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Current Electricity

Current Electricity :-

The study of charges in motion is called current electricity.

Electric current :-

The rate of flow of charge is called electric current.

It has direction but it does not obey vector rules, so it is scalar.

Its SI unit is ampere (A).
Its dimension is A or I.
It is denoted by I or i.

We know,

$$Q = IT$$

$$\therefore \boxed{I = \frac{Q}{t}}$$

$$Q = ne$$

$$\boxed{I = \frac{ne}{t}}$$

Here,

n = no. of electron

$e = 1.6 \times 10^{-19}$ C

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Q) Charge of a conductor is $20\mu C$. How much current will pass through the conductor is 5 minute. Also find number of electron flowing through the conductor.

Soln:- A/q

$Q = 20\mu C = 20 \times 10^{-6}\,C = 2 \times 10^{-5}\,C$

$t = 5\,min = 5 \times 60\,sec = 300\,sec$

$I = ?$

$n = ?$

$$I = \frac{Q}{t}$$

$$= \frac{2\cancel{0} \times 10^{-6}}{30\cancel{0}}$$

$$= \frac{2 \times 10^{-6}}{3 \times 10^{1}}$$

$$= 0.667 \times 10^{-7}$$

$$= 6.67 \times 10^{-8}\,A$$

$$Q = ne$$

$$n = \frac{Q}{e}$$

$$n = \frac{20 \times 10^{-6}}{1.6 \times 10^{-19}}$$

$$= 12.5 \times 10^{-6} \times 10^{19}$$

$$= 12.5 \times 10^{13}$$

$$= 1.25 \times 10^{14}$$ ans

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II Type to obtained (n) no. of electrons

$$I = \frac{ne}{t}$$

$$n = \frac{It}{e}$$

$$= \frac{6.66 \times 10^{-8} \times 300}{1.6 \times 10^{-19}}$$

$$= 1.25 \times 10^{14} \text{ ans}$$

Ohm's Law :-

At constant temperature and constant electron density the potential difference across ends of a conductor is directly proportion to flowing current.

i.e; $V \propto I$

$\Rightarrow V = RI$

$\Rightarrow \boxed{V = IR}$

Here,

R = Resistance
V = Potential difference
I = Current (density)

Resistance :-

The opposition produced against flow of current is called resistance.

It is denoted by R.
From ohm's law
$V = IR$

$\Rightarrow \boxed{R = \frac{V}{I}}$ $\frac{\text{potential difference}}{\text{current}}$

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- SI unit = $\frac{\text{Volt}}{\text{ampere}}$

$= VA^{-1}$

$= \text{ohm} \Rightarrow \Omega$

- Dimension =

$$\frac{ML^2T^{-3}A^{-1}}{A} = ML^2T^{-3}A^{-2}$$

Resistivity / specific resistance :-

The property of a substance due to which resistance is produced is called resistivity.

It is denoted by ρ.

$$\boxed{\rho = \frac{RA}{l}}$$

- SI unit :-

$\because \rho = \frac{RA}{l}$

$= \frac{\Omega m^2}{m} \Rightarrow \Omega m$

- Dimension = $ML^3T^{-3}A^{-2}$

Current Density :-

The amount of current flowing through unit cross-section area of a conductor is called current density.

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- It is denoted by J.
- It is vector quantity

$$J = \frac{\text{Current}}{\text{Area}}$$

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

- SI unit $= \frac{\text{Ampere}}{M^2}$

$$= AM^{-2}$$

- Dimension $= \frac{A}{L^2}$

$$= AL^{-2}$$

Conductance :-

The support produced in flow of electric current is called conductance.

It is denoted by G.
It is inverse of resistance.

$$\boxed{G = \frac{1}{R}}$$

- SI unit $= \frac{1}{\text{ohm}}$

$$= \text{ohm}^{-1}$$

$$= \text{mho}$$

$$= \text{Siemen}$$

$$= S$$

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$$\text{Dimension} = \frac{1}{ML^2T^{-3}A^{-2}}$$
$$\Rightarrow \boxed{M^{-1}L^{-2}T^3A^2}$$

Conductivity / specific Conductance :-

The property of substance due to which conductance produced is called conductivity.

It is denoted by (σ) (sigma).
It is inverse of resistivity.

So, $\boxed{\sigma = \frac{1}{\rho}}$

$$\text{SI unit} = \frac{1}{\Omega m}$$
$$= \Omega^{-1}m^{-1}$$
$$= \text{mho } m^{-1}$$
$$= Sm^{-1}$$

$$\text{Dimension} = \frac{1}{ML^3T^{-3}A^{-2}} = M^{-1}L^{-3}T^3A^2$$

Vector form of Ohm's Law :-

If E is the magnitude of electric field in a conductor of length l, then the potential difference across its ends is

$$V = El$$

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from ohm's law we can write as,

$$V = IR$$

$$V = \frac{I\rho l}{A}$$

$$El = \frac{I\rho l}{A}$$

$$E = J\rho$$

as direction of electric current density $\vec{J}$ is same as $\vec{E}$, then

$$\boxed{\vec{E} = \vec{J}\rho}$$

or

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

Resistor
- → Wire bound resistor → wire bounded with alloy
- → Carbon resistor
  - compact
  - cheap

Resistivities of different substances —

Metals have low resistivity in rang of 10^{-8} Ωm to $10^{-6} \Omega m$.

