20. CURRENT ELECTRICITY

1. INTRODUCTION

Transfer of charge across a cross-section of a conducting medium constitutes an electric current. Any conductor in general offers some resistance to the flow of electric current through it. This means an electric current cannot flow continuously all by itself in a conductor. An electric source is needed to continuously drive electric current through a conductor. Some work is done or energy is supplied by the source to drive the current in a conducting medium. In this chapter we will study the laws and phenomena that govern the flow of electric current in conductors. We will discuss the factors that affect the electrical properties of conductors, what constitutes an electric circuit and the laws of division of current in various branches of a complicated network. Electricity has indeed transformed our lives beyond imagination. Electric energy is used everywhere, right from the lights of our homes, our electronic appliances, computers, automobiles, heavy machines used in our industries, hospitals, aircrafts etc. We will mainly focus on direct current circuits and sources in this chapter. The techniques of circuit analysis developed in this chapter form the backbone of electrical and electronics science and engineering.

2. ELECTRIC CURRENT

In this chapter we will be mainly dealing with current in a conducting medium. Electric current is defined as the rate of flow of electric charge through a certain cross-section of a conductor. If there is to be an electric current through a given surface, there must be a net flow of charge through the surface. The free electrons (conduction electrons)in an isolated conductor are in random chaotic motion in all directions and on an average same number of electrons passes through each side of any imaginary surface. Thus, the net charge passing through any surface in any time interval is zero, and thus the current through the conductor is zero. However, if we connect the ends of the conductor to a battery, an electric field is applied inside the conductor from positive terminal to negative terminal, and the motion of the electrons is biased opposite to the electric field, with the result that an ordered motion with a certain average velocity $\vec{u}$ opposite to the direction of electric field is superimposed on the chaotic motion of the electrons. Thus there is a net flow of negative charge opposite to the electric field, or equivalently flow of net positive charge in the direction of electric field. Thus an electric current flows through the conductor in the direction of electric field.

If charge dq passes through an imaginary surface in time dt, then the current I through that surface is defined as $I = \frac{dq}{dt}$ (definition of current). The direction of the current is the direction of flow of positive charge carriers, or opposite to the flow of electrons.

Also, we can write dq = i dt. The charge that passes though the surface in a time interval extending from 0 to t is given as: $q = \int dq = \int_0^t i\,dt$ (the current i in general varies with time).

The SI unit for current is coulomb per second or the ampere (A), which is an SI base unit:

$$1 \text{ ampere} = 1\text{ A} = 1 \text{ coulomb per second} = 1\text{ Cs}^{-1}.$$

3. CURRENT DENSITY

In general the electric current is distributed non-uniformly over the surface through which it passes. So to analyse the current through an elementary surface of infinitesimal area at any point inside the conducting medium, we introduce a current density vector $\vec{j}$.The magnitude of current density vector at any point P, is equal to the ratio of current dI through an elementary surface perpendicular to the direction of current at P to the area $dS_{\perp}$ of this elementary surface. The direction of $\vec{j}$ is the same as the notion of dI at that point, or the direction of velocity vector $\vec{u}$ of the ordered motion of positive charge carriers.

If ΔI be the current through the area $\Delta S_{\perp}$,the magnitude of average current density is $j = \frac{\Delta I}{\Delta S_{\perp}}$.

The magnitude of current density at the point P is $j = \frac{dI}{dS_{\perp}}$.

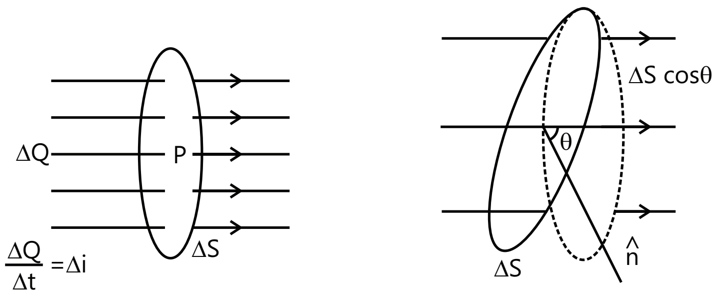


Figure 20.1: Current and current density

If the area dS is not perpendicular to the current dI through it, i.e. the normal to the area makes some angle θ with the notion of the current, then the current density is given as,

$$j = \frac{dI}{dS\cos\theta} \quad \text{or,} \quad dI = jdS\cos\theta$$

If $d\vec{S}$ be the area vector corresponding to the area dS, we have $dI = \vec{j}.d\vec{S}$

For a finite area, $I = \int \vec{j}.d\vec{S}$

An electric current is not a vector quantity. It does not follow the laws of vector addition. The current density is a vector quantity.

PLANCESS CONCEPTS

Direction of Current

- Direction of drift of electrons is in the opposite direction of electric field in conducting wires.
- It is not always along the length of the wire (direction of cross section). We take the component of the velocity along the wire.

Yashwanth Sandupatla (JEE 2012, AIR 821)

4. DRIFT SPEED

A conductor contains a large number of loosely bound electrons called free electrons or conduction electrons. These electrons move randomly in all directions within the entire volume of the conductor, (see Fig. 20.2) and in this process keep on colliding with the atoms/molecules/ions of the conductor, changing their direction of motion at each collision.

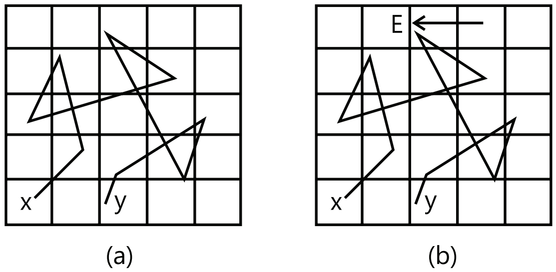


Figure 20.2: Random motion of electron inside conductor

When an electric field is applied inside the conductor, each electron experiences a force in the direction opposite to the field. The chaotic motion of electrons gets biased in favour of this force. At each collision with a molecule, the electron changes its direction of motion and moves with a random velocity but gains an additional velocity $v_e = \frac{eE}{m}\tau$ in the direction opposite to the electric field till the next collision happens and the direction of its motion again changes abruptly. As the average time τ between successive collisions is small, the electrons slowly and steadily drift opposite to the applied field (see Fig. 20.3) with an average drift speed v_d.

The distance drifted during successive collisions can be written as

$$\ell = \frac{1}{2}a(\tau)^2 = \frac{1}{2}\left(\frac{eE}{m}\right)(\tau)^2$$

The drift speed will be given by the relation: $v_d = \frac{\ell}{\tau} = \frac{1}{2}\left(\frac{eE}{m}\right)\tau$

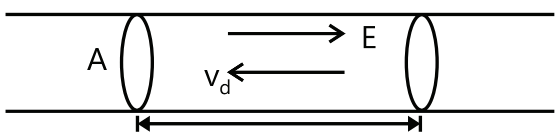


Figure 20.3: Calculating drift speed

Current density can be expressed in terms of the drift speed. Consider a cylindrical conductor of cross-sectional area A in which electric field E exists. Consider a length $L = v_d\Delta t$ of the conductor. The volume of this portion is $Av_d\Delta t$. If there are n free electrons per unit volume of the conductor, the number of free electrons in this portion are nA v_d Δt. All these electrons cross the area A in time Δt. Thus, the charge crossing this cross-section in time Δt is

$\Delta Q = neAv_d\,\Delta t$ or current through the conductor is, $I = \frac{\Delta Q}{\Delta t} = neAv_d$

Therefore current density is: $j = \frac{I}{A} = nev_d$

Illustration 1: If n =8.5 × 10^{28} m^{-3},how long does an electron take to drift from one end of 3 m long wire to its other end? The area of cross section of the wire is 2.0 × 10^{-6} $m^2$and it is carrying a current of 3.0 Ampere. **(JEE MAIN)**

Sol: For constant p.d. across conductor the electrons drifts with constant drift velocity across it. If we find the drift velocity, the time to drift across wire of constant length is easily found out

Given that: (i) Number density n = 8.5 × 10^{28} m^{-3} (ii) Cross-sectional area A = 2.0 × $10^{-6}m^2$

(iii) Current I = 3 A (iv) Charge on electron e = 1.6 × 10^{-19} C

Current in terms of drift speed is expressed as $I = neAv_d$

$\Rightarrow v_d = \frac{I}{neA}$.

Now time taken to cross the length ℓ of the wire is:

$$t = \frac{\ell}{v_d} = \frac{neA\ell}{I} = \frac{8.5\times10^{28}\times1.6\times10^{-19}\times2.0\times10^{-6}\times3}{3}$$

$t = 2.7 \times 10^4$ s.

5. RESISTANCE AND RESISTIVITY

When same potential difference is applied across the ends of two conductors of same shape and size but made of different materials, different currents flow through them. The property of the conductor that makes the difference here is its electrical resistance. The resistance between any two points of a conductor is the ratio of applied potential difference V across those points to the current I that flows through the conductor. Thus resistance R is given as:

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

The SI unit for resistance is the volt per ampere. This unit occurs so often that we give it a special name, the ohm (symbol Ω); that is,

1 ohm = 1 Ω = 1 volt per amp = 1 V/A.

The resistivity ρ of the material is defined as: $\rho = \frac{E}{j}$

Unit of resistivity $= \frac{V/m}{A/m^2} = \frac{V}{A}m = \Omega$.m. In vector form we can write: $\vec{E} = \rho\vec{J}$.

Another property of material is conductivity σ. It is the reciprocal its resistivity, so

$$\sigma = \frac{1}{\rho}$$

The SI unit conductivity is the reciprocal of Ω-m or mho-m^{-1} is sometimes used. (mho is ohm backwards).

5.1 Calculating Resistance from Resistivity

Resistance is a property of a conductor. Resistivity is the property of a material. If we know the resistivity of a material such as copper, we can calculate the resistance of a conductor made of that material. Let A be the cross-sectional area of a wire and L be its length, then resistance is $R = \rho\frac{L}{A}$

Illustration 2: If a wire is stretched to 'n' times its original length how does the R change? On stretching, volume remains constant. **(JEE MAIN)**

Sol: For any deformation in wire the resistance varies inversely w.r.t the area of cross-section of wire, but directly w.r.t. the length of the conductor at the given instant of time.

As the volume remains constant, AL = A'L' ⇒ AL = A'nL (Given L' = nL)

$$\Rightarrow \frac{A'}{A} = \frac{1}{n} \text{ and } \frac{L'}{L} = n$$

Now $R \propto \frac{L}{A} \Rightarrow \frac{R'}{R} = \frac{L'}{A'}\times\frac{A}{L} = n\times n = n^2$ $\Rightarrow R' = n^2 R$

Illustration 3: Resistance of a hollow cylinder **(JEE ADVANCED)**

Consider a hollow cylinder of length L and inner radius a and outer radius b, as shown in Fig. 20.4. The material has resistivity ρ.

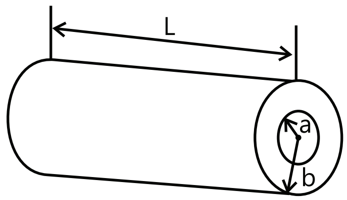


Figure 20.4

(a) Suppose a potential difference is applied between the ends of the cylinder that produces a current flowing parallel to the axis. What is the resistance measured?

(b) If instead the potential difference is applied between the inner and outer surfaces so that current flows radially outward, what is the resistance measured?

Sol: The resistance of the conductor is calculated as $R = \frac{\rho L}{A}$ where A is the area of conductor perpendicular to the direction of current. The larger the area, the lower the resistance offered to charge drifting across conductor.

(a) When a potential difference is applied between the ends of the cylinder, current flows parallel to the axis. In this case, the cross-sectional area perpendicular to the current is $A = \pi(b^2 - a^2)$, and the resistance is given by

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

(b) When the current flows radially outwards, the area of cross-section perpendicular to the current will be the area of cylindrical surface coaxial with the cylinder and its value will increase as the radius of the cylindrical surface increases. Consider an elementary coaxial cylindrical shell of infinitesimal thickness having inner radius r and outer radius r + dr and length L. Its contribution to the resistance of the system is given by $dR = \frac{\rho dr}{2\pi rL}$ where $A = 2\pi rL$ is the area normal to the direction of current flow. The total resistance of the system becomes

$$R = \int_a^b \frac{\rho dr}{2\pi rL} = \frac{\rho}{2\pi L}\log\left(\frac{b}{a}\right)$$

5.2 Colour Code for Carbon Resistors

The resistance value and percentage accuracy for carbon resistors are indicated by a colour code.

The resistor has a set of coloured bands on it. Each colour corresponds to a single digit number.

The first two bands indicate the first two significant digits of the resistance in ohms. The third band indicates the decimal multiplier (10^n) and the last band gives the tolerance or possible variation in the value of the resistance. If the fourth band is absent, it implies that the tolerance is $\pm$ 20%.

Table 20.1: Resistor colour codes

Colour	Number	Multiplier	Tolerance (%)
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	

Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	$\pm$ 5%
Silver		10^{-2}	$\pm$ 20%
No colour			$\pm$ 20%

Example

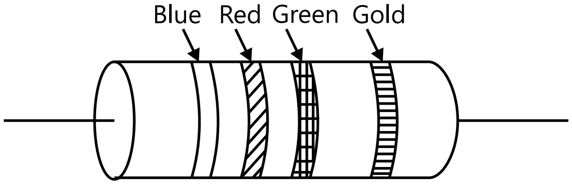


Figure 20.5: Calculating resistance by colour codes

Hint: An easy way to remember the sequence of colours is to memorize the following phrase: **"B B ROY goes Bombay via Gate Way"**, the letters in capital (B, B, R, O, Y, G, B, V, G, W) are the first letters of the colours of the table for Resistor colour code.

In the example shown in the Fig. 20.5, first colour is Blue and stands for numeric value 6, Red corresponds to 2, Green corresponds to 10^5, Gold is $\pm$ 5%, so the value of resistance is (62 × 10^5 Ω) $\pm$ 5%

6. TEMPERATURE DEPENDENCE

Resistivity of a material changes with temperature. If α is the temperature coefficient of resistivity, then change in resistivity with change in temperature is given as $\rho - \rho_0 = \rho_0 \alpha (T - T_0)$.

Here T_0 is the initial temperature and r_0 is the resistivity at that temperature. Usually T_0 = 293 K (room temperature). The sizes of degrees on Celsius or Kelvin scales are identical. We can use any of these scales in this equation as only the temperature difference between two states is used here.

6.1 Thermistor

A thermistor is a type of resistor whose temperature coefficient of resistivity is quite large as compared to standard resistor. A small change in temperature produces a large change in resistivity. In Negative Temperature Coefficient (NTC) thermistors, resistance decreases with increase in temperature. In Positive Temperature Coefficient (PTC) thermistors, resistance increases with increase in temperature. The thermistor is dipped in the bath whose temperature is to be measured. The current is supplied by a battery. If the temperature increases, the current changes because of the change in resistivity. Thus, by noting the change in the current, one can find the change in temperature. A typical thermistor can easily measure a change in temperature of the order of 10^{-3} °C.

Illustration 4: The resistance of a Platinum wire at ice point (0°C) =5 Ω and steam point (100°C) =5.23 Ω. When the thermometer is inserted in a hot bath the resistance is 5.795 Ω. Find the temperature of hot bath? **(JEE MAIN)**

Sol: The resistance of the wire varies linearly with change in temperature as $R_T = R_0(1+\propto\Delta T)$.

Resistance of wire over temperature difference $\Delta T = 100^oC$ is $R_{100} = R_0[1 + \alpha(100-0)] \Rightarrow 5.23 = 5(1 + 100\alpha)$

$\Rightarrow \alpha = \dfrac{0.23}{500}$ For resistance of wire as 5.795 Ω the temperature of wire is found as

$R_T = 5[1 + \alpha (T - 0)] = 5.795$

$$\Rightarrow t = \left(\frac{5.795}{5} - 1\right)\frac{500}{0.23}$$

$\Rightarrow t = 345.65^oC$

6.2 Superconductor

Superconductor is a material which offers zero resistance to flow of electric current through it. Superconductivity is a phenomena exhibited by certain materials wherein there resistivity drops abruptly to zero when they are cooled below a certain temperature. This temperature is called the critical temperature for that material. Above the critical temperature, the resistivity of the material has a non-zero value and increases with increase in temperature.

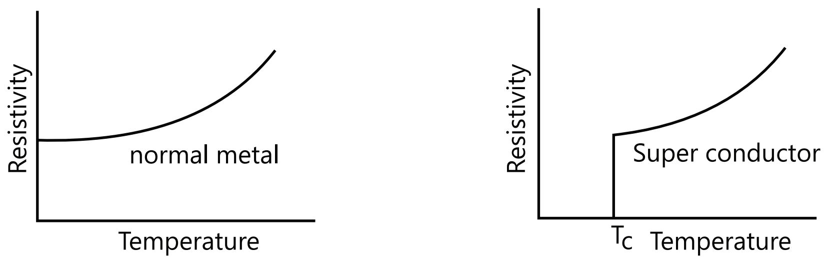


Figure 20.6: Variation of resistance with respect to temperature

7. OHM'S LAW

German scientist George Simon Ohm stated the following law known as Ohm's law:

The current (I) flowing through a conductor is directly proportional to the potential difference (V) across its ends provided the physical conditions (temperature, strain, etc.) do not change, i.e.

$$I \propto V$$

or $$\frac{V}{I} = \text{constant} = R$$

or $$V = IR$$

R is called the resistance of the given conductor. The quantity 1/R is called conductance.

Now for a wire of length L and area of cross-section A we have

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

or $$\frac{I}{A} = j = \frac{V}{L\rho} = \sigma\frac{V}{L}$$

or $$j = \sigma E$$

Limitation of OHM'S Law

A material in which Ohm's law is not valid is called non-ohmic material. The non-validity can be of following types:

(a) Voltage (V) is not proportional to current (I)

(b) The relation between 'V' and 'I' is not unique which means there is more than one value of V for the same current E.g. Ga, As

(c) The relation between 'V' and 'I' depends on the sign of V. This mean, if 'I' is the current in a conducting medium for a certain V, then on reversing the direction of V keeping its magnitude fixed, the current of the same magnitude is not produced in the opposite direction. E.g. In a diode.

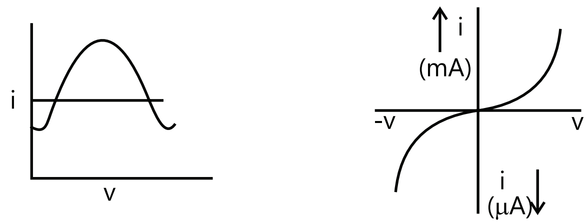


Figure 20.7: Variation of current with respect to voltage in non-ohmic devices

Illustration 5: Calculate the resistance of an aluminium wire of length 50cm and cross sectional area 2.0 mm^2. The resistivity of aluminium is $\rho = 2.6\times10^{-8}\ \Omega m$ **(JEE MAIN)**

Sol: The variation of resistance with length and area is shown as $R = \frac{\rho L}{A}$

The resistance of the wire is $R = \rho\frac{L}{A} = \frac{(2.6\times10^{-8}\Omega m)\times(0.50m)}{2\times10^{-6}m^2} = 0.0065\ \Omega$

8. COMBINATION OF RESISTANCE

8.1 Series Combination

(a) Same current flows through each resistance (See Fig. 20.8).

