CURRENT ELECTRICITY

PHYSICS WALLAH

01 ELECTRIC CURRENT

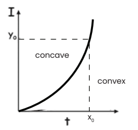
Current $I = \frac{q}{t}$

Average current $I_{av} = \frac{\Delta q}{\Delta t}$

Instantaneous current $I_{inst} = \frac{dq}{dt}$

Average current I_{av}

$= \frac{\text{area under I-t graph}}{\text{total time taken}}$

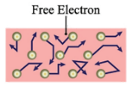


Concave area $= \frac{2}{3} x_0 y_0$

Convex area $= \frac{1}{3} x_0 y_0$

02 DRIFT VELOCITY

Free Electron



$\langle KE \rangle = \frac{3}{2} kT$

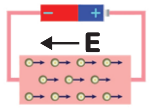
$\langle \frac{1}{2} mv^2 \rangle \approx 10^{-21} J$

Avg. Speed = 105 m/s

Electrons are in random motion

Avg. velocity $= \frac{\vec{v}_1 + \vec{v}_2 + \vec{v}_3 + \dots \vec{v}_n}{n} = 0$

$I_{net} = 0$



E accelerates the electrons

$\vec{v} = \vec{u} + \vec{a}t$

$v_d = a\tau$

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

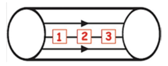
$E = \frac{V}{l}$

$v_d = \frac{eV}{ml}\tau$

03 FACTORS AFFECTING DRIFT VELOCITY

- Dependence on shape

1) Uniform shape

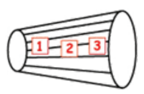


$v_d = \frac{eE}{m}\tau$

Here E is uniform so,

$v_{d1} = v_{d2} = v_{d3}$ $E_1 = E_2 = E_3$

2) Non Uniform shape



$E_1 > E_2 > E_3$

$V_d \propto E$ $V_{d1} > V_{d2} > V_{d3}$

3) Relation B/w Current & Drift velocity

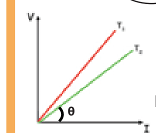
$I = nAV_d e$

n = no. of e's per unit volume

04 OHM'S LAW

$V = I \times R$

Voltage volts (V); Current Amperes (A); Resistance ohms(Ω)



$T_1 > T_2$ **Slope = tanθ = R**

$R = \frac{\rho l}{A}$ ← **Depends on**
1. Material (n & τ changes)
2. Temperature (n & τ changes)
3. Dimension (Length & Area)

$\rho = \frac{RA}{l} = \frac{m}{ne^2\tau}$ ← **Depends on**
1. Material (n & τ changes)
2. Temperature (n & τ changes)

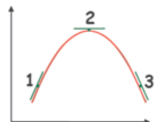
Non-Ohmic Conductor

V-I graph is not linear

Slope of tangent $\frac{dv}{dI} = R$

Resistance is not constant

1) Slope = +ve
Resistance = +ve
V ↑ then I ↑

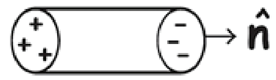


2) Slope = 0
Resistance = 0

3) Slope = -ve
Resistance = -ve
V ↑ then I ↓

05 CURRENT DENSITY

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

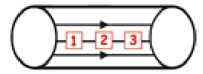


$I = \frac{V}{R} = \frac{V}{\rho l/A}$ $\frac{EA}{\rho}$ $J = \frac{E}{\rho}$, $J \propto E$

Uniform cross section

$E_1 = E_2 = E_3$

$\therefore J_1 = J_2 = J_3$



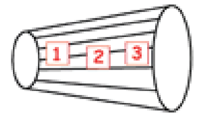
Non-Uniform cross-section

$E_1 > E_2 > E_3$ $J \propto \frac{1}{A}$

$\therefore J_1 > J_2 > J_3$

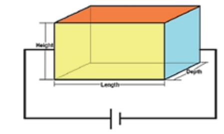
But current is same

$I_1 = I_2 = I_3$

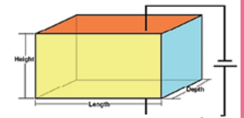


06 DEPENDANCE OF R ON DIMENSION

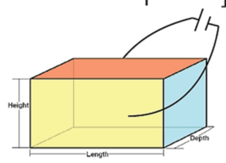
$R = \frac{\rho l}{A} = \frac{\rho l}{bh}$