Insulator have resistivity very high that is more than $10^{4} \Omega m$.

Semiconductor have intermediate resistivity lying between 10^{-6} to 10^{4} Ωm.

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Colour code for Carbon Resistors :-

A colour code is used to indicate the resistance value of carbon resistor and its percentage accuracy.

Colour	Letter	Number	Multiplier	Colour	Tolerance
Black	B	0	10^0	Gold	5%
Brown	B	1	10^1	Silver	10%
Red	R	2	10^2	no fourth band	20%
Orange	O	3	10^3		
yellow	Y	4	10^4		
green	G	5	10^5		
Blue	B	6	10^6		
Violet	V	7	10^7		
Grey	G	8	10^8		
white	W	9	10^9		

There are two system of making colour code:

① First system :-

(i) The first band indicates the first significant figure.

(ii) Second significant figure indicate second significant.

(iii) Third bond indicate power of ten with which above two signicate figure. must be multiplied to get value of R in Ω.

(iv) Fourth band indicates tolerance or possible

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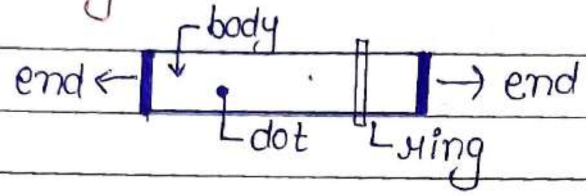
variation in percentage of indicate value. If fourth band absent, it means the tolerence of ±20%.

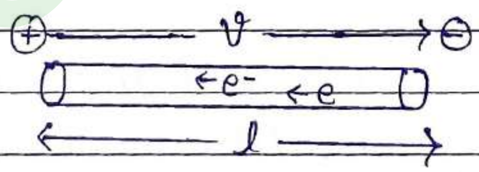
② Second System :-



(i) Colour of body gives 1st significant figure.
(ii) Colour of end gives second significant.
(iii) Colour of dot gives number of zero to be placed after second figure.
(iv) Colour of ring gives percent accuracy of the indicated value.

Drift velocity :-
(V_d)

It may be defined as the average velocity gained by the free e⁻ of conductor in opposite direction of the externally applied electric field.



Electric field of given conductor,

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

e⁻ experiences a colomb's force —

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

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then, acceleration of $e^- = \frac{F}{M} = \frac{-e\vec{E}}{m}$

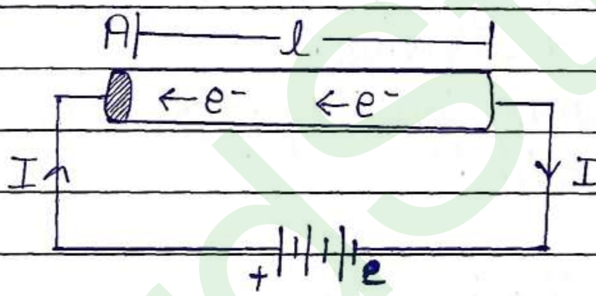
velocity of an electron $= v_1 + a\tau$

$$V_d = \frac{(v_1 + a\tau_1) + (v_2 + a\tau_2) ----}{n}$$

$V_d = a\tau$ [as average velocity = 0]

$$\boxed{V_d = \frac{-eE\tau}{m}}$$

Relation between V_d and current (I) :-



Let a conductor of length 'l' and cross-sectional area 'A' with potential difference 'V' across its terminals, also electric field set up inside conductor is $E = \frac{V}{l}$

Volume = Al
Number of e^- per unit volume = n
Total no. of e^- = $n \times Al$
charge on nAl e^- = $enAl$

Time taken by e^- to cross conductor $= \frac{l}{V_d}$

$\because$ current $= \frac{q}{t}$.

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$$I = \frac{enAl}{l/V_d} = enAV_d$$

$$\boxed{I = enAV_d}$$

Also, the current density is given by

$$j = \frac{I}{A} = \frac{enAV_d}{A}$$

$$j = enV_d$$

$$\boxed{\vec{J} = en\vec{V}_d}$$ in vector form.

Average relaxation time :-

It is the average time the elapes between two successive collision of an electron drifting in a conductor.

Average thermal velocity :-

When a conductor is not connected to any battery, free e^- are move due to their temperature. This is called thermal velocity.

Thermal velocity $= 10^5$ m/s
But Average thermal velocity $= 0$ m/s

Mobility of electrons :-

Magnitude of drift velocity per unit electric field.

