CURRENT ELECTRICITY

Contents

JEE (ADVANCED) SYLLABUS

Current Electricity : Electric current: Ohm's law; Series and parallel arrangements of resistances and cells; Kirchhoff's laws and simple applications; Heating effect of current, Galvanometer, Voltmeter, Ammeter, Potentiometer, Wheat stone bridge , Post office box, Meter bridge.

JEE (MAIN) SYLLABUS

Current Electricity : Drift velocity, Ohm's law, Electrical resistance, Resistances of different materials, V-I characteristics of Ohmic and nonohmic conductors, Electrical energy and power, Electrical resistivity, Colour code for resistors ; Series and parallel combinations of resistors ; Temperature dependence of resistance. Electric Cell and its Internal resistance, potential difference and emf of a cell, combination of cells in series and in parallel. Kirchhoff's laws and their applications. Wheatstone bridge, Metre bridge. Potentiometer-principle and its applications.

CURRENT ELECTRICITY

1. ELECTRIC CURRENT

(a) Time rate of flow of charge through a cross sectional area is called current.
if Δq charge flows in time interval Δt then average current is given by

$I_{av} = \dfrac{\Delta q}{\Delta t}$ and Instantaneous current $i = \lim\limits_{\Delta t \to 0} \dfrac{\Delta q}{\Delta t} = \dfrac{dq}{dt}$.

(b) Direction of current is along the direction of flow of positive charge or opposite to the direction of flow of negative charge. But the current is a scalar quantity.

$$\xrightarrow{\quad i \quad} \qquad \xleftarrow{\quad i \quad}$$
$$q_{\oplus} \longrightarrow \text{velocity} \quad q_{\ominus} \longrightarrow \text{velocity}$$

SI unit of current is ampere and
1 Ampere = 1 coulomb/sec
1 coulomb/sec = 1A

2. CONDUCTOR

In some materials, the outer electrons of each atom or molecule are only weakly bound to it. These electrons are almost free to move throughout the body of the material and are called free electrons. They are also known as conduction electrons. When such a material is placed in an electric field, the free electrons drift in a direction opposite to the field. Such materials are called conductors.

3. INSULATOR

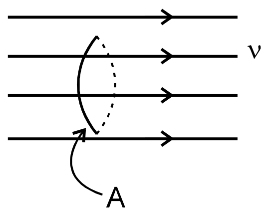
Another class of materials is called insulators in which all the electrons are tightly bound to their respective atoms or molecules. Effectively, there are no free electrons. When such a material is placed in an electric field, the electrons may slightly shift opposite to the field but they can't leave their parent atoms or molecules and hence can't move through long distances. Such materials are also called dielectrics.

4. SEMICONDUCTOR

In semiconductors, the behavior is like an insulator at low levels of temperature. But at higher temperatures, a small number of electrons are able to free themselves and they respond to the applied electric field. As the number of free electrons in a semiconductor is much smaller than that in a conductor, its behavior is in between a conductor and an insulator and hence, the name semiconductor. A free electron in a semiconductor leaves a vacancy in its normal bound position. These vacancies also help in conduction.

Current, velocity and current density

$n \rightarrow$ no. of free charge particles per unit volume
$q \rightarrow$ charge of each free particle
$i \rightarrow$ charge flow per unit time
$i = nqvA$



Current density, a vector, at a point have magnitude equal to current per unit normal area at that point and direction is along the direction of the current at that point

$\vec{J} = \dfrac{di}{ds}\ \vec{n}$ so $di = \vec{J}.\ d\vec{s}$

Current is flux of current density.

Due to principle of conservation of charge :

Charge entering at one end of a conductor = charge leaving at the other end, so current does not change with change in cross section and conductor remains uncharged when current flows through it.

Solved Examples

Example 1. Find free electrons per unit volume in a metallic wire of density 10^4 kg/m^3, atomic mass number 100 and number of free electron per atom is one.

Solution : Number of free charge particle per unit volume

$$(n) = \frac{\text{total free charge particle}}{\text{total volume}}$$

$\therefore$ Number of free electron per atom means total free electrons = total number of atoms.

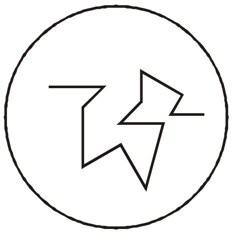
$$= \frac{N_A}{M_W} \times M$$

$$\text{So } n = \frac{\frac{N_A}{M_W} \times M}{V} = \frac{N_A}{M_W} \times d = \frac{6.023 \times 10^{23} \times 10^4}{100 \times 10^{-3}}$$

$n = 6.023 \times 10^{28}$ m^{-3}

5. MOVEMENT OF ELECTRONS INSIDE CONDUCTOR

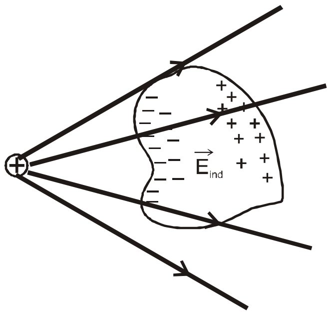
All the free electrons are in random motion due to the thermal energy and relationship in given by $\frac{3}{2}KT = \frac{1}{2}mv^2$



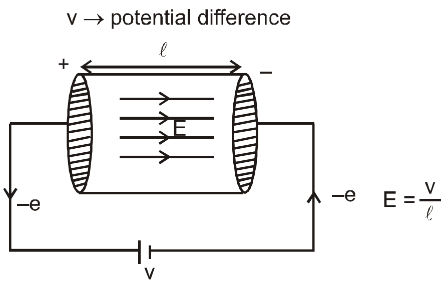
At room temperature its speed is around 10^6 m/sec or 10^3 km/sec

but the average velocity is zero so current in any direction is zero.

When a conductor is placed in an electric field. Then for a small duration electrons, do have an average velocity but its average velocity becomes zero within short interval of time.



When by some means a constant potential difference is applied across the conductor, then the electrons start moving with an acceleration and due to collision with other atoms & electrons, its average velocity becomes nearly constant and is called as drift velocity.



the electric field between the plate $= E = \frac{v}{\ell}$

V_d = drift velocity = average velocity along the wire

hence $i = nAeV_d$ V_d is of the order 10^{-3} m/s

Solved Examples

Example 2. Find the approximate total distance travelled by an electron in the time-interval in which its displacement is one meter along the wire.

Solution : time = $\frac{\text{displacement}}{\text{drift velocity}} = \frac{S}{V_d}$

$\therefore$ V_d = 1 mm/s = 10^{-3} m/s (normally the value of drift velocity is 1 mm/s)
S = 1 m

time = $\frac{1}{10^{-3}}$ = 10^3 s

distance travelled = speed × time $\quad\therefore$ speed = 10^6 m/s
So required distance = $10^6 \times 10^3$ m = 10^9 m

6. RELATION BETWEEN I & V IN A CONDUCTOR

In absence of potential difference across a conductor no net current flows through a cross section. When a potential difference is applied across a conductor the charge carriers (electrons in case of metallic conductors) start drifting in a direction opposite to electric field with average drift velocity. If electrons are moving with velocity v_d, A is area of cross section and n is number of free electrons per unit volume then,

I = nAev$_d$. $\Rightarrow$ $v_d = \frac{\lambda}{\tau}$

$\lambda \rightarrow$ average displacement of electron along the wire between two successive collisions. It is also called **mean free path**.

$\tau \rightarrow$ the time in which the particle does not collide with any other particle and is called as **relaxation time.**

$$\lambda = \frac{1}{2}\left(\frac{eE}{m}\right)\tau^2 = \frac{1}{2}\frac{e\tau^2}{m}.E = \frac{1}{2}\frac{e\tau^2}{m}\times\frac{V}{\ell}$$

$$i = nAe\,.\,\frac{1}{2}\frac{e\tau^2}{m}\times\frac{V}{\ell}\times\frac{1}{\tau} = \left(\frac{nAe^2\tau}{2m\ell}\right)V \Rightarrow \quad i = \frac{nAe^2\tau}{2m\ell}V$$

As temperature (T) $\uparrow$, $\tau\downarrow$

7. ELECTRICAL RESISTANCE

The property of a substance by virtue of which it opposes the flow of electric current through it is termed as electrical resistance. Electrical resistance depends on the size, geometry, temperature and internal structure of the conductor.

We have i = $\frac{nAe^2\tau}{2m\ell}V$

Here $\quad i \propto V$
it is known as Ohm's law

$$i = \frac{V}{R} \Rightarrow R = \frac{2m\ell}{nAe^2\tau} \qquad \Rightarrow \qquad V = IR$$

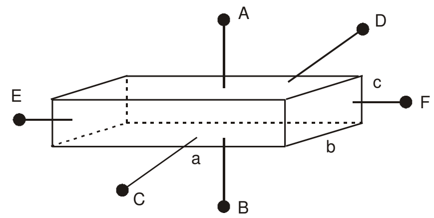
hence $R = \frac{2m\ell}{nAe^2\tau}.\frac{\ell}{A}$ so $\qquad$ Here $R = \frac{\rho\ell}{A} \quad \Rightarrow \quad V = I \times \frac{\rho\ell}{A}$

$$\Rightarrow \frac{V}{\ell} = \frac{I}{A}\rho \Rightarrow E = J\rho \qquad \Rightarrow \qquad J = \frac{I}{A} = \text{current density}$$

ρ is called resistivity (it is also called specific resistance), and $\rho = \frac{2m}{ne^2\tau} = \frac{1}{\sigma}$, σ is called conductivity.

Therefore current in conductors is proportional to potential difference applied across its ends. This is **Ohm's Law**. Units: $R \rightarrow \text{ohm}(\Omega)$, $\rho \rightarrow \text{ohm}-\text{meter}(\Omega-\text{m})$ also called siemens, $\sigma \rightarrow \Omega^{-1}\text{m}^{-1}$.

Solved Examples



Example 3. The dimensions of a conductor of specific resistance ρ are shown below. Find the resistance of the conductor across AB, CD and EF.

Answer : $R_{AB} = \frac{\rho c}{ab}$, $R_{CD} = \frac{\rho b}{ac}$, $R_{EF} = \frac{\rho a}{bc}$

Solution : For a condition

$$R = \frac{\rho\ell}{A} = \frac{\text{Resistivity} \times \text{length}}{\text{Area of cross section}}$$

$$R_{AB} = \frac{\rho c}{ab},\ R_{CD} = \frac{\rho b}{ac},\ R_{EF} = \frac{\rho a}{bc}$$

7.1 Dependence of Resistance on various factors

$$R = \rho\frac{\ell}{A} = \frac{2m}{ne^2\tau}\cdot\frac{\ell}{A}$$

Therefore R depends as

(1) $\propto \ell$ (2) $\propto \frac{1}{A}$ (3) $\propto \frac{1}{n} \propto \frac{1}{\tau}$

(4) and in metals τ decreases as T increases $\Rightarrow$ R also increases.

Results

(a) On stretching a wire (volume constant)

If length of wire is taken into account then $\frac{R_1}{R_2} = \frac{\ell_1^2}{\ell_2^2}$

If radius of cross section is taken into account then, where R_1 and R_2 are initial and final resistances and ℓ_1, ℓ_2 are initial and final lengths and r_1 and r_2 initial and final radii respectively. (If elasticity of the material is taken into consideration, the variation of area of cross-section is calculated with the help of Young's modulus and Poison's ratio)

(b) Effect of percentage change in length of wire

$$\frac{R_2}{R_1} = \frac{\ell^2\left[1+\frac{x}{100}\right]^2}{\ell^2}$$ where ℓ – original length and x - % increment

if x is quite small (say < 5%) then % change in R is

$$\frac{R_2 - R_1}{R_1}\times 100 = \left(\frac{\left(1+\frac{x}{100}\right)^2 - 1}{1}\right)\times 100 \cong 2x\%$$

Solved Examples

Example 4. If a wire is stretched to double its length, find the new resistance if original resistance of the wire was R.

Solution : As we know that $R = \frac{\rho\ell}{A}$

in case $R' = \frac{\rho\ell'}{A'}$

$\ell' = 2\ell$ (volume of the wire remains constant)

$A' = \frac{A}{2} \Rightarrow R' = \frac{\rho \times 2\ell}{A/2} = 4\frac{\rho\ell}{A} = 4R$

Example 5. The wire is stretched to increase the length by 1% find the percentage change in the Resistance.

Solution : As we known that $\therefore\ R = \frac{\rho\ell}{A}$

$$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta\ell}{\ell} - \frac{\Delta A}{A} \text{ and } \frac{\Delta\ell}{\ell} = -\frac{\Delta A}{A}$$

$$\frac{\Delta R}{R} = O + 1 + 1 = 2$$

Hence percentage increase in the Resistance = 2%

Note :

- Above method is applicable when % change is very small.

Temperature Dependence of Resistivity and Resistance :

The resistivity of a metallic conductor nearly increases with increasing temperature. This is because, with the increase in temperature the ions of the conductor vibrate with greater amplitude, and the collision between electrons and ions become more frequent. Over a small temperature range (upto 100ºC), the resistivity of a metal can be represented approximately by the equation,

$$\rho(T) = \rho_0\,[1 + \alpha\,(T - T_0)] \qquad .....(i)$$

where, ρ_0 is the resistivity at a reference temperature T_0 (often taken as 0ºC or 20ºC) and $\rho(T)$ is the resistivity at temperature T, which may be higher or lower than T_0. The factor α is called the temperature coefficient of resistivity.

The resistance of a given conductor depends on its length and area of cross-section besides the resistivity. As temperature changes, the length and area also change. But these changes are quite small and the factor ℓ/A may be treated as constant.

Then, $R \propto \rho$

and hence, $R(T) = R_0\,[1 + \alpha(T - T_0)]$ .....(ii)

In this equation R(T) is the resistance at temperature T and R_0 is the resistance at temperature T_0, often taken to be 0ºC or 20ºC. The temperature coefficient of resistance α is the same constant that appears.

Note :

- The ρ-T equation written above can be derived from the relation,

  α = fractional change in resistivity per unit change in temperature

  $= \frac{d\rho}{\rho dT} = \alpha$ or, $\frac{d\rho}{dT} = \alpha\rho$

$\therefore\ \frac{d\rho}{\rho} = \alpha dT$ (α can be assumed constant for small temperature variation)

$$\therefore\ \int_{\rho_0}^{\rho} \frac{d\rho}{\rho} = \alpha\int_{T_0}^{T} dT \qquad .....(iii)$$

$$\therefore\ \ln\left(\frac{\rho}{\rho_0}\right) = \alpha\,(T - T_0)$$

$$\therefore\ \rho = \rho_0 e^{\alpha(T-T_0)}$$

if $\alpha\,(T - T_0) << 1$ then

$e^{\alpha(T-T_0)}$ can approximately be written as $1 + \alpha(T - T_0)$. Hence,

In the above discussion we have assumed α to be constant. If it is a function of temperature it will come inside the integration in Eq. (iii).

Solved Examples

Example 6. The resistance of a thin silver wire is 1.0 Ω at 20ºC. The wire is placed in liquid bath and its resistance rises to 1.2 Ω. What is the temperature of the bath ? (Here $\alpha = 10^{-2}$ /ºC)

Solution : Here change in resistance is small so we can apply

$R = R_0 (1 + \alpha\Delta\theta)$

$\Rightarrow$ $1.2 = 1 \times (1 + 10^{-2}\,\Delta\theta)$ $\Rightarrow$ $\Delta\theta = 20$ºC

$\Rightarrow$ $\theta - 20 = 20$ $\Rightarrow$ $\theta = 40$º C **Ans.**

Example 7. A conductive wire has resistance of 10 ohm at 0ºC, and α is $\frac{1}{273}$ /ºC, then determine its resistance at 273ºC.

Solution : In such a problem, term $\alpha\,\Delta\,T$ will have a larger value so could not be used directly in $R = R_0\,(1 + \alpha\,\Delta\,T)$. We need to go for basics as

As we know that $\alpha = \frac{dR}{RdT}$

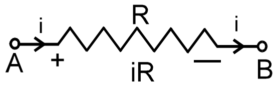
$\Rightarrow$ $\int \frac{dR}{R} = \int \alpha dT$ $\Rightarrow$ $\ell n \frac{R_2}{R_1} = \alpha(T_2 - T_1)$

$\Rightarrow$ $R_2 = R_1 e^{\alpha(T_2 - T_1)}$ $\Rightarrow$ $R_2 = 10e^1$

$\Rightarrow$ $R_2 = 10\,e\,\Omega$ **Ans.**

<u>Electric current in resistance</u>

In a resistor current flows from high potential to low potential High potential is represented by positive (+) sign and low potential is represented by negative (–) sign.



$V_A - V_B = iR$

If $V_1 > V_2$ then current will flow from A to B

and $i = \frac{V_1 - V_2}{R}$

If $V_1 < V_2$ then current will go from B to A and $i = \frac{V_2 - V_1}{R}$

Example 8. Calculate current (i) flowing in part of the circuit shown in figure?

Solution : $V_A - V_B = i \times R$ $\Rightarrow$ $i = \frac{6}{2} = 3A$ **Ans.**

8. ELECTRICAL POWER :

Energy liberated per second in a device is called its power. The electrical power P delivered or consumed by an electrical device is given by P = VI, where V = Potential difference across the device and

I = Current.

If the current enters the higher potential point of the device then electric power is consumed by it (i.e. acts as load). If the current enters the lower potential point then the device supplies power (i.e. acts as source).

Power = $\frac{V.dq}{dt}$ = V I

P = V I

If power is constant then energy = P t

If power is variable then Energy = $\int pdt$

Power consumed by a resistor P = $I^2R = VI = \frac{V^2}{R}$.

When a current is passed through a resistor energy is wasted in overcoming the resistance of the wire. This energy is converted into heat.

$$W = VIt = I^2 Rt = \frac{V^2}{R} t$$

The heat generated (in joules) when a current of I ampere flows through a resistance of R ohm for t second is given by:

$$H = I^2 Rt \text{ Joule} = \frac{I^2 Rt}{4.2} \text{ Calorie}$$

1 unit of electrical energy = 1 Kilowatt hour = 1 KWh = 3.6×10^6 Joule.

Solved Examples

Example 9. If bulb rating is 100 watt and 220 V then determine
(a) Resistance of filament
(b) Current through filament
(c) If bulb operate at 110 volt power supply then find power consumed by bulb.

Solution : Bulb rating is 100 W and 220 V bulb means when 220 V potential difference is applied between the two ends then the power consumed is 100 W

Here V = 220 Volt

P = 100 W

$\frac{V^2}{R} = 100$ So $R = 484\ \Omega$

Since Resistance depends only on material hence it is constant for bulb

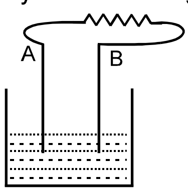
$I = \frac{V}{R} = \frac{220}{22 \times 22} = \frac{5}{11}$ Amp.

Power consumed at 110 V

$\therefore$ Power consumed = $\frac{110 \times 110}{484}$ = 25 W

9. BATTERY (CELL)

A battery is a device which maintains a potential difference across its two terminals A and B. Dry cells, secondary cells, generator and thermocouple are the devices used for producing potential difference in an electric circuit. Arrangement of cell or battery is shown in figure. Electrolyte provides continuity for current.



It is often prepared by putting two rods or plates of different metals in a chemical solution. Some internal mechanism exerts force $(\vec{F}_n)$ on the ions (positive and negative) of the solution. This force drives positive ions towards positive terminal and negative ions towards negative terminal. As positive charge accumulates on anode and negative charge on cathode a potential difference and hence an electric field $\vec{E}$ is developed from anode to cathode. This electric field exerts an electrostatic force $\vec{F} = q\vec{E}$ on the ions. This force $\vec{E}$ is opposite to that of $\vec{F}_n$. In equilibrium (steady state)

$F_n = F_e$ and no further accumulation of charge takes place.

When the terminals of the battery are connected by a conducting wire, an electric field is developed in the wire. The free electrons in the wire move in the opposite direction and enter the battery at positive terminal. Some electrons are withdrawn from the negative terminal. Thus, potential difference and hence, F_e decreases in magnitude while F_n remains the same. Thus, there is a net force on the positive charge towards the positive terminal. With this the positive charge rush towards positive terminal and negative charge rush towards negative terminal. Thus, the potential difference between positive and negative terminal is maintained.

Internal resistance (r) :

The potential difference across a real source in a circuit is not equal to the emf of the cell. The reason is that charge moving through the electrolyte of the cell encounters resistance. We call this the internal resistance of the source.

* The internal resistance of a cell depends on the distance between electrodes ($r \propto d$), area of electrodes ($r \propto \frac{1}{s}$) and nature, concentration ($r \propto c$) and temperature of electrolyte ($r \propto \frac{1}{\text{Temp.}}$).

Solved Example

Example 10. What is the meaning of 10 Amp. hr ?

Solution : It means if the 10 A current is withdrawn then the battery will work for 1 hour.

10 Amp $\longrightarrow$ 1 hr

1 Amp $\longrightarrow$ 10 hr

½ Amp $\longrightarrow$ 20 hr

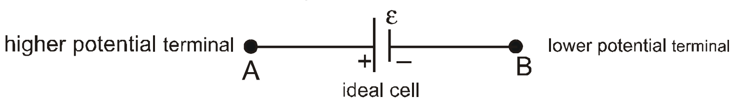
10. ELECTROMOTIVE FORCE : (E.M.F.)

Definition I : Electromotive force is the capability of the system to make the charge flow.

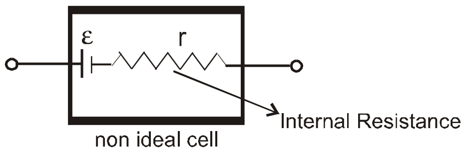
Definition II : It is the work done by the battery for the flow of 1 coloumb charge from lower potential terminal to higher potential terminal inside the battery.

10.1 Representation for battery :

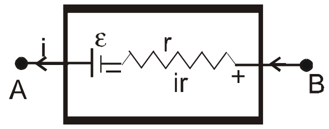
Ideal cell : Cell in which there is no heating effect.



Non ideal cell : Cell in which there is heating effect inside due to opposition to the current flow internally



Case I : Battery acting as a source (or battery is discharging)



$V_A - V_B = \varepsilon - ir$

$V_A - V_B$

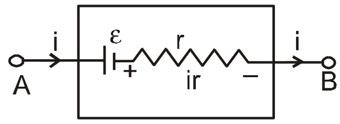
$\Rightarrow$ it is also called terminal voltage.

The rate at which the chemical energy of the cell is consumed = εi

The rate at which heat is generated inside the battery or cell = i^2r

electric power output = $\varepsilon i - i^2r = (\varepsilon - ir)\, i$

Case II : Battery acting as a load (or battery charging)



$V_A - V_B = \varepsilon + ir$

the rate at which chemical energy stored in the cell = εi

thermal power inside the cell = i^2r

electric power input = $\varepsilon i + i^2r = (\varepsilon + ir)\, i = (V_A - V_B)\, i$

Definition III :

Electromotive force of a cell is equal to potential difference between its terminals when no current is passing through the circuit.

Case III : When cell is in open circuit

i = 0 as resistance of open circuit is infinite (∞).

So V = ε, so open circuit terminal voltage difference is equal to emf of the cell.

Case IV :

Short circuiting : Two points in an electric circuit directly connected by a conducting wire are called short circuited, under such condition both points are at same potential.

When cell is short circuited

$i = \frac{\varepsilon}{r}$ and V = 0, short circuit current of a cell is maximum.

Note :

- The potential at all points of a wire of zero resistance will be same.

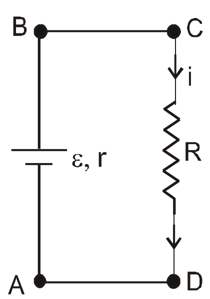
* **Earthing :** If some point of circuit is earthed then its potential is assumed to be zero.

11 RELATIVE POTENTIAL

While solving an electric circuit it is convenient to chose a reference point and assigning its voltage as zero, then all other potentials are measured with respect to this point. This point is also called the common point.

Solved Examples

Example 11. In the given electric circuit find



(a) current
(b) power output
(c) relation between r and R so that the electric power output (that means power given to R) is maximum.
(d) value of maximum power output.
(e) plot graph between power and resistance of load
(f) From graph we see that for a given power output there exists two values of external resistance, prove that the product of these resistances equals r^2.
(g) what is the efficiency of the cell when it is used to supply maximum power.

Solution : (a) In the circuit shown if we assume that potential at A is zero then potential at B is ε – ir. Now since the connecting wires are of zero resistance

$\therefore$ $V_D = V_A = 0$ $\Rightarrow$ $V_C = V_B = \varepsilon - ir$

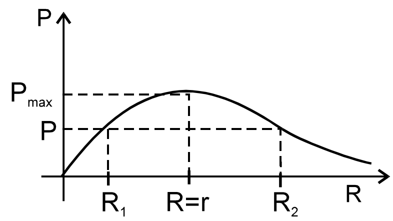
Now current through CD is also i ($\because$ it's in series with the cell).

$\therefore$ $i = \frac{V_C - V_D}{R} = \frac{(\varepsilon - i\ r) - 0}{R}$ Current $i = \frac{\varepsilon}{r + R}$

Note : After learning the concept of series combination we will be able to calculate the current directly

(b) Power output $P = i^2 R = \frac{\varepsilon^2}{(r+R)^2} . R$

(c) $\frac{dP}{dR} = \frac{\varepsilon^2}{(r+R)^2} - \frac{2\varepsilon^2 R}{(r+R)^3} = \frac{\varepsilon^2}{(R+r)^3}[R + r - 2R]$



for maximum power supply $\frac{dP}{dR} = 0$

$\Rightarrow$ $r + R - 2R = 0$ $\Rightarrow$ **r = R**

Here for maximum power output outer resistance should be equal to internal resistance

(d) $P_{max} = \frac{\varepsilon^2}{4r}$

(e) Graph between 'P' and R maximum power output at R = r

$P_{max} = \frac{\varepsilon^2}{4r}$ $\Rightarrow$ $i = \frac{\varepsilon}{r + R}$

(f) Power output $P = \frac{\varepsilon^2 R}{(r+R)^2}$

$P(r^2 + 2rR + R^2) = \varepsilon^2 R$

$R^2 + (2r - \frac{\varepsilon^2}{P}) R + r^2 = 0$

above quadratic equation in R has two roots R_1 and R_2 for given values of ε, P and r such that

$\therefore$ $R_1R_2 = r^2$ (product of roots)

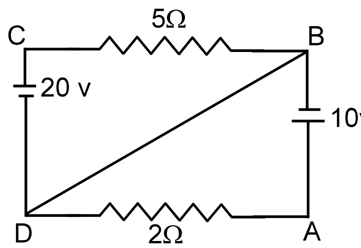
$\mathbf{r^2 = R_1R_2}$

(g) Power of battery spent $= \frac{\varepsilon^2}{(r+r)^2} .2r = \frac{\varepsilon^2}{2r}$

power (output) $= \left(\frac{\varepsilon}{r+r}\right)^2 \times r = \frac{\varepsilon^2}{4r}$

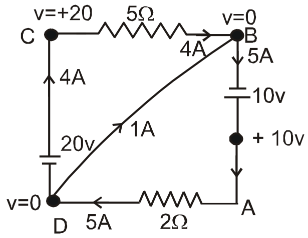
Efficiency $= \frac{\text{power output}}{\text{total power spent by cell}} = \frac{\frac{\varepsilon^2}{4r} \times 100}{\frac{\varepsilon^2}{2r}} = \frac{1}{2} \times 100 = 50\%$

Example 12. In the figure given beside find out the current in the wire BD

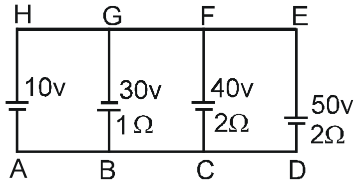


Solution : Let at point D potential = 0 and write the potential of other points then current in wire AD = $\frac{10}{2}$ = 5 A from A to D current in wire CB = $\frac{20}{5}$ = 4A from C to F

$\therefore$ current in wire BD = 1 A from D to B



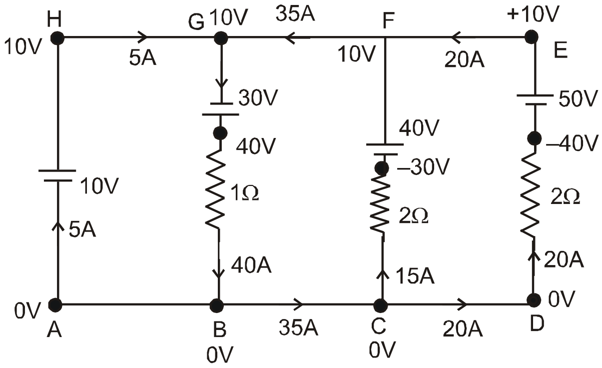
Example 13. Find the current in each wire



Solution : Let potential at point A is 0 volt then potential of other points is shown in figure.

current in BG = $\frac{40-0}{1}$ = 40 A from G to B

current in FC = $\frac{0-(-30)}{2}$ = 15 A from C to F



current in DE = $\frac{0-(-40)}{2}$ = 20 A from D to E

current in wire AH = 40 – 35 = 5 A from A to H

12. KIRCHHOFF'S LAWS

12.1 Kirchhoff's Current Law (Junction law)

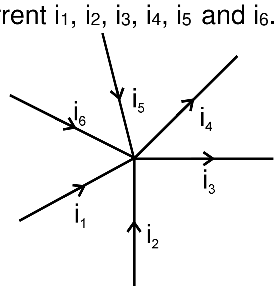
This law is based on law of conservation of charge. It states that " The algebraic sum of the currents meeting at a point of the circuit is zero " or total currents entering a junction equals total current leaving the junction.

$\Sigma I_{in} = \Sigma I_{out}$.

It is also known as KCL (Kirchhoff's current law).

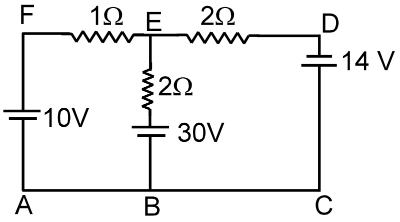
Solved Examples

Example 14. Find relation in between current i_1, i_2, i_3, i_4, i_5 and i_6.

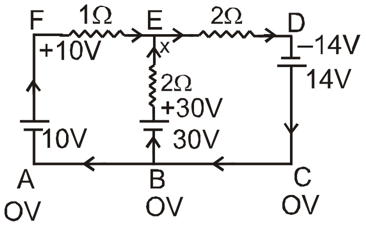


Solution : $i_1 + i_2 - i_3 - i_4 + i_5 + i_6 = 0$

Example 15. Find the current in each wire



Solution :



Let potential at point B = 0. Then potential at other points are mentioned.

∴ Potential at E is not known numerically.

