Lecture 09, Applied Physics

Today's Agenda
→ Lorentz's Force
→ Ampere's Law and its application.

⇒ Lorentz Force :

$\vec{F_B} = q(\vec{v} \times \vec{B})$ ∵ changes direction

∵ perpendicular to plane at all points.

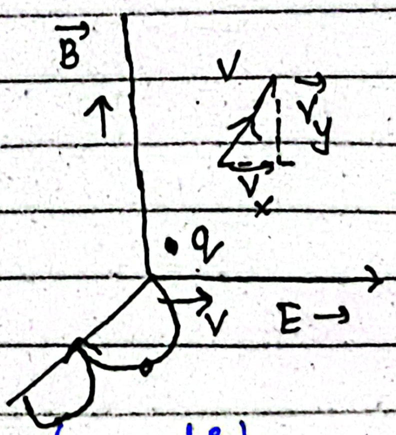
$\vec{F_e} = q\vec{E}$

∵ accelerates

Lorentz force is the vector sum of electric and magnetic field.

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

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



⇒ Initially, charged particle at rest
- → Magnetic force is zero
- → Electric force accelerates the charged particle.
- → As soon as the velocity becomes non-zero, magnetic force will ~~be~~ act in $\vec{v} \times \vec{B}$ direction and it should start revolving in a circle.
- → As now, the motion is opposite to electric field, the electric field will decelerate and it will ~~become~~ be back to rest.

⇒ Cycloid Trajectory

⇒ If Initially charged particle is moving with velocity v, (dir dependent on direction of $\vec{v}$)
⇒ Helical Trajectory
→ $\vec{v}_y$ is parallel to $\vec{B}$, therefore has no effect on magnetic field.

⇒ Velocity Selector:
If we project a charged particle in perpendicular electric and magnetic fields such that net force is zero
∵ Two forces → electric component & magnetic component

$$F_L = 0$$
$$q(E + \vec{v} \times \vec{B}) = 0 \qquad \because \theta = 90^\circ$$
$$q(E + \vec{v}\vec{B}) = 0$$

Either $q = 0$
or $E + vB = 0$
But $q \neq 0$ as we have projected a known charge.
Therefore, $E + vB = 0$

$$E = -vB$$
$$|v| = \frac{|E|}{|B|}$$

∵ If we project a charge particle with this ratio, the charge should pass undeviated.

$F_B = qvB$ $\quad$ $F_e = qE$

$B = \frac{F_B}{qv}$ $\quad$ $E = \frac{F_e}{q}$

$B = Nm^{-1}s$ $\quad$ $E = NC^{-1}$

$$\left\{ \begin{array}{l} |V| = \frac{NC^{-1}}{Nm^{-1}s} \\ ms^{-1} = ms^{-1} \end{array} \right\}$$

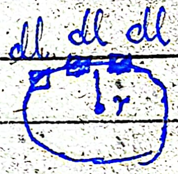
⇒ Ampere's Law : ∵ Counterpart of Gauss's Law

Magnetic field flux for enclosed by a closed loop is μ_0 times the current enclosed by the loop

∵ Amperian loop is always a ring.

⇒ Mathematically,

$$\oint B \cdot dl = \mu_0 \, i_{enc}$$



$\Sigma dl = 2\pi r$
circumference

∵ Electric Flux : $\oint E \cdot dA = \frac{q_{enc}}{\varepsilon_0}$

→ Electric field is a 3-D phenomenon, is observed from 2-D

→ Magnetic field is a 2-D phenomenon, is observed from 1-D

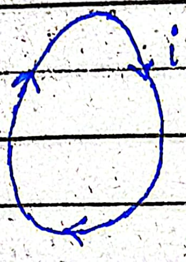
→ Right Hand Rule for wire and loop :

Current carrying wire :

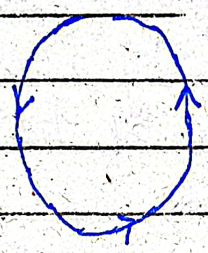
a) Thumb: Direction of current

b) curl of Fingers : Direction of magnetic field

- Current carrying loop:
  a) Thumb: Direction of magnetic field
  b) curl of the fingers: Direction of current.



$\because$ direction of magnetic field is into the page.

