CURRENT ELECTRICITY

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JEE (Advanced) Syllabus

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

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.

CURRENT ELECTRICITY

ELECTRIC CURRENT

If a charge ΔQ crosses an area in time Δt then the average electric current through the area, during this time as

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

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

- Current is a fundamental quantity with dimension $[M^0L^0T^0A^1]$
- Current is a scalar quantity with its SI unit **ampere.**
- The conventional direction of current is the direction of flow of positive charge or applied field. It is opposite to direction of flow of negatively charged electrons.

- The conductor remains uncharged when current flows through it because the charge entering at one end per second is equal to charge leaving the other end per second.
- For a given conductor current does not change with change in its cross–section because current is simply rate of flow of charge.
- If there are n particles per unit volume each having a charge q and moving with velocity v then current through cross–sectional area A is $I = \frac{\Delta q}{\Delta t} = nqvA$
- If a charge q is moving in a circle of radius r with speed v then its time period is $T = 2\pi r/v$. The equivalent current $I = \frac{q}{T} = \frac{qv}{2\pi r}$.

Movement of electrons inside conductor in the absence of applied potential difference:

In absence of applied potential difference the free electrons present in a conductor gain energy from temperature of surrounding and move randomly in the conductor. The average displacement and average velocity is zero. There is no flow of current due to thermal motion of free electrons in a conductor.

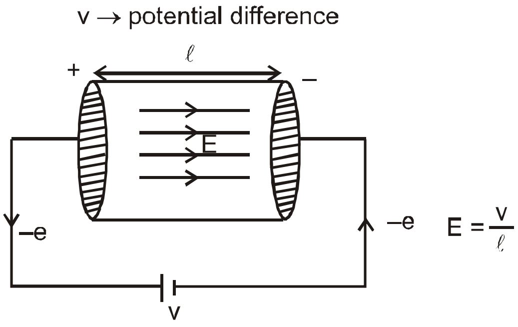
The speed gained by virtue of temperature is called as thermal speed of an electron $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}kt$

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

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

Movement of electrons inside conductor in the presence of applied potential difference

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

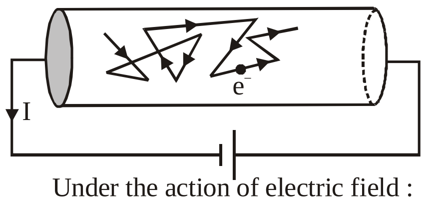


E = $\frac{V}{L}$ where V = emf of the battery, L = length of the conductor.

The field exerts an electric force on free electrons 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. Acceleration of electron $\vec{a} = \frac{\vec{F}}{m} = \frac{-e\vec{E}}{m}$

DRIFT VELOCITY

Drift velocity is defined as the velocity with which the free electrons get drifted towards the positive terminal under the effect of the applied external electric field.



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

At any given time, an electron has a velocity $\vec{v}_1 = \vec{u}_1 + \vec{a}\tau_1$, where $\vec{u}_1$ = the thermal velocity and

$\vec{a}\tau_1$ = the velocity acquired by the electron under the influence of the applied electric field.

τ_1 = the time that has elapsed since the last collision. Similarly, the velocities of the other electrons are

$\vec{v}_2 = \vec{u}_2 + \vec{a}\tau_2, \vec{v}_3 = \vec{u}_3 + \vec{a}\tau_3, ... \vec{v}_N = \vec{u}_N + \vec{a}\tau_N$.

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

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

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

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

Relation between current and drift velocity :

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

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

Time taken by drifting electrons to cross conductor $\Delta t = \dfrac{L}{v_d}$

$\therefore$ current $I = \dfrac{\Delta q}{\Delta t} = neAL\left(\dfrac{v_d}{L}\right) = neAv_d$

- **Mean free path λ :** (λ~10Å) = $\lambda = \dfrac{\text{total distance travelled}}{\text{number of collisions}}$

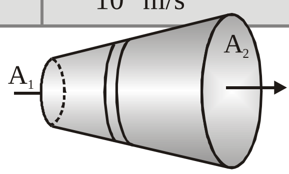
  - **Relaxation time :** The time taken by an electron between two successive collisions is called as relaxation time τ. (τ~10^{-14}s),

    Relaxation time : $\tau = \dfrac{\text{total time taken}}{\text{number of collisions}}$

-

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

- If a steady current flows in a metallic conductor of non uniform cross section. Current density and drift velocity depends on area



$I_1 = I_2$, $A_1 < A_2 \Rightarrow J_1 > J_2$, $E_1 > E_2$, $v_{d_1} > v_{d_2}$

SOLVED EXAMPLE

Example 1. 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.

Solution: Mass of copper per unit volume = 9 × 10^3 kg

Atoms of Cu per unit volume = $\dfrac{9 \times 6.023 \times 10^{29}}{63.5}$ = n.

i = neA V_d.

$V_d = \dfrac{1.5 \times 63.5}{1.6 \times 10^{-19} \times 10^{-7} \times 9 \times 6.023 \times 10^{29}}$ = 1.1 0 × 10^{-3} ms^{-1}.

CURRENT DENSITY (J)

Current density at any point inside a conductor is defined as a vector having magnitude equal to current per unit area surrounding that point. Remember area is normal to the direction of charge flow (or current passes) through that point.

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

• If the cross–sectional area is not normal to the current, but makes an angle θ with the direction of current then

$J = \dfrac{dI}{dA\cos\theta} \Rightarrow dI = JdA\cos\theta = \vec{J}.d\vec{A} \Rightarrow I = \int \vec{J}.\vec{dA}$

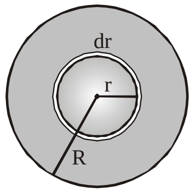
• Current density $\vec{J}$ is a vector quantity. It's direction is same as that of $\vec{E}$. It's S.I. unit is ampere/m^2 and dimension [L^{-2}A].

SOLVED EXAMPLE

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

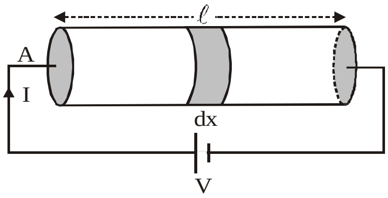
Solution: Consider a circular strip of radius r and thickness dr

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



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

Relation between Current Density, Conductivity and Electric field



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

Total number of electrons in dx distance = n (Adx)

Total charge dQ = n (Adx)e

Current $I = \frac{dQ}{dt} = nAe\frac{dx}{dt}$ = neAv$_d$, Current density $J = \frac{I}{A}$ = nev$_d$

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

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

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

SOLVED EXAMPLE

Example 3. 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.

Solution: (a) $\frac{20\times10^{-3}}{e}$ → no of electrons passing per second

$= \frac{20\times10^{-3}}{1.6\times10^{-19}} = \frac{2\times10^{17}}{1.6}$ = 1.25 × 10^{17}.

(b) j = $\frac{20\times10^{-3}}{\pi(0.2\times10^{-3})^2} = \frac{1}{2\pi}\times10^6$ A/m^2.

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

Vector form of *Ohm's law* $\vec{J} = \sigma\vec{E}$ *(at microscopic level)*

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

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

Here $i \propto V$

it is known as Ohm's law

$i = \frac{V}{R}$

$R = \dfrac{2m\ell}{nAe^2\tau}$

$V = IR$

hence $R = \dfrac{2m}{ne^2\tau} \cdot \dfrac{\ell}{A}$

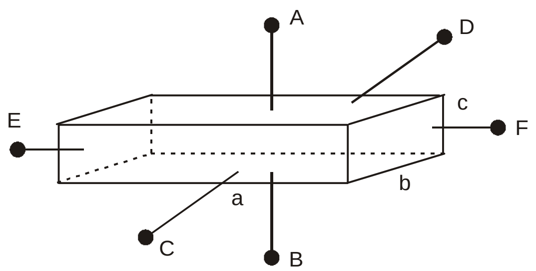
so Here $R = \dfrac{\rho\ell}{A}$

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

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

SOLVED EXAMPLE

Example 4. The dimensions of a conductor of specific resistance ρ are shown below. Find the resistance of the conductor across AB, CD and EF.



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

Solution : For a condition

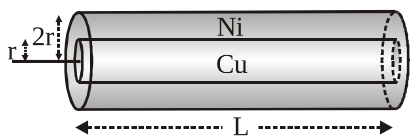
$$R = \frac{\rho\ell}{A} = \frac{\text{Resistivity} \times \text{length}}{\text{Area of cross section}}$$

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

Example 5. A copper wire of length 'ℓ' and radius 'r' is nickel plated till its final radius is 2r. If the resistivity of the copper and nickel are ρ_{Cu} and ρ_{Ni}, then find the equivalent resistance of wire?

Solution: $R = \rho\dfrac{\ell}{A}$; Resistance of copper wire $R_{Cu} = \rho_{Cu}\dfrac{\ell}{\pi r^2}$

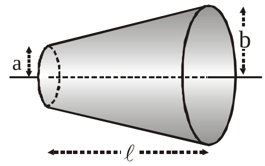
($\because A = \pi r^2$)



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

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

Example 6. Figure shows a conductor of length ℓ carrying current I and having a circular cross – section. The radius of cross section varies linearly from a to b. Assuming that (b – a) << ℓ. Calculate current density at distance x from left end.



Solution: Since radius at left end is a and that of right end is b,

Therefore increase in radius over length ℓ is (b – a).

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

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

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

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

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 $\frac{R_1}{R_2} = \frac{r_2^4}{r_1^4}$, 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 EXAMPLE

Example 7. 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′ = $\frac{\rho\ell'}{A'}$

$\ell' = 2\ell$

$A'\ell' = A\ell$ (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 8. The wire is stretched to increase the length by 1% find the percentage change in the Resistance.

Solution : As we known that

$\therefore$ R = $\frac{\rho\ell}{A}$

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

α = temperature coefficient of resistivity.

= fractional change in resistivity per unit change in temperature

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

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

$$\therefore \quad \int_{\rho_0}^{\rho} \frac{d\rho}{\rho} = \alpha \int_{T_0}^{T} dT$$

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

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

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

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

Hence over a small temperature range (upto 100ºC), the resistivity of a metal can be represented approximately by the equation,

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

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.

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

In this equation R(T) is the resistance at temperature T and R_0 is the resistance at temperature T_0.

SOLVED EXAMPLE

Example 9. 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

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

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

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

Example 10. 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 $\alpha = \frac{dR}{RdT}$

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

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

$$\Rightarrow R_2 = 10\ e\ \Omega$$

Example 11. (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 $(\alpha) = \frac{1}{234}\ ^{\circ}C^{-1}$.

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

Answer : **(i)** 41ºC **(ii)** $\frac{\ell n2}{273}\ ^{\circ}C^{-1}$.

Solution: **(i)** $R_{15} = \frac{200}{10} = 20\ \Omega.\ , R_t = \frac{200}{9}\ \Omega$

$$R_t = R_{15}(1 + \alpha\,\Delta t) \Rightarrow \frac{200}{9} = 20\left(1 + \frac{\Delta t}{234}\right)$$

$$\frac{\Delta t}{234} = \frac{1}{9} \Rightarrow \Delta t = \frac{234}{9} = 26 \Rightarrow t = 26 + 15 = 41^{\circ}\ C.$$

(ii) $\alpha = \frac{1}{R}\frac{dR}{dt} \Rightarrow \alpha\int_0^{273} dt = \int_{10}^{20}\frac{dR}{R}$

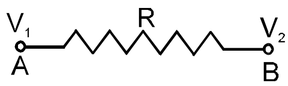
$$\alpha.273 = \ell n\left(\frac{20}{10}\right) \qquad \alpha = \frac{\ell n2}{273}\ ^{\circ}C^{-1}.$$

Electric current in resistance:

In a resistor current flows from high potential to low potential

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

SOLVED EXAMPLE

Example 12. 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.**

COLOUR CODE FOR CARBON RESISTORS

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

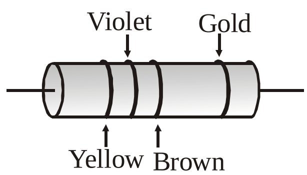
Aid to memory BBROY
Great Britain
Very Good watch of gold & silver

SOLVED EXAMPLE

Example 13. Draw a colour code for 42 k Ω ± 10% carbon resistance.

Solution: According to colour code colour for digit 4 is yellow, for digit 2 it is red, for 3 colour is orange and 1 0% tolerance is represented by silver colour. So colour code should be yellow, red, orange and silver.

Example 14. What is resistance of following resistor.



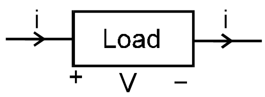
Solution: Number for yellow is 4, Number of violet is 7
Brown colour gives multiplier 10^1, Gold gives a tolerance of ± 5%
So resistance of resistor is $47 \times 10^1\ \Omega \pm 5\% = 470 \pm 5\%\ \Omega$.

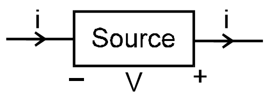
ELECTRICAL POWER

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).

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





$= V\,I$

P = V I

If power is constant then energy = P t

If power is variable then

$$\text{Energy} = \int p\,dt$$

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.

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

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

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

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

SOLVED EXAMPLE

Example 15. 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?

Ans . $\frac{125}{9}$ V

Solution: $V = \frac{W}{Q}$

Q = I × t

= 3 × 12 = 36 C

$V = \frac{500}{36} = \frac{125}{9}$ V **Ans .**

Example 16. 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]

Ans. (a) $\frac{50}{11}$ = 4.55 A (b) $\frac{22 \times 11}{5}$ = 48.4 Ω (c) 1000 W (d) 240 cal s^{-1} (e) 80/3 gm

Solution: (a) $i = \frac{P}{V} = \frac{1000}{220} = \frac{50}{11}$ = 4.55 A

(b) $R = \frac{V^2}{P} = \frac{(220)^2}{1000} = \frac{22 \times 11}{5}$ = 48.4 Ω

(c) P = 1 kW

(d) $H = \frac{Q}{J} = \frac{1000}{4.2}$ = 240 cal/sec

(e) $tH = mL \Rightarrow m = \frac{Ht}{L} = \frac{240 \times 60}{540} = \frac{80}{3}$ gm.

HEATING EFFECT OF CURRENT

CAUSE OF HEATING

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

- **Joules's Law of Heating**

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

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

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

• **SI unit** : joule ; **Practical Units** : 1 kilowatt hour (kWh)

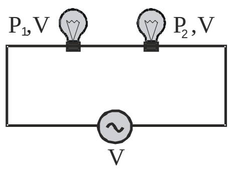
1kWh = 3.6×10^6 joule = 1 unit 1 BTU (British Thermal Unit) = 1055 J

• **Power :** $P = V I = \frac{V^2}{R} = I^2R$ • **SI unit :** Watt

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

- **Series combination of resistors (bulbs)**

Total power consumed $P_{total} = \frac{P_1P_2}{P_1 + P_2}$.



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

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

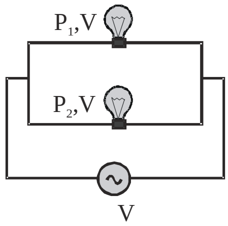
Bulb of lesser wattage will shine more. For same current $P = I^2R$ $P \propto R$ $R\uparrow \Rightarrow P\uparrow$

- **Parallel combination of resistors (bulbs)**

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

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

In parallel combination of bulbs



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

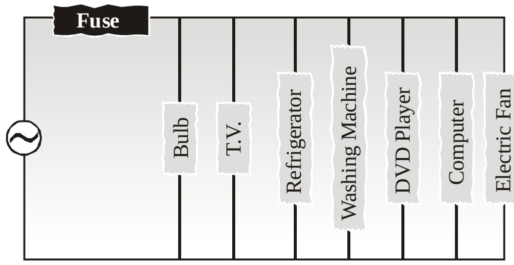
Bulb of greater wattage will shine more.

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

- Two identical heater coils gives total heat H_S when connected in series and H_p when connected in parallel than $\frac{H_P}{H_S} = 4$ [In this, it is assumed that supply voltage is same]
- If a heater boils m kg water in time T_1 and another heater boils the same water in T_2, then both connected in series will boil the same water in time $T_s = T_1 + T_2$ and in parallel $T_P = \frac{T_1T_2}{T_1 + T_2}$ [Use time taken $\propto$ Resistance]
- Instruments based on heating effect of current, works on both A.C. and D.C. Equal value of A.C. (RMS) and D.C. produces, equal heating effect. That why brightness of bulb is same whether it is operated by A.C. or same value D.C.

FUSE WIRE

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



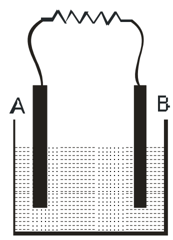
- The fuse wire should have high resistance per unit length and low melting point.
- However the melting point of the material of fuse wire should be above the temperature that will be reached on the passage of the current through the circuit
- A fuse wire is made of alloys of lead (Pb) and tin (Sn).
- Length of fuse wire is immaterial.
- The material of the filament of a heater should have high resistivity and high melting point.
- The temperature of the wire increases to such a value at which, the heat produced per second equals heat lost per second due to radiation from the surface of wire $I^2\left(\frac{\rho\ell}{\pi r^2}\right) = H \times 2\pi r\ell$ $I^2 \propto r^3$

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

BATTERY (CELL)

Cell converts chemical energy into electrical energy.

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 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 ($r \propto c$)
- Temperature of electrolyte ($r \propto \frac{1}{\text{Temp.}}$).

SOLVED EXAMPLE

Example 17. What is the meaning of 20 Amp. hr ?

Solution : It means if the 20 A current is withdrawn then the battery will work for 1 hour.

20 Amp $\longrightarrow$ 1 hr

1 Amp $\longrightarrow$ 20 hr

½ Amp $\longrightarrow$ 40 hr

ELECTROMOTIVE FORCE (E.M.F.)

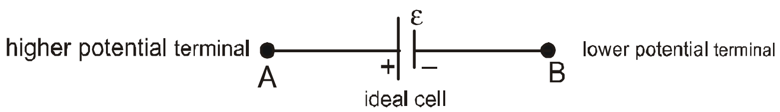
Definition I : Electromotive force is the capability of the system to make the charge flow.

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.

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

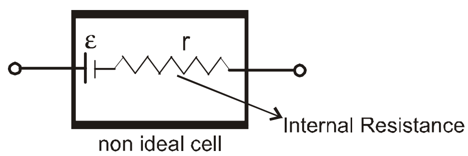
Ideal cell :

Cell in which there is no heating effect.



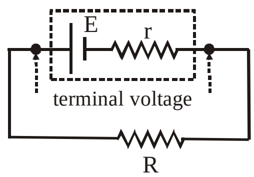
Non ideal cell :

Cell in which there is heating effect inside due to opposition to the current flow internally



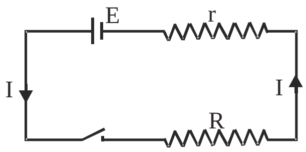
TERMINAL VOLTAGE (V)

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



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

(a) When cell is discharging :

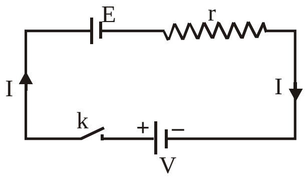


Current inside the cell is from cathode to anode.

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

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

(b) When cell is charging :



Current inside the cell is from anode to cathode.

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

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

(c) When cell is in open circuit :

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

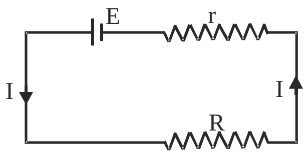
In open circuit terminal potential difference is equal to emf and is the maximum potential difference which a cell can provide.

(d) When cell is short circuited :

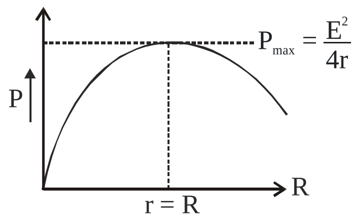
In short circuit $R = 0 \Rightarrow I = \frac{E}{R+r} = \frac{E}{r}$ and $V = IR = 0$

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

(e) Power transferred to load by cell and maximum power transferred :



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



Power transferred by cell to load is maximum when

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

The efficiency of the cell when it is used to supply maximum power :-

Power of battery spent

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

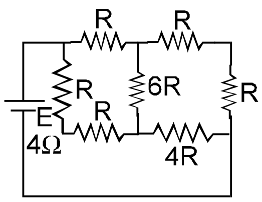
power (output)

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

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

SOLVED EXAMPLE

Example 18. 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 :



Solution: Condition for maximum power is

r = R

$$4 = \frac{6R \times 3R}{9R}$$

R = 2 **Ans.**

Example 19. (a) A car has a fresh storage battery of emf 12 V and internal resistance $5.0 \times 10^{-2}\ \Omega$. 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?

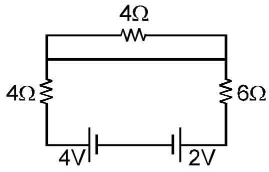
Answer: (a) 7.5 V, (b) 24 mA (c) greater than 12 V.