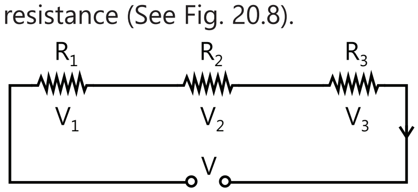


Figure 20.8: Series combination of three resistances

(b) Voltage across each resistance is directly proportional to the value of resistance. $V_1=IR_1$, $V_2=IR_2$

(c) Sum of the voltages across individual resistances is equal to the total voltage applied across the combination i.e.

$V = V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots$

$V = IR_1 + IR_2 + IR_3 + \ldots\ldots\ldots\ldots$

$\frac{V}{I} = R_1 + R_2 + R_3 + \ldots\ldots\ldots = R$

where, R = equivalent resistance.

Note: If n resistances (each equal to R) are connected in series there resultant will be nR (See Fig. 20.9).

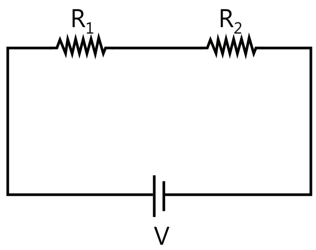


Figure 20.9: Series combination of two resistances

(d) For a series combination of two resistance

(i) Equivalent resistance $R = R_1 + R_2$

(ii) $I = V / (R_1 + R_2)$

(iii) V_1 (voltage across R_1) $= IR_1 = \dfrac{R_1 V}{R_1 + R_2}$

(iv) V_2 (voltage across R_2) $= IR_2 = \dfrac{R_2 V}{R_1 + R_2}$

8.2 Parallel Combination

(a) Same potential difference is applied across each resistance (See Fig. 20.10).

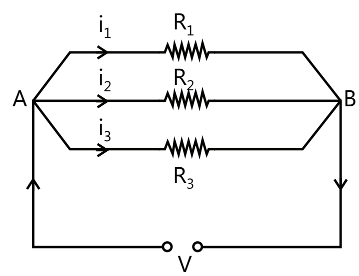


Figure 20.10: Parallel combination of resistances

(b) Current in each resistance is inversely proportional to the value of resistance i.e.

$$I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3} \text{etc.}$$

(c) Current flowing in the combination is the sum of the currents in individual resistances i.e. $I = I_1 + I_2 + I_3$

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \quad \Rightarrow \quad \frac{I}{V} = \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots\ldots\ldots\ldots$$

where R = equivalent resistance.

Note:

(a) You are asked to find R and not $\frac{1}{R}$ in the question, so be careful.

(b) The equivalent resistance of parallel combination is less than the value of the lowest individual resistance in the combination.

(c) For a parallel combination of two resistances

$$I = I_1 + I_2 = \frac{V(R_1 + R_2)}{R_1 R_2}$$

Note:

(a) If n resistance (each equal to R) are connected in parallel, their resultant will be R/n(See Fig. 20.11).

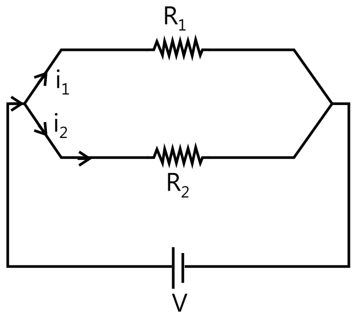


Figure 20.11: Parallel combination of two resistances

(b) If n resistance are connected in series and parallel respectively the ratio of their resultant resistances will be (nR):(R/n) = n^2.

8.3 Division of Current for Parallel Resistors

Consider the circuit shown in Fig. 20.12. Using ohm's law on resistors R_1 and R_2,

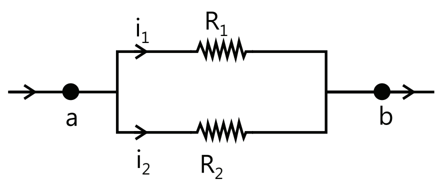


Figure 20.12: Current division

$V_a - V_b = I_1R_1$ and $V_a - V_b = I_2R_2$.

Thus, $I_1R_1 = I_2R_2$ or, $\frac{I_1}{I_2} = \frac{R_1}{R_2}$ ...(i)

We see that the current is divided in resistors, connected in parallel, in inverse ratio of the resistances.

Also, we have $I = I_1 + I_2$ ... (ii)

Solving (i) and (ii) we get I_1 and I_2 in terms of I: $I_1 = \frac{R_2}{R_1 + R_2}I$ and $I_2 = \frac{R_1}{R_1 + R_2}I$

Illustration 6: (a) Three resistors 1Ω, 2Ω and 3Ω are combined in series. What is the total resistance of the combination? **(JEE MAIN)**

(b) If the combination is connected to a battery of e.m.f. 12V and negligible internal resistance, obtain the potential drop across each resistor.

Sol: (a) When resistances in any circuit when connected in series, the net resistance of the circuit increases, and there is a constant potential drop across each resistance depending on amount of current passing through it.

(a) For series combination $R_{eq} = R_1 + R_2 + R_3$, so we get $R_{eq} = 1 + 2 + 3 = 6\Omega$

(b) By Ohm's Law current drawn from the battery, $I = \frac{V}{R_{eq}} = \frac{12}{6} = 2$ A

Again, by Ohm's Law voltage drop across R_1 is, $V_1 = IR_1 = 2 \times 1 = 2V$

Voltage drop across R_2 is, $V_2 = IR_2 = 2 \times 2 = 4V$

Voltage drop across R_3 is,$V_3 = IR_3 = 2 \times 3 = 6V$.

Illustration 7: Given 'n' resistors each of resistance 'R'. How will you combine them to get maximum and minimum effective resistance? What is the ratio of maximum to minimum resistance? **(JEE ADVANCED)**

Sol: When resistances in any circuit when connected in series, the net resistance of the circuit increases while in parallel connection the net resistance of the circuit decreases.

Equivalent resistance of n resistors each of resistance R,

(a) Connected in series is:

$$R_{series} = R_{max} = nR$$

Connected in parallel is: $\frac{1}{R_{parallel}} = \frac{1}{R_{min}} = \frac{n}{R} \Rightarrow R_{min} = \frac{R}{n}$

$$\frac{R_{max}}{R_{min}} = nR \times \frac{n}{R} = n^2$$

9. POWER

Consider a simple circuit wherein a resistance R is connected across the terminals of a battery. The potential difference across the battery is V and a steady current I is drawn from it. The amount of charge dq that moves between the terminals in time interval dt is equal to I dt. This charge dq moves through a decrease in potential of magnitude V across the resistance, and thus its electric potential energy is decreased by an amount,

$$dU = dq\,V = dt\,V$$

By law of conservation of energy, this energy must be converted to some another form. In a resistance this "another form" is nothing but heat energy. The temperature of the resistance rises as a result of heat generated in it when a current is passed through it.

After crossing the resistance this charge again enters the battery at its negative terminal and emerges at the positive terminal. In doing so, it moves through a rise in potential of magnitude V inside the battery, thus its electric potential energy increases by the same amount $dU = V\,I\,dt$.

The battery thus performs work on the charge to increase its electric potential energy and this energy is dissipated in the resistance in the form of heat.

The power P associated with this energy transfer is the rate of work done by the battery or the rate of production of electrical energy, equal to the rate at which heat is dissipated:

$$P = \frac{dU}{dt} = VI \quad \text{(Rate of electrical energy transfer).}$$

The unit of power that follows is the volt-ampere (V.A).

We can write $1V \cdot A = \left(1\,\frac{J}{C}\right)\left(1\,\frac{C}{s}\right) = 1\,\frac{J}{s} = 1\,W$.

Also we can write voltage drop across resistance as $V = I\,R$

The rate of electrical energy dissipation in a resistance comes out to be

$$P = I^2 R \quad \text{or} \quad P = \frac{V^2}{R} \qquad \text{(resistive dissipation)}$$

Caution: P = VI applies to electrical energy transfers of all kinds; P = I2R and P=V2/R apply only to the transfer of electric potential energy to thermal energy in a resistance.

9.1 Joule's Laws of Heating

When electric current flows through a resistor, the temperature of the resistor increases. If the potential difference across the resistor is V and current I flows through it, the work done by the electric source in time t is

W = (potential difference) × (charge) = V (It) = (IR)(It) = I^2Rt

This work is converted into thermal energy of the resistor or heat is produced in the resistor denoted by H. (actually, this energy is not heat as it does not flow due to any temperature difference)

Illustration 8: Consider the following circuit, find power dissipated in the resistor R.

Sol: Power dissipated in any electrical resistance is $P = IV = I^2R = \frac{V^2}{R}$. Power supplied by the source is P = E I

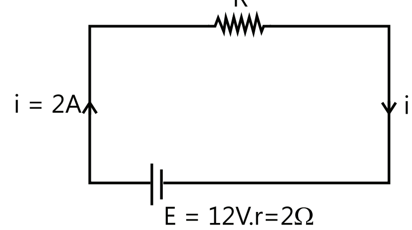


Figure 20.13

Total electrical power produced by the battery is

P_{in} = E I = 12 × 2 = 24W

The power dissipated in the internal resistance of battery is

$I^2r = 2^2 \times 2 = 8W$

The net power output from the battery P_{out} = 24 – 8 = 16W

The power dissipated in the resistor = 16 W

PLANCESS CONCEPTS

Power Method

- Total power(power dissipated plus power generated) in a circuit is zero. This comes from principle of conservation of energy.
- In a circuit generally, battery supplies energy, and resistors always dissipate. But sometime battery might also dissipate(in multi-source circuit)
- Power is dissipated if current and voltage drop are in same direction of a given device and vice-versa. If they are in opposite direction, power is supplied.
- For a collection of devices, net power dissipated is product of voltage drop and current across the terminals.

Vaibhav Gupta (JEE 2009, AIR 54)

9.2 Cell

A cell is an electric source, which converts chemical energy into electrical energy. A chemical solution called electrolyte is filled inside the cell. Two metal rods called electrodes are immersed inside the electrolyte (see Fig. 20.15). These electrodes exchange charges with the electrolyte. The electrode at the higher potential is called positive electrode, and that at the lower potential is called negative electrode. When no current is drawn from the cell, the potential difference between the positive and negative electrodes is called the electromotive force, emf (E).

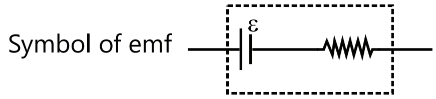


Figure 20.14: Representation of cell

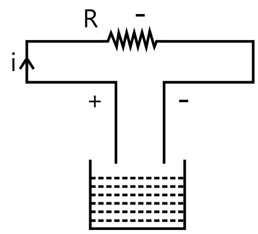


Figure 20.15: Electrolytic cell

When an external resistance (R) is connected across the cell, a current I flows from positive to negative electrode (terminal) through the external resistance. The same current flows though the cell from negative to positive terminal. The resistance offered by the cell when the current flows through it is called the internal resistance (r) of the cell. The internal resistance depends on the nature of the electrolyte, distance between the electrodes and the area of the electrodes inside the electrolyte.

If current I flows through the cell, the potential drop across internal resistance will be I.r. Thus the potential difference across the cell reduces by amount I.r from its value in open circuit, i.e. the emf E. Hence, the potential difference across the cell when current I is drawn from it is

$$V = E - Ir$$

V is called the **terminal potential difference**.

The potential difference across external resistance R, is V = IR, thus, E -Ir = IR, or $I = \frac{E}{R+r}$

(a) When current is drawn from a cell it is called the discharging of a cell. During discharging,

$V = E - I r; V < E$

(b) During charging of the cell, current enters the cell from positive terminal and emerges from negative terminal. Energy is transferred to the cell by a DC source (see Fig. 20.16).

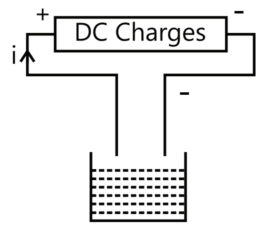


Figure 20.16: Charging of electrolytic cell

During charging $V= E + I r; V > E$

Note: When charging or discharging information is not given, take discharging action.

PLANCESS CONCEPTS

Battery with resistance

- When current is drawn from a battery, the voltage across it is less than rated voltage.
- We need to subtract the voltage drop due to internal resistance of the battery.

Nitin Chandrol (JEE 2012, AIR 1340)

Illustration 9: A storage battery of e.m.f.8.0V and internal resistance 0.5 Ω is being charged by a120V dc supply using a resistor of 15.5 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit? **(JEE ADVANCED)**

Sol: The total potential difference in the circuit is the algebraic sum of voltage drop across the components in the circuit. Using ohm's law we get the potential difference across resistance.

The circuit is as shown in Fig. 20.17. During charging the total potential drop across the battery (including its internal resistance) and the resistance connected in series will be equal to the voltage of the source.

V = E + I r + I R

$I=\frac{V-E}{r+R}=\frac{120-8}{0.5+15.5}=\frac{112}{16}=7\,A$ Terminal voltage = 8 + 7 × 0.5 = 11.5 V

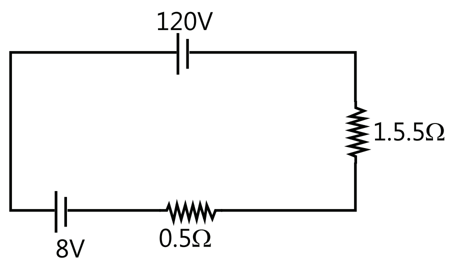


Figure 20.17

9.2.1 Combination of Cell in Series and Parallel

In series combination of cells (see Fig. 20.18) we have

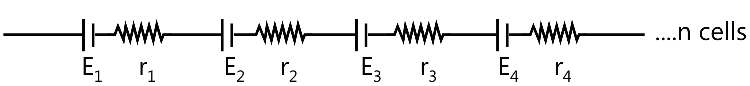


Figure 20.18: Series combination of cells

$E_{net}=\sum E_i$ and $r_{net}=\sum r_i$ For parallel combination of two cells (see Fig. 20.19) we have

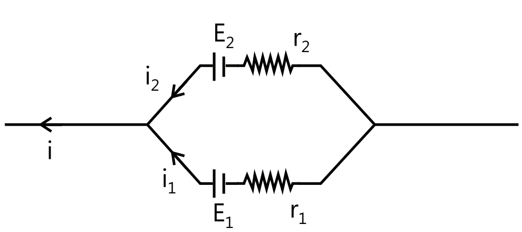


Figure 20.19: Parallel combination of cells

$$V_A - V_B = V = E_1 - i_1 r_1 \Rightarrow i_1 = \frac{E_1 - V}{r_1} \text{ Again, } V_A - V_B = V = E_2 - i_2 r_2 \Rightarrow i_2 = \frac{E_2 - V}{r_2}$$

$$i = i_1 + i_2 \Rightarrow \quad i = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

$$\Rightarrow \quad i = \left[\frac{E_1}{r_1} + \frac{E_2}{r_2}\right] - V\left[\frac{1}{r_1} + \frac{1}{r_2}\right]$$

$$\Rightarrow \quad V\left[\frac{1}{r_1} + \frac{1}{r_2}\right] = \left[\frac{E_1}{r_1} + \frac{E_2}{r_2}\right] - i$$

$$\Rightarrow \quad V = \frac{\left[\frac{E_1}{r_1} + \frac{E_2}{r_2}\right]}{\left[\frac{1}{r_1} + \frac{1}{r_2}\right]} - \frac{i}{\left[\frac{1}{r_1} + \frac{1}{r_2}\right]}$$

$$\Rightarrow \quad V = E_{eq} - ir_{eq} \text{ where } E_{eq} = \left[\frac{\sum \frac{E_i}{r_i}}{\sum \frac{1}{r_i}}\right] \text{ and } \frac{1}{r_{eq}} = \sum \frac{1}{r_i}$$

E_{eq} is the equivalent emf and r_{eq} is the equivalent internal resistance of the cell combination.

If all the cells are identical then for parallel combination, Net Emf = E; Net internal resistance is: $r_{eq} = \frac{r}{n}$ for 'n' cell in parallel.

Illustration 10: Two cells in series have emf 1.5V each and internal resistance 0.5 Wand 0.25 Ω respectively. They are connected to external resistance R that is 2.25 Ω. Find the current in the circuit and potential difference across the resultant cell. **(JEE MAIN)**

Sol: The total potential difference in the circuit is the algebraic sum of voltage drop across the components in the circuit. Using ohm's law we get the potential difference across resistance.

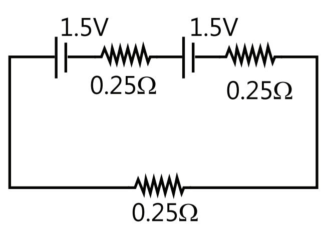


Figure 20.20

E = 1.5V, R = 2.25 W

r = 0.5 Ω, r'= 0.25 W

Total emf =1.5 + 1.5 = 3V;

Current $I = \frac{\text{Total emf}}{\text{Total resistance}} = \frac{3}{0.5 + 0.25 + 2.25} A = 1\ A$; $V_1 = E_1 - Ir_1$ = 1.5 – 1 × 0.5 = 1 V

$V_2 = E_2 - Ir_2$ = 1.5 – 1 × 0.25 = 1.25 V

Total potential difference across resultant cell is $V = V_1 + V_2$ = 2.25 V

9.3 Maximum Power Transfer Theorem

For a cell of given emf and internal resistance, there is a certain value of external resistance R which when connected across the cell will draw maximum power from it.

The current in the resistor R is $I = \frac{E}{R+r}$

The power consumed in the resistance R is $P = I^2R = \frac{E^2R}{(R+r)^2}$

For P to be maximum, $\frac{dP}{dR} = 0$ or $\frac{dP}{dR} = \frac{E^2(R+r)^2 - 2E^2R(R+r)}{(R+r)^4} = 0$

Which gives R = r and $P_{max} = \frac{E^2R}{(R+r)^2} = \frac{E^2r}{(r+r)^2}$ or $P_{max} = \frac{E^2}{4r}$

Kilowatt-hour

It is commercial unit of electrical energy. It is known as 1 unit.

Thus, 1 KW – h = 1000 × 3600 J = 3.6 × 10^6 J

Number of unit consumed = $\frac{\text{Total Power(W) x time(h)}}{1000} = \frac{\text{Total Power(W) x time(s)}}{3.6 \times 10^6}$

10. KIRCHOFF'S LAWS

10.1 Kirchhoff's First Law or Rule (The Junction Law or Kirchhoff's Current Law)

This law is based on law of conservation of charge.