Let potential at E = x

Now applying Kirchhoff's current law at junction E. (This can be applied at any other junction also).

$$\frac{x-10}{1}+\frac{x-30}{2}+\frac{x+14}{2}=0$$

4x = 36 ⇒ x = 9

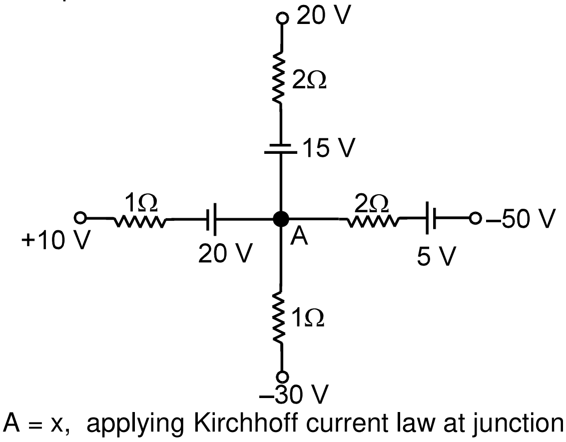
Current in EF = $\frac{10-9}{1}$ = 1A from F to E

Current in BE = $\frac{30-9}{2}=10.5\text{A}$ from B to E

Current in DE = $\frac{9-(-14)}{2}=11.5\text{A}$ from E to D

Solved Example

Example 16. Find the potential at point A



Solution : Let potential at A = x, applying Kirchhoff current law at junction A

$$\frac{x-20-10}{1}+\frac{x-15-20}{2}+\frac{x+45}{2}+\frac{x+30}{1}=0$$

$$\Rightarrow \quad \frac{2x-\ \ 60+x-35+x+45+2x+60}{2}=0$$

⇒ 6x + 10 = 0 ⇒ x = –5/3

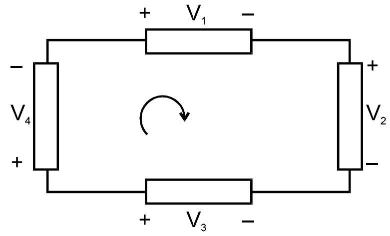
Potential at A = $\frac{-5}{3}$ V

12.2 Kirchhoff's Voltage Law (Loop law) :

"The algebraic sum of all the potential differences along a closed loop is zero.

So $IR + \Sigma$ EMF = 0".

The closed loop can be traversed in any direction. While traversing a loop if potential increases, put a positive sign in expression and if potential decreases put a negative sign. (Assume sign convention)



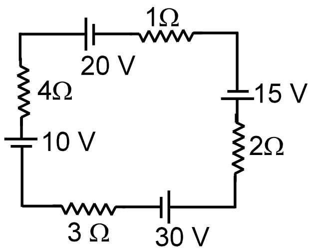
$$-V_1 - V_2 + V_3 - V_4 = 0.$$

Boxes may contain resistor or battery or any other element (linear or nonlinear).

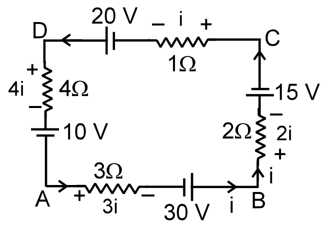
It is also known as **KVL**

Solved Examples

Example 17. Find current in the circuit



Solution : $\because$ all the elements are connected in series current is all of them will be same let current = i



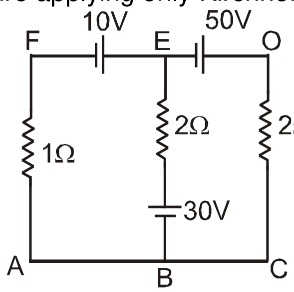
Applying Kirchhoff voltage law in ABCDA loop

$10 + 4i - 20 + i + 15 + 2i - 30 + 3i = 0$

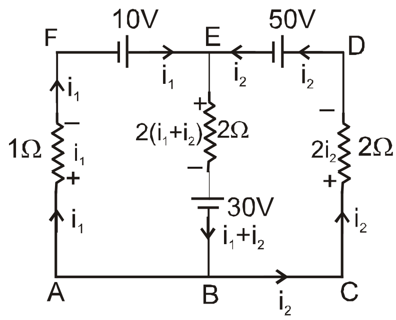
$10i = 25$

$\Rightarrow$ i = 2.5 A

Example 18. Find the current in each wire applying only Kirchhoff voltage law



Solution : Applying Kirchhoff voltage law in loop ABEFA



$i_1 + 30 + 2\,(i_1 + i_2) - 10 = 0$

$3I_1 + 2I_2 + 20 = 0$ .....(i)

Applying Kirchhoff voltage law in BEDCB

$+\,30 + 2(i_1 + i_2) + 50 + 2i_2 = 0$

$4i_2 + 2i_1 + 80 = 0$

$2i_2 + i_1 + 40 = 0$ .....(ii)

Solving (i) and (ii)

$3\left[-40 \ \ -2i_2\right] + 2i_2 + 20 = 0$

$-\,120 - 4i_2 + 20 = 0$

$i_2 = -25$ A and $i_1 = 10$ A $\therefore$ $i_1 + i_2 = -\,15$ A

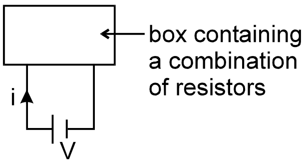
current in wire AF = 10 A from A to F

current in wire EB = 15 A from B to E

current in wire DE = 25 A from E to D.

13. COMBINATION OF RESISTANCES :

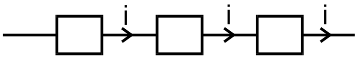
A number of resistances can be connected and all the complicated combinations can be reduced to two different types, namely series and parallel.



The equivalent resistance of a combination is defined as $R_{eq} = \frac{V}{i}$

13.1 Resistances in Series:

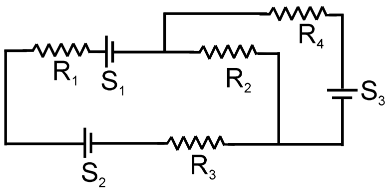
When the resistances (or any type of elements) are connected end to end then they are said to be in series. The current through each element is same.



Resistances in series carry equal current but reverse may not be true.

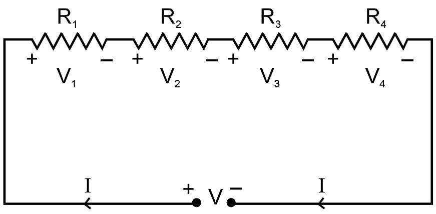
Solved Example

Example 19. Which electrical elements are connected in series?



Solution : Here S_1, S_2, R_1, R_3 connected in one series and R_4, S_3 connected in different series

Equivalent of Resistors :



The effective resistance appearing across the battery (or between the terminals A and B) is

$R = R_1 + R_2 + R_3 + ... + R_n$ (this means R_{eq} is greater then any resistor)

and $V = V_1 + V_2 + V_3 + ... + V_n$.

The potential difference across a resistor is proportional to the resistance. Power in each resistor is also proportional to the resistance

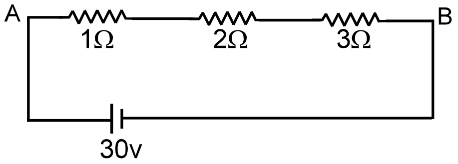
$\because$ $V = IR$ and $P = I^2R$

where I is same through any of the resistor.

$V_1 = \frac{R_1}{R_1 + R_2 + ... + R_n} V$; $V_2 = \frac{R_2}{R_1 + R_2 + ... + R_n} V$; etc

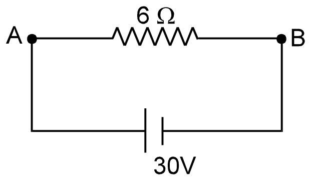
Solved Examples

Example 20. Find the current in the circuit



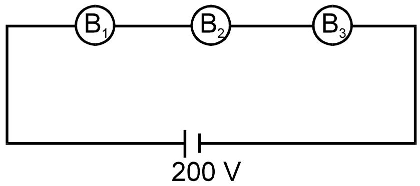
Solution : $R_{eq} = 1 + 2 + 3 = 6\ \Omega$

the given circuit is equivalent to



current $i = \frac{v}{R_{eq}} = \frac{30}{6} = \mathbf{5\ A}$ **Ans.**

Example 21. In the figure shown B_1, B_2 and B_3 are three bulbs rated as (200V, 50 W), (200V, 100W) and (200 V, 25W) respectively. Find the current through each bulb and which bulb will give more light?



Solution : $R_1 = \frac{(200)^2}{50}$; $R_2 = \frac{(200)^2}{100}$; $R_3 = \frac{(200)^2}{25}$

the current following through each bulb is

$$= \frac{200}{R_1 + R_2 + R_3} = \frac{200}{(200)^2\left[\frac{2+1+4}{100}\right]} = \frac{100}{200 \times 7} = \frac{1}{14}\,A$$

Since $R_3 > R_1 > R_2$

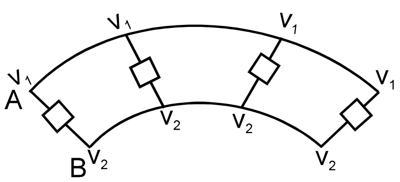
$\therefore$ Power consumed by bulb = i^2R

$\therefore$ if the resistance is of higher value then it will give more light.

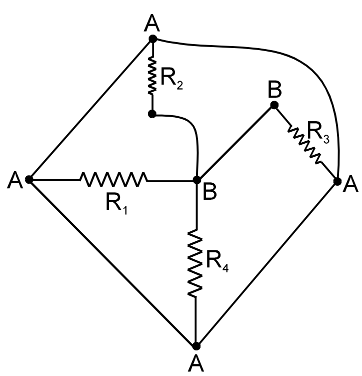
$\therefore$ Here Bulb B_3 will give more light.

13.2 Resistances in Parallel :

A parallel circuit of resistors is one in which the same voltage is applied across all the components in a parallel grouping of resistors R_1, R_2, R_3,........, R_n.



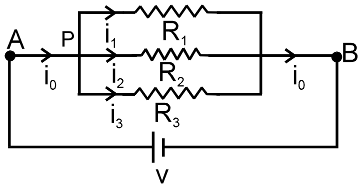
(a)



(b)

In the figure (a) and (b) all the resistors are connected between points A and B so they are in parallel.

Equivalent resistance :



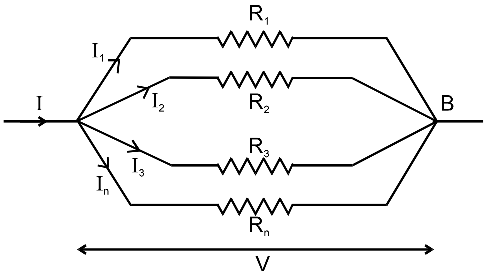
Applying Kirchhoff's junction law at point P

$i_0 = i_1 + i_2 + i_3$

Therefore, $\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ $\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

in general,

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots + \frac{1}{R_n}}$$



Conclusions: (about parallel combination)

(a) Potential difference across each resistor is same.

(b) $I = I_1 + I_2 + I_3 + \ldots\ldots\ldots\ldots I_n$.

(c) Effective resistance (R) then $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}$. (R is less than each resistor).

(d) Current in different resistors is inversely proportional to the resistance.

$I_1 : I_2 : \ldots\ldots\ldots\ldots I_n = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3} : \ldots\ldots\ldots : \frac{1}{R_n}$.

$I_1 = \frac{G_1}{G_1 + G_2 + \ldots\ldots\ldots + G_n} I$, $I_2 = \frac{G_2}{G_1 + G_2 + \ldots\ldots\ldots + G_n} I$, etc.

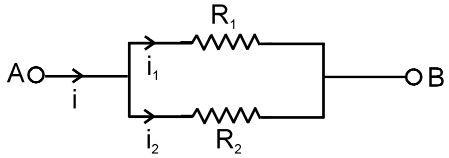
where $G = \frac{1}{R}$ = Conductance of a resistor. [Its unit is Ω^{-1} or $℧$ (mho)]

Solved Example

Example 22. When two resistors are in parallel combination then determine i_1 and i_2, if the combination carries a current i ?

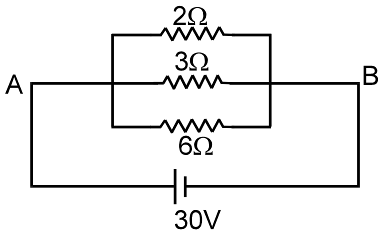
Solution : $\therefore$ $i_1R_1 = i_2R_2$ or $\frac{i_1}{i_2} = \frac{R_2}{R_1}$

$i_1 = \frac{R_2 \; i}{R_1 + R_2}$ $\Rightarrow$ $i_2 = \frac{R_1 \; i}{R_1 + R_2}$,



Note : Remember this law of $i \propto \frac{1}{R}$ in the resistors connected in parallel. It can be used in problems.

Example 23. Find current passing through the battery and each resistor.



Solution : **Method (I) :** It is easy to see that potential difference across each resistor is 30 V.

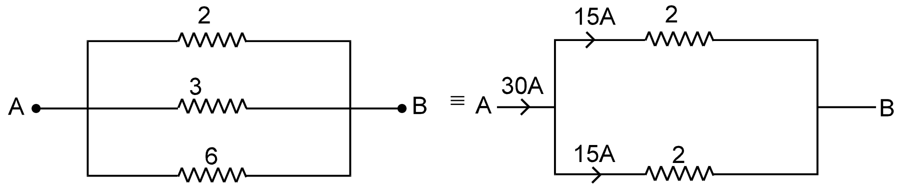
$\therefore$ current is each resistors are $\frac{30}{2}$ = 15 A, $\frac{30}{3} = 10$ A and $\frac{30}{6} = 5$ A

$\therefore$ Current through battery is = 15 + 10 + 5 =30 A.

Method (II) : By ohm's law i = $\frac{V}{R_{eq}}$ $\Rightarrow$ $\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$ = 1Ω

R_{eq} = 1Ω $\Rightarrow$ i = $\frac{30}{1}$ = 30 A

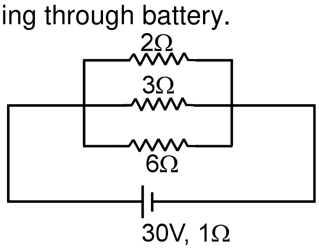
Now distribute this current in the resistors in their inverse ratio.



Current total in 3 Ω and 6 Ω is 15 A it will be divided as 10 A and 5 A.

Note : The method (I) is better. But you will not find such an easy case every where.

Exercise 24. Find current which is passing through battery.

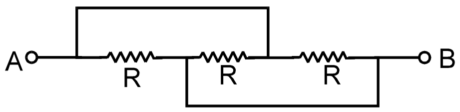


Solution : Here potential difference across each resistor is not 30 V

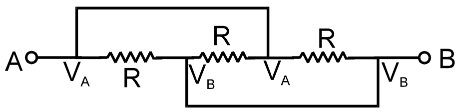
$\because$ Battery has internal resistance. Here the concept of combination of resistors is useful.

R_{eq} = 1 + 1 = 2 Ω ; i = $\frac{30}{2}$ = 15 A.

Example 25. Find equivalent Resistance

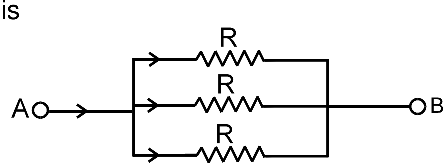


Solution :

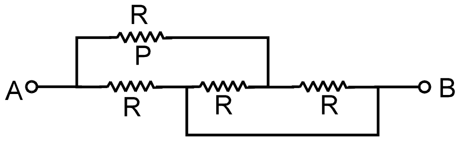


Here all the Resistance are connected between the terminals A and B
Modified circuit is

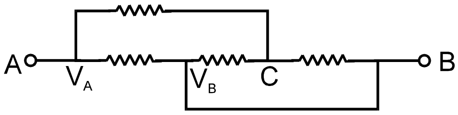
So $R_{eq} = \frac{R}{3}$



Example 26. Find the current in Resistance P if voltage supply between A and B is V volts.

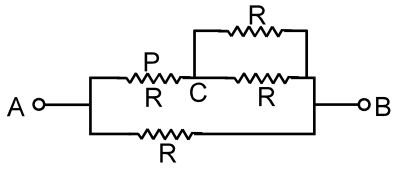


Solution :

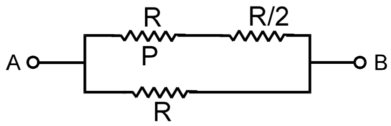


$R_{eq} = \dfrac{3R}{5}$

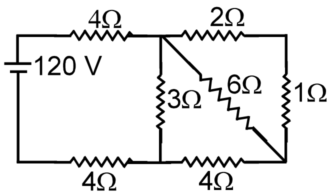
$I = \dfrac{5V}{3R}$ Modified circuit



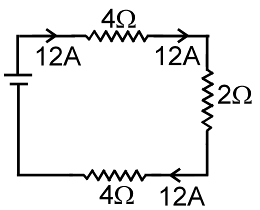
Current in P = $\dfrac{R \times \dfrac{5V}{3R}}{1.5R + R} = \dfrac{2V}{3R}$

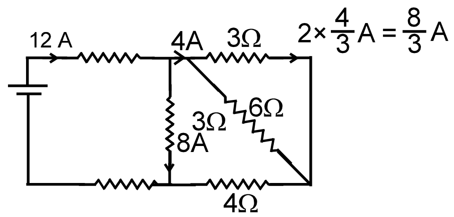


Example 27. Find the current in 2Ω resistance



Solution :





2Ω, 1Ω in series = 3Ω

3Ω, 6Ω in parallel = $\dfrac{18}{9}$ =2Ω

2Ω, 4Ω in series = 6Ω

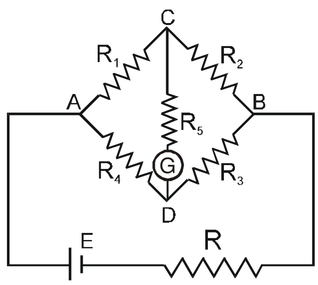
6Ω, 3Ω in parallel = 2Ω

R_{eq} = 4 + 4 + 2 = 10Ω

$i = \dfrac{120}{10}$ = 12A

So current in 2Ω Resistance = $\dfrac{8}{3}$ A

14. WHEATSTONE NETWORK : (4 TERMINALNETWORK)



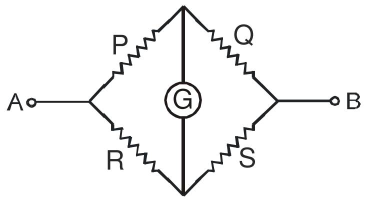
The arrangement as shown in figure, is known as Wheat stone bridge

Here there are four terminals in which except two all are connected to each other through resistive elements.

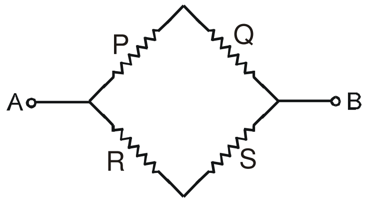
In this circuit if $R_1 R_3 = R_2 R_4$ then $V_C = V_D$ and current in $R_5 = 0$ this is called balance point or null point

When current through the galvanometer is zero (null point or balance point) $\frac{P}{Q} = \frac{R}{S}$, then PS = QR $\Rightarrow$ Here in this case products of opposite arms are equal. Potential difference between C and D at null point is zero. The null point is not affected by resistance R_5, E and R. **It is not affected even if the positions of Galvanometer and battery (E) are interchanged.**

hence, here the circuit can be assumed to be following,

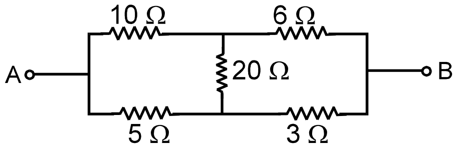


or

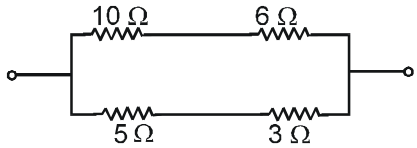


Solved Examples

Example 28. Find equivalent resistance of the circuit between the terminals A and B.



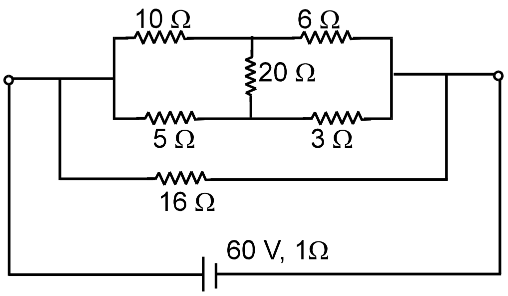
Solution : Since the given circuit is wheat stone bridge and it is in balance condition.



$\because$ 10 × 3 = 30 = 6 × 5

hence this is equivalent to $R_{eq} = \frac{16 \times 8}{16 + 8} = \frac{16}{3} \Omega$

Example 29.



Find (a) Equivalent resistance (b) and current in each resistance

Solution : (a) $R_{eq} = \left(\frac{1}{16} + \frac{1}{8} + \frac{1}{16}\right)^{-1} + 1 = 5 \ \Omega$

(b) $i = \frac{60}{4+1}$ = 12 A

Hence 12 A will flow through the cell.

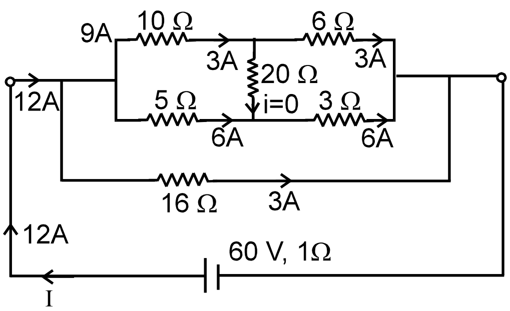
By using current distribution law.

Current in resistance 10Ω and 6Ω = 3A

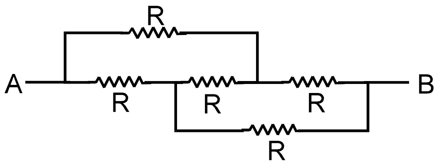
Current in resistance 5Ω and 3Ω = 6A

Current in resistance 20Ω = 0

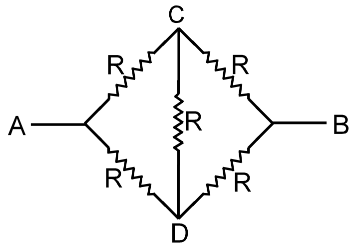
Current in resistance 16Ω = 3A



Example 30. Find the equivalent resistance between A and B



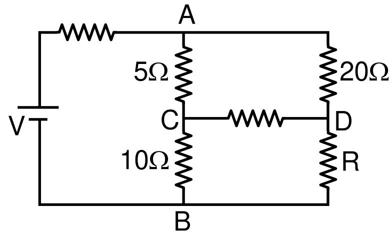
Solution :



This arrangement can be modified as shown in figure since it is balanced wheat stone bridge

$R_{eq} = \dfrac{2R \times 2R}{2R + 2R} = R$

Example 31. Determine the value of R in the circuit shown in figure, when the current is zero in the branch CD.



Solution : The current in the branch CD is zero, if the potential difference across CD is zero.
That means, voltage at point C = voltage at point D.
Since no current is flowing, the branch CD is open circuited. So the same voltage is applied across ACB and ADB

$V_{10} = V \times \dfrac{10}{15} \quad \Rightarrow \quad V_R = V \times \dfrac{R}{20+R}$

$\therefore \quad V_{10} = V_R$ and $V \times \dfrac{10}{15} = V \times \dfrac{R}{20+R}$

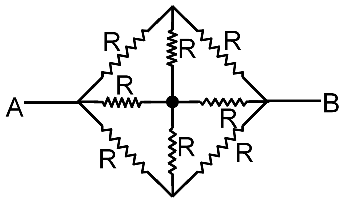
$\therefore \quad R = 40 \ \Omega$ **Ans.**

15. SYMMETRICAL CIRCUITS :

Some circuits can be modified to have simpler solution by using symmetry if they are solved by traditional method of KVL and KCL then it would take much time.

Solved Examples

Example 32. Find the equivalent Resistance between A and B

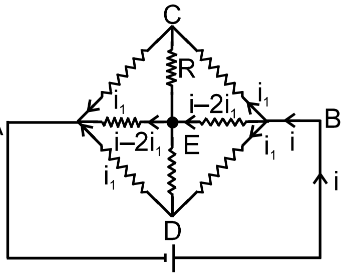


Solution : I **Method :**

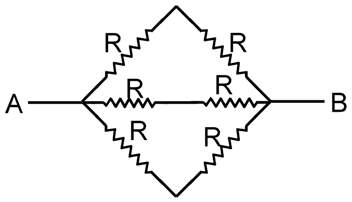
Here no two resistors appear to be in series or parallel no Wheatstone bridge here. This circuit will be solved by using $R_{eq} = \frac{V}{I}$. The branches AC and AD are symmetrical

$\therefore$ Current through them will be same.

The circuit is also similar from left side and right side current distribution while entering through B and an exiting from A will be same. Using all these facts the currents are as shown in the figure. It is clear that current in resistor between C and E is 0 and also in ED is 0. It's equivalent as shown in figure (b)



(fig. a)



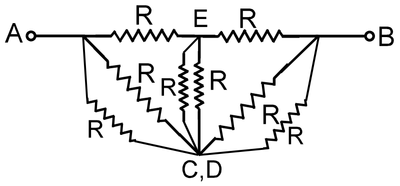
(fig. b)

$R_{eq} = \frac{2R}{3}$

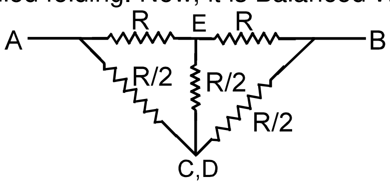
II **Method**

$\because$ The potential difference in R between (B, C) and between (B.D.) is same $V_C = V_D$

Hence the point C and D are same hence circuit



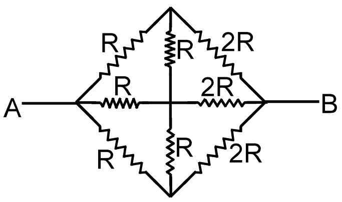
can be simplified as this called folding. Now, it is Balanced Wheatstone bridge



$R_{eq} = \frac{2R \times R}{2R + R} = \frac{2R}{3}$

Note : In II Method it is not necessary to know the currents in CA and DA.

Example 33. Find the equivalent Resistance between A and B

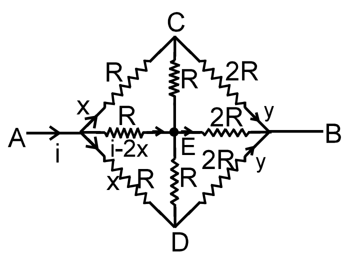


Solution : In this case the circuit has symmetry in the two branches AC and AD at the input

$\therefore$ current in them are same but from input and from exit the circuit is not similar

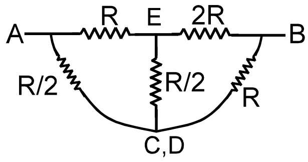
($\because$ on left R and on right 2R)

$\therefore$ on both sides the distribution of current will not be similar.



Here $V_c = V_d$

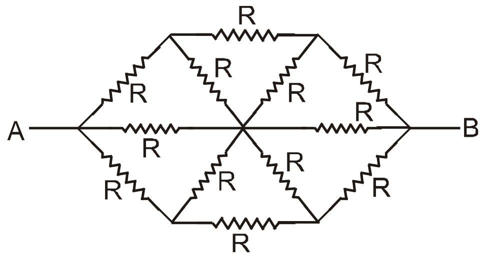
hence C and D are same point the circuit can be simplified that as shown



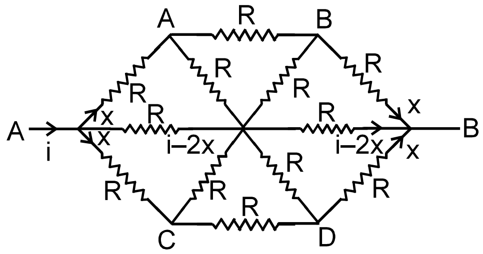
Now it is balanced wheat stone bridge

$$R_{eq} = \frac{3R \times \frac{3R}{2}}{3R + \frac{3R}{2}} = \frac{\frac{9}{2}R}{\frac{9}{2}} = R.$$

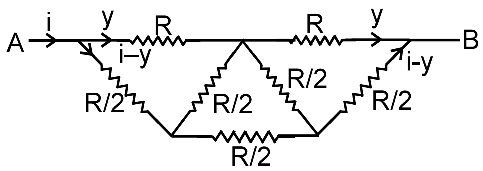
Example 34. Find the equivalent Resistance between A and B



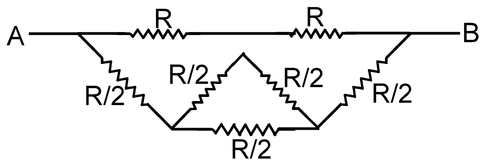
Solution :



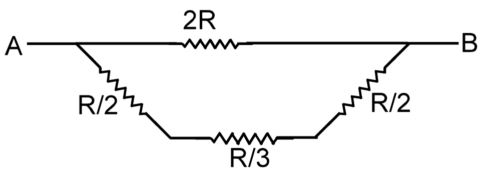
Here $V_A = V_C$ and $V_B = V_D$

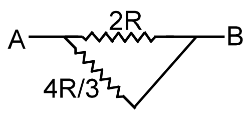


Here the circuit can be simplified as



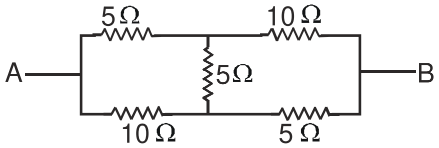
This circuit can be simplified as



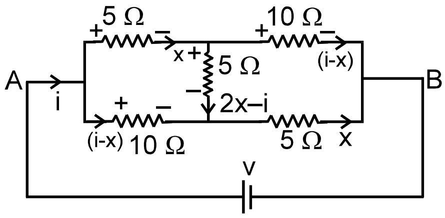


$$R_{eq} = \frac{2R \times \frac{4R}{3}}{\frac{10R}{3}} = \frac{4R}{5}$$ **Ans.**

Example 35. Find the equivalent Resistance between A and B



Solution : It is wheat stone bridge but not balanced. No series parallel connections. But similar values on input side and output. Here we see that even after using symmetry the circuit does not reduce to series parallel combination as in previous examples.



$\therefore$ Applying Kirchhoff voltage law $v - 10(i - x) - 5x = 0$

$v - 10i + 5x = 0$ ......(1)

$10(i - x) - 5(2x - i) - 5x = 0$

$10i - 10x - 10x + 5i - 5x = 0$

$15i - 25x = 0$

$x = \frac{15}{25} i \qquad 5x = 3i$ ......(2)

Using (2) and (1)

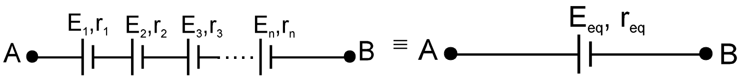
$\therefore v - 10i + 3i = 0$

$\frac{v}{i} = 7\Omega$

$R_{eq} = 7\Omega$ **Ans.**

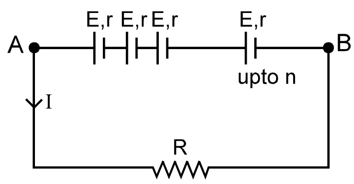
16. GROUPING OF CELLS

16.1 Cells in Series:



Equivalent EMF

$E_{eq} = E_1 + E_2 + ... + E_n$ [write EMF's with polarity]



Equivalent internal resistance $r_{eq} = r_1 + r_2 + r_3 + r_4 + ... + r_n$

If n cells each of emf E, arranged in series and if r is internal resistance of each cell, then total emf = n E so current in the circuit

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

If nr << R then $I = \frac{nE}{R}$ $\longrightarrow$ Series combination is advantageous.