- Denoted by 'μ'
It is given by, $\mu = \frac{V_d}{E} = \frac{e\tau}{m}$

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$$\boxed{\mu = \frac{e\tau}{m}}$$

- SI unit of electron mobility $= m^2V^{-1}s^{-}$

Relation between electric current and mobility for a conductor :-

In a metallic conductor, the electric current is due to free e^- and given by,

$$I = enAV_d$$

But, $V_d = \mu E$

$$\therefore \boxed{I = enA\mu E}$$

Order of drift velocity in a conductor is

$$10^{-4} m/s$$

Order of thermal velocity :

$$10^5 m/s$$

Carrier of current :-

In metals, free electrons are the charge carriers. In ionised gases electrons and positively charged ions are the charge carrier. In an electrolytic both positive and negative ions are the charge carries. In semiconductor like Ge and Si, conduction is due to electrons and holes.

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— A hole is a vacant state from which an electron has been removed ; act as a positive charge carrier.

Resistivity in terms of electron density and relaxation time.

$$V_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml}$$

If cross-sectional area is A and number of e⁻ per unit volume is n, then

$$I = V_d enA$$

$$I = \frac{eV\tau}{ml} \times enA$$

$$\frac{I}{V} = \frac{ne^2\tau A}{ml} \qquad \because R = \frac{V}{I}$$

$$R = \frac{ml}{ne^2\tau A}$$

also $R = \rho l$

On composing value of R we get -

$$\boxed{\rho = \frac{m}{ne^2\tau}}$$

Temperature Dependence of Resistivity :-

The resistivity of any material depends on number of density of free $e^{-(n)}$ and mean collision time (τ).

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① **In case of metals —**

The resistivity of a metal ($\rho \propto \frac{1}{\tau}$) increases and the conductivity decreases with the increase in temperature.

Resistivity ρ at temperature T is given by

$$\rho = \rho_0 \left[1 + \alpha (T - T_0)\right] \quad \text{— (1)}$$

where ρ_0 is resistivity at a lower temp. T_0 and α is coefficient of resistivity.

$$\boxed{\alpha = \frac{\rho - \rho_0}{\rho_0 (T - T_0)}}$$

unit of α = $°C^{-1}$ or K^{-1}

equation (1) can be written in terms of resistivity —

$$R_f = R_0 (1 + \alpha \Delta t)$$

where,

R_f = resistance at $t°C$

R_i = resistance at $0°C$

t = the rise in temperature $\cdot \Delta t$

② **For Semi-conductor and insulator —**

- α is negative Si, Ge
- their resistance decreases with the increase in temperature

③ **For alloys like Constantan, Nichrome and ~~mag~~ manganin —**

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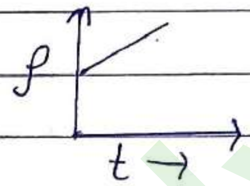
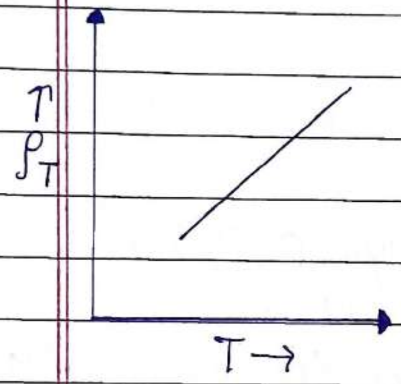
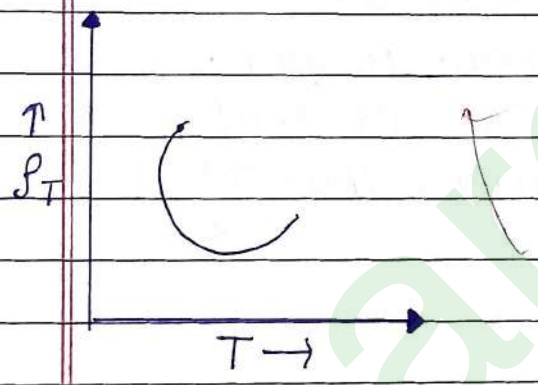
The temperature coefficient of resistance α is very small. ($\alpha \approx 0$). So they are used to make standard resistor.

Alloy $T\uparrow$, $\rho\uparrow$, cond $\downarrow$ (very less) $\Rightarrow$





Graph : Metals
Conductor, $T\uparrow$, $\rho\uparrow$, Cond $\downarrow$



Graph : Non-metals

Graph : Semiconductor
electrolyte and semicond.
$T\uparrow$, $\rho\downarrow$, Cond. $\uparrow$

Ohmic conductors :-
The conductors which obey Ohm's law are called ohmic conductor.

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— For these, V-I graph is straight line passing through the origin.

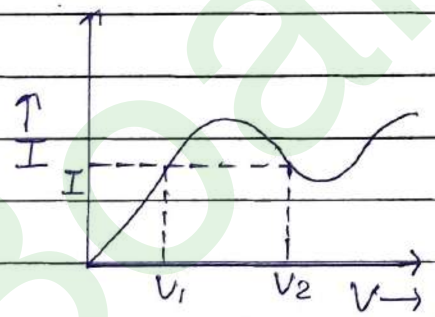
Non Ohmic Conductors :-

The conductor which do not obey ohm's law are called ohmic conductors.