Solution: (a) $V = E - ir = 12 - 90 \times 5 \times 10^{-2} = 12 - 4.5 = 7.5$ V

(b) $I_{max} = \frac{E}{r'} = \frac{12}{500} = 24$ mA

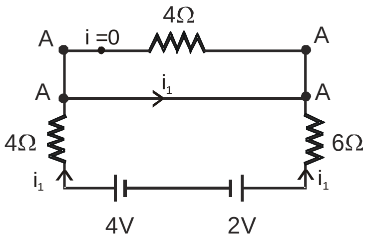
(c) For charging of battery $V = E + ir$, $V > E \Rightarrow V > 12$ V

Example 20. Find the currents through the three resistors shown in figure



Ans. zero in the upper 4 Ω resistor and 0.2 A in the rest two.

Solution:



Potential difference across upper 4Ω resistance is zero so current is also zero.
Other two resistors are in series combination so current is same

$= \frac{4-2}{4+6}$ = 0.2 A.

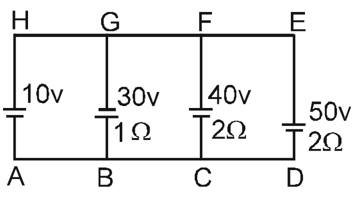
Note :
- The potential at all points of a wire of zero resistance will be same.
- **Earthing :** If some point of circuit is earthed then its potential is assumed to be zero.

REFERENCE 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 EXAMPLE

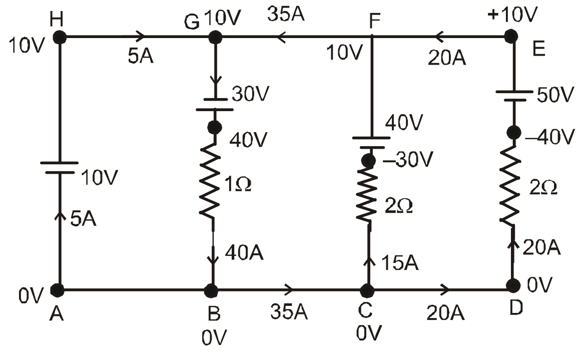
Example 21. Find the current in each wire



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

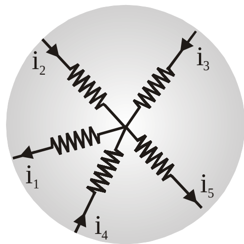
KIRCHHOFF'S LAWS

First law (Kirchhoff's Current Law or Junction law)

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

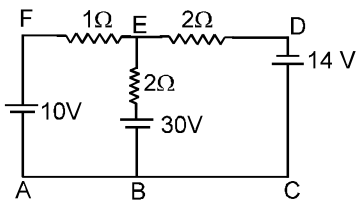
$i_1 - i_2 - i_3 - i_4 + i_5 = 0 \Rightarrow i_1 + i_5 = i_2 + i_3 + i_4$

This is based on law of conservation of charge.

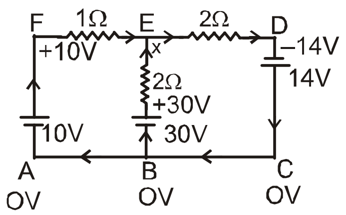


SOLVED EXAMPLE

Example 22. 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).

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

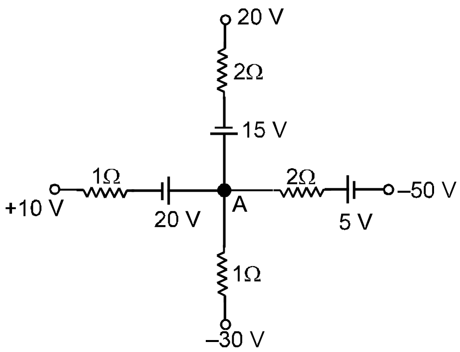
$4x = 36 \Rightarrow x = 9$

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

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

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

Example 23. Find the potential at point A



Solution : Let potential at A = x, applying kirchhoff current law at juction A

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

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

$\Rightarrow$ 6x + 10 = 0 $\Rightarrow$ x = –5/3

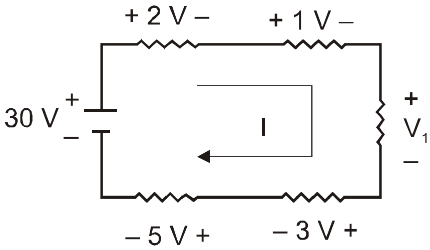
Potential at A = $\frac{-5}{3}$ V

Second law (Kirchhoff's Voltage Law or Loop law) :

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

SOLVED EXAMPLE

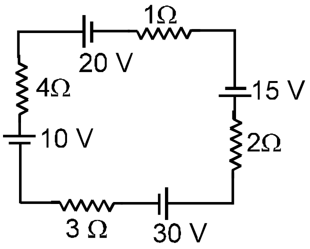
Example 24. For the circuit shown in figure, determine the unknown voltage drop V_1 .



Answer: 19 V

Solution: According to Kirchhoffs Voltage Law, the sum of the potential drops equal to the sum of the potential rises;
Therefore, 30 = 2 + 1 + V_1 + 3 + 5
or V_1 = 30 – 11 = 19 V **Ans.**

Example 25. Find current in the circuit



Solution : $\because$ all the elements are connected in series

current is all of them will be same

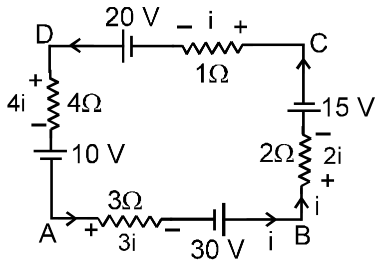
let current = i

Applying kirchhoff voltage law in ABCDA loop

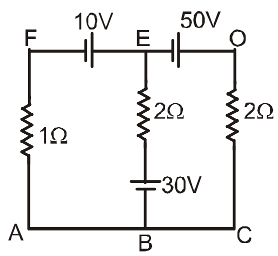
$10 + 4i - 20 + i + 15 + 2i - 30 + 3i = 0$

$10\ i = 25$

$i = 2.5$ A



Example 26. 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 kirchoff 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

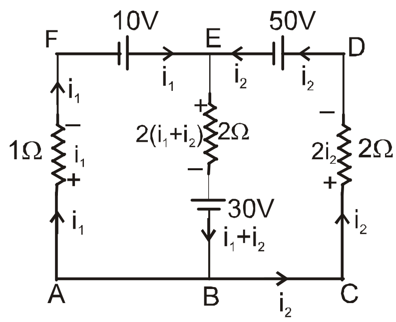
and $i_1 = 10$ A

$\therefore$ $i_1 + i_2 = - 15$ A

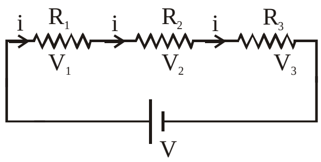
current in wire AF = 10 A from A to F

current in wire EB = 15 A from B to E

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



COMBINATION OF RESISTANCES :



Series Combination

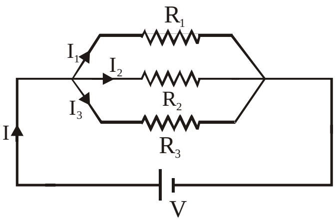
- Same current passes through each resistance
- Voltage across each resistance is directly proportional to it's value

  $V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$
- Sum of the voltage across resistance is equal to the voltage applied across the circuit.

$V = V_1 + V_2 + V_3$

$IR = IR_1 + IR_2 + IR_3$

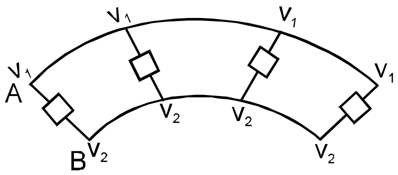
$R = R_1 + R_2 + R_3$ Where R = equivalent resistance

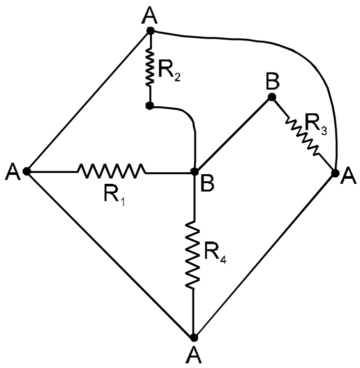


Parallel Combination

- There is same drop of potential across each resistance.
- Current in each resistance is inversely proportional to the value of resistance. $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$, $I_3 = \frac{V}{R_3}$
- Current flowing in the circuit is sum of the currents in individual resistance.

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

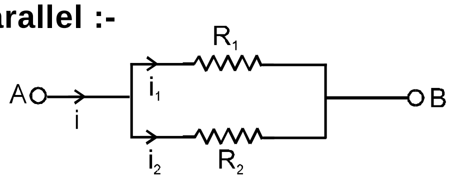
(a)


(b)


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

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

Current division in two resistors in parallel :-



$\therefore \quad i_1R_1 = i_2R_2$

or $\quad \frac{i_1}{i_2} = \frac{R_2}{R_1}$

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

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

SOLVED EXAMPLE

Example 27. Suppose you have three resistors of 20 Ω, 50 Ω and 100 Ω. What minimum and maximum resistances can you obtain from these resistors ?

Ans. 12.5 Ω, 170 Ω.

Solution: For maximum resistance, all resistance are in series

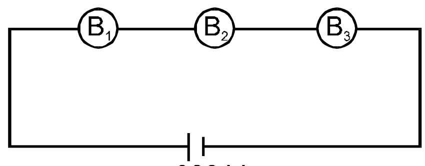
$R_{max} = 20 + 50 + 100 = 170\ \Omega$

For minimum resistance, all resistance are in parallel

$$\frac{1}{R_{min}} = \frac{1}{100} + \frac{1}{50} + \frac{1}{20} = \frac{1+2+5}{100} = \frac{8}{100}$$

$$R_{min} = \frac{100}{8} = 12.5\ \Omega$$

Example 28. 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

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

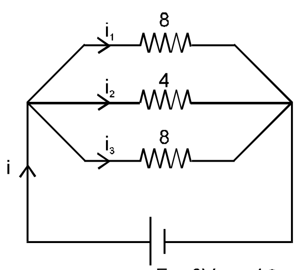
Since $R_3 > R_1 > R_2$

∴ Power consumed by bulb = i^2R

∴ if the resistance is of higher value then it will give more light.

∴ Here Bulb B_3 will give more light.

Example 29. 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

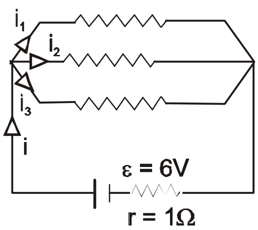
(e) The rate at which heat is generated inside the battery
(f) Electric power output
(g) Which resistance consumes maximum power ?
(h) Power dissipated across 4Ω resistance

Answer: (a) $R = 3\ \Omega$

(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

Solution: (a) $R_{eq} = 2 + 1 = 3\ \Omega$



(b) $i = \frac{\varepsilon}{R_{eq}} = \frac{6}{3} = 2\ A$

$i_1 + i_2 + i_3 = 2\ ;\ i_1 : i_2 : i_3 = \frac{1}{8} : \frac{1}{4} : \frac{1}{8} = 1 : 2 : 1\ ;\ i_1 = i_3 = \frac{1}{2}A, \quad i_2 = 1\ A$

(c) V_{across} battery $= \varepsilon - ir = 6 - 2 \times 1 = 4\ V$ $\quad V_{across}$ each cell $= 4\ V$

(d) P of the cell consumed $P = \varepsilon i = 12\ W$

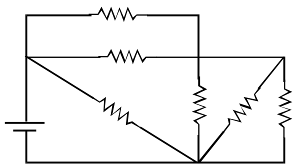
(e) P heat generated in cell $P = i^2 r = 4\ W$

(f) $P_{output} = \varepsilon i - i^2 r = 8\ W$

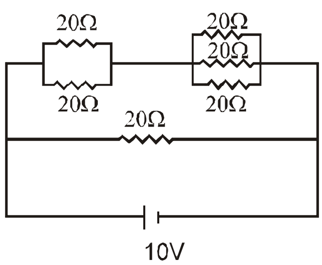
(g) In parallel, $P \propto \frac{1}{R}$ $\quad 4\ \Omega$ consumes Max power

(h) $P_{4\Omega} = \frac{V^2}{R} = \frac{4 \times 4}{4} = 4\ W$

Example 30. 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)



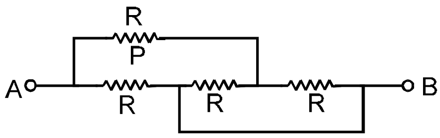
Solution:



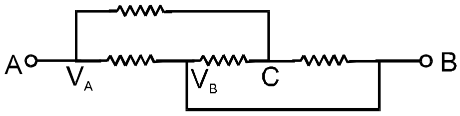
$$R_{eq} = \frac{\left(\frac{20}{2} + \frac{20}{3}\right) \times 20}{\frac{20}{2} + \frac{20}{3} + 20} = \frac{50 \times 20}{110} \qquad R_{eq} = \frac{100}{11}\ \Omega$$

$$P = \frac{V^2}{R} = \frac{(10)^2}{100/11} = 11\ W\ .$$

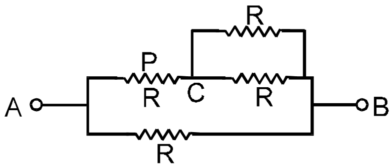
Example 31. Find the current in Resistance P if voltage supply between A and B is V volts



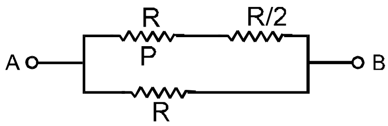
Solution : $R_{eq} = \frac{3R}{5}$



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

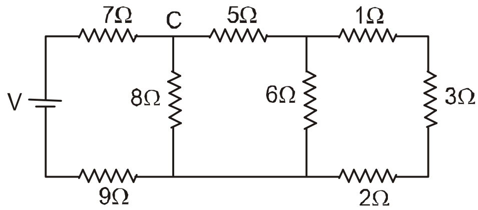


Current in P = $\frac{R \times \frac{5V}{3R}}{1.5R + R}$

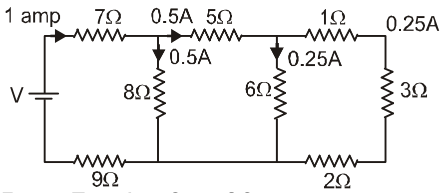


$= \frac{2V}{3R}$

Example 32. In the ladder network shown, current through the resistor 3 Ω is 0.25 A. The input voltage 'V' is equal to



Solution:

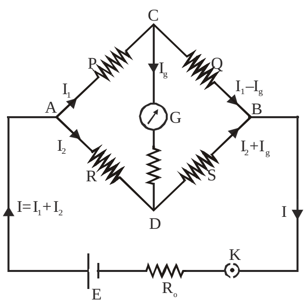


$R_{eq} = 7 + 4 + 9 = 20\Omega$
$V = IR_{eq} = 1 \times 20 = 20$ V

WHEAT STONE BRIDGE

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

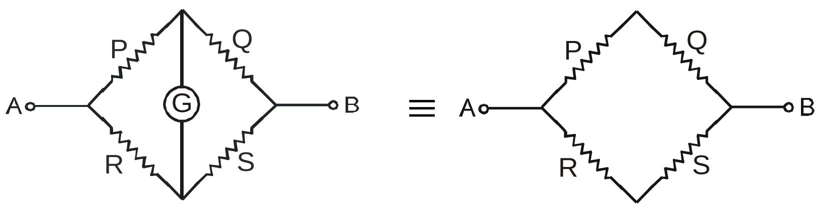
When current through the galvanometer is zero (null point or balance point) $V_C = V_D$.



$V_D = V_C$
$I_1P = I_2R$ & $I_1Q = I_2S$

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

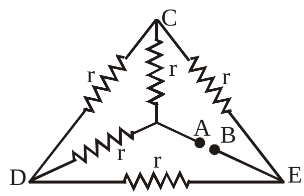
The null point is not affected by resistance in CD branch, E and R_0. **It is not affected even if the positions of Galvanometer and battery (E) are interchanged.**
hence, here the circuit can be assumed to be following,



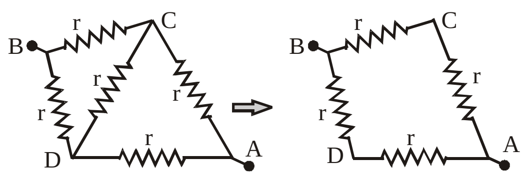
- If $\frac{P}{Q} < \frac{R}{S}$ then $V_C > V_D$ and current will flow from C to D.
- If $\frac{P}{Q} > \frac{R}{S}$ then $V_C < V_D$ and current will flow from D to C.

SOLVED EXAMPLE

Example 33. In the adjoining network of resistors each is of resistance r Ω. Find the equivalent resistance between point A and B

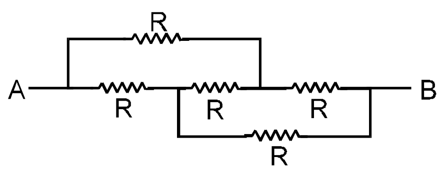


Solution: Given circuit is balanced Wheat stone Bridge

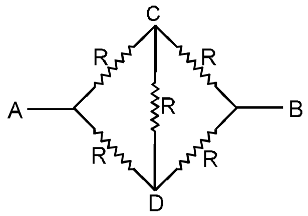


$$\therefore \frac{1}{R_{AB}} = \frac{1}{2r} + \frac{1}{2r} = \frac{1}{r} \quad R_{AB} = r$$

Example 34. Find the equivalent resistance between A and B

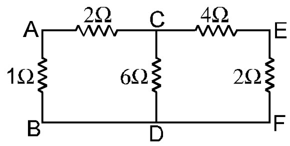


Solution : This arrangement can be modified as shown in figure since it is balanced wheat stone bridge



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

Example 35. 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

Ans. (i) $R_{AB} = 5/6\ \Omega$ (ii) $R_{CD} = 1.5\ \Omega$ (iii) $R_{EF} = 1.5\ \Omega$ (iv) $R_{AF} = 5/6\ \Omega$ (v) $R_{AC} = 4/3\ \Omega$

Solution: (i) $R_{AB} = \frac{5 \times 1}{5+1} = \frac{5}{6}\ \Omega$

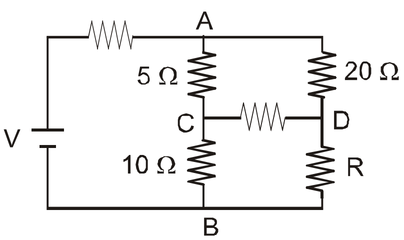
(ii) $$R_{CD} = \frac{\left(\frac{3\times 6}{3+6}\right)\times 6}{\left(\frac{3\times 6}{3+6}\right)+6} = \frac{2\times 6}{2+6} = \frac{3}{2} = 1.5\ \Omega$$

(iii) $$R_{EF} = \frac{\left[\left(\frac{3\times 6}{3+6}\right)+4\right]\times 2}{\left(\frac{3\times 6}{3+6}\right)+4+2} = \frac{(2+4)2}{2+4+2} = \frac{3}{2} = 1.5\ \Omega$$

(iv) $R_{AF} = R_{AB} = \frac{5}{6}\ \Omega$

(v) $$R_{AC} = \frac{\left(\frac{6\times 6}{6+6}+1\right)2}{\left(\frac{6\times 6}{6+6}+1\right)+2} = \frac{(3+1)2}{(3+1)+2} = \frac{4}{3}\ \Omega$$

Example 36. 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

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

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

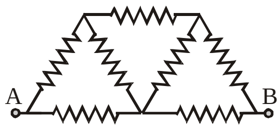
$\therefore\ R = 40 \quad \Omega$ **Ans.**

SYMMETRICAL CIRCUITS

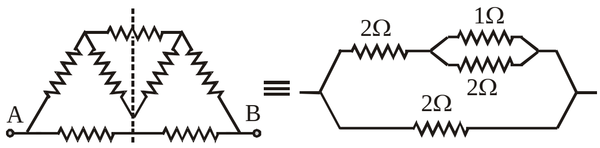
Some circuits can be modified to have simpler solution by using symmetry if they are solved by traditional method of KVL and KCL then it would take much time.