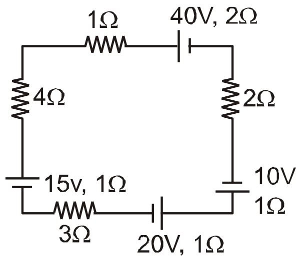
If nr >> R then $I = \frac{E}{r}$ $\longrightarrow$ Series combination is not advantageous.

Note : If polarity of m cells is reversed, then equivalent emf = (n-2m)E while the equivalent resistance is still nr + R, so current in R will be

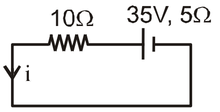
$i = \frac{(n - 2m)E}{nr + R}$.

Solved Examples

Example 36. Find the current in the loop.

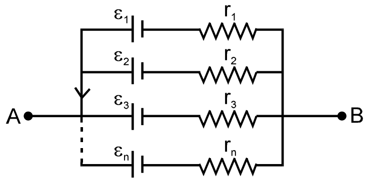


Solution : The given circuit can be simplified as



$$i = \frac{35}{10+5} = \frac{35}{15} = \frac{7}{3}\text{ A} \Rightarrow I = \frac{7}{3}\text{ A}$$

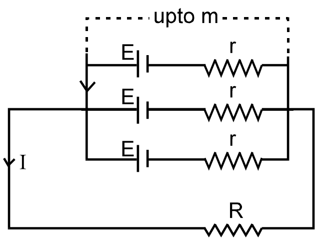
16.2 Cells in Parallel :



$$E_{eq} = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + ... + \frac{\varepsilon_n}{r_n}}{\frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}}$$ [Use emf's with polarity]

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}$$

If m cells each of emf E and internal resistance r be connected in parallel and if this combination is connected to an external resistance then equivalent emf of the circuit = E.



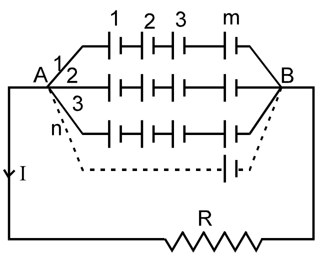
Internal resistance of the circuit = $\frac{r}{m}$.

and $I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$.

If mR << r ; $I = \frac{mE}{r}$ $\longrightarrow$ Parallel combination is advantageous.

If mR >> r ; $I = \frac{E}{R}$ $\longrightarrow$ Parallel combination is not advantageous.

16.3 Cells in Multiple Arc :



mn = number of identical cells.

n = number of rows

m = number of cells in each row.

The combination of cells is equivalent to single cell of

emf = mE

and internal resistance = $\frac{mr}{n}$

Current $I = \frac{mE}{R + \frac{mr}{n}}$

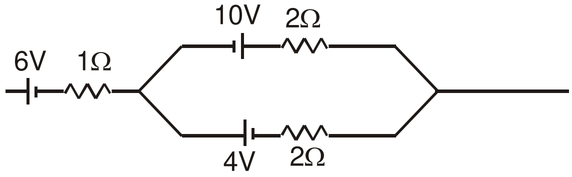
For maximum current nR = mr

or $R = \frac{mr}{n}$ = internal resistance of the equivalent battery.

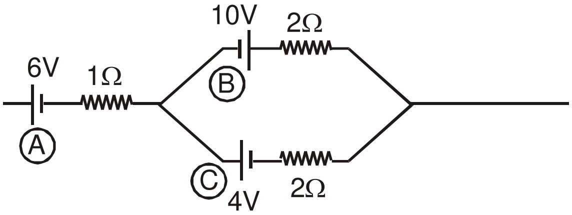
$$I_{max} = \frac{nE}{2r} = \frac{mE}{2R}.$$

Solved Examples

Example 37. Find the emf and internal resistance of a single battery which is equivalent to a combination of three batteries as shown in figure.

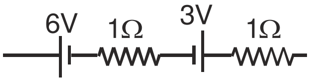


Solution :



Battery (B) and (C) are in parallel combination with opposite polarity. So, their equivalent

$$\varepsilon_{BC} = \frac{\frac{10}{2}+\frac{-4}{2}}{\frac{1}{2}+\frac{1}{2}} = \frac{5-2}{1} = 3V \quad \Rightarrow \quad r_{BC} = 1\Omega.$$

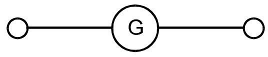


Now, $\varepsilon_{ABC} = 6 - 3 = 3V$

$r_{ABC} = 2\Omega$. **Ans.**

17. GALVANOMETER

Galvanometer is represented as follow:



It consists of a pivoted coil placed in the magnetic field of a permanent magnet. Attached to the coil is a spring. In the equilibrium position, with no current in the coil, the pointer is at zero and spring is relaxed. When there is a current in the coil, the magnetic field exerts a torque on the coil that is proportional to current. As the coil turns, the spring exerts a restoring torque that is proportional to the angular displacement. Thus, the angular deflection of the coil and pointer is directly proportional to the coil current and the device can be calibrated to measure current.

When coil rotates the spring is twisted and it exerts an opposing torque on the coil.

There is a resistive torque also against motion to damp the motion. Finally in equilibrium

$\tau_{magnetic} = \tau_{spring} \Rightarrow$ BINA $\sin\theta = C\phi$

But by making the magnetic field radial $\theta = 90°$.

$\therefore$ BINA $= C\,\phi$

$I \propto \phi$

here B = magnetic field, A = Area of the coil

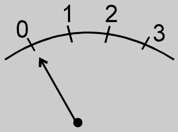
I = Current, C = torsional constant

N = Number of turns, ϕ = angle rotate by coil.

- **Current sensitivity**

The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer CS $= \frac{\phi}{I} = \frac{BNA}{C}$

Note: Shunting a galvanometer decreases its current sensitivity. A linear scale is obtained. The marking on the galvanometer are proportionate.

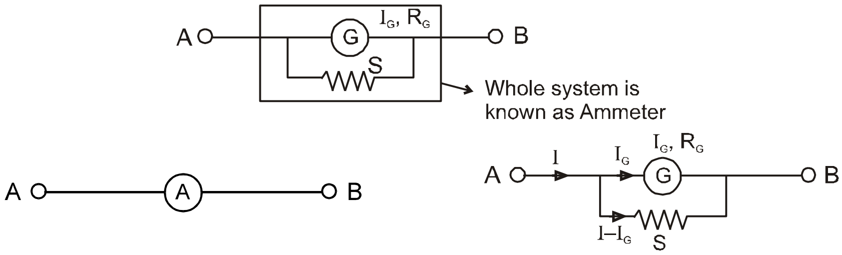


The galvanometer coil has some resistance represented by R_g. It is of the order of few ohms. It also has a maximum capacity to carry a current known as I_g. I_g is also the current required for full scale deflection. This galvanometer is called moving coil galvanometer.

18. AMMETER

A shunt (small resistance) is connected in parallel with galvanometer to convert it into ammeter; An ideal ammeter has zero resistance

Ammeter is represented as follow -



If maximum value of current to be measured by ammeter is I then

$I_G \cdot R_G = (I - I_G)S$

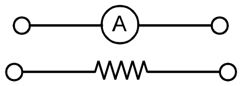
$S = \dfrac{I_G.R_G}{I - I_G}$

$S = \dfrac{I_G \times R_G}{I}$ when $I >> I_G$.

where I = Maximum current that can be measured using the given ammeter.

For measuring the current the ammeter is connected is series.

In calculation it is simply a resistance



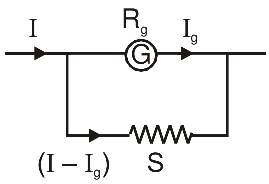
Resistance of ammeter $R_A = \dfrac{R_G.S}{R_G + S}$

for $S << R_G \Rightarrow R_A = S$

Solved Examples

Example 38. What is the value of shunt which passes 10% of the main current through a galvanometer of 99 ohm ?

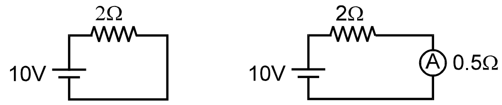
Solution : As in figure $R_g I_g = (I - I_g)S$



$\Rightarrow 99 \times \dfrac{I}{10} = \left(I - \dfrac{I}{10}\right) \times S$

$\Rightarrow S = 11\ \Omega$.

Example 39. Find the current in the circuit (a) & (b) and also determine percentage error in measuring the current through an ammeter.



(a) (b)

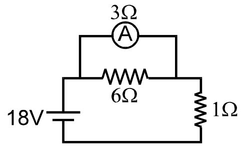
Solution : In A $I = \frac{10}{2} = 5A$

In B $I = \frac{10}{2.5} = 4A$

Percentage error is = $\frac{i - i'}{i} \times 100 = 20\%$ **Ans.**

Here we see that due to ammeter the current has reduced. A good ammeter has very low resistance as compared with other resistors, so that due to its presence in the circuit the current is not affected.

Example 40. Find the reading of ammeter ? Is this the current through 6 Ω ?



Solution : $R_{eq} = \frac{3 \times 6}{3 + 6} + 1 = 3\ \Omega$

Current through battery $I = \frac{18}{3} = 6$ A

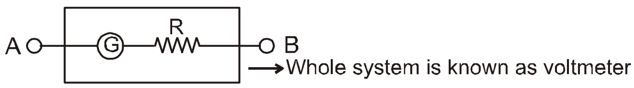
So, current through ammeter = $6 \times \frac{6}{9} = 4$ A

No, it is not the current through the 6 Ω resistor.

Note: Ideal ammeter is equivalent to zero resistance wire for calculation potential difference across it is zero.

19. VOLTMETER

A high resistance is put in series with galvanometer. It is used to measure potential difference across a resistor in a circuit.

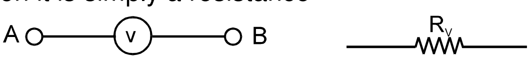


For maximum potential difference $V = I_G \cdot R + I_G R_G$ $\qquad R = \frac{V}{I_G} - R_G$

If $R_G << R \Rightarrow R_S \approx \frac{V}{I_G}$

For measuring the potential difference a voltmeter is connected across that element. (Parallel to that element it measures the potential difference that appears between terminals 'A' and 'B'.)

For calculation it is simply a resistance



Resistance of voltmeter $R_V = R_G + R \approx R$

$I_g = \frac{V_o}{R_g + R}$. $R \to \infty \Rightarrow$ Ideal voltmeter.

A good voltmeter has high value of resistance.

Ideal voltmeter $\to$ which has high value of resistance.

Note :

- For calculation purposes the current through the ideal voltmeter is zero.
- Percentage error in measuring the potential difference by a voltmeter is = $\frac{V - V'}{V} \times 100$

Solved Example

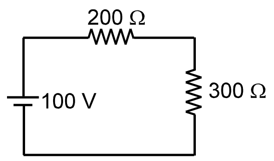
Example 41. A galvanometer has a resistance of G ohm and range of V volt. Calculate the resistance to be used in series with it to extend its range to nV volt.

Solution : Full scale current $i_g = \frac{V}{G}$

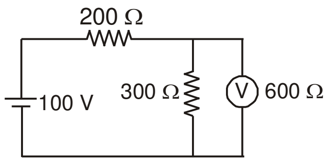
to change its range

$V_1 = (G + R_s)i_g \Rightarrow nV = (G + R_s)\frac{V}{G} \Rightarrow R_s = G(n - 1)$ **Ans.**

Example 42. Find potential difference across the resistance 300 Ω in A and B.



(A)



(B)

Solution : In (A) : Potential difference = $\frac{100}{200+300} \times 300$ = 60 volt

In (B) : Potential difference = $\frac{100}{200 + \frac{300 \times 600}{300 + 600}} \times \frac{300 \times 600}{300 + 600}$ = 50 volt

We see that by connecting voltmeter the voltage which was to be measured has changed. Such voltmeters are not good. If its resistance had been very large than 300 Ω then it would not have affected the voltage by much amount.

Current sensitivity

The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer $CS = \frac{\theta}{I}$

Note : Shunting a galvanometer decreases its current sensitivity.

Solved Examples

Example 43. A galvanometer with a scale divided into 100 equal divisions, has a current sensitivity of 10 division per mA and voltage sensitivity of 2 division per mV. What adoptions are required to use it (a) to read 5A full scale and (b) 1 division per volt ?

Solution : Full scale deflection current $i_g = \frac{\theta}{cs} = \frac{100}{10}$ mA = 10 mA

Full scale deflection voltage $V_g = \frac{\theta}{vs}$

$= mv = 50\ mv$

So galvanometer resistance $G = \frac{V_g}{i_g} = \frac{50mV}{10mA} = 5\ \Omega$

(a) To convert the galvanometer into an ammeter of range 5A, a resistance of value $S\Omega$ is connected in parallel with it such that

$(I - i_g)\ S = i_g\ G$

$(5 - 0.01)\ S = 0.01 \times 5$

$S = \frac{5}{499} \cong 0.01\ \Omega$ **Ans.**

(b) To convert the galvanometer into a voltmeter which reads 1 division per volt, i.e. of range 100 V,

$V = i_g\ (R + G)$

$100 = 10 \times 10^{-3}\ (R + 5)$

$R = 10000 - 5$

$R = 9995\ \Omega \cong 9.995\ k\Omega$ **Ans.**

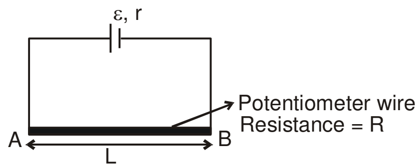
20. POTENTIOMETER

A potentiometer is a linear conductor of uniform cross-section with a steady current set up in it. This maintains a uniform potential gradient along the length of the wire. Any potential difference which is less than the potential difference maintained across the potentiometer wire can be measured using this.

The wire should have high resistivity and low expansion coefficient. For example : Manganin or, Constantine wire etc.

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

$V_A - V_B = \frac{\varepsilon}{R + r}.R$



Potential gradient (x) $\rightarrow$ Potential difference per unit length of wire

$x = \frac{V_A - V_B}{L} = \frac{\varepsilon}{R + r} \cdot \frac{R}{L}$

Solved Examples

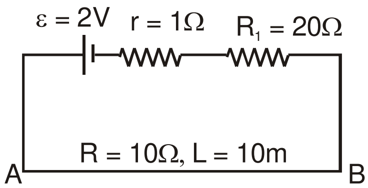
Example 44. Primary circuit of potentiometer is shown in figure determine :

(A) current in primary circuit

(B) potential drop across potentiometer wire AB

(C) potential gradient (means potential drop per unit length of potentiometer wire)

(D) maximum potential which we can measure above potentiometer



Solution : (a) $i = \frac{\varepsilon}{r + R_1 + R} = \frac{2}{1 + 20 + 10} \Rightarrow i = \frac{2}{31}$ A **Ans.**

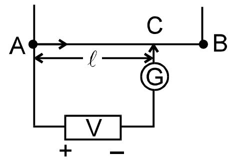
(b) $V_{AB} = iR = \frac{2}{31} \times 10 \Rightarrow v_{AB} = \frac{20}{31}$ volt **Ans.**

(c) $x = \frac{V_{AB}}{L} = \frac{2}{31}$ volt/m **Ans.**

(d) Maximum potential which we can measure by it = potential drop across wire AB = $\frac{20}{31}$ volt

Example 45. How to measure an unknown voltage using potentiometer.

Solution : The unknown voltage V is connected across the potentiometer wire as shown in figure. The positive terminal of the unknown voltage is kept on the same side as of the source of the top most battery. When reading of galvanometer is zero then we say that the meter is balanced. In that condition $V = x\ell$.



20.1 Application of potentiometer

(a) To find emf of unknown cell and compare emf of two cells.

In case I, In figure, (2) is joint to (1) then balance length = ℓ_1

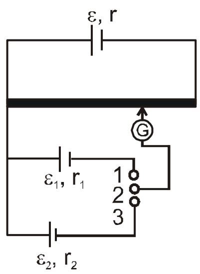
$\varepsilon_1 = x\ell_1$ ....(1)

in case II, In figure, (3) is joint to (2) then balance length = ℓ_2

$\varepsilon_2 = x\ell_2$ ....(2)

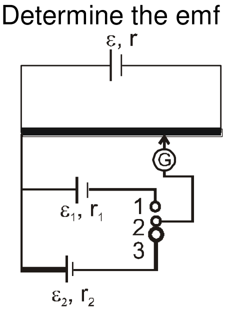
$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}$$

If any one of ε_1 or ε_2 is known the other can be found. If x is known then both ε_1 and ε_2 can be found



Solved Examples

Example 46. In an experiment to determine the emf of an unknown cell, its emf is compared with a standard cell of known emf ε_1 = 1.12 V. The balance point is obtained at 56cm with standard cell and 80 cm with the unknown cell. Determine the emf of the unknown cell.



Solution : Here, ε_1 = 1.12 V ; ℓ_1 = 56 cm ; ℓ_2 = 80 cm

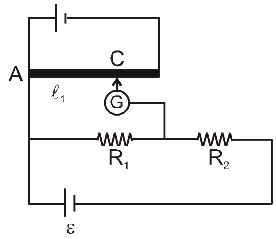
Using equation

$\varepsilon_1 = x\ell_1$ .....(1)

$\varepsilon_2 = x\ell_2$ .....(2)

we get $\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2} \Rightarrow \varepsilon_2 = \varepsilon_1\left(\frac{\ell_2}{\ell_1}\right)$ or $\varepsilon_2 = 1.12\left(\frac{80}{56}\right) = 1.6$ V Ans

(b) To find current if resistance is known



$V_A - V_C = x\ell_1$

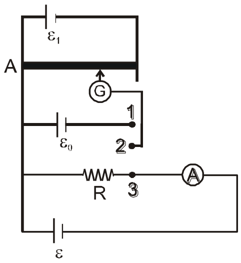
$IR_1 = x\ell_1$; $I = \dfrac{x\ell_1}{R_1}$

Similarly, we can find the value of R_2 also.

Potentiometer is ideal voltmeter because it does not draw any current from circuit, at the balance point.

Solved Examples

Example 47. A standard cell of emf ε_0 = 1.11 V is balanced against 72 cm length of a potentiometer. The same potentiometer is used to measure the potential difference across the standard resistance R = 120 Ω. When the ammeter shows a current of 7.8 mA, a balanced length of 60 cm is obtained on the potentiometer.



(i) Determine the current flowing through the resistor.

(ii) Estimate the error in measurement of the ammeter.

Solution : Here, ℓ_0 = 72 cm ; ℓ = 60 cm ; R = 120 Ω and ε_0 = 1.11 V

(i) By using equation $\varepsilon_0 = x\,\ell_0$ .....(i)

$V = IR = x\,\ell$ .....(ii)

From equation (i) and (ii)

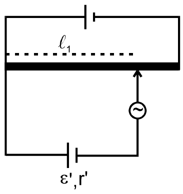
$I = \dfrac{\varepsilon_0}{R}\left(\dfrac{\ell}{\ell_0}\right)$ $\therefore$ $I = \dfrac{1.11}{120}\left(\dfrac{60}{72}\right) = 7.7$ mA

(ii) Since the measured reading 7.8 mA (> 7.7 mA) therefore, the instrument has a positive error.

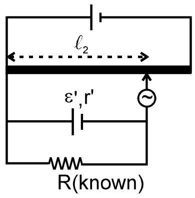
$\Delta I = 7.8 - 7.7 = 0.1$ mA, $\dfrac{\Delta I}{I} = \dfrac{0.1}{7.7} \times 100 = 1.3\,\%$

(c) To find the internal resistance of cell.

I[st] arrangement



2[nd] arrangement



by first arrangement $\varepsilon' = x\ell_1$ .....(1)

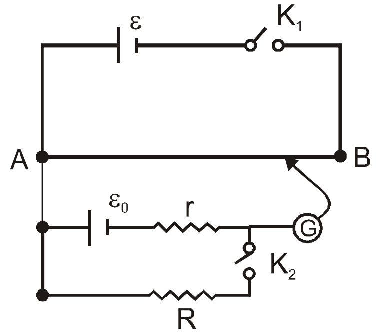
by second arrangement $IR = x\ell_2$

$I = \dfrac{x\ell_2}{R}$, also $I = \dfrac{\varepsilon'}{r'+R}$ $\Rightarrow$ $\dfrac{\varepsilon'}{r'+R} = \dfrac{x\ell_2}{R}$

$\Rightarrow$ $\dfrac{x\ell_1}{r'+R} = \dfrac{x\ell_2}{R}$ $\Rightarrow$ $r' = \left[\dfrac{\ell_1 - \ell_2}{\ell_2}\right] R$

Solved Example

Example 48. The internal resistance of a cell is determined by using a potentiometer. In an experiment, an external resistance of 60Ω is used across the given cell. When the key is closed, the balance length on the potentiometer decreases from 72 cm to 60 cm. calculate the internal resistance of the cell.



Solution : According to equation $\varepsilon_0 = x\ell_0$ ....(i)

$V = IR = x\ell$ ....(ii)

$I = \dfrac{\varepsilon_0}{R+r}$ ....(iii)

From equation (i), (ii) and (iii) we get

$r = R\left(\dfrac{\ell_0}{\ell} - 1\right)$

here $\ell_0 = 72$ cm ; $\ell = 60$ cm ; $R = 60\ \Omega$

$\therefore$ $r = (60)\left(\dfrac{72}{60} - 1\right)$ or $r = 12\ \Omega$.

21. METRE BRIDGE (USE TO MEASURE UNKNOWN RESISTANCE)

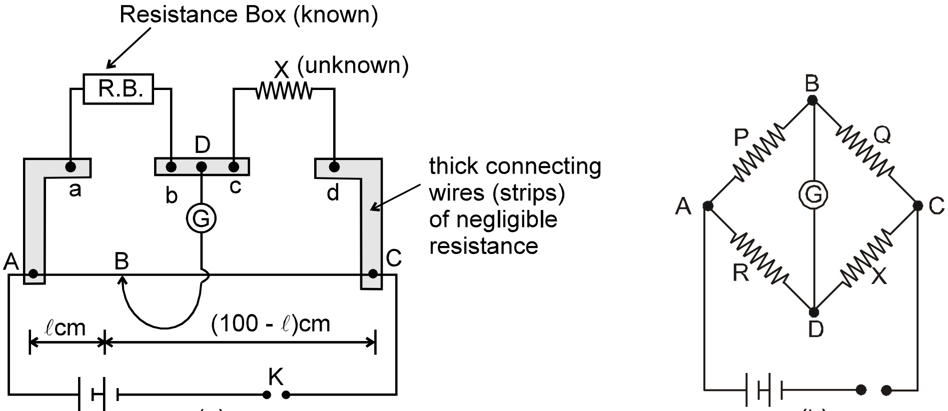
If AB = ℓ cm, then BC = $(100 - \ell)$ cm.

Resistance of the wire between A and B $R \propto \ell$

[$\because$ Specific resistance ρ and cross-sectional area A are same for whole of the wire]

or $R = \sigma\ell$ .....(1)

where σ is resistance per cm of wire.



(a) (b)

Similarly, if Q is resistance of the wire between B and C, then

$Q \propto 100 - \ell$

$\therefore \quad Q = \sigma(100 - \ell)$ ....(2)

Dividing (1) by (2), $\frac{P}{Q} = \frac{\ell}{100-\ell}$

Applying the condition for balanced Wheatstone bridge, we get

$R\ Q = P\ X$

$\therefore \quad x = R\frac{Q}{P}$ or $X = \frac{100-\ell}{\ell} R$

Since R and ℓ are known, therefore, the value of X can be calculated.

Note : For better accuracy, R is so adjusted that ℓ lies between 40 cm and 60 cm.

Solved Example

Example 49. In a meter bridge experiment, the value of unknown resistance is 2Ω. To get the balancing point at 40cm distance from the same end, the resistance in the resistance box will be :

(A) 0.5 Ω (B) 3 Ω (C) 20 Ω (D) 80 Ω

Solution : Apply condition for balance wheat stone bridge,

$$\frac{P}{Q} = \frac{\ell}{100-\ell} = \frac{P}{2} = \frac{100-40}{40}$$

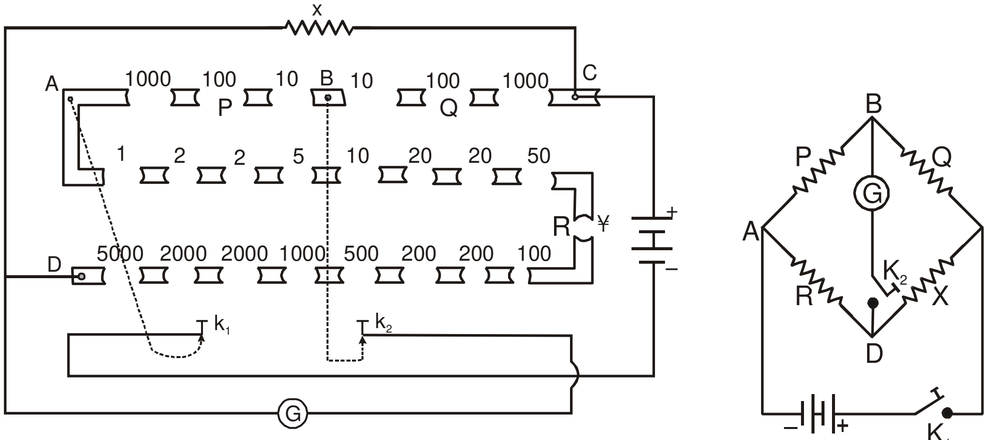
Ans. P = 3Ω.

22. POST-OFFICE BOX

Introduction : It is so named because its shape is like a box and it was originally designed to determine the resistances of electric cables and telegraph wires. It was used in post offices to determine the resistance of transmission lines.

Construction : A post office box is a compact form of Wheatstone bridge with the help of which we can measure the value of the unknown resistance correctly up to 2nd decimal place, i.e., up to 1/100th of an ohm correctly. Two types of post office box are available - plug type and dial type. In the plug-type instrument shown in figure (a), each of the arms AB and BC contains three resistances of 10, 100 and 1000 ohm. These arms are called the ratio arms. While the resistance P can be introduced in the arm AB, the resistance Q can be introduced in the arm BC. The third arm AD, called the resistance arm, is a complete resistance box containing resistances from 1 Ω to 5,000 Ω. In this arm, the resistance R is introduced by taking out plugs of suitable values. The unknown resistance X constitutes the fourth arm CD. Thus, the four arms AB, BC, CD and AD are infect the four arms of the Wheatstone bridge (figure (b)). Two tap keys K_1 and K_2 are also provided. While K_1 is connected internally to the terminal A, K_2 is connected internally to B. These internal connections are shown by dotted lines in figure (a).

A battery is connected between C and key K_1 (battery key). A galvanometer is connected between D and key K_2 (galvanometer key). Thus, the circuit is exactly the same as that shown in figure (b). It is always the battery key which is pressed first and then the galvanometer key. This is because a self-induced current is always set up in the circuit whenever the battery key is pressed or released. If we first press the galvanometer key, the balance point will be disturbed on account of induced current. If the battery key is pressed first, then the induced current becomes zero by the time the galvanometer key is pressed. So, the balance point is not affected.



(a) (b)

Working : The working of the post office box involves broadly the following four steps :

I. Keeping R zero, each of the resistances P and Q are made equal to 10 ohm by taking out suitable plugs from the arms AB and BC respectively. After pressing the battery key first and then the galvanometer key, the direction of deflection of the galvanometer coil is noted. Now, making R infinity, the direction of deflection is again noted. If the direction is opposite to that in the first case, then the connections are correct.

II. Keeping both P and Q equal to 10Ω, the value of R is adjusted, beginning from 1Ω, till 1 Ω increase reverses the direction of deflection. The 'unknown' resistance clearly lies somewhere between the two final values of R.

$$\left[X = R\frac{Q}{P} = R\frac{10}{10} = R\right]$$

As an illustration, suppose with 3Ω resistance in the arm AD, the deflection is towards left and with 4Ω, it is towards right. The unknown resistance lies between 3Ω and 4Ω.

III. Making P 100 Ω and keeping Q 10 Ω, we again find those values of R between which direction of deflection is reversed. Clearly, the resistance in the arm AD will be 10 times the resistance X of the wire.

$$\left[X = R\frac{Q}{P} = R\frac{10}{100} = \frac{R}{10}\right]$$

In the illustration considered in step II, the resistance in the arm AD will now lie between 30 Ω, and 40 Ω. So, in this step, we have to start adjusting R from 30 Ω onwards. If 32 Ω and 33 Ω are the two values of R which give opposite deflections, then the unknown resistance lies between 3.2 Ω and 3.3 Ω.

IV. Now, P is made 1000 Ω and Q is kept at 10 Ω. The resistance in the arm AD will now be 100 times the 'unknown' resistance.

$$\left[X = R\frac{10}{1000} = \frac{R}{100}\right]$$

In the illustration under consideration, the resistance in the arm AD will lie between 320 Ω and 330Ω. Suppose the deflection is to the right for 326 ohm, towards left for 324 ohm and zero deflection for 325Ω then, the unknown resistance is 3.25 Ω.

The post office box method is a less accurate method for the determination of unknown resistance as compared to a metre bridge. This is due to the fact that it is not always possible to arrange resistance in the four arms to be of the same order. When the arms ratio is large, large resistance are required to be introduced in the arm R.

Solved Examples

Example 50. The post office box works on the principle of :
(A) Potentiometer (B) Wheatstone bridge (C) Matter waves (D) Ampere's law

Answer : (B)

Example 51. While using a post office box the keys should be switched on in the following order :
(A) first cell key the and then galvanometer key.
(B) first the galvanometer key and then cell key.
(C) both the keys simultaneously.
(D) any key first and then the other key.

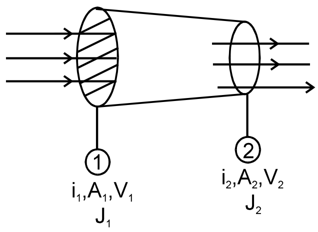
Answer : (A)

Example 52. In a post office box if the position of the cell and the galvanometer are interchanged, then the :
(A) null point will not change (B) null point will change
(C) post office box will not work (D) Nothing can be said.

Answer : (A)

Solved Miscellaneous Problems

Problem 1. Current is flowing from a conductor of non-uniform cross section area if $A_1 > A_2$ then find relation between



(a) i_1 and i_2 (b) j_1 and j_2 (c) v_1 and v_2 (drift velocity)
where i is current, j is current density and V is drift velocity.

Answer : $i_1 = i_2$, $V_1 < V_2$, $J_1 < J_2$

Solution : (a) i = charge flowing through a cross-section per unit time.

