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CURRENT ELECTRICITY

In previous chapters we deal largely with electrostatics that is, with charges at rest. With this chapter we begin to focus on electric currents, that is, charges in motion.

ELECTRIC CURRENT

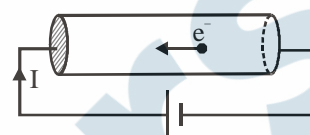
Electric charges in motion constitute an electric current. Any medium having practically free electric charges, free to migrate is a conductor of electricity. The electric charge flows from higher potential energy state to lower potential energy state.

Positive charge flows from higher to lower potential and negative charge flows from lower to higher. Metals such as gold, silver, copper, aluminium etc. are good conductors.

When charge flows in a conductor from one place to the other, then the rate of flow of charge is called electric current (I). When there is a transfer of charge from one point to other point in a conductor, we say that there is an electric current through the area. If the moving charges are positive, the current is in the direction of motion of charge. If they are negative the current is opposite to the direction of motion. If a charge ΔQ crosses an area in time Δt then the average electric current through the area, during this time as

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

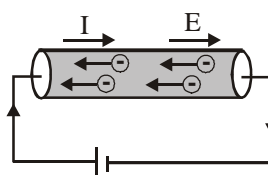
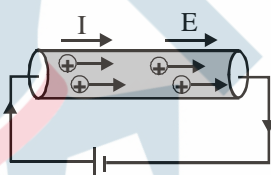
• Instantaneous current $I = \lim_{\Delta t \rightarrow 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$



- Current is a fundamental quantity with dimension $[M^0 L^0 T^0 A^1]$
- Current is a scalar quantity with its SI unit **ampere**.

Ampere : The current through a conductor is said to be one ampere if one coulomb of charge is flowing per second through a cross-section of wire.

- The conventional direction of current is the direction of flow of positive charge or applied field. It is opposite to direction of flow of negatively charged electrons.



- The conductor remains uncharged when current flows through it because the charge entering at one end per second is equal to charge leaving the other end per second.
- For a given conductor current does not change with change in its cross-section because current is simply rate of flow of charge.
- If there are n particles per unit volume each having a charge q and moving with velocity v then

current through cross-sectional area A is $I = \frac{\Delta q}{\Delta t} = nqvA$

- If a charge q is moving in a circle of radius r with speed v then its time period is $T = 2\pi r/v$. The

equivalent current $I = \frac{q}{T} = \frac{qv}{2\pi r}$.

Behavior of conductor in absence of applied potential difference :

In absence of applied potential difference electrons have random motion. The average displacement and average velocity is zero. There is no flow of current due to thermal motion of free electrons in a conductor.

The free electrons present in a conductor gain energy from temperature of surrounding and move randomly in the conductor.

The speed gained by virtue of temperature is called as thermal speed of an electron $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}kt$

So thermal speed $v_{rms} = \sqrt{\frac{3kT}{m}}$ where m is mass of electron

At room temperature $T = 300 \text{ K}$, $v_{rms} = 10^5 \text{ m/s}$

- **Mean free path λ :** $(\lambda \sim 10\text{\AA}) = \lambda = \frac{\text{total distance travelled}}{\text{number of collisions}}$
- **Relaxation time :** The time taken by an electron between two successive collisions is called as relaxation time τ : $(\tau \sim 10^{-14}\text{s})$, Relaxation time : $\tau = \frac{\text{total time taken}}{\text{number of collisions}}$

Behavior of conductor in presence of applied potential difference :

When two ends of a conductors are joined to a battery then one end is at higher potential and another at lower potential. This produces an electric field inside the conductor from point of higher to lower potential

$E = \frac{V}{L}$ where V = emf of the battery, L = length of the conductor.

The field exerts an electric force on free electrons causing acceleration of each electron.

Acceleration of electron $\vec{a} = \frac{\vec{F}}{m} = \frac{-e\vec{E}}{m}$

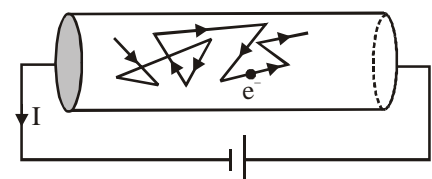
DRIFT VELOCITY

Drift velocity is defined as the velocity with which the free electrons get drifted towards the positive terminal under the effect of the applied external electric field. In addition to its thermal velocity, due to acceleration given by applied electric field, the electron acquires a velocity component in a direction opposite to the direction of the electric field. The gain in velocity due to the applied field is very small and is lost in the next collision.

At any given time, an electron has a velocity $\vec{v}_1 = \vec{u}_1 + \vec{a}\tau_1$, where \vec{u}_1 = the thermal velocity and $\vec{a}\tau_1$ = the velocity acquired by the electron under the influence of the applied electric field.

τ_1 = the time that has elapsed since the last collision. Similarly, the velocities of the other electrons are $\vec{v}_2 = \vec{u}_2 + \vec{a}\tau_2$, $\vec{v}_3 = \vec{u}_3 + \vec{a}\tau_3$, ..., $\vec{v}_N = \vec{u}_N + \vec{a}\tau_N$.

The average velocity of all the free electrons in the conductor is equal to the drift velocity \vec{v}_d of the free electrons



Under the action of electric field :
Random motion of an electron
with superimposed drift

$$\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + \vec{v}_3 + \dots + \vec{v}_N}{N} = \frac{(u_1 + \vec{a}\tau_1) + (\vec{u}_2 + \vec{a}\tau_2) + \dots + (\vec{u}_N + \vec{a}\tau_N)}{N} = \frac{(\vec{u}_1 + \vec{u}_2 + \dots + \vec{u}_N)}{N} + \vec{a} \left(\frac{\tau_1 + \tau_2 + \dots + \tau_N}{N} \right)$$

$$\therefore \frac{\vec{u}_1 + \vec{u}_2 + \dots + \vec{u}_N}{N} = 0 \quad \therefore \vec{v}_d = \vec{a} \left(\frac{\tau_1 + \tau_2 + \dots + \tau_N}{N} \right) \Rightarrow \vec{v}_d = \vec{a}\tau = -\frac{e\vec{E}}{m}\tau$$

Note : Order of drift velocity is 10^{-4} m/s.

Relation between current and drift velocity :

Let n = number density of free electrons and A = area of cross-section of conductor.

Number of free electrons in conductor of length $L = nAL$, Total charge on these free electrons

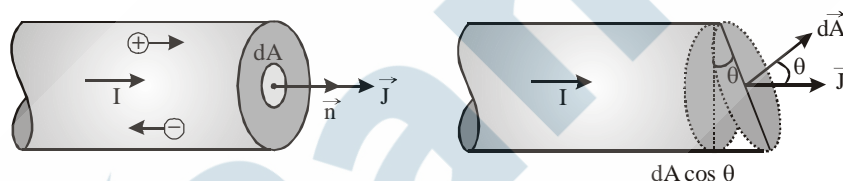
$$\Delta q = neAL$$

Time taken by drifting electrons to cross conductor $\Delta t = \frac{L}{v_d} \therefore$ current $I = \frac{\Delta q}{\Delta t} = neAL \left(\frac{v_d}{L} \right) = neAv_d$

CURRENT DENSITY (J)

Current is a macroscopic quantity and deals with the overall rate of flow of charge through a section. To specify the current with direction in the microscopic level at a point, the term current density is introduced. Current density at any point inside a conductor is defined as a vector having magnitude equal to current per unit area surrounding that point. Remember area is normal to the direction of charge flow (or current passes) through that point.

- Current density at point P is given by $\vec{J} = \frac{dI}{dA} \vec{n}$



- If the cross-sectional area is not normal to the current, but makes an angle θ with the direction of current then $J = \frac{dI}{dA \cos \theta} \Rightarrow dI = J dA \cos \theta = \vec{J} \cdot d\vec{A} \Rightarrow I = \int \vec{J} \cdot d\vec{A}$
- Current density \vec{J} is a vector quantity. It's direction is same as that of \vec{E} . It's S.I. unit is ampere/m² and dimension $[L^{-2}A]$.

Ex. The current density at a point is $\vec{J} = (2 \times 10^4 \hat{j}) \text{ Jm}^{-2}$.

Find the rate of charge flow through a cross sectional area $\vec{S} = (2\hat{i} + 3\hat{j}) \text{ cm}^2$

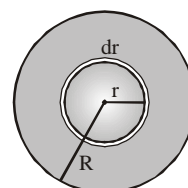
Sol. The rate of flow of charge = current = $I = \int \vec{J} \cdot d\vec{S} \Rightarrow I = \vec{J} \cdot \vec{S} = (2 \times 10^4) [\hat{j} \cdot (2\hat{i} + 3\hat{j})] \times 10^{-4} \text{ A} = 6 \text{ A}$

Ex. A potential difference applied to the ends of a wire made up of an alloy drives a current through it. The current density varies as $J = 3 + 2r$, where r is the distance of the point from the axis. If R be the radius of the wire, then the total current through any cross section of the wire.

Sol. Consider a circular strip of radius r and thickness dr

$$dI = \vec{J} \cdot d\vec{S} = (3 + 2r)(2\pi r dr) \cos 0^\circ = 2\pi(3r + 2r^2) dr$$

$$I = \int_0^R 2\pi(3r + 2r^2) dr = 2\pi \left(\frac{3r^2}{2} + \frac{2}{3}r^3 \right)_0^R = 2\pi \left(\frac{3R^2}{2} + \frac{2R^3}{3} \right) \text{ units}$$



RELATION BETWEEN CURRENT DENSITY, CONDUCTIVITY AND ELECTRIC FIELD

Let the number of free electrons per unit volume in a conductor = n

Total number of electrons in dx distance = $n (A dx)$

Total charge $dQ = n (A dx)e$

Current $I = \frac{dQ}{dt} = nAe \frac{dx}{dt} = neAv_d$, Current density $J = \frac{I}{A} = nev_d$

$$= ne \left(\frac{eE}{m} \right) \tau \because v_d = \left(\frac{eE}{m} \right) \tau \Rightarrow J = \left(\frac{ne^2 \tau}{m} \right) E \Rightarrow J = \sigma E, \text{ where conductivity } \sigma = \frac{ne^2 \tau}{m}$$

σ depends only on the material of the conductor and its temperature.

In vector form $\vec{J} = \sigma \vec{E}$ Ohm's law (at microscopic level)

RELATION BETWEEN POTENTIAL DIFFERENCE AND CURRENT (Ohm's Law)

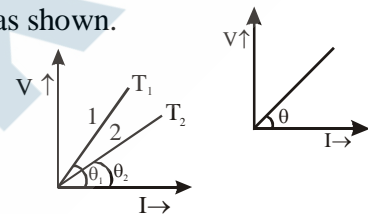
If the physical conditions of the conductor (length, temperature, mechanical strain etc.) remains same, then the current flowing through the conductor is directly proportional to the potential difference across its two ends i.e. $I \propto V \Rightarrow V = IR$ where R is a proportionality constant, known as electric resistance. Ohm's law (at macroscopic level)

- Ohm's law is not a universal law. The substances, which obey ohm's law are known as ohmic.
- Graph between V and I for a metallic conductor is a straight line as shown.

$$\text{Slope of the line} = \tan \theta = \frac{V}{I} = R$$

At different temperatures V - I curves are different.

Here $\tan \theta_1 > \tan \theta_2$ So $R_1 > R_2$ i.e. $T_1 > T_2$



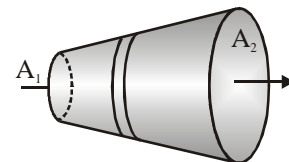
- 1 ampere of current means the flow of 6.25×10^{18} electrons per second through any cross section of conductor.
- Current is a scalar quantity but current density is a vector quantity.
- Order of free electron density in conductors = 10^{28} electrons/ m^3

Terms	Thermal speed	Mean free path	Relaxation time	Drift speed
	v_T	λ	τ	v_d
Order	10^5 m/s	10 \AA	10^{-14} s	10^{-4} m/s

- If a steady current flows in a metallic conductor of non uniform cross section.

Current density and drift velocity depends on area

$$I_1 = I_2, A_1 < A_2 \Rightarrow J_1 > J_2, E_1 > E_2, v_{d1} > v_{d2}$$



- If the temperature of the conductor increases, the amplitude of the vibrations of the positive ions in the conductor also increase. Due to this, the free electrons collide more frequently with the vibrating ions and as a result, the average relaxation time decreases.

Ex. What will be the number of electron passing through a heater wire in one minute, if it carries a current of 8 A.

Sol. $I = \frac{Ne}{t} \Rightarrow N = \frac{It}{e} = \frac{8 \times 60}{1.6 \times 10^{-19}} = 3 \times 10^{21}$ electrons

Ex. A current of 1.34 A exists in a copper wire of cross-section 1.0 mm^2 . Assuming each copper atom contributes one free electron. Calculate the drift speed of the free electrons in the wire. The density of copper is 8990 kg/m^3 and atomic mass = 63.50.

Sol. Mass of 1 m^3 volume of the copper is = $8990 \text{ kg} = 8990 \times 10^3 \text{ g}$

$$\text{Number of moles in } 1 \text{ m}^3 = \frac{8990 \times 10^3}{63.5} = 1.4 \times 10^5$$

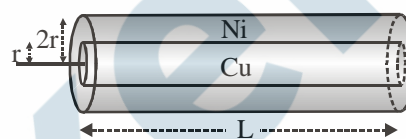
Since each mole contains 6×10^{23} atoms therefore number of atoms in 1 m^3

$$n = (1.4 \times 10^5) \times (6 \times 10^{23}) = 8.4 \times 10^{28}$$

$$\therefore I = neAv_d \therefore v_d = \frac{I}{neA} = \frac{1.34}{8.4 \times 10^{28} \times 1.6 \times 10^{-19} \times 10^{-6}} = 10^{-4} \text{ m/s} = 0.1 \text{ mm/s} (\because 1 \text{ mm}^2 = 10^{-6} \text{ m}^2)$$

Ex. A copper wire of length ' ℓ ' and radius ' r ' is nickel plated till its final radius is $2r$. If the resistivity of the copper and nickel are ρ_{Cu} and ρ_{Ni} , then find the equivalent resistance of wire?

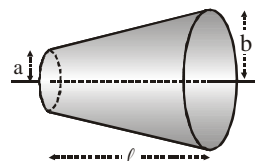
Sol. $R = \rho \frac{\ell}{A}$; Resistance of copper wire $R_{\text{Cu}} = \rho_{\text{Cu}} \frac{\ell}{\pi r^2}$
($\because A = \pi r^2$)



$$\therefore A_{\text{Ni}} = \pi(2r)^2 - \pi r^2 = 3\pi r^2 \Rightarrow \text{Resistance of Nickel wire } R_{\text{Ni}} = \rho_{\text{Ni}} \frac{\ell}{3\pi r^2}$$

Both wire are connected in parallel. So equivalent resistance $R = \frac{R_{\text{Cu}} R_{\text{Ni}}}{R_{\text{Cu}} + R_{\text{Ni}}} = \left(\frac{\rho_{\text{Cu}} \rho_{\text{Ni}}}{3\rho_{\text{Cu}} + \rho_{\text{Ni}}} \right) \frac{\ell}{\pi r^2}$

Ex. Figure shows a conductor of length ℓ carrying current I and having a circular cross-section. The radius of cross section varies linearly from a to b . Assuming that $(b - a) \ll \ell$. Calculate current density at distance x from left end.



Sol. Since radius at left end is a and that of right end is b ,
Therefore increase in radius over length ℓ is $(b - a)$.

$$\text{Hence rate of increase of radius per unit length} = \left(\frac{b - a}{\ell} \right) \text{ Increase in radius over length } x = \left(\frac{b - a}{\ell} \right) x$$

$$\text{Since radius at left end is } a \text{ so radius at distance } x, r = a + \left(\frac{b - a}{\ell} \right) x$$

$$\text{Area at this particular section } A = \pi r^2 = \pi \left[a + \left(\frac{b - a}{\ell} \right) x \right]^2$$

$$\text{Hence current density } J = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{I}{\pi \left[a + \frac{x(b - a)}{\ell} \right]^2}$$

RESISTANCE

The resistance of a conductor is the opposition which the conductor offers to the flow of charge. When a potential difference is applied across a conductor, free electrons get accelerated and collide with positive ions and their motion is thus opposed. This opposition offered by the ions is called resistance of the conductor.

Resistance is the property of a conductor by virtue of which it opposes the flow of current in it.

Unit : ohm, volt/ampere,

Dimension = $M L^2 T^{-3} A^{-2}$

Resistance depends on :

- Length of the conductor ($R \propto \ell$)

- Area of cross-section of the conductor $R \propto \frac{1}{A}$

- Nature of material of the conductor $R = \frac{\rho \ell}{A}$

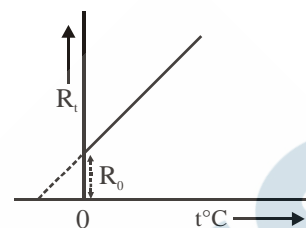
- Temperature $R_t = R_0 (1 + \alpha \Delta t)$

Where

R_t = Resistance at $t^\circ C$, R_0 = Resistance at $0^\circ C$

Δt = Change in temperature, α = Temperature coefficient of resistance

*[For metals : α positive *for semiconductors : α negative]

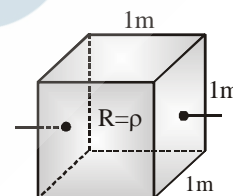


RESISTIVITY

Resistivity : $\rho = RA/\ell$ if $\ell = 1m$, $A = 1m^2$ then $\rho = R$

The specific resistance of a material is equal to the resistance of the wire of that material with unit cross – section area and unit length.

Resistivity depends on (i) Nature of material (ii) Temperature of material ρ does not depend on the size and shape of the material because it is the characteristic property of the conductor material.



Specific use of conducting materials :

- The **heating element** of devices like heater, geyser, press etc are made of **michrome** because it has high resistivity and high melting point. It does not react with air and acquires steady state when red hot at $800^\circ C$.
- **Fuse wire** is made of **tin lead alloy** because it has low melting point and low resistivity. The fuse is used in series, and melts to produce open circuit when current exceeds the safety limit.
- **Resistances** of resistance box are made of **manganin** or **constantan** because they have moderate resistivity and very small temperature coefficient of resistance. The resistivity is nearly independent of temperature.
- The **filament of bulb** is made up of **tungsten** because it has low resistivity, high melting point of $3300 K$ and gives light at $2400 K$. The bulb is filled with inert gas because at high temperature it reacts with air forming oxide.
- The **connection wires** are made of **copper** because it has low resistance and resistivity.

KIRCHHOFF'S LAW

There are two laws given by Kirchhoff for determination of potential difference and current in different branches of any complicated network.

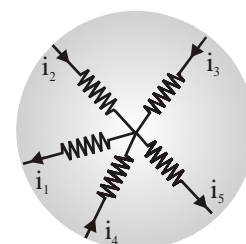
Law of conservation of charge is a consequence of continuity equation

- **First law (Junction Law or Current Law)**

In an electric circuit, the algebraic sum of the current meeting at any junction in the circuit is zero or Sum of the currents entering the Junction is equal to sum of the current leaving the Junction. $\Sigma i = 0$

$$i_1 - i_2 - i_3 - i_4 + i_5 = 0 \Rightarrow i_1 + i_5 = i_2 + i_3 + i_4$$

This is based on law of conservation of charge.



• **Second law (loop rule or potential law)**

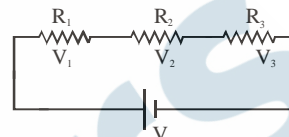
In any closed circuit the algebraic sum of all potential differences and e.m.f. is zero. $\Sigma E - \Sigma IR = 0$ while moving from negative to positive terminal inside the cell, e.m.f. is taken as positive while moving in the direction of current in a circuit the potential drop (i.e. IR) across resistance is taken as positive.

This law is based on law of conservation of energy.

COMBINATION OF RESISTANCE

Series Combination

- Same current passes through each resistance
- Voltage across each resistance is directly proportional to its value
 $V_1 = IR_1, V_2 = IR_2, V_3 = IR_3$
- Sum of the voltage across resistance is equal to the voltage applied across the circuit.
 $V = V_1 + V_2 + V_3 \Rightarrow IR = IR_1 + IR_2 + IR_3 \Rightarrow R = R_1 + R_2 + R_3$ Where R = equivalent resistance



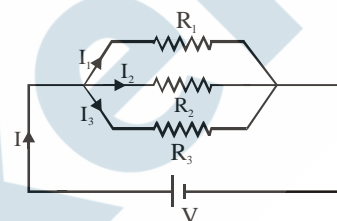
Parallel Combination

- There is same drop of potential across each resistance.
- Current in each resistance is inversely proportional to the

value of resistance. $I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$

- Current flowing in the circuit is sum of the currents in individual resistance.

$$I = I_1 + I_2 + I_3 \Rightarrow \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



- To get maximum resistance, resistance must be connected in series and in series the resultant is greater than largest individual.
- To get minimum resistance, resistance must be connected in parallel and the equivalent resistance of parallel combination is lower than the value of lowest resistance in the combination.