SOLVED EXAMPLE

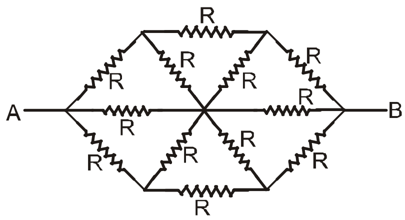
Example 37. Each resistance is of 1 Ω in the circuit diagram shown in figure. Find out equivalent resistance between A and B



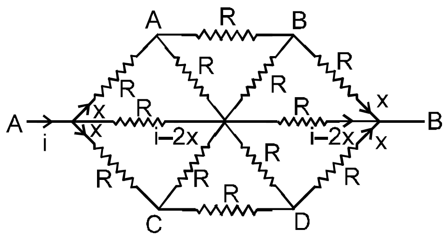
Solution: By symmetric line method $R_{AB} = (2 + 1 \parallel 2) \parallel 2 = \frac{8}{7}\,\Omega$



Example 38. Find the equivalent Resistance between A and B

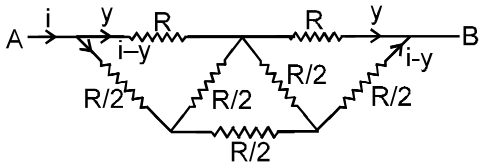


Solution :



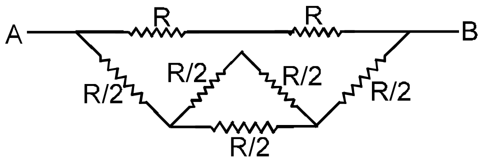
Here $V_A = V_C$ and $V_B = V_D$

Here the circuit can be simplified as

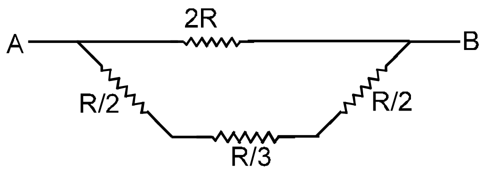


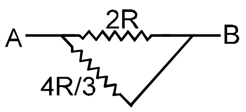
this circuit can be simplified as

$$R_{eq} = \frac{2R \times \frac{4R}{3}}{\frac{10R}{3}}$$

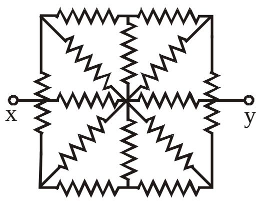


$$= \frac{4R}{5}$$ **Ans.**

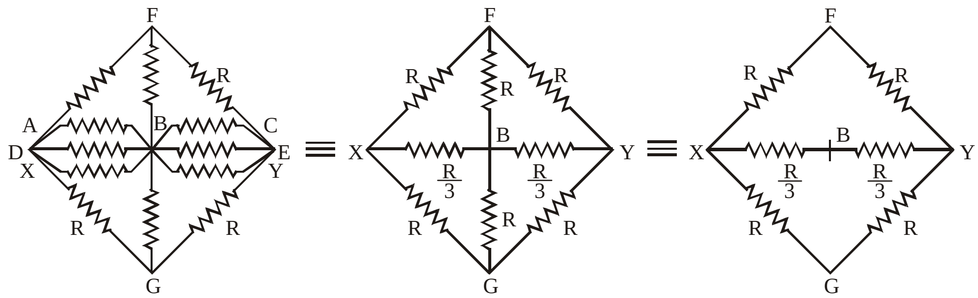




Example 39. Identical resistance of resistance R are connected as in figure then find out net resistance between x and y.

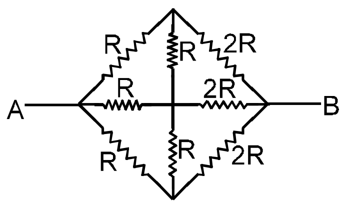


Solution: Given circuit can be modified according to following figures

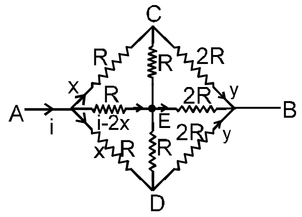


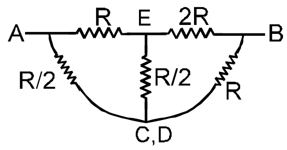
$$\frac{1}{R_{xy}} = \frac{1}{2R} + \frac{3}{2R} + \frac{1}{2R} = \frac{5}{2R} \Rightarrow R_{xy} = \frac{2R}{5}$$

Example 40. 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

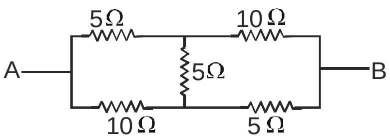




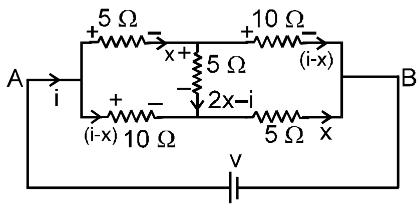
$$R_{eq} = \frac{3R \times \frac{3R}{2}}{3R + \frac{3R}{2}}$$

$$= \frac{\frac{9}{2}R}{\frac{9}{2}} = R.$$

Example 41. **(unbalanced wheat stone bridge)** 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 kirchoff voltage law

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

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

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

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

$15i - 25x = 0$

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

Using (2) and (1)

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

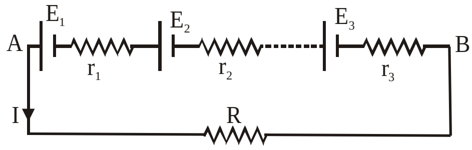
$\frac{v}{i} = 7\Omega$

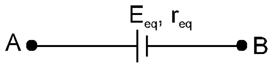
$R_{eq} = 7\Omega$ **Ans.**

COMBINATION OF CELLS

- **Series combination**

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





Equivalent EMF

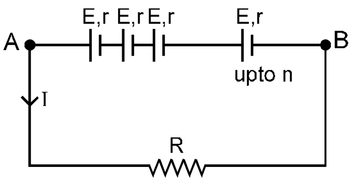
$E_{eq} = E_1 + E_2 + ... + E_n$ [write EMF's with polarity]

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

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

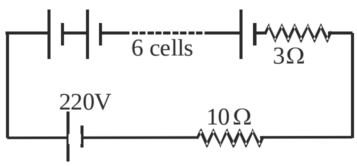
SOLVED EXAMPLE

Example 42. A battery of six cells each of e.m.f. 2 V and internal resistance 0.5 Ω is being charged by D. C. mains of e.m.f. 220 V by using an external resistance of 10 Ω. What will be the charging current.

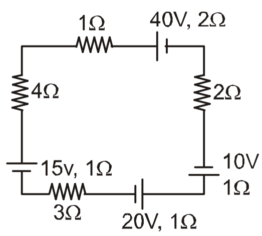
Solution: Net e.m.f of the battery = 12V and total internal resistance = 3Ω

Total resistance of the circuit = 3 + 10 = 13 Ω

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



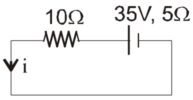
Example 43. Find the current in the loop.



Solution : The given circuit can be simplified as

$$i = \frac{35}{10+5} = \frac{35}{15}$$

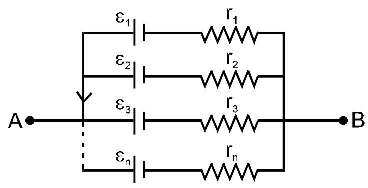
$$= \frac{7}{3}\text{ A} \quad \Rightarrow \quad I = \frac{7}{3}\text{ A}$$



- **Parallel combination**

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

$$E_{eq} = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \ldots + \frac{\varepsilon_n}{r_n}}{\frac{1}{r_1} + \frac{1}{r_2} + \ldots + \frac{1}{r_n}}$$



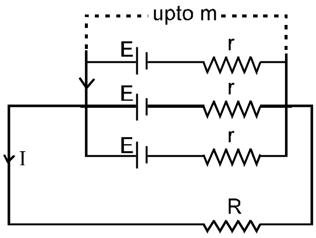
[Use emf's with polarity]

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

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.

- **Mixed combination**

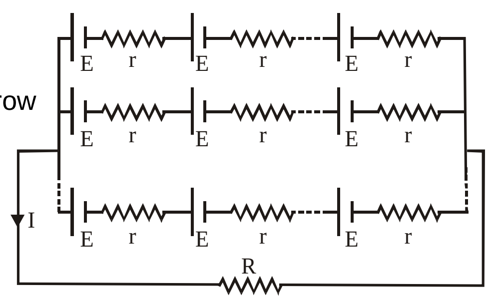
If n cells connected in series and their are m such branches in the circuit then total number of identical cell in this circuit is nm. The internal resistance of the cells connected in a row = nr . Since there are such m rows,

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

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

$E_{net} = nE$

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

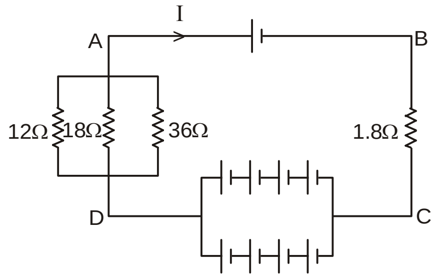


Current in the circuit is maximum when external resistance in the circuit is equal to the total internal resistance of the cells $R = \frac{nr}{m}$

- Series combination is useful when internal resistance is less than external resistance of the cell.
- Parallel combination is useful when internal resistance is greater than external resistance of the cell.
- Power in R (given resistance) is maximum, if its value is equal to net resistance of remaining circuit.
- Internal resistance of ideal cell = 0
- if external resistance is zero than current given by circuit is maximum.

SOLVED EXAMPLE

Example 44. 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.

Ans. (i) $\frac{1}{2}$ = 0.5 A (ii) $\frac{1}{12}$ = 0.0833 A (iii) $1.5 + \frac{1}{2} \times 0.4$ = 1.7 V

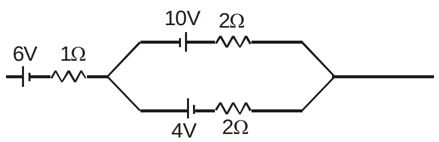
Solution: (i) Effective emf = 4 × 1.5 – 1.5 = 4.5 V
(ii) Effective internal resistance

$r_{eq} = \frac{4 \times 0.4}{2} + 0.4 = 1.2\ \Omega$ $\qquad R_{eq} = 6 + 1.8 + 1.2 = 9\ \Omega$

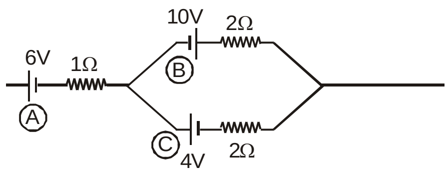
$I = \frac{E}{R_{eq}} = \frac{4.5}{9} = \frac{1}{2}$ amp $\qquad I_{36} = \frac{R_{eq} I}{R_{36}} = \frac{6}{36} \times \frac{1}{2} = \frac{1}{12}$

(ii) $V_{AB} = E + ir = 1.5 + \frac{1}{2} \times 0.4 = 1.5 + 0.2 = 1.7$ V

Example 45. Find the emf and internal resistance of a single battery which is equivalent to a combination of three batteries as shown in figure.

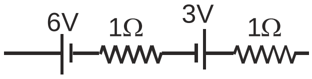


Solution :



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

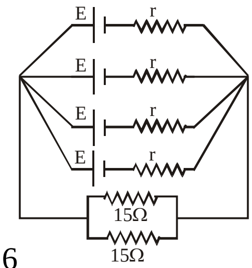
$$\varepsilon_{BC} = \frac{\frac{10}{2} + \frac{-4}{2}}{\frac{1}{2} + \frac{1}{2}} = \frac{5-2}{1} = 3\text{V} \Rightarrow r_{BC} = 1\Omega.$$

Now, 

ε_{ABC} = 6 – 3 = 3V
r_{ABC} = 2Ω. **Ans.**

Example 46. Four identical cells each of e.m.f. 2V are joined in parallel providing supply of current to external circuit consisting of two 15Ω resistors joined in parallel. The terminal voltage of the equivalent cell as read by an ideal voltmeter is 1.6V calculate the internal resistance of each cell.

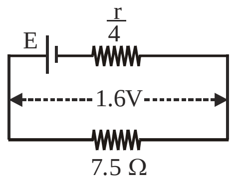
Solution: Total internal resistance of the combination $r_{eq} = \frac{r}{4}$



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

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

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



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

GALVANOMETER (MOVING COIL TYPE)

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

Function: 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

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

But by making the magnetic field radial θ = 90º.

$\therefore$ BINA = C φ

$I \propto \phi$

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 :

- i_g = Current required for full scale deflection of galvanometer.
- R_g = Resistance of galvanometer coil.
- I_g is the current for full scale deflection. If the current for a deflection, of one division on the galvanometer scale is k and N is the total number of divisions on one side of the zero of galvanometer scale, then $I_g = k \times N$.
- A ballistic galvanometer is a specially designed moving coil galvanometer, used to measure charge flowing through the circuit for small time intervals.

SHUNT

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

- **Merits of shunt**

  (i) To protect the galvanometer coil from burning.

  (ii) Any galvanometer can be converted into ammeter of desired range with the help of shunt.

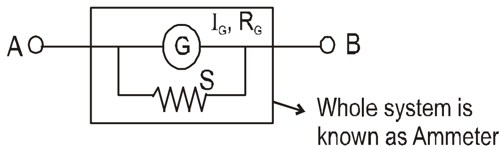
  (iii) The range an ammeter can be changed by using shunt resistance of different values.

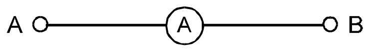
- **Demerits of shunt**

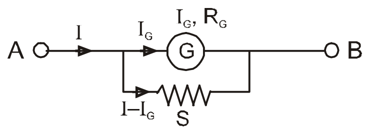
  Shunt resistance decreases the sensitivity of galvanometer.

CONVERSION OF GALVANOMETER INTO AMMETER

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







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

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

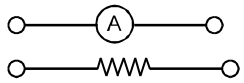
$$S = \frac{I_G.R_G}{I - I_G}$$

$$S = \frac{I_G \times R_G}{I} \qquad \text{when} \quad I >> I_G.$$

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

$$R_A = \frac{R_G.S}{R_G + S}$$

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

SOLVED EXAMPLE

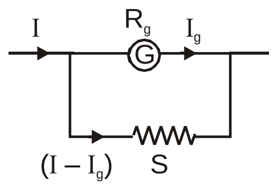
Example 47. Calculate the value of shunt which passes 10% of the main current through a galvanometer of 99ohm.

Solution :

As in figure $R_gI_g = (I - I_g)S$

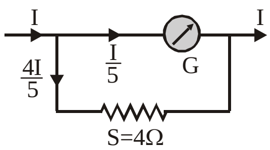
$\Rightarrow$ $99 \times \frac{I}{10} = \left(I - \frac{I}{10}\right) \times S$

$\Rightarrow$ $S = 11\ \Omega$.

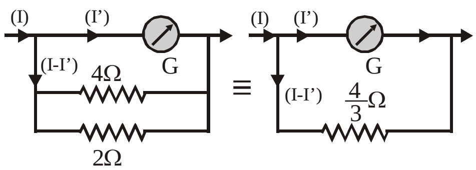


Example 48. When a shunt of 4Ω is attached to a galvanometer, the deflection reduces to 1/5th. If an additional shunt of 2Ω is attached what will be the deflection ?

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

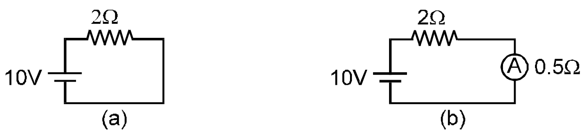


When additional shunt of 2Ω used $I' \times 16 = (I - I')\ \frac{4}{3} \Rightarrow I' = \frac{I}{13}$



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

Example 49. Calculate the current in the circuit (a) & (b) and also determine percentage error in measuring the current through an ammeter.



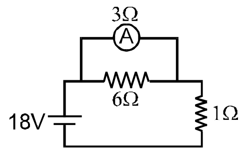
Solution : In A $I = \frac{10}{2} = 5A$

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 50. 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

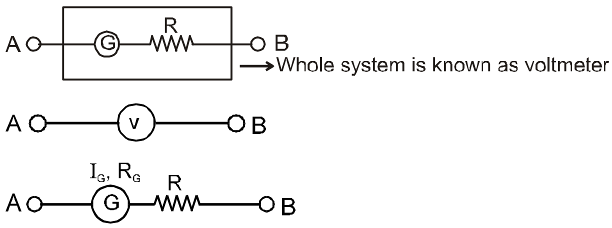
$= 6 \times \frac{6}{9} = 4$ A

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.

CONVERSION OF GALVANOMETER INTO VOLTMETER

- The galvanometer can be converted into voltmeter by connecting high resistance in series with its coil. It is used to measure potential difference across a resistor in a circuit.



For maximum potential difference

$V = I_G \cdot R + I_G R_G$ $R = \frac{V}{I_G} - R_G$

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 → 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 51. A 100 volt voltmeter whose resistance is 20 kΩ is connected in series to a very high resistance R. When it is joined in a line of 110 volt, it reads 5 volt. What is the magnitude of resistance R ?

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

The potential difference across the voltmeter V = IR_V

$\Rightarrow 5 = \frac{110 \times 20 \times 10^3}{(20 \times 10^3 + R)} \Rightarrow 20 \times 10^3 + R = 440 \times 10^3 \Rightarrow R = 420 \times 10^3\ \Omega$

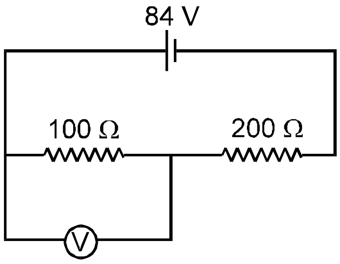
Example 52. A galvanometer has a resistance of G ohm and range of V volt. Calculate the resistance to be used in series with it to extend its range to nV volt.

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

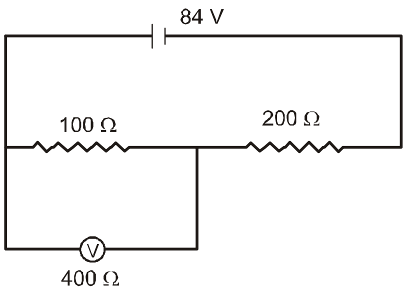
to change its range

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

Example 53. A voltmeter of resistance 400Ω is used to measure the potential difference across the 100Ω resistor in the circuit shown in the figure. (i) What will be the reading of the voltmeter ? (ii) What was the potential difference across 100Ω before the voltmeter was connected ?



Solution:



$R_{eff} = \frac{400 \times 100}{500} + 200 \qquad R_{eff} = 280\ \Omega$

$i = \frac{84}{280}$ A. $\qquad V = \frac{84}{280} \times \frac{100 \times 400}{500} = 24$ V

(b) $i = \frac{84}{300} \qquad V = \frac{84}{300} \times 100 = 28$ V

Current sensitivity

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

SOLVED EXAMPLE

Example 54. A galvanometer having 30 divisions has current sensitivity of 20μA/division. It has a resistance of 25 Ω.

(i) How will you convert it into an ammeter measuring upto 1 ampere.

(ii) How will you convert this ammeter into a voltmeter upto 1 volt.

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

(i) To convert it into ammeter, a shunt is required in parallel with it

shunt resistance $R'_S = \frac{I_g R_g}{(I - I_g)} = \left(\frac{6\times10^{-4}}{1-6\times10^{-4}}\right)25 = 0.015\Omega$

(ii) To convert galvanometer into voltmeter, a high resistance in series with it is required

series resistance $R = \frac{V}{i_g} - R_g = \frac{1}{6\times10^{-4}} - 25$ = 1666.67 – 25 = 1641.67 Ω

Example 55. 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 $V_g = \frac{\theta}{vs}$

$= \frac{100}{2}$ mv

= 50 mv

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

= 5 Ω

(a) to convert the galvanometer into an ammeter of range 5A, a resistance of value SΩ 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.**

POTENTIOMETER

- **Necessity of potentiometer**

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

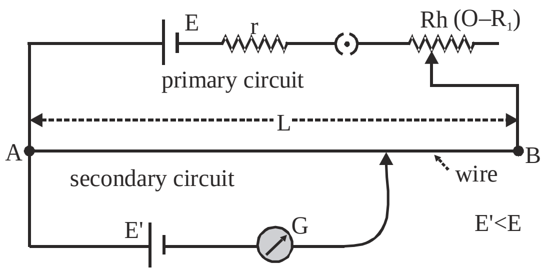
- **Working principle of potentiometer**

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

- **Potentiometer wire**

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

CIRCUIT OF POTENTIOMETER



- **Primary circuit** contains constant source of voltage rheostat or Resistance Box
- **Secondary, Unknown or galvanometer circuit**

  Let ρ = Resistance per unit length of potentiometer wire

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

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

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

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

Note:-

Any potential difference which is less than the potential difference maintained across the potentiometer wire can be measured using this.

