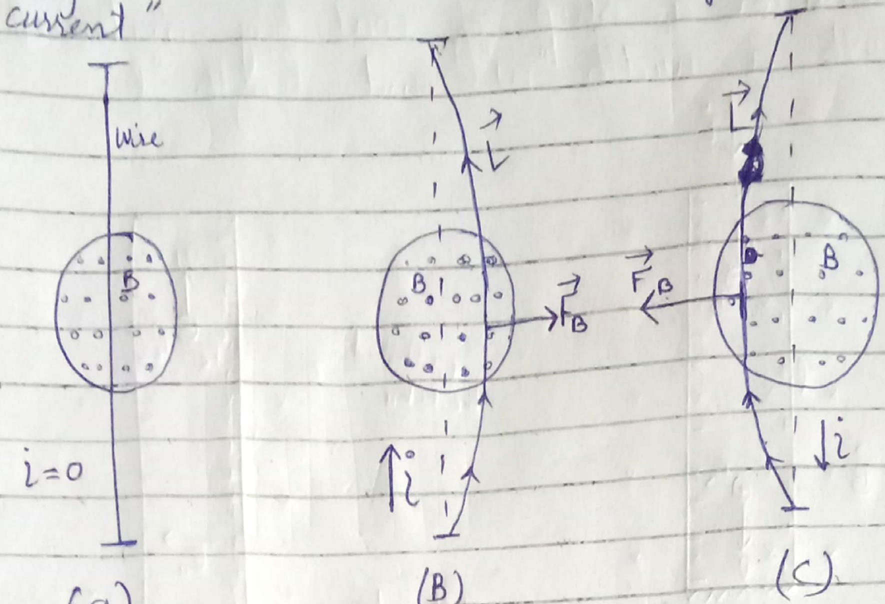
$$\boxed{i = -neV_d A}$$

Current is not a vector and cannot be a vector

so length becomes the new vector.

→ "Where Length Vector $\vec{L}$ is a mathematical tool and it satisfies the laws of Vector"

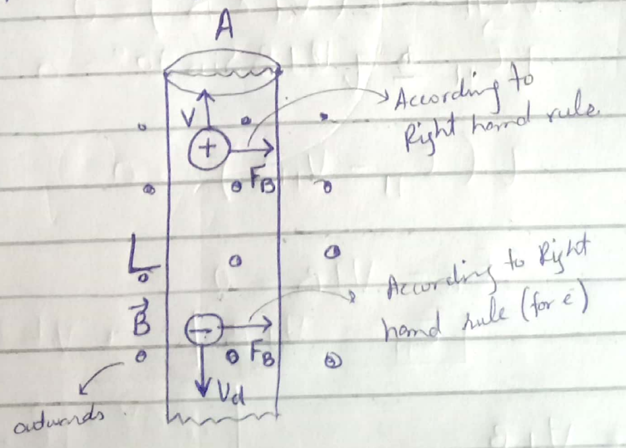
Its magnitude is equal to magnitude of length & its direction is along conventional current"



(a) (B) (C)

* $F = q(\vec{V} \times \vec{B})$ and $F = I(\vec{L} \times \vec{B})$ Both follows 1st Right hand rule.

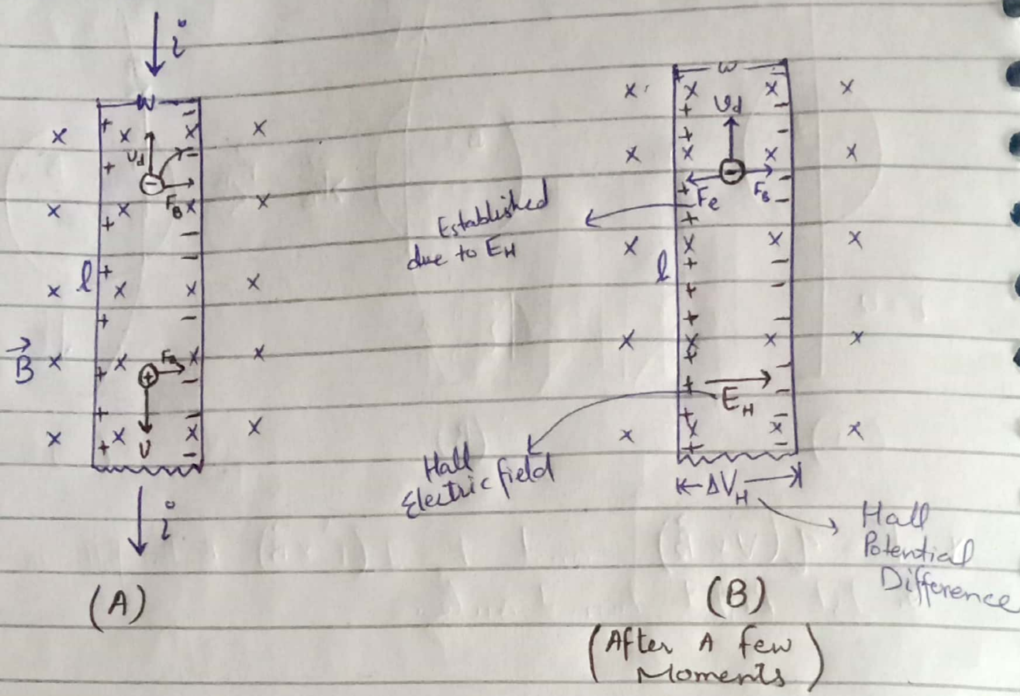
• Macroscopic view of diagram B



i e force acts on same direction (on Both type of charges (+ & -ve) in the wire)

⇒ The Hall Effect :-

- Consider a strip of conducting material with a width "w" and length "l"



$$q\vec{E}_H + q(\vec{V}_d \times \vec{B}) = 0$$

$$q\vec{E}_H - qV_d B \sin 90° = 0$$

$$q(E_H - V_d B) = 0$$

$$E_H - V_d B = 0$$

$$\boxed{E_H = V_d B} \rightarrow \text{Velocity Selector}$$

$$E_H = V_d B$$

$$\frac{\Delta V_H}{W} = \frac{J}{ne} B$$

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

$\Delta V = Er$

$\therefore \Delta V_H = E_H W$

$\boxed{E_H = \frac{\Delta V_H}{W}}$

$\therefore J = neV_d$

$$\frac{\Delta V_H}{w} = \frac{I}{neA} \times B \qquad A = wt$$

$$\Delta V_H = \frac{IB\cancel{w}}{ne\cancel{w}l}$$

$$\boxed{n = \frac{IB}{\Delta V_H e l}}$$

* Significance of Hall Effect:-

1) The hall effect provides a way to determine the density of the charge carriers.

$$\boxed{n = \frac{IB}{\Delta V_H e l}}$$

Table 32.2

* $n \uparrow$ means good conductor

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