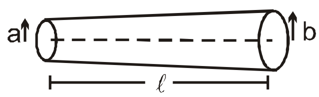
$\therefore\ i_1 = i_2$

(b) $j = \dfrac{i}{A}$ as $A_1 > A_2$ then $j_1 < j_2$

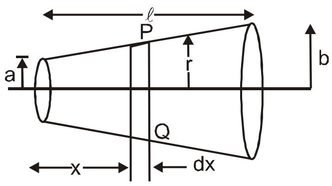
(c) $j = nev_d$

$v_d = \dfrac{j}{ne}$ as $j_1 < j_2$ then, $v_1 < v_2$

Problem 2. Figure shows a conductor of length ℓ having a circular cross-section. The radius of cross-section varies linearly from a to b. The resistivity of the material is ρ. Find the resistance of the conductor.



Solution : In this problem cross–section area is variable so we can't apply formula $\left(R = \dfrac{\rho\ell}{A}\right)$ directly.



So we assume elementary strip 'PQ' of thickness dx and radius r resistance of this strip is :

$$dR = \frac{\rho dx}{\pi r^2}$$

By geometry $= \dfrac{r-a}{x} = \dfrac{b-a}{\ell} \Rightarrow r = \dfrac{b-a}{\ell}x + a$

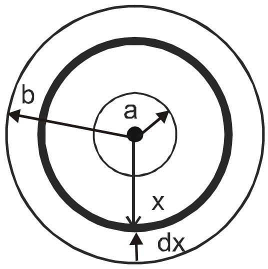
Resistance of conductor is $R = \displaystyle\int_0^{\ell} \frac{\rho dx}{\pi\left\{\frac{b-a}{\ell}x + a\right\}^2}$ $\Rightarrow R = \dfrac{\rho\ell}{\pi ab}$ **Ans.**

Problem 3. A cylindrical tube of length ℓ has inner radius a while outer radius b. What is the resistance of the tube between (a) its ends (b) its inner and outer surfaces ? (The resistivity of its material is ρ)

Solution : (a) $A = \pi(b^2 - a^2)$

$$R = \frac{\rho\ell}{\pi(b^2 - a^2)}$$

(b) $d_R = \frac{\rho dx}{2\pi x\ell}$

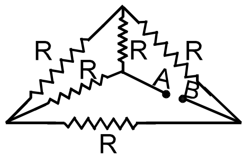


for a section taken at distance x from centre.

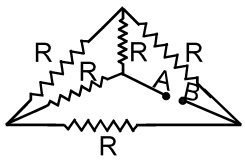
$$d_R = \frac{\rho}{2\pi\ell} \cdot \frac{dx}{x}$$

$$\Rightarrow \quad R = \int dR = \frac{\rho}{2\pi\ell}\int_a^b \frac{dx}{x} = \ell n \frac{b}{a}$$

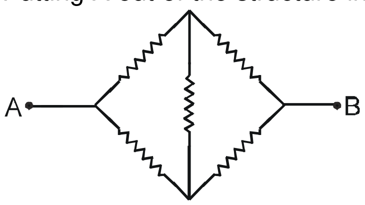
Problem 4. Find the equivalent Resistance between A and B

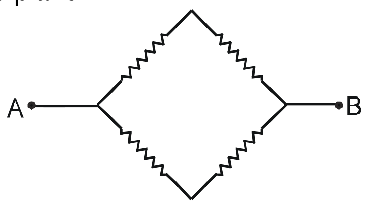


Solution :



Putting A out of the structure in the same plane





$R_{eq} = \frac{2R \times 2R}{2R + 2R} = R$ **Ans. : $R_{eq} = R$**

Problem 5. What shunt resistance is required to convert the 1.0 mA, 20Ω galvanometer into an ammeter with a range of 0 to 50 mA ?

Answer : $S = \frac{20}{49} = 0.408\ \Omega$

Solution : $i_g R_g = (i - i_g)S$

$i_g = 1.0 \times 10^{-3}$ A , G = 20Ω

$i = 50 \times 10^{-3}$ A

$$S = \frac{i_g R_g}{i - v_g} = \frac{1 \times 10^{-3} \times 20}{49 \times 10^{-3}} = 0.408\ \Omega$$

Problem 6. How can we convert a galvanometer with R_g = 20 Ω and i_g = 1.0 mA into a voltmeter with a maximum range of 10 V ?

Answer : A resistance of 9980 Ω is to be connected in series with the galvanometer.

Solution : $v = i_g R_S + i_g R_g$

$10 = 1 \times 10^{-3} \times R_s + 1 \times 10^{-3} \times 20$

$$R_S = \frac{10 - 0.02}{1 \times 10^{-3}} = \frac{9.98}{10^{-3}} = \mathbf{9980\ \Omega}$$

Problem 7. A Potentiometer wire of 10 m length and having 10 ohm resistance, emf 2 volts and a rheostat. If the potential gradient is 1 micro volt/mm, the value of resistance in rheostat in ohms will be :

(A) 1.99 (B) 19.9 (C) 199 (D) 1990

Answer : (D)

Solution : d = 10 m, R = 10Ω,

E = 2volts, $\frac{dv}{d\ell}$ = 1μ v/mm

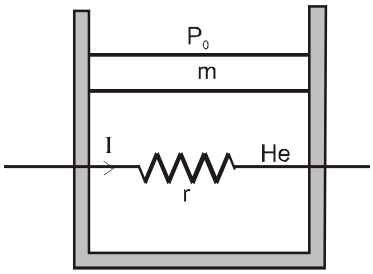
$\frac{dv}{d\ell} = \frac{1\times10^{-6}}{1\times10^{-3}}$ v/m = 1 × 10^{-3} v/m

Across wire potential drop, $\frac{dv}{d\ell} \times \ell = 1 \times 10^{-3} \times 10 = 0.01$ volts

$i = \frac{0.01}{10} = 0.001 = \frac{E}{R+R'}$ (R′ = resistance of rheostat)

$R' = \frac{E}{0.001} - R = \frac{2}{0.001} - 10 = 2000 - 10 = 1990\ \Omega$

Problem 8. A resistance coil of resistance r connected to an external battery, is placed inside an adiabatic cylinder fitted with a frictionless piston of mass m and same area A. Initially cylinder contains one mole of ideal gas He. A current I flows through the coil such that temperature of gas varies as $T = T_0 + at + bt^2$, keeping pressure constant with time t. Atmosphere pressure above piston is P_0. Find



(a) Current I flowing through the coil as function of time and

(b) Speed of piston as function of time.

Solution : Heat produced by coil inside the cylinder in time dt is

$dQ = I^2 r\, dt$ .....(i)

(a) As we know

$\Rightarrow dQ = nC_p dT$ .....(ii)

$I^2 r\, dt = \frac{5R}{2} dT \left(C_p = \frac{5R}{2}\right)$

Here $T = T_0 + at + bt^2 \Rightarrow \frac{dT}{dt} = (a + 2bt)$

$I = \sqrt{\left[\frac{5R}{2r}(2bt+a)\right]}$ .....(ii)

$\left(C_p = \frac{5R}{2}\right)$

Pressure is constant PV = RT ⇒ PdV = RdT

PA dx = RdT

Velocity $v = \frac{dx}{dt} = \frac{R}{PA}\cdot\frac{dT}{dt} = \frac{R}{PA}$ (2bt + a) (here $P_0A + mg = PA$)

$= \frac{R}{P_0A + mg}$ (2bt + a) **Ans.**

Exercise-1

✍ **Marked Questions can be used as Revision Questions.**

PART - I : SUBJECTIVE QUESTIONS

Section (A) : Definition of Current, Current densities & Drift velocities

A-1. The current through a wire depends on time as $i = i_0 + \alpha \sin \pi t$, where $i_0 = 10$ A and $\alpha = \frac{\pi}{2}$ A. Find the charge crossed through a section of the wire in 3 seconds, and average current for that interval.

A-2.✍ Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 1.0×10^{-7} m^2 carrying a current of 1.5 A. Assume that each copper atom contributes roughly one conduction electron. The density of copper is 9.0×10^3 kg m^{-3} and its atomic mass is 63.5 amu.

A-3. A current of 5 A exists in a 10 Ω resistance for 4 minutes.
(i) How many coulombs and
(ii) How many electrons pass through any cross section of the resistor in this time?
Charge of the electron = 1.6×10^{-19} C.

Section (B) : Resistance

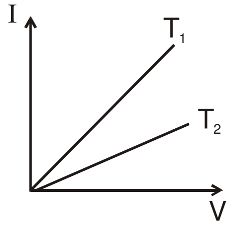
B-1. A cyllindrical conducting wire of radius 0.2 mm is carrying a current of 20 mA. (a) How many electrons are transferred per second between the supply and the wire at one end? (b) Write down the current density in the wire.

B-2.✍ A battery sets up an electric field of 25 N/C inside a uniform wire of length 2 m and a resistance of 5 Ω. Find current through the wire.

B-3. **(i)** A potential difference of 200 volt is applied to a coil at a temperature of 15ºC and the current is 10 A. What will be the temperature of the coil when the current has fallen to 9 A, the applied voltage being the same as before? Temperature coefficient of resistance $(\alpha) = \frac{1}{234}$ ºC^{-1}.

(ii) A platinum wire has resistance of 10 ohm at 0ºC and 20 ohm at 273ºC. Find the value of temperature coefficient of resistance.

B-4. The current-voltage graphs for a given metallic wire at two different temperature T_1 and T_2 are shown in the figure. Which one is higher, T_1 or T_2

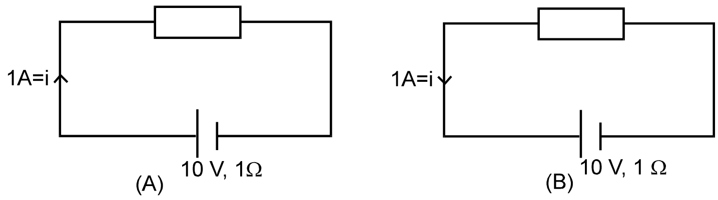


B-5. If a copper wire is stretched to make it 0.1% longer, what is the percentage change in its resistance ?

B-6 A rectangular carbon block has dimensions 1.0 cm × 1.0 cm × 50 cm.
(i) What is the resistance measured between the two square ends?
(ii) Between two opposing rectangular faces?
Resistivity of carbon at 20º C is 3.5×10^{-5} Ωm.

Section (C) : Power, Energy, Battery, EMF, Terminal voltage & Kirchoff's laws

C-1. In following diagram boxes may contain resistor or battery or any other element

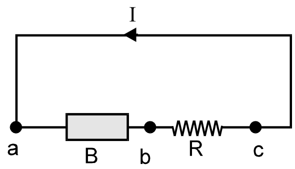


then determine in each case

(a) E.m.f. of battery
(b) Battery is acting as a source or load
(c) Potential difference across each battery
(d) Power input to the battery or output by the battery.
(e) The rate at which heat is generated inside the battery.
(f) The rate at which the chemical energy of the cell is consumed or increased.
(g) Potential difference across box
(h) Electric power output across box.

C-2. A resistor with a current of 3 A through it converts 500 J of electrical energy to heat energy in 12 s. What is the voltage across the resistor?

C-3. The figure shows the current I in a single-loop circuit with a battery B and resistance R (and wires of negligible resistance). Then find the order of following at the point a, b and c

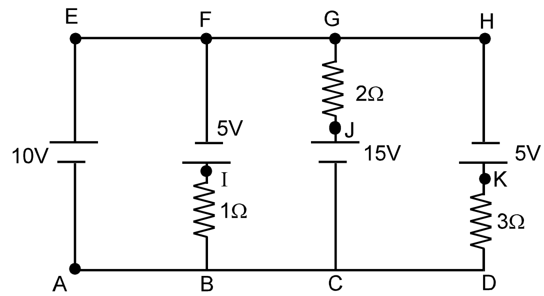


(a) The magnitude of the current,
(b) The electric potential, and
(c) The electric potential energy of the charge carriers (electron), greatest first.

C-4. (a) A car has a fresh storage battery of emf 12 V and internal resistance 5.0×10^{-2} Ω. If the starter draws a current of 90 A, what is the terminal voltage of the battery when the starter is on?
(b) After long use, the internal resistance of the storage battery increases to 500 Ω. What maximum current can be drawn from the battery? Assume the emf of the battery to remain unchanged.
(c) If the discharged battery is charged by an external emf source, is the terminal voltage of the battery during charging greater or less than its emf 12 V?

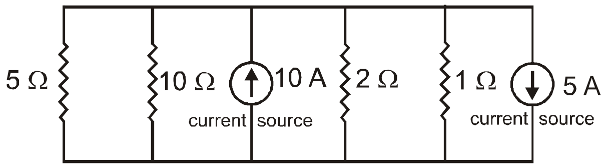
C-5. 1 kW, 220 V electric heater is to be used with 220 V D.C. supply.
(a) What is the current in the heater.
(b) What is its resistance.
(c) What is the power dissipated in the heater.
(d) How much heat in calories is produced per second.
(e) How many grams of water at 100º C will be converted per minute into steam at 100º C with the heater. (latent heat of vaporisation of water = 540 cal/g)] [J = 4.2 J/cal]

C-6. In following circuit potential at point 'A' is zero then determine

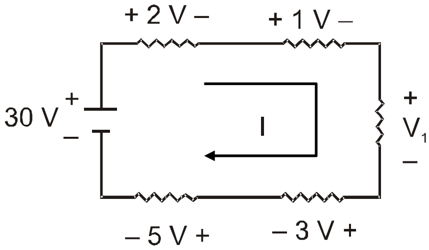


(a) Potential at each point
(b) Potential difference across each resistance
(c) Identify the batteries which act as a source
(d) Current in each battery
(e) Which resistance consumes maximum power
(f) Which battery consume or gives maximum power.

C-7. For the circuit shown in figure, find the voltage across 10 Ω resistor and the current passing through it.

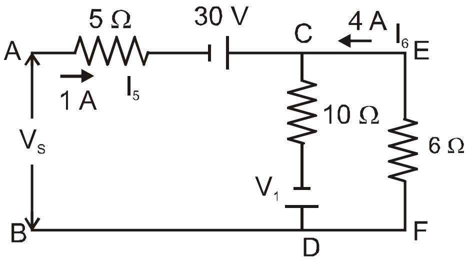


C-8. For the circuit shown in figure, determine the unknown voltage drop V_1.



C-9. A resistor develops 400 J of thermal energy in 10 s when a current of 2 A is passed through it.
(a) Find its resistance.
(b) If the current is increased to 4 A, what will be the energy developed in 20 s.

C-10. Find the current in 10 Ω resistance, V_1, and source voltage V_s in the circuit shown in figure ($V_s = V_A - V_B$)

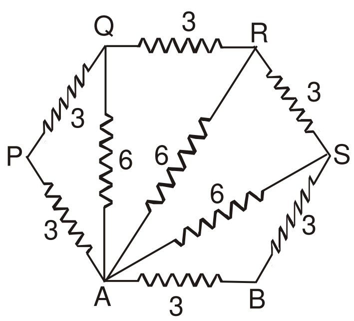


Section (D) : Combination of Resistance

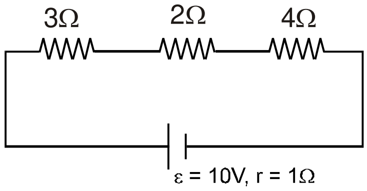
D-1. Two electric bulbs, each designed to operate with a power of 500 watts in 220 volt line, are connected in series with a 110 volt line. What will be the power generated by each bulb? **[JEE 1977]**

D-2. Two (non-physics) students, A and B living in neighboring hostel rooms, decided to economies by connecting their bulbs in series. They agreed that each would install a 100 W bulb in their own rooms and that they would pay equal shares of the electricity bill. However, both decided to try to get better lighting at the other's expense; A installed a 200 W bulb and B installed a 50 W bulb. Which student is more likely to fail the end-of-term examinations?

D-3. All resistance in diagram (fig.) are in ohms. Find the effective resistance between the points A and B. **[JEE 1979]**

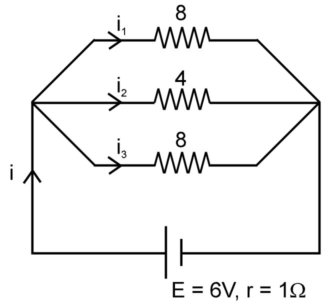


D-4. In the given circuit determine



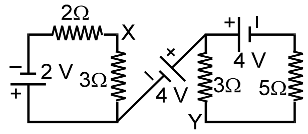
(a) Equivalent resistance (Including internal resistance).
(b) Current in each resistance
(c) Potential difference across each resistance
(d) The rate at which the chemical energy of the cell is consumed
(e) The rate at which heat is generated inside the battery
(f) Electric power output
(g) Potential difference across battery
(h) Which resistance consumes maximum power
(i) Power dissipated in 3 Ω resistance.

D-5. In given circuit determine



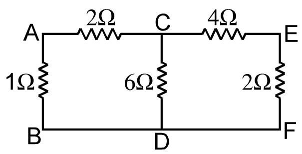
(a) Equivalent resistance (Including internal resistance).
(b) Current i, i_1, i_2 and i_3
(c) Potential difference across battery and each resistance
(d) The rate at which the chemical energy of the cell is consumed
(e) The rate at which heat is generated inside the battery
(f) Electric power output
(g) Which resistance consumes maximum power ?
(h) Power dissipated across 4Ω resistance

D-6. (a) Determine the potential difference between X and Y in the circuit shown in Figure.



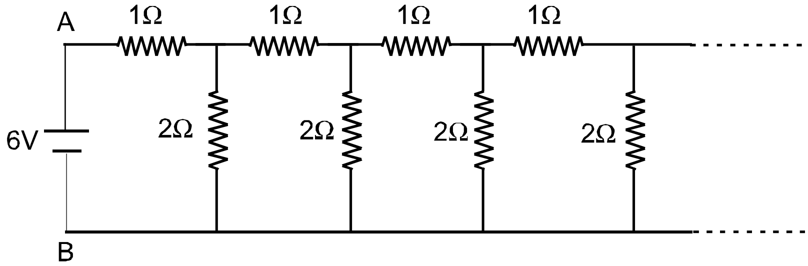
(b) If intermediate cell has internal resistance r = 1Ω then determine the potential difference between X and Y.

D-7. Find the equivalent resistance of the circuit given in figure between the following point:



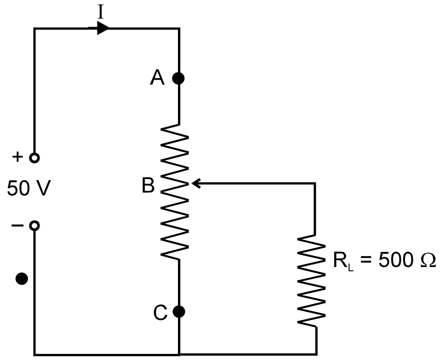
(i) A and B (ii) C and D (iii) E and F (iv) A and F
(v) A and C

D-8. An infinite ladder network of resistance is constructed with 1Ω and 2Ω resistance, as shown in figure.



(i) Show that the effective resistance between A and B is 2Ω.
(ii) What is the current that passes through the 2Ω resistance nearest to the battery ?

D-9. As shown in figure a variable rheostat of 2 kΩ is used to control the potential difference across 500 ohm load. (i) If the resistance AB is 500 Ω, what is the potential difference across the load ? (ii) If the load is removed, what should be the resistance at BC to get 40 volt between B and C ?

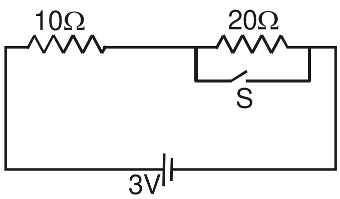


D-10. ABCD is a square where each side is uniform wire of resistance 1 Ω. Find a point E on CD such that if a uniform wire of resistance 1 Ω is connected across AE and a potential difference is applied across A and C, the points B and E will be equipotential.

D-11. Suppose you have three resistors of 20 Ω, 50 Ω and 100 Ω. What minimum and maximum resistances can you obtain from these resistors ?

D-12. Three bulbs, each having a resistance of 180 Ω, are connected in parallel to an ideal battery of emf 60 V. Find the current delivered by the battery when
(a) all the bulbs are switched on, (b) two of the bulbs are switched on and
(c) only one bulb is switched on.

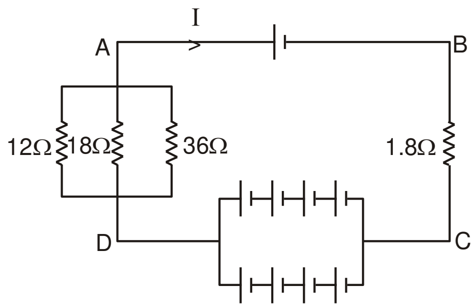
D-13. Consider the circuit shown in figure. Find the current through the 10Ω resistor when the switch S is (a) opened (b) closed.



Section (E) : Combination of Cells

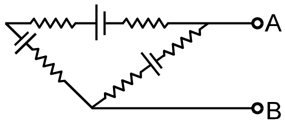
E-1. Six lead-acid type of secondary cells, each of emf 2.0 V and internal resistance 0.015 Ω, are joined in series to provide a supply to a resistance of 8.5 Ω. Determine : (i) the current drawn from the supply and (ii) its terminal voltage.

E-2. In the figure each cell has an emf of 1.5 V and internal resistance of 0.40 Ω. Calculate:

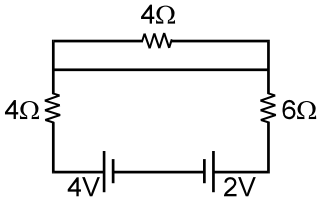


(i) current I (ii) current in the 36 Ω resistor
(iii) potential difference across A and B.

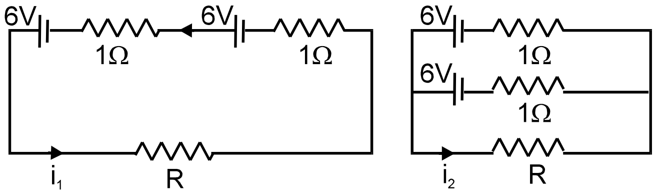
E-3. In the circuit shown all five resistors have the same value 200 ohms and each cell has an emf 3 volts. Find the open circuit voltage and the short circuit current for the terminals A and B.



E-4. Find the currents through the three resistors shown in figure



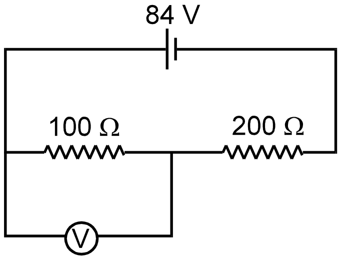
E-5. Find the value of i_1/i_2 in figure if (a) R = 0.1 Ω, (b) R = 1Ω (c) R = 10 Ω. Note from your answer that in order to get more current from a combination of two batteries they should be joined in parallel if the external resistance is small and in series if the external resistance is large as compared to the internal resistances.



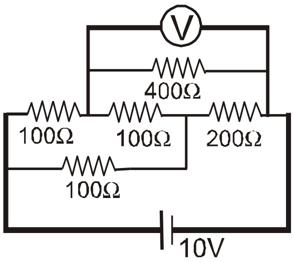
Section (F) : Instrument

F-1. A galvanometer has a resistance of 30 ohm and a current of 2 mA is needed to give a full scale deflection. What is the resistance needed and how is it to be connected to convert the galvanometer. **[REE 1986]**
(a) Into an ammeter of 0.3 ampere range ? (b) Into a voltmeter of 0.2 volt range ?

F-2. A voltmeter of resistance 400Ω is used to measure the potential difference across the 100Ω resistor in the circuit shown in the figure. (a) What will be the reading of the voltmeter ? (b) What was the potential difference across 100 Ω before the voltmeter was connected ?

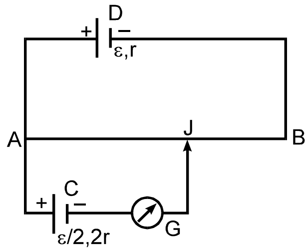


F-3. An electrical circuit is shown in the figure. Calculate the potential difference across the resistance of 400 ohm, as will be measured by the voltmeter V of resistance 400 ohm, either by applying Kirchhoff's rules or otherwise. **[JEE 1996, 5]**

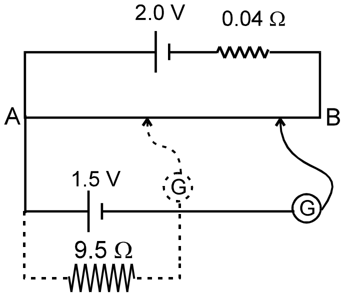


F-4. A battery of emf 1.4 V and internal resistance 2 Ω is connected to a resistor of 100 Ω through an ammeter. The resistance of the ammeter is 4/3 Ω. A voltmeter has also been connected to find the potential difference across the resistor.
(i) Draw the circuit diagram.
(ii) The ammeter reads 0.02 A. What is the resistance of the voltmeter ?
(iii) The voltmeter reads 1.10 V, what is the zero error in the voltmeter ?
(Hint : zero error = observed reading – actual reading)

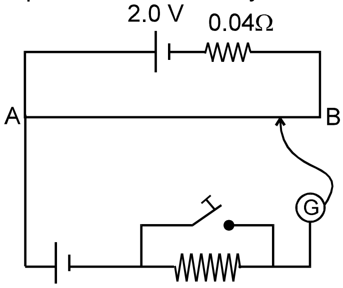
F-5. In the fig. the potentiometer wire AB of length L & resistance 9 r is joined to the cell D of e.m.f. ε and internal resistance r. The cell C's e.m.f. is ε/2 and its internal resistance is 2 r. The galvanometer G will show no deflection then find length AJ :



F-6. Figure shows a 2.0 V potentiometer used for the determination of internal resistance of 1.5 V cell. The balance point of the cell without 9.5 Ω in the external circuit is 70 cm. When a resistor of 9.5 Ω is used in the external circuit of the cell, the balance point shifts to 60 cm length of the potentiometer wire. Determine the internal resistance of the secondary cell.

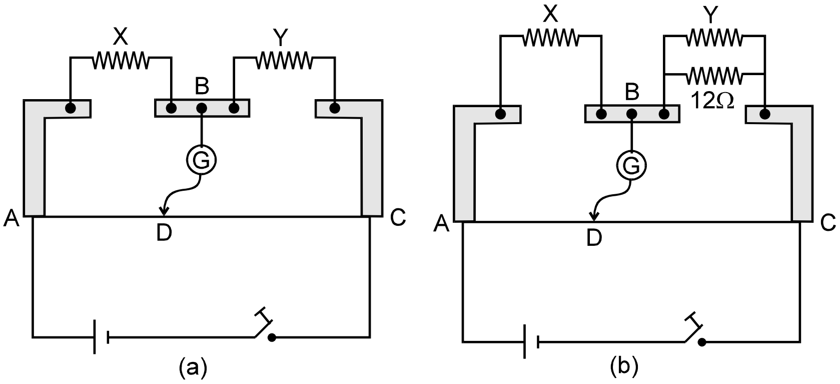


F-7. Figure shows a potentiometer with a cell of emf 2.0 V and internal resistance 0.04 Ω maintaining a potential drop across the potentiometer wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents up to a few ampere) gives a balance point of 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600 kΩ is put in series with it which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf E and the balance point found similarly turns out to be at 82.3 cm length of the wire.



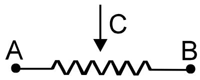
(a) What is the value of E ?
(b) What purpose does the high resistance of 600 kΩ have ?
(c) Is the balance point affected by this high resistance?
(d) Is the balance point affected by the internal resistance of the driver cell?
(e) Would the method work in the above situation if the driver cell of the potentiometer had an emf of 1.0 V instead of 2.0 V?
(f) Would the circuit work well for determining extremely small emf, say, of the order of few mV (such typical emf of thermocouple)?

F-8. Figure shows a metre bridge (which is nothing but a practical Wheatstone Bridge) consisting of two resistors X and Y together in parallel with a metre long constantan wire of uniform cross-section. With the help of a movable contact D, one can change the ratio of the resistances of the two segments of the wire until a sensitive galvanometer G connected across B and D shows no deflection. The null point is found to be at a distance of 30 cm from the end A. The resistor Y is shunted by a resistance of 12.0 Ω and the null point is found to shift by a distance of 10 cm. Determine the resistance of X and Y.



(a) (b)

F-9. Connect a battery to the terminals and complete the circuit diagram so that it works as a potential divider meter. Indicate the output terminals also. **[IIT-JEE (Main) 2003, 2/60]**



PART - II : ONLY ONE OPTION CORRECT TYPE

Section (A) : Definltion of current, Current densities, Drift

A-1. The drift velocity of electrons in a conducting wire is of the order of 1mm/s, yet the bulb glows very quickly after the switch is put on because

(A) The random speed of electrons is very high, of the order of 10^6 m/s
(B) The electrons transfer their energy very quickly through collisions
(C) Electric field is set up in the wire very quickly, producing a current through each cross section, almost instantaneously
(D) All of above

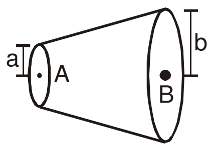
A-2. In the presence of an applied electric field ($\vec{E}$) in a metallic conductor.

(A) The electrons move in the direction of $\vec{E}$
(B) The electrons move in a direction opposite to $\vec{E}$
(C) The electrons may move in any direction randomly, but slowly drift in the direction of $\vec{E}$.
(D) The electrons move randomly but slowly drift in a direction opposite to $\vec{E}$.

A-3. The potential difference applied to an X-ray tube is 5 kV and the current through it is 3.2 mA. Then the number of electrons striking the target per second is **[IIT-JEE (Scr.) 2002, 3/105]**

(A) 2×10^{16} (B) 5×10^{16} (C) 1×10^{17} (D) 4×10^{15}

A-4 An electric current passes through non uniform cross-section wire made of homogeneous and isotropic material. If the j_A and j_B be the current densities and E_A and E_B be the electric field intensities at A and B respectively, then



(A) $j_A > j_B$; $E_A > E_B$ (B) $j_A > j_B$; $E_A < E_B$ (C) $j_A < j_B$; $E_A > E_B$ (D) $j_A < j_B$; $E_A < E_B$

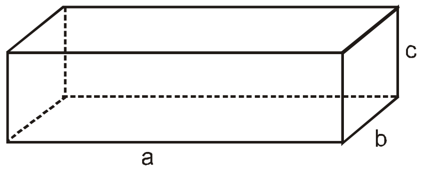
Section (B) : Resistance

B-1. A piece of copper and another of germanium are cooled from room temperature to 80 K. The resistance of :

(A) each of the them increases (B) each of them decreases

(C) copper increases and germanium decreases (D) copper decreases and germanium increases

B-2. All the edges of a block in cuboidal shape with parallel faces are equal. Its longest edge is twice its shortest edge. The ratio of the maximum to minimum resistance between parallel faces is:



(A) 2 (B) 4 (C) 8

(D) indeterminate unless the length of the third edge is specified.