• **In general :**

- Resistivity of alloys is greater than their metals.
- Temperature coefficient of alloys is lower than pure metals.
- The resistivity of an insulator (e.g. amber) is greater than the metal by a factor of 10^{22}

Ex. The resistance $4R, 16R, 64R \dots \infty$ are connected in series. Find their equivalent resistance.

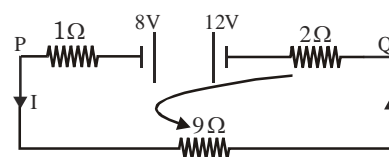
Sol. Resultant of the given combination $R_{eq} = 4R + 16R + 64R + \dots \infty = \infty$

Ex. Resistance $R, 2R, 4R, 8R \dots \infty$ are connected in parallel. What is their resultant resistance ?

Sol. $\frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{2R} + \frac{1}{4R} + \frac{1}{8R} \dots \infty = \frac{1}{R} \left[1 + \frac{1}{2} + \frac{1}{4} + \dots \infty \right] = \frac{1}{R} \left[\frac{1}{1 - \frac{1}{2}} \right] = \frac{2}{R} \Rightarrow R_{eq} = \frac{R}{2}$

Ex. In the given circuit calculate potential difference between the points P and Q.

Sol. Applying Kirchhoff's voltage law (KVL)



$$12 - 8 = (1)I + (9)I + (2)I \Rightarrow I = \frac{1}{3} \text{ A}$$

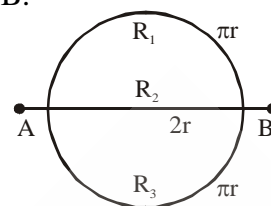
Potential difference between the points P and Q, $V_P - V_Q = 9 \times \frac{1}{3} = 3 \text{ volt}$

Ex. A wire of $\rho_L = 10^{-6} \Omega/\text{m}$ is turned in the form of a circle of diameter 2 m. A piece of same material is connected in diameter AB. Then find resistance between A and B.

Sol. $\therefore R = \rho_L \times \text{length}$

$$\therefore R_1 = \pi \times 10^{-6} \Omega, R_2 = 2 \times 10^{-6} \Omega, R_3 = \pi \times 10^{-6} \Omega$$

$$\frac{1}{R_{AB}} = \frac{1}{\pi \times 10^{-6}} + \frac{1}{2 \times 10^{-6}} + \frac{1}{\pi \times 10^{-6}}; R_{AB} = 0.88 \times 10^{-6} \text{ ohm.}$$



CELL

Cell convert chemical energy into electrical energy.

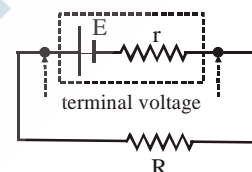
ELECTRO MOTIVE FORCE (E. M. F.)

The potential difference across the terminals of a cell when it is not giving any current is called emf of the cell. The energy given by the cell in the flow of unit charge in the whole circuit (including the cell) is called the emf of the cell.

- emf depends on : (i) nature of electrolyte (ii) metal of electrodes
- emf does not depend on : (i) area of plates (ii) distance between the electrodes (iii) quantity of electrolyte (iv) size of cell

TERMINAL VOLTAGE (V)

- When current is drawn through the cell or current is supplied to cell then, the potential difference across its terminals called terminal voltage.
- When I current is drawn from cell, then terminal voltage is less than it's e.m.f. $V = E - Ir$

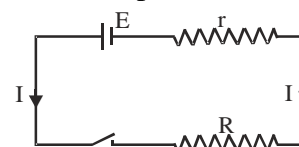


- **Terminal Potential Difference :** The potential difference between the two electrodes of a cell in a closed circuit i.e. when current is being drawn from the cell is called terminal potential difference.

(a) When cell is discharging :

Current inside the cell is from cathode to anode.

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

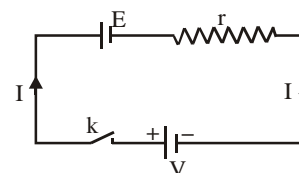


When current is drawn from the cell potential difference is less than emf of cell. Greater is the current drawn from the cell smaller is the terminal voltage. When a large current is drawn from a cell its terminal voltage is reduced.

(b) When cell is charging :

Current inside the cell is from anode to cathode.

$$\text{Current } I = \frac{V - E}{r} \Rightarrow V = E + Ir$$



During charging terminal potential difference is greater than emf of cell.

(c) When cell is in open circuit :

$$\text{In open circuit } R = \infty \therefore I = \frac{E}{R + r} = 0 \Rightarrow V = E$$

In open circuit terminal potential difference is equal to emf and is the maximum potential difference which a cell can provide.

(d) **When cell is short circuited :**

In short circuit $R = 0 \Rightarrow I = \frac{E}{R + r} = \frac{E}{r}$ and $V = IR = 0$

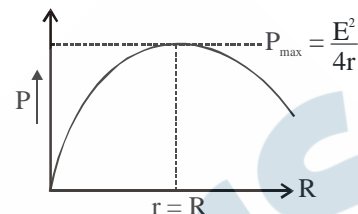
In short circuit current from cell is maximum and terminal potential difference is zero.

(e) **Power transferred to load by cell :**

$$P = I^2 R = \frac{E^2 R}{(r + R)^2} \Rightarrow P = P_{\max} \text{ if } \frac{dP}{dR} = 0 \Rightarrow r = R$$

Power transferred by cell to load is maximum when

$$r = R \text{ and } P_{\max} = \frac{E^2}{4r} = \frac{E^2}{4R}$$



COMBINATION OF CELLS

• **Series combination**

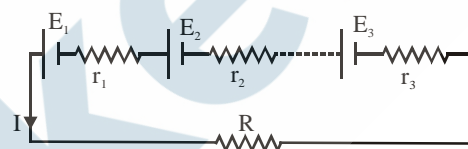
When the cells are connected in series the total e.m.f. of the series combination is equal to the sum of the e.m.f.'s of the individual cells and internal resistance of the cells also come in series.

Equivalent internal resistance $r = r_1 + r_2 + r_3 + \dots$

Equivalent emf $= E = E_1 + E_2 + E_3 + \dots$

Current $I = \frac{E_{\text{net}}}{r_{\text{net}} + R}$, If all n cell are identical then $I = \frac{nE}{nr + R}$

• If $nr \gg R$, $I = \frac{E}{r} \approx$ current from one cell • If $nr \ll R$, $I = \frac{nE}{R} \approx n \times$ current from one cell



• **Parallel combination**

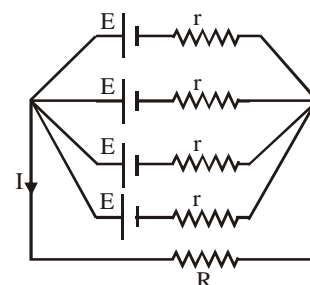
When the cells are connected in parallel, the total e.m.f. of the parallel combination remains equal to the e.m.f. of a single cell and internal resistance of the cell also come in parallel. If m identical cell

connected in parallel then total internal resistance of this combination $r_{\text{net}} = \frac{r}{m}$. Total e.m.f. of this combination $= E$

$$\text{Current in the circuit } I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$$

If $r \ll mR$ $I = E/R =$ Current from one cell

If $r \gg mR$ $I = \frac{mE}{r} = m \times$ current from one cell



• **Mixed combination**

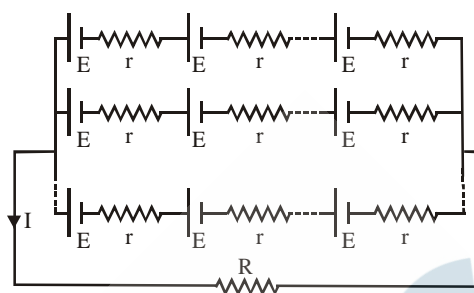
If n cells connected in series and there are m such branches in the circuit then total number of identical cell in this circuit is nm . The internal resistance of the cells connected in a row $= nr$. Since there are such m rows,

Total internal resistance of the circuit $r_{\text{net}} = \frac{nr}{m}$

Total e.m.f. of the circuit = total e.m.f. of the cells connected in a row

$$E_{\text{net}} = nE$$

$$\text{Current in the circuit } I = \frac{E_{\text{net}}}{R + r_{\text{net}}} = \frac{nE}{R + \frac{nr}{m}}$$



Current in the circuit is maximum when external resistance in the circuit is equal to the total internal

resistance of the cells $R = \frac{nr}{m}$

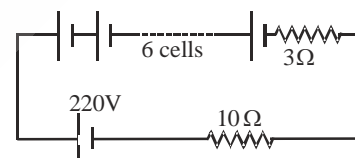
- At the time of charging a cell when current is supplied to the cell, the terminal voltage is greater than the e.m.f. E , $V = E + Ir$
- Series combination is useful when internal resistance is less than external resistance of the cell.
- Parallel combination is useful when internal resistance is greater than external resistance of the cell.
- Power in R (given resistance) is maximum, if its value is equal to net resistance of remaining circuit.
- Internal resistance of ideal cell = 0
- if external resistance is zero then current given by circuit is maximum.

Ex. A battery of six cells each of e.m.f. 2 V and internal resistance 0.5Ω is being charged by D. C. mains of e.m.f. 220 V by using an external resistance of 10Ω . What will be the charging current.

Sol. Net e.m.f. of the battery = 12V and total internal resistance = 3Ω

Total resistance of the circuit = $3 + 10 = 13 \Omega$

$$\text{Charging current } I = \frac{\text{Net e.m.f.}}{\text{total resistance}} = \frac{220 - 12}{13} = 16 \text{ A}$$



Ex. A battery of six cells each of e.m.f. 2 V and internal resistance 0.5Ω is being charged by D. C. mains of e.m.f. 220 V by using an external resistance of 10Ω . What is the potential difference across the battery?

Sol. In case of charging of battery, terminal potential $V = E + Ir = 12 + 16 \times 3 = 60$ volt.

Ex. Four identical cells each of e.m.f. 2V are joined in parallel providing supply of current to external circuit consisting of two 15Ω resistors joined in parallel. The terminal voltage of the equivalent cell as read by an ideal voltmeter is 1.6V calculate the internal resistance of each cell.

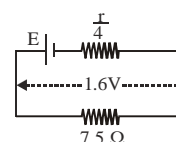
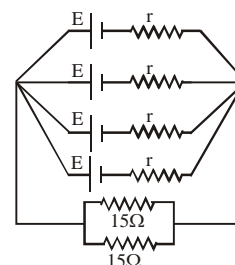
Sol. Total internal resistance of the combination $r_{\text{eq}} = \frac{r}{4}$

Total e.m.f. $E_{\text{eq}} = 2\text{V}$

$$\text{Total external resistance } R = \frac{15 \times 15}{15 + 15} = \frac{15}{2} = 7.5 \Omega$$

$$\text{Current drawn from equivalent cell } I = \frac{\text{terminal potential}}{\text{external resistance}} = \frac{1.6}{7.5} \text{ A}$$

$$\therefore E - I \left(\frac{r}{4} \right) = 1.6 \quad \therefore E - I \left(\frac{r}{4} \right) = 1.6 \Rightarrow r = 7.5 \Omega$$



Ex. The e.m.f. of a primary cell is 2 V, when it is shorted then it gives a current of 4 A. Calculate internal resistance of primary cell.

Sol. $I = \frac{E}{r + R}$, If cell is shorted then $R = 0$, $I = \frac{E}{r} \therefore r = \frac{E}{I} = \frac{2}{4} = 0.5 \Omega$

Ex. n rows each containing m cells in series, are joined in parallel. Maximum current is taken from this combination in a 3Ω resistance. If the total number of cells used is 24 and internal resistance of each cell is 0.5Ω , find the value of m and n.

Sol. Total number of cell $mn = 24$, For maximum current $\frac{mr}{n} = R \Rightarrow 0.5 m = 3 n$, $m = \frac{3n}{0.5} = 6n$

$$\therefore 6n \times n = 24 \Rightarrow n = 2 \text{ and } m \times 2 = 24 \Rightarrow m = 12$$

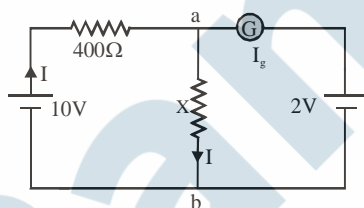
Ex. In the given circuit calculate potential difference between A and B.

Sol. First applying KVL on left mesh $2 - 3 I_1 - 2 I_1 = 0 \Rightarrow I_1 = 0.4 \text{ amp}$.
Now applying KVL on right mesh. $4 - 5 I_2 - 3 I_2 = 0 \Rightarrow I_2 = 0.5 \text{ amp}$.

Potential difference between points A and B

$$V_A - V_B = -3 \times 0.4 - 4 + 3 \times 0.5 = -3.7 \text{ volt.}$$

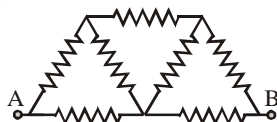
Ex. In the following circuit diagram, the galvanometer reading is zero. If the internal resistance of cells are negligible then what is the value of X ?



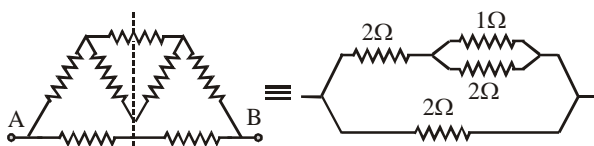
Sol. $\therefore I_g = 0 \quad \therefore I = \frac{10}{400 + X}$
also potential difference across X is 2V $\Rightarrow I X = 2$

$$\frac{10X}{400 + X} = 2 \left(\because I = \frac{10}{400 + X} \right) \Rightarrow X = 100 \Omega$$

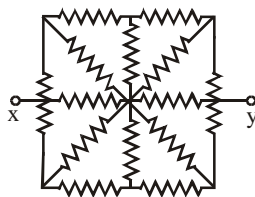
Ex. Each resistance is of 1Ω in the circuit diagram shown in figure. Find out equivalent resistance between A and B



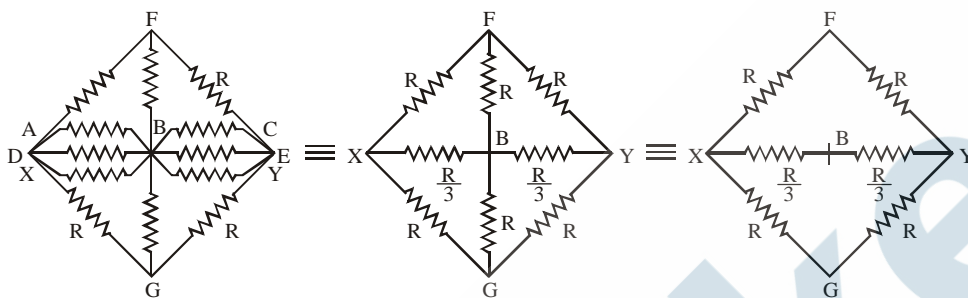
Sol. By symmetric line method $R_{AB} = (2 + 1 \parallel 2) \parallel 2 = \frac{8}{7} \Omega$



Ex. Identical resistance of resistance R are connected as in figure then find out net resistance between x and y .



Sol. Given circuit can be modified according to following figures



$$\frac{1}{R_{xy}} = \frac{1}{2R} + \frac{3}{2R} + \frac{1}{2R} = \frac{5}{2R} \Rightarrow R_{xy} = \frac{2R}{5}$$

HEATING EFFECT OF CURRENT

CAUSE OF HEATING

The potential difference applied across the two ends of conductor sets up electric field. Under the effect of electric field, electrons accelerate and as they move, they collide against the ions and atoms in the conductor, the energy of electrons transferred to the atoms and ions appears as heat.

- Joules's Law of Heating**

When a current I is made to flow through a passive or ohmic resistance R for time t , heat Q is produced such that

$$Q = I^2 R t = P \times t = V I t = \frac{V^2}{R} t$$

Heat produced in conductor does not depend upon the direction of current.

- SI unit** : joule ;

Practical Units : 1 kilowatt hour (kWh)

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ joule} = 1 \text{ unit}$$

$$1 \text{ BTU (British Thermal Unit)} = 1055 \text{ J}$$

- Power** : $P = V I = \frac{V^2}{R} = I^2 R$

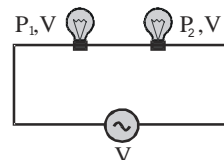
- SI unit** : Watt

The watt-hour meter placed on the premises of every consumer records the electrical energy consumed.

- Series combination of resistors (bulbs)**

$$\text{Total power consumed } P_{\text{total}} = \frac{P_1 P_2}{P_1 + P_2}$$

$$\text{If } n \text{ bulbs are identical } P_{\text{total}} = \frac{P}{n}$$



In series combination of bulbs : Brightness \propto Power consumed by bulb $\propto V \propto R \propto \frac{1}{P_{\text{rated}}}$

Bulb of lesser wattage will shine more. For same current $P = I^2 R$ $P \propto R$ $R \uparrow \Rightarrow P \uparrow$

- Parallel combination of resistors (bulbs)**

Total power consumed $P_{\text{total}} = P_1 + P_2$

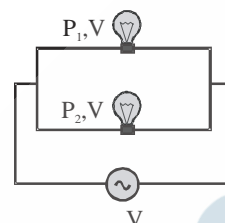
If n bulbs are identical $P_{\text{total}} = nP$

In parallel combination of bulbs

Brightness \propto Power consumed by bulb $\propto I \propto \frac{1}{R}$

Bulb of greater wattage will shine more.

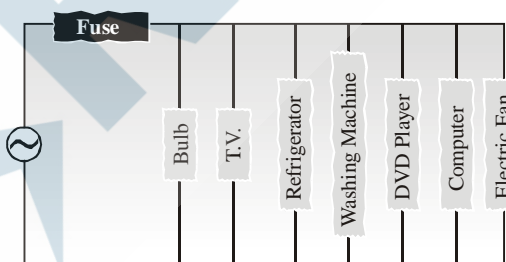
For same V more power will be consumed in smaller resistance $P \propto \frac{1}{R}$



- Two identical heater coils gives total heat H_s when connected in series and H_p when connected in parallel than $\frac{H_p}{H_s} = 4$ [In this, it is assumed that supply voltage is same]
- If a heater boils m kg water in time T_1 and another heater boils the same water in T_2 , then both connected in series will boil the same water in time $T_s = T_1 + T_2$ and in parallel $T_p = \frac{T_1 T_2}{T_1 + T_2}$ [Use time taken \propto Resistance]
- Instruments based on heating effect of current, works on both A.C. and D.C. Equal value of A.C. (RMS) and D.C. produces, equal heating effect. That why brightness of bulb is same whether it is operated by A.C. or same value D.C.

FUSE WIRE

The fuse wire for an electric circuit is chosen keeping in view the value of safe current through the circuit.



- The fuse wire should have high resistance per unit length and low melting point.
- However the melting point of the material of fuse wire should be above the temperature that will be reached on the passage of the current through the circuit
- A fuse wire is made of alloys of lead (Pb) and tin (Sn).
- Length of fuse wire is immaterial.
- The material of the filament of a heater should have high resistivity and high melting point.
- The temperature of the wire increases to such a value at which, the heat produced per second equals

heat lost per second due to radiation from the surface of wire $I^2 \left(\frac{\rho \ell}{\pi r^2} \right) = H \times 2\pi r \ell$ $I^2 \propto r^3$

H = heat lost per second per unit area due to radiation.

Ex. An electric heater and an electric bulb are rated 500 W, 220 V and 100 W, 220 V respectively. Both are connected in series to a 220 V a.c. mains. Calculate power consumed by (i) heater (ii) bulb.