It states that the sum of all current smeeting at any point (junction) must be equal to the sum of all current leaving that point (junction).

or

The algebraic sum of all the current meeting at a point (junction) in a closed electrical circuit (for example see Fig. 20.21) is zero. i.e. $\sum I_k = 0$ ... (i)

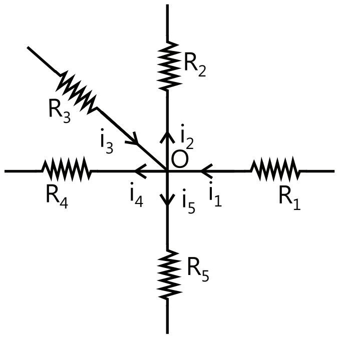


Figure 20.21

Here we need to choose the sign of each current I_k. Each term I_k is an algebraic quantity. The currents leaving a junction and currents meeting at a junction are supposed to have opposite signs. For example if we assume former to be positive then the latter has to be assumed negative and vice-versa(which one to be decided positive or negative is immaterial). The sign convention once decided for a particular junction has to be followed for all the currents at that junction.

Illustration 11: Consider a point or junction O in an electrical circuit. Let I_1, I_3 be the currents entering the point O and I_2, I_4, I_5 be the current leaving point O.

Sol: According to KCL, the algebraic sum of the current entering and leaving the junction is zero. So apply KCL to the junction O.

According to Kirchhoff's first law, $I_1 + I_3 = I_2 + I_4 + I_5$ ... (i)

Equation (i) can also be written as $I_1 + I_3 + (-I_2) + (-I_4) + (-I_5) = 0$; $I_1 + I_3 - I_2 - I_4 - I_5 = 0$ ($\sum I_k = 0$)

Note: Kirchhoff's First law is based on the law of conservation of charge i.e. on the fact that charge does not remain accumulated at a junction or a point of a circuit.

10.2 Kirchhoff's Second Law (The Loop Law or Kirchhoff's Voltage Law)

This law is based on the law of conservation of energy.

The algebraic sum of all the potential differences ΔV_k, along a closed loop in a circuit is zero.

$$\sum_{\text{Closed loop}} \Delta V_k = 0$$

The rules for determining the sign of ΔV across a resistor and a battery are shown below:

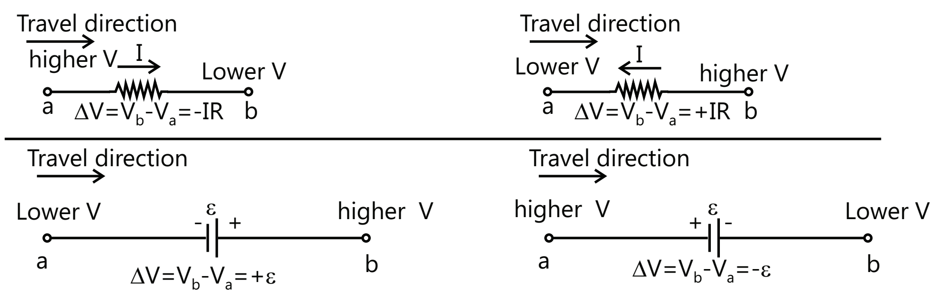


Figure 20.22: Convention for determining Δ V

Note: The choice of direction of loop traversal is arbitrary. The same equation is obtained whether the closed loop is traversed clockwise or anti-clockwise.

Illustration 12: A battery of 10V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistance $1\,\Omega$. Find the equivalent resistance and the current along each edge of the cube. **(JEE MAIN)**

Sol: Using KCL, the current distribution across each branch of the cube is as shown in Fig. 20.23. potential difference across each branch is given by Ohm's law. P.D. across diagonally opposite points equals equivalent resistance multiplied by input current.

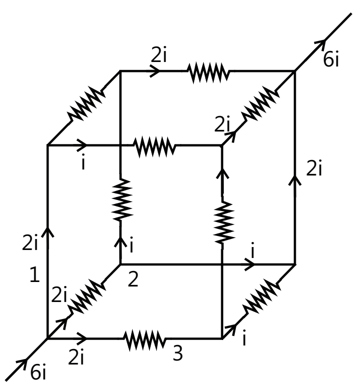


Figure 20.23

Current enters one end and leaves at diagonally opposite end.

Each branch has equal resistance, so by symmetry same current will flow through the three branches 1, 2 and 3.

If say 6i current enters the cubical network at one end and leaves the diagonally opposite end then the current distribution in all the branches will be as shown in the adjacent Fig. 20.23.

Potential difference (P.D.) across the diagonally opposite ends taking any shortest path (any shortest path will have three branches having currents 2i, i, and 2i)

$$2i\times r + i\times r + 2ir = 6iR_{eq}$$

$$5ir = 6iR_{eq};\ R_{eq} = \frac{5}{6}r = \frac{5}{6}\,\Omega$$

Again, $6iR_{eq} = 10\text{ V} \Rightarrow i = 2\text{ A}$

PLANCESS CONCEPTS

It is highly advised to solve numerous problems on Kirchhoff's laws and ohm's law to get hold over the concepts and criticalities.

Chinmay S Purandare (JEE 2012, AIR 698)

11. WHEATSTONE BRIDGE

Wheatstone bridge is an arrangement of four resistors in the form of a loop. The value of one of the four resistors is unknown and is calculated in terms of the other three known resistors.

Construction: It consists of four branches P, Q, R and S arranged to form a loop ABCD (see Fig. 20.24). A source of e.m.f. E is connected across points A and C. A galvanometer is connected across points B and D. Unknown resistor is put in branch S. Out of the remaining three branches, one branch contains a variable resistance and the other two branches have fixed resistors.

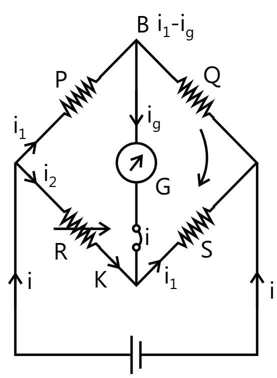


Figure 20.24

Principle: When the battery is connected, the galvanometer shows the presence of current Ig through it. The value of variable resistance R is adjusted in such a way that the galvanometer shows no deflection. At this stage, the points B and D are at same potential and hence no current flows through the galvanometer. The Wheatstone bridge at this stage is said to be balanced and ratio of P and Q is equal to ratio of R and S.

i.e. $\frac{P}{Q} = \frac{R}{S}$ or $S = \left(\frac{Q}{P}\right)R$ Knowing P, Q and R, the value of S can be calculated.

Illustration 13: Find the value of R in circuit (see Fig. 20.25) so that there is no current in the $50\,\Omega$ resistor.

(JEE MAIN)

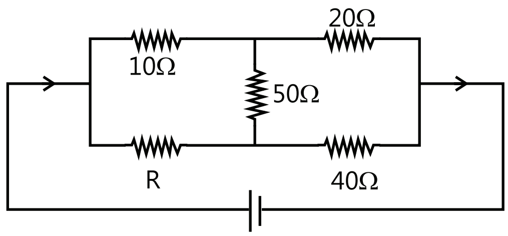


Figure 20.25

Sol: For Wheatstone network, when the bridge is in balanced condition the, ratio of resistance in the opposite branches is equal.

Using Wheatstone bridge principle there will be no current in the 50 Ω resistor if the bridge is balanced.

$$\frac{10\Omega}{R}=\frac{20\Omega}{40\Omega} \qquad \text{or} \qquad R = 20\ \Omega$$

12. METRE BRIDGE OR SLIDE WIRE BRIDGE

Metre Bridgeworks on the principle of Wheatstone bridge. i.e. $\frac{P}{Q}=\frac{R}{S}$

Construction: Consider a circuit shown in Fig. 20.26. It consists of magnenin or constantan wire AB of length 1 m (hence the name meter bridge). The wire is of a uniform area of cross-section and is fixed on wooden board parallel to a metre scale. Let the resistance of the wire between A and J be P and that between J and B be Q. The resistance R between A and C is known and the resistance X between C and B is unknown. A galvanometer is connected between C and J. The jockey J is slid on the wire AB till we get null point (zero reading of the galvanometer). If length AJ is ℓ then we have,

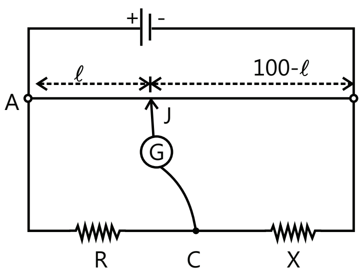


Figure 20.26

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

By Wheatstone-bridge principle we get

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

$$\text{or} \qquad X=\left(\frac{100-\ell}{\ell}\right)R$$

Thus, by knowing R and ℓ we get the value of X.

13. POTENTIOMETER

A potentiometer is a device used to measure the potential difference across points in a circuit. It acts as an ideal voltmeter, because it does not draw any current from the circuit element across which it is connected.

Construction: It consists of a long uniform mangen in or constantan wire AB fixed on a wooden board. The schematic diagram of a potentiometer is shown in Fig. 20.27.

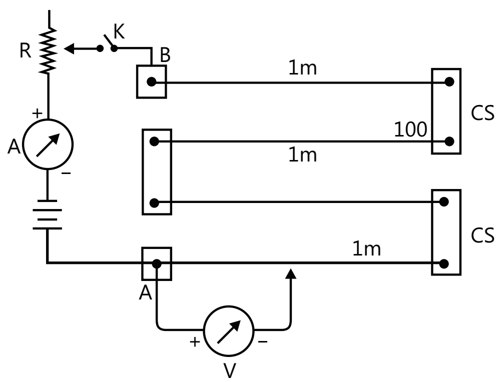


Figure 20.27: Potentiometer circuit

Actually, this long wire AB consist of four equal parts each 1 m long. These four parts of the wire are connected to one another by thick copper strips (CS).

Principle: It works on the principle that potential difference across any part of a uniform wire is directly proportional to the length of that part, when a constant current flows through the wire. According to Ohm's law V = IR, but $R \propto \ell$ for uniform cross-section.

$\therefore \quad V \propto \ell,$ provided I is constant.

We measure the length of the wire which has same potential difference as that of the circuit element. This length is obtained with the help of a jockey connected to a galvanometer by ensuring zero deflection.

13.1 Comparison of E.M.F.S of Two Cells Using Potentiometer

(a) Comparison of EMF of Two Primary Cells. In the circuit shown, the cell of emf E_1 is balanced for a length l_1 on the potentiometer wire. The cell of emf E_2 is balanced for a length l_2 on the potentiometer wire. Then we can write $E_1 \propto \ell_1$ and $E_2 \propto \ell_2$ $\therefore$ $\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$. The emf of a cell can be determined by this method only when emf of another cell is known to us.

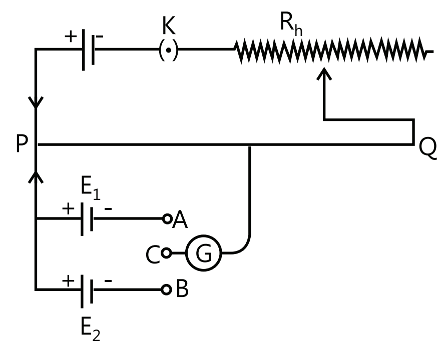


Figure 20.28: Deduction of cell e.m.f. using potentiometer circuit

Illustration 14: In a potentiometer, a cell of e.m.f 1.5V gives a balance point at 30cm length of the wire. Another battery gives new balance point at 60 cm. Find e.m.f. of the battery. **(JEE MAIN)**

Sol: For potentiometer circuit, $E \alpha \ell$. Thus we take the ratio of l_1 to l_2 to find E_2.

From the formula $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ we get $E_2 = E_1 \times \frac{l_2}{l_1} = 1.5 \times \frac{60}{30} = 3$ V

13.2 Determination of Internal Resistance of a Cell Using Potentiometer

The arrangement for measuring the internal resistance r of a cell using potentiometer.

Procedure

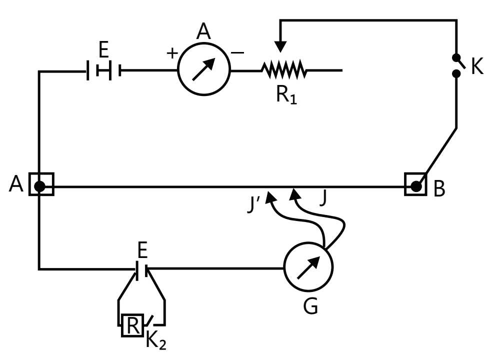


Figure 20.29: Determination of internal resistance of cell

Step 1: Key K_1 is closed and key K_2 is kept open. E.m.f. (E) of the cell is balanced for a length ℓ_1 on the potentiometer wire. Therefore

$$E \propto \ell_1 \quad ....(i)$$

Step 2: Both keys K_1 and $K_2$are closed. A known resistance (R) is connected across the cell. Potential difference across the cell is balanced for a length ℓ_2 of the potentiometer wire. Therefore

$$V \propto \ell_2 \quad ....(ii)$$

Dividing (i) by (ii) we get,

$$\frac{E}{V} = \frac{\ell_1}{\ell_2} \quad ....(iii)$$

We know, internal resistance of a cell is given by,

$$r = \left(\frac{E}{V} - 1\right)R \quad .... (iv)$$

Using (iii) in (iv), we get,

$$r = \left(\frac{\ell_1}{\ell_2} - 1\right)R \quad .... (v)$$

Note: A potentiometer can be used to compare/determine unknown resistances and to calibrate ammeters and voltmeter.

Illustration 15: A potentiometer with 1.5V cell is used for finding the internal resistance of a 1.2V cell. The balance point corners at 65cm.If a resistor of 10 Ω is used as shown in the Fig. 20.30, the balance point changes to 55cm. Calculate the internal resistance of the cell. **(JEE MAIN)**

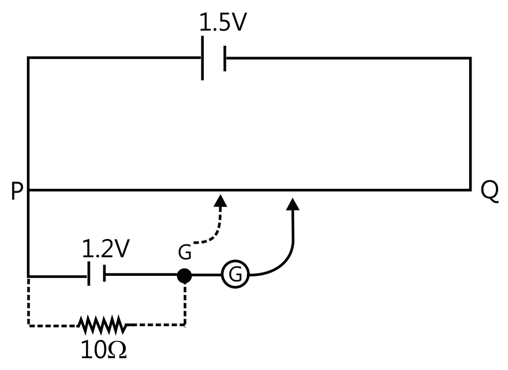


Figure 20.30

Sol: For potentiometer circuit, $E \propto \ell$

or $R \propto \ell$ Thus we take the ratio of resistance

Internal resistance of the cell can be calculated by the formula,

$$r = \left(\frac{\ell_1 - \ell_2}{\ell_2}\right)R = \frac{65-55}{55} \times 10\ \Omega = 1.82\ \Omega.$$

13.3 Measurement of Unknown Small Resistance Using Potentiometer

The arrangement for measuring the unknown small resistance is shown in Fig. 20.31.

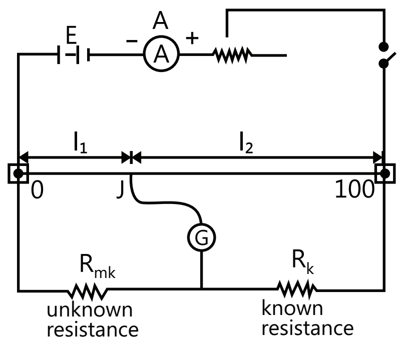


Figure 20.31: Potentiometer circuit to determine unknown resistance

Procedure: Close key K_1. Find point Jon the wire AB of potentiometer such that, the galvanometer G gives no deflection. Length AJ is l_1 and length JB is l_2. Using the principle of balanced Wheatstone bridge, we get, $\frac{l_1}{l_2} = \frac{R_{uk}}{R_k}$; $R_{uk} = R_k \frac{l_1}{l_2}$

Precaution: Sliding of jockey should not be allowed. Itis not to be pressed roughly on the wire. It should be assured that all connections are made with thick copper wires or strips. All connections should be tight. Key should be opened after every reading to avoid unnecessary heating up of the wire.

Illustration 16: In a meter bridge the null point is found at 33.7 cm. If a resistance of $12\,\Omega$ is connected in parallel with S, null point is 51.9 cm. Find R and S? **(JEE MAIN)**

Sol: For potentiometer circuit, $E \propto l$ or $R \propto \ell$. Thus we take the ratio of resistance

Case-I: Initial null point is ℓ = 33.7cm

$$\frac{R}{S} = \frac{\ell}{100-\ell} \;;\; \frac{R}{S} = \frac{33.7}{100-33.7} = \frac{33.7}{66.3}$$

Case-II: New null point is ℓ = 51.9 cm. Resistance S and $12\,\Omega$ are in parallel.

$$S_{eq} = \frac{S\times 12}{S+12} \text{ and } \frac{R}{S_{eq}} = \frac{51.9}{48.1} \;;.\; \frac{R(S+12)}{12S} = \frac{51.9}{48.1} \;.;.\; \frac{33.7}{66.3}\frac{(S+12)}{12} = \frac{51.9}{48.1}$$

S = 13.5 Ω and R = 6.86 Ω $R_1 + \frac{R_0}{2} = \frac{RR_0}{2R+R_0} + \frac{R_0}{2}$

Illustration17: A resistance of R$R = \rho\left(\frac{l}{A}\right)$ draws current form a potentiometer.The potentiometer has total resistance R_0 $R = \rho\left(\frac{l}{A}\right)$. Drive an expression for the voltage across R when the sliding contact is in middle of the potentiometer. **(JEE MAIN)**

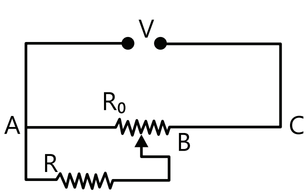


Figure 20.32

Sol: As the resistance R_0 and R, are in parallel combination the equivalent resistance of circuit drops and using ohm's law we get the current through the resistance.

When the sliding contact is in the middle, only half of the resistance R_0 is included between A and B. So, the total resistance between A and B is R_1, $\frac{1}{R_1} = \frac{1}{R} + \frac{1}{R_0/2}$; $R_1 = \frac{\frac{RR_0}{2}}{R + \frac{R_0}{2}} = \frac{RR_0}{2R + R_0}$

Total resistance (R_{eq}) between A and C, $R_{eq} = R_1 + \frac{R_0}{2} = \frac{RR_0}{2R + R_0} + \frac{R_0}{2}$

Current drawn from supply is, $i = \frac{V}{R_{eq}} = \frac{V}{R_1 + \frac{R_0}{2}} = \frac{2V}{2R_1 + R_0}$

Potential drop across A-B will be

$$V_R = iR_1 = \frac{2V}{2R_1 + R_0} \times \frac{RR_0}{2R + R_0} = \frac{2V}{2\left(\frac{RR_0}{2R + R_0}\right) + R_0} \times \frac{RR_0}{2R + R_0} = \frac{2VR}{4R + R_0}$$

14. AMMETER AND VOLTMETER

14.1 Ammeter

Electric current in an electric circuit is measured by an Ammeter which is a modified form of a galvanometer. If a galvanometer is directly used to measure the electric current flowing in the circuit, then two problems arise: (i) the large resistance of the galvanometer will change the electric current in the circuit, and (ii) large amount of current in the circuit may damage or burn the galvanometer. Thus, galvanometer cannot be directly used to measure the current in the circuit. A device with practically zero or very low resistance is required for this purpose. Thus ammeter should have low resistance.