Section (C) : Power, Energy, Battery, EMF and Terminal voltage

C-1. In an electric circuit containing battery, the positive charge inside the battery

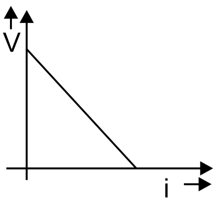
(A) always goes from the positive terminal to the negative terminal

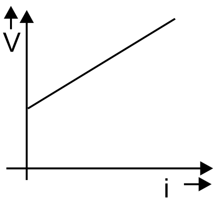
(B) may go from the positive terminal to the negative terminal

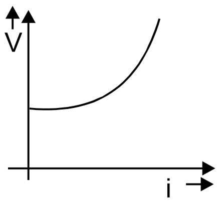
(C) always goes from the negative terminal to the positive terminal

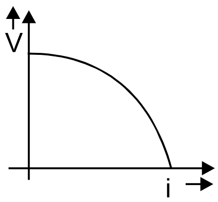
(D) does not move.

C-2. If internal resistance of a cell is proportional to current drawn from the cell. Then the best representation of terminal potential difference of a cell with current drawn from cell will be :

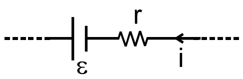
(A) 

(B) 

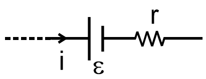
(C) 

(D) 

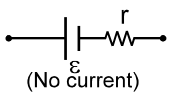
C-3.



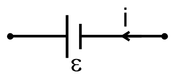
(a)



(b)



(c)



(b)

In which of the above cells, the potential difference between the terminals of a cell exceeds its emf.

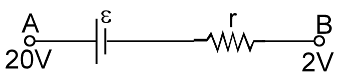
(A) a (B) b (C) c (D) d

C-4. A resistor of resistance R is connected to a cell of internal resistance 5 Ω. The value of R is varied from 1 Ω to 5 Ω. The power consumed by R:

(A) increases continuously (B) decreases continuously

(C) first decreases then increases (D) first increases then decreases.

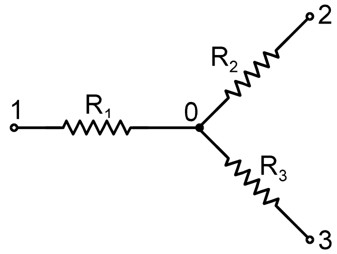
C-5. In the figure a part of circuit is shown :



(A) current will flow from A to B (B) current may flow from A to B

(C) current will flow from B to A (D) the direction of current will depend on *r*.

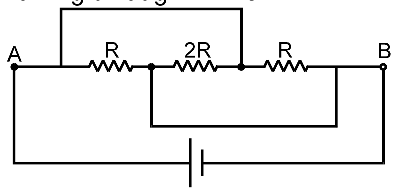
C-6. **(i)** Find the current flowing through the resistance R_1 of the circuit shown in figure if the resistances are equal to $R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, and $R_3 = 30\ \Omega$, and the potentials of points 1, 2 and 3 are equal to $\varphi_1 = 10$ V, $\varphi_2 = 6$ V, and $\varphi_3 = 5$ V.



(A) 0.1 A (B) 0.2 A (C) 0.3 A (D) 0.4 A

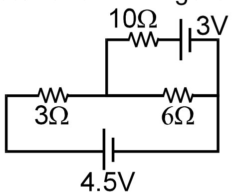
(ii) In the previous question potential at point 0 is
(A) 15 V (B) 20 V (C) 25 V (D) 8 V

C-7. In the figure shown the current flowing through 2 R is :



(A) from left to right (B) from right to left (C) no current (D) None of these

C-8. Find the current through the 10 Ω resistor shown in figure



(A) zero (B) 1 A (C) 2A (D) 5 A

C-9. The efficiency of a cell when connected to a resistance R is 60%. What will be its efficiency if the external resistance is increased to six times :
(A) 80 % (B) 90% (C) 55% (D) 95%

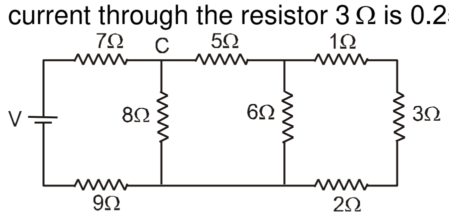
Section (D) : Combination of Resistance

D-1. Two coils connected in series have resistances 600 Ω and 300 Ω at 20°C and temperature coefficient of resistivity 0.001 K^{-1} and 0.004 K^{-1} respectively.

(a) The resistance of the combination at temperature 50°C is
(A) 426 Ω (B) 954 Ω (C) 1806 Ω (D) 214 Ω

(b) The effective temperature coefficient of the combination is
(A) $\frac{1}{1000}$ degree^{-1} (B) $\frac{1}{250}$ degree^{-1} (C) $\frac{1}{500}$ degree^{-1} (D) $\frac{3}{1000}$ degree^{-1}

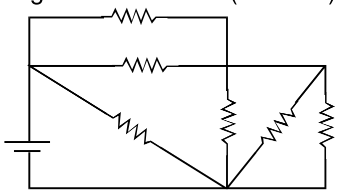
D-2. In the ladder network shown, current through the resistor 3 Ω is 0.25 A. The input voltage 'V' is equal to



(A) 10 V (B) 20 V (C) 5 V (D) $\frac{15}{2}$ V

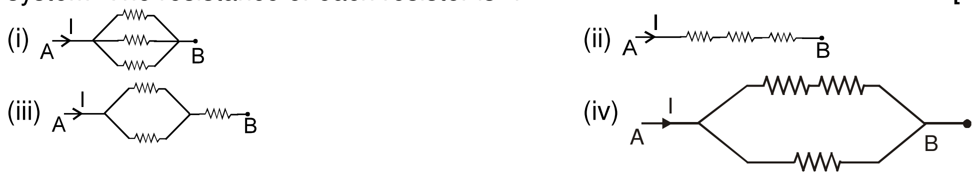
D-3. If 2 bulbs rated 2.5 W – 110 V and 100 W – 110 V are connected in series to a 220 V supply then
(A) 2.5 W bulb will fuse (B) 100 W bulb will fuse (C) both will fuse (D) both will not fuse

D-4. In the figure shown each resistor is of 20 Ω and the cell has emf 10 volt with negligible internal resistance. Then rate of joule heating in the circuit is (in watts)



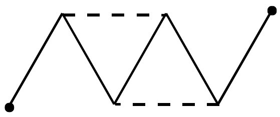
(A) 100/11 (B) 10000/11 (C) 11 (D) None of these

D-5. Arrange the order of power dissipated in the given circuits, if the same current is passing through the system. The resistance of each resistor is ' r '. **[IIT-JEE (Scr.) 2003, 3/84]**



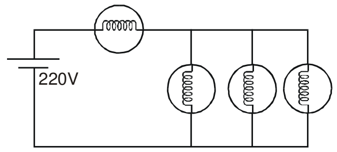
(A) $P_2 > P_3 > P_4 > P_1$ (B) $P_1 > P_4 > P_3 > P_2$ (C) $P_1 > P_2 > P_3 > P_4$ (D) $P_4 > P_3 > P_2 > P_1$

D-6. Five identical resistors each of resistance 1Ω are initially arranged as shown in the figure by clear lines. If two similar resistances are added as shown by the dashed lines then change in resistance in final and initial arrangement is



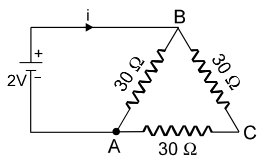
(A) 2 Ω (B) 1 Ω (C) 3 Ω (D) 4 Ω

D-7. Four identical bulbs each rated 100 watt, 220 volts are connected across a battery as shown. The total electric power consumed by the bulbs is :



(A) 75 watt (B) 400 watt (C) 300 watt (D) 400/3 watt

D-8. The current i in the circuit of figure is - **[JEE 1983]**

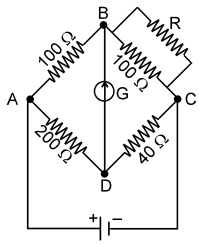


(A) $\frac{1}{45}$amp. (B) $\frac{1}{15}$amp. (C) $\frac{1}{10}$amp. (D) $\frac{1}{5}$amp.

D-9. Three equal resistors connected in series across a source of emf together dissipate 10 watts of power. What would be the power dissipated if the same resistors are connected in parallel across the same source of emf ? **[JEE 1972]**

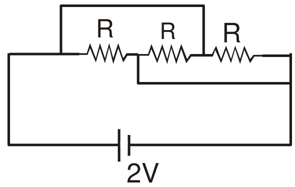
(A) 60 watt (B) 90 watt (C) 100 watt (D) 30 watt

D-10. The given Wheatstone bridge is showing no deflection in the galvanometer joined between the points B and D (Figure). Calculate the value of R.



(A) 25 Ω (B) 50 Ω (C) 40 Ω (D) 100 Ω

D-11. Three equal resistance each of R ohm are connected as shown in figure. A battery of 2 volts of internal resistance 0.1 ohm is connected across the circuit. Calculate the value of R for which the heat generated in the exeternal circuit is maximum. **[REE 1990]**

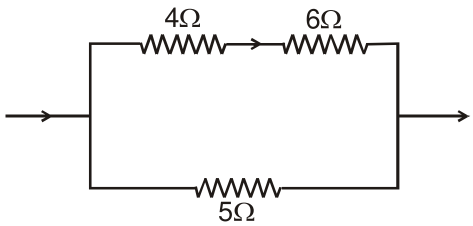


(A) 0.1 Ω (B) 0.2 Ω (C) 0.3 Ω (D) 0.4 Ω

D-12. A wire of resistance 0.1 ohm cm^{-1} bent to form a square ABCD of side 10 cm. A similar wire is connected between the corners B and D to form the diagonal BD. Find the effective resistance of this combination between corners A and C. If a 2V battery of negligible internal resistance is connected across A and C calculate the total power dissipated. **[JEE - 1971]**

(A) 1 Ω, 3 W (B) 1 Ω, 4 W (C) 2 Ω, 3 W (D) 2 Ω, 4 W

D-13. In the circuit shown in figure the heat produced in the 5Ω resistor due to the current flowing through it is 10 calories per second. **[JEE' 1981; 2M]**



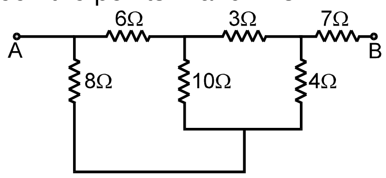
The heat generated in the 4Ω resistor is :

(A) 1 cal/s (B) 2 cal/s (C) 3 cal/s (D) 4 cal/s

D-14. A 50 W bulb is in series with a room heater and the combination is connected across the mains. To get max. heater output, the 50 W bulb should be replaced by :

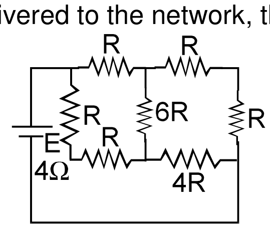
(A) 25 W (B) 10 W (C) 100 W (D) 200 W

D-15. The equivalent resistance between the points A and B is :



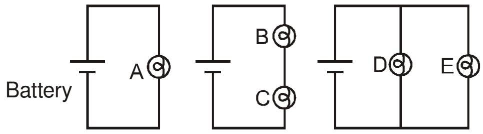
(A) $\frac{36}{7}$ Ω (B) 10 Ω (C) $\frac{85}{7}$ Ω (D) none of these

D-16. A battery of internal resistance 4 ohm is connected to the network of resistance as shown. In the order that the maximum power can be delivered to the network, the value of R in ohm should be : **[JEE - 1995]**



(A) 4/9 (B) 2 (C) 8/3 (D) 18

D-17. In these three circuits all the batteries are identical and have negligible internal resistance, and all the light bulbs are identical. Rank all 5 light bulbs (A, B, C, D, E) in order of brightness from brightness to dimmest.



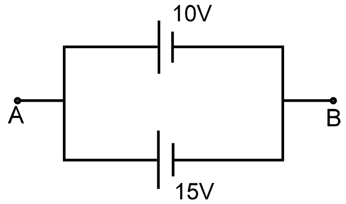
(A) A = B = C > D = E (B) A > B = C > D = E (C) A = D = E > B = C (D) A = D = E > B > C

Section (E) : Combination of Cells

E-1. Two nonideal batteries are connected in parallel. Consider the following statements
(I) The equivalent emf is smaller than either of the two emfs.
(II) The equivalent internal resistance is smaller than either of the two internal resistance.
(A) Both I and II are correct (B) I is correct but II is wrong
(C) II is correct but I is wrong (D) Each of I and II is wrong.

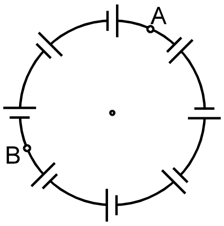
E-2. 12 cells each having the same emf are connected in series and are kept in a closed box. Some of the cells are wrongly connected. This battery is connected in series with an ammeter and two cells identical with each other and also identical with the previous cells. The current is 3 A when the external cells support this battery and is 2 A when the cells oppose the battery. How many cells in the battery are wrongly connected?
(A) one (B) two (C) three (D) none

E-3. Two cells of e.m.f. 10 V & 15 V are connected in parallel to each other between points A & B. The cell of e.m.f. 10 V is ideal but the cell of e.m.f. 15 V has internal resistance 1 Ω. The equivalent e.m.f. between A and B is :



(A) $\frac{25}{2}$ V (B) not defined (C) 15 V (D) 10 V

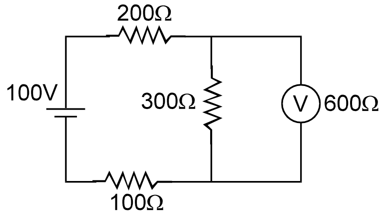
E-4. N sources of current with different emf's are connected as shown in figure. The emf's of the sources are proportional to their internal resistances, i.e. E = αR, where α is an assigned constant. The connecting wire resistance is negligible. The potential difference between points A and B dividing the circuit in n and N – n links



(A) 0 (B) nE/2 (C) NE (D) (N – n)E

Section (F) : Instrument

F-1. The reading of voltmeter is



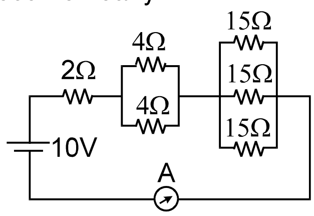
(A) 50V (B) 60 V (C) 40V (D) 80 V

F-2. The length of a wire of a potentiometer is 100 cm, and the emf of its standard cell is E volt. It is employed to measure the emf of a battery whose internal resistance is 0.5 ohm. If the balance point is obtained at 30 cm from the positive end, the emf of the battery is **[AIEEE 2003, 4/300]**

(A) $\frac{30E}{100}$ (B) $\frac{30E}{100.5}$ (C) $\frac{30E}{(100-0.5)}$

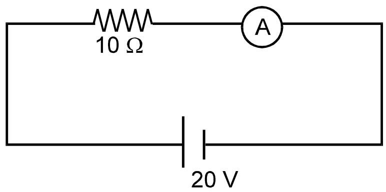
(D) $\frac{30(E-0.5i)}{100}$, $\frac{30(E-0.5i)}{100}$, where i is the current in the potentiometer

F-3. The current through the ammeter shown in figure is 1 A. If each of the 4Ω resistor is replaced by 2Ω resistor, the current in circuit will become nearly :



(A) $\frac{10}{9}$ A (B) $\frac{5}{4}$ (C) $\frac{9}{8}$ A (D) $\frac{5}{8}$ A

F-4. The ammeter shown in figure consists of a 480 Ω coil connected in parallel to a 20 Ω shunt. Find the reading of the ammeter.



(A) $\frac{50}{73}$ A (B) $\frac{40}{53}$ A (C) $\frac{50}{93}$ A (D) $\frac{73}{50}$ A

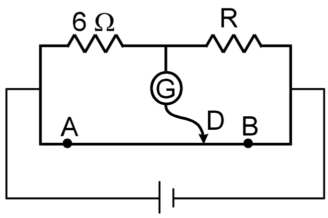
F-5. A galvanometer together with an unknown resistance in series is connected to two identical batteries each of 1.5 V. When the batteries are connected in series, the galvanometer records a current of 1A, and when the batteries are in parallel the current is 0.6 A. What is the internal resistance of the battery? **[JEE - 1973]**

(A) $r = \frac{2}{3}\Omega$ (B) $r = \frac{2}{5}\Omega$ (C) $r = \frac{1}{3}\Omega$ (D) $r = \frac{3}{2}\Omega$

F-6. A potentiometer wire of length 100 cm has a resistance of 10 ohm. It is connected in series with a resistance and an accumulator of emf 2V and of negligible internal resistance. A source of emf of 10 mV is balanced against a length of 40 cm of the potentiometer wire. What is the value of external resistance ? **[JEE - 1976]**

(A) 890 Ω (B) 600 Ω (C) 650 Ω (D) 790 Ω

F-7. The meter-bridge wire AB shown in figure is 50 cm long. When AD = 30 cm, no deflection occurs in the galvanometer. Find R.



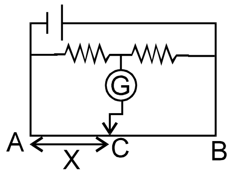
(A) 1 Ω (B) 2 Ω (C) 3 Ω (D) 4 Ω

F-8. The current in a conductor and the potential difference across its ends are measured by an ammeter and a voltmeter. The meters draw negligible currents. The ammeter is accurate but the voltmeter has a zero error (that is, it does not read zero when no potential difference is applied). Then the zero error is (if the readings for two different conditions are 1.75 A, 14.4 V and 2.75 A, 22.4 V.)

(A) 0.4 volt (B) 0.8 volt (C) –0.4 volt (D) –0.8 volt

F-9. In the given circuit, no current is passing through the galvanometer. If the cross-sectional diameter of the wire AB is doubled, then for null point of galvanometer, the value of AC would be:

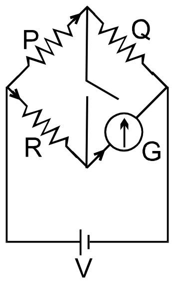
[IIT-JEE(Scr.) - 2003, 3/84]



(A) 2 X (B) X (C) $\frac{X}{2}$ (D) None

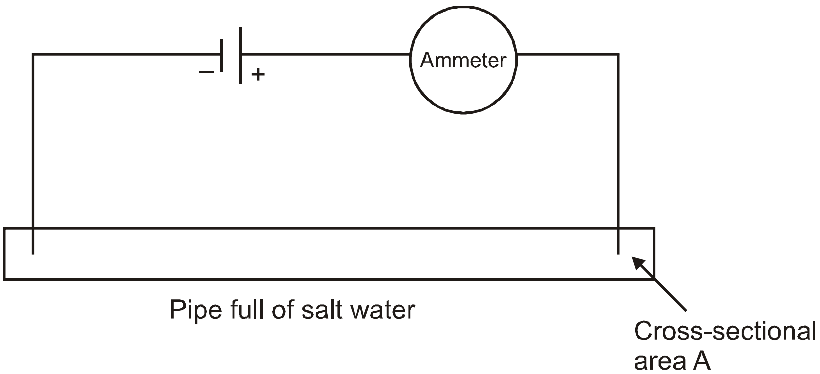
F-10. In the circuit shown, $P \neq R$, the reading of the galvanometer is same with switch S open or closed. Then

[IIT-JEE 1999, 2/200]



(A) $I_R = I_G$ (B) $I_P = I_G$ (C) $I_Q = I_G$ (D) $I_Q = I_R$

F-11. Salt water contains n sodium ions (Na+) per cubic meter and n chloride ions (Cl^-) per cubic meter. A battery is connected to metal rods that dip into a narrow pipe full of salt water. The cross sectional area of the pipe is A. The magnitude of the drift velocity of the sodium ions is V_{Na} and the magnitude of the drift velocity of the chloride ions is V_{Cl}. Assume that $V_{Na} > V_{Cl}$ (+e is the charge of a proton).



What is the magnitude of the ammeter reading ?

(A) $enAV_{Na} - enAV_{Cl}$ (B) $enAV_{Na} + enAV_{Cl}$ (C) $enAV_{Na}$ (D) $enAV_{Cl}$

PART - III : MATCH THE COLUMN

1. **Match the following :**
The following table gives the lengths of four copper rods at the same temperature, their diameters, and the potential differences between their ends.

Rod	Length	Diameter	Potential Difference
1	L	3d	V
2	2L	d	3V
3	3L	2d	2V
4	3L	d	V

Correctly match the physical quantities mentioned in the left column with the rods as marked.

Column-I	Column-II
(A) Greatest Drift speed of the electrons.	(p) Rod 1
(B) Greatest Current	(q) Rod 2
(C) Greatest rate of thermal energy produced	(r) Rod 3
(D) Greatest Electric field	(s) Rod 4

2. Match the statements in Column I with the current element in Column II

Column-I	Column-II
(A) Current always flows from higher potential to lower potential	(p) A Resistor
(B) Energy dissipated in an element is always zero	(q) Ideal cell/Battery
(C) Current flow through the element is always zero	(r) Non-Ideal cell/Battery
(D) Potential difference may/will be zero	(s) Short-circuited resistor

Exercise-2

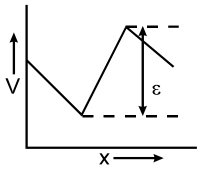
✍ **Marked Questions can be used as Revision Questions.**

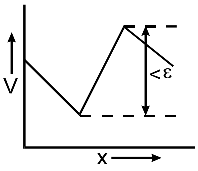
PART - I : ONLY ONE OPTION CORRECT TYPE

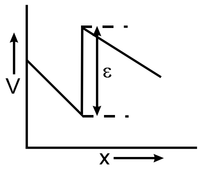
1. If a copper wire is stretched to make its radius decrease by 0.1%, the percentage change in its resistance is approximately.
(A) – 0.4% (B) + 0.8% (C) + 0.4% (D) + 0.2%

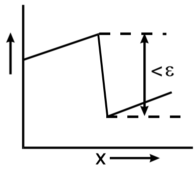
2. The potential difference between the terminals of a battery of emf 10 V and internal resistance 1Ω drops to 9.8 V when connected across an external resistance. The resistance of the external resistor is
(A) 49 Ω (B) 25 Ω (C) 31 Ω (D) 43 Ω

3. The two ends of a uniform conductor are joined to a cell of emf ε and some internal resistance. Starting from the midpoint P of the conductor, we move in the direction of the current and return to P. The potential V at every point on the path is plotted against the distance covered (x). Which of the following best represents the resulting curve?

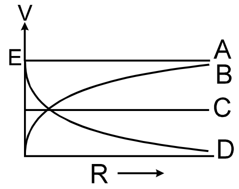
(A)


(B)


(C)


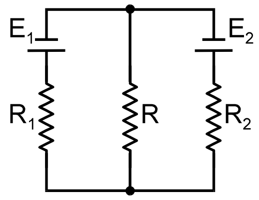
(D)


4. A cell of emf E having an internal resistance r is connected to an external resistance R. The potential difference V across the resistance R varies with R as shown in figure by the curve :



(A) A (B) B (C) C (D) D

5. In a circuit shown in figure resistances R_1 and R_2 are known, as well as emf's E_1 and E_2. The internal resistances of the sources are negligible. At what value of the resistance R will the thermal power generated in it be the highest ?

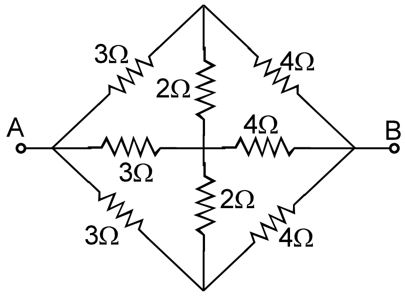


(A) $R_1 + R_2$ (B) $R_1 - R_2$ (C) $\sqrt{R_1R_2}$ (D) $\frac{R_1R_2}{R_1+R_2}$

6. A resistor R is connected to a parallel combination of two identical batteries each with emf E and an internal resistance r. The potential drop across the resistance R is. **[Olympiad 2016_Stage-1]**

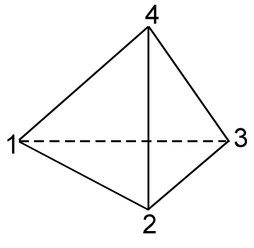
(A) $\frac{2ER}{2R+r}$ (B) $\frac{ER}{R+2r}$ (C) $\frac{ER}{2R+r}$ (D) $\frac{2ER}{R+2r}$

7. The equivalent resistance between A and B will be (in Ω)



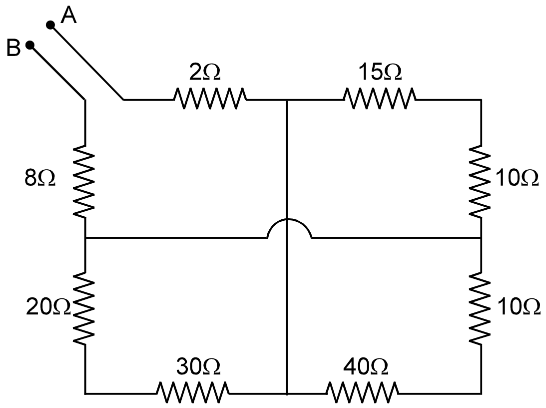
(A) 2/7 (B) 8 (C) 4/3 (D) 7/3

8. A wire is in the form of a tetrahedron. The resistance of each edge is r. The equivalent resistances between corners 1–2 and 1–3 are respectively



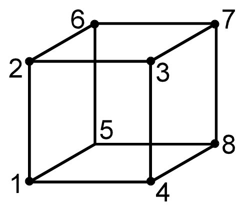
(A) $\frac{r}{2}, \frac{r}{2}$ (B) r, r (C) $\frac{r}{2}$, r (D) r, $\frac{r}{2}$

9. The equivalent resistance between points A and B is :



(A) $\frac{65}{2}\ \Omega$ (B) $\frac{45}{2}\ \Omega$ (C) $\frac{5}{2}\ \Omega$ (D) $\frac{91}{2}\ \Omega$

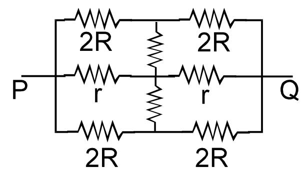
10. In the question find the resistance between points 1 - 3.



(A) $\frac{3}{4}R$ (B) $\frac{5}{6}R$ (C) $\frac{3}{5}R$ (D) $\frac{6}{5}R$

11. The effective resistance between points P and Q of the electrical circuit shown in the figure is:

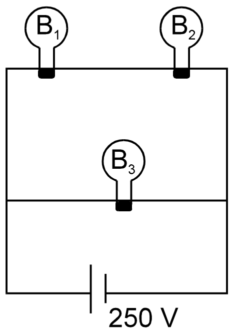
[IIT-JEE(Scr.) - 2002, 3/105]



(A) $\frac{2Rr}{R+r}$ (B) $\frac{2R(R+r)}{3R+r}$ (C) $2r+4R$ (D) $\frac{5R}{2}+2r$

12. A 100 W bulb B_1 and two 60 W bulbs B_2 and B_3 are connected to a 250 V source as shown in the figure. Now W_1, W_2 and W_3 are the output powers of the bulbs B_1, B_2 and B_3 respectively. Then:

[IIT-JEE(Scr.) - 2002, 3/105]

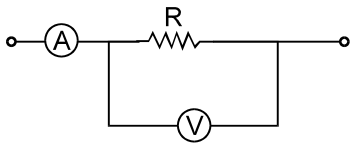


(A) $W_1 > W_2 = W_3$ (B) $W_1 > W_2 > W_3$ (C) $W_1 < W_2 = W_3$ (D) $W_1 < W_2 < W_3$

13. When a galvanometer is shunted with a 4Ω resistance, the deflection is reduced to one - fifth. If the galvanometer is further shunted with a 2Ω wire, determine current in galvanometer now if initially current in galvanometer is I_0 (given main current remain same).

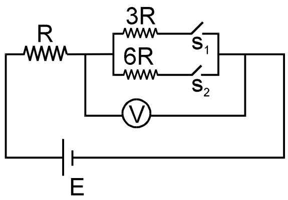
(A) $I_0/13$ (B) $I_0/5$ (C) $I_0/8$ (D) $5I_0/13$

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



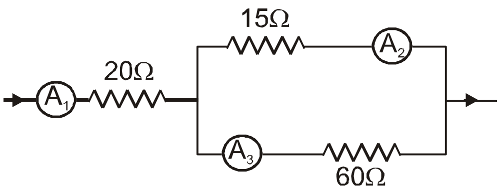
(A) 5 Ω (B) less than 5Ω (C) greater than 5Ω (D) between 4Ω and 5Ω.

15. 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 and reading of voltmeter is V_3 when both S_1 and S_2 are closed. Then



(A) $V_3 > V_2 > V_1$ (B) $V_2 > V_1 > V_3$ (C) $V_3 > V_1 > V_2$ (D) $V_1 > V_2 > V_3$

16. If the reading of ammeter A_3 in figure is 0.75 A. Neglecting the resistances of the ammeters, the reading of ammeter A_2 will be :

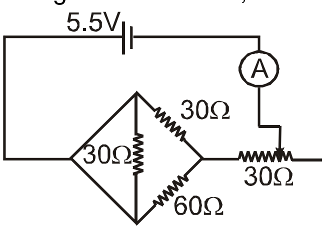


(A) 1.5 A (B) 3 A (C) 4.5 A (D) 6 A

17. In the previous question the reading of ammeter A_1 will be :

(A) 6.75 A (B) 5.25 A (C) 3.75 A (D) 2.25 A

18. The resistance of the rheostat shown in figure is 30 Ω. Neglecting the ammeter resistance, the ratio of minimum and maximum currents through the ammeter, as the rheostat is varied, will be :



(A) $\frac{2}{5}$ (B) $\frac{83}{15}$ (C) $\frac{9}{43}$ (D) $\frac{19}{43}$

19. An ammeter and a voltmeter are joined in series to a cell. Their readings are A and V respectively. If a resistance is now joined in parallel with the voltmeter,

(A) both A and V will increase (B) both A and V will decrease

(C) A will decrease, V will increase (D) A will increase, V will decrease

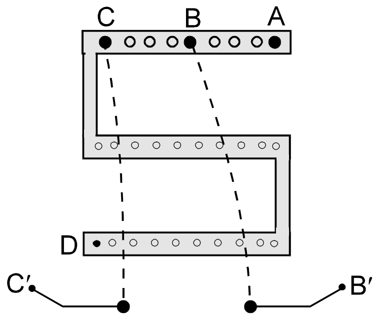
20. An ammeter and a voltmeter are connected in series to a battery with an emf ε = 6.0 V. When a certain resistance is connected in parallel with the voltmeter, the reading of the voltmeter decrease η = 2.0 times, whereas the reading of the ammeter increase the same number of times. Find the voltmeter reading after the connection of the resistance.