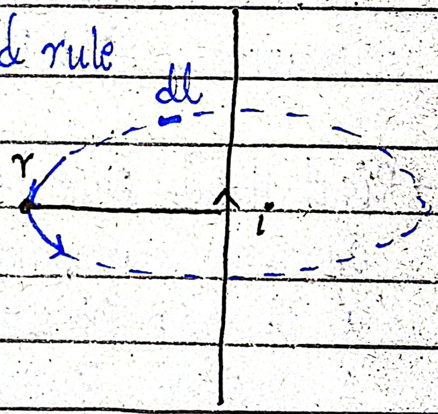


$\because$ direction of magnetic field is out of the page.

⇒ Example:

Calculate direction and magnitude of magnetic field due to a current carrying wire 'i' at a distance 'r'. Assume the current density (current per unit length) is uniform.

Direction of magnetic field by right-hand rule is counter-clockwise.



⇒ Now, we take an amperian loop.

$i_{enc} = i$ $\because$ as current density is uniform.

$\oint B \cdot dl = \mu_0 i_{enc}$

$\because \phi = 0 \rightarrow$ angle b/w B and dl as both are parallel (circl

$\oint B dl = \mu_0 i_{enc}$

$B \oint dl = \mu_0 i_{enc}$

$\because \oint dl = 2\pi r$

$\vec{B}(2\pi r) = \mu_0 i$

$\vec{B} = \frac{\mu_0 i}{2\pi r} \hat{\phi}$ $\quad$ $\because$ circular direction

$\Rightarrow$ Magnetic field due to a current-carrying wire at a distance r in the direction $\hat{\phi}$.

$\because \phi \rightarrow$ rotates $360°$

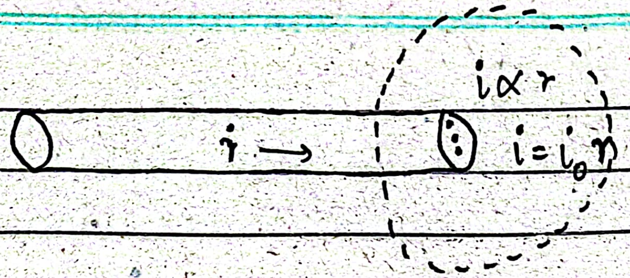
$\theta \rightarrow$ rotates $180°$.

- $\vec{B}$ decreases with distance.

As we move from a farther distance towards the wire, $\vec{B}$ keeps on increasing. At the wire itself, mathematically $\vec{B}$ becomes infinite, but physically...

$\because g = \frac{GM}{R}$

But $g = 0$ at centre.



→ Outside the wire:

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

→ Inside the wire: → a certain fraction of total i is enclosed

9/04/2025 Applied Physics

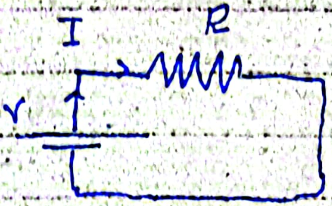
Today's Agenda
1- Ohm's Law
2- Drift Velocity
3- Microscopic Form of ohm's Law
4-

⇒ ohm's Law:
∵ I is directly proportional to V applied.
Current produced in a "system" (conductor) is directly proportional to the voltage applied.

$V \propto I$ ∵ V → independent coordinate.

$V = RI$ — (I)

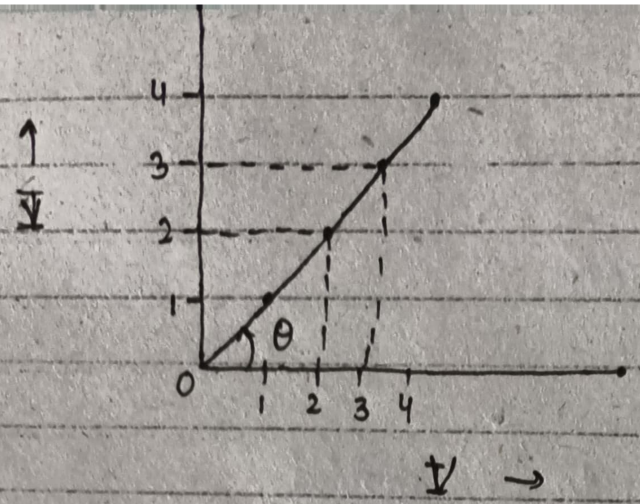
∵ R is the proportionality constant.



(I) ⇒ straight line relation/equation.
∵ Voltage vs Current graph is known as I-V

All devices (conductors) that obey ohm's law are called ohmic devices.