Conversion of Galvanometer into Ammeter by using Shunt

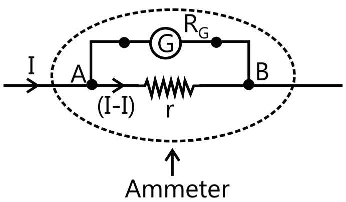


Figure 20.33: Representation of Ammeter circuit

A galvanometer can be converted into an ammeter by connecting a low resistance called shunt, parallel to the galvanometer.

Let R_G and r_s be the resistances of the galvanometer and the shunt respectively.

Let I be the maximum current to be measured by an ammeter in the circuit.

Let I_g be the maximum current that can flowt hrough the galvanometer corresponding to which galvanometer gives the full scale deflection.

The resistance of the shunt must be such that the remaining current ($I-I_g$) should pass through the shunt.

Since R_G and r_s are in parallel, the potential difference across them is same.

i.e. $I_g R_G = (I - I_g) r_s$ or $r_s = \left(\frac{I_g}{I - I_g}\right) R_G$.

This is the required value of shunt resistance to convert a galvanometer into an ammeter of range 0 to I ampere.

Effective resistance of ammeter: The total effective resistance R_{eff} of an ammeter is gives by

$$\frac{1}{R_{eff}}=\frac{1}{R_G}+\frac{1}{r_s}=\frac{R_G+r_s}{R_G r_s} \text{ or } R_{eff} = \frac{R_G r_s}{R_G+r_s}$$

Since $R_G >> r_s$, so $(R_G + r_s) = R_G$

Hence $R_{eff} = r_s$

Thus, an ammeter is a low resistance device.

14.2 Voltmeter

Potential difference across a circuit element is measured by an instrument called voltmeter. The voltmeter is to be connected in parallel to the circuit element across which potential difference is to be measured. The resistance of the voltmeter has to be very large.

Conversion of galvanometer into voltmeter: A galvanometer is converted into a voltmeter by connecting a large resistance in series with it.

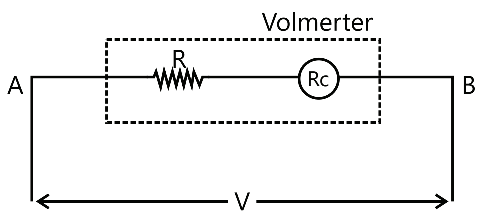


Figure 20.34: Equivalent voltmeter circuit

Let R_G and R be the resistances of the galvanometer and a resistor connected in series with it respectively. R is very large as compared to R_G.

Let V be the potential difference to be measured by the voltmeter.

Let I_g be the current for which the galvanometer gives the full scale deflection.

Potential difference across voltmeter is

$$V=I_g R + I_g R_G = I_g(R + R_G)$$

$$\therefore \quad R+R_G=\frac{V}{I_g} \quad \text{or} \quad R=\frac{V}{I_g}-R_G$$

This is the value of resistance R which has to be connected in series to the galvanometer to convert it into a voltmeter of range 0 to V volt.

Effective resistance of the voltmeter is given by $R_{eff} = (R + R_G)$ which is very high.

Thus, voltmeter is a high resistance device.

Illustration 18: A galvanometer having a coil of resistance 12 Ω gives full scale deflection for a current of 4 mA. How can it be converted into a voltmeter of range 0 to 24 V? **(JEE MAIN)**

Sol: When we connect a large resistance in series to the galvanometer, the current through it reduces. Thus such a galvanometer can be connected across high potential difference.

Galvanometer is converted into voltmeter by connecting a large resistance say R in series to the coil. Value of R can be calculated using the formula $R = \frac{V}{I_g} - R_G = \frac{24}{4 \times 10^{-3}} - 12 = 5988\ \Omega$

15. POST OFFICE BOX

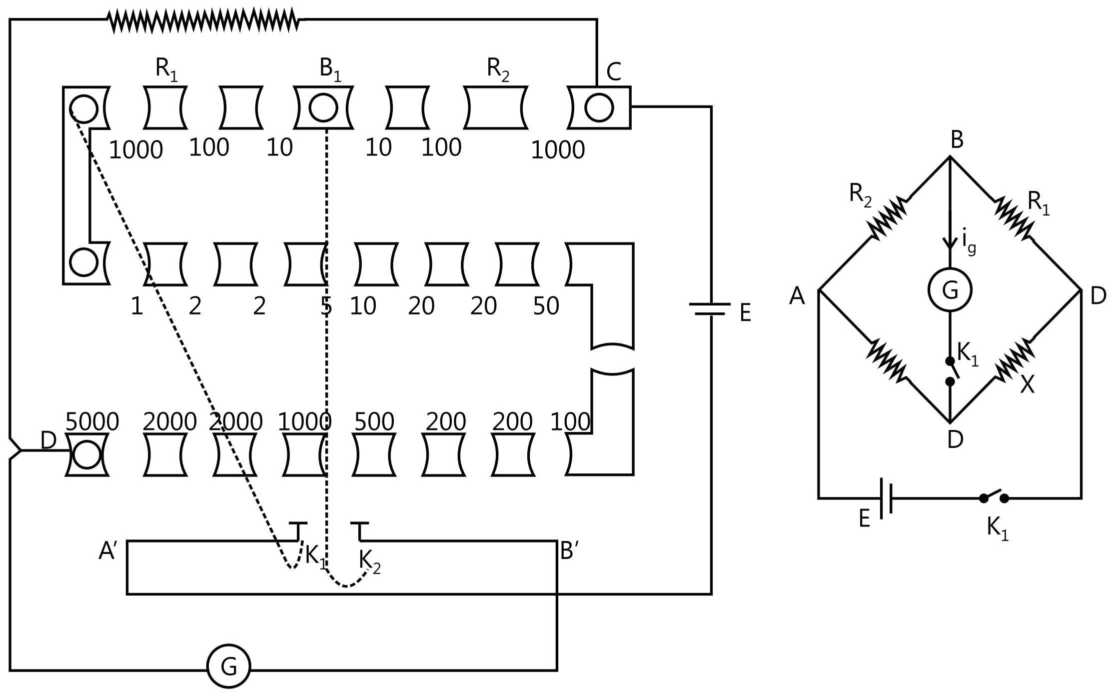


Figure 20.35: Post office box as equivalent Wheatstone bridge network

Post office box is a form of Wheatstone bridge. The unknown resistance X is given as $X = R\left(\frac{R_2}{R_1}\right)$

The arms having resistances R_1 and R_2 are called the ratio arms.

The ratio $\frac{R_2}{R_1}$ can be adjusted to have values in multiples of 10, e.g. 1, 10, 100, 1000, $\frac{1}{10}, \frac{1}{100}, \frac{1}{1000}$ and so on.

The accuracy in the measured value of X depends on the selection of the ratio $\frac{R_2}{R_1}$.

If $\frac{R_2}{R_1}$ is selected as 1, then the value of the unknown resistance is measured within accuracy of ± 1 Ω.

If $\frac{R_2}{R_1}$ is selected as $\frac{1}{10}$, then the value of the unknown resistance is measured within accuracy of ± 0.1 Ω.

If $\frac{R_2}{R_1}$ is selected as $\frac{1}{100}$, then the value of unknown resistance is measured within accuracy of ± 0.01 Ω and so on.

Illustration 19: The value of an unknown resistance is obtained by using a post office box. Two consecutive readings of R are observed as the galvanometer deflects in the opposite direction for three different value of R_1. These two values are recorded under the column I and II in the following observation table. **(JEE MAIN)**

S.No.	**R_1 (Ω)**	**R_2 (Ω)**	**R lies in between**		**X=R(R_2/ R_1)**	
			I Ω	II Ω	I Ω	II Ω
1	10	10	16	17		
2	100	10	163	164		
3	1000	10	1638	1639		

Determine the value of the unknown resistance.

Sol: The table listed above computes the value of unknown resistance for different values of ratio R_2: R_1. The average of the final values will give the best estimate for the unknown resistance.

The observation table may be complete as follows:

S.No.	**R_1 (Ω)**	**R_2 (Ω)**	**R lies in between**		**X=R(R_2/ R_1)**	
			I Ω	II Ω	I Ω	II Ω
1	10	10	16	17	16.0	17.0
2	100	10	163	164	16.3	16.4
3	1000	10	1638	1639	16.38	16.39

The value of the unknown resistance lies in-between 16.38 Ω and 16.39 Ω

The unknown value may be the average of the two i.e. $X = \dfrac{16.38 + 16.39}{2} = 16.385\ \Omega$.

PROBLEM-SOLVING TACTICS

(a) Never think of current in terms of electrons and get confused in direction or vector analysis. Instead, it would be easier to think of current in terms of flow of positive charges because it is equivalent. However, my advice is to remember the reality in questions which intentionally deals with this concept.

(b) While solving a problem always remember that it is the resistivity and conductivity that is same for materials and not the resistance and conductance itself. This will help you avoid silly mistakes. Also note that Temperature dependence formula is very analogous to length expansion formula.

(c) The problems related to devices are quite easy and always remember that they are always solved by ratios and proportions. And one good thing is they do not require much of calculation too.

(d) Questions on combination of resistances can be solved more easily by identifying symmetry in breaking down the problem to basic series and parallel circuit.Symmetry, in this context implies equal resistances or equal distribution of current. This can help you in solving big complicated looking circuits.

(e) Questions related to power are easy and require use of law of conservation of energy.

(f) Applying Kirchhoff's Rules: Kirchhoff's rules can be used to analyse multi-loop circuit. The steps are summarized below:

(i) Draw a circuit diagram, and label all the quantities, both known and unknown. The number of unknown quantities must be equal to the number of linearly independent equations we obtain.

(ii) Assign a direction to the current in each branch of the circuit. (If the actual direction of current is opposite to that assumed initially, the value of current obtained will be a negative number.)

(iii) Apply the junction rule to all but one of the junctions. (Applying the junction rule to the last junction will not yield any independent equation.)

(iv) Apply the loop rule to the loops in the circuit.

Obtain as many independent equations using both the Kirchhoff's Laws as there are number of unknowns.

FORMULAE SHEET

1. Ohm's Law V = IR

2. Current flowing through cross-section area of conductor is $I = \int \vec{J}.d\vec{A}$

3. The current is defined as $I = \frac{q}{t} = \frac{nALe}{L/v_d} = nAev_d$

4. Current in terms of resistivity is defined as $I = \frac{E}{\rho}A$

5. Drift velocity for charge is $v_d = \frac{I}{neA}$

6. Time taken by charge to drift across conductor is $t = \frac{neA\ell}{I}$

7. The current density of a conductor is $\vec{J} = (ne)\vec{v}_d$

8. Conductivity σ is related to current density as $\vec{J} = \sigma\vec{E}$

9. Mobility of charges ì $= \frac{v_d}{E}$

10. Resistivity of conductor is $\rho = \frac{E}{J} = \frac{1}{\sigma}$

11. For Series Network of resistance , net resistance $R_{eq} = \sum_{i=1}^{n} R_i$

12. Voltage division in two resistances (see Fig. 20.36)

$V = V_1 + V_2$ where $V_1 = \frac{R_1}{R_1 + R_2}V$ and $V_2 = \frac{R_2}{R_1 + R_2}V$

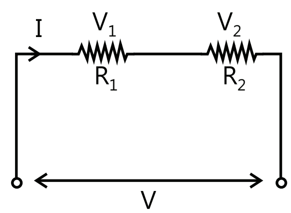


Figure 20.36

For Parallel Network of resistance, net resistance is $\frac{1}{R_{eq}} = \sum_{i=1}^{n}\left(\frac{1}{R_i}\right)$

13. Current division in two resistances (see Fig. 20.37)

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

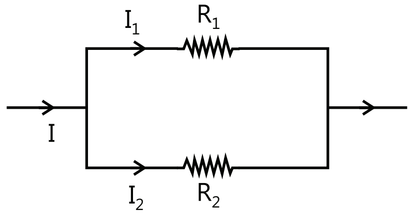


Figure 20.37

14. Kirchhoff's Voltage Law: For closed loop $\sum V_i = 0$

15. Kirchhoff's Current Law: At junction $\sum I_i = 0$

16. For circuit of series combination of cell, $I = \frac{\sum_i E_i}{\sum_i r_i + R}$ where E_i and r_i are values for i^{th} cell.

17. For circuit of parallel combination of cell, $E_{eq} = \frac{\sum \frac{E_i}{r_i}}{\sum \frac{1}{r_i}}$ and $R_{eq} = R + \frac{1}{\sum \frac{1}{r_i}}$

18. Relation of resistance to the resistivity of conductor is $R = \rho \frac{\ell}{A}$

19. Temperature dependence of resistivity is expressed as $\rho - \rho_0 = \rho_0 \alpha (T - T_0)$

20. Power consumed in any electrical device is P= IV and, resistive power dissipation $P = I^2 R = \frac{V^2}{R}$

21. For DC circuit of Resistance and Capacitance, (i) applied voltage $E = \frac{q}{C} + IR$,

(ii) Current in the circuit $I = I_o e^{-t/\tau}$ where $\tau_C = R_{eq} C$ is the time constant of the circuit

(iii) Charge stored by capacitor is $q = Q(1 - e^{-t/\tau})$

22. For potentiometer $E \propto \ell \Rightarrow R \propto \ell$

23. For Wheatstone bridge network of resistance $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

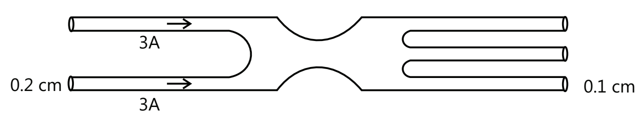
24. For meter bridge, the ratio of resistance $\frac{R_1}{R_2} = \frac{\ell_1}{\ell_2} = \frac{\ell_1}{100 - \ell_1}$

25. Internal resistance of cell is given by $r = \left(\frac{E}{V} - 1\right) R = \left(\frac{\ell_1}{\ell_2} - 1\right) R$

Solved Examples

JEE Main/Boards

Example 1: 3 A current is flowing through two identical conductors having diameter equal to 0.2 cm. These conductors are then split into three identical conductors each having 0.1cm diameter (see figure below) Calculate the drift velocities in the thicker and the thinner conductors.



The electron density = 7× 10^{28} m^{-3}. All the conductors are made of the same material. The electric charge on electron is equal to = 1.6 × 10^{-19}C

Sol: At the junction the algebraic sum of currents is zero. The drift velocity of charges is the ratio of current density to the charge density.

The current density in the thicker wire

$$=\frac{I}{A}=\frac{3}{\pi r^2}=\frac{3}{\pi(0.1\times10^{-2})^2}$$

Current density J = nev_d

$$\therefore\ V_d=\frac{J}{ne}$$

$$=\frac{3}{\pi(0.1\times10^{-2})^2\times7\times10^{28}\times1.6\times10^{-19}}$$

$$\therefore\quad V_d=8.5\times10^{5}ms^{-1}$$

6A total current is flowing through the three identical conductors (As per Kirchhoff's First Law).

∴ The current flowing through each of the wires =2A

$$\therefore\quad V_d'=\frac{J'}{ne}$$

$$=\frac{2}{\pi\left(\frac{0.1}{2}\times10^{-2}\right)^2\times7\times10^{28}\times1.6\times10^{-19}}$$

$$=2.3\times10^{-4}\ ms^{-1}$$

Example 2: A potential difference of 200 volt is maintained across a conductor of resistance 100ohm. Calculate the number of electrons flowing through it in one second. Charge on electron, e = 1.6 × 10^{-19}C

Sol: Number of electrons flowing per sec, through conductor is the ratio of total charge flowing to the charge ofan electron.

Here V = 200 volt; R = 100 ohm;

e = 1.6 × 10^{-19}C

Now $I=\frac{V}{R}=\frac{200}{100}=2$ ampere

Charge flowing in t = 1 sec, q =I t = 2 × 1 = 2C

Therefore, number of Ω electrons flowing through the conductor flowing in 1 s,

$$n=\frac{q}{e}=\frac{2}{1.6\times10^{-19}}=1.25\times10^{19}$$

Example 3: A negligibly small current is passed through a wire of length 15 m and uniform cross-section

6.0 × 10^{-7} m^2 $\rho=\frac{5\times6\times10^{-7}}{15}=2\times10^{7}\Omega m$

and its resistance is measured to be $R=\rho\frac{L}{A}$.

What is the resistivity of the material at the temperature of the experiment?

Sol: The resistance of the conductor is calculated as

$$R=\frac{\rho L}{A}.$$

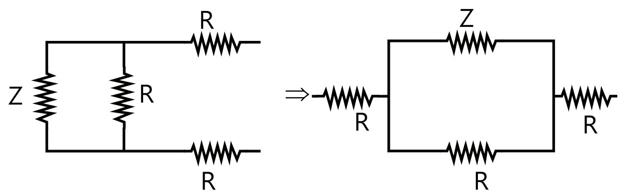
Using $R=\rho\frac{L}{a}$, we get . $\rho=\frac{R\times a}{L}$.

i.e. $\rho=\frac{5\times6\times10^{-7}}{15}=2\times10^{7}\ \Omega m$

Example 4: Determine the current drawn from 12V supply with internal resistance 0.5Ω by the infinite network shown in figure. Each resistance has 1Ω resistance.

Sol: The equivalent resistance of the circuit is deduced by reducing it to simple network. Using Ohm's law we get the current through network.

Let the total resistance of the circuit be Z and a set of three resistor of



value R each be connected to it as shown in the figure, adding of these resistors will not change the value of Z because the network is infinite then

$$Z = R + \frac{ZR}{Z+R} + R = 2R + \frac{ZR}{Z+R}$$

Or $Z = 2 + \frac{Z}{I+Z}$ i.e. $Z_2 - 2Z - 2 = 0$

or $Z = 1 \pm \sqrt{3}$ or $Z = 1 \pm \sqrt{3} = 2.73\Omega$

(value of Z cannot be negative).

Current drawn, $I = \frac{E}{Z+r} = \frac{12}{2.73} = 3.71A$

Example 5: A wire carries a current of 1.2 A, when a potential difference of 1.8 V is applied across it. What is its conductance? If the wire is of length 3 m and area of cross-section 5.4 × 10^{-6} m^2, calculate its conductivity.

Sol: Resistivity is reciprocal of conductivity.