- **Applications of potentiometer**

• To measure potential difference across a resistance. • To find out emf of a cell • Comparison of two emfs E_1/E_2 • To find out internal resistance of a primary cell • Comparison of two resistance. • To find out an unknown resistance which is connected in series with the given resistance.	• To find out current in a given circuit • Calibration of an ammeter or to have a check on reading of (A) • Calibration of a voltmeter or to have a check on reading of (V) • To find out thermocouple emf (e_t) (mV or mV)

SOLVED EXAMPLE

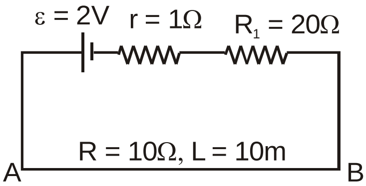
Example 56. Primary circuit of potentiometer is shown in figure determine :

(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 **Ans.**

Application of potentiometer

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

In case I,

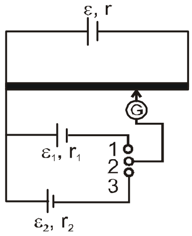
In figure, (2) is joint to (1) then balance length = ℓ_1

$\varepsilon_1 = x\ell_1$ ....(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 EXAMPLE

Example 57. There is a definite potential difference between the two ends of a potentiometer. Two cells are connected in such a way that first time help each other, and second time they oppose each other. They are balanced on the potentiometer wire at 120 cm and 60 cm length respectively. Compare the electromotive force of the cells.

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

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

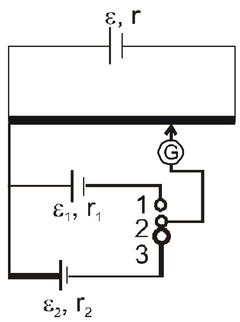
$E_1 + E_2 = x \times 120$ cm ...(i)

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

$E_1 - E_2 = x \times 60$ cm ...(ii)

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

Example 58. In an experiment to determine the em*f* of an unknown cell, its emf is compared with a standard cell of known emf $\varepsilon_1 = 1.12$ 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, $\varepsilon_1 = 1.12$ V; $\ell_1 = 56$ cm; $\ell_2 = 80$ cm

Using equation

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

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

we get $\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2} \Rightarrow \varepsilon_2 = \varepsilon_1\left(\frac{\ell_2}{\ell_1}\right)$

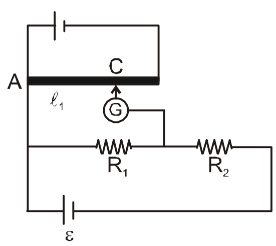
or $\varepsilon_2 = 1.12\left(\frac{80}{56}\right) = 1.6$ V Ans

(b) To find current if resistance is known

$V_A - V_C = x\ell_1$

$IR_1 = x\ell_1$

$I = \frac{x\ell_1}{R_1}$



Similarly, we can find the value of R_2 also.

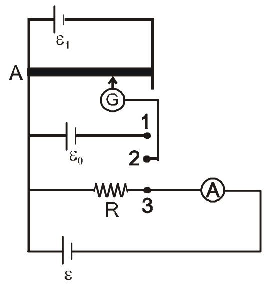
Potentiometer is ideal voltmeter because it does not draw any current from circuit, at the balance point.

SOLVED EXAMPLE

Example 59. 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)

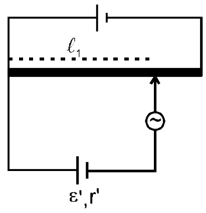
$$I = \frac{\varepsilon_0}{R}\left(\frac{\ell}{\ell_0}\right) \quad \therefore \quad I = \frac{1.11}{120}\left(\frac{60}{72}\right) = 7.7 \text{ mA}$$

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

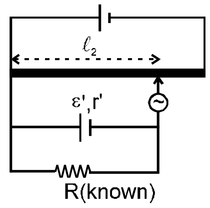
$$\Delta I = 7.8 - 7.7 = 0.1 \text{ mA}, \qquad \frac{\Delta I}{I} = \frac{0.1}{7.7} \times 100 = 1.3\ \%$$

(c) To find the internal resistance of cell.

Ist arrangement



2nd arrangement



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

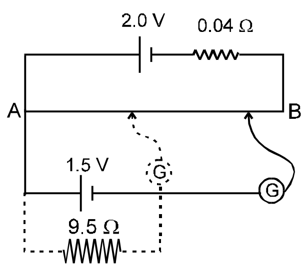
by second arrangement $IR = x\ell_2$

$$I = \frac{x\ell_2}{R},$$

also $$I = \frac{\varepsilon'}{r'+R} \Rightarrow \frac{\varepsilon'}{r'+R} = \frac{x\ell_2}{R} \Rightarrow \frac{x\ell_1}{r'+R} = \frac{x\ell_2}{R} \Rightarrow r' = \left[\frac{\ell_1 - \ell_2}{\ell_2}\right]R$$

SOLVED EXAMPLE

Example 60. 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.



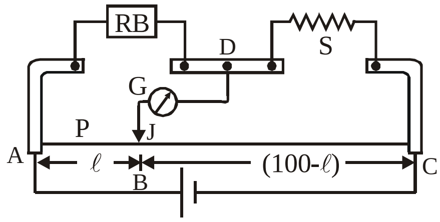
Ans. $\left(\frac{70}{60} - 1\right) \times 9.5 = \frac{9.5}{6}$ ohm

Solution: $r = \frac{R(\ell - \ell')}{\ell} = 9.5\left(\frac{70-60}{60}\right) = 9.5\left(\frac{70}{60} - 1\right) = \frac{9.5}{6}\ \Omega$

METRE BRIDGE (USED TO MEASURE UNKNOWN RESISTANCE)

It is based on principle of whetstone bridge. It is used to find

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



AB = ℓ cm P = r ℓ

BC = (100 – ℓ) cm Q = r(100 – ℓ)

where r = resistance per unit length on wire.

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

Note :
- The bridge is most sensitive when the resistance in all the four branches of the bridge is of same order.
- For better accuracy, R is so adjusted that ℓ lies between 40 cm and 60 cm.

SOLVED EXAMPLE

Example 61. 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?

Solution : Apply condition for balance wheat stone bridge,

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

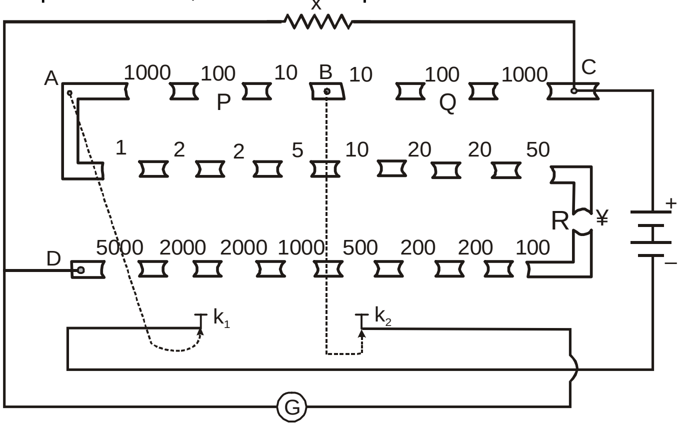
Ans. : P = 3Ω.

POST-OFFICE BOX

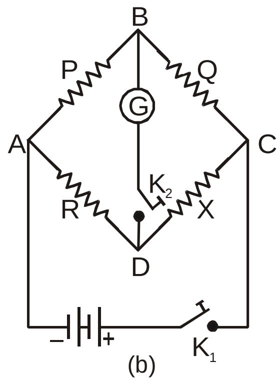
INTRODUCTION: It is based on Wheatstone bridge. It is so named because its shape is like a box and it was originally designed to determine the resistances of electric cables and telegraph wires. It was used in post offices to determine the resistance of transmission lines.

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 EXAMPLE

Example 62. 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. **Ans. :** (A)

Example 63. The post office box works on the principle of :

(A) Potentiometer (B) Wheatstone bridge

(C) Matter waves (D) Ampere's law **Ans. :** (B)

Example 64. 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. **Ans. :** (A)

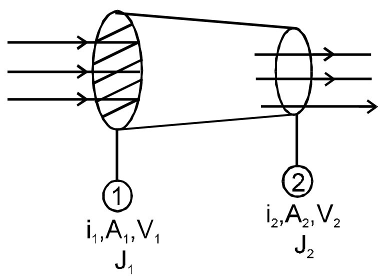
MISCELLANEOUS SOLVED EXAMPLE

Problem 1. The current density at a point is $\vec{J} = \left(2\times10^4\hat{j}\right)\text{Jm}^{-2}$.

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

Solution: The rate of flow of charge = current = I = $\int \vec{J}.d\vec{S} \Rightarrow$ I = $\vec{J}.\vec{S} = \left(2\times10^4\right)\left[\hat{j}\cdot\left(2\hat{i}+3\hat{j}\right)\right]\times10^{-4}\,\text{A} = 6\text{A}$

Problem 2. 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) $j = \frac{i}{A}$

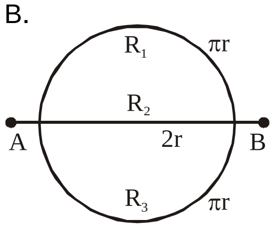
as $A_1 > A_2$ then $j_1 < j_2$

(c) $j = nev_d$

$v_d = \frac{j}{ne}$

as $j_1 < j_2$ then, $v_1 < v_2$

Problem 3. A wire of $\rho_L = 10^{-6}\ \Omega/\ m$ is turned in the form of a circle of diameter 2 m. A piece of same material is connected in diameter AB. Then find resistance between A and B.



Solution: $\because$ $R = \rho_L \times$ length

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

$\frac{1}{R_{AB}} = \frac{1}{\pi\times10^{-6}} + \frac{1}{2\times10^{-6}} + \frac{1}{\pi\times10^{-6}}$; $R_{AB} = 0.88 \times 10^{-6}$ ohm.

Problem 4. 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

Solution: $R_{2.5\ W} = \frac{(110)^2}{2.5}\ \Omega$, $R_{100W} = \frac{(110)^2}{100}$ $\Rightarrow$ $R_{2.5} > R_{100}$.

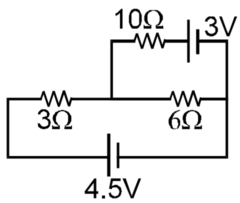
In series current passes through both bulb are same

$P_{2.5} = i^2 R_{2.5}$, $P_{100} = i^2 R_{100}$

$P_{2.5} > P_{100}$ due to $R_{2.5} > R_{100}$ & $\because$ $P_{2.5} > 2.5W$ & $P_{100} < 100$ W (can be verified)

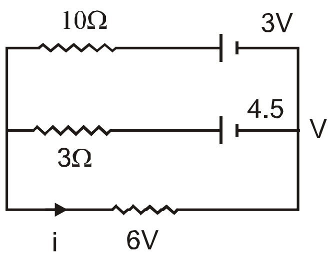
Therefore 2.5 W bulb will fuse

Problem 5. Find the current through the 10 Ω resistor shown in figure



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

Solution:



$$E_q = \frac{\frac{4.5}{3}+\frac{3}{10}}{\frac{1}{3}+\frac{1}{10}} = \frac{54}{13} = V$$

$$r_{eq} = \frac{3\times10}{13} = \frac{30}{13}\ \Omega$$

$$i = \frac{54/13}{6+\frac{30}{13}} = \frac{54}{108} = \frac{1}{2}\text{ amp.}$$

$$V_{6\Omega} = i.R = \frac{1}{2} \times 6 = 3V$$

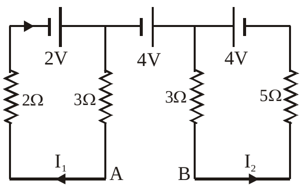
There fore current in 10Ω is zero.

Problem 6. n rows each containing m cells in series, are joined in parallel. Maximum current is taken from this combination in a 3 Ω resistance. If the total number of cells used is 24 and internal resistance of each cell is 0.5 Ω , find the value of m and n.

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

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

Problem 7. In the given circuit calculate potential difference between A and B.



Solution: First applying KVL on left mesh $2 - 3\,I_1 - 2\,I_1 = 0 \Rightarrow I_1 = 0.4$ amp.
Now applying KVL on right mesh. $4 - 5\,I_2 - 3\,I_2 = 0 \Rightarrow I_2 = 0.5$ amp.
Potential difference between points A and B
$V_A - V_B = -3 \times 0.4 - 4 + 3 \times 0.5 = -3.7$ volt.

Problem 8. What shunt resistance is required to convert the 1.0 mA, 20Ω galvanometer into an ammeter with a range of 0 to 50mA ?

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 , $G = 20\Omega$
$i = 50 \times 10^{-3}$ A

$$S = \frac{i_g R_g}{i - v_g} = \frac{1\times10^{-3}\times20}{49\times10^{-3}} = 0.408\ \Omega$$

Problem 9. How can we convert a galvanometer with $R_g = 20\ \Omega$ 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 : $v = i_g R_S + i_g R_g$

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

$$R_S = \frac{10-0.02}{1\times10^{-3}} = \frac{9.98}{10^{-3}} = \mathbf{9980\ \Omega}$$

Problem 10. 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

Solution : d = 10 m , R = 10Ω ,

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

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

Across wire potential drop ,

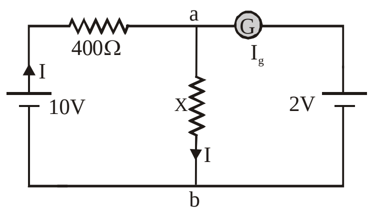
$$\frac{dv}{d\ell} \times \ell = 1 \times 10^{-3} \times 10 = 0.01 \text{ volts}$$

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

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

Answer : (D)

Problem 11. In the following circuit diagram, the galvanometer reading is zero. If the internal resistance of cells are negligible then what is the value of X ?



Sol. ∵ $I_g = 0 \therefore I = \frac{10}{400+X}$

also potential difference across X is 2V ⇒ I X = 2

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

Exercise # 1

PART - I : SUBJECTIVE QUESTIONS

SECTION (A) : DEFINITION OF CURRENT, CURRENT DENSITIES & DRIFT VELOCITIES

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

A-2. A current of 2.5 A exists in a 10 Ω resistance for 4 minutes.

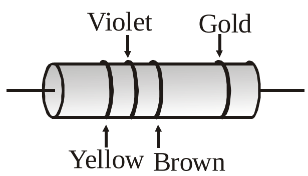
(i) How many coulombs and

(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. What is resistance of following resistor.

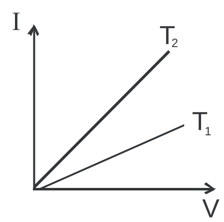


B-2. A copper wire of length L, and cross section area A carries a current I. If the specific resistance of copper is ρ, the electric field in the wire is.

B-3. A battery sets up an electric field of 50 N/C inside a uniform wire of length 2 m and a resistance of 10 Ω. Find current through the wire.

B-4. Two conductors are made of the same material and have the same length. Conductor A is a solid wire of diameter 1mm. Conductor B is a hollow tube of outer diameter 2mm and inner diameter 1mm. Find the ratio of resistance R_A to R_B.

B-5. 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



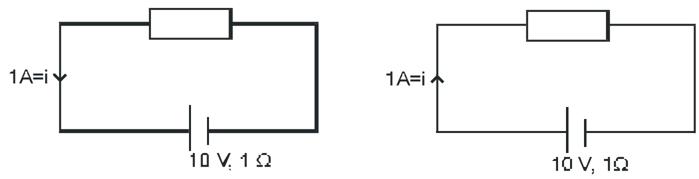
B-6. If a copper wire is stretched to make it 0.1% longer, what is the percentage change in its resistance?

[JEE' 1978]

SECTION (C) : POWER, ENERGY, BATTERY, EMF, TERMINAL VOLTAGE & KIRCHOFF'S LAWS

C-1. If a cell of constant E.M.F. produces the same amount of the heat during the same time in two independent resistors R_1 and R_2, when they are separately connected across the terminals of the cell, one after the another, find the internal resistance of the cell.

C-2. In following diagram boxes may contain resistor or battery or any other element



(A) (B)

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.

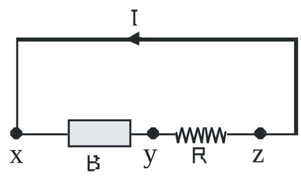
(e) The rate at which heat is generated inside the battery.

(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-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 x,y and z

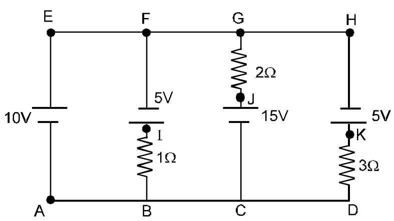


a) The magnitude of the current,

b) The electric potential, and

c) The electric potential energy of the charge carriers (electron), greatest first.

C-4. In following circuit potential at point 'A' is zero then determine



(a) Potential at each point

(b) Potential difference across each resistance

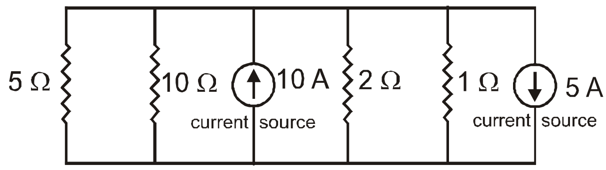
(c) Identify the batteries which act as a source

(d) Current in each battery

(e) Which resistance consumes maximum power

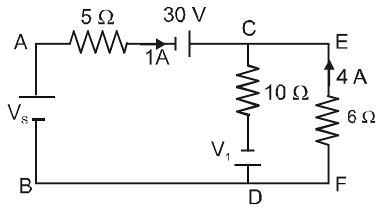
(f) Which battery consume or gives maximum power.

C-5. For the circuit shown in figure, find the voltage across 10 Ω resistor and the current passing through it.



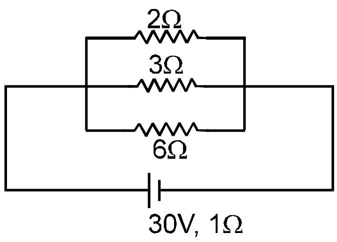
C-6. A resistor develops 200 J of thermal energy in 5 s when a current of 2 A is passed through it. (a) Find its resistance. (b) If the current is increased to 4 A, what will be the energy developed in 10 s.

C-7. Find the current in 10 Ω resistance, V_1, and source voltage V_s in the circuit shown in figure

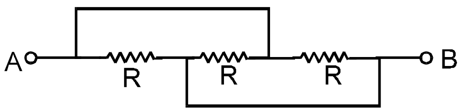


SECTION : (D) COMBINATION OF RESISTANCE

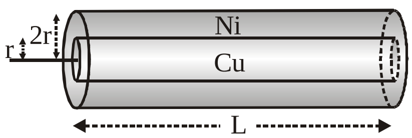
D-1. Find current which is passing through battery.



D-2. Find equivalent Resistance



D-3. A copper wire of length 'ℓ' and radius 'r' is nickel plated till its final radius is 2r. If the resistivity of the copper and nickel are ρ_{Cu} and ρ_{Ni}, then find the equivalent resistance of wire?

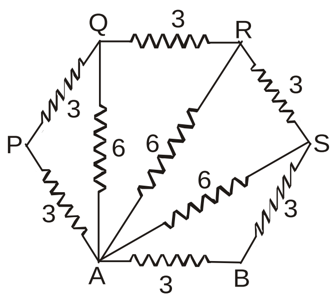


D-4. Two electric bulbs, each designed to operate with a power of 500 watts in 220 volt line, are connected in series. Now they are connected with a 110 volt line. What will be the power generated by each bulb?

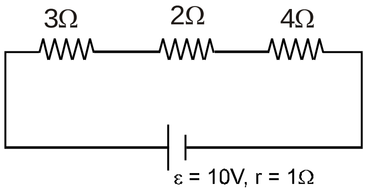
[JEE – 1977]

D-5. All resistance in diagram (fig.) are in ohms. Find the effective resistance between the points A and B.

[JEE – 1979]



D-6. In the given circuit determine



(a) Potential difference across each resistance

(b) The rate at which the chemical energy of the cell is consumed

(c) The rate at which heat is generated inside the battery

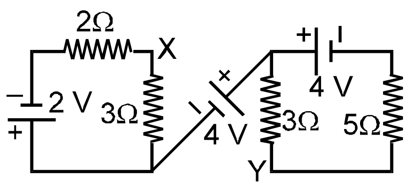
(d) Electric power output

(e) Potential difference across battery

(f) Which resistance consumes maximum power

(g) Power dissipated in 2 Ω resistance.

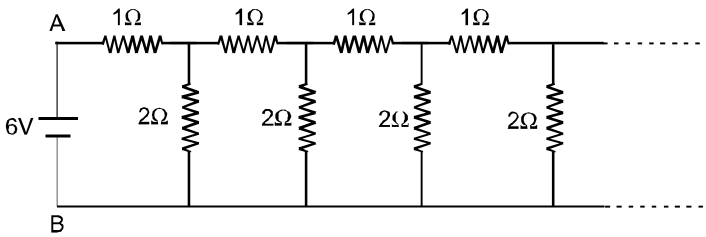
D-7.



(a) Find $V_X - V_Y$.

(b) If intermediate cell has internal resistance r = 1Ω then find $V_X - V_Y$.