Voltage (mV)	Current (mA)
0	0
1	1
2	2
3	3
4	4



∵ Independent coordinate is always on the horizontal axis.

$$\text{Slope} = \frac{\Delta I}{\Delta V}$$

or slope $= \tan\theta$ ∵ θ = inclination.

$y = mx + c$

c : vertical intercept.

m : slope

y : dependent coordinate (I)

x : independent coordinate (V)

$y = I$ & $x = V$ & $m = \frac{1}{R}$

$$I = \left(\frac{1}{R}\right)(V)$$

Slope : $m = \frac{I_{(3)} - I_{(2)}}{V_{(3)} - V_{(2)}}$

$= \frac{(3-2)\ mA}{(3-2)\ mV}$

$= 1\ \frac{A}{V} \Rightarrow \frac{1}{R}$

∵ Reciprocal of resistance is conductance.

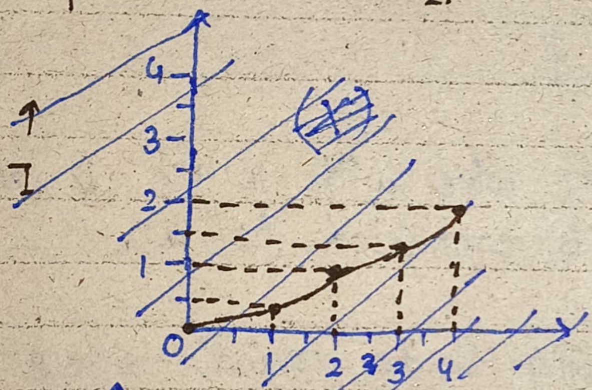
The unit of resistance is ohm (Ω)

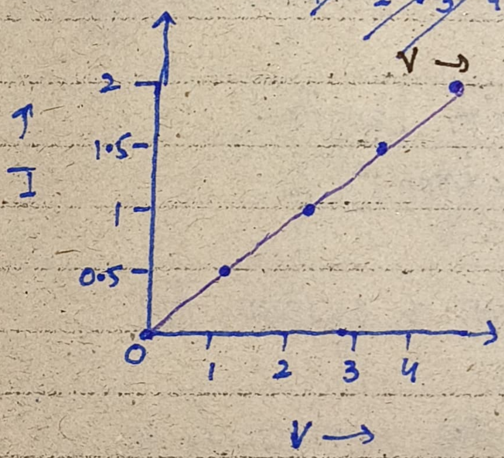
$$1\ \Omega = \frac{1V}{1A}.$$

$1m = 10^{-3}$
$1\mu = 10^{-6}$

V (mV)	I (μA)	I (mA)
0	0	0
1	0.5	0.0005
2	1	0.001
3	1.5	0.0015
4	2.	0.002

0×10^{-6}
0.5×10^{-6}
$\cancel{500} \times 10^{-3}$





$$m = \frac{I_{(3)} - I_{(2)}}{V_{(3)} - V_{(2)}}$$

$$m = \frac{(1.5 \times 10^{-6} - 1 \times 10^{-6})\ A}{(3 \times 10^{-3} - 2 \times 10^{-3})\ V}$$

$$m = \frac{0.5 \times 10^{-6}}{1 \times 10^{-3}}$$

$$m = 0.5 \times 10^{-3}$$

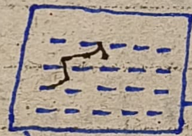
$$\frac{1}{R} = \frac{1}{2} \times 10^{-3} \ \frac{A}{V}$$

$$R = 2 \times 10^{3} \ VA^{-1}$$

$$R = 2 \times 10^{3} \ \Omega$$

⇒ Drift Velocity :

→ Free ~~ca~~rriers (electrons)

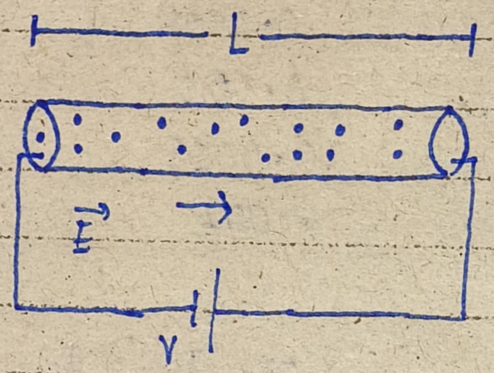


→ Lattice

∵ Cu : 10^{28} electrons/m^3

∵ velocity with which the $\bar{e}$ moves is called thermal velocity $\sim 10^{6}$ m/s

∵ Alot of collisions so net gain of velocity in random motion is zero.