Here V = 1.8V1 = 1.2 A;

l = 3 m and A = 5.4 × 10^{-6} m^2 The resistance of wire.

$$R = \frac{V}{1} = \frac{1.8}{1.2} = 1.5\Omega$$

Therefore conductance of wire.

$$G = \frac{1}{R} = \frac{1}{1.5} = 0.67\Omega^{-1}$$

Now, $R = \rho\frac{1}{A}$ or $\rho = \frac{RA}{l}$

Also, conductivity of wire, $\sigma = \frac{I}{\rho}$

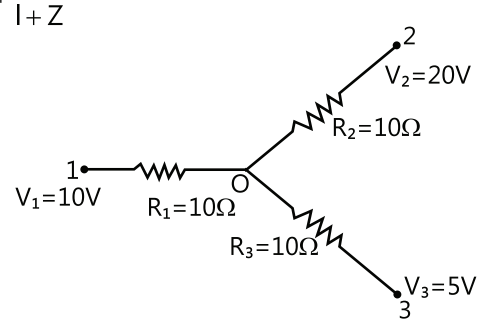
Or $\sigma = \frac{1}{RA} = \frac{3}{1.5 \times 5.4 \times 10^{-6}} = 3.7 \times 10^{5}\,\Omega^{-1}\,m^{-1}$

Example 6: Calculate the current flowing through the resistor R_1 in the given circuit. R_1 = 10Ω, R_2 = 20Ω and R_3 = 30Ω The potentials of the points 1, 2 and 3 are respectively, V_1 = 10v. Calculate V_2 = 6v and V_3 = 5v. Calculate the potential at the junction.

Sol: Use the KVL and KCL at junction to get current followed by application of Ohm's law to get value of resistance.

O the junction point in the above circuit (see figure). The potential at point 1, 2 and 3 is higher than the potential existing at points 2 and 3. Hence, the direction of the current is from point 1to O, from O to 2 and from O to point 3. The figure indicates the electric current and their direction.

$$Z = 2 + \frac{Z}{I+Z}$$

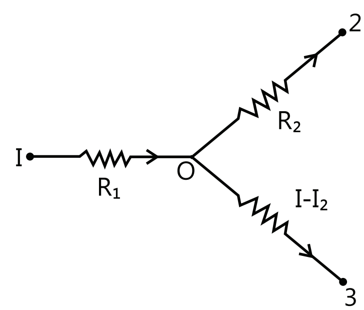


Now for the 1O2 path, we have,

V_1 - $IR_1 - I_2R_2 = V_2$

$\therefore\ 10 - 10I - 20I_2 = 6$

$\therefore\ 10I - 20I_2 = 4$ ....(i)



For the 1O3 path, we have

$10I + 30(I - I_2) = 5$

$\therefore\ 40I - 30I_2 = 5$ ....(ii)

Solving equation (i) and (ii), and we have

I = 0.2 A

Let V_0 be the potential at point O, then

$10 - V_0 = IR_1$

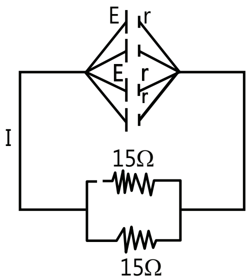
$\therefore\ 10 - V_0 = 2$

$\therefore\ V_0 = 8V$

Example 7: Four identical cells, each of emf 2V, are joined in parallel providing supply of current to external circuit consisting of two 15 Ω resistors joined in parallel. The terminal voltage of the cells as read by an ideal voltmeter is 1.6 V. Calculate the internal resistance of each cell.

Sol: For parallel connection of n identical cells, the net emf is equal to that of one cell and the net internal resistance is the parallel combination of resistances of all the cells $r_{eq} = \frac{r}{n}$.

Four cells are connected in parallel to the parallel combination of two 15 Ω resistors as shown in figure.



Let r be internal resistance of each cell and I be the current I in the circuit. Since the cells are connected in parallel.

Total e.m.f in the circuit – e.m.f. one cell -2V

Further, total internal resistance of the cells is gives by

$$\frac{1}{r'}r = \frac{1}{r}+\frac{1}{r}+\frac{1}{r}+\frac{1}{r'} = \frac{4}{r^4} \text{ or } r' = r/4$$

Let R be resistance of the parallel combination of two 15 Ω resistors. Then, total external resistance,

$$R = \frac{15\times15}{15+15}.75\Omega$$

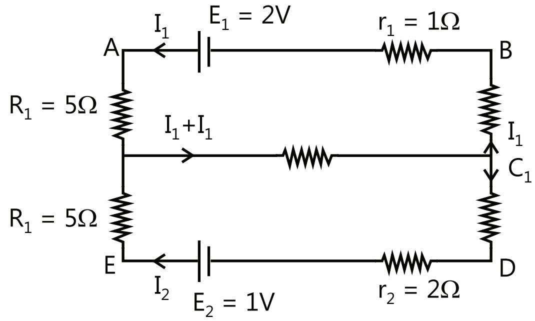
Now, internal resistance of the parallel combination of cells is given by

$$r' = \left(\frac{E}{V}-1\right)R \text{ or } \frac{r}{4} = \left(\frac{2}{1.6}-1\right)\times 7.5 \text{ or } r = 7.5\ \Omega$$

Example 8: Two cell of e.m.f. 2V and 1 V and of internal resistance 1Ω and 2Ω respectively have their positive terminals connected by a wire of 10Ω resistance and their negative terminals by a wire of 4Ω resistance. Another coil of 10 Ω is connected between the middle points of these wires. Find the potential difference across the 10Ω coil.

Sol: Use KVL and KCL and solve to get the current through the resistances and total current through the circuit. Use Ohm's law to get the equivalent P.D. across R.

The positive terminals of the cells E_1 and E_2 are connected to the wire AE of resistance 10Ω and negative terminals to the wire BD of resistance 4Ω. The resistance of 10Ω is connected between the middle points F and C of the wires AE and BD respectively. (See figure)



$$\therefore R_1 = R_2 = \frac{10}{2} = 5\Omega;\quad R_3 = R_4 = \frac{4}{2} = 2\Omega$$

The distribution of current in various branches is shown in the figure.

In closed part ABCFA of the circuit

$$I_1\times r_1 + I_1\times R_3 + (I_1\times I_2)R + I_1\times R_3 = E_a$$

or $\quad I_1\times1 + I_1\times5 + (I_1\times I_2)\times10 + I_1\times2 = 2$

or $\quad 9I_1 + 5I_2 = 1$ ....(i)

In closed part CDRFC of the circuit:

$$I_2\times r_2 + I_2\times R_2 + (I_1\times I_2)R + I_2\times R_4 = E_2$$

or $\quad I_2\times2 + I_2\times5 + (I_1\times I_2)\times10 + I_1\times2 = 1$

$10I_1 + 9I_2 = 1$ ....(ii)

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

Solving equation (i) and (ii) we have

$$I_2 = \frac{14}{121}A \text{ and } I_2 = \frac{1}{121}A$$

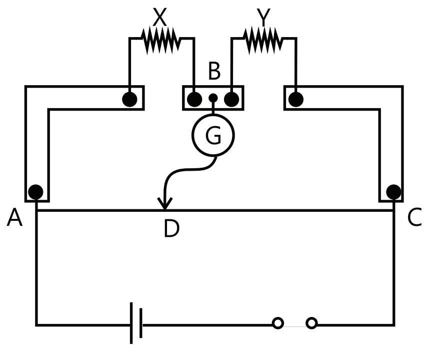
Therefore, current thought resistance R,

$$I_1 + I_2 = \frac{4}{121} + \left[-\frac{1}{121}\right] = \frac{13}{121}A$$

Potential difference across the resistance R

$$(I_1+I_2)R = \frac{13}{121}\times10 = 1.0744\,V$$

Example 9: (a) In a meter bridge (See figure), the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5Ω. Determine the resistance of X Why are the connection between resistors in a Wheatstone or Meter Bridge made of thick copper strips?



(b) Determine the balance point of the bridge above if X and Y interchanged.

(c) What happens if the galvanometer and cell are interchanged at the balance point of the bridge?

Would the galvanometer show any current?

Sol: For potentiometer circuit, $E \propto \ell \Rightarrow R \propto \ell$. Thus we take the ratio of resistances.

(a) (i) Using $X - R\dfrac{1}{100-I}$, we get

$$X = \frac{12.5(39.5)}{(100-39.5)} = \frac{12.5(39.5)}{6} = 8.2\Omega$$

(ii) Thick copper strips are used to reduce their resistance because this resistance is not

Accounted for in the calculations.

(b) Interchanging R and X we get

$$R = X\frac{1}{100-I} \quad \text{i.e. } 100R - RI = X_I$$

$$\text{i.e.} \quad I = \frac{R100}{R+X} \quad \text{i.e.} \quad I = \frac{12.5\times 100}{12.5+8.2}$$

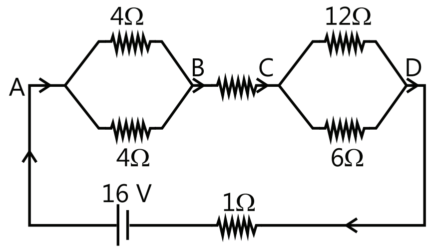
(c) In this case also the galvanometer will not show current.

Example 10: A network of resistors is connected to a 16 V battery with internal resistance of 1Ω, as shown in figure.

(a) Compute the equivalent resistance of the network.

(b) Obtain the current each resistor.

(c) Obtain the voltage drops V_{AB}, V_{BC}, V_{CD},



Sol: Compute R_{equ} first than compute the current through network. Then use Ohm's law to get P.D. across each arm.

(a) The network is a simple series and parallel combination of resistors. First the two 4Ω resistors in parallel are equivalent to a resistor $= \left[\dfrac{4\times 4}{4+4}\right]\Omega = 2\Omega$

In the way, the 12Ω and 6Ω resistor in parallel are equivalent to a resistor of $\left[\dfrac{12\times 6}{12+6}\right]\Omega = 4\Omega$.

The equivalent resistance R of the network is obtained by combining these resistors (2Ω and 4Ω) with 1Ω in series, that is, R = 2Ω + 4Ω + 1Ω = 7Ω.

(b) The total current I in the circuit is

$$I = \frac{E}{R+r} = \frac{16V}{(7+1)\Omega} = 2A$$

Consider the resistors between A and B. If I_1 is the current in one of the 4_Ω resistors and I_2 the current in the other, $I_1 \times 4 = I_2 \times 4$

That is $I_1 = I_2$, which is otherwise obvious form the symmetry of two arms.

But $I_1 + I_2 = I = 2A$. Thus $I_1 = I_2 = 1A$

That is current in each 4Ω resistor 1 A. Current in 1Ω resistor between Band C would be 2 A.

Now consider the resistance between C and D. If 1_3 is the current in the 12Ω resistor, and I_4 in the 6Ω resistor,

$I_3 \times 12 = I_4 \times 6$, i.e., $I_4 = 2b$

But, $I_3 + I_4 - I = 2A$

Thus, $I_3 = \left[\dfrac{2}{3}A\right], I_4 = \left[\dfrac{4}{3}A\right]_3^4 A]$

That is the current in the $12R = X\dfrac{I}{100-I}$ resistor is (2/3)

A, while the current in the $6I = \dfrac{R100}{R+X}$ resistor (4/3)A,

(c) The voltage drops across AB is

$V_{AB} = I_1 \times 4 = 1A \times 4\Omega = 4V$

This can also be obtained by multiplying the total current between A and B by equivalent resistance between A and B that is,

$V_{AB} = 2A \times 2\Omega = 4V$

The voltage drop across BC is.

$V_{BC} = 12\Omega \times 1\Omega = 2V$

Finally, the voltage drop across CD is

$V_{CD} = 12\Omega \times I_3 = 12\Omega \times \left[\frac{2}{3}\right] A = 8V$

This can alternatively be obtained by multiplying total current between C and D by the equivalent resistance between C and D that is, $V_{CD} = 2A \times 4\Omega = 8V$

Note that the total voltage drop across AD is

$4V + 2V + 8V = 14V$

Thus the terminal voltage of battery is 14V, white its emf is 16V. The loss of the voltage (=2V) is accounted for the resistance 1 Ω of the battery $[2A \times 1\Omega = 2V]$.

Example 11: The four arms of Wheatstone bridge (See figure) have the following resistance:

$AB = 10\Omega$, $BC = 10\Omega$, $CD = 5\Omega$ and $DA = \Omega$

A galvanometer of $15 R = 2\Omega + 4\Omega + 1\Omega = 7\Omega$ resistance is connected across BD. Calculate the current through the galvanometer when a potential difference of 10 V is maintained across AC.

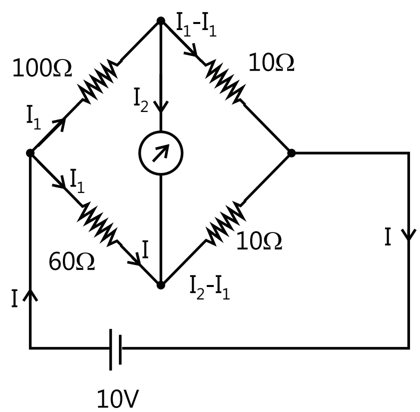
Sol: Use KVL for current distribution across each component as shown in circuit (see figure) and solve to get current through galvanometer.

Considering the mesh BADB, we have

$100I_1 + 15I, -60 I_2 = 0$

or $20I_1 + 3I_2 - 12I_2 = 0$

(a)



Considering the mesh BCDB. We have

$10(I_1 + I_g) - 15I_g - 5(I_1 - I_g) = 0$

$10I_1 + 30I_g \; 5I_2 = 5$; $20I_1 + 6I_g = I_2 = 0$

(b) Considering the mesh ADCEA,

$60I_2 + 5(I_1 - I_g) = 10$

$65I_2 + 5I_g = 10$; $13I_2 + I_g = 2$

(c) Multiplying Eq. (b) by 10

$20I_1 + 60\, I_g - 10I_2 = 0$

(d) Form Eqs. (d) and (a) we have

$I_2 = 31.5I_g$

Substituting the value of I_2 into Eq. (c), we get

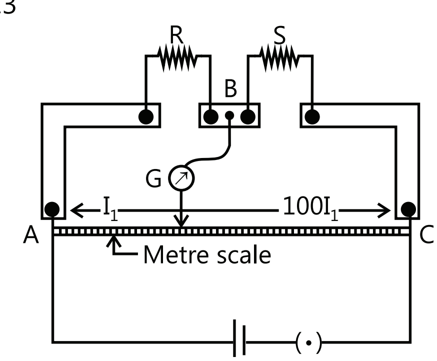
$13(31.5I_g) + I_g = 2$; $410.5 + I_g = 2$; $I_g = 4.87mA$

Example 12: In a meter bridge (See figure), the null point is found at distance of 33.7cm from A. If now a resistance of 12 Ω connected in parallel with S, the null point occurs at 51.9cm. Determine the values of Rand S.

Sol: for meter bridge $E \propto \ell \Rightarrow R \propto \ell$

From the first balance point, we get

$\frac{R}{S} = \frac{3}{66.3}$ ....(i)



After S is connected in parallel with a resistance of 12 Ω, the resistance across the gap changes form S to S_{eq} where $S_{eq} = \frac{12S}{S+12}$

and hence the new balance condition now gives

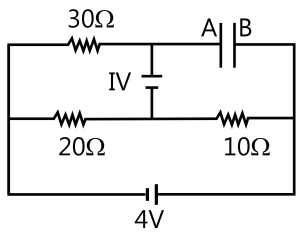
$\frac{51.9}{48.1} = \frac{R(S+12)}{12S} \cdot \frac{33.7}{66.3}$ .....(ii)

Substituting the value of R/S form Eq. (i), we get

$\frac{51.9}{48.1} = \frac{R(S+12)}{12S} \cdot \frac{33.7}{66.3}$

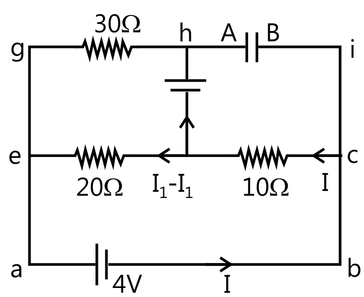
Which gives S = 13.5Ω. Using the value of R/S above, we get R = 6.86Ω

Example 13: Calculate the potential difference between the plates A and B of the capacitor in adjacent circuit.



Sol: Use KVL for current distribution across each component and compute the p.d. across plates A and B.

The distribution of the current shown in figure. Applying Kirchhoff's second Law to the closed loop abedea



We have,

$= 10I = 20(I - I_1) + 4 = 0$; $\therefore$ $30I - 20I_1 = 4$.

For the dhge loop

$20(I - I_1) + I = 30I_1 = 0$; $\therefore$ $20I = 50I_1 = -1$

Solving equation (i) and (ii), we have,

$I_1 = 0.1A$ and $I = 0.2$ A.

The pd between the two plates of the capacitor is equal to the pd between c and h point. Let $100I_1 + 15I_1 - 60I_2 = 0$ be the potential at point c and let $20I1 + I_g - 21_2 = 0$ be the potential at h. For the path odh, we have

$\therefore$ $V_c = 10 \times 0.2 + 1 = V_b$

$\therefore$ $V_c = V_a = 2 = 1 + 1$

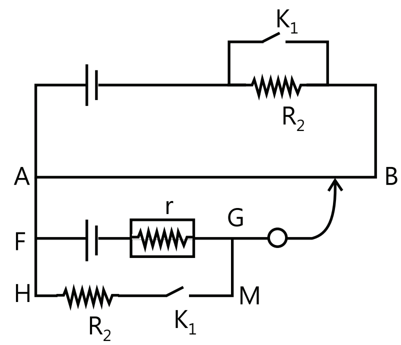
$\therefore$ The potential difference between the two capacitor = 1 V

Example 14: A potentiometer circuit is shown in the figure, the length of the potentiometer wire is equal to 50 cm E_1 = 4V. The internal resistance of the battery can ignored. The values of the resistance R_1 and R_2 are 15 Ω and 5 Ω. The balanced point is obtained at a distance of 31.25 cm from the end A, where both the keys are open. When both the keys are closed the balanced point is obtained at only 5 cm. Calculate.

(a) The emf of E_1

(b) The internal resistance of E_2

The resistance of the potentiometer wire R_{AB} = 10Ω.



Sol: For potentiometer circuit,

$E \propto \ell$. Use KVL and solve for the current in the circuit. Use Ohm's law to get internal resistance of cell E_2.

(a) Resistance R_1 is connected into the circuit when both the keys are open while R_2 gets

Disconnected

$\varepsilon_1 = 4V \qquad \therefore \varepsilon_2 = \left(\dfrac{\varepsilon_1 \rho}{R_1 + R_{AB}}\right) I_1$

$\rho = \dfrac{10}{0.5} = 20\Omega m^{-4}$

$R_1 = 15\Omega \ \therefore \ \varepsilon_2 = \left(\dfrac{4+20}{5+10}\right) 31.25 \times 10^{-2}$

$R_{AB} = 10\Omega \ \therefore \varepsilon_2 = 1V$

$I_2 = 31.25cm = 31.25 \times 10^{-2} m$

(b) Resistance R_1 gets short circuited when both of the keys are closed, in other words resistance R_1 is not connected in the circuit while R_2 gets connected.