Sol. $P = \frac{V^2}{R}$ or $R = \frac{V^2}{P}$, For heater. Resistance $R_h = \frac{(220)^2}{500} = 96.8 \Omega$,

For bulb resistance $R_L = \frac{(220)^2}{100} = 484 \Omega$

Current in the circuit when both are connected in series $I = \frac{V}{R_L + R_h} = \frac{220}{484 + 96.8} = 0.38 \text{ A}$

(i) Power consumed by heater $= I^2 R_h = (0.38)^2 \times 96.8 = 13.98 \text{ W}$

(ii) Power consumed by bulb $= I^2 R_L = (0.38)^2 \times 484 = 69.89 \text{ W}$

Ex. A heater coil is rated 100 W, 200 V. It is cut into two identical parts. Both parts are connected together in parallel, to the same source of 200 V. Calculate the energy liberated per second in the new combination.

Sol. $\therefore P = \frac{V^2}{R}$ $\therefore R = \frac{V^2}{P} = \frac{(200)^2}{100} = 400 \Omega$

Resistance of half piece $= \frac{400}{2} = 200 \Omega$

Resistance of pieces connected in parallel $= \frac{400}{2} = 100 \Omega$

Energy liberated/second $P = \frac{V^2}{R} = \frac{200 \times 200}{100} = 400 \text{ W}$

Ex. The power of a heater is 500W at 800°C. What will be its power at 200°C. If $\alpha = 4 \times 10^{-4}$ per °C?

Sol. $P = \frac{V^2}{R} \therefore \frac{P_{200}}{P_{800}} = \frac{R_{800}}{R_{200}} = \frac{R_0(1 + 4 \times 10^{-4} \times 800)}{R_0(1 + 4 \times 10^{-4} \times 200)} \Rightarrow P_{200} = \frac{500 \times 1.32}{1.08} = 611 \text{ W}$

Ex. When a battery sends current through a resistance R_1 for time t , the heat produced in the resistor is Q . When the same battery sends current through another resistance R_2 for time t , the heat produced in R_2 is again Q . Determine the internal resistance of battery.

Sol. $\left[\frac{E}{R_1 + r} \right]^2 R_1 = \left[\frac{E}{R_2 + r} \right]^2 R_2 \Rightarrow r = \sqrt{R_1 R_2}$

Ex. How much time heater will take to increase the temperature of 100 g water by 50°C if resistance of heating coil is 484Ω and supply voltage is 220V a.c.

Sol. Heat given by heater = heat taken by water $\Rightarrow \frac{V^2}{R} t = ms \Delta\theta \Rightarrow \frac{220 \times 220}{484} t = 100 \times 10^{-3} (4.2 \times 10^3) (50) \Rightarrow t = 210 \text{ s}$

GALVANOMETER

The instrument used to measure strength of current, by measuring the deflection of the coil due to torque produced by a magnetic field, is known as galvanometer.

SHUNT

The small resistance connected in parallel to galvanometer coil, in order to control current flowing through the galvanometer, is known as shunt.

- **Merits of shunt**

- (i) To protect the galvanometer coil from burning.
- (ii) Any galvanometer can be converted into ammeter of desired range with the help of shunt.
- (iii) The range an ammeter can be changed by using shunt resistance of different values.

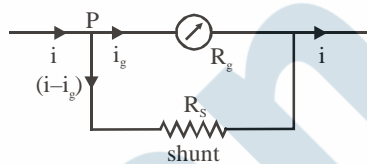
- **Demerits of shunt**

Shunt resistance decreases the sensitivity of galvanometer.

CONVERSION OF GALVANOMETER INTO AMMETER

A galvanometer can be converted into an ammeter by connecting low resistance in parallel to its coil.

- The value of shunt resistance to be connected in parallel to galvanometer coil is given by : $R_s = \frac{R_g i_g}{i - i_g}$



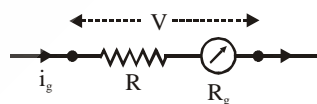
Where i = Range of ammeter

i_g = Current required for full scale deflection of galvanometer.

R_g = Resistance of galvanometer coil.

CONVERSION OF GALVANOMETER INTO VOLTMETER

- The galvanometer can be converted into voltmeter by connecting high resistance in series with its coil.
- The high resistance to be connected in series with galvanometer coil is given by $R = \frac{V}{i_g} - R_g$



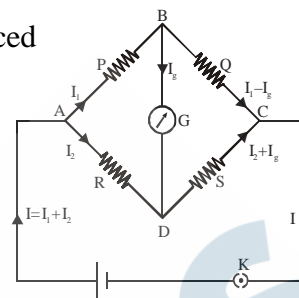
- The rate of variation of deflection depends upon the magnitude of deflection itself and so the accuracy of the instrument.
- A suspended coil galvanometer can measure currents of the order of 10^{-9} ampere.
- I_g is the current for full scale deflection. If the current for a deflection, of one division on the galvanometer scale is k and N is the total number of divisions on one side of the zero of galvanometer scale, then $I_g = k \times N$.
- A ballistic galvanometer is a specially designed moving coil galvanometer, used to measure charge flowing through the circuit for small time intervals.

WHEAT STONE BRIDGE

- The configuration in the adjacent figure is called Wheat Stone Bridge.
- If current in galvanometer is zero ($I_g = 0$) then bridge is said to be balanced

$$V_D = V_B \Rightarrow I_1 P = I_2 R \text{ \& \; } I_1 Q = I_2 S \Rightarrow \frac{P}{Q} = \frac{R}{S}$$

- If $\frac{P}{Q} < \frac{R}{S}$ then $V_B > V_D$ and current will flow from B to D.
- If $\frac{P}{Q} > \frac{R}{S}$ then $V_B < V_D$ and current will flow from D to B.



METRE BRIDGE

It is based on principle of whetstone bridge. It is used to find out unknown resistance of wire. AC is 1 m long uniform wire R.B. is known resistance and S is unknown resistance. A cell is connected across 1 m long wire and Galvanometer is connected between Jockey and midpoint D. To find out unknown resistance we touch jockey from A to C and find balance condition. Let balance is at B point on wire.

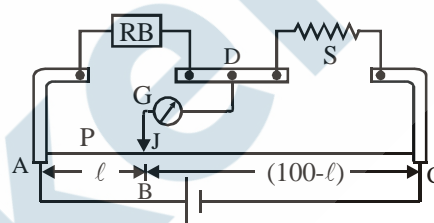
$$AB = \ell \text{ cm}$$

$$BC = (100 - \ell) \text{ cm}$$

$$P = r \ell$$

$$Q = r(100 - \ell)$$

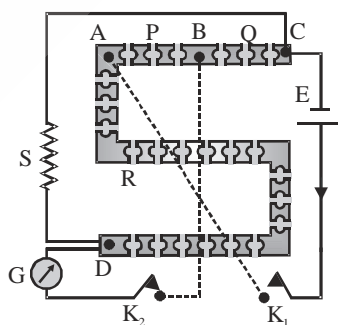
where r = resistance per unit length on wire.



$$\text{At balance condition : } \frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{r\ell}{r(100-\ell)} = \frac{R}{S} \Rightarrow S = \frac{(100-\ell)}{\ell} R$$

POST OFFICE BOX

It is also based on wheat stone bridge. The resistance of 10Ω , 100Ω , and 1000Ω are often connected between AB and BC. These are known as ratio arms. Resistance from 1Ω to 5000Ω are connected between A and D, this is known arm. Unknown resistance is connected between C and D.



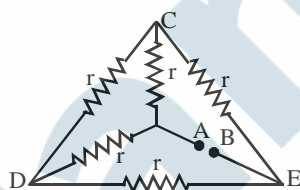
A cell is connected between A and C with key K_1 and Galvanometer is connected between B and D with key K_2 .

First we select ratio of resistance Q and P. For given value of S we will take value of resistance from known arm in such a way that Galvanometer show null deflection $S = \frac{Q}{P} R$. On decreasing the

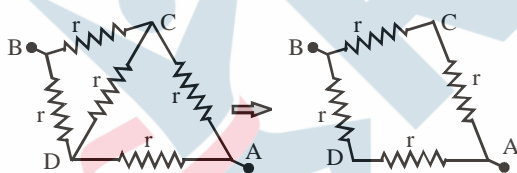
value of $\frac{Q}{P}$ the sensitivity of the box increases. It is used to find out the breakage in telegraph line in post and telegraph offices.

- To increase the range of an ammeter a shunt is connected in parallel with the galvanometer.
- To convert an ammeter of range I ampere and resistance $R_g \Omega$ into an ammeter of range nI ampere, the value of resistance to be connected in parallel will be $R_g(n - 1)$
- To increase the range of a voltmeter a high resistance is connected in series with it.
- To convert a voltmeter of resistance $R_g \Omega$ and range V volt into a voltmeter of range nV volt, the value of resistance to be connected in series will be $(n - 1)R_g$.
- Resistance of ideal ammeter is zero & resistance of ideal voltmeter is infinite.
- The bridge is most sensitive when the resistance in all the four branches of the bridge is of same order.

Ex. In the adjoining network of resistors each is of resistance $r \Omega$. Find the equivalent resistance between point A and B



Sol. Given circuit is balanced Wheat stone Bridge



$$\therefore \frac{1}{R_{AB}} = \frac{1}{2r} + \frac{1}{2r} = \frac{1}{r} \quad R_{AB} = r$$

Ex. A 100 volt voltmeter whose resistance is $20 \text{ k}\Omega$ is connected in series to a very high resistance R. When it is joined in a line of 110 volt, it reads 5 volt. What is the magnitude of resistance R ?

Sol. When voltmeter connected in 110 volt line, Current through the voltmeter $I = \frac{110}{(20 \times 10^3 + R)}$

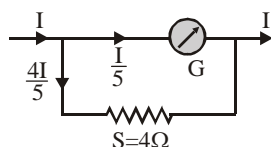
The potential difference across the voltmeter $V = IR_v$

$$\Rightarrow 5 = \frac{110 \times 20 \times 10^3}{(20 \times 10^3 + R)}$$

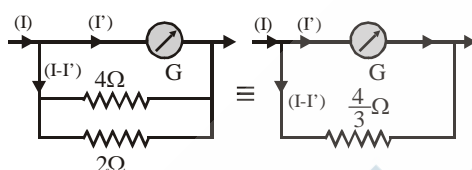
$$\Rightarrow 20 \times 10^3 + R = 440 \times 10^3 \Rightarrow R = 420 \times 10^3 \Omega$$

Ex. When a shunt of 4Ω is attached to a galvanometer, the deflection reduces to $1/5^{\text{th}}$. If an additional shunt of 2Ω is attached what will be the deflection ?

Sol. Initial condition : When shunt of 4Ω used $\frac{I}{5} \times G = \frac{4}{5} I \times 4 \Rightarrow G = 16\Omega$



When additional shunt of 2Ω used $I' \times 16 = (I - I') \frac{4}{3} \Rightarrow I' = \frac{I}{13}$



\therefore it will reduce to $\frac{I}{13}$ of the initial deflection

Ex. A galvanometer having 30 divisions has current sensitivity of $20\mu\text{A}/\text{division}$. It has a resistance of 25Ω .

- How will you convert it into an ammeter measuring upto 1 ampere.
- How will you convert this ammeter into a voltmeter upto 1 volt.

Sol The current required for full scale deflection $I_g = 20\mu\text{A} \times 30 = 600\mu\text{A} = 6 \times 10^{-4}\text{A}$

- To convert it into ammeter, a shunt is required in parallel with it

$$\text{shunt resistance } R'_s = \frac{I_g R_g}{(I - I_g)} = \left(\frac{6 \times 10^{-4}}{1 - 6 \times 10^{-4}} \right) 25 = 0.015\Omega$$

- To convert galvanometer into voltmeter, a high resistance in series with it is required

$$\text{series resistance } R = \frac{V}{i_g} - R_g = \frac{1}{6 \times 10^{-4}} - 25 = 1666.67 - 25 = 1641.67\Omega$$

POTENTIOMETER

- Necessity of potentiometer**

Practically voltmeter has a finite resistance. (ideally it should be ∞) in other words it draws some current from the circuit. To overcome this problem potentiometer is used because at the instant of measurement, it draws no current from the circuit. It means its effective resistance is infinite.

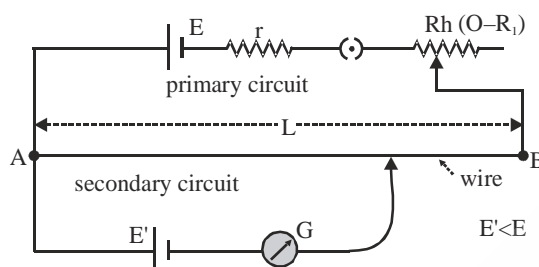
- Working principle of potentiometer**

Any unknown potential difference is balanced on a known potential difference which is uniformly distributed over entire length of potentiometer wire. This process is named as zero deflection or null deflection method.

- Potentiometer wire**

Made up of alloys of magnin, constantan, Eureka. Specific properties of these alloys are high specific resistance, negligible temperature co-efficient of resistance (α). Invariability of resistance of potentiometer wire over a long period.

CIRCUITS OF POTENTIOMETER



- **Primary circuit** contains constant source of voltage rheostat or Resistance Box

- **Secondary, Unknown or galvanometer circuit**

Let ρ = Resistance per unit length of potentiometer wire

- **Potential gradient (x) (V/m)**

The fall of potential per unit length of potentiometer wire is called potential gradient.

$$x = \frac{V}{L} = \frac{\text{current} \times \text{resistance of potentiometer wire}}{\text{length of potentiometer wire}} = I \left(\frac{R}{L} \right)$$

The potential gradient depends only on primary circuit and is independent of secondary circuit.

- **Applications of potentiometer**

<ul style="list-style-type: none"> • To measure potential difference across a resistance. • To find out emf of a cell • Comparison of two emfs E_1/E_2 • To find out internal resistance of a primary cell • Comparison of two resistance. • To find out an unknown resistance which is connected in series with the given resistance. 	<ul style="list-style-type: none"> • To find out current in a given circuit • Calibration of an ammeter or to have a check on reading of (A) • Calibration of a voltmeter or to have a check on reading of (V) • To find out thermocouple emf (e_t) (mV or mV)
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Different between potentiometer and voltmeter

Potentiometer	Voltmeter
<ul style="list-style-type: none"> • It measures the unknown emf very accurately • While measuring emf it does not draw any current from the driving source of known emf. • While measuring unknown potential difference the resistance of potentiometer becomes infinite. • It is based on zero deflection method. • It has a high sensitivity. • It is used for various applications like measurement of internal resistance of cell, calibration of ammeter and voltmeter, measurement of thermo emf, comparison of emf's etc. 	<ul style="list-style-type: none"> • It measures the unknown emf approximately. • While measuring emf it draws some current from the source of emf. • While measuring unknown potential difference the resistance of voltmeter is high but finite. • It is based on deflection method. • Its sensitivity is low. • It is only used to measure emf or unknown potential difference.

Ex. There is a definite potential difference between the two ends of a potentiometer. Two cells are connected in such a way that first time help each other, and second time they oppose each other. They are balanced on the potentiometer wire at 120 cm and 60 cm length respectively. Compare the electromotive force of the cells.

Sol. Suppose the potential gradient along the potentiometer wire = x and the emf's of the two cells are E_1 and E_2 .

When the cells help each other, the resultant emf = $(E_1 + E_2)$

$$E_1 + E_2 = x \times 120 \text{ cm} \dots(i)$$

When the cells oppose each other, the resultant emf = $(E_1 - E_2)$

$$E_1 - E_2 = x \times 60 \text{ cm} \dots(ii)$$

$$\text{From equation (i) and (ii)} \quad \frac{E_1 + E_2}{E_1 - E_2} = \frac{120 \text{ cm}}{60 \text{ cm}} = \frac{2}{1} \Rightarrow E_1 + E_2 = 2(E_1 - E_2) \Rightarrow 3E_2 = E_1 \Rightarrow \frac{E_1}{E_2} = \frac{3}{1}$$

COLOUR CODE FOR CARBON RESISTORS

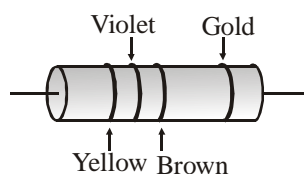
Colour	Strip A	Strip B	Strip C	Strip D (Tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Grey	8	8	10^8	
White	9	9	10^9	
Gold	-	-	10^{-1}	$\pm 5 \%$
Silver	-	-	10^{-2}	$\pm 10 \%$
No colour	-	-	-	$\pm 20 \%$

Aid to memory BBROY
Great Britain
Very Good watch of gold & silver

Ex. Draw a colour code for $42 \text{ k } \Omega \pm 10\%$ carbon resistance.

Sol. According to colour code colour for digit 4 is yellow, for digit 2 it is red, for 3 colour is orange and 10% tolerance is represented by silver colour. So colour code should be yellow, red, orange and silver.

Ex. What is resistance of following resistor.



Sol. Number for yellow is 4, Number of violet is 7

Brown colour gives multiplier 10^1 , Gold gives a tolerance of $\pm 5\%$

So resistance of resistor is $47 \times 10^1 \Omega \pm 5\% = 470 \pm 5\% \Omega$.

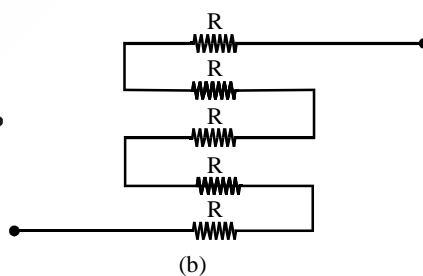
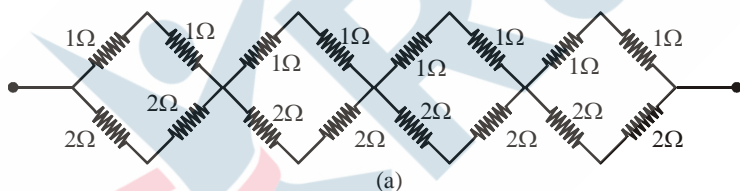
EXERCISE # S-1

Microscopic analysis

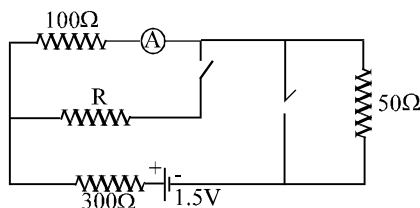
1. A copper wire of length L , and cross section area A carries a current I . If the specific resistance of copper is ρ , the electric field in the wire is _____.
2. A copper wire carries a current density j (= current per unit area). Assuming that n = No. of free electrons per unit volume, e = electronic charge, $\langle v \rangle$ = average speed due to thermal agitation. The distance which will be covered by an electron during its displacement l along the wire _____.
3. The total momentum of electrons in a straight wire of length ℓ carrying a current I is _____ (mass of electron = m_e , charge of electron = e)
4. Two conductors are made of the same material and have the same length. Conductor A is a solid wire of diameter 1mm. Conductor B is a hollow tube of outer diameter 2mm and inner diameter 1mm. Find the ratio of resistance R_A to R_B .

Ohm's law and circuit analysis

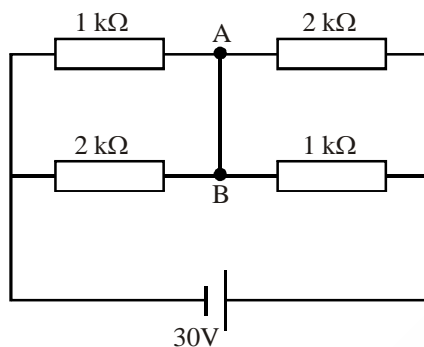
5. (a) Given n resistors each of resistance R , how will you combine them to get the (i) maximum (ii) minimum effective resistance? What Is the ratio of the maximum to minimum resistance?
 (b) Given the resistances of 1Ω , 2Ω , 3Ω , how will be combine them to get an equivalent resistance of (i) $(11/3)\Omega$ (ii) $(11/5)\Omega$ (iii) 6Ω (iv) $(6/11)\Omega$?
 (c) Determine the equivalent resistance of networks shown in figures



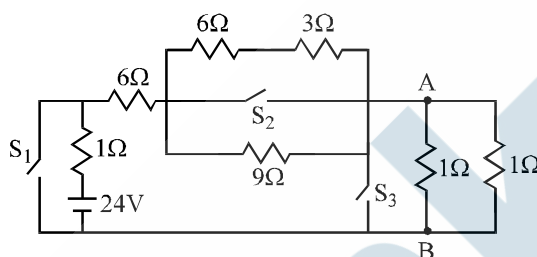
6. In the circuit shown in figure the reading of ammeter is the same with both switches open as with both closed. Then find the resistance R . (ammeter is ideal)



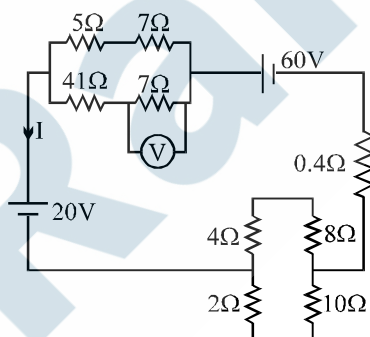
7. Find the current (in mA) in the wire between points A and B.