Consider a cross-section of conducting wire with length L and cross-sectional area A. The wire is connected to a battery of voltage V.

∵ The electric field corresponding to the applied voltage is : $\vec{E} = \frac{V}{L}$ ∵ L : Cross-section Length

∵ The electric force on the charge (electrons) is $\vec{F} = e\vec{E}$

∵ When uneven forces are applied on a system, the system accelerates.

The electron gain a net velocity from -ive terminal to +ive terminal. Thermal velocity is cancelled out due to random motion. This net velocity gained is called drift velocity.

$$\vec{F} = ma \qquad ∵ \vec{F} = e\vec{E}$$

$$m\frac{dv}{dt} = e\vec{E} \qquad ∵ a = \frac{dv}{dt}$$

$$\frac{dv}{dt} = \frac{e\vec{E}}{m}$$

$$dv = \frac{e\vec{E}}{m}\, dt$$

Taking integration on b/s

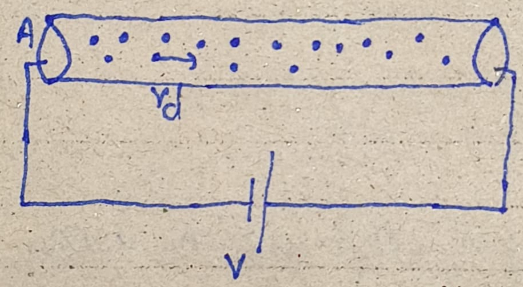
$$\int_0^{v_d} dv = \int_0^{\tau} \frac{eE}{m}\, dt$$ ∵ τ : mean free time
Time b/w successive collisions

$$v \Big|_0^{v_d} = \frac{eE}{m}\, t \Big|_0^{\tau}$$

$$v_d = \frac{eE}{m}\tau$$

∵ e, m and τ are fixed. Therefore, the electric field defines the drift velocity.

Drift velocity is apparently of the of 10^{-5} m/s



⇒ The charges are moving with v_d velocity. The time taken to move length L is dt. If dq amount of charge move through the wire in dt then current is?

$$I = \frac{dq}{dt} \quad \text{— (I)}$$ ∵ Battery is not a source of charge.

$s = vt$

$L = v_d\, dt$

$$dt = \frac{L}{v_d} \quad \text{— (II)}$$ ∵ dt : time taken for charge to move from one end to the other.

The amount of charge dq flowing

$$dq = Ne \quad — (III)$$

Number density = charges / volume

$$n = \text{number density}$$

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

$$N = nV$$

$$V = AL$$

$$N = nAL \quad — (IV)$$

Put value of (IV) in (III)

$$dq = nALe \quad — (V)$$

Put value of (V) and (II) in (I)

$$I = \frac{neAL}{L} v_d$$

$$I = neAv_d$$

∵ I : current flowing

∵ Current density : current per cross-section area.

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

$$J = \text{Current density} = nev_d$$

Put value of $v_d = \frac{eE}{m}\tau$ in J

$$\bar{J} = \frac{ne^2E}{m}\tau$$

$$\bar{J} = \left(\frac{ne^2\tau}{m}\right)\bar{E}$$

∵ $\frac{ne^2\tau}{m}$: conductivity $= \sigma$

Reciprocal of resistivity

∵ Material specific, constant parameter.

$$J = \sigma \vec{E} \quad — \text{VII}$$

$\because \frac{1}{\sigma}$ = Resistivity ~~of~~ ρ

VII is the microscopic form of ohm's Law

$\because$ Cu : $\tau \sim 10^{-14}$ sec

$\because$ Cu : $n \sim 10^{28}$ electron/m^3

Conductivity $= \sigma = \frac{ne^2 \tau}{m}$

$= (10^{28})$

Units of σ :

$$\sigma = \frac{ne^2 \tau}{m}$$

$$= \frac{N}{m^3} \cdot \frac{c^2}{kg} \cdot \frac{1}{sec}$$

$\because$ N = number

$\because$ Conductivity of Cu and Al :

Exp :

Derive ohm law from $J = \sigma E$

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

$$\frac{I}{A} = \sigma E \Rightarrow I = A\sigma E$$

$$I = A\sigma \frac{V}{L}$$

$$I = \left(\frac{A\sigma}{L}\right)(V)$$

$$I = \left(\frac{A}{L\rho}\right)(V)$$

$$I = \frac{1}{R}(V) \qquad \because \frac{\rho L}{A} = R$$

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

1) Is R dependent on L & A ?
2) What is the difference between resistance and resistivity ?