Let V_{12} be the pd between point A and jockey which is equal to the p.d. between points F and G of the circuit.

$$V_{12} = \frac{\varepsilon_1 \times I_2 \times \rho}{R_{AB}} = \frac{4 \times 5 \times 10^{-2} \times 20}{10}$$

$\therefore$ $V_{12} = 4 \times 10^{-2} V$

Now, the pd. between point F and G = E_2 – Ir

Where 1 = current flowing through the battery E_2. It can be seen from the diagram that current does flow from the circuit FHMG'F, even if the galvanometer shown zero deflection which means that current flow the E_2 battery which results in a pd between point 'F' and 'G'.

$E_2 = Ir$

The pd should be equal to V_{12} using equation in the above result, we have,

$40\times10^{-2} = \varepsilon_1 = Ir$

The current flowing in the circuit FHMG'F' is equal to.

$$I = \frac{\varepsilon_1}{R_2 + r}$$

$$\therefore \quad 40\times10^{-2} = \varepsilon_2 - \frac{\varepsilon_2 r}{R_2 + r} = \varepsilon_2\left[1 - \frac{r}{R_2 + r}\right]$$

$$= \varepsilon_2 - \frac{\varepsilon_2 + r - r}{R_2 + r} \;\therefore\; 40\times10^{-2} = \varepsilon_2\left[\frac{R_2}{R_2 + r}\right] = 1\left[\frac{5}{5 + r}\right]$$

$$\therefore\; 5 + r = \frac{5}{40\times10^{-2}} = 12.5\Omega$$

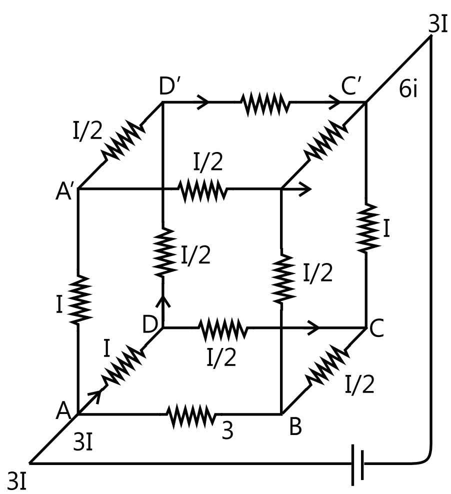
$$\therefore\; r = 12.5 - 5 = 7.5\Omega$$

JEE Advanced/Boards

Example 1: A battery of 10 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistance 1Ω (see figure below). Determine the equivalent resistance of the network and the current along each edge of the cube.

Sol: Use KVL and for p.d. across each component and solve for current though each component.

The network is not reducible to a simple series and parallel combinations of resistors. There is however, clear symmetry in the problem which we can exploit to obtain the equivalent resistance of the network.



The path AA', AD and AB are obviously symmetrically placed in the network. Thus, the current in each must be same say, I, Further, at the corners A', B and D, the incoming current I must split equally into the two outgoing branches. In this manner, the current in all the 12 edges of the cube are easily written down in terms of I, using Kirchhoff's a first rule and the symmetry in the problem. Next take a closed loop, say, ABCC'EA, and apply Kirchhoff's second rule:

= IR = (1/2)IR - IR + ε = 0

where R is the resistance of each edge and ε the emf of battery. Thus, $\varepsilon = \frac{5}{2}IR$

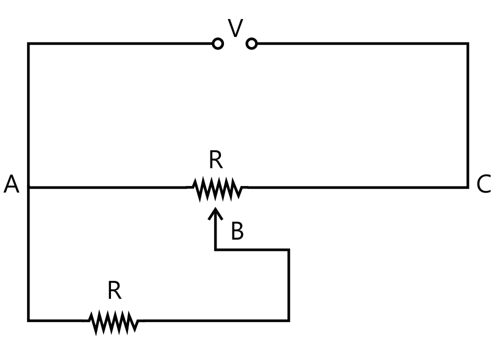
The equivalent R_{eq} of the network is

$$R_{eq} = \frac{\varepsilon}{3I} = \frac{5}{6}R$$

For R = 1 Ω, R_{eq}=(5/6)Ω and for $\varepsilon = 10V$, the total current (=3I) in the network is 3I = 10V/(5/6)Ω = 12A, i.e., I = 4A

The current flowing in each edge can now be read off from the figure.

Example 2: A resistance of RΩ draws current from a potentiometer. The potentiometer has a total resistance R_0Ω (see figure). A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R When the sliding contact is in the middle of the potentiometer.



Sol: Use formulae for series and parallel combination of resistances. P.D. across each branch is given by Ohm's law.

While the slide is in the middle of the potentiometer only half of its resistance (R_0/2) will be between the points A and B. Hence, The total resistance between A and B, say R_1 will be given by the following expression:

$$\frac{1}{R_1} = \frac{1}{R} + \frac{1}{(R_0/2)} \;;\; R_1 = \frac{R_0 R}{R_0 + 2R}$$

The total resistance between A and C will be sum of resistance between A and B and B and C, i.e. $R_1 + R_0/2$

$\therefore$ The current flowing through the potentiometer will be

$$I = \frac{V}{R_1 + R_0/2} = \frac{2V}{2R_1 + R_0}$$

The voltage V_1 taken form the potentiometer will be the product of current I and resistance R_1,

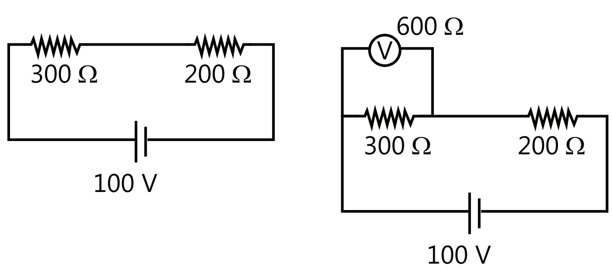
$$V_1 = IR_1 = \left[\frac{2V}{2R_1 + R_0}\right] \times R_1$$

Substituting for R_1, we have a

$$V_1 = \frac{2V}{2\left(\frac{R_0 \times R}{R_0 + 2R}\right) + R_0} \times \frac{R_0 \times R}{R_0 + 2R}$$

$$V_1 = \frac{2VR}{2R + R_0 + 2R} \text{ or } V_1 = \frac{2VR}{R_0 + 4R}$$

Example 3: (a) Find the potential drops across the two resistors shown in figure (a). (b) A voltmeter of resistance 600Ω is used to measure the potential drop across the 300Ω resistor (see figure (b)). What will be the measured potential drop?



Sol: Find the equivalent resistance in both the circuit and then find the p.d. using Ohm's law.

(a) The current in the circuit is $\frac{100V}{300\Omega + 200\Omega} = 0.2A$

The potential drop across the 300Ω resistor is $300\Omega \times 0.2A = 60V$

Similarly, the drop across the 200Ω resistor is 40V.

(b) The equivalent resistance, when the voltmeter is connected across 300Ω, is (see figure (b))

$$R = 200\Omega + \frac{600\Omega \times 300\Omega}{600\Omega + 300\Omega} = 400\Omega$$

Thus, the main current form the battery is

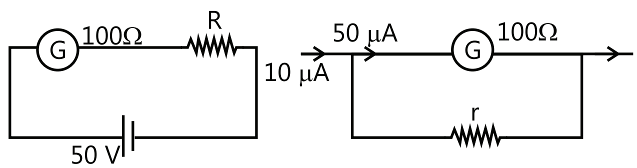
$$i = \frac{100V}{400\Omega} = 0.25A$$

The potential drop across the 200 Ω resistance is, therefore, 200Ω × 0.25 A = 50 V and that across 300is also 50 V. This is also the potential drop across the voltmeter and hence the reading of voltmeter is 50 V.

Example 4: A galvanometer has a coil of resistance 100 Ω showing a full-scale deflection at 50 μA. What resistance should be added to use it as (a) a voltmeter of range 50 V (b) an ammeter of range 10mA?

Sol: To convert galvanometer to voltmeter, connect a large resistance in series with it. To convert galvanometer to ammeter, connect a small resistance in parallel with it. The current through the galvanometer should not exceed its full scale current.

(a) When a potential difference of 50 V is applied across the voltmeter, full-scale deflection should take place. Thus, 50 μA should go through the coil. We



add a resistance R in series with the given coil to achieve this (see figure (a)).

We have, $50\,\mu A = \frac{50V}{100\Omega + R}$

or $R = 10^6\Omega - 100\Omega \approx 10^6\Omega$

(b) When a current of 10mA is passed through the ammeter, 50μA should go through the coil. We add a resistance r in parallel to the coil to achieve this (see figure (b)).

The current through the coil is

$$50\,\mu A = (10 mA)\frac{r}{r + 100\Omega} \text{ or } r = 0.5\Omega$$

JEE Main/Boards

Exercise 1

Q.1 The storage battery of a car has an emf of 12V. If the internal resistance of the battery is 0.4 Ω, what is the maximum current that can be drawn from the battery?

Q.2 A battery of emf 10V and internal resistance 3Ω is connected to a resistor. If the current in the circuit is 0.5A, what is the resistance of the resistor? What is the terminal voltage of the battery when the circuit is closed?

Q.3 (a) There resistor 1 Ω, 2 Ω, and 3Ω are combined in series. What is the total resistance of the combination?

(b) If the combination is connected to a battery of emf 12 V and negligible internal resistance, obtain the potential drop across each resistor.

Q.4 (a) Three resistors 2Ω, 4Ω and 5Ω are combined in parallel. What is the total resistance of the combination?

(b) If the combination is connected to battery of emf 20V and negligible internal resistance, determine the current through each resistor, and the total current drawn from the battery

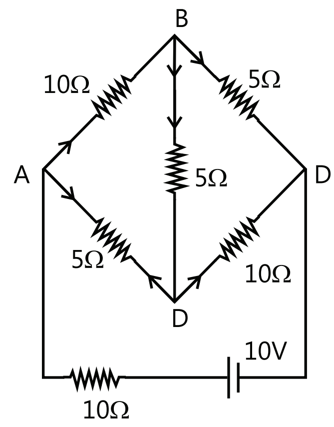
Q.5 At room temperature (27.0 ° C) the resistance of a heating element is 100Ω. What is the temperature of the element if the resistance is found a be 117Ω, given that the temperature coefficient of the material of the resistor is 1.70×10^{-6} °C^{-1}.

Q.6 A negligibly small current is passed through a wire of length 15m and uniform cross–section 6.0×10^{-7} m^2, and its resistance is measured to be 5.0Ω. What is the resistivity of the material oat the temperature of the experiment?

Q.7 A silver wire has a resistance of 2.1Ω at 27.5°C, and a resistance of 2.7Ω at 100°C. Determine the temperature coefficient of resistivity of silver.

Q.8 A heating element using nichrome connected to a 230V supply drawn an initial current of 3.2A which settles after a few seconds to a steady value of 2.8A. What is the steady temperature of the heating element if the room temperature is 27.0°C? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is 1.70×10^{-4} °C^{-1}.

Q.9 Determine the current in each branch of the network shown in figure:



Q.10 A storage battery of emf 8.0FV and internal resistance 0.5Ω is being changed bya 120V DC supply using a series resistor by a 15.5Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?

Q.11 In potentiometer arrangement, a cell of emf 1.25V gives a balance point at 35.0cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0cm, what is the emf the second cell?

Q.12 The number density of free electrons in a copper conductor as estimated is 8.5×10^{28}m^{-3}. How long does an electron take to drift form one end of a wire 3.0m long to its other end? The area of cross- section of the wire is 2.0×10^{6} m^2 and it is carrying a current of 3.0A.

Q.13 The earth's surface has a negative surface charge density of 10^{-9}cm^{-2}. The potential difference of 400kV between the top of the atmosphere and the surface results (due to the low conductivity of the lower atmosphere) in a current of only 1800A over the entire globe. If there were no mechanism of sustaining atmosphere electric field, how much time (roughly) would be required to neutralise the earth's surface? (This never happens in practices because there is a mechanism to replenish electric charges, namely the continual thunderstorms and lighting in different parts of the globe). (Radius of earth = 6.37×10^6 m)

Q.14 (a) Six lead-acid type of secondary cells each of emf 2.0V and internal resistance 0.015Ω are joined in series to provide a supply to a resistance of 8.5Ω. What are the current drawn from the supply and its terminal voltage?

(b) A secondary cell after long use has an emf of 1.9V and a large internal resistance of 380Ω. What maximum current can be drawn from the cell? Could the cell drive the starting motor of a car?

Q.15 Two wire of equal length, one aluminium and the other of copper have the same resistance. Which of the two wire is lighter? Hence explain why aluminium wires are preferred for overhead power cables.

($\rho_{A1} = 2.63 \times 10^{-8}\ \Omega$m, $\rho_{A2} = 1.72 \times 10^{-8}\ \Omega$m,

Relative density of Al = 2.7, of Cu = 8.9)

Q.16 Answer the following questions:

(a) A steady current flow in a metallic conductor of non-uniform cross-section. Which of these quantities is constant along the conductor: current, current density, electric field drift speed?

(b) Is ohm's law universally applicable for all conducting elements? If not, given examples of elements which do not obey ohm's law.

(c) A low voltage supply from which one needs high currents must have very low internal resistance. Why?

(d) A high tension (HT) supply, of say 6kV, must have a very large internal resistance. Why?

Q.17 Choose the correct alternative:

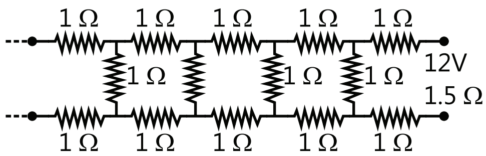
(a) Alloys of metals usually have (greater/less) resistivity than that of their constituent metals.

(b) Alloys usually have much (lower/higher) temperature coefficients of resistance than pure metals.

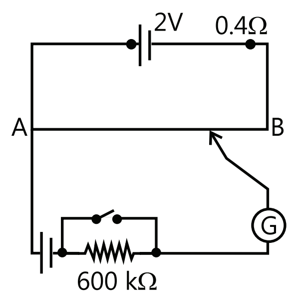
(c) The resistance of the alloy manganin (is nearly independent of / increases rapidly with increases of) temperature.

(d) The resistivity of a typical insulator (e.g., amber) is greater than that of a metal by a factor of the order of (10^{22}\$10^3$).

Q.18 Determine the current drawn from a 12V supply with internal resistance 0.5Ω by the infinite network shown in figure. Each resistor has 1Ω resistance.



Q.19 Figure shows a potentiometer with a cell of 2.0V and internal resistance 0.40Ω maintaining a potential drop across the resistor wire AB. A Standard cell which maintains a constant emf of 1.02V (for every moderate up to a few mA) Give a balance point at 63.7cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600kΩ is put in series with it, which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf ε and the balance point found similarly, turns out to be at 82.3cm length of the wire.



(a) What is the values ε?

(b) What purpose does the high resistance of 600 kΩ have?

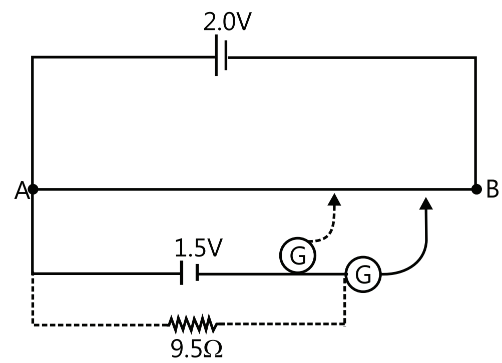
(c) Is the balance point affected by this high resistance?

(d) Is the balance point affected by the internal resistance of the driver cell?

(e) Would the method work in the above situation if the driver cell of the potentiometer had an emf 1.0V instead of 2.0V?

(f) Would the circuit work well for determining an extremely small emf, say of the order of a few mV (such as the typical emf of a thermo-couple)? If not, how will you modify the circuit?

Q.20 Figure shows a 2.0 V potentiometer used for the determining of internal resistance of a 1.5 V cell.The balance point of the cell in open circuit is 76.3cm. When a resistor or 9.5 W is used in the external circuit of the cell, the balance point shifts to 64.8 cm length of the potentiometer wire. Determine the internal resistance of the cell.



Q.21 A galvanometer coil has a resistance of 12Ω and the meter shows full scale deflection for a current of 3mA. How will you convert the bridge into a voltmeter of range 0 to 18 V?

Q.22 A galvanometer coil has resistance of 15Ω and the meter shows full scale deflection for a current of 4mA. How will you convert the meter into an ammeter of range 0to 6 A?

Q.23 A 10 m long wire of uniform cross-section of 20Ω resistance is fitted in a potentiometer. This wire is connected in series with a battery of 5volt, along with an external resistance of 480Ω. If an unknown emf E is balanced at 6.0 m length of this wire, calculate (i) the potential gradient of the potentiometer wire, (ii) the value of the unknown emf E.

Q.24 (a) Three cells of emf 2.0V, 1.8V, and 1.5V are connected in series. Their internal resistances are 0.05Ω, 0.7Ω and 1Ω, respectively. If the battery is connected to an external resistor of 4Ω via a very low resistance ammeter, what would be the reading in the ammeter?

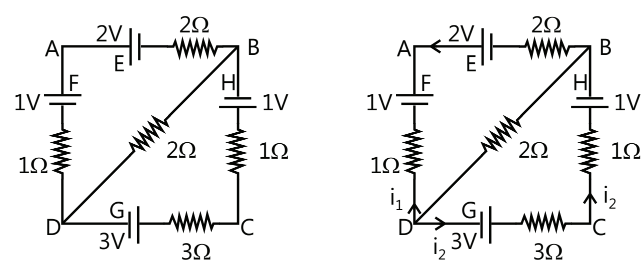
(b) If the three cells above were joined in parallel, would they be characterized by a definite and internal resistance (independent of external circuit)?If not, how will you obtain currents in different branches of the circuit?

Q.25 A galvanometer with a coil of resistance 12.0Ω shows a full scale deflection for a current of 2.5 mA. How will you convert the galvanometer into (a) an ammeter of range 0 to 7.5A, (b) a voltmeter of range 0 to 10.0V. Determine the net resistance of the meter in each case. When an ammeter is put in a circuit, does it read (slightly) less or more than the actual current in the original circuit? When a voltmeter is put a cross a part of circuit, does it read (slightly) less or more than the original voltage drop? Explain.

Q.26 With two resistance R_1 and R_2 (> R_1) in the two gaps of a meter bridge, the balance point was found to be $\frac{1}{3}$ m from the zero end. When a 6Ω resistance is connected in series with the smaller of the two resistance, the point is shifted to $\frac{2}{3}$ m from the same end. Calculate R_1 and R_2.

Q.27 A set of 4cells, each of emf 2 V and internal resistance 1.05Ω, are connected across an external load of 10Ω. with 2 rows, 2cells in each branch. Calculate the current in each branch and potential difference across 10Ω.

Q.28 In the circuit shown in figure E,F,G and H are cells of emf 2,1,3 and 1 V respectively. The resistances 2,1,3 and 1Ω are their respective internal resistance.Calculate (a) the potential difference between B and D and (b) the potential difference across the terminals of each of the cells G and H.