D-8.

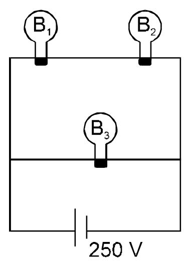


An infinite ladder network of resistance is shown in figure.

(i) Calculate the effective resistance between A and B.

(ii) Find the current through the 2Ω resistance nearest to the battery ?

D-9. 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]**



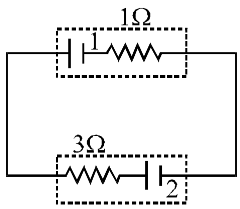
SECTION (E) : COMBINATION OF CELLS

E-1. A battery of six cells each of e.m.f. 2 V and internal resistance 0.5 W is being charged by D. C. mains of e.m.f. 220 V by using an external resistance of 10 W. What will be the charging current.

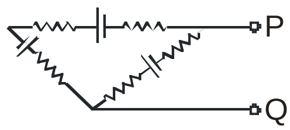
E-2. A battery consists of a variable number n of identical cells having internal resistance connected in series. The terminals of the battery are short circuited and the current I measured. Draw graph between I and n?

E-3. In **previous problem**, if the cell had been connected in parallel (instead of in series) Draw graph between I and n?

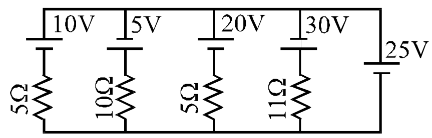
E-4. In the figure shown, battery 1 has emf = 6 V and internal resistance = 1 Ω. Battery 2 has emf = 2V and internal resistance = 3 Ω. The wires have negligible resistance. What is the potential difference across the terminals of battery 2 ?



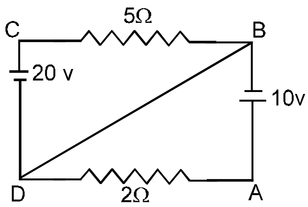
E-5. In the circuit shown all five resistors have the same value 200 ohms and each cell has an emf 3 volts. Find the open circuit voltage and the short circuit current for the terminals P and Q.



E-6. Find the current through 25V cell & power supplied by 20V cell in the figure shown.

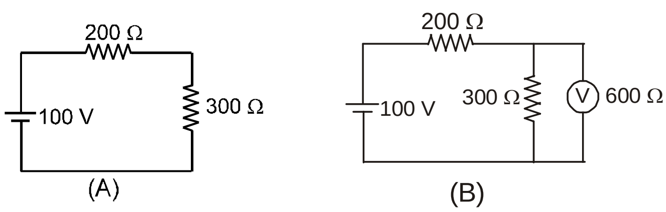


E-7. In the figure given beside find out the current in the wire BD

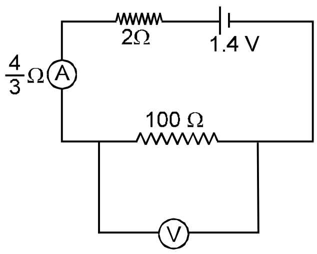


SECTION (F) : INSTRUMENT

F-1. A voltmeter of resistance 600Ω is used to measure the potential difference across the 300Ω resistor in the circuit shown in the figure. (i) What will be the reading of the voltmeter ? (ii) What was the potential difference across 300 Ω before the voltmeter was connected ?



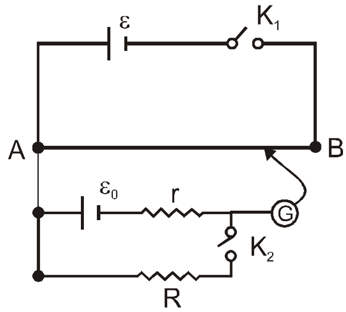
F-2.



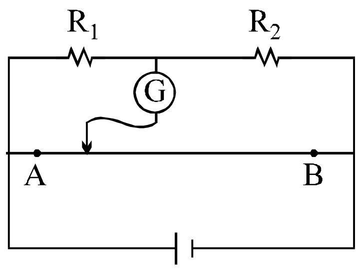
(i) The ammeter reads 0.02 A. What is the resistance of the voltmeter ?

(ii) The voltmeter reads 1.10 V, what is the zero error in the voltmeter ?

F-3. 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.



F-4. In the figure shown for which values of R_1 and R_2 the balance point for Jockey is at 40 cm from A. When R_2 is shunted by a resistance of 10 Ω, balance shifts to 50 cm. Find R_1 and R_2. (AB = 1 m):



F-5. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell ?

PART - II : OBJECTIVE QUESTIONS

*** Marked Questions are one or more than one correct type.**

SECTION (A) : DEFINITION OF CURRENT, CURRENT DENSITIES, DRIFT

A-1. Two wires each of radius of cross section r but of different materials are connected together end to end (in series). If the densities of charge carriers in the two wires are in the ratio 1 : 4, the drift velocity of electrons in the two wires will be in the ratio:

(A) 1 : 2 (B) 2 : 1 (C) 4 : 1 (D) 1 : 4

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

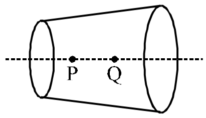
(A) The electrons move in the direction of $\vec{E}$

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



(A) $v_P = v_Q$ (B) $v_P < v_Q$ (C) $v_P > v_Q$ (D) Data insufficient

A-4.* A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section?

(A) drift speed (B) free-electron density.

(C) current density (D) the charge crossing in a given time interval

A-5.* When no current is passed through a conductor

(A) the average speed of a free electron over a large period of time is zero

(B) the free electrons do not move

(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

SECTION (B) : RESISTANCE

B-1. A resistor has a color code of green, blue; brown and silver. What is its resistance?

(A) 56 Ω ± 5% (B) 560 Ω ± 10% (C) 560 Ω ± 5% (D) 5600 Ω ± 10%

B-2.* The current density in a wire is 20 A/cm^2 and the electric field in the wire is 10 V/cm. If ρ = resistivity of material, σ = conductivity of the material then (in S.I. units) :

(A) $\rho = 50 \times 10^{-4}$ (B) $\rho = 500$ (C) $\sigma = 15 \times 10^{-3}$ (D) $\sigma = 200$

B-3. Which of the following quantities do not change when an ohmic resistor connected to a battery is heated due to the current?

(A) drift speed (B) resistivity

(C) resistance (D) number of free electrons

SECTION (C) : POWER, ENERGY, BATTERY, EMF AND TERMINAL VOLTAGE

C-1. In a battery connected in an electric circuit, the positive charge inside the battery

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

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

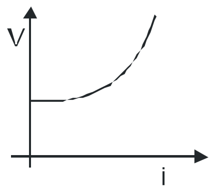
(C) always goes from the negative terminal to the positive terminal

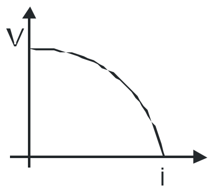
(D) does not move.

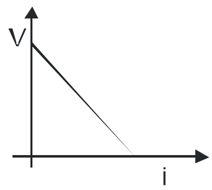
C-2. Power generated across a uniform wire connected across a supply is H. If the wire is cut into n equal parts and all the parts are connected in parallel across the same supply, the total power generated in the wire is

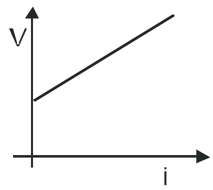
(A) $\frac{H}{n^2}$ (B) n^2H (C) nH (D) $\frac{H}{n}$

C-3. If internal resistance (r) of a cell is proportional to current (i) drawn from the cell. Then the best representation of terminal potential difference (v) of a cell with current drawn from cell will be:

(A) 

(B) 

(C) 

(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. A simple circuit contains an ideal battery and a resistance R. If a second resistor is placed in parallel with the first,

(A) the potential across R will decrease

(B) the current through R will decreased

(C) the current delivered by the battery will increase

(D) the power dissipated by R will increased.

C-6. In the figure a part of circuit is shown :

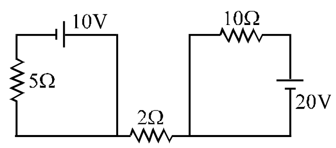
(A) current will flow from A to B

(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-7. In the figure shown the current through 2Ω resistor is

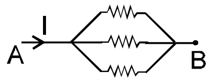


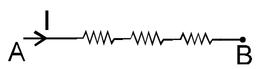
(A) 2 A (B) 0 A (C) 4 A (D) 6 A

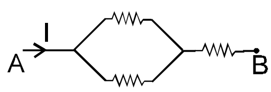
C-8. The efficiency of a cell when connected to a resistance R is 60%. What will be its efficiency if the external resistance is increased to six times.

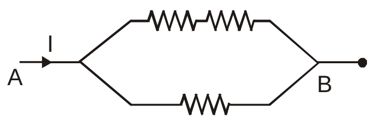
(A) 80 % (B) 90% (C) 55% (D) 95%

C-9. 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]**

(i) 

(ii) 

(iii) 

(iv) 

(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) $P_4 > P_3 > P_2 > P_1$

SECTION (D) : COMBINATION OF RESISTANCE

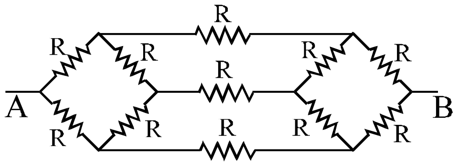
D-1. Two resistances of equal magnitude R and having temperature coefficient α_1 and α_2 respectively are connected in parallel. The temperature coefficient of the parallel combination is, approximately

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

D-2. The equivalent resistance between the terminal points A and B in the network shown in figure is :-

(A) $\frac{7R}{5}$ (B) $\frac{5R}{6}$

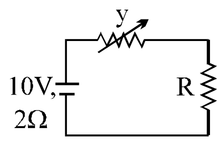
(C) $\frac{7R}{12}$ (D) $\frac{5R}{12}$



D-3. Two bulbs rated (25 W – 220V) and (100W – 220V) are connected in series to a 440 V line. Which one is likely to fuse?

(A) 25 W bulb (B) 100 W bulb (C) both bulbs (D) none

D-4. In the figure shown the power generated in y is maximum when y = 5Ω. Then R is :-

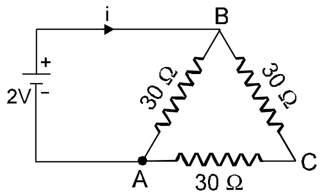


(A) 2 Ω (B) 6 Ω (C) 5 Ω (D) 3 Ω

D-5. The current i in the circuit of figure is - **[JEE - 1983]**

(A) $\frac{1}{45}$ amp. (B) $\frac{1}{15}$ amp.

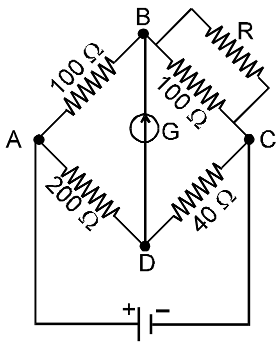
(C) $\frac{1}{10}$ amp. (D) $\frac{1}{5}$ amp.



D-6. 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]**

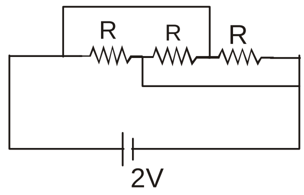
(A) 60 watt (B) 90 watt (C) 100 watt (D) 30 watt

D-7. The given Wheatstone bridge is showing no deflection in the galvanometer joined between the points B and D (Figure). Calculate the value of R.



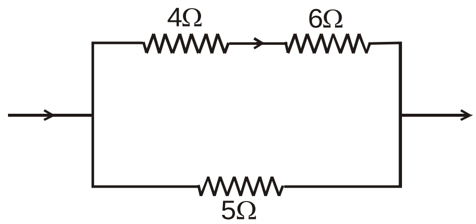
(A) 25 Ω (B) 50 Ω (C) 40 Ω (D) 100 Ω

D-8. 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

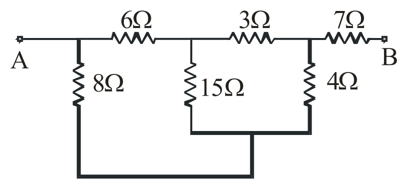
D-9. In the circuit shown in figure the heat produced in the 5Ω resistor due to the current flowing through it is 10 calories per second. **[JEE' 1981; 2M]**



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-10. The equivalent resistance between the points A and B is :



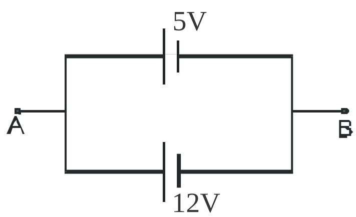
(A) $\frac{36}{7}$ Ω (B) $\frac{85}{7}$ Ω (C) 10 Ω (D) none of these

SECTION (E) : COMBINATION OF CELLS

E-1. 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?

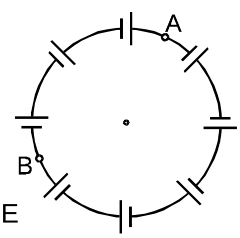
(A) one (B) two (C) three (D) none

E-2. Two cells of e.m.f. 5 V & 12 V are connected in parallel to each other between points A & B. The cell of e.m.f. 5 V is ideal but the cell of e.m.f. 12 V has internal resistance 2 Ω. The equivalent e.m.f. between A and B is:



(A) 5 V (B) not defined
(C) 20 V (D) 12 V

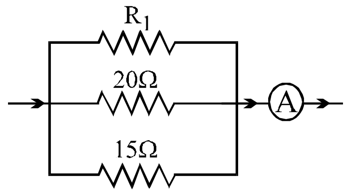
E-3. N sources of current with different emf's are connected as shown in figure. The emf's of the sources are proportional to their internal resistances, i.e. E = αR, where α is an assigned constant. The connecting wire resistance is negligible. The potential difference between points A and B dividing the circuit in n and N – n links



(A) 0 (B) nE/2 (C) NE (D) (N – n)E

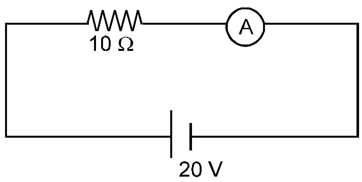
SECTION (F) : INSTRUMENT

F-1. In the given circuit the current flowing through the resisitance 20 ohms is 0.3 ampere while the ammetre reads 0.8 ampere. What is the value of R_1?



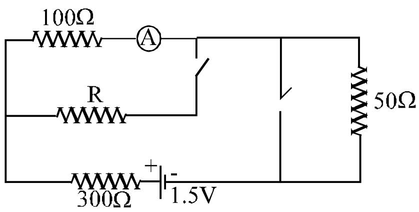
(A) 30 ohms (B) 40 ohms
(C) 50 ohms (D) 60 ohms

F-2. 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) $\frac{50}{93}$ A (C) $\frac{40}{53}$ A (D) $\frac{13}{50}$ A

F-3. In the circuit shown in figure the reading of ammeter is the same with both switches open as with both closed. Then find the resistance R. (ammeter is ideal)

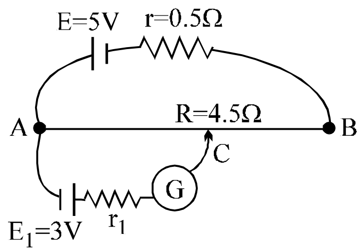


(A) 100 Ω (B) 200 Ω (C) 400 Ω (D) 600 Ω

F-4. A potentiometer wire has length 10 m and resistance 10Ω. It is connected to a battery of EMF 11 volt and internal resistance 1 Ω, then the potential gradient in the wire is :-

(A) 10 V/m (B) 1 V/m (C) 0.1 V/m (D) none

F-5. In the given potentiometer circuit length of the wire AB is 3 m and resistance is R = 4.5 Ω. The length AC for no deflection in galvanometer is :-



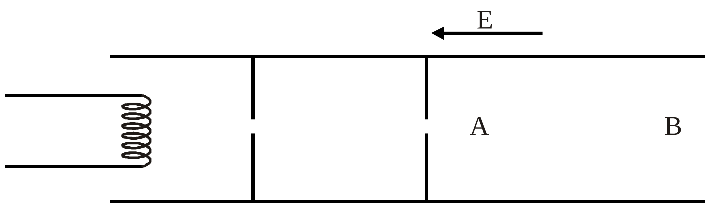
(A) 2 m (B) 1.8 m
(C) dependent on r_1 (D) none of these

F-6.* 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 200Ω. 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

PART-III : MATCH THE COLUMN

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



	Column-I		**Column-II**
(A)	Speed of an electron	(P)	Increases
(B)	Number of free electrons per unit volume	(Q)	Decreases
(C)	Current density	(R)	Remains same
(D)	Electric potential	(S)	any of the above is possible

2. **Match the following :**

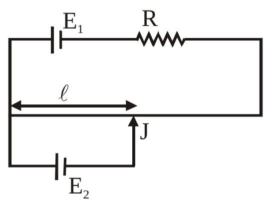
The following table gives the lengths of four copper rods at the same temperature, their diameters, and the potential differences between their ends.

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.

(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

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

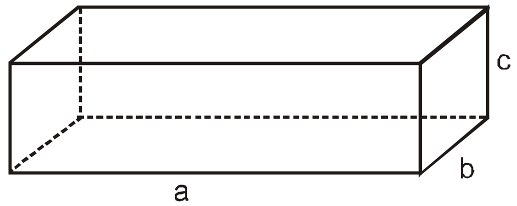


	Column-I		**Column-II**
(A)	If E_1 is increased	(P)	ℓ should increase
(B)	If R is increased	(Q)	ℓ should decrease
(C)	If E_2 is increased	(R)	ℓ should remain the same to again get the null point

Exercise # 2

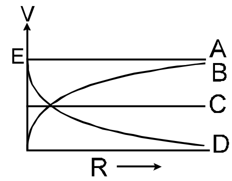
PART-I : OBJECTIVE QUESTIONS

1. 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.

2. 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 :

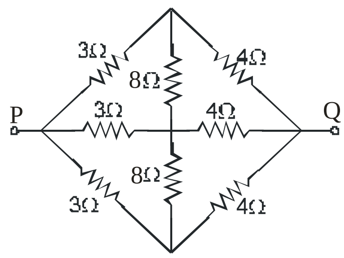


(A) A (B) B (C) C (D) D

3. 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 :

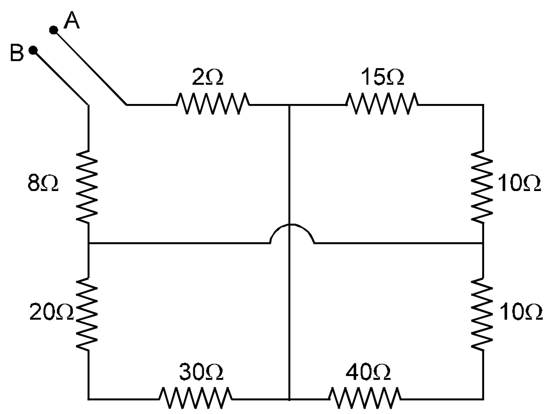
(A) 49 Ω (B) 25 Ω (C) 31 Ω (D) 43 Ω

4. The equivalent resistance between P and Q will be



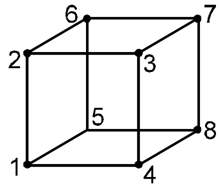
(A) 2/7 Ω
(B) 8 Ω
(C) 4/3 Ω
(D) 7/3 Ω

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



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

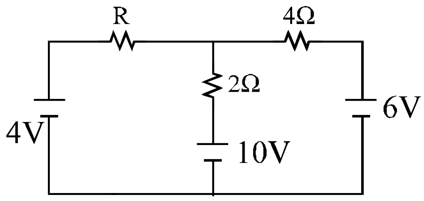
6. Find the resistance of a wire frame shaped as a cube (figure) when measured between points 1-7 and 1-3.



(A) $\frac{5}{3}R, \frac{3}{2}R$ (B) $\frac{5}{6}R, \frac{3}{4}R$

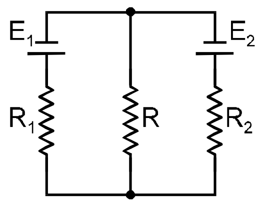
(C) $\frac{3}{5}R, \frac{5}{2}R$ (D) $\frac{6}{5}R, \frac{5}{6}R$

7. For what value of R in circuit, current through 4Ω resistance is zero.



(A) 2Ω (B) 1Ω (C) 3Ω (D) 4Ω

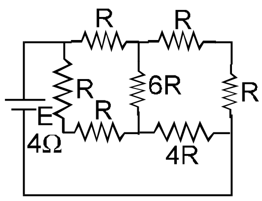
8. In a circuit shown in figure resistances R_1 and R_2 are known, as well as emf's E_1 and E_2. The internal resistances of the sources are negligible. At what value of the resistance R will the thermal power generated in it be the highest ?