Applied Physics 16/04/2025

Lecture No. 12 :

Today's Agenda

→ Semi-conductor Physics
→
→ Energy Band Theory

} Serway Jewett

Energy Band Theory divides materials into:
1- Conductors
2- Insulators
3- Semi-conductor

Valence Band
Conductor Band

} Not physical bands.

1 Semi-conductor Physics :-
2 → Energy Levels
→ Hole Concept
→ PN Junction.

Lattice
↳ Periodic arrangement of atoms in a crystal

Boltzmann Constant

$K_B T$ = Thermal energy

$T = 300^\circ K$

$K_B T = 0.025$ eV.

Lecture # 13

→ P.N Junction diode.
→ Forward and Reverse Bias. } floyd
→ Voltage and current divider.
→ Kirchhoff's Law.

⇒ Kirchoff's Law:

There are two laws:-

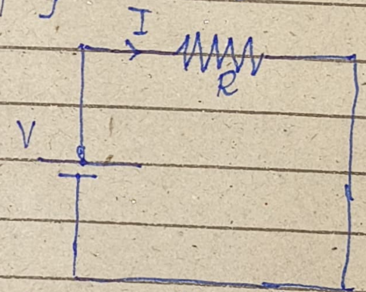
1- Sum of voltage in a closed circuit is zero.
2- Incoming currents is equal to outgoing currents at a Junction.

∴ Junction (where two or more lines meet)

Ohmic Devices

→ Resistor circuits → Always apply ohm's law.

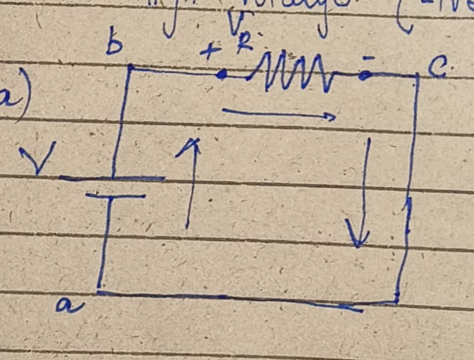
$V = IR$ —— (I)



∴ Resistor has no positive or negative terminal.

∴ Low to high voltage (-ive to +ive) is considered positive.

(a)



V: Applied Voltage.

V_R: Voltage Across Resistor.

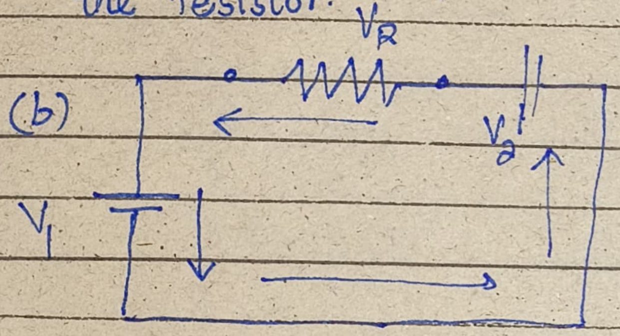
$V + (-V_R) = 0$

$V - V_R = 0$

$V = V_R$

∴ The applied voltage of battery is entirely passed through the resistor.

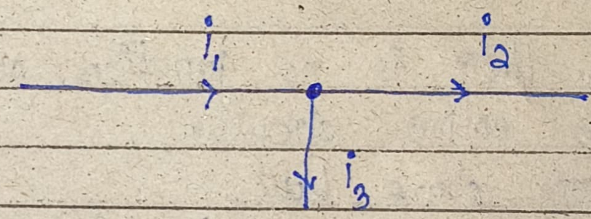
(b)