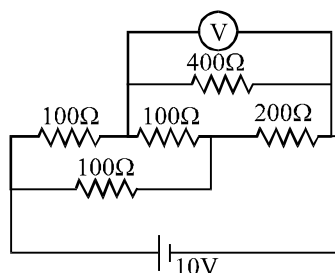
8. If the switches S_1 , S_2 and S_3 in the figure are arranged such that current through the battery is minimum, find the voltage across points A and B.



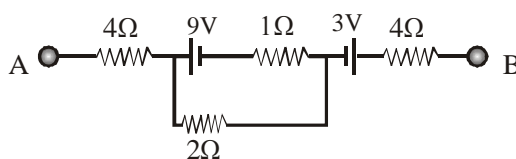
9. Find the current I & voltage V in the circuit shown.



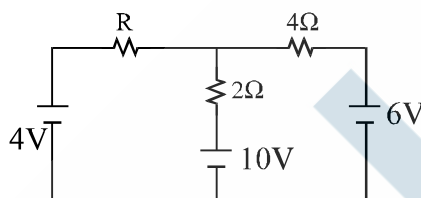
10. An electrical circuit is shown in the figure. Calculate the potential difference across the resistance of 400 ohm, as will be measured by the voltmeter V of resistance 400 ohm, either by applying Kirchhoff's rules or otherwise.



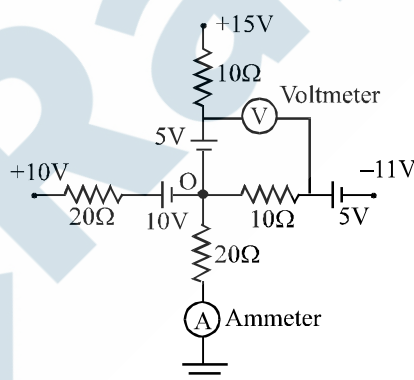
11. In the circuit shown in figure potential difference between point A and B is 16V. Find the current passing through 2Ω resistance.



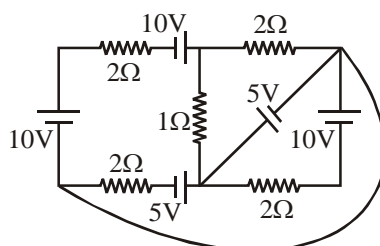
12. An enquiring physics student connects a cell to a circuit and measures the current drawn from the cell to I_1 . When he joins a second identical cell in series with the first, the current becomes I_2 . When the cells are connected in parallel, the current through the circuit is I_3 . Show that relation between the current is $3 I_3 I_2 = 2 I_1 (I_2 + I_3)$
13. For what value of R in circuit, current through 4Ω resistance is zero.



14. The potential of certain points in the circuit are maintained at the values indicated. The Voltmeter and Ammeter are ideal. Find the potential of the cross junction point in the circuit (at center O) and the readings of Voltmeter and Ammeter. All cells are ideal.

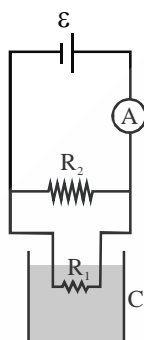


15. In the given circuit diagram, the current through the 1Ω resistor is given by I amp. Fill $2 I$ in OMR sheet.

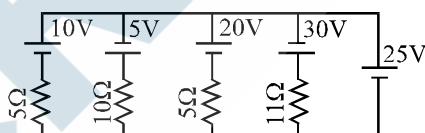


Joule heating

16. If a cell of constant E.M.F. produces the same amount of the heat during the same time in two independent resistors R_1 and R_2 , when they are separately connected across the terminals of the cell, one after the another, find the internal resistance of the cell.
17. The coil of a calorimeter C has a resistance of $R_1 = 60\Omega$. The coil R_1 is connected to the circuit as shown in figure. What is the rise in temperature ($^{\circ}\text{C}$) of 240 grams of water poured into the calorimeter when it is heated for 7 minutes during which a current flows through the coil and the ammeter shows 3A? The resistance $R_2 = 30\Omega$. [Disregard the resistances of the battery and the ammeter, and the heat losses and heat capacity of the calorimeter and the resistor and specific heat of water = $4200 \text{ J/kg}^{\circ}\text{C}$]



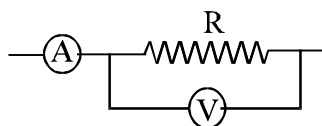
18. An electric kettle has two windings. When one of them is switched on, the water in the kettle begins to boil in 15 minutes, and when the other is switched on it takes 30 minutes for water to boil. If the two windings are joined in series and switched on, water in the kettle begin to boil in $\frac{\alpha}{4}$ hr. Assuming no heat loss to the surrounding fill the value of α in OMR sheet.
19. Find the current through 25V cell & power supplied by 20V cell in the figure shown.



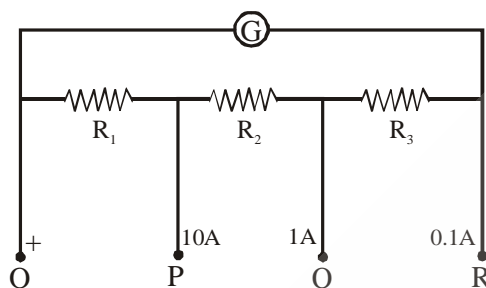
20. A person decides to use his bath tub water to generate electric power to run a 40 watt bulb. The bath tub is located at a height of 10 m from the ground & it holds 200 litres of water. If we install a water driven wheel generator on the ground, at what rate should the water drain from the bath tub to light bulb? How long can we keep the bulb on, if the bath tub was full initially. The efficiency of generator is 90%. ($g = 10\text{m/s}^2$)

Instruments

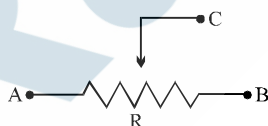
21. A part of a circuit is shown in figure. Here reading of ammeter is 5 ampere and voltmeter is 96V & voltmeter resistance is 480 ohm. Then find the resistance R



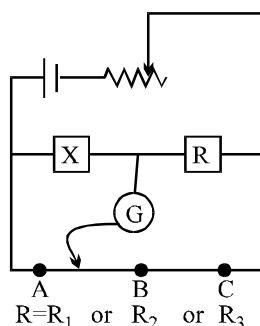
22. The resistance of the galvanometer G in the circuit is 25Ω . The meter deflects full scale for a current of 10 mA . The meter behaves as an ammeter of three different ranges. The range is $0\text{--}10\text{ A}$, if the terminals O and P are taken; range is $0\text{--}1\text{ A}$ between O and Q ; range is $0\text{--}0.1\text{ A}$ between O and R . Calculate the resistance R_1 , R_2 and R_3 .



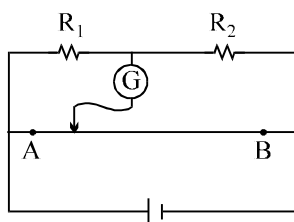
23. A galvanometer having 50 divisions provided with a variable shunt is used to measure the current as an ammeter when connected in series with a resistance of 90Ω and a battery of internal resistance 10Ω . It is observed that when the shunt resistance are 10Ω , 50Ω , respectively the deflection are respectively 9 & 30 divisions. What is the resistance of the galvanometer? Further if the full scale deflection of the galvanometer movement is 300 mA , find the emf of the cell.
24. Draw the circuit for experimental verification of Ohm's law using a source of variable D.C. voltage, a main resistance of 100Ω , two galvanometers and two resistances of values $10^6\Omega$ and $10^{-3}\Omega$ respectively. Clearly show the positions of the voltmeter and the ammeter. [IIT-JEE' 2004]
25. How a battery is to be connected so that shown rheostat will behave like a potential divider? Also indicate the points about which output can be taken. [IIT-JEE' 2003]



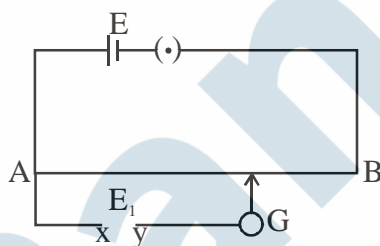
26. An unknown resistance X is to be determined using resistances R_1 , R_2 or R_3 . Their corresponding null points are A , B and C . Find which of the above will give the most accurate reading and why? [IIT-JEE 2005]



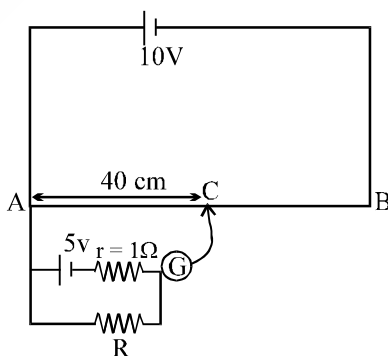
27. In the figure shown for which values of R_1 and R_2 the balance point for Jockey is at 40 cm from A. When R_2 is shunted by a resistance of $10\ \Omega$, balance shifts to 50 cm. Find R_1 and R_2 . ($AB = 1\text{ m}$):



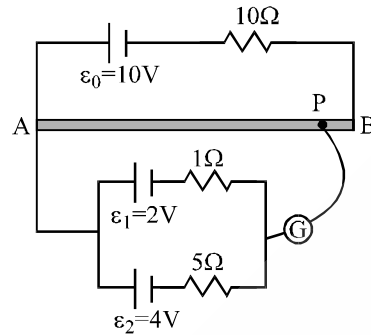
28. While doing an experiment with potentiometer it was found that the deflection is one sided and two cases are possible
- the deflection decreased while moving from one end A of the wire to the end B;
 - the deflection increased while the jockey was moved towards the end B. Then
- Which terminal + or -ve of the cell E_1 is connected at X in case (i) and how is E_1 related to E ?
 - Which terminal of the cell E_1 is connected at X in case (ii)?



29. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell ?
30. A potentiometer wire AB is 100 cm long and has a total resistance of 10 ohm. If the galvanometer shows zero deflection at the position C, then find the value of unknown resistance R.

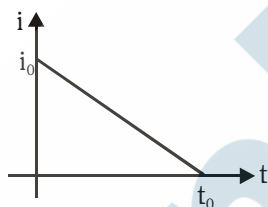


31. A battery of emf $\varepsilon_0 = 10 \text{ V}$ is connected across a 1 m long uniform wire having resistance $10\Omega/\text{m}$. Two cells of emf $\varepsilon_1 = 2\text{ V}$ and $\varepsilon_2 = 4\text{ V}$ having internal resistances 1Ω and 5Ω respectively are connected as shown in the figure. If a galvanometer shows no deflection at the point P, find the distance of point P from the point A.

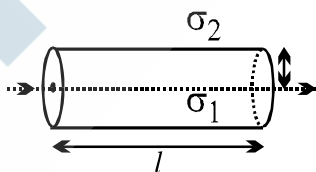


EXERCISE # S-2

1. A long cylinder with uniformly charged surface and cross sectional radius $a = 1.0$ cm moves with a constant velocity $v = 10$ m/s, along its axis. An electric field strength at the surface of the cylinder is equal to $E = 0.9$ KV/cm. Find the resulting convection current, that is, the current caused by mechanical transfer of charge.
2. A resistance R of thermal coefficient of resistivity $= \alpha$ is connected in parallel with a resistance $= 3R$, having thermal coefficient of resistivity $= 2\alpha$. Find the value of α_{eff} .
3. Relation between current in conductor and time is shown in figure then determine.

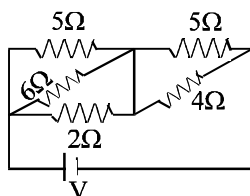


- (i) Total charge flow through the conductor
 - (ii) Write expression of current in terms of time
 - (iii) If resistance of conductor is R then total heat dissipated across resistance R is
4. A long conductor of circular cross-section has radius r and length l as shown in the figure. The conductivity of the material near the axis is σ_1 and increases linearly with the distance from axis and becomes σ_2 near the surface. Find the resistance of the conductor if the current enters from the one end and leaves from the other end.

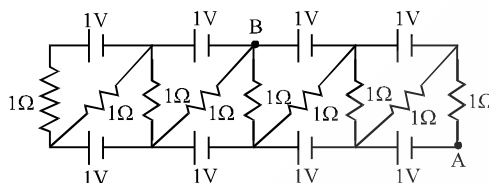


5. (a) The current density across a cylindrical conductor of radius R varies according to the equation $J = J_0 \left(1 - \frac{r}{R}\right)$, where r is the distance from the axis. Thus the current density is a maximum J_0 at the axis $r = 0$ and decreases linearly to zero at the surface $r = R$. Calculate the current in terms of J_0 and the conductor's cross sectional area is $A = \pi R^2$.
 (b) Suppose that instead the current density is a maximum J_0 at the surface and decreases linearly to zero at the axis so that $J = J_0 \frac{r}{R}$. Calculate the current.

6. Find the resistor in which maximum heat will be produced.

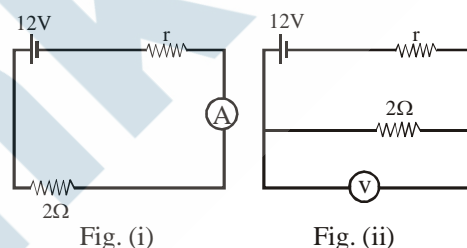


7. Find the potential difference $V_A - V_B$ for the circuit shown in the figure.

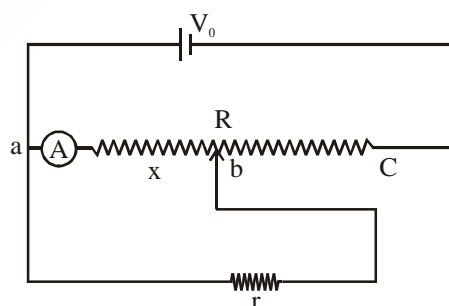


8. A galvanometer (coil resistance 99Ω) is converted into an ammeter using a shunt of 1Ω and connected as shown in the figure (i). The ammeter reads $3A$. The same galvanometer is converted into a voltmeter by connecting a resistance of 101Ω in series. This voltmeter is connected as shown in figure (ii). Its reading is found to be $4/5$ of the full scale reading. Find

- (i) internal resistance r of the cell
(ii) range of the ammeter and voltmeter
(iii) full scale deflection current of the galvanometer



9. An accumulator of emf $2V$ and negligible internal resistance is connected across a uniform wire of length $10m$ and resistance 30Ω . The appropriate terminals of a cell of emf $1.5V$ and internal resistance 1Ω is connected to one end of the wire, and the other terminal of the cell is connected through a sensitive galvanometer to a slider on the wire. What length of the wire will be required to produce zero deflection of the galvanometer? How will the balancing change (a) when a coil of resistance 5Ω is placed in series with the accumulator, (b) the cell of $1.5V$ is shunted with 5Ω resistor?
10. A constant voltage $V_0 (= 12V)$ is applied to a potential divider of resistance $R (= 4\Omega)$, connected to an ideal ammeter. A constant resistor $r (= 2\Omega)$ is connected to the sliding contact of the potential divider (as shown). Find the minimum current (in A) measured by ammeter.

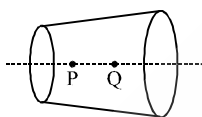


EXERCISE # O-1

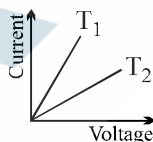
SINGLE CORRECT TYPE QUESTIONS

Microscopic analysis

1. A wire has a non-uniform cross-section as shown in figure. A steady current flows through it. The drift speed of electrons at points P and Q is v_P and v_Q .

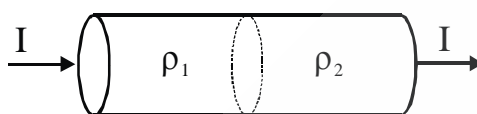


- (A) $v_P = v_Q$ (B) $v_P < v_Q$ (C) $v_P > v_Q$ (D) Data insufficient
2. Two wires each of radius of cross section r but of different materials are connected together end to end (in series). If the densities of charge carriers in the two wires are in the ratio 1 : 4, the drift velocity of electrons in the two wires will be in the ratio:
- (A) 1 : 2 (B) 2 : 1 (C) 4 : 1 (D) 1 : 4
3. An insulating pipe of cross-section area 'A' contains an electrolyte which has two types of ions → their charges being $-e$ and $+2e$. A potential difference applied between the ends of the pipe result in the drifting of the two types of ions, having drift speed = v ($-ve$ ion) and $v/4$ ($+ve$ ion). Both ions have the same number per unit volume = n . The current flowing through the pipe is
- (A) $nev A/2$ (B) $nev A/4$ (C) $5nev A/2$ (D) $3nev A/2$
4. The current in a metallic conductor is plotted against voltage at two different temperatures T_1 and T_2 . Which is correct



- (A) $T_1 > T_2$ (B) $T_1 < T_2$ (C) $T_1 = T_2$ (D) none
5. A metal rod of length 10 cm and a rectangular cross-section of $1 \text{ cm} \times \frac{1}{2} \text{ cm}$ is connected to a battery across opposite faces. The resistance will be
- (A) maximum when the battery is connected across $1 \text{ cm} \times \frac{1}{2} \text{ cm}$ faces.
- (B) maximum when the battery is connected across $10 \text{ cm} \times 1 \text{ cm}$ faces.
- (C) maximum when the battery is connected across $10 \text{ cm} \times \frac{1}{2} \text{ cm}$ faces.
- (D) same irrespective of the three faces.

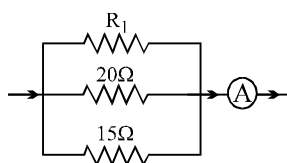
6. Consider a current carrying wire (current I) in the shape of a circle. Note that as the current progresses along the wire, the direction of \mathbf{j} (current density) changes in an exact manner, while the current I remain unaffected. The agent that is *essentially* responsible for is
- (A) source of emf.
 (B) electric field produced by charges accumulated on the surface of wire.
 (C) the charges just behind a given segment of wire which push them just the right way by repulsion.
 (D) the charges ahead.
7. Two long straight cylindrical conductors with resistivities ρ_1 and ρ_2 respectively are joined together as shown in figure. If current I flows through the conductors, the magnitude of the total free charge at the interface of the two conductors is :-



- (A) zero (B) $\frac{(\rho_1 - \rho_2) I \epsilon_0}{2}$ (C) $\epsilon_0 I |\rho_1 - \rho_2|$ (D) $\epsilon_0 I |\rho_1 + \rho_2|$
8. **Statement 1 :** The drift speed of electrons in metals is small (in the order of a few mm/s) and the charge of an electron is also very small ($= 1.6 \times 10^{-19} \text{C}$), yet we can obtain a large current in a metal. **and**
- Statement 2:** At room temperature, the thermal speed of electron is very high (about 10^7 times the drift speed).
- (A) Statement-1 is True, Statement-2 is True ; Statement-2 is a correct explanation for Statement-1.
 (B) Statement-1 is True, Statement-2 is True ; Statement-2 is not a correct explanation for Statement-1.
 (C) Statement-1 is True, Statement-2 is False.
 (D) Statement-1 is False, Statement-2 is True.

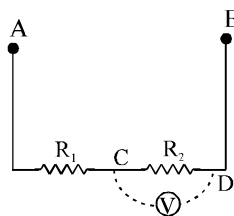
Ohm's law & circuit analysis

9. A storage battery is connected to a charger for charging with a voltage of 12.5Volts. The internal resistance of the storage battery is 1Ω . When the charging current is 0.5 A, the emf of the storage battery is:
- (A) 13 Volts (B) 12.5 Volts (C) 12 Volts (D) 11.5 Volts
10. In the given circuit the current flowing through the resistance 20 ohms is 0.3 ampere while the ammetre reads 0.8 ampere. What is the value of R_1 ?

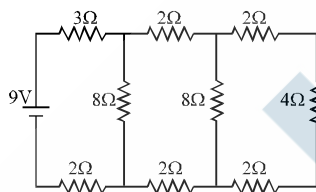


- (A) 30 ohms (B) 40 ohms (C) 50 ohms (D) 60 ohms

11. Resistances R_1 and R_2 each 60Ω are connected in series as shown in figure. The Potential difference between A and B is kept 120 volt. Then what will be the reading of voltmeter connected between the point C & D if resistance of voltmeter is 120Ω .