(A) $R_1 + R_2$ (B) $R_1 - R_2$

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

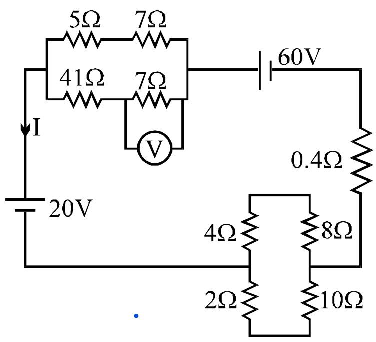
9. A battery of internal resistance 4 ohm is connected to the network of resistance as shown. In the order that the maximum power can be delivered to the network, the value of R in ohm should be : **[JEE - 1995]**



(A) 4/9 (B) 2

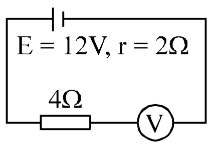
(C) 8/3 (D) 18

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



(A) 1.5 A, 2.5 V (B) 2.5 A, 3.5 V (C) 3.5 A, 1.5 V (D) 5.5 A, 2.5 V

11. By error, a student places moving-coil voltmeter V (nearly ideal) in series with the resistance in a circuit in order to read the current, as shown. The voltmeter reading will be



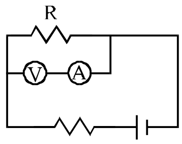
(A) 0 (B) 4V (C) 6V (D) 12V

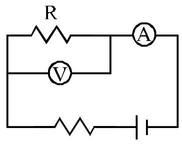
12. An ammeter and a voltmeter are joined in series to a cell. Their readings are A and V respectively. If a resistance is now joined in parallel with the voltmeter,

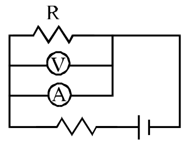
(A) both A and V will increase (B) both A and V will decrease

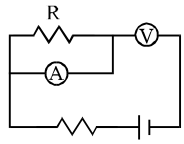
(C) A will decrease, V will increase (D) A will increase, V will decrease

13. Which of the following wiring diagrams could be used to experimentally determine R using ohm's law ? Assume an ideal voltmeter and an ideal ammeter.

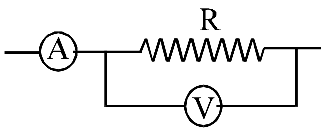
(A) 

(B) 

(C) 

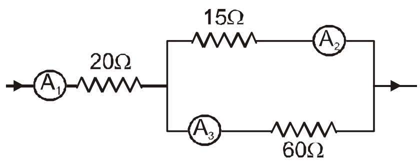
(D) 

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



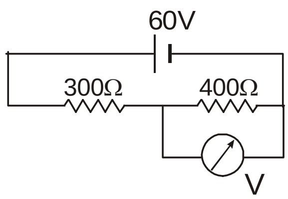
(A) 10 ohm (B) 20 ohm (C) 30 ohm (D) 40 ohm

15. If the reading of ammeter A_3 in figure is 0.75 A. Neglecting the resistances of the ammeters, the reading of ammeter A_1 and A_2 will be :



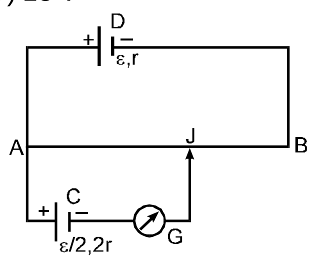
(A) 1.5 A, 2A (B) 3.75 A, 3 A (C) 4.5 A, 5A (D) 6 A, 3A

16. In the circuit shown, reading of the voltmeter connected across 400 Ω resistance is 30 V. If it is connected across 300 Ω resistance then reading will be



(A) 45 V (B) 32.5 V (C) 22.5 V (D) 18 V

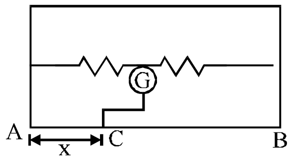
17. In the fig. the potentiometer wire AB of length L & resistance 9 r is joined to the cell D of e.m.f. ε & internal resistance r. The cell C's e.m.f. is $\varepsilon/2$ and its internal resistance is 2 r. The galvanometer G will show no deflection when the length AJ is:



(A) 4L/9 (B) 5L/9

(C) 7L/18 (D) 11L/18

18. In the given circuit, no current is passing through the galvanometer. If the cross-sectional diameter of AB is doubled then for null point of galvanometer the value of AC would **[IIT-JEE' 2003 (Scr)]**



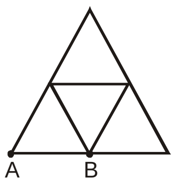
(A) x
(B) x/2
(C) 2x
(D) None

PART - II : SUBJECTIVE QUESTIONS

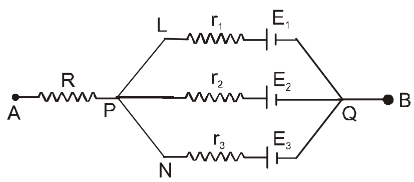
1. The current density in a cylindrical conductor of radius R varies according to the equation $J = J_0 \frac{r}{R}$, where r = radial distance from the axis and J_o is the current density at the surface of cylinder. If the current in conductor is $\frac{nJ_o \pi R^2}{3}$ then find n.

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 lengths of Q and P. **[REE - 96]**

3. In the diagram resistance between any two junctions is R. Equivalent resistance across terminals A and B is $\frac{xR}{18}$. Find x.



4. 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]**

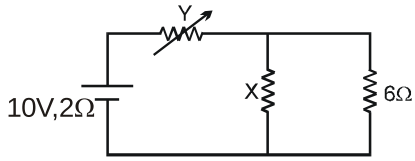


(i) Find potential difference (in volts) between the points A and B with A & B unconnected.

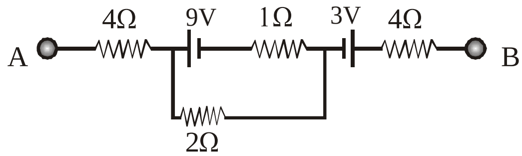
(ii) If r_2 is short circuited and the point A is connected to point B through a zero resistance wire, find the current (in Amp.) through the resistor R.

5. 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. If the number of parallel groups consisting of an equal number of cells connected in series, at which the external resistance generates the highest thermal power is n then find n.

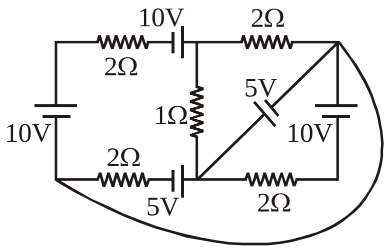
6. For a particular resistance X in the figure shown the thermal power generated in ' Y ' is maximum when Y 4 Ω. Then X is:



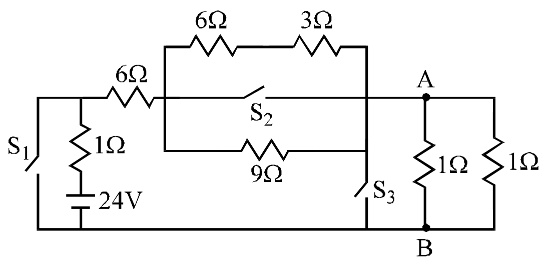
7. In the circuit shown in figure potential difference between point A and B is 16V. If the current passing through 2Ω resistance is $\frac{X}{10}$ A. Find X.



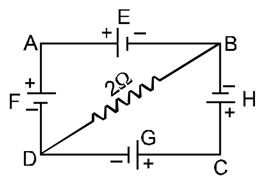
8. In the given circuit diagram, the current through the 1Ω resistor is given by I amp. Find 2I.



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



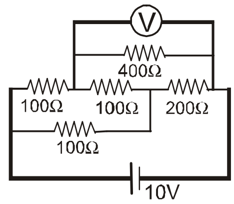
10. In the circuit shown in fig. E, F, G and H are cells of emf 2, 1,3 and 1 volts and their internal resistances are 2, 1, 3 and 1 ohm respectively.



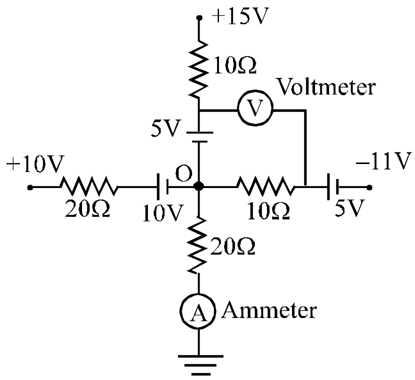
(i) If the potential difference between B and D is $\frac{n}{13}$ then find n.

(ii) If the potential difference across the terminals of the cell G is $\frac{m}{13}$ then find m.

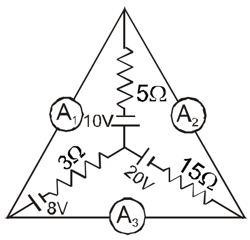
11. The potential difference across the resistance of 400 ohm, as measured by the voltmeter V of resistance 400 ohm is x/3 volt then find x. **[JEE' 1996, 5]**



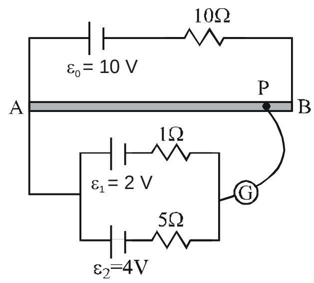
12. The potential of certain points in the circuit are maintained at the values indicated. The Voltmeter and Ammeter are ideal. The potential of the cross junction point in the circuit (at center O) is x/3 volt and the readings of Voltmeter is y/3 volt and Ammeter is z/15 A respectively then find value of x,y and z. All cells are ideal.



13. 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 the readings (in amperes) of meters A_1, A_2, and A_3 are X, Y and Z respectively then find the value of $\frac{17X + Z}{Y}$.

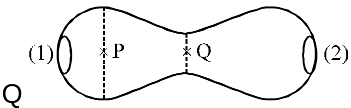


14. A battery of emf $\varepsilon_0 = 10$ V is connected across a 1 m long uniform wire having resistance 10Ω/m. Two cells of emf $\varepsilon_1 = 2$V and $\varepsilon_2 = 4$V having internal resistances 1Ω and 5Ω respectively are connected as shown in the figure. If a galvanometer shows no deflection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



PART - III : ONE OR MORE THAN ONE CORRECT OPTIONS

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



(A) the current at the cross-section P equals the current at the cross-section Q

(B) the electric field intensity at P is less than that at Q.

(C) the rate of heat generated per unit time at Q is greater than that at P

(D) the number of electrons crossing per unit area of cross-section at P is less than that at Q.

2. Potential difference across the terminals of a non ideal battery is

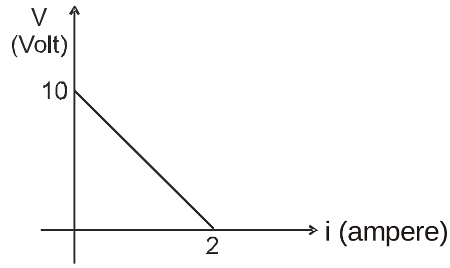
(A) zero when it is short circuited

(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.

3. 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)



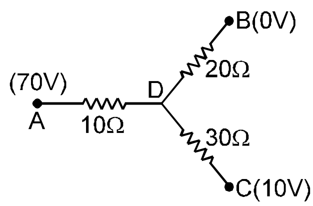
(A) internal resistance of the battery is 5Ω

(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.

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



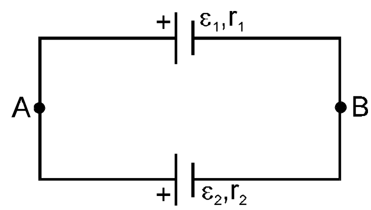
(A) Point D is at a potential of 40 V

(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.

5. 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.



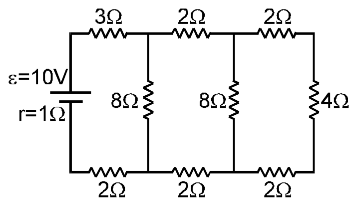
(A) One cell will supply energy to the other

(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) $V_A - V_B = \dfrac{(\varepsilon_1 r_2 + \varepsilon_2 r_1)}{r_1 + r_2}$

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



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

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;

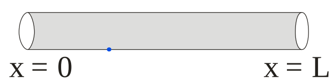
(A) Maximum power is delivered to the load if K = $\sqrt{\frac{NR}{r}}$.

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

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

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

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



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

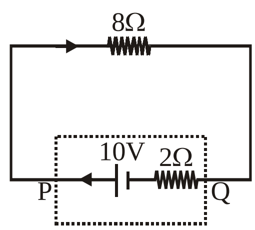
(A) Resistance of wire is $\frac{\rho_0 L}{A}.\ln(2)$

(B) Current density inside the wire is $\frac{V}{\rho_o L\ell n(2)}$

(C) Electric field at distance x is $\frac{V}{(L+x)\ell n(2)}$

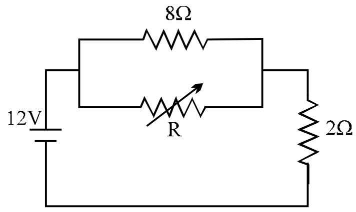
(D) Electric field at x = L is $\frac{V}{(\ln 2)L}$

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



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

10. The value of the resistance R in figure is adjusted such that power dissipated in the 2Ω resistor is maximum. Under this condition



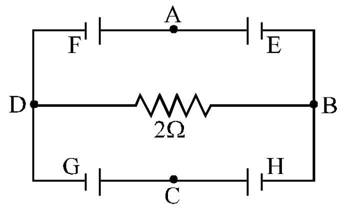
(A) R = 0

(B) R = 8Ω

(C) power dissipated in the 2 Ω resistor is 72 W.

(D) power dissipated in the 2 Ω resistor is 8 W.

11. In the circuit shown E, F, G and H are cells of e.m.f. 2V, 1V, 3V and 1V respectively and their internal resistances are 2Ω, 1Ω, 3Ω and 1Ω respectively.



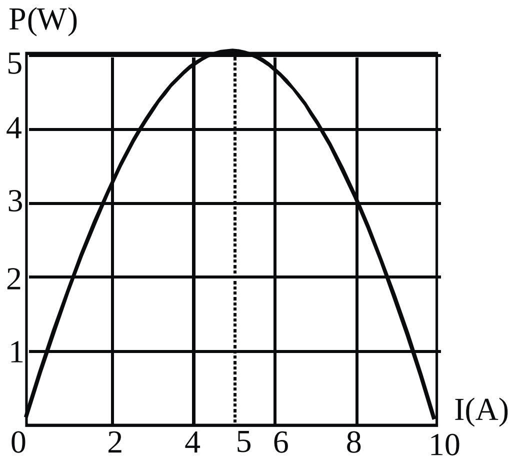
(A) $V_D - V_B = -2/13$ V

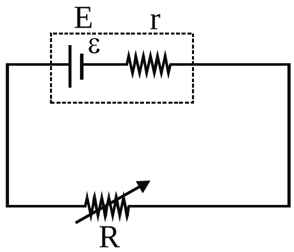
(B) $V_D - V_B = 2/13$ V

(C) $V_G = 21/13$ V = potential difference across G.

(D) $V_H = 19/13$ V = potential difference across H.

12. Figure shows the net power dissipated in R versus the current in a simple circuit shown.





(A) The internal resistance of battery is 0.2Ω

(B) The emf of battery is 2V

(C) R at which power is 5W is 2.5 Ω

(D) At i = 2A, power is 3.2 W

13. 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]**

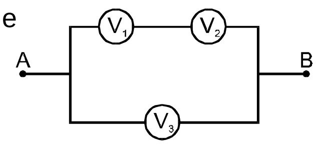
(A) 50 V range with 10 kΩ resistance is series

(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

14. 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 :



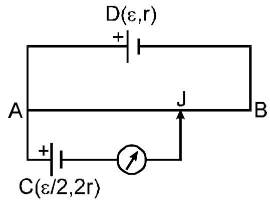
(A) $V_1 = V_2$

(B) $V_1 \neq V_2$

(C) $V_1 + V_2 = V_3$

(D) $V_1 + V_2 > V_3$

15. 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 $\geq$ r.

(D) Balance cannot be obtained.

16. Mark out the correct options.

(A) An ammeter should have small resistance.

(B) An ammeter should have large resistance.

(C) A voltmeter should have small resistance.

(D) A voltmeter should have large resistance.

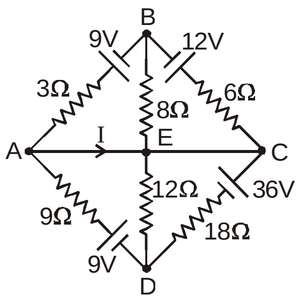
17. In a potentiometer wire experiment the emf of a battery in the primary circuit is 20V and its internal resistance is 5Ω. There is a resistance box in series with the battery and the potentiometer wire, whose resistance can be varied from 120Ω to 170Ω. Resistance of the potentiometer wire is 75Ω. The following potential differences can be measured using this potentiometer.

(A) 5V (B) 6V (C) 7V (D) 8V

PART - IV : COMPREHENSION

Comprehension # 1

In the shown circuit all cells are ideal.



1. The magnitude of current through 8Ω resistor connected between points B and E is equal to :

(A) 0.25 A (B) 0.5 A (C) 1 A (D) 2 A

2. The magnitude of current I through conducting wire connected between A and E is equal to :

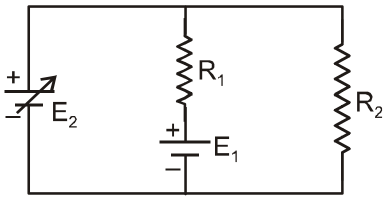
(A) $\frac{1}{3}$ A (B) 1 A (C) $\frac{4}{3}$ A (D) Zero

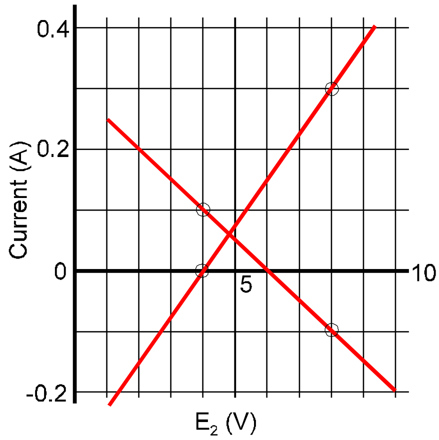
3. Let potential at points B and D be V_B and V_D respectively. Then $V_B - V_D$ is equal to :

(A) 4V (B) – 4V (C) 20 V (D) – 20 V

Comprehension # 2

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)





4. The value of emf E_1 is

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

5. The resistance R_1 has value

(A) 10 Ω (B) 20 Ω (C) 30 Ω (D) 40 Ω

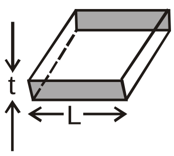
6. The resistance R_2 is equal to :

(A) 10 Ω (B) 20 Ω (C) 30 Ω (D) 40 Ω

Exercise # 3

PART - I : JEE (ADVANCED) / IIT-JEE PROBLEMS (PREVIOUS YEARS)

1. Consider a thin square sheet of side L and thickness t, made of a material of resistivity ρ. The resistance between two opposite faces, shown by the shaded areas in the figure is : **[IIT-JEE 2010; 3/163, –1]**



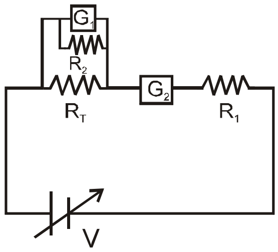
(A) directly proportional to L (B) directly proportional to t

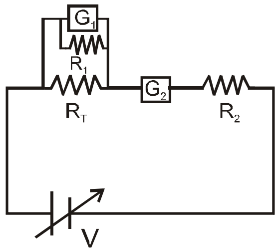
(C) independent of L (D) independent of t

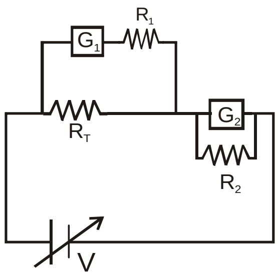
2. Incandescent bulbs are designed by keeping in mind that the resistance of their filament increases with increase in temperature. If at room temperature, 100 W, 60 W and 40 W bulbs have filament resistances R_{100}, R_{60} and R_{40}, respectively, the relation between these resistance is : **[IIT-JEE 2010; 3/163, –1]**

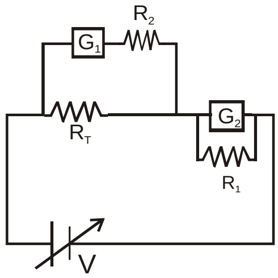
(A) $\frac{1}{R_{100}} = \frac{1}{R_{40}} + \frac{1}{R_{60}}$ (B) $R_{100} = R_{40} + R_{60}$ (C) $R_{100} > R_{60} > R_{40}$ (D) $\frac{1}{R_{100}} > \frac{1}{R_{60}} > \frac{1}{R_{40}}$

3. To verify Ohm's law, a student is provided with a test resistor R_T, a high resistance R_1, a small resistance R_2, two identical galvanometers G_1 and G_2, and a variable voltage source V. The correct circuit to carry out the experiment is : **[IIT-JEE 2010; 3/163, –1]**

(A) 

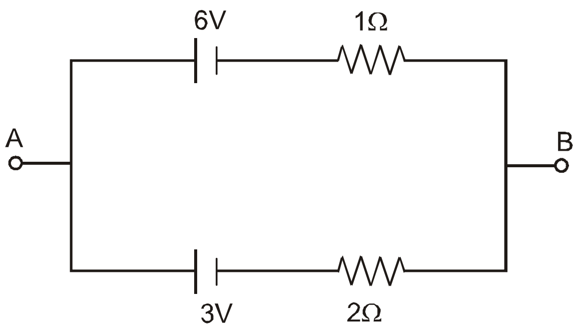
(B) 

(C) 

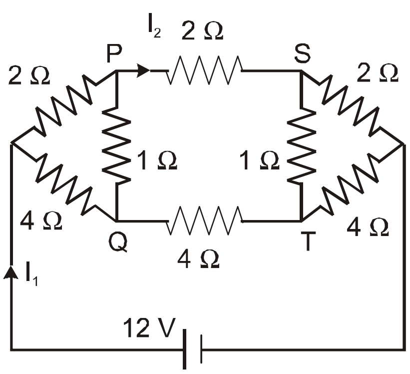
(D) 

4. 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]**

5. 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]**



6. 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.