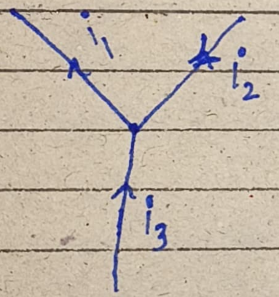


$$-V_1 + V_2 - V_R = 0$$

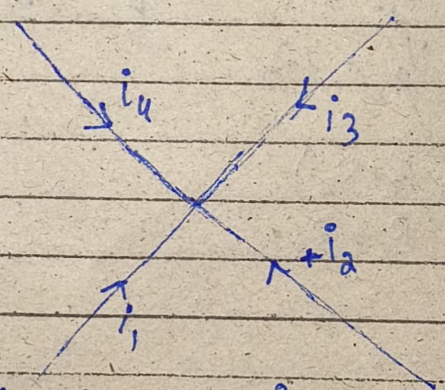
By Kirchoff's Junction Rule:

$$i_1 = i_2 + i_3$$

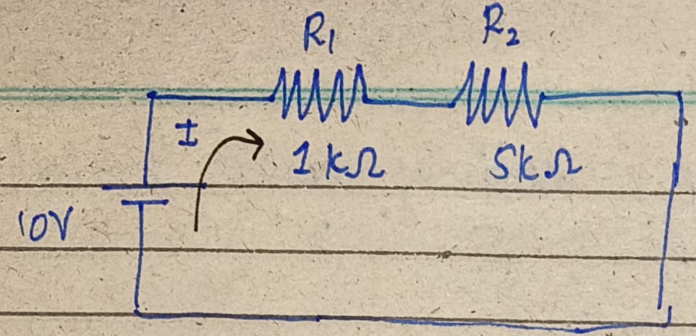




$$\{ i_3 + i_2 = i_1 \}$$



$$i_1 + i_2 + i_3 + i_4 = 0$$



→ Find total current
→ Find V_{R_1} + & V_{R_2}

Apply kirchoff's first law

$$V + (-V_{R_1}) + (-V_{R_2}) = 0$$
$$V - V_{R_1} - V_{R_2} = 0$$
$$V = V_{R_1} + V_{R_2}$$

∵ As there is no junction, current I moves through the entire circuit.

From ohm's law,

$$\left.\begin{aligned} V_{R_1} &= IR_1 \\ V_{R_2} &= IR_2 \end{aligned}\right\} \quad \text{II}$$

$$V = I(R_1 + R_2)$$
$$\frac{V}{I} = R_1 + R_2$$

$R_{eq} = R_1 + R_2$ $\qquad$ R_{eq} : Total Resistance.

In series circuit total resistance is sum of individual resistances.

$$R_{eq} = \sum_{i=1}^{n} R_i$$

Current in a series circuit is same across all its components
∵ voltage is divided.