- (A) 48 V (B) 24 V (C) 40V (D) None
12. In the circuit shown in the figure, the current through :

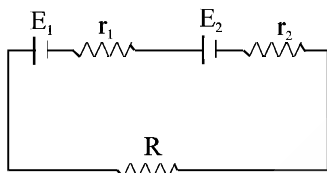


- (A) the 3Ω resistor is 0.50 A (B) the 3Ω resistor is 0.25 A
(C) 4Ω resistor is 0.50 A (D) the 4Ω resistor is 0.25 A
13. A simple circuit contains an ideal battery and a resistance R . If a second resistor is placed in parallel with the first,
- (A) the potential across R will decrease
(B) the current through R will decreased
(C) the current delivered by the battery will increase
(D) the power dissipated by R will increased.
14. The equivalent resistance of a group of resistances is R . If another resistance is connected in parallel to the group , its new equivalent becomes R_1 & if it is connected in series to the group , its new equivalent becomes R_2 we have :
- (A) $R_1 > R$ (B) $R_1 < R$ (C) $R_2 > R$ (D) $R_2 < R$
15. An energy source will supply a constant current into the load, if its internal resistance is-
- [AIEEE - 2005]**
- (A) equal to the resistance of the load (B) very large as compared to the load resistance
(C) zero (D) non-zero but less than the resistance of the load
16. When a current of 4 A flows within a battery from its positive to negative terminal, the potential difference across the battery is 12 volts. The potential difference across the battery is 9 volts when a current of 2 A flows within it from its negative to its positive terminal. The internal resistance and the e.m.f. of the battery are :-
- (A) 0.1Ω , 4V (B) 0.2Ω , 5V (C) 0.5Ω , 10V (D) 0.7Ω , 10V

17. Two resistances of equal magnitude R and having temperature coefficient α_1 and α_2 respectively are connected in parallel. The temperature coefficient of the parallel combination is, approximately

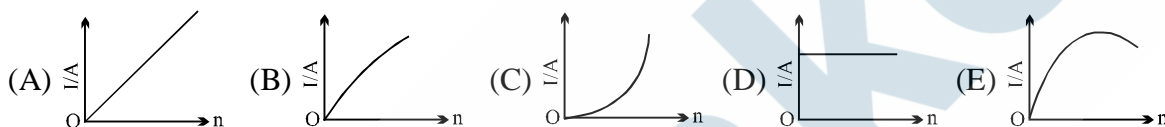
(A) $2(\alpha_1 + \alpha_2)$ (B) $\frac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2}$ (C) $\frac{\alpha_1 - \alpha_2}{2}$ (D) $\frac{\alpha_1 + \alpha_2}{2}$

18. Under what condition current passing through the resistance R can be increased by short circuiting the battery of emf E_2 . The internal resistances of the two batteries are r_1 and r_2 respectively.

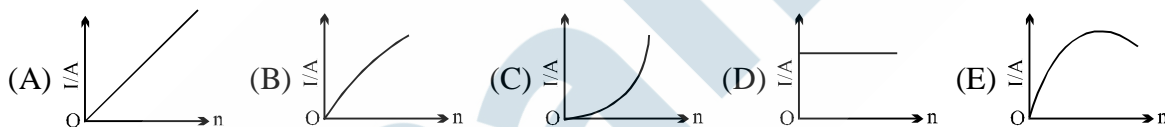


(A) $E_2 r_1 > E_1 (R + r_2)$ (B) $E_1 r_2 > E_2 (R + r_1)$ (C) $E_2 r_2 > E_1 (R + r_2)$ (D) $E_1 r_1 > E_2 (R + r_1)$

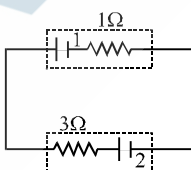
19. A battery consists of a variable number n of identical cells having internal resistance connected in series. The terminals of the battery are short circuited and the current I measured. Which one of the graph below shows the relationship between I and n ?



20. In **previous problem**, if the cell had been connected in parallel (instead of in series) which of the above graphs would have shown the relationship between total current I and n ?

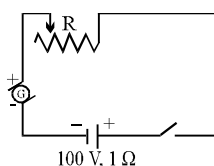


21. In the figure shown, battery 1 has emf = 6 V and internal resistance = 1 Ω . Battery 2 has emf = 2V and internal resistance = 3 Ω . The wires have negligible resistance. What is the potential difference across the terminals of battery 2 ?



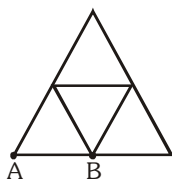
(A) 4 V (B) 1.5 V (C) 5 V (D) 0.5 V

22. The battery in the diagram is to be charged by the generator G . The generator has a terminal voltage of 120 volts when the charging current is 10 amperes. The battery has an emf of 100 volts and an internal resistance of 1 ohm. In order to charge the battery at 10 amperes charging current, the resistance R should be set at :-

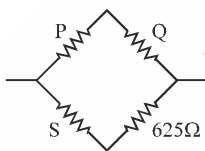


(A) 0.1 Ω (B) 0.5 Ω (C) 1.0 Ω (D) 5.0 Ω

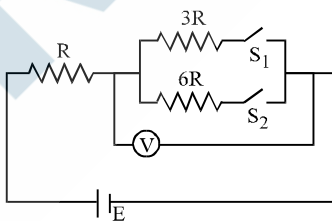
23. In the diagram resistance between any two junctions is R . Equivalent resistance across terminals A and B is :-



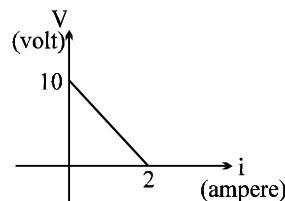
- (A) $\frac{11R}{7}$ (B) $\frac{18R}{11}$ (C) $\frac{7R}{11}$ (D) $\frac{11R}{18}$
24. A Wheatstone's bridge is balanced with a resistance of $625\ \Omega$ in the third arm, where P, Q and S are in the 1st, 2nd and 4th arm respectively. If P and Q are interchanged, the resistance in the third arm has to be increased by $51\ \Omega$ to secure balance. The unknown resistance in the fourth arm is :-



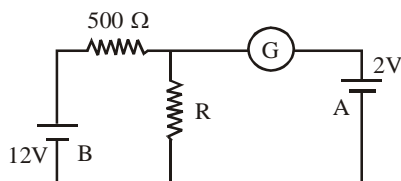
- (A) $625\ \Omega$ (B) $650\ \Omega$ (C) $676\ \Omega$ (D) $600\ \Omega$
25. One end of a Nichrome wire of length $2L$ and cross-sectional area A is attached to an end of another Nichrome wire of length L and cross-sectional area $2A$. If the free end of the longer wire is at an electric potential of 8.0 volts, and the free end of the shorter wire is at an electric potential of 1.0 volt, the potential at the junction of the two wires is equal to :-
- (A) $2.4\ \text{V}$ (B) $3.2\ \text{V}$ (C) $4.5\ \text{V}$ (D) $5.6\ \text{V}$
26. In the circuit shown in figure reading of voltmeter is V_1 when only S_1 is closed, reading of voltmeter is V_2 when only S_2 is closed. The reading of voltmeter is V_3 when both S_1 and S_2 are closed then



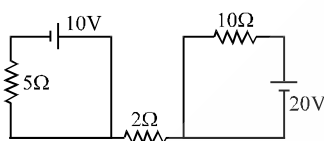
- (A) $V_2 > V_1 > V_3$ (B) $V_3 > V_2 > V_1$ (C) $V_3 > V_1 > V_2$ (D) $V_1 > V_2 > V_3$
27. A battery of emf E and internal resistance r is connected across a resistance R . Resistance R can be adjusted to any value greater than or equal to zero. A graph is plotted between the current (i) passing through the resistance and potential difference (V) across it. Select the correct alternative.
- (A) internal resistance of battery is $5\ \Omega$
 (B) emf of the battery is $20\ \text{V}$
 (C) maximum current which can be taken from the battery is $4\ \text{A}$
 (D) V - i graph can never be a straight line as shown in figure.



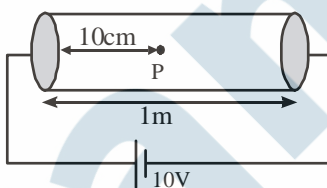
28. In the circuit, the galvanometer G shows zero deflection. If the batteries A and B have negligible internal resistance, the value of the resistor R will be- [AIEEE - 2005]



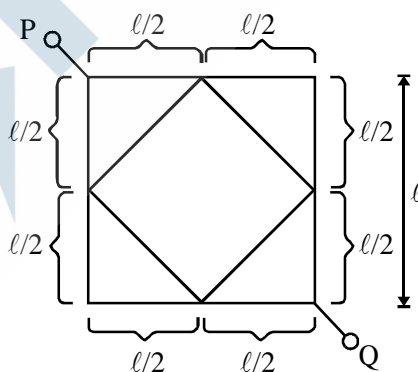
- (A) 200 Ω (B) 100 Ω (C) 500 Ω (D) 1000 Ω
 29. In the figure shown the current through 2 Ω resistor is [IIT-JEE 2005 (Scr)]



- (A) 2 A (B) 0 A (C) 4 A (D) 6 A
 30. A cylindrical solid of length 1m and radius 1 m is connected across a source of emf 10V and negligible internal resistance shown in figure. The resistivity of the rod as a function of x (x measured from left end) is given by $\rho = bx$ [where b is a positive constant]. Find the electric field (in SI unit) at point P at a distance 10 cm from left end.

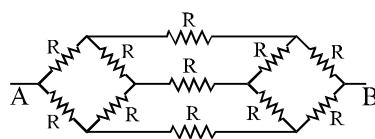


- (A) 1 (B) 2 (C) 3 (D) 4
 31. If the wire has resistivity ρ and cross sectional area A, the equivalent resistance between P and Q is :-

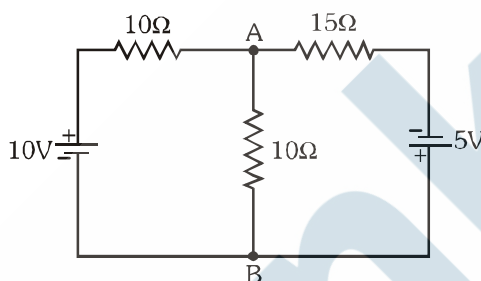


- (A) $\frac{\rho l}{\sqrt{2}A}$ (B) $\frac{\sqrt{2}\rho l}{A}$ (C) $\frac{2\rho l}{A}$ (D) $\frac{\rho l}{A}$

32. The equivalent resistance between the terminal points A and B in the network shown in figure is :-



- (A) $\frac{7R}{5}$ (B) $\frac{5R}{6}$ (C) $\frac{7R}{12}$ (D) $\frac{5R}{12}$
33. An electric bell has a resistance of 5Ω and requires a current of 0.25 A to work it. Assuming that the resistance of the bell wire is 1Ω per 15m and that the bell push is 90m distance from the bell. How many cells each of emf 1.4V and internal resistance 2Ω , will be required to work the circuit-
- (A) 3 (B) 4 (C) 5 (D) Can't be determined
34. A circuit is arranged as shown. Then, the current from A to B is

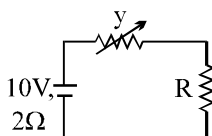


- (A) $+500\text{ mA}$ (B) $+250\text{ mA}$ (C) -250 mA (D) -500 mA

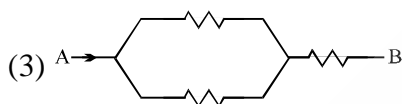
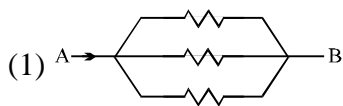
Joule heating

35. Power generated across a uniform wire connected across a supply is H . If the wire is cut into n equal parts and all the parts are connected in parallel across the same supply, the total power generated in the wire is
- (A) $\frac{H}{n^2}$ (B) n^2H (C) nH (D) $\frac{H}{n}$
36. When electric bulbs of same power, but different marked voltage are connected in series across the power line, their brightness will be :
- (A) proportional to their marked voltage
 (B) inversely proportional to their marked voltage
 (C) proportional to the square of their marked voltage
 (D) inversely proportional to the square of their marked voltage
37. Two bulbs rated ($25\text{ W} - 220\text{V}$) and ($100\text{W} - 220\text{V}$) are connected in series to a 440 V line. Which one is likely to fuse?
- (A) 25 W bulb (B) 100 W bulb (C) both bulbs (D) none
38. Rate of dissipation of Joule's heat in resistance per unit volume is (symbols have usual meaning)
- (A) σE (B) σJ (C) $J E$ (D) None
39. If the length of the filament of a heater is reduced by 10% , the power of the heater will
- (A) increase by about 9% (B) increase by about 11%
 (C) increase by about 19% (D) decrease by about 10%

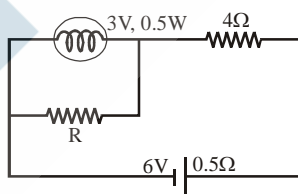
40. Two bulbs one of 200 volts, 60 watts & the other of 200 volts, 100 watts are connected in series to a 200 volt supply. The power consumed will be
 (A) 37.5 watt (B) 160 watt (C) 62.5 watt (D) 110 watt
41. In the figure shown the power generated in y is maximum when $y = 5\Omega$. Then R is :-



- (A) 2Ω (B) 6Ω (C) 5Ω (D) 3Ω
42. Arrange the order of power dissipated in the given circuits, if the same current is passing through all circuits and each resistor is ' r '
 [IIT-JEE' 2003 (Scr)]

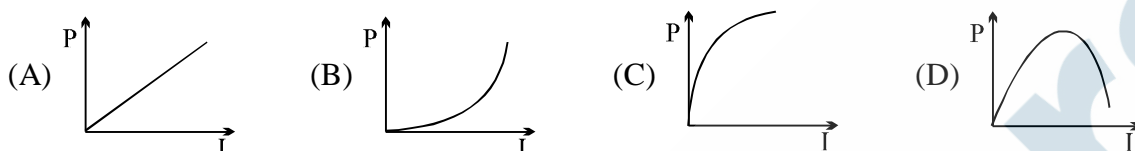
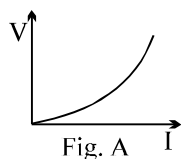


- (A) $P_2 > P_3 > P_4 > P_1$ (B) $P_3 > P_2 > P_4 > P_1$ (C) $P_4 > P_3 > P_2 > P_1$ (D) $P_1 > P_2 > P_3 > P_4$
43. A rigid container with thermally insulated walls contains a coil of resistance 100Ω , carrying current 1 A. Change in internal energy after 5 min will be
 [IIT-JEE 2005]
 (A) zero (B) 10 kJ (C) 20 kJ (D) 30 kJ
44. The value of the resistance R in the circuit shown below so that electric bulb consumes the rated power is :-



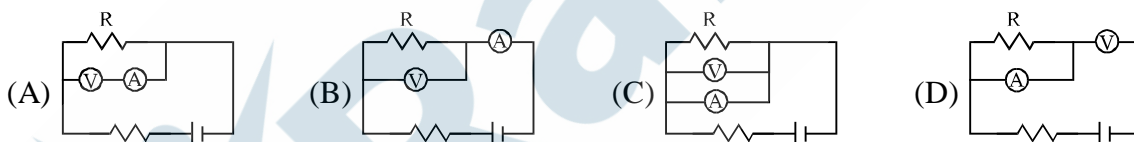
- (A) 4 ohm (B) 6 ohm (C) 8 ohm (D) 10 ohm
45. A variable load R is connected to a voltage source of internal resistance r . Then choose the **INCORRECT** statement out of the following :-
 (A) If $R = r$, maximum power is transferred to the load
 (B) If current is maximum, power transfer to load is also maximum
 (C) If $R \ll r$, the voltage source supplied a fixed current to the load
 (D) Power supplied to load is minimum if load is either too low or too high

46. The variation of current (I) and voltage (V) is as shown in figure A. The variation of power P with current I is best shown by which of the following graph

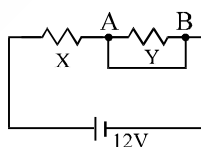


Instruments

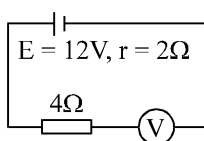
47. A galvanometer has a resistance of 20Ω and reads full-scale when 0.2 V is applied across it. To convert it into a 10 A ammeter, the galvanometer coil should have a
 (A) 0.01Ω resistor connected across it (B) 0.02Ω resistor connected across it
 (C) 200Ω resistor connected in series with it (D) 2000Ω resistor connected in series with it
48. A galvanometer coil has a resistance 90Ω and full scale deflection current 10 mA . A 910Ω resistance is connected in series with the galvanometer to make a voltmeter. If the least count of the voltmeter is 0.1 V , the number of divisions on its scale is
 (A) 90 (B) 91 (C) 100 (D) none
49. Which of the following wiring diagrams could be used to experimentally determine R using ohm's law? Assume an ideal voltmeter and an ideal ammeter.



50. When an ammeter of negligible internal resistance is inserted in series with circuit it reads 1 A . When the voltmeter of very large resistance is connected across X it reads 1 V . When the point A and B are shorted by a conducting wire, the voltmeter measures 10 V across the battery. The internal resistance of the battery is equal to :-

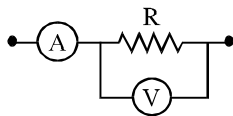


- (A) zero (B) 0.5Ω (C) 0.2Ω (D) 0.1Ω
51. By error, a student places moving-coil voltmeter V (nearly ideal) in series with the resistance in a circuit in order to read the current, as shown. The voltmeter reading will be

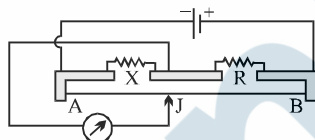


- (A) 0 (B) 4V (C) 6V (D) 12V

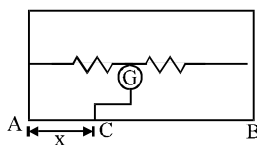
52. In the circuit shown the readings of ammeter and voltmeter are 4A and 20V respectively. The meters are non ideal, then R is :



- (A) 5Ω (B) less than 5Ω (C) greater than 5Ω (D) between 4Ω & 5Ω
53. In a balanced wheat stone bridge, current in the galvanometer is zero. It remains zero when:
 [1] battery emf is increased
 [2] all resistances are increased by 10 ohms
 [3] all resistances are made five times
 [4] the battery and the galvanometer are interchanged
 (A) only [1] is correct (B) [1], [2] and [3] are correct
 (C) [1], [3] and [4] are correct (D) [1] and [3] are correct
54. The figure shows a metre-bridge circuit, with $AB = 100$ cm, $X = 12\Omega$ and $R = 18\Omega$, and the jockey J in the position of balance. If R is now made 8Ω , through what distance will J have to be moved to obtain balance?