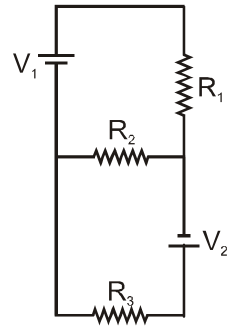
7. Heater of electric kettle is made of a wire of length L and diameter d. It takes 4 minutes to raise the temperature of 0.5 kg water by 40K. This heater is replaced by a new heater having two wires of the same material, each of length L and diameter 2d. The way these wires are connected is given in 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.

8. 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 $R_1 = R_2 = R_3$

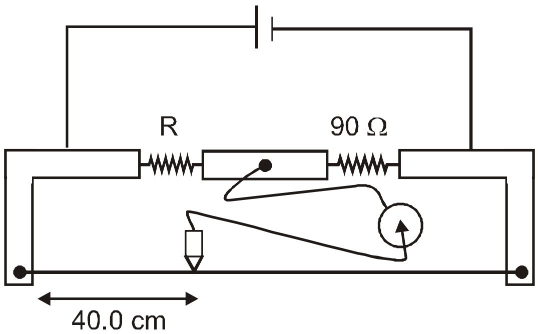
(B) $V_1 = V_2$ and $R_1 = 2R_2 = R_3$

(C) $V_1 = 2V_2$ and $2R_1 = 2R_2 = R_3$

(D) $2V_1 = V_2$ and $2R_1 = R_2 = R_3$

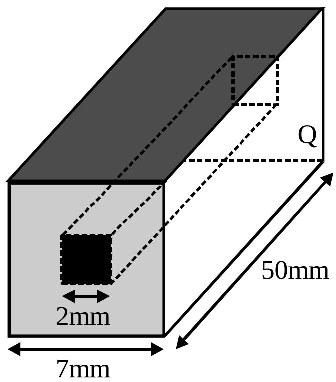
9. A galvanometer gives full scale deflection with 0.006 A current. By connecting it to a 4990 Ω resistance, it can be converted into a voltmeter of range 0-30 V. If connected to a $\frac{2n}{249}\Omega$ resistance, it becomes an ammeter of range 0-1.5 A. The value of n is. **[JEE (Advanced) 2014; 3/60, –1]**

10. 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) $135 \pm 0.23\Omega$

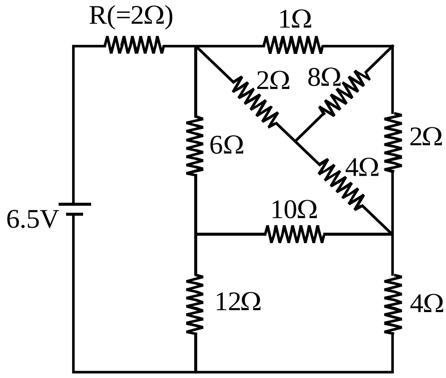
11. In an aluminum (Al) bar of square cross section, a square hole is drilled and is filled with iron (Fe) as shown in the figure. The electrical resistivities of Al and Fe are $2.7 \times 10^{-8}\ \Omega$ m and $1.0 \times 10^{-7}\Omega$m, respectively. The electrical resistance between the two faces P and Q of the composite bar is: **[JEE (Advanced) 2015; 3/60]**



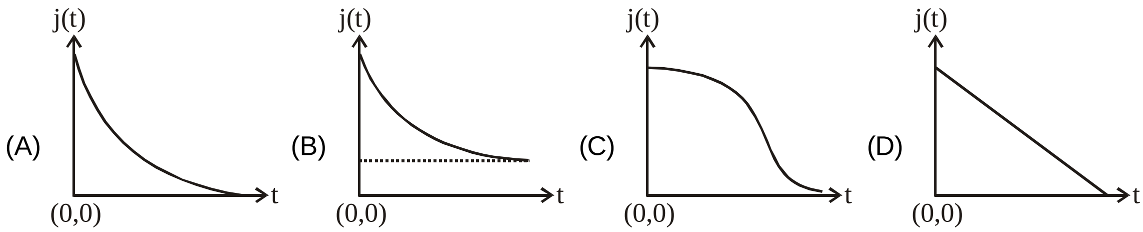
(A) $\frac{2475}{64}\mu\Omega$ (B) $\frac{1875}{64}\mu\Omega$ (C) $\frac{1875}{49}\mu\Omega$ (D) $\frac{2475}{132}\mu\Omega$

12. In the following circuit, the current through the resistor R (= 2Ω) is I Amperes. The value of I is

[JEE (Advanced) 2015; 3/60]



13. 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]**



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

(A) The temperature distribution over the filament is uniform **[JEE (Advanced) 2016]**

(B) The resistance over small sections of the filament decreases with time

(C) The filament emits more light at higher band of frequencies before it breaks up

(D) The filament consumes less electrical power towards the end of the life of the bulb

15.* 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]**

(A) The maximum voltage range is obtained when all the components are connected in series

(B) The maximum voltage range is obtained when the two resistors and one galvanometer are connected in series, and the second galvanometer is connected in parallel to the first galvanometer

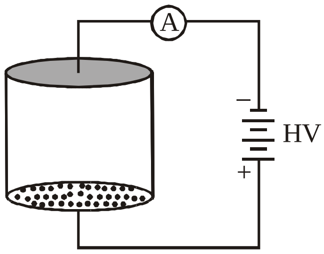
(C) The maximum current range is obtained when all the components are connected in parallel

(D) The maximum current range is obtained when the two galvanometers are connected in series and the combination is connected in parallel with both the resistors.

Paragraph for Questions No. 16 and 17

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 collision between the balls and the interaction between them is negligible. (Ignore gravity)

[JEE (Advanced) 2016]



16. Which of the following statements is correct ?

(A) The balls will bounce back to the bottom plate carrying the opposite charge they went up with

(B) the balls will execute simple harmonic motion between the two plates

(C) The balls will bounce back to the bottom plate carrying the same charge they went up with

(D) The balls will stick to the top plate and remain there

17. The average current in the steady state registered by the ammeter in the circuit will be :

(A) Proportional to $V_0^{1/2}$ (B) Proportional to V_0^2

(C) Proportional to the potential V_0 (D) Zero

18. A moving coil galvanometer has 50 turns and each turn has an area 2×10^{-4} m^2. The magnetic field porduced by the magnet inside the galvanometer is 0.02 T. The torsional constant of the suspension wire is 10^{-4} N m 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 50 Ω. This galvanometer is to be converted into an ammeter capable of measuring current in the range 0 – 1.0 A. 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]

19. Two identical moving coil galvanometer have 10 Ω resistance and full scale deflection at 2 µA current. One of them is converted into a voltmeter of 100 mV full scale reading and the other into an Ammeter of 1 mA full scale current using appropriate resistors. These are then used to measure the voltage and current in the Ohm's law experiment with R = 1000 Ω resistor by using an ideal cell. Which of the following statement(s) is/are correct ? **[JEE Advanced-2019]**

(A) The measured value of R will be 978 Ω < R < 982 Ω.

(B) The resistance of the Voltmeter will be 100 kΩ.

(C) The resistance of the Ammeter will be 0.02 Ω (round off to 2nd decimal place)

(D) If the ideal cell is replaced by a cell having internal resistance of 5 Ω then the measured value of R will be more than 1000 Ω.

PART - I : JEE(MAIN) / AIEEE PROBLEMS (PREVIOUS YEARS)

1. 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) $\frac{\alpha_1+\alpha_2}{2}$, $\frac{\alpha_1+\alpha_2}{2}$

2. 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%

3. 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

4. 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

5. 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

6. 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.

7. 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]

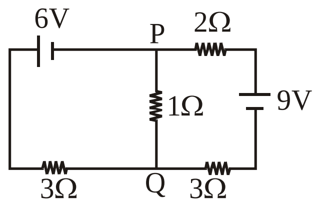
(1) 8 A (2) 10 A (3) 12 A (4) 14 A

8. 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^{-6} Ωm (2) 1.6×10^{-5} Ωm (3) 1.6×10^{-8} Ωm (4) 1.6×10^{-7} Ωm

9. In the circuit shown, the current in the 1Ω resistor is :- **[JEE (Main) 2015; 4/120, –1]**



(1) 0.13 A, from Q to P (2) 0.13 A, from P to Q

(3) 1.3 A, from P to Q (4) 0A

10. A galvanometer having a coil resistance of 100Ω gives a full scale deflection, when a current of 1 mA is passed through it. The value of the resistance, which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10A, is :- **[JEE (Main) 2016; 4/120, –1]**

(1) 3Ω (2) 0.01Ω (3) 2Ω (4) 0.1Ω

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

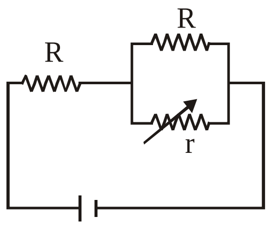
(1) $r_s = 1\Omega$ in series with galvanometer

(2) $r_s = 0.5\ \Omega$ in parallel with the galvanometer

(3) $r_s = 0.5\ \Omega$ in series with the galvanometer

(4) $r_s = 1\ \Omega$ in parallel with galvanometer

12. In the circuit shown, the resistance r is a variable resistance. If for r = f R, the heat generation in r is maximum then the value of f is : **[JEE (Main) 2016, Online]**



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

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

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

14. Which of the following statements is false ? **[JEE (Main) 2017]**

(1) A rheostat can be used as a potential divider

(2) Kirchhoff's second law represents energy conservation

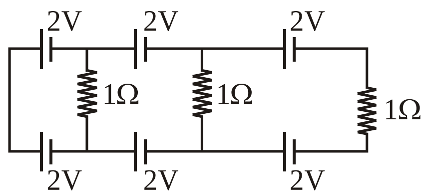
(3) Wheatstone bridge is the most sensitive when all the four resistances are of the same order of magnitude.

(4) In a balanced wheatstone bridge if the cell and the galvanometer are exchanged, the null point is disturbed.

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

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

16. In the above circuit the current in each resistance is :- **[JEE (Main) 2017]**



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

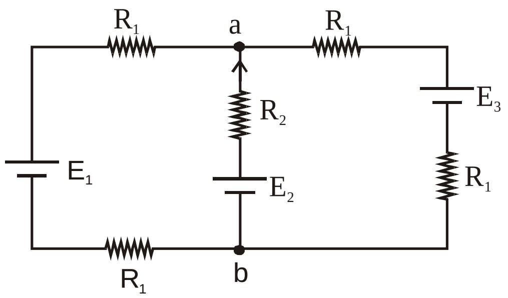
17. In a potentiometer experiment, it is found that no current passes through the galvanometer when the terminals of the cell are connected across 52 cm of the potentiometer wire. If the cell is shunted by a resistance of 5 Ω, a balance is found when the cell is connected across 40 cm of the wire. Find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

(1) 1.5 Ω (2) 2 Ω (3) 2.5 Ω (4) 1 Ω

18. On interchanging the resistances, the balance point of a meter bridge shifts to the left by 10 cm. The resistance of their series combination is 1 kΩ. How much was the resistance on the left slot before interchanging the resistances ? **[JEE (Main) 2018]**

(1) 505 kΩ (2) 550 kΩ (3) 910 kΩ (4) 990 kΩ

19. For the circuit shown, with $R_1 = 1.0\Omega$, $R_2 = 2.0\ \Omega$, $E_1 = 2$ V and $E_2 = E_3 = 4$ V, the potential difference between the points 'a' and 'b' is approximately (in V) : **[JEE (Main) 2019-S1_April]**

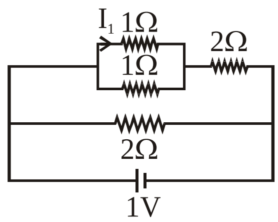


(1) 2.7 (2) 3.3 (3) 2.3 (4) 3.7

20. A 200 Ω resistor has a certain color code. If one replaces the red color by green in the code, the new resistance will be : **[JEE (Main) April 2019-S1]**

(1) 100 Ω (2) 400 Ω (3) 500 Ω (4) 300 Ω

21. The current I_1 (in A) flowing through 1 Ω resistor in the following circuit is : **[JEE (Main) Jan. 2020-S1]**



(1) 0.5 (2) 0.2 (3) 0.25 (4) 0.4

22. In a building there are 15 bulbs of 45 W, 15 bulbs of 100 W, 15 small fans of 10 W and 2 heaters of 1 kW. The voltage of electric main is 220 V. The minimum fuse capacity (rated value) of the building will be: **[JEE (Main) Jan. 2020-S2]**

(1) 10 A (2) 25 A (3) 15 A (4) 20 A

23. Four resistances of 15Ω, 12Ω, 4Ω and 10Ω respectively in cyclic order to form Wheatstone's network. The resistance that is to be connected in parallel with the resistance of 10Ω to balance the network is ________ Ω. **[JEE-Main 2020-S3_Jan]**

Answers

Exercise # 1

PART - I

SECTION (A) :

A-1. 31 C , $\frac{31}{3}$ A **A-2.** (i) Q = 600 C (ii) n = 75/2 x 10^{20}

SECTION (B) :

B-1. 470 ± 5% Ω. **B-2.** Iρ/A **B-3.** 10 A. **B-4.** 3 : 1

B-5. T_1 **B-6.** 0.2 %

SECTION (C) :

C-1. $\sqrt{R_1R_2}$

C-2. (a) E = 10 V each ; (b) (A) act as a load and (B) act as source ; (c) V_A = 11V, V_B = 9 V
(d) P_A = 11 W, P_B = 9 W (e) Heat rate = 1 W each ; (f) 10 W each ; (g) 11V, 9V (h) 11W, –9W

C-3. (a) all equal (b) y, then x and z equal (c) x, z equal, y

C-4. (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-5. $\frac{25}{9}$ V = 2.78 V, $\frac{5}{18}$ A = 0.278 A **C-6.** (a) 10 Ω. (b) 1600 J

C-7. 5 A, 74 V, 49 V (+ve terminal is connected at point B)

SECTION (D):

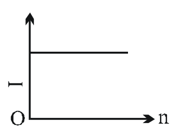
D-1. 15 A **D-2.** $\frac{R}{3}$ **D-3.** $\left(\frac{\rho_{Cu}\rho_{Ni}}{3\rho_{Cu}+\rho_{Ni}}\right)\frac{\ell}{\pi r^2}$ **D-4.** $\frac{125}{4}$ = 31.25 watt

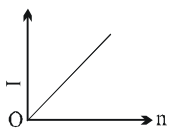
D-5. R_f = 2Ω.

D-6. (a) V_3 = 3V, V_2 = 2V, V_4 = 4V (b) 10 W (c) 1 W (d) 9W (e) 9V (f) 4 Ω resistance (g) 2 W.

D-7. (a) 3.7 V (b) 3.7 V **D-8.** (i) 2 Ω; (ii) 1.5 A **D-9.** $W_1 < W_2 < W_3$

SECTION (E) :

E-1. **16A** **E-2.** 

E-3. 

E-4. **5 V**

E-5. $V_Q - V_P$ =21/5 = 4.2 V, I = 35/2 mA = 17.5 mA (Q to P)

E-6. 12A, – 20W **E-7.** 1 A from D to B

SECTION (F) :

F-1. (i) 50 V; (ii) 60 V **F-2.** (i) 200 Ω (ii) $1.1-\frac{4}{3}=-0.23$ V

F-3. r = (60) $\left(\frac{72}{60}-1\right)=12\,\Omega$ **F-4.** $\frac{10}{3}\Omega,\ 5\Omega$ **F-5.** 2.25 V

PART - II

SECTION (A) :

A-1. (C) **A-2.** (D) **A-3.** (C) **A-4.** (B,D) **A-5.** (C,D)

SECTION (B) :

B-1. (B) **B-2.** (A,D) **B-3.** (D)

SECTION (C) :

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

SECTION (D) :

D-1. (D) **D-2.** (A) **D-3.** (A) **D-4.** (D) **D-5.** (C)
D-6. (B) **D-7.** (A) **D-8.** **(C)** **D-9.** (B) **D-10.** (B)

SECTION (E) :

E-1. (A) **E-2.** (A) **E-3.** (A)

SECTION (F) :

F-1. (D) **F-2.** (A) **F-3.** (D) **F-4.** (B) **F-5.** (D)
F-6. (A,B,C)

PART - III

1. (A) $\rightarrow$ P; (B) $\rightarrow$ Q; (C) $\rightarrow$ R; (D) $\rightarrow$ P **2.** (A) $\rightarrow$q; (B) $\rightarrow$p; (C) $\rightarrow$p; (D) $\rightarrow$q
3. (A) $\rightarrow$ Q; (B) $\rightarrow$ P; (C) $\rightarrow$ P

Exercise # 2

PART - I

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

PART - II

1. 2 **2.** 4 **3.** 11 **4.** (i) 2 (ii) 2 **5.** 3
6. 3 **7.** 35 **8.** 5 **9.** 1
10. (i) 2 (ii) 21 **11.** 20 **12.** 4, 37, 1 **13.** 41 **14.** 47

PART - III

1.	(A,B,C,D)	**2.**	(A,B,D)	**3.**	(A,B,C)	**4.**	(A,B,D)	**5.**	(A,B,C,D)
6.	(A), (D)	**7.**	(A,D)	**8.**	(A,B,C)	**9.**	(B,D)	**10.**	(A,C)
11.	(A,C,D)	**12.**	(A,B,D)	**13.**	(B,C)	**14.**	(B,C)	**15.**	(B,C)
16.	(A,D)	**17.**	(ABC)						

PART - IV

1.	(C)	**2.**	(D)	**3.**	(A)	**4.**	(B)	**5.**	(B)
6.	(D)								

Exercise # 3

PART - I

1.	(C)	**2.**	(D)	**3.**	(C)	**4.**	4	**5.**	5
6.	(A,B,C,D)	**7.**	(B,D)	**8.**	(A,B,D)	**9.**	5	**10.**	(C)
11.	(B)	**12.**	1	**13.**	(A)	**14.**	(C,D)	**15.**	(B,C)
16.	(A)	**17.**	(B)	**18.**	05.55	**19.**	(A,C)		

PART - I

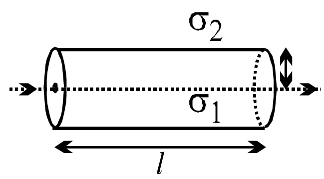
1.	(4)	**2.**	(2)	**3.**	(3)	**4.**	(3)	**5.**	(4)
6.	(4)	**7.**	(3)	**8.**	(2)	**9.**	(1)	**10.**	(2)
11.	(2)	**12.**	(3)	**13.**	(1)	**14.**	(4)	**15.**	(3)
16.	(2)	**17.**	(1)	**18.**	(2)	**19.**	(2)	**20.**	(3)
21.	(2)	**22.**	(4)	**23.**	10.00				

Ranker Problems

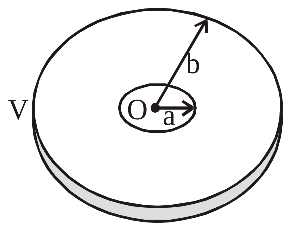
SUBJECTIVE QUESTIONS

1. A long cylinder with uniformly charged surface and cross sectional radius a = 1.0 cm moves with a constant velocity v = 10 m/s, along its axis. An electric field strength at the surface of the cylinder is equal to E = 0.9 KV/cm. Find the resulting covection current, that is, the current caused by mechanical transfer of charge.