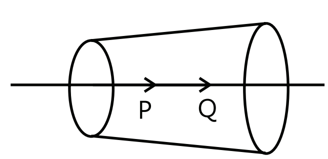


Exercise 2

Q.1 A current I flow through a uniform wire of diameter d when the mean electron drift velocity is V. The same current will flow through a wire of diameter d/2made of the same material if the mean drift velocity of the electron is:

(A) V/4 (B) V/2 (C) 2V (D) 4V

Q.2 A wire has a non- uniform cross- section as shown in figure. A steady current flows through it. The drift speed of electrons at point p and q is V_p and V_Q.



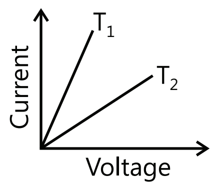
(A) $V_P = V_Q$ (B) $V_P < V_Q$

(C) $V_P > V_Q$ (D) Data insufficient

Q.3 A uniform copper wire carriers a current i amperes and has p carriers per cubic meter. The length of the wire is l meters and its cross-section area is s meter^2. If the charge on a carrier is q coulombs, the drift velocity in ms^{-1} is given by

(A) i/lsp (B) i/psq (C) psq/i (D) i/pslq

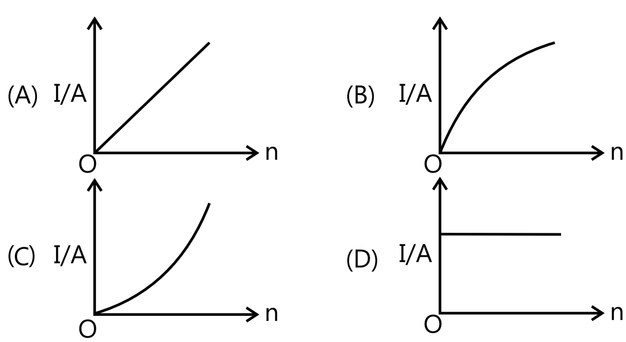
Q.4 The current in a metallic conductor is plotted against voltage at two different temperatures T_1 and T_2. Which is correct



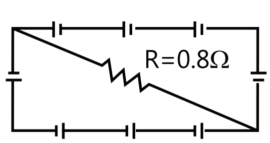
(A) $T_1 > T_2$ (B) $T_1 < T_2$

(C) $T_1 = T_2$ (D) None of these

Q.5 A battery consists of a variable number n of identical cells having internal resistance connected in series. The terminal of the battery are short circuited and the current I measured. Which one of the graph below shows the relationship between I and n?

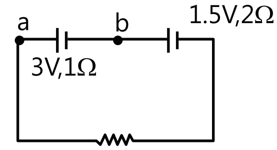


Q.6 A circuit is comprised of eight identical batteries and a resistor R = 0.8Ω. Each battery has an emf 1.0V and internal resistance of 0.2Ω. The voltage difference across any of the battery is



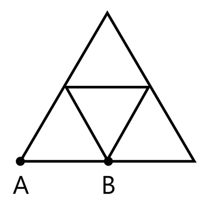
(A) 0.5 V (B) 1.0 V (C) 0 V (D) 2 V

Q.7 Two batteries one of the emf 3 V, internal resistance 1 ohm and the other of emf 15 V, internal resistance 2 ohm are connected in series with a resistance R as shown. If the potential difference between a and b is zero the resistance of R in ohm is



(A) 5 (B) 7 (C) 3 (D) 1

Q.8 In the diagram resistance between any two junctions is R. Equivalent resistance across terminals A and B is



(A) $\frac{11R}{7}$ (B) $\frac{18R}{11}$ (C) $\frac{7R}{11}$ (D) $\frac{11R}{18}$

Q.9 When electric bulbs of same power, but different marked voltage are connected in series across the power line, their brightness will be:

(A) Proportional to their marked voltage

(B) Inversely proportional to their marked voltage

(C) Proportional to the square of their marked voltage

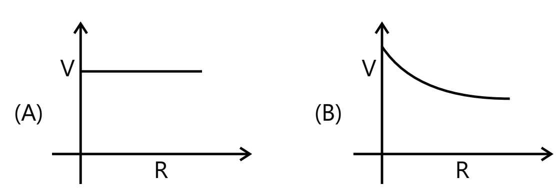
(D) Inversely proportional to the square of their marked voltage

Q.10 Two bulbs rated (25W – 220 V) and (100W – 220V) are connected in series to a 440 V line. Which one is likely to fuse?

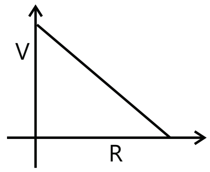
(A) 25 W bulb (B) 100 W bulb

(C) Both bulbs (D) None

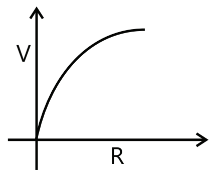
Q.11 A cell of emf E has an internal resistance r & is connected to rheostat. When resistance R of rheostat is changed correct graph of potential across it is (see figure)



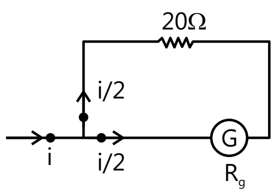
(C)



(D)



Q.12 The battery in the diagram is to be charged by the generator G. The generator has a terminal voltage of 120 volts when the charging current is 10 amperes. The battery has an emf of 100 volts and an internal resistance of 1 ohm. In order to charge the battery at 10 amperes charging current, the resistance R should be set at



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

Q.13 In a galvanometer, the deflection becomes one half when the galvanometer is shunted by a 20Ω resistor. The galvanometer resistance is

(A) 5 Ω (B) 10 Ω (C) 40 Ω (D) 20 Ω

Q.14 A galvanometer has a resistance of 20Ω and reads full-scale when 0.2 V is applied across it. To convert it into a 10 A ammeter, the galvanometer coil should have a

(A) 0.01Ω resistor connected across it

(B) 0.02Ω resistor connected across it

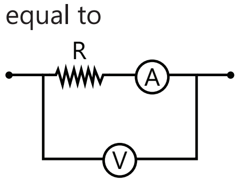
(C) 200Ω resistor connected in series with it

(D) 2000Ω resistor connected in series with it

Q.15 A galvanometer coil has a resistance 90Ω and full scale deflection current 10 mA. A 910Ω resistance is connected in series with the galvanometer to make a voltmeter. If the least count of the voltmeter is 0.1V, the number of divisions on its scale is

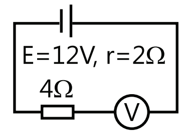
(A) 90 (B) 91 (C) 100 (D) None

Q.16 In the circuit shown the resistance of voltmeter is 10,000 ohm and that of ammeter is 20 ohm. The ammeter reading is 0.10 Amp and voltmeter reading is 12 volt. Then R is equal to



(A) 122 Ω (B) 140 Ω (C) 116 Ω (D) 100 Ω

Q.17 By error, a student place moving-coil voltmeter V (nearly ideal) in series with the resistance in a circuit in order to read the current, as shown (see figure). The voltmeter reading will be



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

Q.18 Statement-I: Conductivity of a metallic conductor decreases with increases in temperature.

Statement-II: On increasing temperature the number of free electrons in the metallic conductor decreases.

(A) Statement-I is true, statement-II is true and statement-II is correct explanation for statement-I.

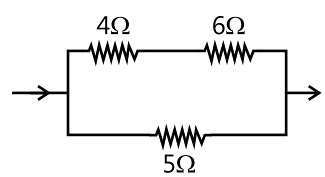
(B) Statement-I is true, statement-II is true and statement-II is NOT the correct explanation for statement-I

(C) Statement-I is true, statement-II is false.

(D) Statement-I is false, statement-II is true.

Previous Years' Questions

Q.1 In the circuit shown in figure the heat produced the 5Ω resistor due to the current flowing through it is 10 cal/s. ***(1981)***

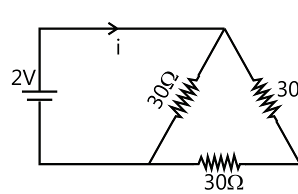


The heat generated in the 4Ω resistor is

(A) 1 cal/s (B) 2 cal/s

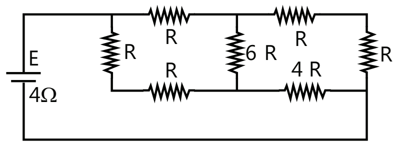
(C) 3 cal/s (D) 4 cal/s

Q.2 The current i in the circuit (see figure) is



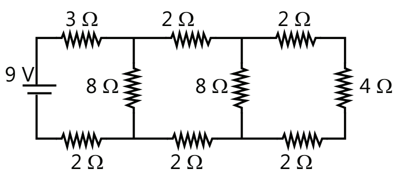
(A) $\frac{1}{45}$A (B) $\frac{1}{15}$A (C) $\frac{1}{10}$A (D) $\frac{1}{5}$A

Q.3 A battery of internal resistance 4Ω is connected to the network of resistances as shown in figure. In order that the maximum power can be delivered to the network, the value of R in Ω should be. ***(1995)***



(A) $\frac{4}{9}$ (B) 2 (C) $\frac{8}{3}$ (D) 18

Q.4 In the circuit shown in the figure, the current through ***(1998)***



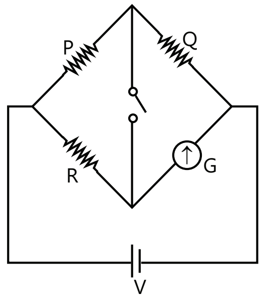
(A) The 3Ω resistor is 0.50A

(B) The 3Ω resistor is 0.25A

(C) The 4Ω resistor is 0.50A

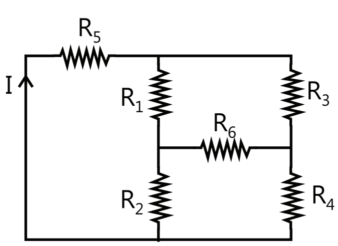
(D) The 4Ω resistor is 0.25A

Q.5 In the circuit shown P ≠ R, the reading of galvanometer is same with switch S open or closed. Then ***(1999)***



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

Q.6 In the given circuit, it is observed that the current I is independent of the value of the resistance R_6. Then, the resistance values must satisfy ***(2001)***



(A) $R_1R_2R_5 = R_3R_4R_6$

(B) $\frac{1}{R_5}+\frac{1}{R_6}=\frac{1}{R_1+R_2}+\frac{1}{R_3+R_4}$

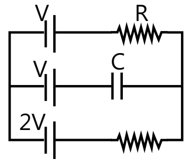
(C) $R_1R_4 = R_2R_3$

(D) $R_1R_3 = R_2R_4$

Q.7 A wire of length L and 3 identical cells of negligible internal resistance are connected in series. Due to the current, the temperature of the wire is raised by ΔT in a time t. A number N of similar cells is now connected in series with a wire of the same material and cross-section but of length 2L. The temperature of the wire is raised by the same amount ΔT in the time. The value of N is ***(2001)***

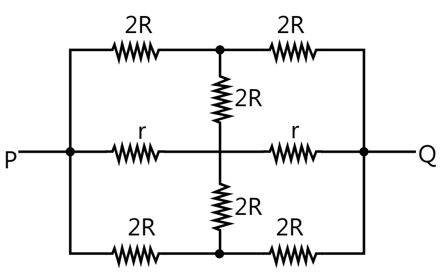
(A) 4 (B) 6 (C) 8 (D) 9

Q.8 In the given circuit, with steady current, the potential difference across the capacitor must be ***(2001)***



(A) V (B) V/2 (C) V/3 (D) 2V/3

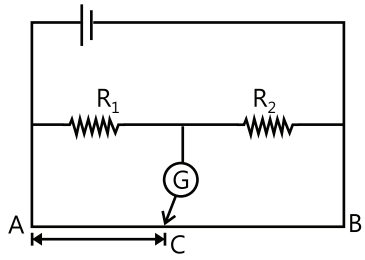
Q.9 The effective resistance between point P and Q of the electrical circuit shown in the figure is ***(2002)***



(A) $\frac{2Rr}{R+r}$ (B) $\frac{8R(R+r)}{3R+r}$

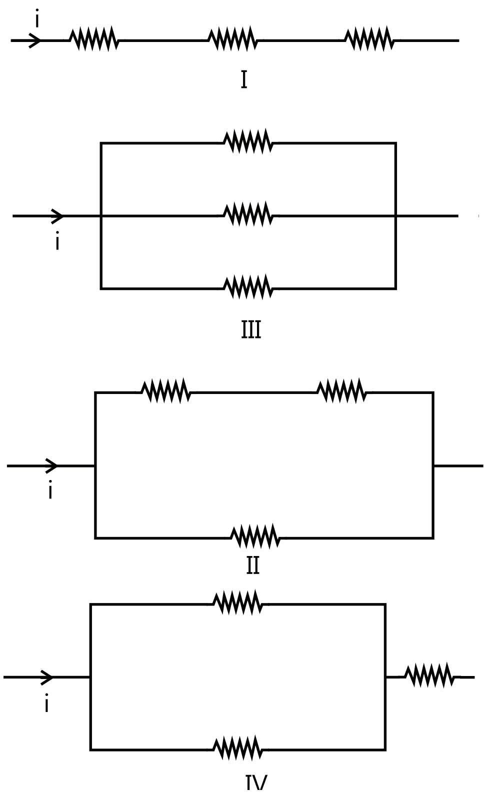
(C) $2r+4R$ (D) $\frac{5R}{2}+2r$

Q.10 In shown arrangement of the experiment of the meter bridge if AC corresponding to null deflection of galvanometer is x, what would be its value if the radius of the wire AB is doubled? ***(2003)***



(A) x (B) x/4 (C) 4x (D) 2x

Q.11 The three resistance of equal value are arranged in the different combinations shown below. Arrange them in increasing order of power dissipation ***(2003)***



(A) III<II<IV<I (B) II<III<IV<I

(C) I<IV<III<II (D) I<III<II<IV

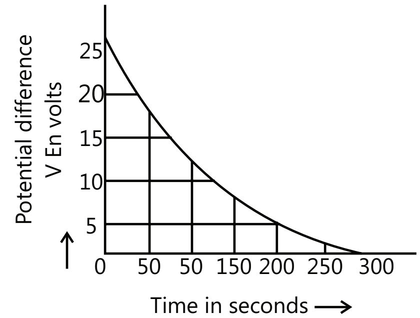
Q.12 The figure shows an experimental plot for discharging of a capacitor in an R-C circuit. The time constant τ of this circuit lies between : ***(2012)***

(A) 150 sec and 200 sec

(B) 0 and 50 sec

(C) 50 sec and 100 sec

(D) 100 sec and 150 sec



Q.13 The electric bulbs marked 25 W – 220 V and 100 W – 220 V are connected in series to a 440 V supply. Which of the bulbs will fuse ? ***(2012)***

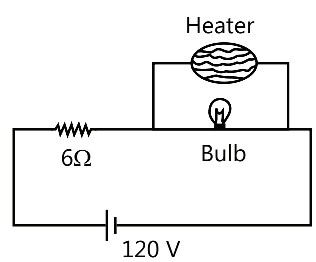
(A) Both (B) 100 W

(C) 25 W (D) Neither

Q.14 The supply voltage to a room is 120 V. The resistance of the lead wires is $6\,\Omega$. 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 ? ***(2013)***

(A) 2.9 Volt (B) 13.3 Volt

(C) 10.04 Volt (D) Zero volt



Q.15 This question has statement-I and statement-II. Of the four choices given after the statements, choose the one that best describes the two statement.

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. **(2013)**

(A) Statement-I is true, statement-II is true, statement-II is not the correct explanation of statement-I

(B) Statement-I is true, statement-II is false

(C) Statement-I is false, statement-II is true

(D) Statement-I is true, statement-II is true, statement-II is the correct explanation of statement-I

Q.16 In a large building, there are 15 bulbs of 40 W, 5 bulbs of 100 W, 5 fans of 80 W and 1 heater of 1kW. The voltage of the electric mains is 220 V. The minimum capacity of the main fuse of the building will be: ***(2014)***

(A) 12 A (B) 14 A (C) 8 A (D) 10 A

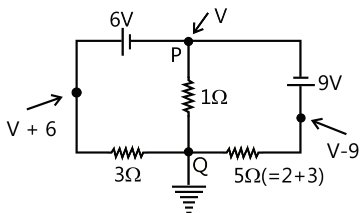
Q.17 In the circuit shown, the current in the 1Ω resistor is: ***(2015)***

(A) 0 A

(B) 0.13 A, from Q to P

(C) 0.13 A, from P to Q

(D) 1.3 A, from P to Q



Q.18 When 5V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is 2.5 $\times 10^{-4}$ ms^{-1}. If the electron density in the wire is 8×10^{28} ms^{-3}, the resistivity of the material is close to: ***(2015)***

(A) 1.6×10^{-7} Ωm (B) 1.6×10^{-6} Ωm

(C) 1.6×10^{-5} Ωm (D) 1.6×10^{-8} Ωm

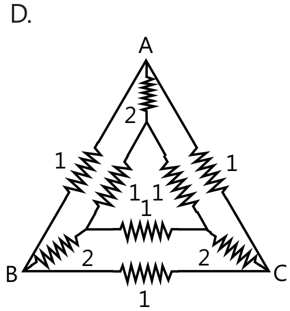
Q.19 A galvanometer having a coil resistance of 100Ω gives a full scale deflection, when a current of 1 mA is passed through it. The value of the resistance, which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10 A is: ***(2016)***

(A) 2Ω (B) 0.1Ω (C) 3Ω (D) 0.01Ω

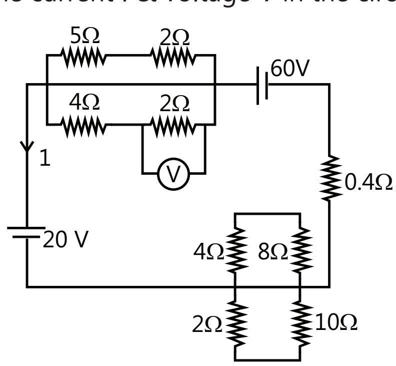
JEE Advanced/Boards

Exercise 1

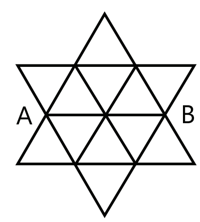
Q.1 A network of nine conductors connects six point A, B, C, D, E and F as shown in figure. The figure denotes resistances in ohms. Find the equivalent resistance between A and D.



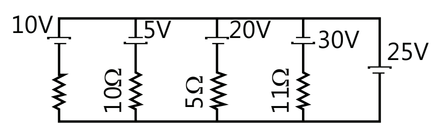
Q.2 Find the current I & voltage V in the circuit shown.



Q.3 Find the equivalent resistance of the circuit between points A and B shown in figure is: (each branch is of resistance = 1Ω)

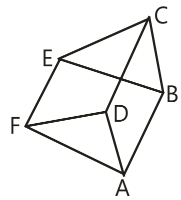


Q.4 Find the current through 25V cell &power supplied by 20V cell in the figure.