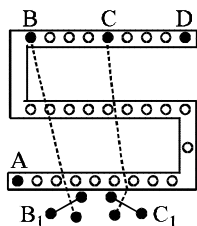


- (A) 10 cm (B) 20 cm (C) 30 cm (D) 40 cm
55. In a metre bridge experiment, null point is obtained at 20 cm from one end of the wire when resistance X is balanced against another resistance Y . If $X < Y$, then where will be the new position of the null point from the same end, if one decides to balance a resistance of $4X$ against Y ? [AIEEE - 2004]
 (A) 50 cm (B) 80 cm (C) 40 cm (D) 70 cm
56. A resistance R is to be measured using a meter bridge. Student chooses the standard resistance S to be 100Ω . He finds the null point at $l_1 = 2.9$ cm. He is told to attempt to improve the accuracy. Which of the following is a useful way?
 (A) He should measure l_1 more accurately.
 (B) He should change S to 1000Ω and repeat the experiment.
 (C) He should change S to 3Ω and repeat the experiment.
 (D) He should give up hope of a more accurate measurement with a meter bridge.
57. In the given circuit, no current is passing through the galvanometer. If the cross-sectional diameter of AB is doubled then for null point of galvanometer the value of AC would [IIT-JEE' 2003 (Scr)]

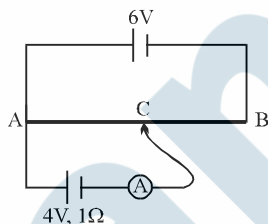


- (A) x (B) $x/2$ (C) $2x$ (D) None

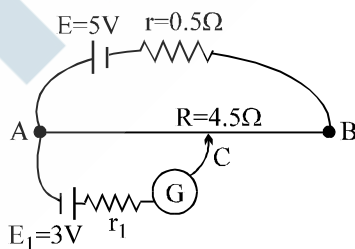
58. For the post office box arrangement to determine the value of unknown resistance, the unknown resistance should be connected between [IIT-JEE' 2004 (Scr)]



- (A) B and C (B) C and D (C) A and D (D) B₁ and C₁
59. A potentiometer wire has length 10 m and resistance 10Ω. It is connected to a battery of EMF 11 volt and internal resistance 1 Ω, then the potential gradient in the wire is :-
 (A) 10 V/m (B) 1 V/m (C) 0.1 V/m (D) none
60. A 6 V battery of negligible internal resistance is connected across a uniform wire of length 1 m. The positive terminal of another battery of emf 4V and internal resistance 1 Ω is joined to the point A as shown in figure. The ammeter shows zero deflection when the jockey touches the wire at the point C. The AC is equal to :-

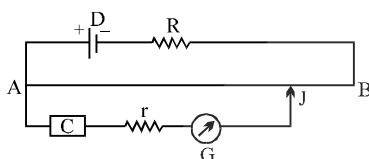


- (A) 2/3 m (B) 1/3 m (C) 3/5 m (D) 1/2 m
61. In the given potentiometer circuit length of the wire AB is 3 m and resistance is $R = 4.5 \Omega$. The length AC for no deflection in galvanometer is :-

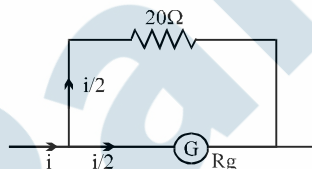


- (A) 2 m (B) 1.8 m (C) dependent on r_1 (D) none of these
62. The length of a potentiometer wire is ℓ . A cell of emf E is balanced at a length $\ell/3$ from the positive end of the wire. If the length of the wire is increased by $\ell/2$. At what distance will the same cell give a balance point.
- (A) $\frac{2\ell}{3}$ (B) $\frac{\ell}{2}$ (C) $\frac{\ell}{6}$ (D) $\frac{4\ell}{3}$

63. Two cells of emf's approximately 5V and 10V are to be accurately compared using a potentiometer of length 400cm.
- (A) The battery that runs the potentiometer should have voltage of 8V.
 (B) The battery of potentiometer can have a voltage of 15V and R adjusted so that the potential drop across the wire slightly exceeds 10V.
 (C) The first portion of 50 cm of wire itself should have a potential drop of 10V.
 (D) Potentiometer is usually used for comparing resistances and not voltages.
64. In the given potentiometer circuit, the resistance of the potentiometer wire AB is R_0 . C is a cell of internal resistance r . The galvanometer G does not give zero deflection for any position of the jockey J. Which of the following cannot be a reason for this ?



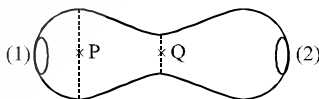
- (A) $r > R_0$ (B) $R \gg R_0$
 (C) emf of C > emf of D (D) The negative terminal of C is connected to A.
65. A resistor has a color code of green, blue; brown and silver. What is its resistance?
 (A) $56 \Omega \pm 5\%$ (B) $560 \Omega \pm 10\%$ (C) $560 \Omega \pm 5\%$ (D) $5600 \Omega \pm 10\%$
66. In a galvanometer, the deflection becomes one half when the galvanometer is shunted by a 20Ω resistor. The galvanometer resistance is



- (A) 5Ω (B) 10Ω (C) 40Ω (D) 20Ω

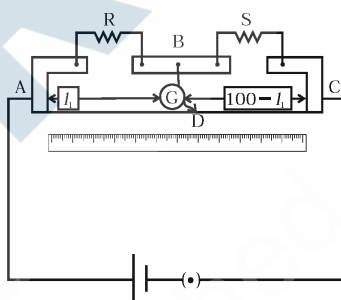
MULTIPLE CORRECT TYPE QUESTIONS

67. A metallic conductor of irregular cross-section is as shown in the figure. A constant potential difference is applied across the ends (1) and (2). Then :



- (A) the current at the cross-section P equals the current at the cross-section Q
 (B) the electric field intensity at P is less than that at Q.
 (C) the rate of heat generated per unit time at Q is greater than that at P
 (D) the number of electrons crossing per unit area of cross-section at P is less than that at Q.
68. A current passes through an ohmic conductor of nonuniform cross section. Which of the following quantities are independent of the cross-section?
 (A) the charge crossing in a given time interval.
 (B) drift speed
 (C) current density
 (D) free-electron density

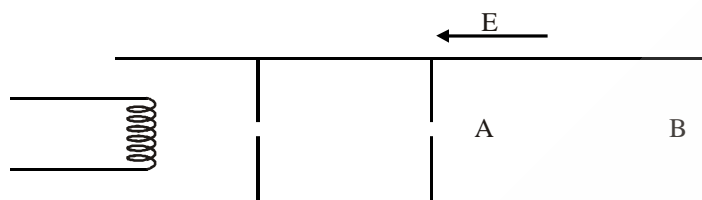
69. A battery is of emf E is being charged from a charger such that positive terminal of the battery is connected to terminal A of charger and negative terminal of the battery is connected to terminal B of charger. The internal resistance of the battery is r .
- (A) Potential difference across points A and B must be more than E .
 (B) A must be at higher potential than B
 (C) In battery, current flows from positive terminal to the negative terminal
 (D) No current flows through battery
70. Two identical fuses are rated at 10A. If they are joined
- (A) in parallel, the combination acts as a fuse of rating 20A
 (B) in parallel, the combination acts as a fuse of rating 5A
 (C) in series, the combination acts as a fuse of rating 10A.
 (D) in series, the combination acts as a fuse of rating 20A.
71. A micrometer has a resistance of 100Ω and a full scale range of $50\mu\text{A}$. It can be used as a voltmeter or a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combination(s).
- (A) 50 V range with $10\text{ k}\Omega$ resistance in series.
 (B) 10 V range with $200\text{ k}\Omega$ resistance in series.
 (C) 5 mA range with 1Ω resistance in parallel.
 (D) 10 mA range with $1\text{ k}\Omega$ resistance in parallel.
72. Mark out the correct options.
- (A) An ammeter should have small resistance. (B) An ammeter should have large resistance.
 (C) A voltmeter should have small resistance. (D) A voltmeter should have large resistance.
73. In a meter bridge the point D is a neutral point as shown in figure.



- (A) The meter bridge can have no other neutral point for this set of resistances.
 (B) When the jockey contacts a point on meter wire left of D, current flows to B from the wire through galvanometer.
 (C) When the jockey contacts a point on the meter wire to the right of D, current flows from B to the wire through galvanometer.
 (D) When R is increased, the neutral point shifts to left.

MATRIX MATCH TYPE QUESTION

74. Electrons are emitted by a hot filament and are accelerated by an electric field as shown in figure. The two stops at the left ensure that the electron beam has a uniform cross-section. Match the entries of column-I with column-II as electron move from A to B :



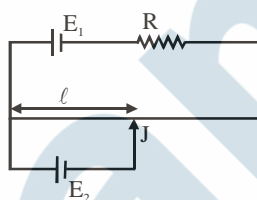
Column-I

- (A) Speed of an electron
(B) Number of free electrons per unit volume
(C) Current density
(D) Electric potential

Column-II

- (P) Increases
(Q) Decreases
(R) Remains same
(S) any of the above is possible

75. In the potentiometer arrangement shown in figure, null point is obtained at length ℓ .



Column-I

- (A) If E_1 is increased
(B) If R is increased
(C) If E_2 is increased

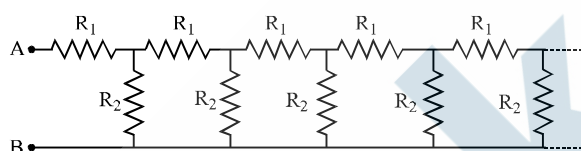
Column-II

- (P) ℓ should increase
(Q) ℓ should decrease
(R) ℓ should remain the same to again get the null point

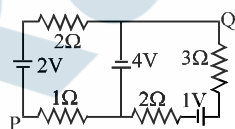
EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

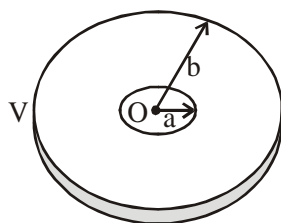
- Which of the following quantities do not change when an ohmic resistor connected to a battery is heated due to the current?
 (A) drift speed (B) resistivity
 (C) resistance (D) number of free electrons
- Consider an infinite ladder network shown in figure. A voltage V is applied between the points A and B. This applied value of voltage is halved after each section.



- (A) $R_1/R_2 = 1$ (B) $R_1/R_2 = 1/2$ (C) $R_1/R_2 = 2$ (D) $R_1/R_2 = 3$
- A wire of length L and 3 identical cells of negligible internal resistances are connected in series. Due to the current, the temperature of the wire is raised by ΔT in time t . N number of similar cells is now connected in series with a wire of the same material and cross section but of length $2L$. The temperature of the wire is raised by the same amount ΔT in the same time t . The value of N is :
 (A) 4 (B) 6 (C) 8 (D) 9
 - In the circuit shown, what is the potential difference V_{PQ} ?



- (A) $+3V$ (B) $+2V$ (C) $-2V$ (D) none
- A circular portion is cut of a disc of thickness t , its resistivity is ρ and radii of disc are a and b ($b > a$). A potential difference is maintained between outer and inner cylindrical surfaces of the disc. What is resistance of the disc ?



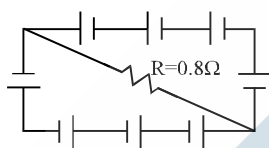
- (A) $\frac{\rho}{2\pi t} \ln\left(\frac{b}{a}\right)$ (B) $\rho\left(\frac{1}{a} - \frac{1}{b}\right)$ (C) $2\pi\rho t\left(\frac{1}{a^2} - \frac{1}{b^2}\right)$ (D) $\frac{\rho}{2\pi t}\left(\frac{b^2 - a^2}{ab}\right)$

6. The wire shown in figure has a uniform cross-section A.

$$\overline{\quad\quad\quad} \quad x=0 \quad \quad \quad x=L$$

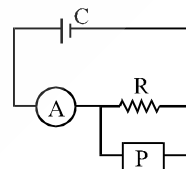
Resistivity of the material of wire is given by $\rho = \rho_0 \left(\frac{L}{L+x} \right)$. A potential difference V is applied across the wire :-

- (A) Resistance of wire is $\frac{\rho_0 L}{A} \cdot \ln(2)$ (B) Current density is variable inside the wire
(C) Electric field at $x=0$ is $\frac{2V}{(\ln 2) \cdot L}$ (D) Electric field at $x=L$ is $\frac{V}{(\ln 2) \cdot L}$
7. A circuit is comprised of eight identical batteries and a resistor $R = 0.8\Omega$. Each battery has an emf of 1.0 V and internal resistance of 0.2Ω . The voltage difference across any of the battery is



- (A) 0.5V (B) 1.0V (C) 0 V (D) 2 V

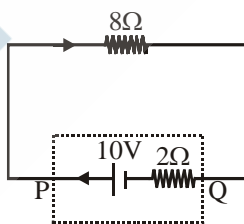
8. An ammeter A of finite resistance, and a resistor R are joined in series to an ideal cell C. A potentiometer P is joined in parallel to R. The ammeter reading is I_0 and the potentiometer reading is V_0 . P is now replaced by a voltmeter of finite resistance. The ammeter reading now is I and the voltmeter reading is V.



- (A) $I > I_0, V < V_0$ (B) $I > I_0, V = V_0$ (C) $I = I_0, V < V_0$ (D) $I < I_0, V = V_0$
9. The sensitivity of post-office box for determination of resistance of 5Ω is maximum when, P and Q both are
- (A) 1Ω (B) 10Ω (C) 100Ω (D) 1000Ω

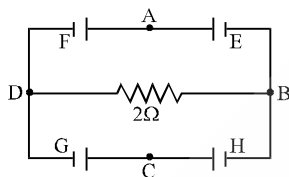
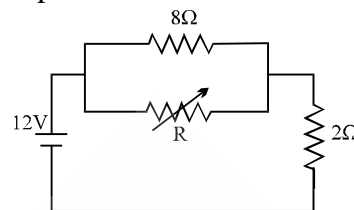
MULTIPLE CORRECT TYPE QUESTIONS

10. A battery of emf 10 volt and internal resistance 2Ω is connected to an external resistance 8Ω as shown in the figure :-

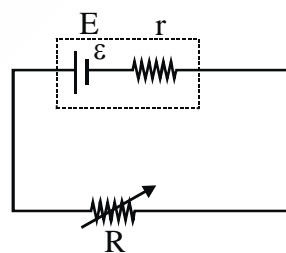
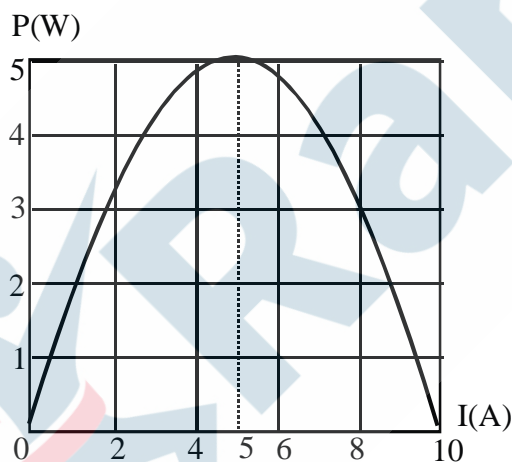


- (A) Work done due to conservative electric field while a unit positive charge passes through battery from Q to P (along the arrow) is 8 Joule.
(B) Work done due to conservative electric field while a unit positive charge passes through battery from Q to P (along the arrow) is - 8 Joule.
(C) Work done due to conservative electric field while a unit positive charge passes through 8Ω along the arrow is -8 Joule.
(D) Work done due to non conservative electric field while a unit positive charge moves from Q to P (along the arrow) is 10 Joule.

11. The value of the resistance R in figure is adjusted such that power dissipated in the 2Ω resistor is maximum. Under this condition
- (A) $R = 0$
 (B) $R = 8\Omega$
 (C) power dissipated in the 2Ω resistor is 72 W .
 (D) power dissipated in the 2Ω resistor is 8 W .
12. In the circuit shown E, F, G and H are cells of e.m.f. $2\text{V}, 1\text{V}, 3\text{V}$ and 1V respectively and their internal resistances are $2\Omega, 1\Omega, 3\Omega$ and 1Ω respectively.



- (A) $V_D - V_B = -2/13\text{ V}$
 (B) $V_D - V_B = 2/13\text{ V}$
 (C) $V_G = 21/13\text{ V}$ = potential difference across G .
 (D) $V_H = 19/13\text{ V}$ = potential difference across H .
13. Figure shows the net power dissipated in R versus the current in a simple circuit shown.



- (A) The internal resistance of battery is 0.2Ω (B) The emf of battery is 2V
 (C) R at which power is 5W is 2.5Ω (D) At $i = 2\text{A}$, power is 3.2 W
14. In a potentiometer wire experiment the emf of a battery in the primary circuit is 20V and its internal resistance is 5Ω . There is a resistance box in series with the battery and the potentiometer wire, whose resistance can be varied from 120Ω to 170Ω . Resistance of the potentiometer wire is 75Ω . The following potential differences can be measured using this potentiometer.
- (A) 5V (B) 6V (C) 7V (D) 8V

EXERCISE-JM

- Statement-1 :** The temperature dependence of resistance is usually given as $R = R_0(1 + \alpha\Delta t)$. The resistance of a wire changes from 100Ω to 150Ω when its temperature is increased from 27°C to 227°C . This implies that $\alpha = 2.5 \times 10^{-3}/^\circ\text{C}$.

Statement-2 : $R = R_0(1 + \alpha\Delta t)$ is valid only when the change in the temperature ΔT is small and $\Delta R = (R - R_0) \ll R_0$. [AIEEE-2009]

 - Statement-1 is true, Statement-2 is true; Statement-2 is not the correct explanation of Statement-1
 - Statement-1 is false, Statement-2 is true
 - Statement-1 is true, Statement-2 is false
 - Statement-1 is true, Statement-2 is true; Statement-2 is the correct explanation of Statement-1
- Two conductors have the same resistance at 0°C but their temperature coefficients of resistance are α_1 and α_2 . The respective temperature coefficients of their series and parallel combinations are nearly : [AIEEE-2010]

 - $\frac{\alpha_1 + \alpha_2}{2}, \frac{\alpha_1 + \alpha_2}{2}$
 - $\frac{\alpha_1 + \alpha_2}{2}, \alpha_1 + \alpha_2$
 - $\alpha_1 + \alpha_2, \frac{\alpha_1 + \alpha_2}{2}$
 - $\alpha_1 + \alpha_2, \frac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2}$
- If a wire is stretched to make it 0.1 % longer its resistance will :- [AIEEE-2011]

 - decrease by 0.2%
 - decrease by 0.05%
 - increase by 0.05%
 - increase by 0.2%
- If 400Ω of resistance is made by adding four 100Ω resistance of tolerance 5%, then the tolerance of the combination is : [AIEEE - 2011]

 - 20%
 - 5%
 - 10%
 - 15%
- The current in the primary circuit of a potentiometer is 0.2 A. The specific resistance and cross-section of the potentiometer wire are 4×10^{-7} ohm metre and $8 \times 10^{-7} \text{ m}^2$ respectively. The potential gradient will be equal to :- [AIEEE - 2011]

 - 0.2 V/m
 - 1 V/m
 - 0.5 V/m
 - 0.1 V/m
- Two electric bulbs marked 25W-220 V and 100 W-220 V are connected in series to a 440 V supply. Which of the bulbs will fuse ? [AIEEE - 2012]

 - Neither
 - Both
 - 100 W
 - 25 W
- The supply voltage to a room is 120V. The resistance of the lead wires is 6Ω . A 60 W bulb is already switched on. What is the decrease of voltage across the bulb, when a 240 W heater is switched on in parallel to the bulb? [JEE-Main2013]

 - zero Volt
 - 2.9 Volt
 - 13.3 Volt
 - 10.04 Volt

8. This question has Statement I and Statement II. Of the four choice given after the Statements, choose the one that best describes the two Statements. [JEE-Main 2013]

Statement-I : Higher the range, greater is the resistance of ammeter.

Statement-II : To increase the range of ammeter, additional shunt needs to be used across it.