$R = \frac{\rho h}{lb}$



$R = \frac{\rho b}{lh}$

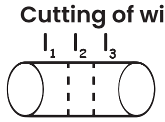


$\frac{R_{max}}{R_{min}} = \frac{(\text{max length})^2}{(\text{min length})^2}$

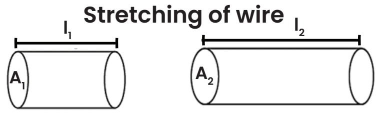
07 CUTTING & STRETCHING OF WIRE

$R_1 \propto l_1$
$R_2 \propto l_2$
$R_3 \propto l_3$

Cutting of wire



Stretching of wire



Before stretching After stretching

$\frac{R_1}{R_2} = \left(\frac{l_1}{l_2}\right)^2 = \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{r_2}{r_1}\right)^4 = \left(\frac{d_2}{d_1}\right)^4$

If l become nl then R become n² R

If r become r/n then R become n⁴ R

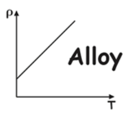
If change in length>10% $\frac{R_2 - R_1}{R_1} \times 100 = \frac{l_2^2 - l_1^2}{l_1^2} \times 100$

If change in length <10%

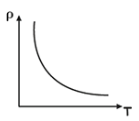
1) % change in R = 2×% change in length
2) % change in R = 2×% change in area
3) % change in R = 4×% change in radius

08 TEMPERATURE DEPENDANCE OF RESISTANCE

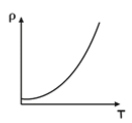
Metals, α = +Ve
If T↑ R↑



For semiconductor α = -ve
If T↑, R↓



α = slightly increasing with temp.
Resistance slightly increases with T



Variation of resistance with temperature $\alpha = \frac{\Delta R}{R \Delta T}$

Equivalent temp. Coefficient

SERIES:

$\alpha_s = \frac{\alpha_1 R_1 + \alpha_2 R_2}{R_1 + R_2}$

if $R_1 = R_2$ $\alpha = \frac{\alpha_1 + \alpha_2}{2}$

PARALLEL:

$\alpha_p = \frac{\frac{\alpha_1}{R_1} + \frac{\alpha_2}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2}}$

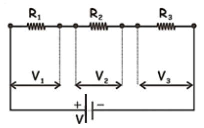
if $R_1 = R_2$ $\alpha = \frac{\alpha_1 + \alpha_2}{2}$

09 GROUPING OF RESISTANCE

Series Combination

Current is constant
voltage is divided
$R_s = R_1 + R_2 + R_3 + \dots R_n$

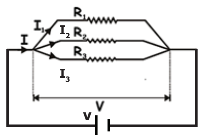
If resistors are identical: $R_s = nR$



Parallel Combination

voltage is constant
current is divided

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \frac{1}{R_n}$



If resistors are identical: $R_P = \frac{R}{n}$

Shortcut for two resistors in parallel

$\frac{R_1 R_2}{R_1 + R_2}$

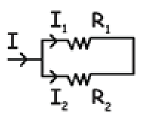
R_1, R_2 → R_s Bigger than largest value of resistance