$R_{eq} = 1k\Omega + 5k\Omega$

$R_{eq} = 6\,k\Omega$

$R_{eq} = 6 \times 10^3\,\Omega$

$\frac{V}{I} = R_{eq}$ ---- III

$\frac{10\,V}{I} = 6 \times 10^3\,\Omega$

$10V = I\,(6 \times 10^3\,\Omega)$

$\frac{10\,V}{6 \times 10^{+3}\,\Omega} = I$

$I = \frac{10}{6} \times 10^{-3}\,A$

$I = 1.67\,mA$

Put value of I in II

$V_{R_1} = IR_1$

$= (1.67 \times 10^{-3})(1 \times 10^{+3})$

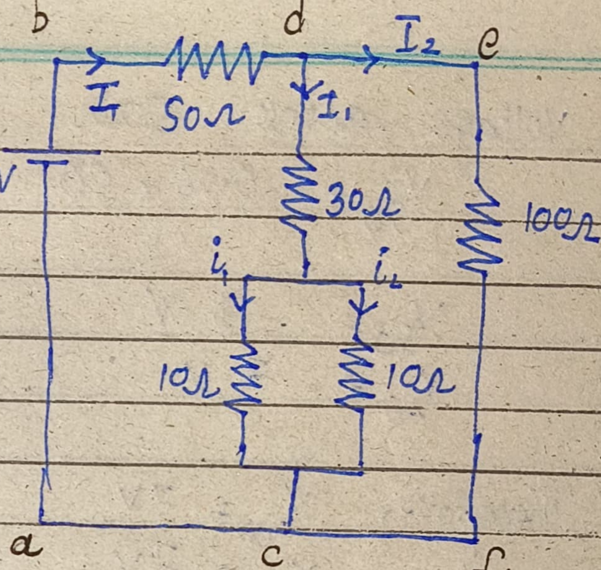
$V_{R1} = 1.67\ V$

As we kno

(i) Find voltage across all resistances

(ii) Find total current

(iii) Find equivalent resistance



$$\frac{1}{R_{eq_1}} = \frac{1}{10} + \frac{1}{10}$$

$$R_{eq_1} = 5\ \Omega$$

$$R_{eq_2} = 5 + 30 = 35\ \Omega$$

$$\frac{1}{R_{eq_3}} = \frac{1}{35} + \frac{1}{100}$$

$$= \frac{100+35}{3500} = \frac{135}{350}$$

$$R_{eq_3} = \frac{3500}{135} = 26\ \Omega$$

$$R_{eq} = 50 + \cancel{38}\ 26 = \cancel{52.6} \text{ or } 76\ \Omega$$

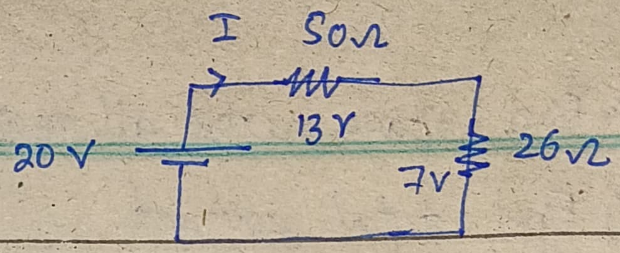
By ohm's Law,

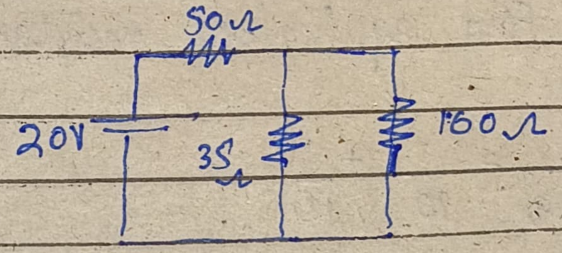
$$V = IR_{eq}$$

$$20 = I\,\cancel{(52.6)}(76)$$

$$I = \frac{20\ V}{\cancel{52.6\ \Omega}\ (76\ \Omega)}$$

$$\cancel{I = 0.3\ A} \quad I = 0.26\ A.$$





Voltage across 50Ω

$V_{50} = 0.26 \times 50$

$V_{50} = 13\ V$

$V_{26} = 7\ V$

Therefore, $V_{35} = 7V$

$V_{100} = 7V$

$I_1 = \frac{V_{35}}{R_{35}} = \frac{7V}{35\Omega} = \frac{1}{5}\ A = 0.2\ A.$

$I_2 = \cancel{*}\ I - I_1 = 0.26 - 0.2 = 0.06\ A.$

For cd branch :

$V = 7V$

$I_1 = 0.2A$

$i_1 = \frac{1}{10} = 0.1\ \Omega$

$i_2 = 0.1\ A$

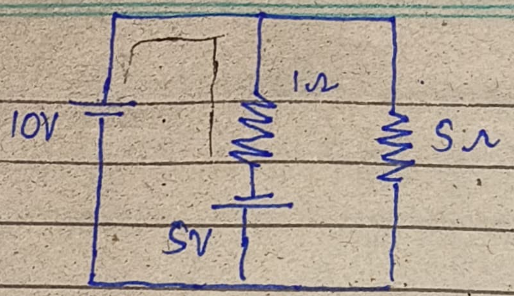
$V = IR$

$= 0.2 \times 30 = \frac{1}{5} \times 30$

$V = 6\ V$

$V_{cd} = 1V$

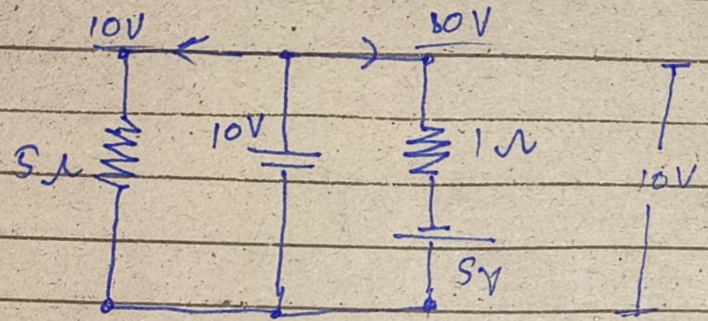
∴ Norton Theorem



By applying Kirchoff's Law

$$(10V) + (-V_1) + 5V = 0$$

$$V_1 = 15V$$



$$V = IR$$
$$10 = I_1(5)$$
$$2A = I_1$$

$$V = I_2 R_1$$
$$10 = I_2(1\Omega)$$
$$10\,A = I_2$$