- (1) Statement-I is true, Statement-II is true, Statement-II is the **correct** explanation of Statement-I
 (2) Statement-I is true, Statement-II is true, Statement-II is **not** the correct explanation of Statement-I.
 (3) Statement-I is **true**, Statement-II is false.
 (4) Statement-I is **false**, Statement-II is true.
9. In a large building, there are 15 bulbs of 40 W, 5 bulbs of 100 W, 5 fans of 80 W and 1 heater of 1kW. The voltage of the electric mains is 220 V. The minimum capacity of the main fuse of the building will be : [JEE-Main 2014]

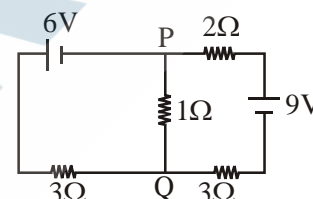
- (1) 12 A (2) 14 A (3) 8 A (4) 10 A

10. When 5V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is $2.5 \times 10^{-4} \text{ ms}^{-1}$. If the electron density in the wire is $8 \times 10^{28} \text{ m}^{-3}$, the resistivity of the material is close to :- [JEE-Main 2015]

- (1) $1.6 \times 10^{-6} \Omega\text{m}$ (2) $1.6 \times 10^{-5} \Omega\text{m}$ (3) $1.6 \times 10^{-8} \Omega\text{m}$ (4) $1.6 \times 10^{-7} \Omega\text{m}$

11. In the circuit shown, the current in the 1Ω resistor is :- [JEE-Main 2015]

- (1) 0.13 A, from Q to P
 (2) 0.13 A, from P to Q
 (3) 1.3 A, from P to Q
 (4) 0A



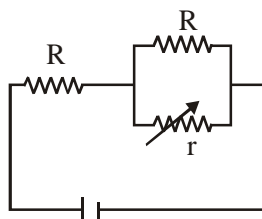
12. A galvanometer having a coil resistance of 100Ω gives a full scale deflection, when a current of 1 mA is passed through it. The value of the resistance, which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10A, is :- [JEE-Main 2016]

- (1) 3Ω (2) 0.01Ω (3) 2Ω (4) 0.1Ω

13. A 50Ω resistance is connected to a battery of 5V. A galvanometer of resistance 100Ω is to be used as an ammeter to measure current through the resistance, for this a resistance r_s is connected to the galvanometer. Which of the following connections should be employed if the measured current is within 1% of the current without the ammeter in the circuit ? [JEE-Mains (Online) 2016]

- (1) $r_s = 1\Omega$ in series with galvanometer (2) $r_s = 0.5\Omega$ in parallel with the galvanometer
 (3) $r_s = 0.5\Omega$ in series with the galvanometer (4) $r_s = 1\Omega$ in parallel with galvanometer

14. In the circuit shown, the resistance r is a variable resistance. If for $r = fR$, the heat generation in r is maximum then the value of f is : [JEE-Mains (Online) 2016]



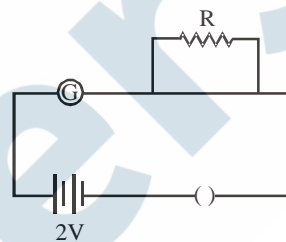
- (1) 1 (2) $\frac{1}{4}$ (3) $\frac{1}{2}$ (4) $\frac{3}{4}$

15. The resistance of an electrical toaster has a temperature dependence given by $R(T) = R_0 [1 + \alpha(T - T_0)]$ in its range of operation. At $T_0 = 300 \text{ K}$, $R = 100 \Omega$ and at $T = 500 \text{ K}$, $R = 120 \Omega$. The toaster is connected to a voltage source at 200 V and its temperature is raised at a constant rate from 300 to 500 K in 30 s . The total work done in raising the temperature is :- [JEE-Mains (Online) 2016]

- (1) $400 \ln \frac{1.5}{1.3} \text{ J}$ (2) 300 J (3) $400 \ln \frac{5}{6} \text{ J}$ (4) $200 \ln \frac{2}{3} \text{ J}$

16. A galvanometer has a 50 division scale. Battery has no internal resistance. It is found that there is deflection of 40 divisions when $R = 2400 \Omega$. Deflection becomes 20 divisions when resistance taken from resistance box is 4900Ω . Then we can conclude : [JEE-Mains (Online) 2016]

- (1) Resistance of galvanometer is 200Ω .
 (2) Resistance required on R.B. for a deflection of 10 divisions is 9800Ω .
 (3) Full scale deflection current is 2 mA .
 (4) Current sensitivity of galvanometer is $20 \mu\text{A}/\text{division}$.



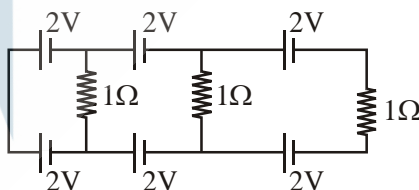
17. Which of the following statements is false ? [JEE-Main 2017]

- (1) A rheostat can be used as a potential divider
 (2) Kirchhoff's second law represents energy conservation
 (3) Wheatstone bridge is the most sensitive when all the four resistances are of the same order of magnitude.
 (4) In a balanced wheatstone bridge if the cell and the galvanometer are exchanged, the null point is disturbed.

18. When a current of 5 mA is passed through a galvanometer having a coil of resistance 15Ω , it shows full scale deflection. The value of the resistance to be put in series with the galvanometer to convert it into a voltmeter of range $0 - 10 \text{ V}$ is :- [JEE-Main 2017]

- (1) $2.535 \times 10^3 \Omega$ (2) $4.005 \times 10^3 \Omega$ (3) $1.985 \times 10^3 \Omega$ (4) $2.045 \times 10^3 \Omega$

19. In the above circuit the current in each resistance is :- [JEE-Main 2017]



- (1) 0.5 A (2) 0 A (3) 1 A (4) 0.25 A

20. In a potentiometer experiment, it is found that no current passes through the galvanometer when the terminals of the cell are connected across 52 cm of the potentiometer wire. If the cell is shunted by a resistance of 5Ω , a balance is found when the cell is connected across 40 cm of the wire. Find the internal resistance of the cell. [JEE-Main 2018]

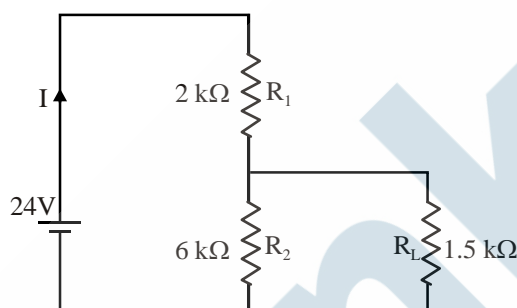
- (1) 1.5Ω (2) 2Ω (3) 2.5Ω (4) 1Ω

21. On interchanging the resistances, the balance point of a meter bridge shifts to the left by 10 cm. The resistance of their series combination is $1\text{ k}\Omega$. How much was the resistance on the left slot before interchanging the resistances ? **[JEE-Main 2018]**
- (1) $505\text{ k}\Omega$ (2) $550\text{ k}\Omega$ (3) $910\text{ k}\Omega$ (4) $990\text{ k}\Omega$
22. Two batteries with e.m.f 12 V and 13 V are connected in parallel across a load resistor of $10\ \Omega$. The internal resistances of the two batteries are $1\ \Omega$ and $2\ \Omega$ respectively. The voltage across the load lies between. **[JEE-Main 2018]**
- (1) 11.5 V and 11.6 V (2) 11.4 V and 11.5 V
(3) 11.7 V and 11.8 V (4) 11.6 V and 11.7 V

EXERCISE - JA

1. For the circuit shown in the figure

[IIT-JEE 2009]



- (A) the current I through the battery is 7.5 mA
 (B) the potential difference across R_L is 18V
 (C) ratio of powers dissipated in R_1 and R_2 is 3
 (D) if R_1 and R_2 are interchanged, magnitude of the power dissipated in R_L will decrease by a factor of 9
2. Incandescent bulbs are designed by keeping in mind that the resistance of their filament increases with the increase in temperature. If at room temperature, 100 W, 60 W and 40 W bulbs have filament resistance R_{100} , R_{60} and R_{40} , respectively, the relation between these resistances is [IIT-JEE 2010]

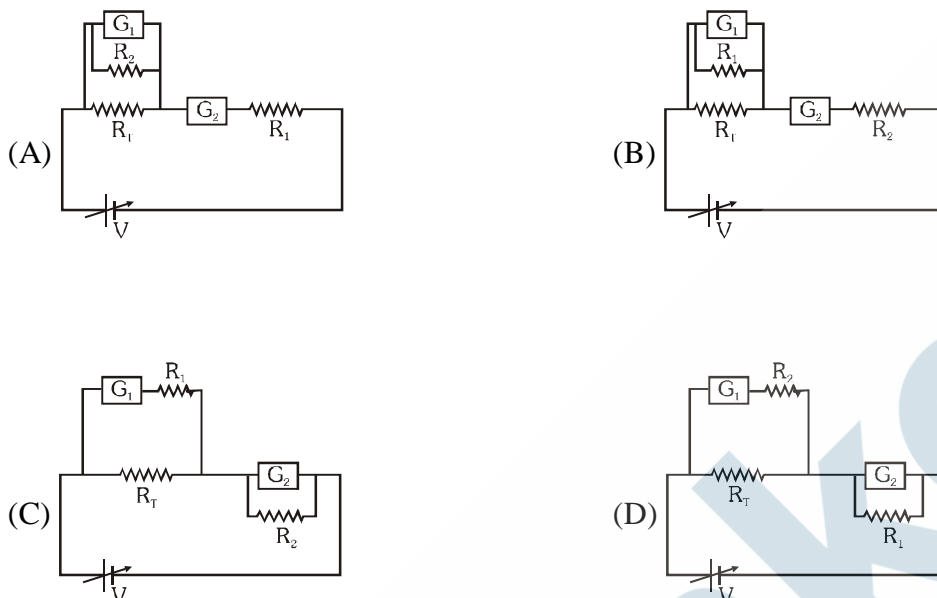
(A) $\frac{1}{R_{100}} = \frac{1}{R_{40}} + \frac{1}{R_{60}}$

(B) $R_{100} = R_{40} + R_{60}$

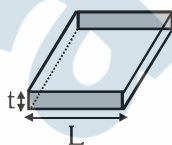
(C) $R_{100} > R_{60} > R_{40}$

(D) $\frac{1}{R_{100}} > \frac{1}{R_{60}} > \frac{1}{R_{40}}$

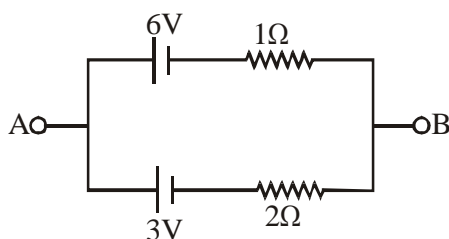
3. To verify Ohm's law, a student is provided with a test resistor R_T , a high resistance R_1 , a small resistance R_2 , two identical galvanometers G_1 and G_2 , and a variable voltage source V . The correct circuit to carry out the experiment is :— **[IIT-JEE 2010]**



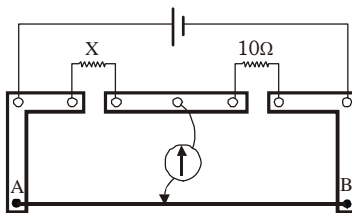
4. Consider a thin square sheet of side L and thickness t , made of a material of resistivity ρ . The resistance between two opposite faces, shown by the shaded areas in the figure is **[IIT-JEE 2010]**



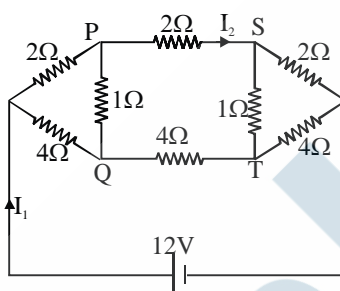
- (A) directly proportional to L (B) directly proportional to t
 (C) independent of L (D) independent of t
5. When two identical batteries of internal resistance 1Ω each are connected in series across a resistor R , the rate of heat produced in R is J_1 . When the same batteries are connected in parallel across R , the rate is J_2 . If $J_1 = 2.25 J_2$ then the value of R in Ω is **[IIT-JEE 2010]**
6. Two batteries of different emfs and different internal resistances are connected as shown. The voltage across AB in volts is **[IIT-JEE 2011]**



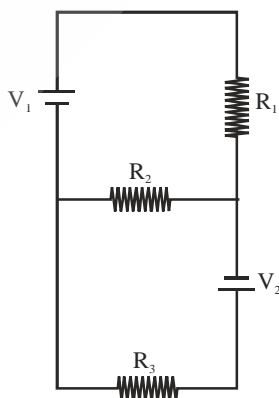
7. A meter bridge is set-up as shown, to determine an unknown resistance 'X' using a standard 10 ohm resistor. The galvanometer shows null point when tapping-key is at 52 cm mark. The end-corrections are 1 cm and 2 cm respectively for the ends A and B. The determined value of 'X' is [IIT-JEE 2011]



- (A) 10.2 ohm (B) 10.6 ohm (C) 10.8 ohm (D) 11.1 ohm
8. For the resistance network shown in the figure, choose the correct option(s). [IIT-JEE 2012]

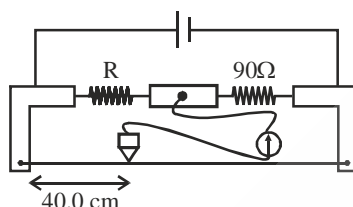


- (A) the current through PQ is zero (B) $I_1 = 3A$
 (C) The potential at S is less than that at Q (D) $I_2 = 2A$
9. Heater of an electric kettle is made of a wire of length L and diameter d . It takes 4 minutes to raise the temperature of 0.5 kg water by 40 K. This heater is replaced by a new heater having two wires of the same material, each of length L and diameter $2d$. The way these wires are connected is given in the options. How much time in minutes will it take to raise the temperature of the same amount of water by 40 K ? [JEE Advanced 2014]
- (A) 4 if wires are in parallel (B) 2 if wires are in series
 (C) 1 if wires are in series (D) 0.5 if wires are in parallel
10. Two ideal batteries of emf V_1 and V_2 and three resistances R_1 , R_2 and R_3 are connected as shown in the figure. The current in resistance R_2 would be zero if :- [JEE Advanced 2014]

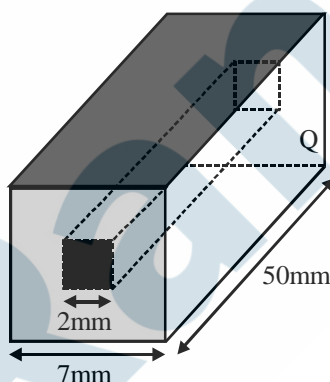


- (A) $V_1 = V_2$ and $R_1 = R_2 = R_3$ (B) $V_1 = V_2$ and $R_1 = 2R_2 = R_3$
 (C) $V_1 = 2V_2$ and $2R_1 = 2R_2 = R_3$ (D) $2V_1 = V_2$ and $2R_1 = R_2 = R_3$

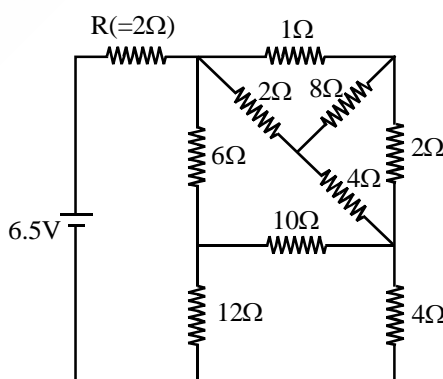
11. A galvanometer gives full scale deflection with 0.006 A current. By connecting it to a $4990\ \Omega$ resistance, it can be converted into a voltmeter of range 0 - 30 V. If connected to a $\frac{2n}{249}\ \Omega$ resistance, it becomes an ammeter of range 0 - 1.5 A. The value of n is :- **[JEE Advanced 2014]**
12. During an experiment with a metre bridge, the galvanometer shows a null point when the jockey is pressed at 40.0 cm using a standard resistance of $90\ \Omega$, as shown in the figure. The least count of the scale used in the metre bridge is 1 mm. The unknown resistance is :- **[JEE Advanced 2014]**



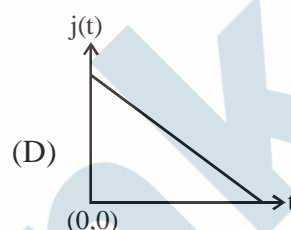
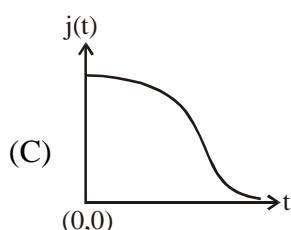
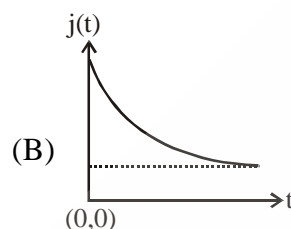
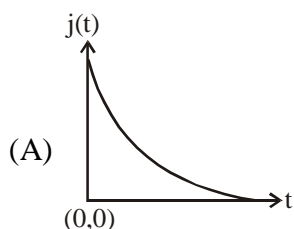
- (A) $60 \pm 0.15\ \Omega$ (B) $135 \pm 0.56\ \Omega$ (C) $60 \pm 0.25\ \Omega$ (D) $135 \pm 0.23\ \Omega$
13. In an aluminum (Al) bar of square cross section, a square hole is drilled and is filled with iron (Fe) as shown in the figure. The electrical resistivities of Al and Fe are $2.7 \times 10^{-8}\ \Omega\text{ m}$ and $1.0 \times 10^{-7}\ \Omega\text{ m}$, respectively. The electrical resistance between the two faces P and Q of the composite bar is : **[JEE Advanced-2015]**



- (A) $\frac{2475}{64}\ \mu\Omega$ (B) $\frac{1875}{64}\ \mu\Omega$ (C) $\frac{1875}{49}\ \mu\Omega$ (D) $\frac{2475}{132}\ \mu\Omega$
14. In the following circuit, the current through the resistor R ($= 2\ \Omega$) is I Amperes. The value of I is **[JEE Advanced-2015]**



15. An infinite line charge of uniform electric charge density λ lies along the axis of an electrically conducting infinite cylindrical shell of radius R . At time $t = 0$, the space inside the cylinder is filled with a material of permittivity ϵ and electrical conductivity σ . The electrical conduction in the material follows Ohm's law. Which one of the following graphs best describes the subsequent variation of the magnitude of current density $j(t)$ at any point in the material? [JEE Advanced-2016]



16. An incandescent bulb has a thin filament of tungsten that is heated to high temperature by passing an electric current. The hot filament emits black-body radiation. The filament is observed to break up at random locations after a sufficiently long time of operation due to non-uniform evaporation of tungsten from the filament. If the bulb is powered at constant voltage, which of the following statement(s) is(are) true? [JEE Advanced-2016]

- (A) The temperature distribution over the filament is uniform
- (B) The resistance over small sections of the filament decreases with time
- (C) The filament emits more light at higher band of frequencies before it breaks up
- (D) The filament consumes less electrical power towards the end of the life of the bulb

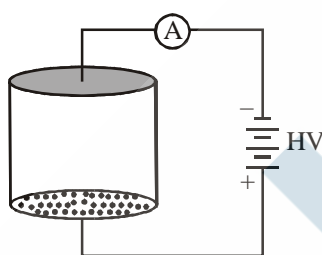
17. Consider two identical galvanometers and two identical resistors with resistance R . If the internal resistance of the galvanometers $R_G < R/2$, which of the following statement(s) about any one of the galvanometers is(are) true ?

- (A) The maximum voltage range is obtained when all the components are connected in series
- (B) The maximum voltage range is obtained when the two resistors and one galvanometer are connected in series, and the second galvanometer is connected in parallel to the first galvanometer
- (C) The maximum current range is obtained when all the components are connected in parallel
- (D) The maximum current range is obtained when the two galvanometers are connected in series and the combination is connected in parallel with both the resistors.

Paragraph for Questions No. 18 and 19

Consider an evacuated cylindrical chamber of height h having rigid conducting plates at the ends and an insulating curved surface as shown in the figure. A number of spherical balls made of a light weight and soft material and coated with a conducting material are placed on the bottom plate. The balls have a radius $r \ll h$. Now a high voltage source (HV) is connected across the conducting plates such that the bottom plate is at $+V_0$ and the top plate at $-V_0$. Due to their conducting surface, the balls will get charged, will become equipotential with the plate and are repelled by it. The balls will eventually collide with the top plate, where the coefficient of restitution can be taken to be zero due to the soft nature of the material of the balls. The electric field in the chamber can be considered to be that of a parallel plate capacitor. Assume that there are no collision between the balls and the interaction between them is negligible. (Ignore gravity)

[JEE Advanced-2016]

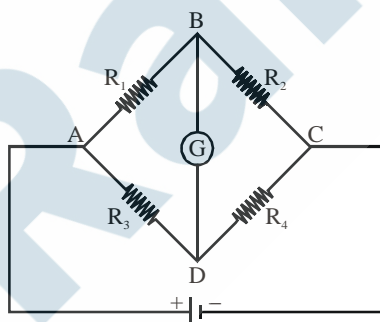


18. Which of the following statements is correct ?
 (A) The balls will bounce back to the bottom plate carrying the opposite charge they went up with
 (B) the balls will execute simple harmonic motion between the two plates
 (C) The balls will bounce back to the bottom plate carrying the same charge they went up with
 (D) The balls will stick to the top plate and remain there
19. The average current in the steady state registered by the ammeter in the circuit will be :
 (A) Proportional to $V_0^{1/2}$
 (B) Proportional to V_0^2
 (C) Proportional to the potential V_0
 (D) Zero

CURRENT ELECTRICITY

(CBSE Previous Year's Questions)

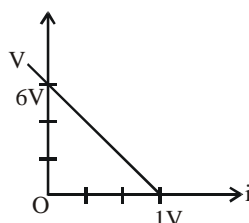
1. Explain how does the resistivity of a conductor depend upon (i) number density ' n ' of free electrons, and (ii) relaxation time ' λ '. [2; CBSE-2004]
2. Two cells of emf 1.5 V and 2 V and internal resistance 1 ohm and 2 ohm respectively are connected in parallel to pass a current in the same direction through an external resistance of 5 ohm.
(i) Draw the circuit diagram.
(ii) Using Kirchhoff's laws, calculate the current through each branch of the circuit and potential difference across the 5 ohm resistor. [3; CBSE-2005]
3. You are given ' n ' resistors, each of resistance ' r '. These are first connected to get minimum possible resistance. In the second case, these are again connected differently to get maximum possible resistance. Compute the ratio between the minimum and maximum values of resistance so obtained. [2; CBSE-2006]
4. Draw a circuit diagram using a metre bridge and write the necessary mathematical relation used to determine the value of an unknown resistance. Why cannot such an arrangement be used for measuring very low resistances? [2; CBSE-2006]
5. Which one of the two, an ammeter or a millianuneter, has a higher resistance and why? [2; CBSE-2006]
6. The given figure shows a network of resistances R_1 , R_2 , R_3 and R_4 .