— Non ohmic situation may be of the following type :-

(i) V-I graph do not pass through origin.
(ii) V-I relationship is not linear.
(iii) V-I relationship depends on the sign of V for some absolute value of V.
(iv) V-I relationship is non-unique.
↳ behaviour of $\boxed{GaAs}$

Example : water voltmeter, thyristor, a p-n junction etc.



non-unique

Graph : behaviour of GaAs.

$I = \frac{\varepsilon}{R+r}$ $\frac{\varepsilon}{R+r} = \frac{V}{R}$ $R+r = \frac{\varepsilon R}{V}$

By ohm's law $VR + Vr = \varepsilon R$ $r = \frac{\varepsilon R}{V} - R$

$I = \frac{V}{R}$ $V(R+r) = \varepsilon R$ $\boxed{r = R\left(\frac{\varepsilon}{V} - 1\right)}$

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Electromotive force (emf) :-

potential difference between two electrodes when no current is following.

↳ denoted by 'ε'
↳ Unit – Volt (v)

$$\varepsilon = V_1 - (-V_2)$$
$$\varepsilon = V_1 + V_2$$

Internal resistance :-

The resistance offered by electrolyte of cell to the flow of current between its ~~cell~~ electrodes is called internal resistance.

It depends on –

(i) Nature of electrolyte.
(ii) Concentration of electrolyte [$C\uparrow, r\uparrow$]
(iii) Distance between electrode. [$d\uparrow, r\uparrow$]
(iv) Temperature of electrolyte. [temp. $\uparrow$, $r\downarrow$]
(v) Area of electrode. [$A\uparrow, r\downarrow$]

Terminal potential difference (V) :-

potential difference across the terminals of a cell when a current is being drawn from it is called its terminal potential difference.

→ It is less than emf of cell in closed circuit.

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Relation between emf (ε), terminal potential difference (V) and internal resistance (r) :-

$$\boxed{V = \varepsilon - Ir}$$

$$\boxed{I = \frac{\varepsilon}{R+r}}$$

$$\varepsilon = V_1 - (-V_2)$$
$$\boxed{\varepsilon = V_1 + V_2}$$

$$\boxed{I_{max} = \frac{\varepsilon}{r}}$$

Note :- Terminal potential difference is less than emf of cell.
Exception - charging of cell.

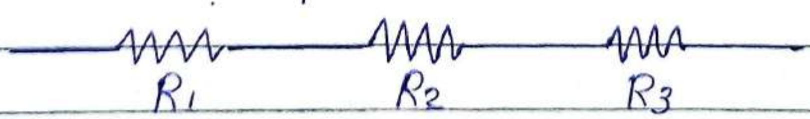
$$\boxed{V = \varepsilon + Ir} \quad : V > \varepsilon$$

Resistance in series :-

When a number of resistance are connected in series, their equivalent resistance (R_s) is equal to the sum of individual resistance.

$$R_s = R_1 + R_2 + R_3 -----$$

↳ Resistance in series have same current but different potential difference



$V = IR_1$ $\quad V_2 = IR_2$ $\quad V_3 = IR_3$

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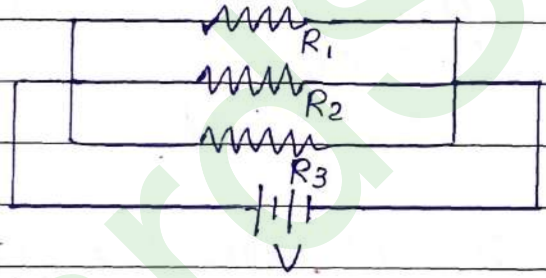
Resistance in Parallel :-

When a number of resistances are connected in parallel, the reciprocal of their equivalent resistance (R_p) is equal to sum of reciprocal of individual resistance.

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

For two resistance in parallel:

$$\boxed{R_p = \frac{R_1 R_2}{R_1 + R_2}}$$



Kirchhoff's Law :-

These law enables us to determine the current and voltages in different part of electrical circuit.

First law or junction Rule :-

In an electric circuit the algebraic sum of current at any junction is zero. or, the sum of current, entering the junction is equal to the sum of current leaving that junction.

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Mathematically :

$$\Sigma I = 0$$

Justification :- This law is based on the law of conservation of charge.

Second law or loop rule :-

Around any loop of a network, the sum of charges in potential must be zero. or, the algebraic of emfs in any loop of a circuit is equal to the sum of the product of current and resistance in it.

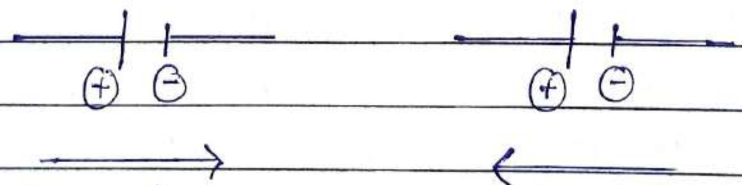
Mathematically,

$$\Sigma \Delta V = 0$$

$$\Sigma \mathcal{E} = \Sigma IR$$

Justification :- This law is based on the law of conservation of energy.