(A) 2 V (B) 4V (C) 8V (D) 18V

21. A galvanometer has resistance 100Ω and it requires current 100μA for full scale deflection. A resistor 0.1Ω is connected in parallel to make it an ammeter. The smallest current required in the circuit to produce the full scale deflection is **[IIT-JEE (Scr.) - 2005, 3/84]**

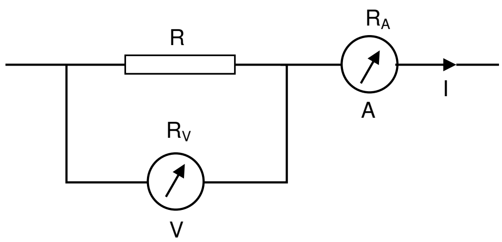
(A) 1000.1 mA (B) 1.1 mA (C) 10.1 mA (D) 100.1 mA

22. Between which points should the terminals of unknown resistance be connected in a post office box arrangement to get its value **[IIT-JEE(Scr.) - 2004, 3/84]**



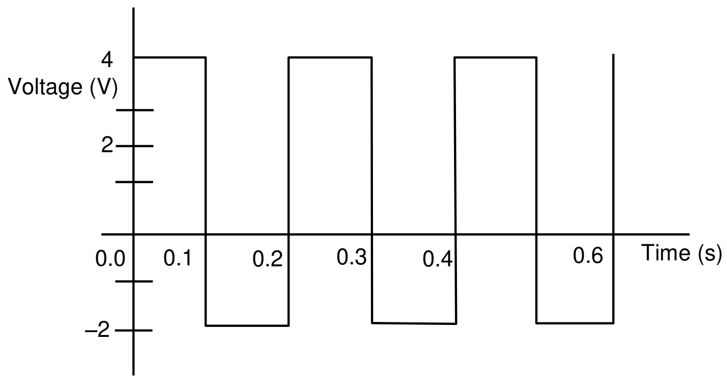
(A) A and B (B) B and C (C) C and D (D) A and D

23. Let V and I be the readings of the voltmeter and the ammeter respectively as shown in the figure. Let R_V and R_A be their corresponding resistance Therefore, **[Olympiad (Stage-1) 2017]**



(A) $R = \dfrac{V}{I}$ (B) $R = \dfrac{V}{I-\left(\dfrac{V}{R_V}\right)}$ (C) $R = R_V - R_A$ (D) $R = \dfrac{V(R+R_A)}{IR_A}$

24. A 10 ohm resistor is connected to a supply voltage alternating between +4V and –2V as shown in the following graph. The average power dissipated in the resistor per cycle is **[Olympiad (Stage-1) 2017]**



(A) 1.0 W (B) 1.2 W (C) 1.4W (D) 1.6W

25. Two cells each of emf E and internal resistance r_1 and r_2 respectively are connected in series with an external resistance R. The potential difference between the terminals of the first cell will be zero when R is equal to **[Olympiad (Stage-1) 2017; AIEEE-2005, 4/300]**

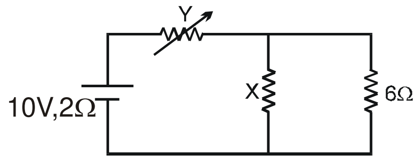
(A) $\frac{r_1 + r_2}{2}$ (B) $\sqrt{r_1^2 - r_2^2}$ (C) $r_1 - r_2$ (D) $\frac{r_1 r_2}{r_1 + r_2}$

PART - II : SINGLE AND DOUBLE VALUE INTEGER TYPE

1. The current density in a cylindrical conductor of radius R varies according to the equation $J = J_0\left(1 - \frac{r}{R}\right)$, where r = 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 $r = \frac{2}{\sqrt{\pi}}$. Current in terms of J_0 is given by $n\left(\frac{J_0}{6}\right)$ then value of n will be.

2. 1 m long metallic wire is broken into two unequal parts P and Q. P of the wire is uniformly extended into another wire R. Length of R is twice the length of P and the resistance of R is equal to that of Q. Find the ratio of the length of Q and P **[REE - 1996]**

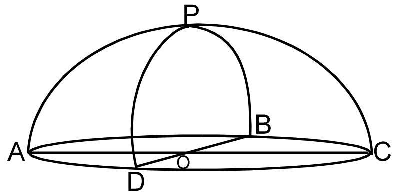
3. For a given resistance X in the figure shown the thermal power generated in ' Y ' is maximum when Y = 4 Ω. Then resistance X (in Ω) is:



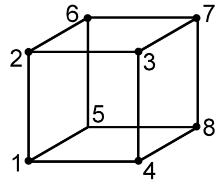
4. A series parallel combination of batteries consisting of a large number N = 300 of identical cells, each with an internal resistances r = 0.3 Ω, is loaded with an external resistance R = 10 Ω. Find number 'n' of parallel groups consisting of an equal number of cells connected in series, at which the external resistance generates the highest thermal power.

5. The internal resistance of an accumulator battery of emf 6V is 10Ω when it is fully discharged. As the battery gets charged up, its internal resistance decreases to 1Ω. The battery in its completely discharged state is connected to a charger which maintains a constant potential difference of 9V. The current through the battery just after the connections are made is I_1 and after a long time when it is completely charged is I_2. Find $10I_1 + I_2$ in amperes.

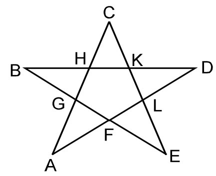
6. A hemispherical network of radius a is made by using a conducting wire of resistance per unit length 'r'. The equivalent resistance across OP is given by $\left[\frac{\pi + n}{8}\right]$ ar the value of n will be.



7. Find the resistance in ohm of a wire frame shaped as a cube (figure) when measured between points 1-7 if each resistance is 6Ω



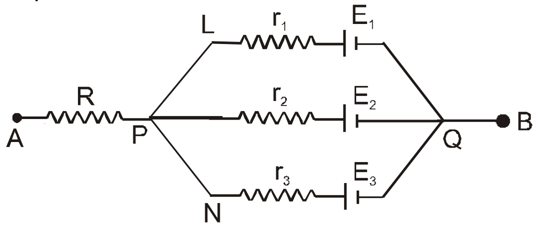
8. The figure is made of a uniform wire and represents a regular five pointed star. The resistance of a section EL is 2 ohm. Find the resistance in ohm of the star across F and C. (sin 18º $\simeq \frac{1}{3}$)



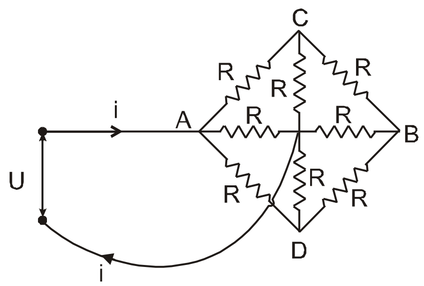
9. In the circuit shown in fig. E_1 = 3 volt, E_2 = 2 volt, E_3 = 1 volt and R = r_1 = r_2 = r_3 = 1 ohm. **[JEE - 1981]**

(i) Find potential difference in Volt between the points A and B with A & B unconnected.

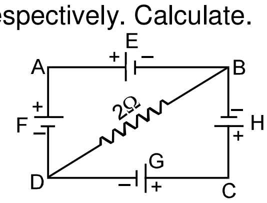
(ii) If r_2 is short circuited and the point A is connected to point B through a zero resistance wire, find the current through R in ampere.



10. The resistance of each resistor in the circuit diagram shown in figure is the same and equal to R = 1Ω. The voltage across the terminals is U = 7V. Determine the current i(Ampere) the leads if their resistance can be neglected.



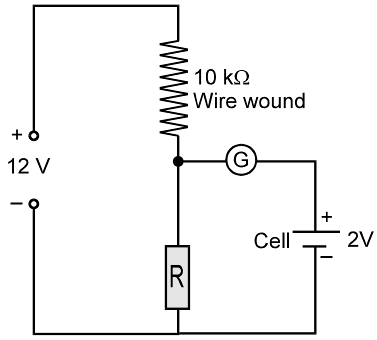
11. In the circuit shown in fig. E, F, G and H are cells of emf 2, 1, 3 and 1 volts and their internal resistances are 2, 1, 3 and 1 ohm respectively. Calculate. **[JEE - 1981]**



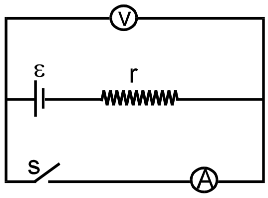
(i) The potential difference between B and D is given by $\left(\frac{13-n}{13}\right)$ Volt then valu of n will be.

(ii) The ratio of potential difference across the terminals of the cell G to cell H is given by $\left(\frac{n+2}{19}\right)$ the value of n will be.

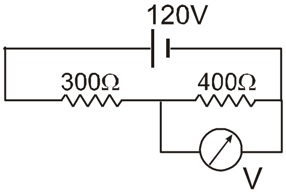
12. If the galvanometer in the circuit of figure reads zero, calculate the value of the resistor R (in kΩ) assuming that the 12 V source has negligible internal resistance.



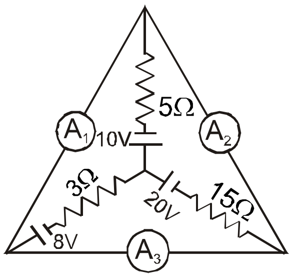
13. Figure shows an arrangement to measure the emf ε and internal resistance r of a battery. The voltmeter has a very high resistance and the ammeter has a very small resistance. The voltmeter reads 1.52 V when the switch S is open. When the switch is closed the voltmeter reading drops to 1.45 V and the ammeter reads 1.0 A. The internal resistance of the battery in mΩ will be ?



14. In the circuit shown, reading of the voltmeter connected across 400 Ω resistance is 60 V. If it is connected across 300 Ω resistance then reading in volt will be



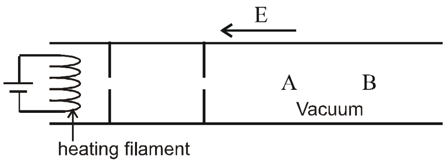
15. In the given circuit the ammeter A_1 and A_2 are ideal and the ammeter A_3 has a resistance of $1.9 \times 10^{-3}\ \Omega$. If sum of readings of all three meters is given by $\left(\frac{2n}{27}\right)$ Ampere the value of n will be.



16. Two resistors, 400 Ω, and 800 Ω are connected in series with a 6 V battery. It is desired to measure the current in the circuit. An ammeter of 10 Ω resistance is used for this purpose. The reading of ammeter will be $\frac{N}{1210}$ A. Similarly, if a voltmeter of 1000 Ω resistance is used to measure the potential difference across the 400 Ω resistor, the reading of voltmeter is $\frac{P}{19}$ V. Then the value of N and P are :

PART - III : ONE OR MORE THAN ONE OPTIONS CORRECT TYPE

1. A continuous beam of electrons emitted by a heating filament are accelerated in free space by an electric field as shown in figure. The two stops at the left ensure that the electron beam has a uniform cross-section. Which of the following is/are correct :



(A) Linear momentum of electron increases from A to B.
(B) The electric current is from right to left
(C) The magnitude of the current is same at A and B.
(D) The current density is same at A and B.

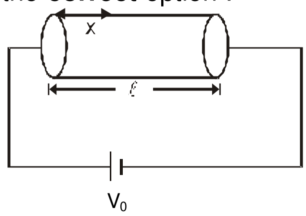
2. A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section?
(A) the charge crossing in a given time interval (B) drift speed
(C) current density (D) free-electron density.

3. When no current is passed through a conductor
(A) the free electrons do not move
(B) the average speed of a free electron over a large period of time is zero
(C) the average velocity of a free electron over a large period of time is zero
(D) the average of the velocities of all the free electrons at an instant is zero

4. The current density in a wire is 10 A/cm^2 and the electric field in the wire is 5 V/cm. If ρ = resistivity of material, σ = conductivity of the material then (in S.I. units) :
(A) $\rho = 5 \times 10^{-3}$ (B) $\rho = 200$ (C) $\sigma = 5 \times 10^{-3}$ (D) $\sigma = 200$

5. A bulb is connected to an ideal battery of emf 10 V so that the resulting current is 10 mA. When the bulb is connected to 220 V mains (ideal), the current is 50 mA. Choose the correct alternative (s)
(A) In the first case, the resistance of the bulb is 1kΩ and in second case, it is 4.4 kΩ.
(B) It is not possible since ohm's law is not followed
(C) The increase in resistance is due to heating of the filament of the bulb when it is connected to 220V mains
(D) None of these

6. The cross section area and length of a cylindrical conductor are A and ℓ respectively is connected with a voltage source V_0. The conductivity varies as, $\sigma = \sigma_0 \frac{\ell}{x}$ where x ($0 < x < \ell$) is the distance along the axis of the cylinder from one of its end as shown in the figure. Choose the **correct** option :



(A) The electric resistance of cylinder along its axis is $\frac{\ell}{2\sigma_0 A}$
(B) The electric current in the wire will be $\frac{V_0\sigma_0 A}{2\ell}$
(C) The current density in the wire will be $\frac{2V_0\sigma_0}{\ell}$
(D) The electric field in the wire at x in cylinder will be $\frac{2V_0}{\ell^2}x$

7. N cells each of e.m.f. E & identical resistance r are grouped into sets of K cells connected in series. The (N/K) sets are connected in parallel to a load of resistance R, then;

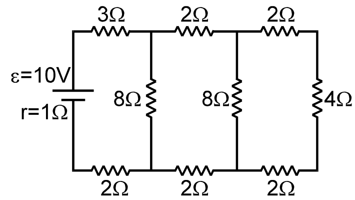
(A) Maximum power is delivered to the load if K = $\sqrt{\dfrac{NR}{r}}$.

(B) Maximum power is delivered to the load if K = $\sqrt{\dfrac{r}{NR}}$

(C) Maximum power delivered to the load is $\dfrac{E^2}{4Nr}$

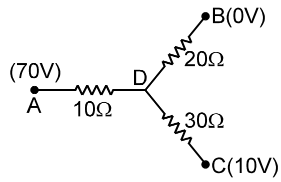
(D) Maximum power delivered to the load is $\dfrac{NE^2}{4r}$

8. In the circuit shown, the cell has emf = 10 V and internal resistance = 1 Ω



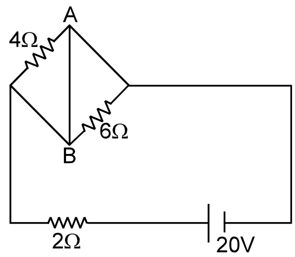
(A) The current through the 3Ω resistor is 1 A.
(B) The current though the 3Ω resistor is 0.5 A
(C) The current through the 4Ω resistor is 0.5 A.
(D) The current through the 4Ω resistor is 0.25 A

9. In the network shown, points A, B and C are potentials of 70 V, zero and 10 V respectively.



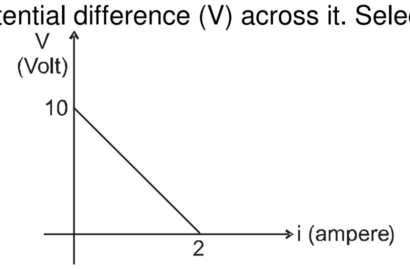
(A) Point D is at a potential of 40 V
(B) The currents in the sections AD, DB, DC are in the ratio 3 : 2 : 1
(C) The currents in the sections AD, DB, DC are in the ratio 1 : 2 : 3
(D) The network draws a total power of 200 W.

10. In the circuit shown in figure



(A) power supplied by the battery is 200 watt
(B) current flowing in the circuit is 5 A
(C) potential difference across 4 Ω resistance is equal to the potential difference across 6Ω resistance
(D) current in wire AB is zero

11. 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 (s)

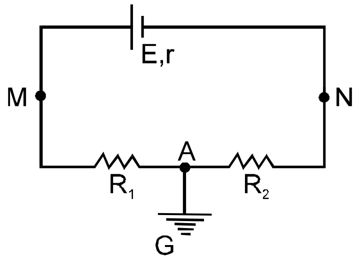


(A) internal resistance of the battery is 5Ω
(B) emf of the battery is 10 V
(C) maximum current which can be taken from the battery is 2 A
(D) V-i graph can never be a straight line as shown in figure.

12. Potential difference across the terminals of a non ideal battery is
(A) zero when it is short circuited
(B) less than its emf when current flows from negative terminal to positive terminal inside the battery
(C) zero when no current is drawn from the battery
(D) greater than its emf when current flows from positive terminal to negative inside the battery.

13. A cell of emf ε and internal resistance r drives a current i through an external resistance R.
(A) The cell is generating ε i power
(B) Heat is produced in R at the rate ε i
(C) Heat is produced in R at the rate $\varepsilon i \left(\frac{R}{R+r}\right)$
(D) Heat is produced in the cell at the rate $\varepsilon i \left(\frac{r}{R+r}\right)$

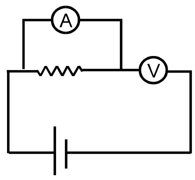
14. In the given figure, E = 12V, $R_1 = 3\Omega$, $R_2 = 2\Omega$ and $r = 1\,\Omega$. Then choose the correct option/s



(A) potential of point M is 6V
(B) potential of point N is – 4V
(C) potential of point M is 12V
(D) current in wire AG is zero

15. In a potentiometer wire experiment the emf of a battery in the primary circuit is 20volt 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

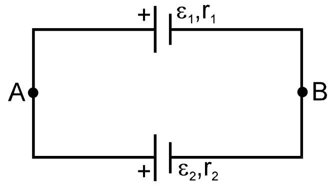
16. By mistake, a voltmeter is placed in series and an ammeter in parallel with a resistance in an electric circuit, with a cell in series.



(A) The main current in the circuit will be very low and almost all current will flow through the ammeter, if resistance of ammeter is much smaller than the resistance in parallel.
(B) If the devices are ideal, a large current will flow through the ammeter and it will be damaged
(C) If the devices (including battery) are ideal, ammeter will read zero current and voltmeter will read the emf of cell
(D) The devices may get damaged if emf of the cell is very high and the meters are nonideal.

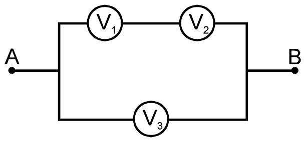
17. A micro-ammeter has a resistance of 100 Ω and full scale range of 50 μA. It can be used as a voltmeter and an ammeter of a higher range provided a resistance is added to it. Pick the correct range and resistance combination (s) : **[1991; 2M]**
(A) 50 V range with 10 kΩ resistance is series
(B) 10 V range with 200 kΩ resistance in series
(C) 5 mA range with 1 Ω resistance in parallel
(D) 10 mA range with 1 Ω resistance in parallel

18. Two cells of unequal emfs ε_1 and ε_2, and internal resistances r_1 and r_2 are joined as shown. V_A and V_B are the potentials at A and B respectively.



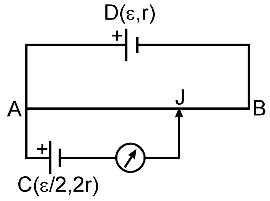
(A) One cell will supply energy to the other
(B) The potential difference across both the cells will be equal
(C) The potential difference across one cell will be greater than its emf.
(D) $V_A - V_B = \dfrac{(\varepsilon_1 r_2 + \varepsilon_2 r_1)}{r_1 + r_2}$

19. Three voltmeters, all having different resistances, are joined as shown. When some potential difference is applied across A and B, their readings are V_1, V_2, V_3 :



(A) $V_1 = V_2$ (B) $V_1 \neq V_2$ (C) $V_1 + V_2 = V_3$ (D) $V_1 + V_2 > V_3$

20. In the potentiometer arrangement shown, the driving cell D has emf ε and internal resistance r. The cell C, whose emf is to be measured, has emf $\varepsilon/2$ and internal resistance 2r. The potentiometer wire is 100-cm long. If balance is obtained at the length AJ = ℓ.



(A) ℓ = 50 cm
(B) ℓ > 50 cm
(C) Balance will be obtained only if resistance of AB is ≥ r.
(D) Balance cannot be obtained.

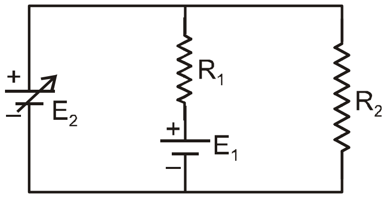
21. Choose the correct alternatives
(A) It is easier to start a car engine on a warm day than on a chilly cold day because the internal resistance of battery decreases with rise in temperature
(B) It is more economical to transmit electric power at high voltage and low current rather than at low voltage and high current because heat loss is proportional to square of current.
(C) The heating coil of an electric iron is enclosed in mica sheets because mica is a bad conductor of heat and good conductor of electricity
(D) The heating coil of an electric iron is enclosed in mica sheets because mica is a good conductor of heat and bad conductor of electricity.

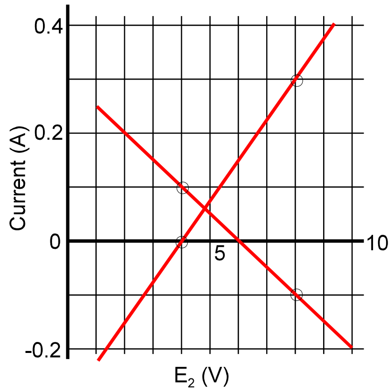
22. Which of the following statement/s is/are correct of a source of emf (such as a primary cell) ?
(A) Inside the cell there always exist an electrostatic field and a non-electrostatic field of equal magnitude directed opposite to it. **[Olympiad 2015 (stage-1)]**
(B) Potential difference is the work of an electrostatic field whereas electromotive force is the work of a non-electrostatic field.
(C) Under certain condition current can flow from positive terminal to negative terminal within the cell.
(D) When an external resistance is connected to the cell, the electrostatic field inside the cell decreases in magnitude compared to the non-electrostatic field.

PART - IV : COMPREHENSION

Comprehension -1

In the circuit given below, both batteries are ideal. Emf E_1 of battery 1 has a fixed value, but emf E_2 of battery 2 can be varied between 1.0 V and 10.0 V. The graph gives the currents through the two batteries as a function of E_2, but are not marked as which plot corresponds to which battery. But for both plots, current is assumed to be negative when the direction of the current through the battery is opposite the direction of that battery's emf. (Direction of emf is from negative to positive)





1. The value of emf E_1 is

(A) 8 V (B) 6 V (C) 4 V (D) 2V

2. The resistance R_1 has value

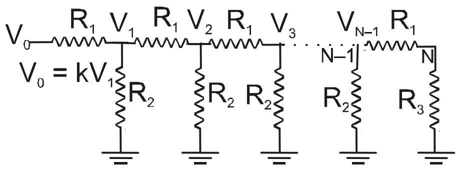
(A) 10 Ω (B) 20 Ω (C) 30 Ω (D) 40 Ω

3. The resistance R_2 is equal to :

(A) 10 Ω (B) 20 Ω (C) 30 Ω (D) 40 Ω

Comprehension - 2

A network of resistance is constructed with R_1 and R_2 as shown in the figure. The potential at the points 1, 2, 3,........, N are V_1, V_2, V_3,........., V_n respectively each having a potential K time smaller than previous one. Find :



4. $\left(\frac{R_1}{R_2}\right) \times \left(\frac{R_2}{R_3}\right)$ in terms of K.

(A) K–1 (B) $K^2 - 1$ (C) $\frac{1}{K+1}$ (D) $\frac{K-1}{K+1}$

5. Current that passes through the resistance R_2 nearest to the V_0 in terms V_0, K and R_3.

(A) $\left[\frac{(K+1)}{K^2}\right]\frac{V_0}{R_3}$ (B) $\left[\frac{(K-1)}{K}\right]\frac{V_0}{R_3}$ (C) $\left[\frac{(K-1)}{K^2}\right]\frac{V_0}{R_3}$ (D) $\left[\frac{(K+1)}{K^2}\right]\frac{V_0}{R_3}$

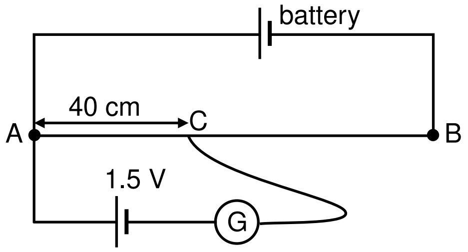
Comprehension-3

Group of Q. 6 to 8 is based on the following paragraph.

A nichrome wire AB, 100 cm long and of uniform cross section is mounted on a meter scale the points A and B coinciding with 0 cm and 100 cm marks respectively. The wire has a resistance S = 50 ohm. Any point C along this wire, between A and B is called a variable point to which on end of and electrical element is connected. In the following questions this arrangement will be referred to as 'wire AB'.

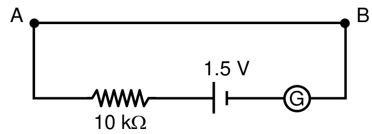
[Olympiad 2016 Stage-1]

6. The emf of a battery is determined using the following circuit with 'wire AB'. The galvanometer shows zero deflection when one of its terminals is connected to point C. If the internal resistance of the battery is 4 ohm, its emf is **[Olympiad 2016_Stage-1]**



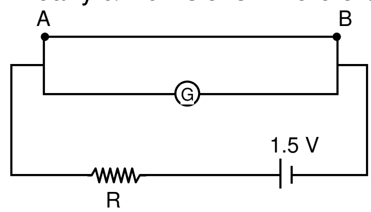
(A) 3.75 volt (B) 4.05 volt (C) 2.50 volt (D) 9.0 volt

7. In the circuit adjacent arrangement it is found that deflection in the galvanometer is 10 divisions. Also the voltage across the 'wire AB' is equal to the across the galvanometer. Therefore, the current sensitivity of the galvanometer is about. **[Olympiad 2016_Stage-1]**



(A) 0.050 div/μA. (B) 0.066 div/μA (C) 0.0140 div/μA (D) data insufficient

8. In the adjacent circuit a resistance R is used. Initially with 'wire AB' not in the circuit, the galvanometer shows a deflection of d divisions. Now, the 'wire AB' is connected parallel to the galvanometer and the galvanometer shows a deflection nearly d/2 divisions. Therefore **[Olympiad 2016 Stage-1]**



(A) R = G (B) R << G (C) R >> G (D) $R = \frac{SG}{S+G}$

Comprehension-4

Group of question Nos 9 to 12 are based on the following paragraph and its subsequent continuation of after some question.

The following question are concerned with experiments of the characterization and use of a moving coil galvanometer.

The series combination of variable resistance R, one 100 Ω resistor and moving coil galvanometer is connected to a mobile phone charger having negligible internal resistance. The zero of the galvanometer lies at the centre and the pointer can move 30 division full scale on either side depending on the direction of current. The reading of the galvanometer is 10 divisions and the voltages across the galvanometer and 100 Ω resistor are respectively 12 mV and 16 mV. **[Olympiad (Stage-1) 2017]**

9. The figure of merit of the galvanometer is microampere per division is :
(A) 16 (B) 20 (C) 32 (D) 10

10. The resistance of the galvanometer is ohm is :
(A) 50Ω (B) 75 Ω (C) 100 Ω (D) 80 Ω

The series combination of the galvanometer with a resistance of R is connected across an ideal voltage supply of 12 V and this time the galvanometer shows full scale deflection of 30 divisions.

11. The value of R is nearly
(A) 12.5 kΩ (B) 25 kΩ (C) 75 kΩ (D) 100 kΩ

12. A 24 Ω resistance is connected to a 5 V battery with internal resistance of 1Ω. A 25 kΩ resistance is connected in series with the galvanometer and this combination is used to measure the voltage across the 24 Ω resistance. The number of divisions shown in the galvanometer is
(A) 6 (B) 8 (C) 10 (D) 12

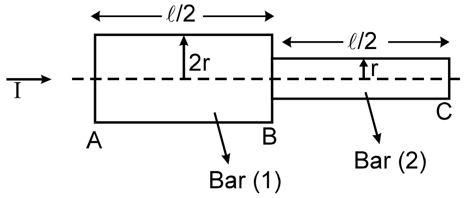
Exercise-3

✍ **Marked Questions can be used as Revision Questions.**

*** Marked Questions may have more than one correct option.**

PART - I : JEE (ADVANCED) / IIT-JEE PROBLEMS (PREVIOUS YEARS)

1.✍ Two bars of equal resistivity ρ and radii 'r' and '2r' are kept in contact as shown. An electric current I is passed through the bars. Which one of the following is correct? **[IIT-JEE 2006; 3/184]**

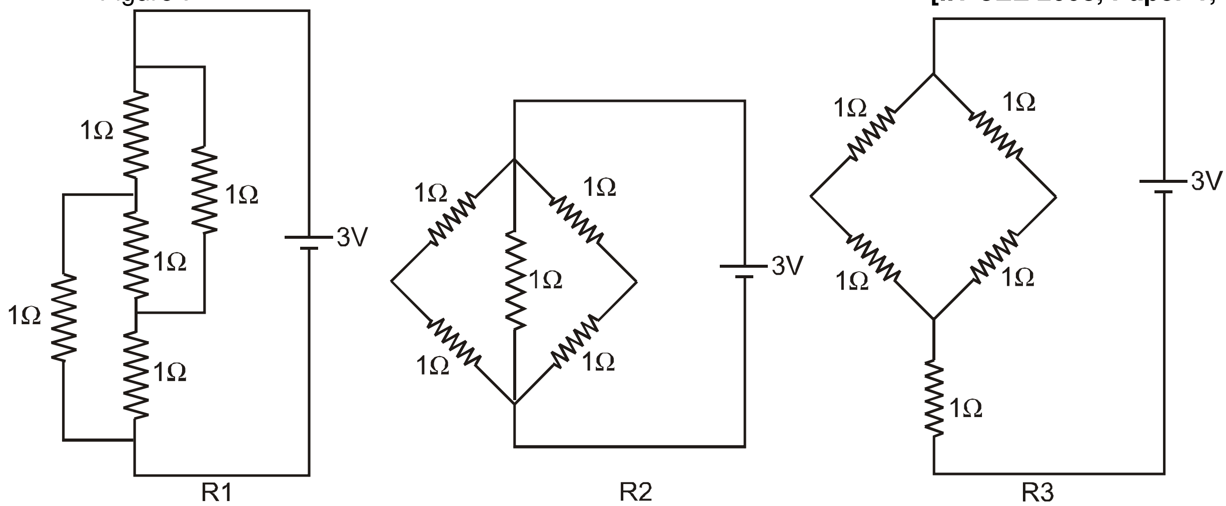


(A) Heat produced in bar (1) is 2 times the heat produced in bar (2)
(B) Electric field in both halves is equal
(C) Current density across AB is double that across BC.
(D) Potential difference across BC is 4 times that across AB.

2. A resistance of 2 Ω is connected across one gap of a metre-bridge (the length of the wire is 100 cm) and an unknown resistance, greater than 2 Ω, is connected across the other gap. When these resistances are interchanged, the balance point shifts by 20 cm. Neglecting any corrections, the unknown resistance is **[IIT-JEE 2007; Paper-1, 3/81]**

(A) 3 Ω (B) 4 Ω (C) 5 Ω (D) 6 Ω

3. Figure shows three resistor configurations R1, R2 and R3 connected to 3 V battery. If the power dissipated by the configuration R1, R2 and R3 is P1, P2 and P3, respectively, then
Figure : **[IIT-JEE 2008, Paper-1, 3/163]**

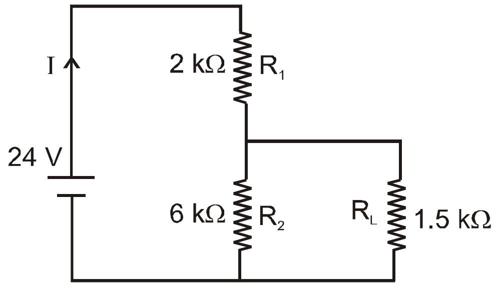


(A) P1 > P2 > P3 (B) P1 > P3 > P2 (C) P2 > P1 > P3 (D) P3 > P2 > P1

4. **STATEMENT-1 :** In a Meter Bridge experiment, null point for an unknown resistance is measured. Now, the unknown resistance is put inside an enclosure maintained at a higher temperature. The null point can be obtained at the same point as before by decreasing the value of the standard resistance.
and **[IIT-JEE 2008, Paper-1, 3/163]**
STATEMENT-2 : Resistance of a metal increases with increase in temperature.