2. A long conductor of circular cross-section has radius r and lengh *l* as shown in the figure. The conductivity of the material near the axis is σ_1 and increases linearly with the distance from axis and becomes σ_2 near the surface. Find the resistance of the conductor if the current enters from the one end and leaves from the other end.

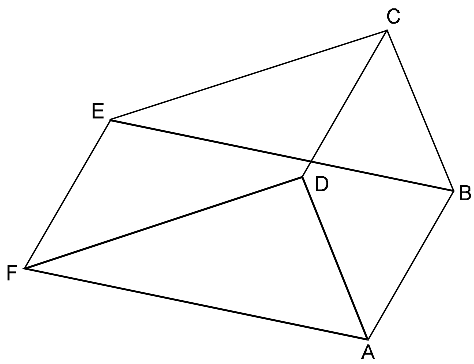


3. A circular portion is cut of a disc of thickness t, its resistivity is ρ and radii of disc are a and b (b > a). A potential difference is maintained between outer and inner cylindrical surfaces of the disc. What is resistance of the disc ?



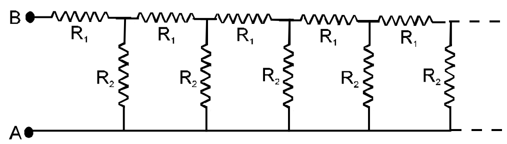
4. When a cell is connected in a circuit, a current I_1 flows in the circuit. When one more identical cell is connected in series with the first one, a current I_2 is found to flow in the circuit. When same cell is connected in parallel with the first one, the current is found to be I_3. Show that: $3I_2I_3 = 2I_1(I_2 + I_3)$.

5. In the circuit shown in figure, all wires have equal resistance r. Calculate equivalent resistance between A and B?

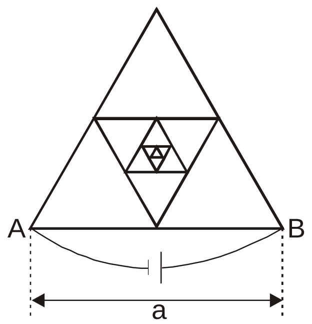


6. A battery is made by joining m rows of identical cells in parallel. Each row consists of n cells joined in series. This battery sends a maximum current I in a given external resistor. Now the cells are so arranged that instead of m rows, n rows are joined in parallel and each row consists of m cells joined in series. Find the current through the same external resistor (Total number of cells which is equal to nm is connected)

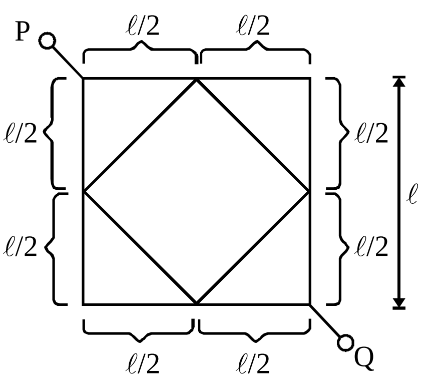
7. Consider an infinite ladder network shown in fig. A voltage is applied between points A and B. If the voltage is halved after each section, find the ratio R_1/R_2. Suggest a method to terminate it after a few sections without introducing much error in attenuation. **[REE - 1998]**



8. 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.



9. If the wire has resistivity ρ and cross sectional area A, the equivalent resistance between P and Q is :-

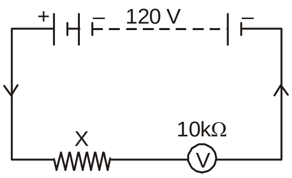


(A*) $\frac{\rho\ell}{\sqrt{2}A}$ (B) $\frac{\sqrt{2}\rho\ell}{A}$ (C) $\frac{2\rho\ell}{A}$ (D) $\frac{\rho\ell}{A}$

10. 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]**

11. 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]**

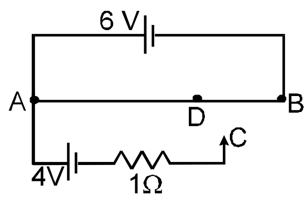
12. A D.C. supply of 120 volt is connected to a large resistance X. A volt meter of resistance 10 kΩ, placed in series in the circuit reads 4 volts. What is the value of X? What do you think is the purpose in using a voltmeter, instead of an ammeter, to determine the large resistance X?



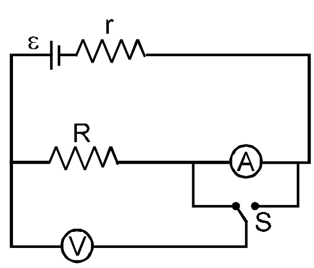
13. A galvanometer having 30 divisions has current sensitivity of 20 μA/div. It has a resistance of 25 ohm. How will you convert it to an ammeter measuring upto 1 ampere ? How will you now convert this ammeter into a voltmeter reading upto 1 volt ? **[REE - 1987]**

14. 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]**

15. 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) ?

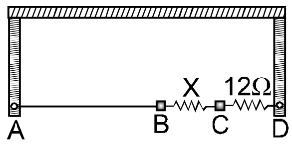


16. The emf ε and the internal resistance r of the battery shown in figure are 4.3 V and 1.0 Ω respectively. The external resistance R is 50 Ω. The resistances of the ammeter and voltmeter are 2.0 Ω and 200 Ω respectively. (a) Find the readings of the two meters. (b) The switch is thrown to the other side. What will be the readings of the two meters now ?



17. 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]**

18. 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]**

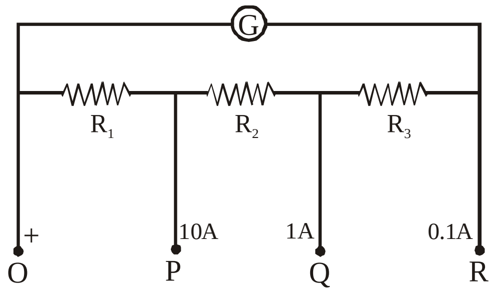


(a) Are there positive and negative terminals on the galvanometer?

(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.

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



20. A galvanometer having 50 divisions provided with a variable shunt is used to measure the current as an ammeter when connected in series with a resistance of 90 Ω and a battery of internal resistance 10 Ω. It is observed that when the shunt resistance are 10 Ω, 50 Ω, respectively the deflection are respectively 9 & 30 divisions. What is the resistance of the galvanometer? Further if the full scale deflection of the galvanometer movement is 300 mA, find the emf of the cell.

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

(i) internal resistance r of the cell

(ii) range of the ammeter and voltmeter

(iii) full scale deflection current of the galvanometer

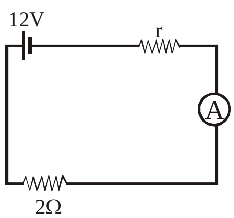


Fig. (i)

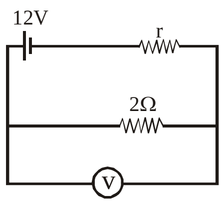
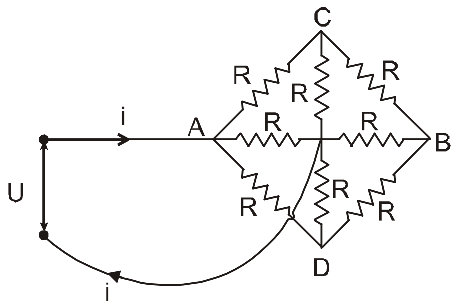


Fig. (ii)

22. 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.

23. The resistance of each resistor in the circuit diagram shown in figure is the same and equal to R. The voltage across the terminals is U. If the value of current i in leads is $\frac{15}{n}\frac{U}{R}$ then find n. (Neglect resistance of leads)



Answers

RANKER PROBLEMS

1. 5×10^{-7} A

2. $\frac{1}{R} = \frac{\pi r^2}{3l}(2\sigma_2 + \sigma_1)$

3. $\frac{\rho}{2\pi t}\ln\left(\frac{b}{a}\right)$

4. $\frac{3r}{5}$

6. $\frac{2mnI}{m^2+n^2}$

7. $\frac{1}{2}$

8. $R_{AB} = \frac{a\rho(\sqrt{7}-1)}{3}$

9. $\frac{\rho\ell}{\sqrt{2}A}$

10. 4/9 kg/sec; 450 sec

11. 400Ω, $\frac{16}{5} = 3.2$ V, $\frac{68}{21} = 3.238$ V

12. 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.

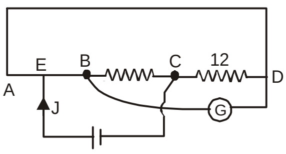
13. $S = \frac{15 \times 10^{-3}}{1 - 0.6 \times 10^{-3}} \approx 0.015\ \Omega$ in parallel ; R = 0.985 Ω in series.

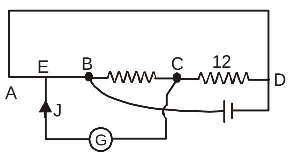
14. $S = \frac{0.1}{10 - 10^{-3}} \cong 0.01\Omega$, yes, E = 2V, r = 0.5 – 0.01 = 0.49 Ω.

15. (a) 6 V, 2 V (b) AD = $\frac{200}{3}$ = 66.7 cm (c) zero (d) 6 V, – 1.5 V, no such point D exists.

16. (a) 0.1 A, 4.0 V; (b) $\frac{1083.6 \times 200}{10652 \times 252} = 0.08$ A, $4.3 - \frac{1083.6}{10652} = 4.2$ V

17. $\frac{R_{BD}}{R_{AC}} = \frac{59}{35}$

18. (a) No; (b) 

or 

(c) 8 Ω

19. $R_1 = 0.0278\Omega$, $R_2 = 0.25\Omega$, $R_3 = 2.5\Omega$

20. 233.3Ω, 144V

21. (i) 1.01Ω (ii) 0-5 A, 0-10V, (iii) 0.05 A

22. (a) t_s = 30 min. (b) $t_p = \frac{20}{3}$ min.

23. 7

Self Assessment Test

JEE (ADVANCED) PAPER-1

SECTION-1 : ONE OPTION CORRECT (Maximum Marks - 12)

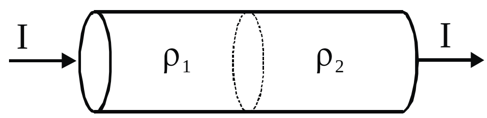
1. A resistance R of thermal coefficient of resistivity = α is connected in parallel with a resistance = 3R, having thermal coefficient of resistivity = 2α. Find the value of α_{eff}.

(A) $\frac{5}{4}\alpha$ (B) $\frac{5}{2}\alpha$ (C) $\frac{5}{3}\alpha$ (D) 3α

2. 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) .

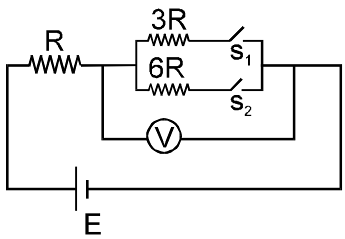
(A) $I_0/13$ (B) $I_0/5$ (C) $I_0/8$ (D) $5I_0/13$

3. Two long straight cylindrical conductors with resistivities ρ_1 and ρ_2 respectively are joined together as shown in figure. If current I flows through the conductors, the magnitude of the total free charge at the interface of the two conductors is :-



(A) zero (B) $\frac{(\rho_1-\rho_2)I\varepsilon_0}{2}$ (C) $\varepsilon_0 I|\rho_1-\rho_2|$ (D) $\varepsilon_0 I|\rho_1+\rho_2|$

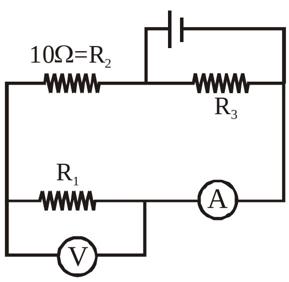
4. In the circuit shown in figure reading of voltmeter is V_1 when only S_1 is closed, reading of voltmeter is V_2 when only S_2 is closed and reading of voltmeter is V_3 when both S_1 and S_2 are closed. Then



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

SECTION-2 : ONE OR MORE THAN ONE CORRECT (Maximum Marks - 32)

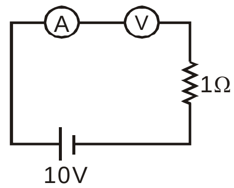
5. In the shown circuit, the power dissipated in resistor R_3 is 30W. The reading of ammeter and voltmeter are 500 mA and 10V respectively. Ammeter, voltmeter and battery are ideal.



(A) the resistance R_1 is 20Ω (B) the resistance R_3 is $7.5\ \Omega$

(C) emf of battery is 15V (D) power supplied by battery is 37.5 W

6. In the shown figure



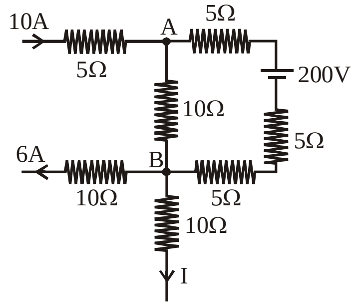
(A) If both ammeter and voltmeter are ideal, then reading of ammeter is zero, reading of voltmeter is 10 V

(B) If both ammeter and voltmeter are ideal, then reading of ammeter is 10 A, reading of voltmeter is 0 V

(C) If ammeter is non ideal, voltmeter is ideal, then reading of ammeter is less than 10A, reading of voltmeter is10 V

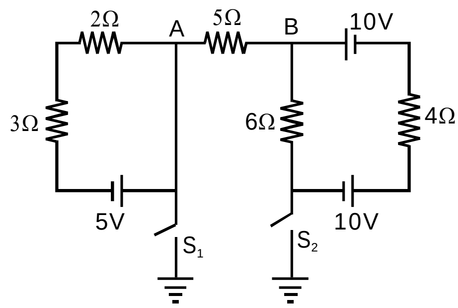
(D) If ammeter is ideal, voltmeter is non ideal, then reading of ammeter is less than 10 A, reading of voltmeter is less than 10V

7. In the given diagram choose correct options :-



(A) The value of I is 4A
(B) The current from the cell is 4A.
(C) Voltage drop across AB is 140 V.
(D) The current from the cell is 10A.

8. In the figure shown current will flow through branch A–B if



(A) both S_1 and S_2 are open.
(B) S_1 is open and S_2 is closed.
(C) S_1 is closed and S_2 is open.
(D) S_1 and S_2 both are closed.

9. A metal sphere of radius a is surrounded by a concentric metal sphere of inner radius of b, where b > a. The space between the spheres is filled with a material whose electrical conductivity σ varies with the electric field strength E as $\sigma = kE$ where k is a constant. A potential difference V is maintained between spheres.

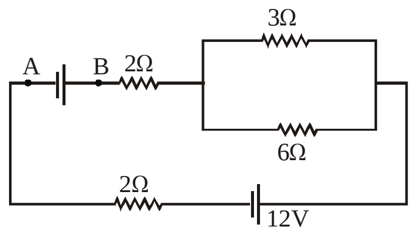
(A) Current is $4\pi r^2 kE^2$, where $(a < r < b)$

(B) Current is $2\pi r^2 kE^2$, where $(a < r < b)$

(C) Potential difference between spheres is $V = \sqrt{\frac{I}{4\pi k}}\ell n\left(\frac{b}{a}\right)$ where I is total current

(D) Potential difference between spheres is $V = \sqrt{\frac{I}{2\pi k}}\ell n\left(\frac{b}{a}\right)$ where I is total current

10. The current through the 3Ω resistor (as shown in figure) is 2A. Then the value of $V_A – V_B$ will be



(A) 20 V (B) 6 V (C) –6V (D) – 20 V

11. A student used potentiometer and galvanometer to make variable range voltmeter (V) as shown. He used this voltmeter in figure–2.

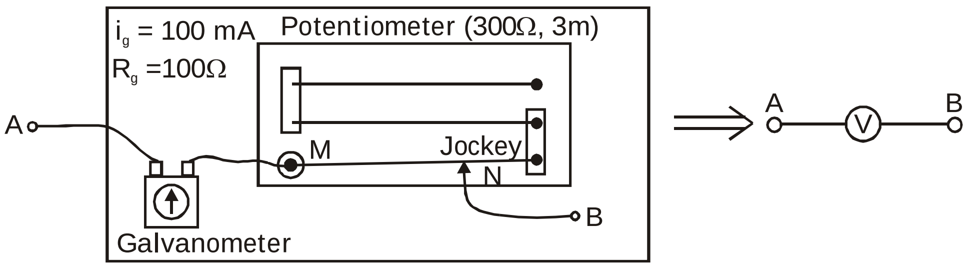
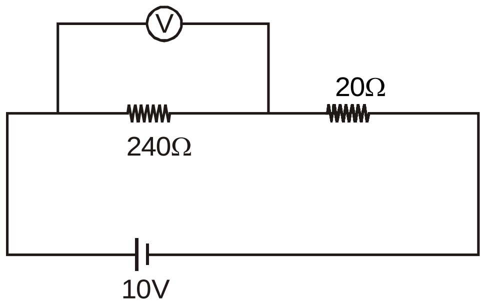


Figure-1 : MN – length of potentiometer wire between point M and N



Figure–2

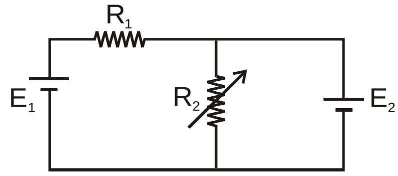
(A) Reading of voltmeter is 8V when MN = 20 cm

(B) Reading of voltmeter is 7V when MN = 140 cm

(C) Maximum range of voltmeter is 40 volt

(D) Sensitivity of voltmeter decreases with increase in length MN

12. In the circuit shown both cells are ideal and of fixed emf, the resistor of resistance R_1 has fixed resistance and the resistance of resistor R_2 can be varied (but the value of R_2 is not zero). Then :



(A) The electric power delivered to resistor of resistance R_1 is independent of R_2

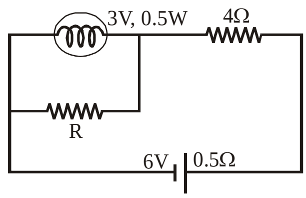
(B) Electric power delivered by E_1 is independent of R_2

(C) Electric power delivered by E_1 is dependent on R_2

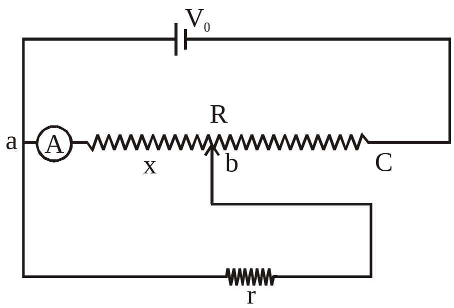
(D) Electric power delivered to R_1 is dependent on R_2.

SECTION-3 : NUMERICAL VALUE TYPE (Maximum Marks - 18)

13. The value of the resistance R in the circuit shown below so that electric bulb consumes the rated power is :-



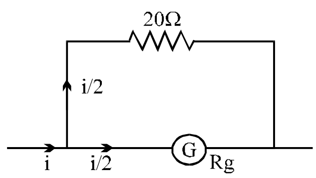
14. A constant voltage V_0 (= 12V) is applied to a potential divider of resistance R (= 4Ω), connected to an ideal ammeter. A constant resistor r (= 2 Ω) is connected to the sliding contact of the potential divider (as shown). Find the minimum current (in A) measured by ammeter.



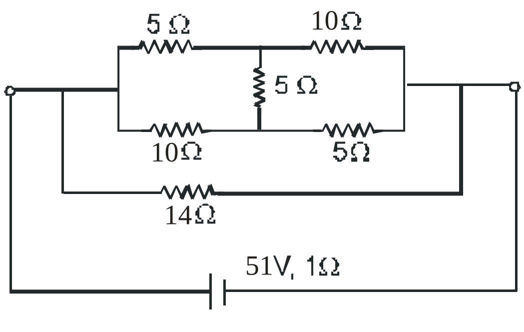
15. An ammeter and a voltmeter are connected in series to a battery with an emf 6V. When a certain resistance is connected in parallel with the voltmeter, the reading of the voltmeter decrease 2 times, whereas the reading of the ammeter increase the same number of times. Find the voltmeter reading (in volts) after the connection of the resistance.

16. ABCD is a square where each side is uniform wire of resistance 1 Ω. A point E on CD is 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 are equipotential. If CE: ED = $\sqrt{n}$: 1 then find n.

17. In a galvanometer, the deflection becomes one half when the galvanometer is shunted by a 20Ω resistor. The galvanometer resistance is



18. Find the current through battery in amperes**.**



Answers

SAT (Self Assessment Test)

1.	(A)	**2.**	(A)	**3.**	(C)	**4.**	(B)	**5.**	(A,B,C,D)
6.	(A,C,D)	**7.**	(A,B,C)	**8.**	(D)	**9.**	(A,C)	**10.**	(B,D)
11.	(A,C,D)	**12.**	(A,B)	**13.**	6	**14.**	2	**15.**	2
16.	2	**17.**	20	**18.**	9				