→ R_p Lower than smallest value of resistance

10 CURRENT & VOLTAGE DIVIDER RULE

Current Divider Rule

V = Constant $I \propto \frac{1}{R}$



$I_1 = \frac{I \times R_2}{R_1 + R_2}$, $I_2 = \frac{I \times R_1}{R_1 + R_2}$

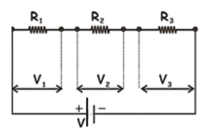
Voltage Divider Rule

$V_1 = IR_1$, $V_2 = IR_2$, $V_3 = I_3 R_3$

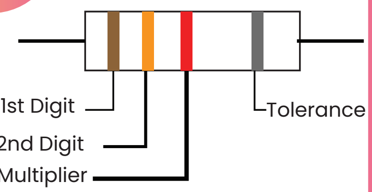
$V_1 = \frac{V \times R_1}{R_1 + R_2 + R_3}$

$V_2 = \frac{V \times R_2}{R_1 + R_2 + R_3}$

$V_3 = \frac{V \times R_3}{R_1 + R_2 + R_3}$



11 COLOUR CODING



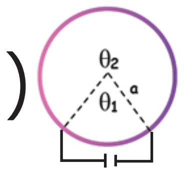
Resistor color code

Color	Digit	Multiplier	Tolerance (%)
Black	0	10^0	
Brown	1	10^1	1
Red	2	10^2	2
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	0.5
Blue	6	10^6	0.25
Violet	7	10^7	0.1
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
silver		10^{-2}	10
none			20

12 GEOMETRICAL DIAGRAM

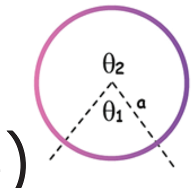
Circle formed by wire having uniform resistance per unit length (r)

$R_{eff} = ra\left(\frac{\theta_1 \theta_2}{\theta_1 + \theta_2}\right)$



When resistance of wire forming circle is given

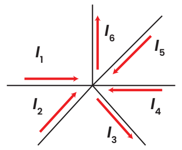
$R_{eff} = \frac{R}{2\pi}\left(\frac{\theta_1 \theta_2}{\theta_1 + \theta_2}\right)$



PHYSICS WALLAH

13 KIRCHHOFF'S LAW

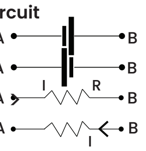
1. Junction Rule



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

$$I_1 + I_2 + I_4 + I_5 = I_3 + I_6$$

2. Open Circuit



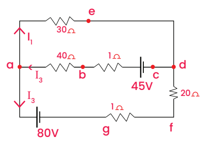
(1) A — B $V_A - V_B = -E$

(2) A — B $V_A - V_B = +E$

(3) A — B $V_A - V_B = IR$

(4) A — B $V_A - V_B = -IR$

Closed Circuit



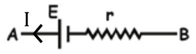
(1) abcdea

$40I_1 + I_3 - 45 + 30I_1 = 0$

(1) aedfga

$-30I_1 + 20I_2 + I_3 + 80 = 0$

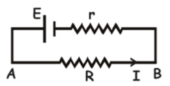
14 CELL & INTERNAL RESISTANCE



$V_A - V_B = E - Ir$

Terminal potential difference (TPD)

1) When current is drawn from cell



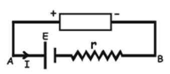
$V = V_A - V_B = E - Ir$

TPD< EMF

$V = E - Ir = IR \Rightarrow I = \frac{E}{R+r}$

So, $V = \frac{E}{R+r}R$

2) When current is given to cell

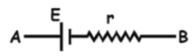


$V = V_A - V_B = E + Ir$

TPD> EMF

15 CELL & INTERNAL RESISTANCE

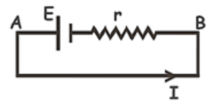
3) When cell is in open circuit



Here, I=0

TPD=E

3) When cell is in short circuit



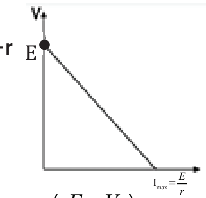
$$I = I_{max} = \frac{E}{r}$$

$$TPD = 0$$

16 CELL & INTERNAL RESISTANCE

Slope of graph =-r

y intercept=E

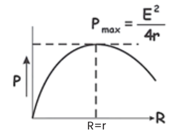


Internal Resistance $r = \left(\frac{E-V}{V}\right)R$

Power delivered by cell during withdrawl of current

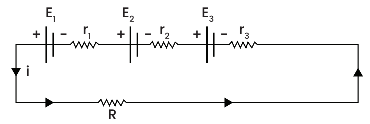
$P = I^2R = \left(\frac{E}{R+r}\right)^2 R$ $P_{max} = \frac{E^2}{4r}$, when R=r