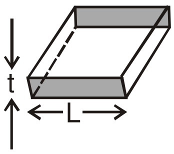
(A) STATEMENT-1 is True, STATEMENT-2 is True; STATEMENT-2 is a correct explanation for STATEMENT-1
(B) STATEMENT-1 is True, STATEMENT-2 is True; STATEMENT-2 is NOT a correct explanation for STATEMENT-1
(C) STATEMENT-1 is True, STATEMENT-2 is False
(D) STATEMENT-1 is False, STATEMENT-2 is True.

5*. For the circuit shown in the figure **[IIT-JEE 2009; 4/160, –1]**



(A) the current I through the battery is 7.5 mA
(B) the potential difference across R_L is 18 V
(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

6. Consider a thin square sheet of side L and thickness t, made of a material of resitivity ρ. The resistance between two opposite faces, shown by the shaded areas in the figure is : **[IIT-JEE 2010; 3/163, –1]**

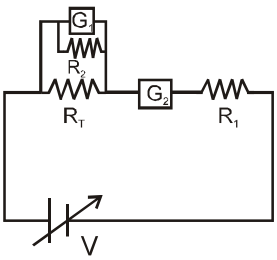


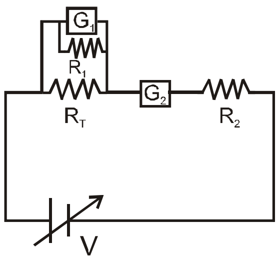
(A) directly proportional to L
(B) directly proportional to t
(C) independent of L
(D) independent of t

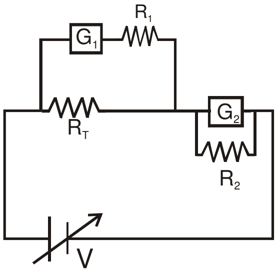
7. Incandescent bulbs are designed by keeping in mind that the resistance of their filament increases with increase in temperature. If at room temperature, 100 W, 60 W and 40 W bulbs have filament resistances R_{100}, R_{60} and R_{40}, respectively, the relation between these resistance is : **[IIT-JEE 2010; 3/163, –1]**

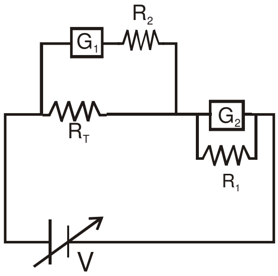
(A) $\frac{1}{R_{100}} = \frac{1}{R_{40}} + \frac{1}{R_{60}}$ (B) $R_{100} = R_{40} + R_{60}$ (C) $R_{100} > R_{60} > R_{40}$ (D) $\frac{1}{R_{100}} > \frac{1}{R_{60}} > \frac{1}{R_{40}}$

8. 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; 3/163, –1]**

(A)


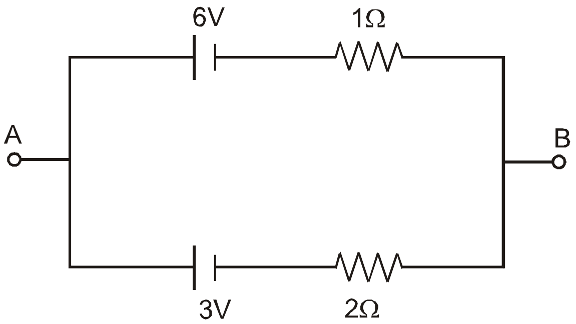
(B)


(C)


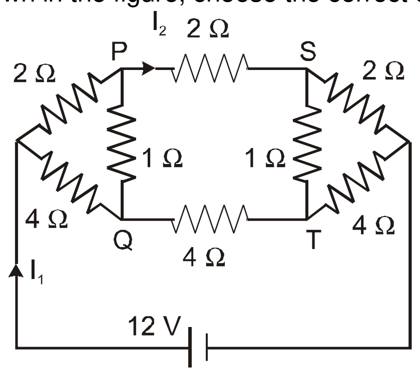
(D)


9. 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 $J_1 = 2.25\ J_2$ the value of R in Ω is : **[IIT-JEE 2010; 3/163]**

10. Two batteries of different emfs and different internal resistances are connected as shown. The voltage across AB in volts is **[IIT-JEE 2011; 4/160]**



11*. For the resistance network shown in the figure, choose the correct option(s). **[JEE-2012, Paper-1 : 4/66]**

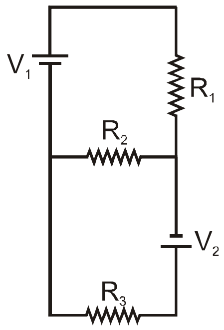


(A) The current through PQ is zero.
(B) $I_1 = 3$ A.
(C) The potential at S is less than that at Q.
(D) $I_2 = 2$ A.

12*. Heater of 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 40K. 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 40K ? **[JEE (Advanced) 2014, 3/60, –1]**

(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.

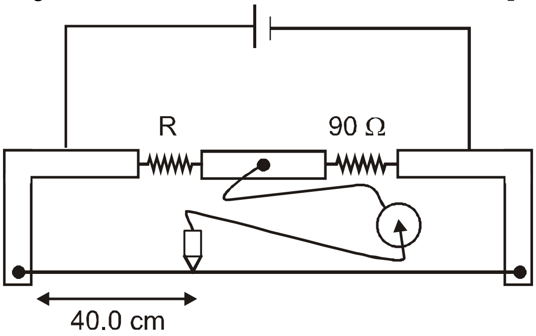
13*. Two ideal batteries of emf V_1 and V_2 and three resistances R_1, R_2 and R_3 are connected as shown in the figure. The current in resistance R_2 would be zero if **[JEE (Advanced) 2014, 3/60, –1]**



(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 $2R_1 = R_2 = R_3$

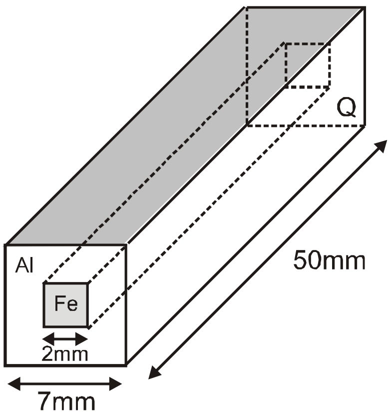
14. A galvanometer gives full scale deflection with 0.006 A current. By connecting it to a 4990Ω resistance, it can be converted into a voltmeter of range 0-30 V. If connected to a $\frac{2n}{249}\Omega$ resistance, it becomes an ammeter of range 0-1.5 A. The value of n is. **[JEE (Advanced) 2014, 3/60]**

15. During an experiment with a metre bridge, the galvanometer shows a null point when the joceky is pressed at 40.0 cm using a standard resistance of 90 Ω, as shown in the figure. The least count of the scale used in the meter bridge is 1 mm. The unknown resistance is **[JEE (Advanced) 2014, 3/60, –1]**



(A) $60 \pm 0.15\Omega$ (B) $135 \pm 0.56\Omega$ (C) $60 \pm 0.25\Omega$ (D) $135 \pm 0.23\Omega$

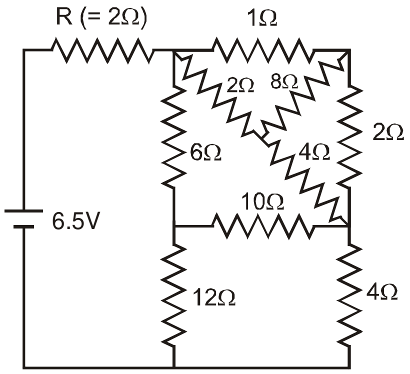
16. In an aluminum (Al) bar of square cross section, a square hole is drilled and is filled with iron (Fe) as shown in the figure, The electrical resistivities of Al and Fe are 2.7×10^{-8} Ω m and 1.0×10^{-7} Ω m, respectively. The electrical resistance between the two faces P and Q of the composite bar is **[JEE (Advanced) 2015 ; 4/88, –2]**



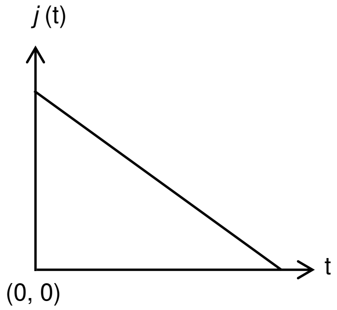
(A) $\frac{2475}{64}\mu\Omega$ (B) $\frac{1875}{64}\mu\Omega$ (C) $\frac{1875}{49}\mu\Omega$ (D) $\frac{2475}{132}\mu\Omega$

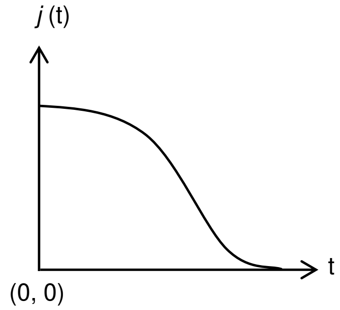
17. In the following circuit, the current through the resistor R (= 2Ω) is I Amperes. The valeu of I is :

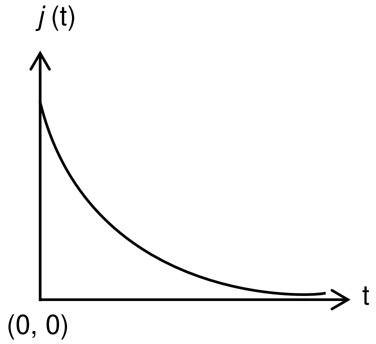
[JEE (Advanced) 2015 ; P-2,4/88]

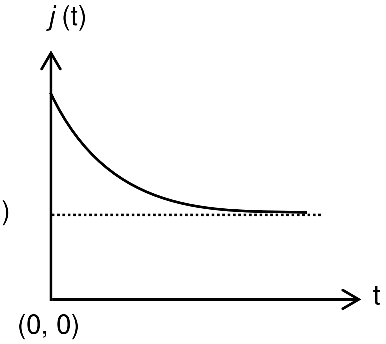


18. An infinite line charge of uniform electric charge density λ lies along the axis of an electrically conducting infinite cylindrical shell of radius R. At time t = 0, the space inside the cylinder is filled with a material of permittivity ε and electrical conductivity σ. The electrical conduction 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 ; P-1, 3/62, –1]**

(A) 

(B) 

(C) 

(D) 

19.* Consider two identical galvanometers and two identical resistors with resistance R. If the internal resistance of the galvanometers R_C < R/2, which of the following statement(s) about any one of the galvanometers is (are) true ? **[JEE (Advanced) 2016 ; P-2, 4/62, –2]**

(A) The maximum voltage range is obtained when all the components are connected in series

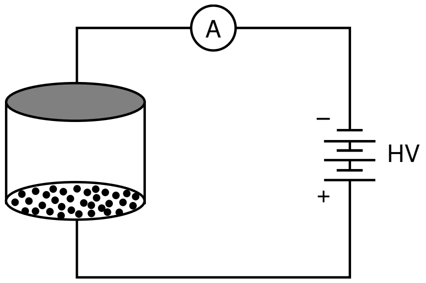
(B) The maximum voltage range is obtained when the two resistors and one galvanometer are connected in series, and the second galvanometer is connected in parallel to the first galvanometer

(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 Question Nos. 20 to 21

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 << 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 collisions between the balls and the interaction between them is negligible. (Ignore gravity) **[JEE (Advanced) 2016 ; P-2, 3/62]**



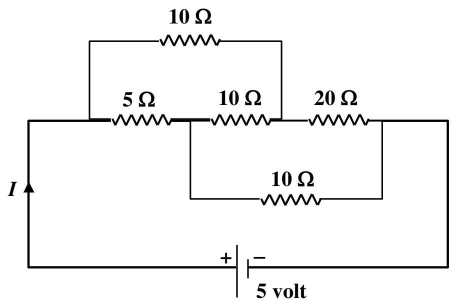
20. Which one of the following statements is correct? **[JEE (Advanced) 2016 ; P-2, 3/62]**
(A) The balls will execute simple harmonic motion between the two plates
(B) The balls will bounce back to the bottom plate carrying the opposite charge they went up with
(C) The balls will bounce back to the bottom plate carrying the same charge they went up with
(D) The balls will stick to the top plate and remain there

21. The average current in the steady state registered by the ammeter in the circuit will be **[JEE (Advanced) 2016 ; P-2, 3/62]**
(A) proportional to V_0^2 (B) proportional to $V_0^{1/2}$
(C) proportional to the potential V_0 (D) zero

22. A moving coil galvanometer has 50 turns and each turn has an area 2×10^{-4} m^2. The magnetic field produced by the magnet inside the galvanometer is 0.02T. The torsional constant of the suspension wire is 10^{-4} Nm rad^{-1}. When a current flows through the galvanometer, a full scale deflection occurs if the coil rotates by 0.2 rad. The resistance of the coil of the galvanometer is 50Ω. This galvanometer is to be converted into an ammeter capable of measuring current in the range 0 – 1.0A. For this purpose, a shunt resistance is to be added in parallel to the galvanometer. The value of this shunt resistance, in ohms, is __________. **[JEE (Advanced) 2018 ; P-2, 3/60]**

PART - II : JEE (MAIN) / AIEEE PROBLEMS (PREVIOUS YEARS)

1. The current I drawn from the 5 volt source will be **[AIEEE 2006, 3/180]**



(1) 0.67 A (2) 0.17 A (3) 0.33 A (4) 0.5 A

2. In a Wheat stone's bridge, three resistances P, Q and R are connected in the three arms and the fourth arm is formed by two resistances S_1 and S_2 connected in parallel. The condition for the bridge to be balanced will be **[AIEEE 2006, 3/180]**
(1) $\frac{P}{Q} = \frac{R(S_1+S_2)}{2S_1S_2}$ (2) $\frac{P}{Q} = \frac{R}{S_1+S_2}$ (3) $\frac{P}{Q} = \frac{2R}{S_1+S_2}$ (4) $\frac{P}{Q} = \frac{R(S_1+S_2)}{S_1S_2}$

3. An electric bulb is rated 220 volt - 100 watt. The power consumed by it when operated on 110 volt will be **[AIEEE 2006, 4½/180]**
(1) 25 watt (2) 50 watt (3) 75 watt (4) 40 watt

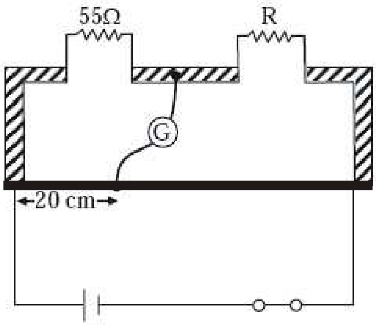
4. A material 'B' has twice the specific resistance of 'A'. A circular wire made of 'B' has twice the diameter of a wire made of 'A'. Then for the two wires to have the same resistance, the ratio ℓ_A/ℓ_B of their respective lengths must be **[AIEEE 2006, 1½/180]**
(1) 2 (2) 1 (3) 1/2 (4) 1/4

5. The Kirchhoff's first law $\left(\sum i = 0\right)$ and second law $\left(\sum iR = 0 = \sum E\right)$, where the symbols have their usual meanings, are respectively based on **[AIEEE 2006, 1½/180]**
(1) conservation of charge, conservation of energy
(2) conservation of charge, conservation of momentum
(3) conservation of energy, conservation of charge
(4) conservation of momentum, conservation of charge

6. The resistance of a wire is 5 ohm at 50º C and 6 ohm at 100ºC. The resistance of the wire at 0ºC will be **[AIEEE 2007, 3/120]**

(1) 2 ohm (2) 1 ohm (3) 4 ohm (4) 3 ohm

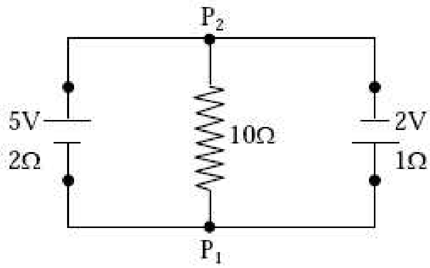
7. Shown in the figure below is a meter-bridge set up with null deflection in the galvanometer. **[AIEEE 2008, 3/105]**



The value of the unknown resistor R is

(1) 220 Ω (2) 110 Ω (3) 55 Ω (4) 13.75 Ω

8. A 5 V battery with internal resistance 2 Ω and a 2V battery with internal resistance 1Ω are connected to a 10Ω resistor as shown in the figure. **[AIEEE 2008, 3/105]**



The current in the 10 Ω resistor is -

(1) 0.03 A P_1 to P_2 (2) 0.03 A P_2 to P_1 (3) 0.27 A P_1 to P_2 (4) 0.27 A P_2 to P_1

9. Two conductors have the same resistance at 0ºC 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, 8/144]**

(1) $\frac{\alpha_1+\alpha_2}{2}$, $\alpha_1 + \alpha_2$ (2) $\alpha_1 + \alpha_2$, $\frac{\alpha_1+\alpha_2}{2}$ (3) $\alpha_1 + \alpha_2$, $\frac{\alpha_1\alpha_2}{\alpha_1+\alpha_2}$ (4) $\frac{\alpha_1+\alpha_2}{2}$, $\frac{\alpha_1+\alpha_2}{2}$

10. If a wire is stretched to make it 0.1% longer, its resistance will : **[AIEEE - 2011, 4/120, –1]**

(1) increase by 0.05% (2) increase by 0.2% (3) decrease by 0.2% (4) decrease by 0.05%

11. 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 8×10^{-7} m^2 respectively. The potential gradient will be equal to : **[AIEEE 2011, 11 May; 4/120, –1]**

(1) 1 V/ m (2) 0.5 V/m (3) 0.1 V/m (4) 0.2 V/m

12. Two electric bulbs marked 25W – 220V and 100W – 220 V are connected in series to a 440 V supply. Which of the bulbs will fuse ? **[AIEEE 2012 ; 4/120, –1]**

(1) both (2) 100W (3) 25W (4) neither

13. The supply voltage to room is 120 V. The resistance of the lead wires is 6 Ω. 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 (Main) 2013, 4/120, –1]**

(1) zero Volt (2) 2.9 Volt (3) 13.3 Volt (4) 10.04 Volt

14. This questions has Statement I and Statement II. Of the four choices given after the Statements, choose the one that best describes the two Statements. **[JEE (Main) 2013, 4/120, –1]**

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, Statment-II is true, Statement-II is the correct explanation of Statement -I.

(2) Statement-I is true, Statment-II is true, Statement - II is not the correct explanation of Statement - I.

(3) Statement-I is true, Statment-II is false.

(4) Statement-I is false, Statment-II is true.

15. In a large building, there are 15 bulbs of 40W, 5 bulbs of 100 W, 5 fans of 80 W and 1 heater of 1 kW. The voltage of the electric mains is 220 V. The minimum capacity of the main fuse of the building will be **[JEE (Main) 2014 ; 4/120, –1]**

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

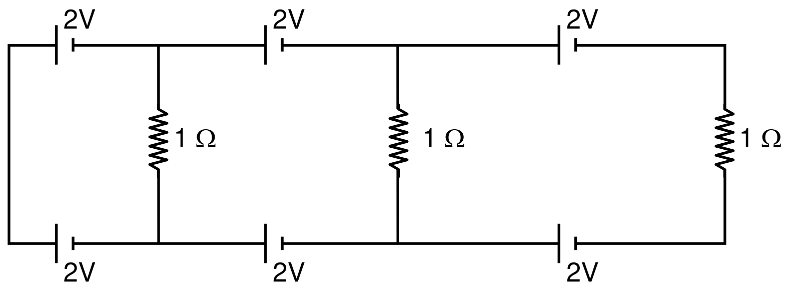
16. When 5V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is 2.5×10^{-4} ms^{-1}. If the electron density in the wire is 8×10^{28} m^{-3}, the resistivity of the material is close to : **[JEE (Main) 2015; 4/120, –1]**

(1) 1.6×10^{-8} Ωm (2) 1.6×10^{-7} Ωm (3) 1.6×10^{-6} Ωm (4) 1.6×10^{-5} Ωm

17. A galvanometer having a coil resistance of 100 Ω 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 10 A, is : **[JEE (Main) 2016; 4/120, –1]**

(1) 2 Ω (2) 0.1 Ω (3) 3 Ω (4) 0.01 Ω

18.



In the above circuit the current in each resistance is : **[JEE (Main) 2017, 4/120, –1]**

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

19. Which of the following statements is false ? **[JEE (Main) 2017, 4/120, –1]**

(1) Krichhoff's second law represents energy conservation.

(2) Wheatstone bridge is the most sensitive when all the four resistance are of the same order of magnitude

(3) In a balanced wheatstone bridge if the cell and the galvanometer are exchanged, the null point is disturbed

(4) A rheostat can be used as a potential divider.

20. When a current of 5mA is passed through a galvanometer having a coil of resistance 15Ω, it shows full scale defection. The value of the resistance to be put in series with the galvanometer to convert it into a voltmeter of range 0 – 10 V is : **[JEE (Main) 2017, 4/120, –1]**

(1) 4.005×10^3 Ω (2) 1.985×10^3 Ω (3) 2.045×10^3 Ω (4) 2.535×10^3 Ω

21. Two batteries with e.m.f 12V and 13V are connected in parallel across a load resistor of 10Ω. The internal resistance of the two batteries are 1Ω and 2Ω respectively. The voltage across the load lies between : **[JEE (Main) 2018, 4/120, –1]**
(1) 11.4V and 11.5 V (2) 11.7V and 11.8V (3) 11.6V and 11.7V (4) 11.5V and 11.6V

22. 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 resistance of 5 Ω, 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; 4/120, –1]**
(1) 2 Ω (2) 2.5 Ω (3) 1 Ω (4) 1.5 Ω

23. 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 1KΩ. How much was the resistance on the left slot before interchanging the resistances ? **[JEE (Main) 2018; 4/120, –1]**
(1) 550 Ω (2) 910 Ω (3) 990 Ω (4) 505 Ω

Answers

EXERCISE-1

PART - I

Section (A) :

A-1. 31 C, $\frac{31}{3}$ A

A-2. $\frac{1.5\times63.5\times10^{-3}}{1.6\times6\times9}$ = 1.1 × 10^{-3} ms^{-1}
or 1.1 mm s^{-1}

A-3. (i) Q = 1200 C (ii) n = 75 × 10^{20}

Section (B) :

B-1. (a) n = $\frac{2}{1.6}\times10^{17}$ = 1.25 × 10^{17}
(b) $\frac{1}{2\pi}\times10^{6}$ A/m².

B-2. 10 A **B-3.** (i) 41ºC, (ii) $\frac{\ell n2}{273}$ ºC^{-1}.

B-4. T_2 **B-5.** 0.2 %

B-6 (i) R = $\frac{0.35}{2}$ = 0.175 Ω (ii) R = 7 x 10^{-5} Ω

Section (C) :

C-1. (a) E = 10 V each
(b) (A) act as a source and (B) act as load
(c) V_A = 9V, V_B = 11 V
(d) P_A = 9 W, P_B = 11 W
(e) Heat rate = 1 W each
(f) 10 W each (g) 9V, 11V (h) –9W, 11 W

C-2. $\frac{125}{9}$ V

C-3. (a) all equal
(b) b, then a and c equal
(c) a, c equal, b

C-4. (a) 7.5 V, (b) 24 mA (c) greater than 12V.

C-5. (a) $\frac{50}{11}$ = 4.55 A (b) $\frac{22\times11}{5}$ = 48.4 Ω
(c) 1000 W (d) 240 cal s^{-1}
(e) 80/3 gm

C-6. (a) $V_A = V_B = V_C = V_D = 0$ V,
$V_E = V_F = V_G = V_H = 10$ V,
$V_I = V_J = V_K = 15$ V
(b) V_1 = 15 V, V_2 = 5V, V_3 = 15 V
(c) each act as a source
(d) 17.5 A (↑), 15A(↓) 2.5 A (↑), 5A (↓) from left to right in given circuit.
(e) 1 Ω resistance (f) left most battery.

C-7. $\frac{25}{9}$ V = 2.78 V, $\frac{5}{18}$ A = 0.278 A

C-8. 19 V **C-9.** (a) 10 Ω. (b) 3200 J

C-10. 5A, 74 V, 49 V (+ve terminal is connected at point B)

Section (D) :

D-1. $\frac{125}{4}$ = 31.25 watt.

D-2. P_A = 8 W & P_B = 32 W, A is more likely to fail his examinations

D-3. R_f = 2Ω.

D-4. (a) R = 10 Ω (b) 1A in each
(c) V_3 = 3V, V_2 = 2V, V_4 = 4V
(d) 10 W (e) 1 W (f) 9W
(g) 9V (h) 4 Ω resistance (i) 3 W.

D-5. (a) R = 3 Ω
(b) i = 2A, i_1 = $\frac{1}{2}$ A, i_2 = 1A, i_3 = $\frac{1}{2}$ A
(c) V = 4V in each
(d) 12 W (e) 4W (f) 8 W
(g) 4Ω (h) 4W

D-6. (a) 3.7 V (b) 3.7 V

D-7. (i) R_{AB} = 5/6 Ω (ii) R_{CD} = 1.5 Ω
(iii) R_{EF} = 1.5 Ω (iv) R_{AF} = 5/6 Ω
(v) R_{AC} = 4/3 Ω

D-8. (ii) 1.5 A

D-9. (i) $\frac{150}{7}$ = 21.43 V, (ii) 1600 Ω

D-10. CE: ED = $\sqrt{2}$: 1

D-11. 12.5 Ω, 170 Ω.

D-12. (a) 1 A (b) 2/3 A (c) 1/3 A

D-13. (a) 0.1 A (b) 0.3 A

Section (E) :

E-1. (i) $\frac{12}{8.59}$ = 1.4 A, (ii) $\frac{12\times8.5}{8.59}$ = 11.9 V

E-2. (i) $\frac{1}{2}$ = 0.5 A (ii) $\frac{1}{12}$ = 0.0833 A

(iii) $1.5+\frac{1}{2}\times0.4$ = 1.7 V

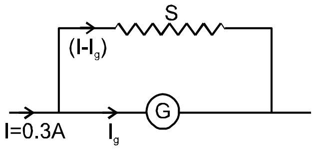
E-3. $V_B - V_A$ =21/5 = 4.2 V, I = 35/2 mA = 17.5 mA (B to A)

E-4. zero in the upper 4 Ω resistor and 0.2 A in the rest two.

E-5. (a) $\frac{1.2}{2.1}$ = 0.57, (b) 1, (c) $\frac{10.5}{6}$ = 1.75

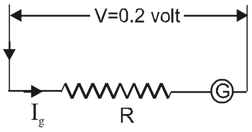
Section (F) :

F-1.



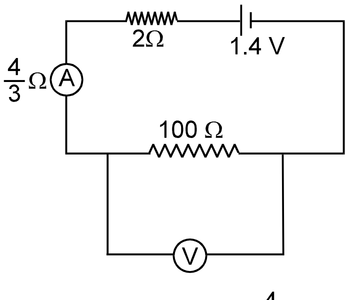
(a) S = $\frac{30\times2\times10^{-3}}{0.3-2\times10^{-3}}$ = 0.2013 Ω

(b) R = 70 Ω



F-2. (a) 24 V, (b) 28 V **F-3.** $\frac{20}{3}$ V

F-4. (i)



(ii) 200 Ω (iii) $1.1-\frac{4}{3}$ = –0.23 V

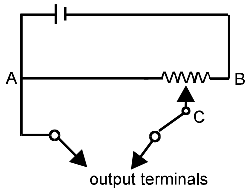
F-5. 5L/9

F-6. $\left(\frac{70}{60}-1\right)\times9.5$ = $\frac{9.5}{6}$ ohm

F-7. (a) 1.25 V,
(b) saving of galvanometer from damage and to prevent the cell discharging fast
(c) No, (d) Yes, (e) No, (f) No

F-8. x = $\frac{20}{7}$ Ω, Y = $\frac{20}{3}$ Ω

F-9.



PART - II

Section (A) :

A-1. (C) **A-2.** (D) **A-3.** (A)
A-4. (A)

Section (B) :

B-1. (D) **B-2.** (B)

Section (C) :

C-1. (B) **C-2.** (D) **C-3.** (B)
C-4. (A) **C-5.** (B) **C-6.** (i) (B), (ii) (D)
C-7. (B) **C-8.** (A) **C-9.** (B)

Section (D) :

D-1. (a) (B), (b) (C) **D-2.** (B)
D-3. (A) **D-4.** (C) **D-5.** (A)
D-6. (A) **D-7.** (A) **D-8.** (C)
D-9. (B) **D-10.** (A) **D-11.** (C)
D-12. (B) **D-13.** (B) **D-14.** (D)
D-15. (C) **D-16.** (B) **D-17.** (C)

Section (E) :

E-1. (C) **E-2.** (A) **E-3.** (D)
E-4. (A)

Section (F) :

F-1. (C) **F-2.** (A) **F-3.** (A)
F-4. (A) **F-5.** (C) **F-6.** (D)
F-7. (D) **F-8.** (A) **F-9.** (B)
F-10. (A) **F-11.** (B)

PART - III

1. (A) → q ; (B) → p ; (C) → p ; (D) → q

2. (A) → p ; (B) → q,s ; (C) → s ; (D) → p, r, s

EXERCISE-2

PART - I

1.	(C)	**2.**	(A)	**3.**	(B)
4.	(B)	**5.**	(D)	**6.**	(A)
7.	(D)	**8.**	(A)	**9.**	(B)
10.	(A)	**11.**	(A)	**12.**	(D)
13.	(A)	**14.**	(C)	**15.**	(B)
16.	(B)	**17.**	(C)	**18.**	(A)
19.	(D)	**20.**	(A)	**21.**	(D)
22.	(D)	**23.**	(B)	**24.**	(A)
25.	(C)				

PART - II

1.	8	**2.**	4	**3.**	3
4.	3	**5.**	6	**6.**	2
7.	5	**8.**	2	**9.**	(i) 2 (ii) 2
10.	15	**11.**	(i) 11 (ii) 19		
12.	2	**13.**	70	**14.**	45
15.	58	**16.**	6 & 30		

PART - III

1.	(ABCD)	**2.**	(AD)	**3.**	(CD)
4.	(AD)	**5.**	(AC)	**6.**	(ACD)
7.	(AD)	**8.**	(AD)	**9.**	(ABD)
10.	(AC)	**11.**	(ABC)	**12.**	(ABD)
13.	(ACD)	**14.**	(ABD)	**15.**	(ABC)
16.	(ACD)	**17.**	(BC)	**18.**	(ABCD)
19.	(BC)	**20.**	(BC)	**21.**	(ABD)
22.	(BCD)				

PART - IV

1.	(B)	**2.**	(B)	**3.**	(D)
4.	(A)	**5.**	(C)	**6.**	(B)
7.	(B)	**8.**	(C)	**9.**	(A)
10.	(B)	**11.**	(B)	**12.**	(D)

EXERCISE-3

PART - I

1.	(D)	**2.**	(A)	**3.**	(C)
4.	(D)	**5.**	(AD)	**6.**	(C)
7.	(D)	**8.**	(C)	**9.**	4
10.	5	**11.**	(ABCD)	**12.**	(BD)
13.	(ABD)	**14.**	5	**15.**	(C)
16.	(B)	**17.**	1	**18.**	(C)
19.	(BC)	**20.**	(B)	**21.**	(A)
22.	5.56 or 5.55				

PART - II

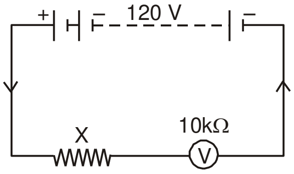
1.	(4)	**2.**	(4)	**3.**	(1)
4.	(3)	**5.**	(1)	**6.**	(3)
7.	(1)	**8.**	(2)	**9.**	(4)
10.	(2)	**11.**	(3)	**12.**	(3)
13.	(4)	**14.**	(4)	**15.**	(3)
16.	(4)	**17.**	(4)	**18.**	(1)
19.	(3)	**20.**	(2)	**21.**	(4)
22.	(4)	**23.**	(1)		

High Level Problems (HLP)

SUBJECTIVE QUESTIONS

1. A galvanometer having 30 divisions has current sensitivity of 20 μA/div. It has a resistance of 25 ohm. How will you convert it to an ammeter measuring upto 1 ampere ? How will you now convert this ammeter into a voltmeter reading upto 1 volt ? **[REE - 1987]**

2. A D.C. supply of 120 volt is connected to a large resistance X. A volt meter of resistance 10 kΩ, placed in series in the circuit reads 4 volts. What is the value of X? What do you think is the purpose in using a voltmeter, instead of an ammeter, to determine the large resistance X?