- emf of cell is taken as positive if the direction of transversal is from negative to positive terminal.



$V = -\mathcal{E}$ $\qquad$ $V = +\mathcal{E}$

- If the path is opposite of I in resistor then $\Delta V = +ve$.

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Combination of cells –

Cells in series :–

When the negative terminal of one cell is connected to the positive terminal of the other cell and so on, the cells are said to be connected in series.

Note: ① The equivalent of emf of a series combination of n cells is equal to the sum of their individual emf.

$$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \dots + \varepsilon_n$$

② The equivalent internal resistance of a series combination of n cells is equal to the sum of their individual internal resistance.

$$r_{eq} = r_1 + r_2 + r_3 + \dots r_n$$

③ If one of cell, ε_2, say, is turned around in opposition, to other cells, then,

$$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \dots \varepsilon_n$$

Cells in parallel :–

In this type of combination the positive pole of all the cell are connected to a common point and negative to another.

For a parallel combination of n cells,

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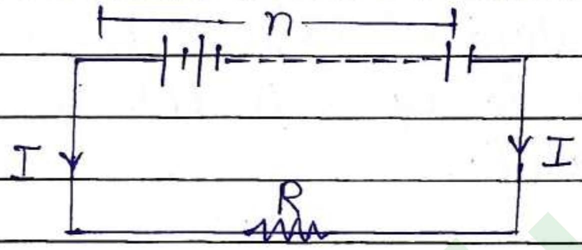
$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \cdots + \frac{\varepsilon_n}{r_n}$$

and, $$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \cdots + \frac{1}{r_n}$$

Condition for maximum current from a series combination of cells –



Total emf of ~~an~~ cells in series = $n\varepsilon$

Total internal resistance of n cell in series $= nr$

Total resistance of circuit $= R + nr$

The current in circuit is,

$$I = \frac{\text{Total emf}}{\text{Total resistance}}$$

$$\boxed{I = \frac{n\varepsilon}{R + nr}}$$

Special case –

Case(1) If $R >>> nr$ then,

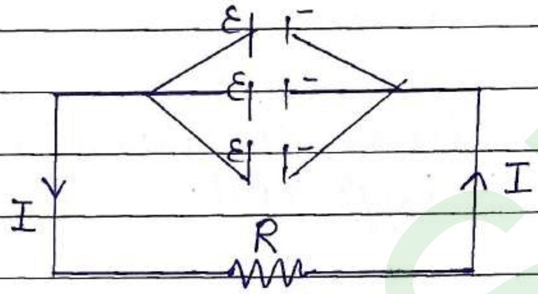
$\boxed{I = \frac{nE}{R}}$ n times the current (ε/R) that can be drawn from one cell.

Case (ii) If $R <<< nr$, then

$$I = \frac{n\varepsilon}{nr} = \frac{\varepsilon}{r}$$

$\boxed{I = \frac{\varepsilon}{r}}$ the current given by a single cell.

Condition for maximum current from parallel Combination of cell :



Since, all the m internal resistance are connected in parallel, their equivalent resistance R' is given by -

$$\frac{1}{R_1} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \text{-----} m = \frac{m}{r}$$

$$R' = \frac{r}{m}$$

Total resistance in the circuit,

$$= R + R' = R + \frac{r}{m}$$

As only the effect of joining m cell in parallel is to get a single cell of larger size with same chemical materials,

Total emf of parallel combination = emf due to single cell which is 'ε'.

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The current in circuit is –

$$I = \frac{\varepsilon}{R + r/m}$$

$$\boxed{I = \frac{m\varepsilon}{mR + r}}$$

Special case –

Case (i) If $R <<< \frac{r}{m}$, then

$\boxed{I = \frac{m\varepsilon}{r}}$ ⇒ m times the current due to a single cell.

Case (ii) If $R >>> \frac{r}{m}$, then.

$\boxed{I = \frac{\varepsilon}{R}}$ ⇒ Current given by a single cell.

Mixed Grouping of cells :–

In this type of combination same cells which are connected in series and all such series are connected in parallel.

Total number of cell = mn

Net emf of each row of n cell in series $= n\varepsilon$

and total internal resistance = nr

As m such rows are connected in parallel so total internal resistance 'r' of combination is given by,

$$\frac{1}{r_1} = \frac{1}{nr} + \frac{1}{nr} + \frac{1}{nr} + \cdots + \frac{m}{nr}$$

$$r' = \frac{nr}{m}$$

Total resistance of circuit,

$$= R + r'$$
$$= R + \frac{nr}{m}$$

The current through the external resistance R,

$$I = \frac{\text{Total emf}}{\text{total resistance}}$$

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

$$\boxed{I = \frac{mnE}{mR + nr}}$$

Current I will be maximum if the denominator, i.e $(mR + nr)$ is minimum

Now,

$$mR + nr = (\sqrt{mR})^2 + (\sqrt{nR})^2$$
$$= (\sqrt{mR})^2 + (\sqrt{nR})^2 - 2\sqrt{mR}\sqrt{nr} + 2\sqrt{mR}\sqrt{nr}$$

As the perfect square can't be -ve so, $mR + nr$ will be maximum if

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$$\sqrt{mR} - \sqrt{nr} = 0$$

$$mR = nr$$

$$\boxed{R = \frac{nr}{m}}$$

External resistance = Total internal resistance of the cell.