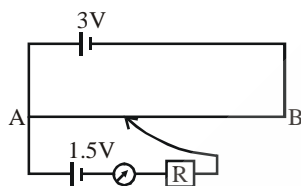
Using Kirchhoff's laws, establish the balance condition for the network.

[2; CBSE-2007]

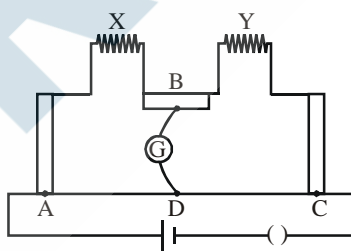
7. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is as shown below. What is the emf of each, cell [1; CBSE-2008]



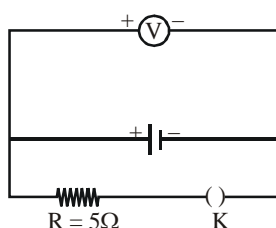
8. Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons. **[3; CBSE-2008]**
9. A number of identical cells, n each of emf E , internal resistance r connected in series are charged by a d.c source of emf E' , using a resistor R . (i) Draw the circuit arrangement. (ii) Deduce the expressions for (a) the charging current and (b) the potential difference across the combination of the cells. **[3; CBSE-2008]**
10. A potentiometer wire of length 1m is connected to a drive cell of emf 3V as shown in the figure. When a cell of 1.5 V emf is used in the secondary circuit, the balance point is found to be 60cm. On replacing this cell and using a cell of unknown emf, the balance point shifts to 80cm



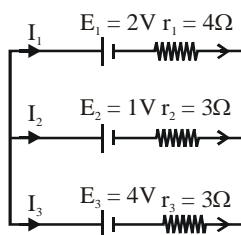
- (i) Calculate unknown emf of the cell.
 (ii) Explain with reason, whether the circuit works, if the drive cell is replaced with a cell emf 1V.
 (iii) Does the high resistance R , used in the secondary circuit affect the balance point ? Justify your answer. **[3; CBSE-2008]**
11. A cell of emf ' E ' and internal resistance ' r ' is connected across a variable resistor ' R '. Plot a graph showing the variation of terminal potential ' V ' with Resistance R . **[2; CBSE-2009]**
12. Derive an expression for drift velocity of the free electrons in a conductor in terms of relaxation time. **[2; CBSE-2009]**
13. The figure shows experimental set up of a bridge. When the two unknown resistances X and Y are inserted, the null point D is obtained 40 cm from the end A . when a resistance of 10 is connected in series with X , the null point shifts by 10 cm. find the position of the null point when the 10 resistance is instead connected in series with resistance ' Y '. Determine the values of the resistances X and Y . **[3; CBSE-2009]**



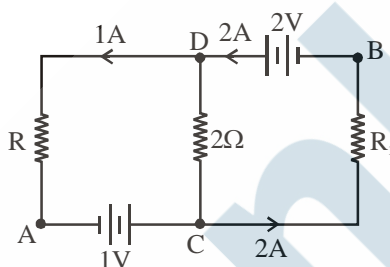
14. Write any two factors on which internal resistance of a cell depends. The reading on a high resistance voltmeter, when a cell is connected across it, is 2.2 V. When the terminals of the cell are also connected to a resistance of 5Ω as shown in the figure, the voltmeter reading drops to 1.8 V. Find the internal resistance of the cell. **[3; CBSE-2010]**



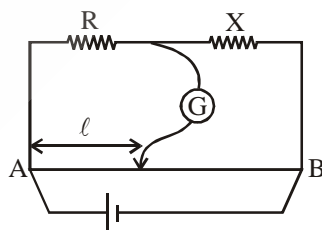
15. State Kirchhoff's rules. Use these rules to write the expressions for the currents I_1 , I_2 and I_3 in the circuit diagram shown. [3; CBSE-2010]



16. In the given circuit, assuming point A to be at zero potential, use Kirchhoff's rules to determine the potential at point B. [2; CBSE-2011]

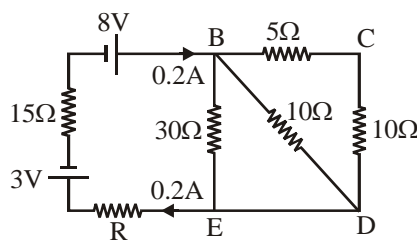


17. In the meter bridge experiment, balance point was observed at J with $AJ = l$.
 (i) The values of R and X were doubled and then interchanged. What would be the new position of balance point ?
 (ii) If the galvanometer and battery are interchanged at the balance position, how will balance point get affected ? [2; CBSE-2011]



18. Two heating elements of resistance R_1 and R_2 when operated at a constant supply of voltage, V , consume powers P_1 and P_2 respectively. Deduce the expressions for the power of their combination when they are, in turn, connected in (i) series and (ii) parallel across the same voltage supply. [3; CBSE-2011]

19. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2A . What would be the potential difference between points B and E ? [3; CBSE-2012]

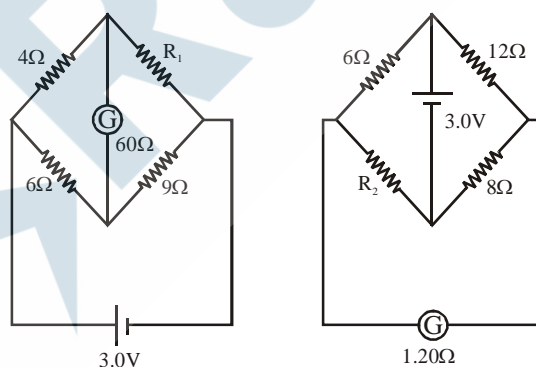


20. Define relaxation time of the free electrons drifting in a conductor. How is it related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material. [3; .CBSE-2012]
21. Two identical cells, each of emf E , having negligible internal resistance, are connected in parallel with each other across an external resistance R . What is the current through this resistance? [CBSE-2013]
22. Explain the term 'drift velocity' of electrons in a conductor. Hence obtain the expression for the current through a conductor in terms of 'drift velocity'.

OR

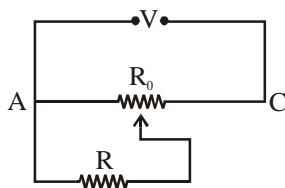
Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell. [CBSE-2013]

23. Define the current sensitivity of a galvanometer. Write its S. I. unit. Figure shows two circuits each having a galvanometer and a battery of 3V . When the galvanometers in each arrangement do not show any deflection, obtain the ratio R_1/R_2 . [CBSE-2013]

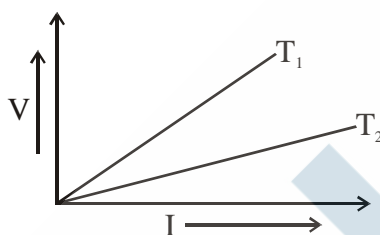


24. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $2.5 \times 10^{-7} \text{ m}^2$ carrying a current of 1.8 A . Assume the density of conduction electrons to be $9 \times 10^{28} \text{ m}^{-3}$. [CBSE-2014]
25. A cell of emf ' E ' and internal resistance ' r ' is connected across a variable resistor ' R '. Plot a graph showing variation of terminal voltage ' V ' of the cell versus the current ' I '. Using the plot, show how the emf of the cell and its internal resistance can be determined. [CBSE-2014]

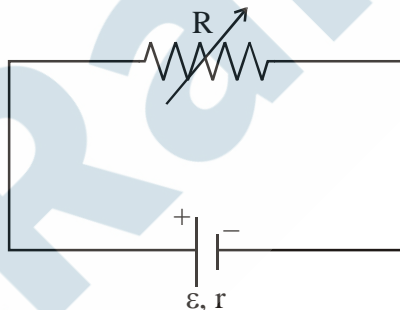
26. A resistance of $R\Omega$ draws current from a potentiometer as shown in the figure. The potentiometer has a total resistance $R_0\Omega$. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R when the sliding contact is in the middle of the potentiometer. [CBSE-2014]



27. $V - I$ graph for a metallic wire at two different temperatures T_1 and T_2 is as shown in the figure. Which of the two temperatures is higher and why? [1; CBSE-2015]

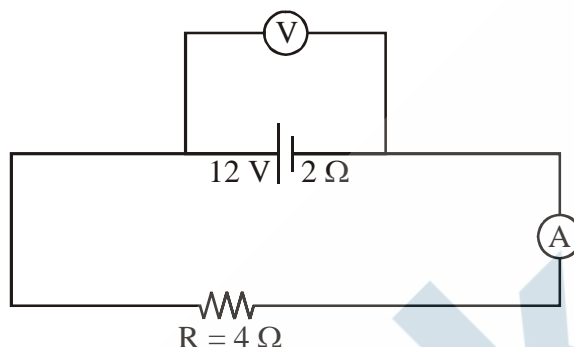


28. A variable resistor R is connected across a cell of emf ϵ and internal resistance r as shown in the figure. Draw a plot showing the variation of (i) terminal voltage V and (ii) the current I , as a function of R . [2; CBSE-2015]

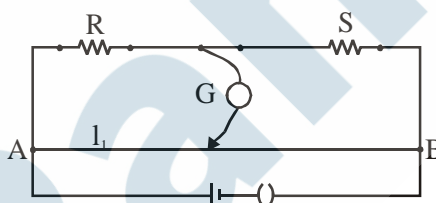


29. A potential difference V is applied across a conductor of length L and diameter D . How is the drift velocity, v_d , of charge carriers in the conductor affected when (i) V is halved, (ii) L is doubled and (iii) D is halved? Justify your answer in each case. [3; CBSE-2015]
30. Define mobility of a charge carrier. What is its relation with relaxation time? [1; CBSE-2016]
31. When 5V potential difference is applied across a wire of length 0.1m, the drift speed of electrons is 2.5×10^{-4} m/s. If the electron density in the wire is $8 \times 10^{28} \text{ m}^{-3}$, calculate the resistivity of the material of wire. [2; CBSE-2016]
32. Two identical cells of emf 1.5 V each joined in parallel supply energy to an external circuit consisting of two resistances of 7Ω each joined in parallel. A very high resistance voltmeter reads the terminal voltage of cells to be 1.4 V. Calculate the internal resistance of each cell. [3; CBSE-2016]

33. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Which wire gets heated up more ? Justify your answer. [CBSE-2017]
34. (a) The potential difference applied across a given resistor is altered so that the heat produced per second increases by a factor of 9. By what factor does the applied potential difference change ?
 (b) In the figure shown, an ammeter A and a resistor of $4\ \Omega$ are connected to the terminals of the source. The emf of the source is 12 V having an internal resistance of $2\ \Omega$. Calculate the voltmeter and ammeter readings. [CBSE-2017]

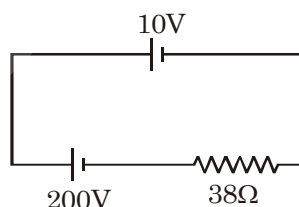


35. (a) Write the principle of working of a metre bridge.
 (b) In a metre bridge, the balance point is found at a distance l_1 with resistance R and S as shown in the figure. [CBSE-2017]



An unknown resistance X is now connected in parallel to the resistance S and the balance point is found at a distance l_2 . Obtain a formula for X in terms of l_1 , l_2 and S .

36. Two electric bulbs P and Q have their resistance in the ratio of $1 : 2$. They are connected in series across a battery. Find the ratio of the power dissipation in these bulbs. [CBSE-2018]
37. A 10 V cell of negligible internal resistance is connected in parallel across a battery of emf 200 V and internal resistance $38\ \Omega$ as shown in the figure. Find the value of current in the circuit. [CBSE-2018]



In a potentiometer arrangement for determining the emf of a cell, the balance point of the cell in open circuit is 350 cm . When a resistance of $9\ \Omega$ is used in the external circuit of the cell, the balance point shifts to 300 cm . Determine the internal resistance of the cell.

38. (a) Define the term 'conductivity' of a metallic wire. Write its SI unit. [CBSE-2018]
 (b) Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of number density and relaxation time. Hence obtain the relation between current density and the applied electric field E .

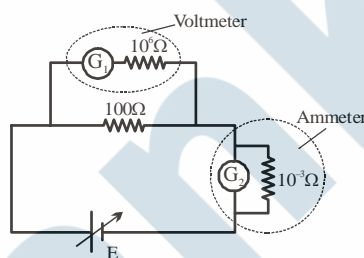
ANSWER KEY

EXERCISE - S-1

1. Ans. $I\rho/A$ 2. Ans. $S = e n l \langle v \rangle / j$ 3. Ans. $p = I m_e l/e$ 4. Ans. 3 : 1
 5. Ans. (a) (i) in series, (ii) all in parallel: n^2 .
 (b) (i) Join 1Ω , 2Ω in parallel and the combination in series with 3Ω ,
 (ii) parallel combination of 2Ω and 3Ω in series with 1Ω ,
 (iii) all in series, (iv) all in parallel.
 (c) (i) $(16/3)\Omega$, (ii) $5R$.
 6. Ans. 600Ω 7. Ans. 7.5 mA 8. Ans. 1 V 9. Ans. $I = 2.5\text{ A}$, $V = 3.5\text{ Volts}$
 10. Ans. $20/3\text{ V}$ 11. Ans. 3.5 A 13. Ans. 1Ω 14. Ans. $x = \frac{4}{3}\text{ V}$, $12\frac{1}{3}\text{ V}$, $\frac{1}{15}\text{ A}$
 15. Ans. 5 16. Ans. $\sqrt{R_1 R_2}$ 17. Ans. 25 18. Ans. 3 19. Ans. 12 A , -20 W
 20. Ans. $4/9\text{ kg/sec.}$, 450 sec 21. Ans. 20 ohm 22. Ans. $R_1 = 0.0278\Omega$, $R_2 = 0.25\Omega$, $R_3 = 2.5\Omega$

23. Ans. 233.3Ω , 144 V

24. Ans.



25. Ans. Battery should be connected across A and B. Out put can be taken across the terminals A and C or B and C
 26. Ans. This is true for $r_1 = r_2$; So R_2 given most accurate value 27. Ans. $\frac{10}{3}\Omega$, 5Ω
 28. Ans. (a) +ve, $E_\ell > E$ (b) -ve 29. Ans. 2.25 V 30. Ans. 4 ohm 31. Ans. 46.67 cm

EXERCISE - S-2

1. Ans. $5 \times 10^{-7}\text{ A}$ 2. Ans. $\alpha_{\text{eff}} = \frac{5}{4}\alpha$ 3. Ans. (i) $\frac{1}{2}i_0 t_0$ (ii) $i = i_0 \left(1 - \frac{t}{t_0}\right)$ (iii) $\frac{R t_0 i_0^2}{3}$
 4. Ans. $\frac{1}{R} = \frac{\pi r^2}{3l} (2\sigma_2 + \sigma_1)$ 5. Ans. (a) $J_0 A/3$; (b) $2J_0 A/3$ 6. Ans. 4Ω
 7. Ans. $-\frac{22}{9}\text{ V}$ 8. Ans. (i) 1.01Ω (ii) $0-5\text{ A}$, $0-10\text{ V}$, (ii) 0.05 A
 9. Ans. 7.5 m , 8.75 m , 6.25 m 10. Ans. 2

EXERCISE - O-1

- | | | | | | |
|--------------|----------------|--------------|--------------|--------------|--------------|
| 1. Ans. (C) | 2. Ans. (C) | 3. Ans. (D) | 4. Ans. (B) | 5. Ans. (A) | 6. Ans. (B) |
| 7. Ans. (C) | 8. Ans. (B) | 9. Ans. (C) | 10. Ans. (D) | 11. Ans. (A) | 12. Ans. (D) |
| 13. Ans. (C) | 14. Ans. (B,C) | 15. Ans. (B) | 16. Ans. (C) | 17. Ans. (D) | 18. Ans. (B) |
| 19. Ans. (D) | 20. Ans. (A) | 21. Ans. (C) | 22. Ans. (C) | 23. Ans. (D) | 24. Ans. (B) |
| 25. Ans. (A) | 26. Ans. (A) | 27. Ans. (A) | 28. Ans. (B) | 29. Ans. (B) | 30. Ans. (B) |
| 31. Ans. (A) | 32. Ans. (A) | 33. Ans. (C) | 34. Ans. (B) | 35. Ans. (B) | 36. Ans. (C) |
| 37. Ans. (A) | 38. Ans. (C) | 39. Ans. (B) | 40. Ans. (A) | 41. Ans. (D) | 42. Ans. (A) |
| 43. Ans. (D) | 44. Ans. (B) | 45. Ans. (B) | 46. Ans. (B) | 47. Ans. (B) | 48. Ans. (C) |
| 49. Ans. (B) | 50. Ans. (C) | 51. Ans. (D) | 52. Ans. (C) | 53. Ans. (C) | 54. Ans. (B) |
| 55. Ans. (A) | 56. Ans. (C) | 57. Ans. (A) | 58. Ans. (C) | 59. Ans. (B) | 60. Ans. (A) |
| 61. Ans. (D) | 62. Ans. (B) | 63. Ans. (B) | 64. Ans. (A) | 65. Ans. (B) | 66. Ans. (D) |

MULTIPLE CORRECT TYPE QUESTIONS

- | | | | |
|--------------------|----------------|-------------------|----------------|
| 67. Ans. (A,B,C,D) | 68. Ans. (A,D) | 69. Ans. (A,B,C) | 70. Ans. (A,C) |
| 71. Ans. (B,C) | 72. Ans. (A,D) | 73. Ans. (A,B, C) | |

MATRIX MATCH TYPE QUESTION

- | | |
|-----------------------------|------------------------|
| 74. Ans. A-P; B-Q; C-R; D-P | 75. Ans. A-Q; B-P; C-P |
|-----------------------------|------------------------|

EXERCISE - O-2**SINGLE CORRECT TYPE QUESTIONS**

- | | | | | | |
|-------------|-------------|-------------|-------------|-------------|-------------|
| 1. Ans. (D) | 2. Ans. (B) | 3. Ans. (B) | 4. Ans. (B) | 5. Ans. (A) | 6. Ans. (A) |
| 7. Ans. (C) | 8. Ans. (A) | 9. Ans. (A) | | | |

MULTIPLE CORRECT TYPE QUESTIONS

- | | | | | |
|-----------------|----------------|------------------|-------------------|------------------|
| 10. Ans. (B, D) | 11. Ans. (A,C) | 12. Ans. (A,C,D) | 13. Ans. (A, B,D) | 14. Ans. (A,B,C) |
|-----------------|----------------|------------------|-------------------|------------------|

EXERCISE - JM

- | | | | | | |
|--------------|--------------|--------------|--------------|--------------|--------------|
| 1. Ans. (2) | 2. Ans. (1) | 3. Ans. (4) | 4. Ans. (2) | 5. Ans. (4) | 6. Ans. (4) |
| 7. Ans. (4) | 8. Ans. (4) | 9. Ans. (1) | 10. Ans. (2) | 11. Ans. (1) | 12. Ans. (2) |
| 13. Ans. (2) | 14. Ans. (3) | 15. Ans. (1) | 16. Ans. (4) | 17. Ans. (4) | 18. Ans. (3) |
| 19. Ans. (2) | 20. Ans. (1) | 21. Ans. (2) | 22. Ans. (1) | | |

EXERCISE - JA

- | | | | |
|----------------|------------------|--------------|----------------------|
| 1. Ans. (A, D) | 2. Ans. (D) | 3. Ans. (C) | 4. Ans. (C) |
| 5. Ans. 4 | 6. Ans. 5 | 7. Ans. (B) | 8. Ans. (A, B, C, D) |
| 9. Ans. (B,D) | 10. Ans. (A,B,D) | 11. Ans. 5 | 12. Ans. (C) |
| 13. Ans. (B) | 14. Ans. 1 | 15. Ans. (A) | 16. Ans. (C,D) |
| 17. Ans. (B,C) | 18. Ans. (A) | 19. Ans. (B) | |