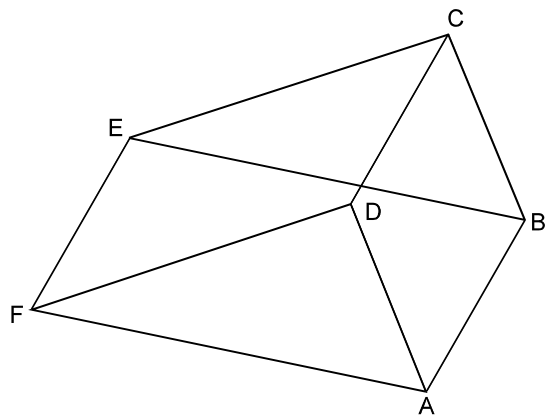
3. A person decides to use his bath tub water to generate electric power to run a 40 watt bulb. The bath tub is located at a height of 10 m from the ground and it holds 200 liters of water. If we install a water driven wheel generator on the ground, at what rate should the water drain from the bath tub to light bulb? How long can we keep the bulb on, if the bath tub was full initially. The efficiency of generator is 90 %. ($g = 10m/s^{-2}$) **[REE - 1990]**

4. A cell of emf 3.4 volt and internal resistance 3 Ω connected to an ammeter having resistance 2 Ω and to an external resistance of 100 Ω. When a voltmeter is connected across the 100 Ω resistance the ammeter reading is 0.04 ampere. Find the voltage read by the voltmeter and its resistance. Had the voltmeter been an ideal one, what would have been its reading. **[REE - 1990]**

5. When a cell is connected in a circuit, a current I_1 flows in the circuit. When one more identical cell is connected in series with the first one, a current I_2 is found to flow in the circuit. When same cell is connected in parallel with the first one, the current is found to be I_3. Show that $3I_2I_3 = 2I_1(I_2 + I_3)$.

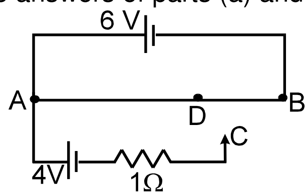
6. A battery is made by joining m rows of identical cells in parallel. Each row consists of n cells joined in series. This battery sends a maximum current I in a given external resistor. Now the cells are so arranged that instead of m rows, n rows are joined in parallel and each row consists of m cells joined in series. Find the current through the same external resistor (Total number of cells which is equal to nm is connected)

7. In the circuit shown in figure, all wires have equal resistance r. Calculate equivalent resistance between A and B?

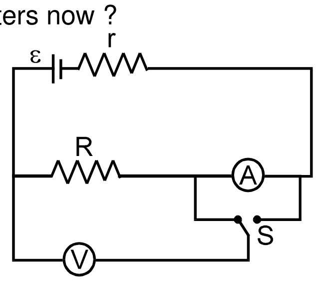


8. A galvanometer having a coil resistance of 100 ohms gives a full scale deflection when a current of one milli-ampere is passed through it. What is the value of resistance which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10 amperes? A resistance of the required value is available but it will get burnt if the energy dissipated in it is greater than one watt. Can it be used for the above described conversion of the galvanometer? When this modified galvanometer is connected across the terminals of battery, it shows a current 4 amp. The current drops to 1 amp., when the resistance of 1.5 ohm is connected in series with modified galvanometer. Find the emf and internal resistance of battery. **[JEE - 1972]**

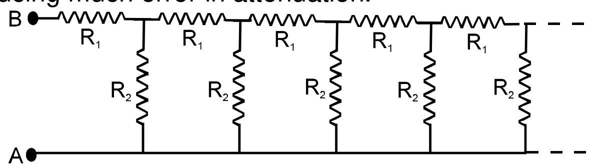
9. A 6 volt battery of negligible internal resistance is connected across a uniform wire AB of length 100 cm. The positive terminal of another battery of emf 4V and internal resistance 1Ω is joined to the point A as shown in figure. Take the potential at B to be zero. (a) What are the potentials at the points A and C ? (b) At which point D of the wire AB, the potential is equal to the potential at C. (c) If the point C and D are connected by a wire, what will be the current through it ? (d) If the 4V battery is replaced by 7.5 V battery, what would be the answers of parts (a) and (b) ?



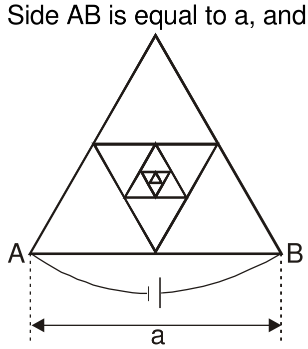
10. The emf ε and the internal resistance r of the battery shown in figure are 4.3 V and 1.0 Ω respectively. The external resistance R is 50 Ω. The resistances of the ammeter and voltmeter are 2.0 Ω and 200 Ω respectively. (a) Find the readings of the two meters. (b) The switch is thrown to the other side. What will be the readings of the two meters now ?



11. Consider an infinite ladder network shown in fig. A voltage is applied between points A and B. If the voltage is halved after each section, find the ratio R_1/R_2. Suggest a method to terminate it after a few sections without introducing much error in attenuation. **[REE - 1998]**



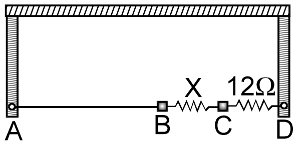
12. Determine the resistance R_{AB} between points A and B of the frame made of thin homogeneous wire (as shown in figure), assuming that the number of successively embedded equilateral triangles (with sides decreasing by half) tends to infinity. Side AB is equal to a, and the resistance of unit length of the wire is ρ.



13. A nichrome wire of uniform cross-sectional area is bent to form a rectangular loop ABCD. Another nichrome wire of the same cross-section is connected to form the diagonal AC. Find out the ratio of the resistances across BD and AC if AB = 0.4 m and BC = 0.3 m. **[REE - 2000]**

14. An electric heater has heating coils A and B, when coil A is switched on, the water boils in 10 minute, and when coil B is switched on the water boils in 20 minute. Calculate the time taken by water, to boil if the coils connected in **[REE - 2000]**
(a) Series and (b) Parallel all switched on.

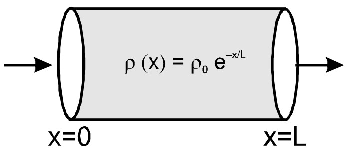
15. A thin uniform wire AB of length 1 m, an unknown resistance X and a resistance of 12 Ω are connected by thick conducting strips, as shown in the figure. A battery and a galvanometer (with a sliding jockey connected to it) are also available. Connections are to be made to measure the unknown resistance X using the principle of Wheatstone bridge. Answer the following question. **[IIT-JEE (Main) 2002; (1+2+2)/60]**



(a) Are there positive and negative terminals on the galvanometer?
(b) Copy the figure in your answer book and show the battery and the galvanometer (with jockey) connected at appropriate points.
(c) After appropriate connections are made, it is found that no deflection takes place in the galvanometer when the sliding jockey touches the wire at a distance of 60 cm from A. Obtain the value of the resistance X.

16. In a potentiometer circuit, two wires of same material of resistivity ρ, one of radius of cross-section ' a ' and other of radius of cross-section ' 2 a ' are joined in series. They are of length ℓ and 2 ℓ respectively. This combination acts as the potentiometer wire of length 3 ℓ. The emf of the cell in the primary circuit is ε and internal resistance is $\frac{\rho\ell}{2\pi a^2}$. This cell is connected to the potentiometer wire by a conducting wire of negligible resistance with positive terminal of the cell connected to one end (call it A) of longer wire. The negative terminal of the cell is connected to one end of the smaller wire. The remaining ends of the two wires are joined together. Find:
(i) The maximum voltage which can be balanced on the potentiometer wire.
(ii) The length, measured from point A, where cell of emf $\frac{\varepsilon}{2}$ will balance.
(iii) If positive terminal of cell of emf $\frac{\varepsilon}{2}$ and internal resistance $\frac{\rho\ell}{2\pi a^2}$ is connected to point A and other terminal is joined to the junction of the two wires, then find the current through this cell.

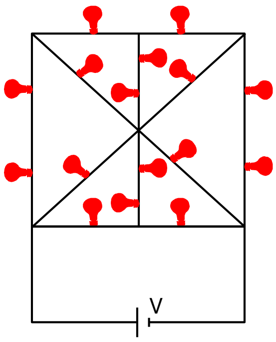
17. A rod of length L and cross-section area A lies along the x-axis between x = 0 and x = L. The material obeys Ohm's law and its resistivity varies along the rod according to, $\rho(x) = \rho_0 e^{-x/L}$. The end of the rod at x = 0 is at a potential V_0 and it is zero at x = L



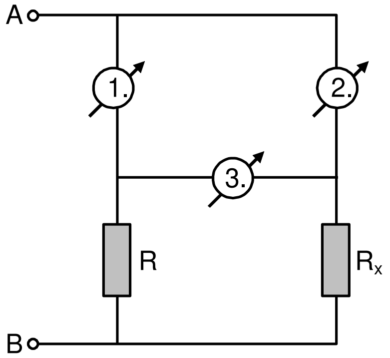
(a) Find the total resistance of the rod and the current in the wire.
(b) Find the electric potential V(x) in the rod as a function of x.

18. A galvanometer having 50 divisions provided with a variable shunt S is used to measure the current when connected in series with a resistance of 90 Ω and a battery of internal resistance 10 Ω. It is observed that when the shunt resistances are 10 Ω & 50 Ω respectively, the deflection are respectively 9 and 30 divisions. What is the resistance of the galvanometer? Further, if the full scale deflection of the galvanometer movement require 200 mA, find the emf of the cell.

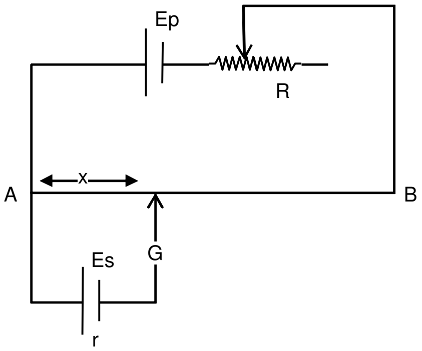
19. Standard rating of each bulb is P, V. If total power consumption by combination is $\frac{3XP}{5}$ then calculate 'X'.



20. In the circuit shown the three ammeters (marked as 1, 2, 3) are identical, each have a resistance $R_0 = 2\Omega$. Between points A and B there is a constant potential difference of 19V. The first and second ammeter read $I_1 = 2.5$A and $I_2 = 1.5$A respectively.
(a) What is the reading of third ammeter?
(b) Calculate value of resistance R.
(c) Investigate what happens to current I_3 if the value of R_x is changed.Show approximately graphical variation of I_3 vs R_x.
Note : Reading of ammeter implies current through branch of ammeter.

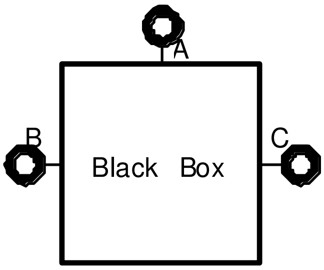


21. Consider a potentiometer circuit, Primary cell is ideal. The length of potentiometer wire is 1m and the resistance per unit length of potentiometer wire varies with length as $\lambda = 2x\Omega$/m. Where x is distance from end A. Resistance of Rheostat varies with time as $R = t^2\Omega$. Null deflection point for secondary cell is obatained at $x = \frac{1}{2}$ m and at t = 1 sec. If emf of secondary cell is $\frac{1}{\gamma}$ times of emf of primary cell, find γ.



22. This question is about a closed electrical black box with three terminals A, B, and C as shown. It is known that the electrical elements connecting the points A, B, C inside the box are resistances (if any) in delta formation. A student is provided a variable power supply, an ammeter and a voltmeter. Schematic symbols for these elements are given in part (a). She is allowed to connect these elements externally between only two of the terminals (AB or BC or CA) at a time to form a suitable circuit.

[Olympied 2016]



(a) Draw a suitable circuit using the above elements to measure voltage across the terminals A and B and the current drawn from power supply as per Ohm's law.

(b) She obtains the following readings in volt and milliampere for the three possible connections to the black box.

AB		BC		AC	
V (V)	*I* (mA)	*V* (V)	*I* (mA)	*V* (V)	*I* (mA)
0.53	0.54	0.83	0.17	0.85	0.15
0.77	0.77	1.65	0.35	1.70	0.30
1.02	1.01	2.47	0.53	2.55	0.45
1.49	1.51	3.29	0.71	3.4	0.60
1.98	2.02	4.11	0.89	4.25	0.75
2.49	2.51	4.94	1.06	5.10	0.90

In each case plot V (on Y-axis) -I (on X-axis) on the graph papers provided. Preferably use a pencil to plot. Calculate the values of resistances from the plots. Show your calculations below for each plot clearly indicating graph number.

(c) From your calculations above draw the arrangement of resistances inside the box indicating their values.

HLP Answers

1. $S = \dfrac{15\times10^{-3}}{1-0.6\times10^{-3}} \approx 0.015\ \Omega$ in parallel ; R = 0.985 Ω in series.

2. 290 kΩ, Due to very small value of current, Ammeter has not been used. The ammeter reading would have been very small. Note that this is unusual use of a voltmeter. It is meant only for the measurement of high resistance.

3. 4/9 kg/sec; 450 sec

4. 400Ω, $\dfrac{16}{5} = 3.2$ V, $\dfrac{68}{21} = 3.238$ V

6. $\dfrac{2mnI}{m^2+n^2}$

7. $\dfrac{3r}{5}$

8. $S = \dfrac{0.1}{10-10^{-3}} \cong 0.01\Omega$, yes, E = 2V, r = 0.5 – 0.01 = 0.49 Ω.

9. (a) 6 V, 2 V (b) AD = $\dfrac{200}{3} = 66.7$ cm (c) zero (d) 6 V, – 1.5 V, no such point D exists.

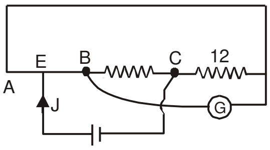
10. (a) 0.1 A, 4.0 V(b) $\dfrac{1083.6\times200}{10652\times252} = 0.08$ A, $4.3 - \dfrac{1083.6}{10652} = 4.2$ V

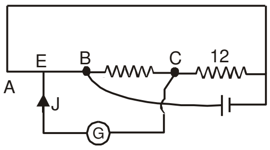
11. $\dfrac{1}{2}$

12. $R_{AB} = \dfrac{a\rho(\sqrt{7}-1)}{3}$

13. $\dfrac{R_{BD}}{R_{AC}} = \dfrac{59}{35}$

14. (a) t_s = 30 min. (b) $t_p = \dfrac{20}{3}$ min.

15. (a) No (b) 

or 

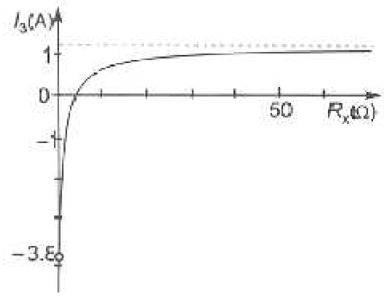
(c) 8 Ω

16. (i) $v_0 = \dfrac{3\varepsilon}{4}$ (ii) $\dfrac{5\,\ell}{2}$ (iii) $\dfrac{\varepsilon}{7R}$, where $R = \dfrac{\rho\ell}{A}$ and $A = 2\pi a^2$

17. (a) $R = \rho_o \dfrac{L}{A}\left(\dfrac{e-1}{e}\right)$, $i = \dfrac{V_0}{R}$, (b) $V(x) = \dfrac{V_o(e^{-x/L} - e^{-1})}{1-e^{-1}}$ **18.** $R_g = \dfrac{700}{3}\,\Omega$, E = 96 volt.

19. 2

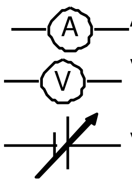
20. (a) 1A, (b) 4Ω $I_3 = \dfrac{V(R_x - R)}{(2R_0 + 3R)R_x + R_0(R_0 + 2R)}$



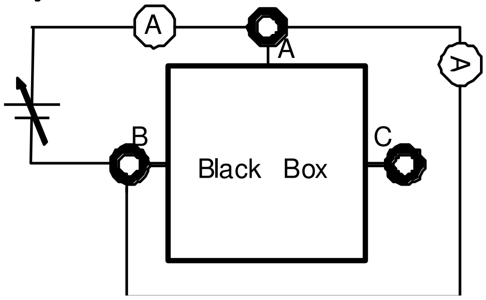
The graph of the function is a hyperbola. Its special points are: at $R_x = 0$ I_3= –3.8 A ; at R_x ; = 4I_3 = 0; at $R_x = 32\Omega$ I_3 = 1A ; If $R_x \to \infty$, I_3 tends to 19/16 = 1.1875A.

21. 8

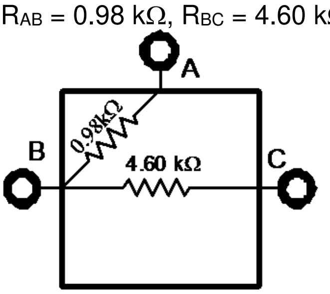
22. (a)

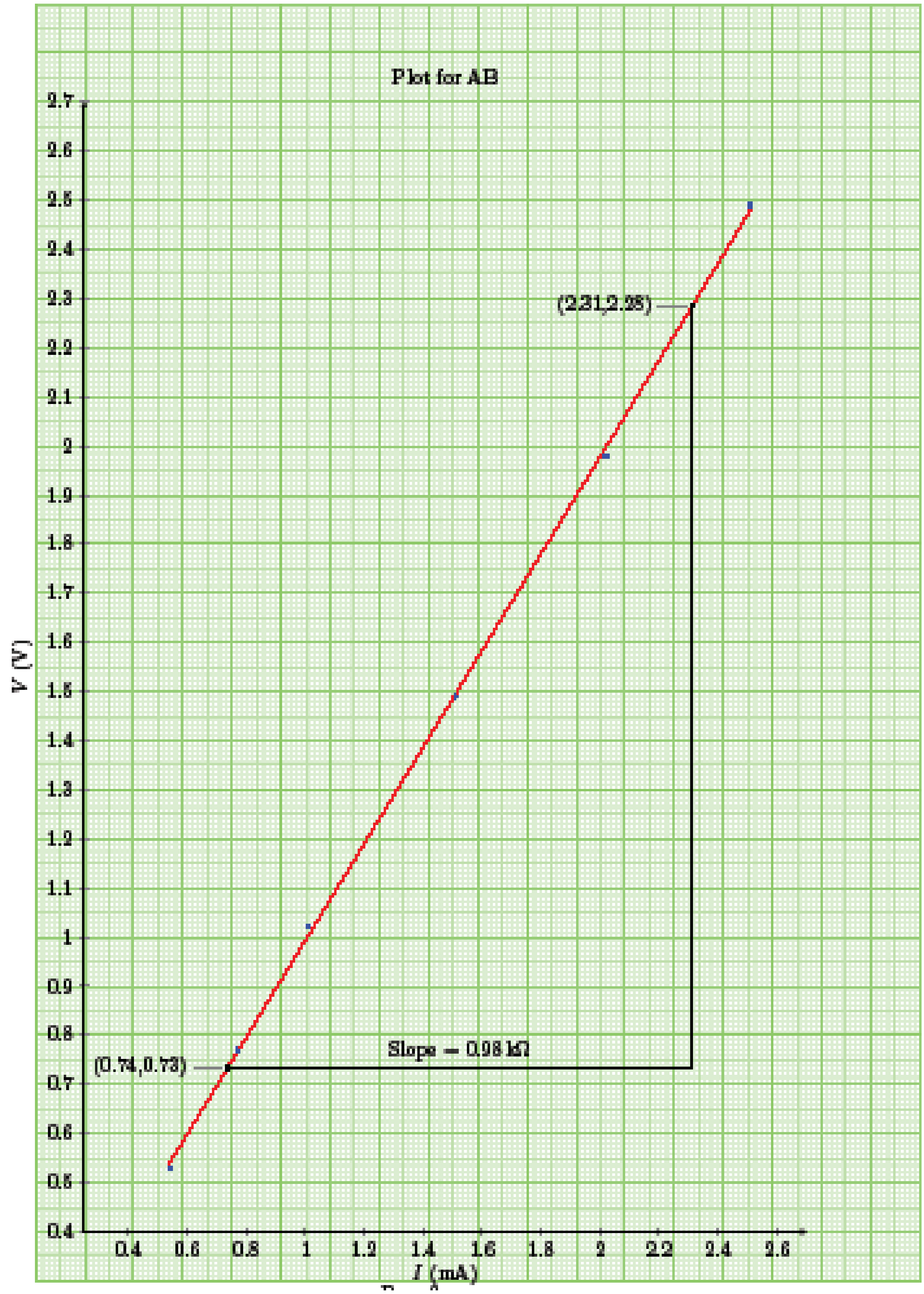


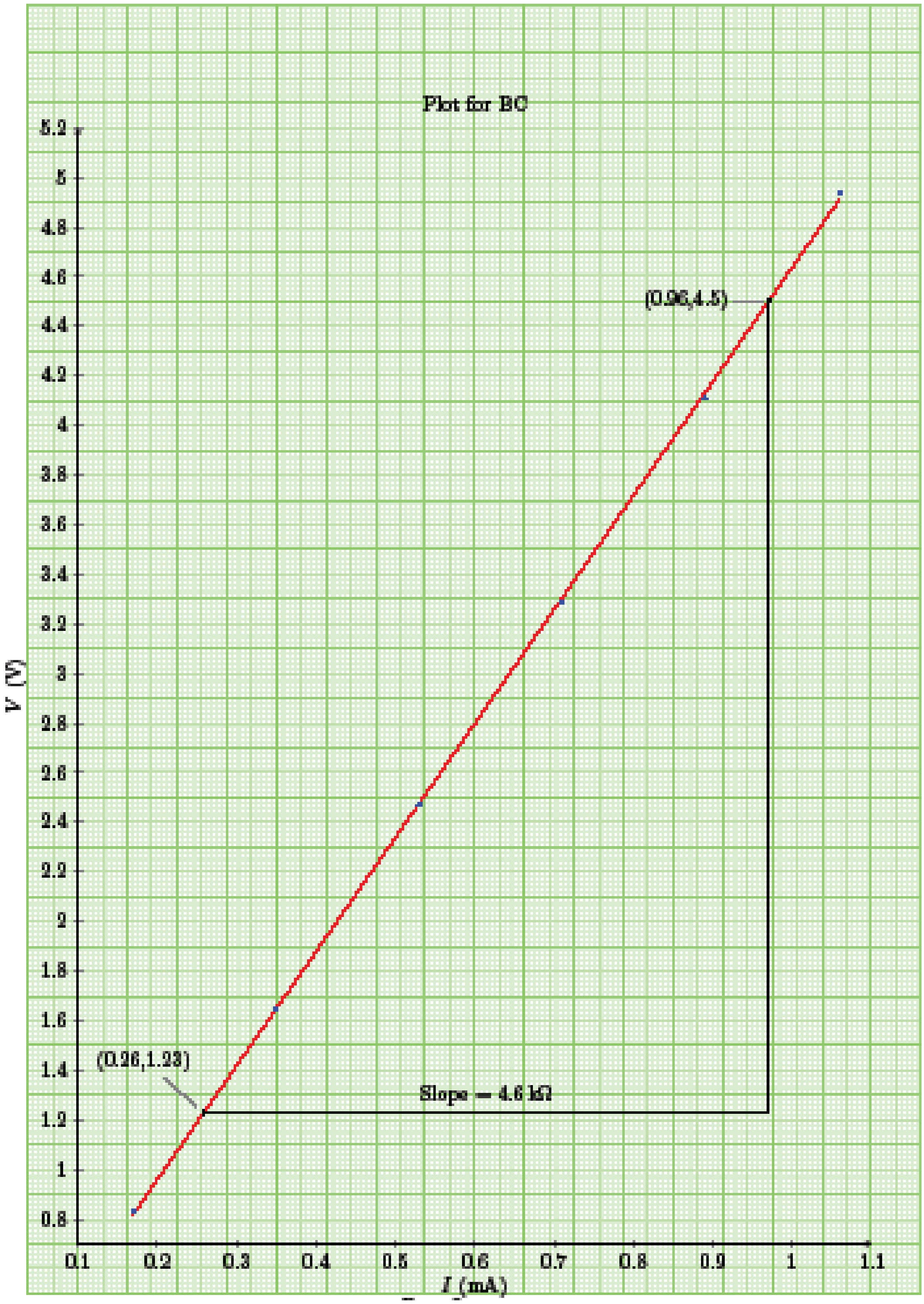
Ammeter
Voltmeter
Variable Power supply

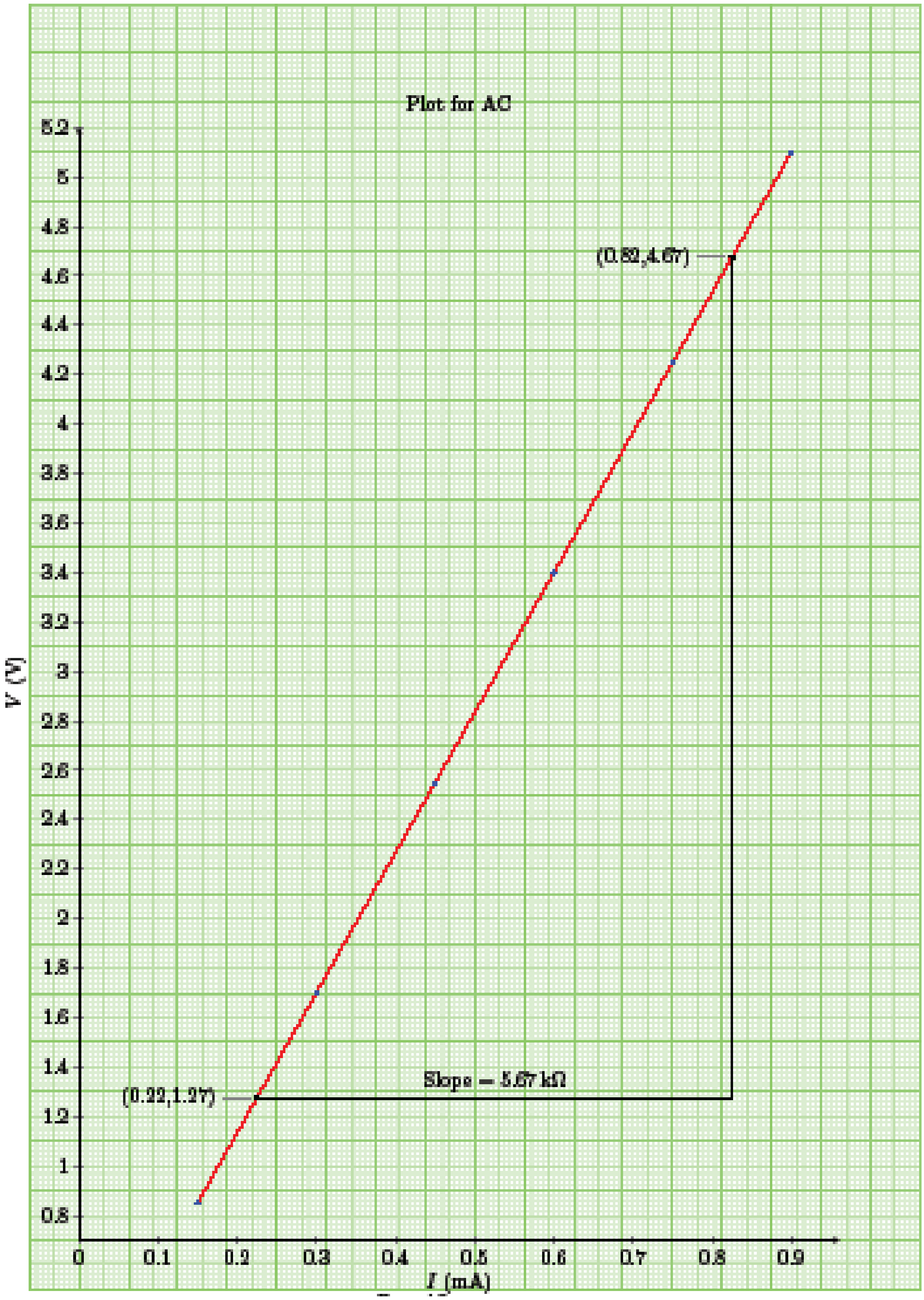


(b) See graphs for the calculations of slopes.
R_{AB} = 0.98 kΩ, R_{BC} = 4.60 kΩ, R_{CA} = 5.67 kΩ

(c) 


Plot for AB
V (V)
I (mA)
(2.31,2.28)
(0.74,0.73)
Slope = 0.98 kΩ
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6


Plot for BC
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
V (V)
(0.96,4.5)
(0.26,1.23)
Slope = 4.6 kΩ
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
I (mA)



Plot for AC
V (V)
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
(0.82,4.67)
(0.22,1.27)
Slope = 5.67 kΩ
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
I (mA)