Heating effect of current :-

The phenomenon of the production of heat in a resistor by flow of an electric current through it is called heating effect of current or joule heating. It is a irreversible process.

Joule's Law of Heating :-

It states that the amount of heat H produced in a resistor is —

(i) directly proportional to the square of current for given R.

(ii) directly proportional to the resistance R for a given I,

(iv) Inversly proportional to the resistance R for a given I.

(iv) Directly proportional to the time t for which the current flows through the resistor.

Mathematically,

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$$H = VIt \text{ joule}$$
$$= I^2Rt \text{ joule}$$
$$= \frac{V^2t}{R} \text{ joule}$$

Or $$H = \frac{VIt}{4.18} \text{ cal.}$$
$$= \frac{I^2Rt}{4.18} \text{ cal}$$
$$= \frac{V^2t}{4.18R} \text{ cal}$$

Electric Power :- It is the rate at which an electric appliance converts electric energy into other form of energy. Or, it is rate at which a work is done by a source of emf in maintaining an electric current through a circuit.

Electric power,
$$P = \frac{W}{t}$$
$$P = \frac{Vq}{t}$$
$$P = VI$$
Or, $$P = I^2R$$
Or, $$P = \frac{V^2}{R}$$

SI unit of power is watt.

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The power of an appliance is one watt. if One ampere of current flows through it on applying a potential difference of 1 volt across it.

$$1 \text{ watt} = \frac{1 \text{ Joule}}{1 \text{ Second}}$$
$$= 1 \text{ volt} \times 1 \text{ Ampere}$$
$$1 W = 1 JS^{-1} = 1 VA$$

Or 1 Kilowatt (kW) = 1000 W

1 kWh = 1 unit (Board of Trade unit).

$$1 \text{ kWh} = 1000 W \times 3600 S$$
$$= 3600000 \ W \cdot S$$
$$1 \text{ kWh} = 3.6 \times 10^6 \ W \cdot S$$
$$1 \text{ kWh} = 3.6 \times 10^6 \text{ joule}$$

Power rating :- Power rating of an electrical appliance is the electrical energy consumed per second by the appliance when connected across the marked voltage of the mains.

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

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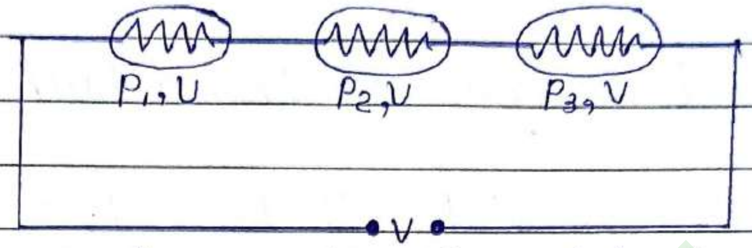
Power Consumed by a Series combination of appliances —



Series combination of bulbs.

Resistance of three given bulbs is —

$$R_1 = \frac{V^2}{P_1}, \quad R_2 = \frac{V^2}{P^2}, \quad R_3 = \frac{V^2}{P_3}$$

As bulbs are connected in series —

$$R = R_1 + R_2 + R_3$$

If P is the effective power of combination then,

$$\frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3}$$

Or,

$$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}$$

Thus, for series combination of appliances the reciprocal of effective power is equal to the sum of reciprocal of individual power of appliances.

Clearly, when N bulb of same power P are connected in series.

$$P_{eff} = \frac{P}{N}$$

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As the bulb are connected in series, current I through each bulb will be same.

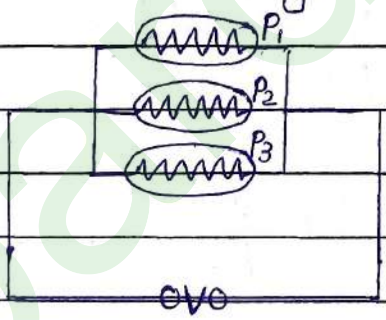
The brightness of three bulb will be :

$P_1' = I^2R_1$, $P_2' = I^2R_2$, $P_3' = I^2R_3$

As $R \propto \frac{1}{P}$, the lowest wattage (power) will have maximum resistance and will glow maximum.

as, $P = I^2R$ also,
$P \propto R$ Brightness $\propto$ power.
$R\uparrow ; P\uparrow$

→ Power consumed by a parallel combination :-



Parallel combination of bulb.

Resistance of three bulb,

$R_1 = \frac{V^2}{P_1}$, $R_2 = \frac{V^2}{P_2}$, $R_3 = \frac{V^2}{P_3}$

As the bulb are connected in parallel, their effective resistance R is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Multiplying both side by V^2, we get

$$\frac{V^2}{R} = \frac{V^2}{R_1} + \frac{V^2}{R_2} + \frac{V^2}{R_3}$$

or $P = P_1 + P_2 + P_3$

Thus, for a parallel combination of appliances, the effective power is equal to the sum of power of individual appliances.