Maximum power transfered



17 COMBINATION OF CELLS

1) **Series Combination**



(a) $E_{equivalent} = E_1 + E_2 + E_3 + \dots + E_n$

(b) $r_{equivalent} = r_1 + r_2 + r_3 + \dots + r_n$

(c) Current, $i = \frac{\sum E_i}{\sum r_i + R}$

(d) If all cells have equal emf E and equal internal resistance r then $i = \frac{nE}{nr + R}$

1) If nr >> R => $i = \frac{E}{r}$

2) If nr << R => $i = \frac{nE}{R}$

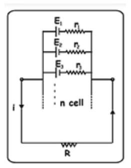
(e) Power dissipated in circuit $P = I^2R = \left(\frac{nE}{nr+R}\right)^2 R$

Conditions for maximum power: R=nr

$P_{max} = nE^2/4r$

18 COMBINATION OF CELLS

2) **Parallel Combination**



a) $E_{equivalent} = \dfrac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3} \dots \frac{E_n}{r_n}}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots \frac{1}{r_n}}$

b) $r_{equivalent} = \dfrac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots \frac{1}{r_n}}$

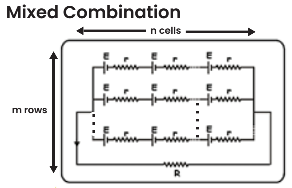
(c) If all cells have equal emf. E & internal resistance r then $E_{equivelent} = E$

$r_{equivalent} = \frac{r}{n} \Rightarrow$ current $i = \dfrac{E}{\frac{r}{n} + R}$

(d) Power dissipated in the circuit $P = I^2R = \left(\frac{nE}{r + nR}\right)^2 R$

Conditions for maxiumum power $R = \frac{r}{n}$

3) **Mixed Combination**



$r_{net} = \frac{nr}{m}$ Total emf $= E_{net} = nE$

$I = \frac{E_{net}}{R + r_{net}} = \frac{nE}{R + \frac{nr}{m}}$

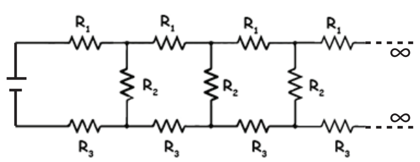
$P_{max} = \frac{E_{eq}}{4R} = \frac{mnE^2}{4r}$ $[\because R = \frac{nr}{m}]$

n cells connected in series and there are m such branches in the circuit.

Internal resistance of cells connected in a row =nr

19 COMBINATION OF CELLS

Infinite resistors

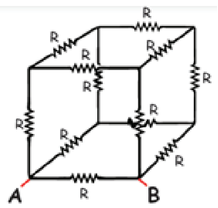


$$R_{eq} = \frac{R_1 + R_3}{2}\left[1 + \sqrt{1 + \frac{4R_2}{R_1 + R_3}}\right]$$

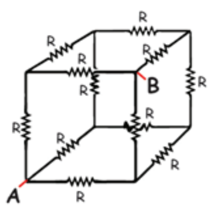
If all resistors are equal $R_{eq} = R(1 + \sqrt{3})$