If N bulbs are connect in parallel.

$$P_{eff.} = NP$$

The brightness of three bulb will be,

$$P_1 = \frac{V^2}{R_1}, \quad P_2 = \frac{V^2}{R_2}, \quad P_3 = \frac{V^2}{R^3}$$

As the resistance of higest power bulb is minimum, it will glow with maximum brightness.

Power $\propto$ Brightness.

Electric Energy :- The total workdone by the source of emf in mainting an electric current in a circuit for a given time is called electrical energy consumed in the circuit.

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Electric energy,

$$\omega = p \cdot t$$
$$= VIt \text{ joule} = I^2RT \text{ joule}$$

SI unit of electric energy is joule (J)

1 joule = 1 volt x 1 ampere x 1 second
= 1 watt x 1 second.

Efficiency of a source of emf –

$$\eta = \frac{\text{output power}}{\text{input power}}$$

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

Maximum power Theorem :-
It states that the output power of a source of emf is maximum when the external resistance in the circuit is equal to the internal resistance of source.

$$I = \frac{\text{total emf}}{\text{total resistance}}$$

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

Power output,

$$P = I^2R$$

$$P = \left(\frac{\mathcal{E}}{R+r}\right)^2 R$$

$$P = \frac{\mathcal{E}^2R}{(R+r)^2}$$

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Power output will be maximum when
$R = r$

$\because P = \frac{\varepsilon^2 r}{(r+r)^2} = \frac{\varepsilon^2 r}{(2r)^2}$

$P = \frac{\varepsilon^2 r}{4r^2} = \boxed{\frac{\varepsilon^2}{4r} = P}$

Wheatstone Bridge :-

It is an arrangement of four resistance, P, Q, R and S joind to form a quadrilateral ABCD with a Battery between A and C and sensitive galvanometer between A and D. The resistance are so adjusted that no current flower through the galvanometer. The Bridge is then said to be balanced.

In the balanced condition.

$$\boxed{\frac{P}{Q} = \frac{R}{S}}$$

Knowing any three resistance, fourth can be computed.

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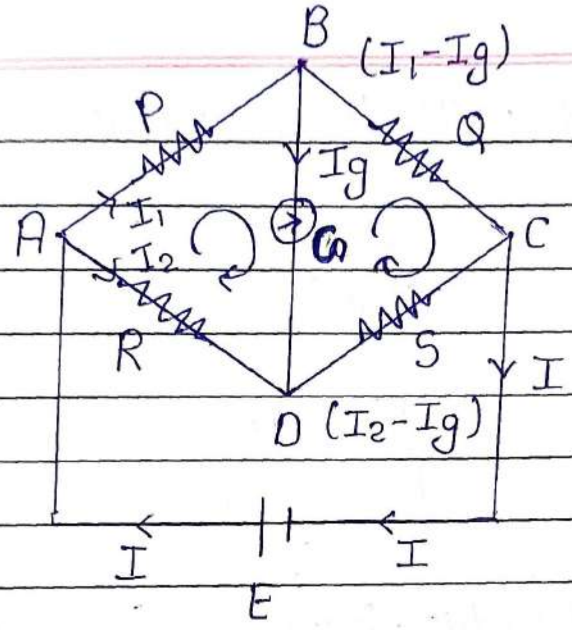

In loop ABCD $\Delta V = 0$

$I_1 P + I_g G - I_2 R = 0$

In balance bridge, $I_g = 0$

$I_1 P = I_2 R$ —— (1)

In loop BCDB

$(I_1 - I_g) Q - (I_2 + I_g) S - I_g G = 0$

In Balance, $I_g = 0$

$I_1 Q - I_2 S = 0$

$I_1 Q = I_2 S$ —— (2)

Divide (1) by (2)

$$\frac{I_1 P}{I_1 Q} = \frac{I_2 R}{I_2 S}$$

$\Rightarrow \boxed{\frac{P}{Q} = \frac{R}{S}}$ proved.

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Q.) At room temperature (27.0°C) the resistance of a heating element is 100 Ω. What is the temperature of the element if the resistance is found to be 117 Ω. Given that the temperature coefficient of the material of the resistor is 1.70×10^{-4} °C^{-1}.

Soln- A/q

$t_1 = 27°C = 273 + 27 = 300 K$

$R_1 = 100 \Omega$

$R_2 = 117 \Omega$

$\alpha = 1.70 \times 10^{-4}$ °C^{-1}

$t_2 = ?$

We know that

$$\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$$

$$t_2 - t_1 = \frac{R_2 - R_1}{R_1 \times \alpha}$$

$$d_2 - 300 = \frac{117 - 100}{100 \times 1.70 \times 10^{-4}}$$

$$t_2 - 300 = \frac{\cancel{17}\ 10}{10^2 \times \cancel{17} \times 10^{-4}}$$

$$t_2 - 300 = 10^3$$

$$t_2 - 300 = 1000$$

$$t_2 = 1000 + 300$$

$$= 1300 K$$

$$= 1300 - 273$$

$$= 1027°C \text{ ans.}$$

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Q.) A sliver wire has a resistance of 2.1 Ω at 27.5°C, and a resistance of 2.7 Ω at 100°C. Determine the temperature coefficient of resistivity of silver.