20 3D CIRCUIT

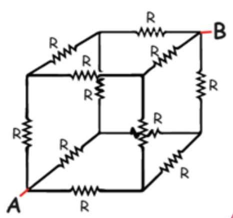
Edge $R_{eq} = \frac{7R}{12}$



Face $R_{eq} = \frac{3R}{4}$



Body $R_{eq} = \frac{5R}{6}$



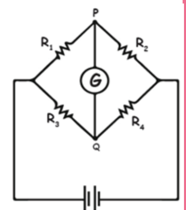
21 WHEATSTONE BRIDGE

1) **Balanced WSB**

Balanced Condition $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

$V_p = V_Q$

Current through G = 0

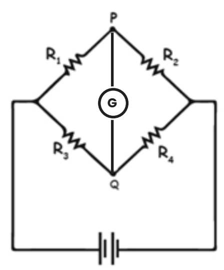


2) **Unbalanced WSB**

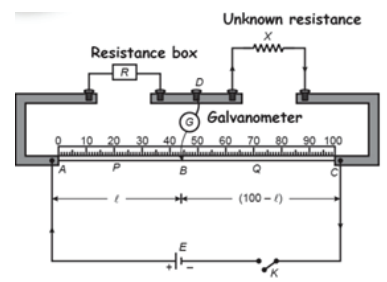
$V_P \neq V_Q$

if $\frac{R_1}{R_2} > \frac{R_3}{R_4}$

then $V_Q > V_P$

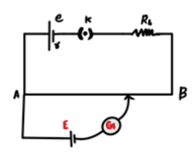


22 METER BRIDGE



$$\frac{P}{Q} = \frac{R}{X} = \frac{\ell}{100 - \ell}$$

POTENTIOMETER



23 POTENTIOMETER

POTENTIAL

$$V_{AB} = \left(\frac{e}{r + R_h + R}\right)R$$

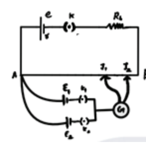
where, R= Resistance of potentiometer wire

POTENTIAL GRADIENT

$$x = \frac{V_{AB}}{L} = \frac{\frac{eR}{r + R_h + R}}{L} = \left(\frac{e}{r + R_h + R}\right)\frac{R}{L}$$

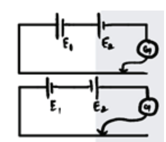
1. COMPARISON OF CELL

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$



2. BOTH BATTERIES ARE CONNECTED TOGETHER

(Once with same polarity then with opposite polarity)

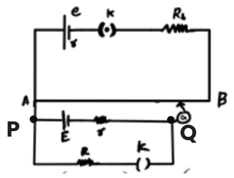


$$\frac{E_1}{E_2} = \frac{l_1 + l_2}{l_1 - l_2}$$

PHYSICS WALLAH

24 POTENTIOMETER

3. CALCULATION OF INTERNAL RESISTANCE



$$r = R\left(\frac{E}{V} - 1\right) = R\left(\frac{\ell_1}{\ell_2} - 1\right)$$

$E = V_{PQ}$ when key is open

$V = V_{PQ}$ when key is close

25 HEATING EFFECT OF ELECTRIC CURRENT

POWER

$$P = \frac{dH}{dt} = VI = \frac{V^2}{R} = I^2R$$

ELECTRIC KETTLE

Time taken for first coil- t_1, time taken for second coil-t_2

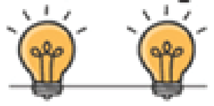
if they are connected in series	if they are connected in parallel
$t_s = t_1 + t_2$	$t_p = \dfrac{t_1 t_2}{t_1 + t_2}$

BULB

$$P_{rated} = \frac{V_{rated}^2}{R} \Rightarrow R = \frac{V_{rated}^2}{P_{rated}}$$

CONNECTED IN SERIES

VP_1 VP_2



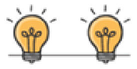
$P_{dissipated} = I^2R$

$P_{dissipated} \propto R$

Brightness $\propto R$

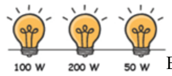
26 HEATING EFFECT OF ELECTRIC CURRENT

V,P_1 V,P_2



$$P_{dissipated} \, \alpha \, \frac{(V_{rated})^2}{P_{rated}}$$

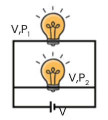
$$P_{d(\text{ brighness})} \, \alpha \, \frac{1}{P_{rated}}$$