Soln:- A/q

$R_1 = 2.1\ \Omega$

$t_1 = 27.5°C = 27.5 + 273 = 300.5\ K$

$R_2 = 2.7\ \Omega$

$t_2 = 100°C = 100 + 273 = 373\ K$

$\alpha = ?$

we know that,

$$\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$$

$$\alpha = \frac{2.7 \times 2.1}{2.1\,(373 - 300.5)}$$

$$\alpha = \frac{0.6}{2.1 \times 72.5} \Rightarrow \frac{0.6}{152.25}$$

$$\alpha = 0.00394\ °C^{-1}$$

Q.) A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A. which settles after a few second to a steady value of 2.8 A. what is the steady temperature of the heating element if the room temperature is 27.0 °C? Temperature coefficient of resistance of nichrome overaged the temperature range involved is $1.70 \times 10^{-4}\ C^{-1}$.

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Solⁿ:- A/q

$V = 230\,V$

$I_1 = 3.2\,A$

$I_2 = 2.8\,A$

$t_1 = 27°C = 300\,K$

$\alpha = 1.70 \times 10^{-7}\,°C^{-1}$

$t_2 = ?$

$$R_1 = \frac{V}{I_1} = \frac{230}{3.2}$$

$$R_2 = \frac{V}{I_2} = \frac{230}{2.8}$$

$$\alpha = \frac{R_2 - R_1}{R_1(d_2 - t_1)}$$

$$t_2 - t_1 = \frac{R_2 - R_1}{R_1 \times \alpha}$$

$$t_2 - t_1 = \frac{\frac{230}{2.8} - \frac{230}{3.2}}{\frac{230}{3.2} \times 1.7 \times 10^{-4}}$$

$$t_2 - t_1 = \frac{230\,(1/2.8 - 1/3.2)}{230 \times (1.7 \times 10^{-4})}$$

$$t_2 - t_1 = \frac{\frac{3.2}{2.8} - \frac{3.2}{3.2}}{1.7 \times 10^{-4}}$$

$$t_2 - t_1 = \frac{8/7 - 1}{1.7 \times 10^{-4}}$$

$$t_2 - t_1 = \frac{1}{7 \times 1.7 \times 10^{-4}} \Rightarrow \frac{10^4}{11.9}$$

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$$t_2 - t_1 = \frac{100}{11.9} \times 10^2$$

$$t_2 - t_1 = 8.4 \times 10^2$$

$$t_2 - 300 = 840$$

$$t_2 = 840 + 300$$

$$t_2 = 1140\ K$$

$$t_2 = 1140 - 273 \Rightarrow 867\ °C \text{ ans}$$

Q.) The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4 Ω. what is the maximum current that can be drawn from the battery?

Solⁿ:- A/q

$E = 12\,V$

$r = 0.4\,\Omega$

$I_{max} = ?$

we know that,

$$I_{max} = \frac{E}{R}$$

$$\therefore I_{max} = \frac{12\,V}{0.4\,\Omega}$$

$$I_{max} = 30\,V\,\Omega^{-1}$$

$$= 30\,A \text{ ans}$$

Q.) A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the

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Current in the circuit is 0.5 A. what is the resistance of the resistor? what is the terminal voltage of the battery when the circuit is closed?

Soln:- A/q

$E = 10V$
$r = 3\Omega$
$I = 0.5A$
$R = ?$
$V = ?$

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

$$R = \left(\frac{E}{I}\right) - r$$

$$= \left(\frac{10}{0.5}\right) - 3 \Rightarrow 20 - 3 \Rightarrow 17\Omega$$

we know that,

$$V = IR$$
$$= 0.5A \times 17\Omega$$
$$= 8.5V \text{ ans.}$$

Q.) A storage battery of emf 8.0V and internal resistance 0.5 Ω is being charged by a 120 V dc supply using a series resistor of 15.5 Ω. what is the terminal voltage of the battery during charging? what is the purpose of having a series resistor in the charging circuit?

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Soln:- A/q

$E = 8V$
$r = 0.5\,\Omega$
$R = 15.5\,\Omega$

Supply voltage = 120 V
$V = ?$

Total emf of cell $= 120 - 8$
$= 112$ V

Total resistance $= 15.5 + 0.5$
$= 16\,\Omega$

$$I = \frac{\text{Total emf}}{\text{Total resistance}}$$

$$I = \frac{112}{16} = 7A$$

Now,
$E = V - Ir$
$V - Ir = E$
$V = E + Ir$
$= 8 + 7 \times 0.5$
$= 8 + 3.5$
$= 11.5$ V ans

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