If $(P_1)_{rated} \geq (P_1)_{rated}$ then $P_{d_1} < P_{d_2}$

Brightness : $B_3 > B_1 > B_2$

CONNECTED IN PARALLEL



$$P_{rated} = \frac{(V_{rated})^2}{R}$$

$$P_d = \frac{V^2}{R} \Rightarrow P_d \alpha \frac{1}{R}$$

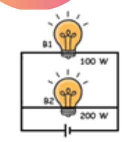
$$\Rightarrow P_{d(\text{brighness})} \propto \frac{1}{\frac{(V_{rated})^2}{P_{rated}}} \qquad \Rightarrow P_{d(\text{brighness})} \propto \frac{P_{rated}}{(V_{rated})^2}$$

$$P_{d(\text{ brighness})} \propto P_{rated}$$

if $(P_1)_R > (P_2)_R$

$\Rightarrow$ Brightness $(P_d)_1 > (P_d)_2$

27 HEATING EFFECT OF ELECTRIC CURRENT

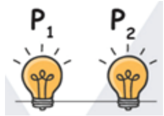


$P_{B2} > P_{B1}$

COMBINATION OF BULBS

SERIES

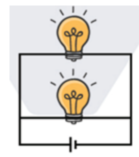
P_1 P_2



TOTAL POWER

$$P = \frac{P_1 P_2}{P_1 + P_2}$$

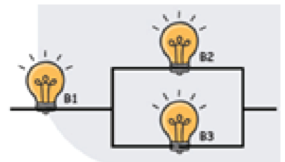
PARALLEL



$$P = P_1 + P_2$$

28 HEATING EFFECT OF ELECTRIC CURRENT

FUSED BULB

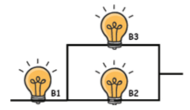


If bulb 2 is fused then,

<u>for bulb 3</u>	<u>for bulb 1</u>
R ↑	V ↓
V ↑	P ↓
P ↑	B ↓
B ↑	

If bulb is added in parallel:-

for example if bulb 3 is added in parallel to 2 then



<u>for bulb 3</u>	<u>for bulb 1</u>
R ↓	V ↑
V ↓	P ↑
P ↓	B ↑
B ↓	

29 CONVERSION OF GALVANOMETER

Current sensitivity

$$S_i = \frac{\theta}{I}$$

where, θ= angle of deflection in galvanometer

I= Corresponding current in galvanometer

Unit: $\frac{\text{divisions}}{\text{ampere}}$ OR $\frac{\text{rad}}{\text{A}}$

Voltage sensitivity

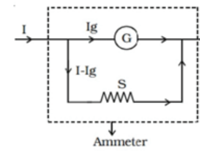
$$S_v = \frac{\theta}{V}$$

where, θ= angle of deflection in galvanometer

V=Corresponding voltage across galvanometer

$\frac{\text{divisions}}{\text{voltage}}$ OR $\frac{\text{rad}}{\text{V}}$

GALVANOMETER TO AMMETER



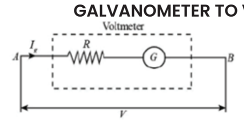
$$S = \frac{I_g G}{I - I_g} = \frac{G}{n - 1}$$

$$\text{Where } n = \frac{I}{Ig}$$

RESISTANCE OF AMMETER $R = \dfrac{GS}{G+S}$

RESISTANCE OF IDEAL AMMETER = 0

GALVANOMETER TO VOLTMETER



$$V = I_g G + I_g R$$

$$R = \frac{V}{I_g} - G = \left(\frac{V}{V_g} - 1\right)G$$

$= (n-1)G$

where, $n = \frac{V}{V_g}$

RESISTANCE OF VOLTMETER = G + R

RESISTANCE OF IDEAL VOLTMETER = ∞