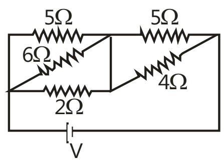


Q.5 In a cell of constant E.M.F. produces the same amount of the heat during the same time in two independent resistor R_1 and R_2, when they are separately connected across the terminals of the cell, one after the another, find the internal resistance of the cell.

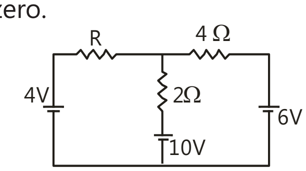
Q.6 In the circuit shown in figure, all wires have equal resistance r. Find the equivalent resistance between A and B.



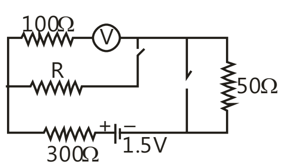
Q.7 Find the resistor in which maximum heat will be produced.



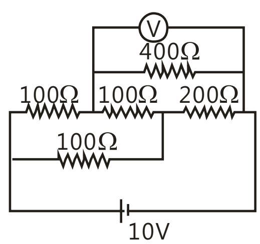
Q.8 For what value of R in circuit, current through 4Ω resistance is zero.



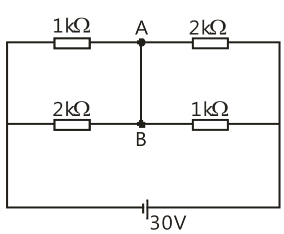
Q.9 In the circuit shown in figure, the reading of ammeter is the same with both switches open as with both closed. Then find the resistance R.(ammeter is ideal)



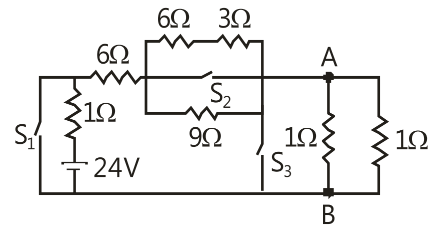
Q.10 An electrical circuit is shown in the figure. Calculate the potential difference across the resistance of 400 ohm, as will be measured by the voltmeter V of resistance 400 ohm, either by applying Kirchhoff's rules or otherwise.



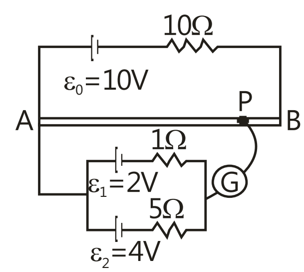
Q.11 Find the current (in mA) in the wire between points A and B.



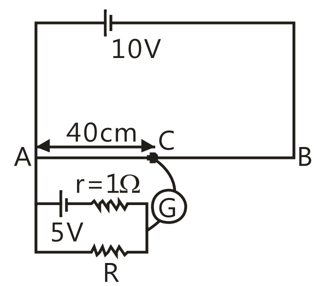
Q.12 If switches S_1, S_2 and S_3 in the figure are arranged such that current through the battery isminimum, find the voltage across points A and B.



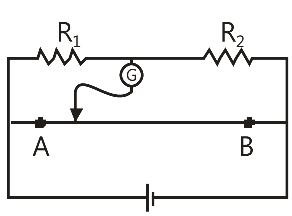
Q.13 A battery of emf e_0 = 10V is connected across a 1 m long uniform wire having 10Ω\m. Two cells of emf ε_1= 2V and ε_2 = 4Vhaving internal resistances 1Ω and 5Ω respectively are connected as shown in the figure. If a galvanometer shown no deflection at the point P, find the distance of point P from the point a.



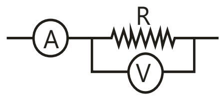
Q.14 Potentiometer wire AB is 100 cm long and has a total resistance of 10 ohm. If the galvanometer shows zero deflection at the position C, then find the value of unknown resistance R.



Q.15 In the figure for which value 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 10Ω, balance shifts to 50 cm. Find R_1 and R_2(AB=1 m):



Q.16 A part of a circuit is shown in figure. Here reading of ammeter is 5 ampere and voltmeter is 96 V and voltmeter resistance is 480 ohm. The find the resistance R

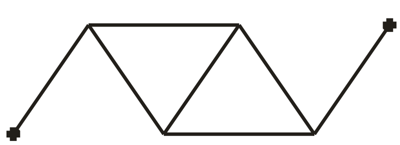


Q.17 A accumulator of emf 2 Volt and negligible internal resistance is connected across a uniform wire of length 10 m and resistance 30Ω The appropriate terminals of a cell of emf 1.5 Volt and internal resistance 1Ω is connected of one end of the wire, and other terminal of the cell is connected through sensitive galvanometer to a slider on the wire. What length of the wire will be required to produce zero deflection of the galvanometer?

How will the balancing change (a) when a coil of resistance 5Ω is placed series with the accumulator, (b) the cell of 1.5 volt is shunted with 5Ω resistor?

Q.18 (a) The current density across a cylindrical conductor of radius R varies according to the equation, $J = J_0\left(1-\frac{r}{R}\right)$ where r is the distance from the axis. Thus the current density is a maximum J_0 at the axis r = 0 and decreases linearly to zero at the surface r = R. Calculate the current in terms of J_0 and conductor's cross sectional area is $A = \pi R_2$. (b) Suppose that instead the current density is a maximum J_0 at the surface and decreases linearly to zero at the axis so that $J = J_0\frac{r}{R}$. Calculate the current.

Q.19 What will be the change in the resistance of a circuit consisting of five identical conductors if two similar conductors are added as shown by the dashed line in figure.

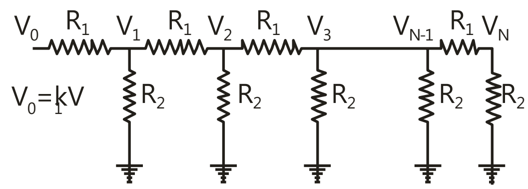


Q.20 The current I though a rod of a certain metallic oxide is given by $I=2V^{5/2}$, where V is the potential difference across it. The rod is connected in series with a resistance to a 6V battery of negligible internal resistance. What value should the series resistance have so that:

(i) The current in the current is 0.44

(ii) The power dissipated in the rod is twice that dissipated in the resistance.

Q.21 A network of resistance is constructed with R_1 and R_2 as shown in the figure. The potential at the point 1,2,3,..., N are $V_1, V_2, V_3, ..., V_n$ respectively each having a potential k time smaller than previous one. Find:

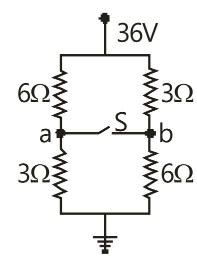


(i) $\frac{R_1}{R_2}$ and $\frac{R_2}{R_3}$ in terms of k

(ii) Current that passes through the resistance R_2 nearest to the V_0 in terms V_0, k & R_3.

Q.22 A person decides to use his bath tub water to generate electric power to run a 40 watt bulb. The bath tube is located at a height of 10 m from the ground & 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 tube to light bulb? How long can we keep the bulb on, if the bath tub was full initially. The efficiency of generator is 90%. ($g = 10\ m/s^{-2}$)

Q.23 In the circuit shown in figure, calculate the following:



(i) Potential difference between point a and b when switch S is open

(ii) Current through S in the circuit when S is closed.

Q.24 A rob length L and cross-section area A lies along the x-axis between x = 0 and x = L. The material obeys Ohm's law and its resistivity varies along the rod according to $\rho(x) = \rho_0 e_{x/L}$. The end of rod at x = 0 is at a potential V_0 and it is zero at x = L.

(a) Find the total resistance of the rod and the current in the wire.

(b) Find the electric potential in the rod as a function of x.

Q.25 An ideal cell having a steady emf of 2 volt is connected across the potentiometer wire of length 10 m. The potentiometer wire of magnesium and having resistance of 11.5Ω/m. An another cell gives a null point at 6.9 m. If a resistance of 5Ω is put in series with potentiometer wire, find the new position of the null point.

Exercise 2

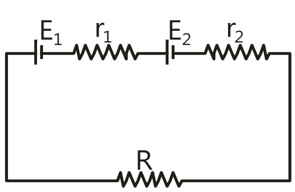
Single Correct Choice Type

Q.1 An insulating pipe of cross-section area 'A' contains an electrolyte which has two types of ions → their charge begin-e and +2 e. A potential difference applied between the ends of the pipe result in the drifting of the two types of ions, having drift speed = v (-v e ion) and v/4 (+v e ion). Both ions have the same number per unit volume = n. The current flowing through the pipe is

(A) nev A/2 (B) nev A/4

(C) 5nev A/2 (D) 3nev A/2

Q.2 Under what condition current passing through the resistance R can be increased by short circuiting the battery of emf E_2. The internal resistance of the two batteries are r_1 and r_2 respectively.



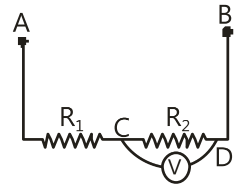
(A) $E_2r_1 > E_1(R + r_2)$ (B) $E_1r_2 > E_2(R + r_1)$

(C) $E_2r_2 > E_1(R + r_2)$ (D) $E_1r_1 > E_2(R + r_1)$

Q.3 Awire of length L and 3 identical cells of negligible internal resistance are connected in series. Due to the current, the temperature of the wire is raised by ΔT in time t. N number of similar cells is now connected in series with a wire of the same material and cross section but of length 2L. The temperature of the wire is raised by the same amount ΔT in the same time t. The value of N is:

(A) 4 (B) 6 (C) 8 (D) 9

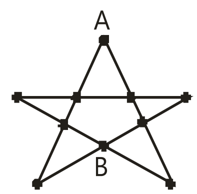
Q.4 Resistance $R_1$and R_2 each 60Ω are connected in series as shown in figure. The Potential difference between A and B is kept 120 volt. Then what will be the reading of voltmeter connected between the point C and D if resistance of voltmeter is 120Ω.



(A) 48V (B) 24V

(C) 40V (D) None of these

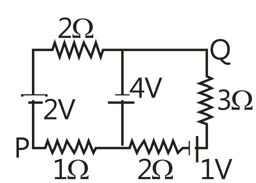
Q.5 The resistance of all the wires between any two adjacent dots is R. The equivalent resistance between A and B as shown in figure is:



(A)7/3 R (B) 7/6 R

(C) 14/8 R (D) None of these

Q.6 In the circuit shown, what is the potential difference V_{PQ}?



(A) +3V (B) +2V

(C) -2V (D) None of these

Q.7 One end of a Nichrome wire of length 2L and cross-sectional area A is attached to an end of another Nichrome wire of length L and cross- sectional area 2A. If the free end of the longer wire is at an electric potential of 8.0 volt, and the free end of the shorter wire is at an electric potential of 1.0 volt, the potential at the junction of the two wire is equal to

(A) 2.4 V (B) 3.2 V (C) 4.5 V (D) 5.6 V

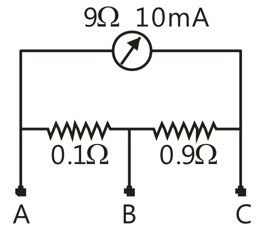
Q.8 Rate of dissipation Joule's heat in resistance per unit volume (Symbols have usual meaning)

(A) σE (B) σJ (C) JE (D) None of these

Q.9 A millimetre of range 10 mA and resistance 9Ω is joined in a circuit as shown (see figure). The meter gives full-scale deflection for current I when A and B are used as its terminals, i.e. current enters leaves at A and leaves at B (C is left isolated). The value of I is

(A) 100 mA (B) 900 mA

(C) 1 A (D) 1.1 A



Q.10 In a balance Wheatstone bridge, current in the galvanometer is zero. It remains when:

(i) Battery emf is increased

(ii) All resistance are increased by 10 ohms

(iii) All resistance are made five times

(iv) The battery and the galvanometer are interchanged

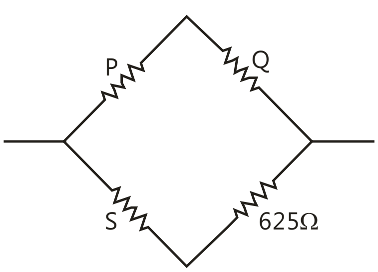
(A) Only (i) is correct

(B) (i), (ii) and (iii) are correct

(C) (i), (iii) and (iv) are correct

(D) (i) and (iii) are correct

Q.11 A Wheatstone's bridge is balanced with a resistance of 625Ω in the third arm, where P, Q and S are in the 1st, 2nd and 4th arm respectively. If P and Q are interchanged, the resistance in the third arm has to be increased by 51Ω to secure balance. The unknown resistance in the fourth arm is



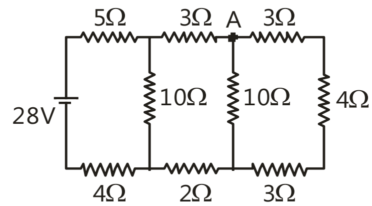
(A) 625Ω (B) 650Ω (C) 676Ω (D) 600Ω

Q.12 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

Q.13 Consider the circuit shown in the figure.



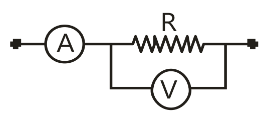
(A) The current in the 5 Ω resistor is 2 A

(B) The current in the 5 Ω resistor 1 A

(C) The potential difference $V_A - V_B$ is a 10V

(D) The potential difference $V_A - V_B$ is 5V

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



(A) 5 Ω

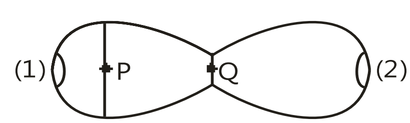
(B) Less than 5 Ω

(C) Greater than 5 Ω

(D) Between 4 Ω and 5 Ω

Multiple Correct Choice Type

Q.15 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:



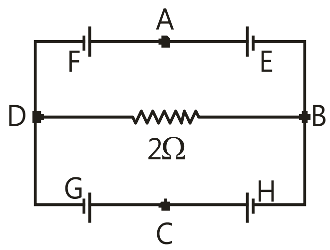
(A) The current at the cross-section P equals the current at cross-section Q

(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 that at P

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

Q.16 In the circuit shown E, F, G and H are cells of e.m.f 2V,1V, 3V and 1V respectively and their internal resistance are 2Ω, 1Ω, 3Ω and 1Ω respectively.



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

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

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

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

Q.17 A micrometre has a resistance of 100Ω and a full scale range of 50μA. It can be used as a voltmeter or a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combination (s)

(A) 50V range with 10kΩ resistance in series.

(B) 10V range with 200kΩ resistance in series.

(C) 5mA range with 1Ω resistance in parallel

(D) 10mA range with 1kΩ resistance in parallel.

Q.18 In a potentiometer wire experiment the emf of a battery in the primary circuit is 20V and its internal resistance is 5Ω. There is 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 75 Ω. The following potential difference can be measured using this potentiometer.

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

Q.19 A current passes through an ohmic conductor of non-uniform cross-section. Which of the following quantities are independent of the cross- section?

(A) The charge crossing in a given time interval.

(B) Drift speed

(C) Current density

(D) Free-electron density

Q.20 Mark out the correct options.

(A) An ammeter should have small resistance

(B) An ammeter should have large resistance

(C) A voltage should have small resistance

(D) A voltage should have large resistance

Assertion Reasoning Type

(A) Statement-I is true, statement-II is true and statement-II is correct explanation for statement-I.

(B) Statement-I is true, statement-II is true and statement-II is true and statement-II is NOT the correct explanation for statement-I

(C) Statement-I is true, statement-II is false.

(D) Statement-I is false, statement-II is true

Q.21 Statement-I: When two conduction wires of different resistivity having same cross section area are joined in series, the electric field in them would be equal when they carry current.

Statement-II: When wires are in series they carry equal current.

Q.22 Statement-I: potential difference across the terminals of a battery is always less than its emf .

Statement-II: A battery always has some internal resistance.

Q.23 Statement-I: Knowing that rating is done at steady of the filament, an electric bulb connected to a source having rated voltage consumes more than rated power just after it is switched on.

Statement-II: When filament is at room temperature its resistance is less than its resistance when the bulb is fully illuminated.

Comprehension Type

Paragraph 1: Two persons are pulling a square of side a along one of the diameters horizontally to make it rhombus. Plane of rhombus is always vertical and uniform magnetic field B exist perpendicular to plane. They start pulling at t = 0 and with constant velocity v.

Q.24 The induced emf in the frame when angle at corner being pulled is 60°

(A) Bav (B) 2Bav (C) $\frac{Bav}{2}$ (D) $\frac{Bav}{4}$

Q.25 If the resistance of the frame is R the current induced is

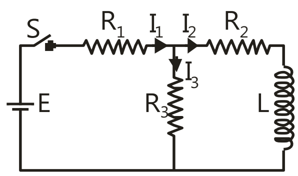
(A) $\frac{Bav}{2R}$ (B) $\frac{2Bav}{2R}$ (C) $\frac{Bav}{2}$ (D) $\frac{Bav}{4R}$

Q.26 Finally square frame reduces to straight wire. The total charge flown is

(A) $\frac{a^2B}{R}$ (B) $\frac{a^2B}{2R}$ (C) $\frac{aB}{R}$ (D) $\frac{aB}{R}$

Paragraph 2: In case of analysis of circuits, containing cells, resistance and inductances two things are very important one is conservation of charge which leads to the fact that at any junction of circuit incoming current is equal to outgoing current. The other thing is that sum of voltage drop in a closed loop is equal to zero. Inductors have a unique property by which they oppose the change in magnetic flux linked to them.

The voltage drop across resistor is V_R = IR and across inductor is $L\frac{dI}{dt}$. In the steady state current through inductor becomes constant which leads to zero voltage drop across inductor. i.e. it behaves like short circuit. Refer to circuit (see figure) E = 10V, $R_1 = 2\Omega$, $R_2 = 3\Omega$, $R_3 = 6\Omega$ and L = 5H



Q.27 The current I_1 just after pressing the switch S is

(A) $\frac{10}{8}$A (B) $\frac{10}{5}$A (C) $\frac{10}{12}$A (D) $\frac{10}{6}$A

Q.28 The current I_1 long after pressing the switch S is

(A) $\frac{10}{4}$A (B) $\frac{10}{5}$A (C) $\frac{10}{12}$A (D) $\frac{10}{6}$A

Q.29 The current I_2 long after pressing the switch S is

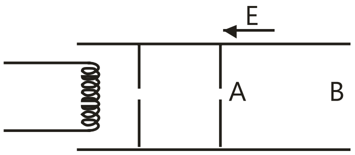
(A) $\frac{10}{4}$A (B) $\frac{10}{5}$A (C) $\frac{10}{12}$A (D) $\frac{10}{6}$A

Q.30 The current through R_2 just after releasing the switch S is

(A) $\frac{10}{4}$A (B) $\frac{10}{5}$A (C) $\frac{10}{6}$A (D) $\frac{10}{6}$A

Match the Columns

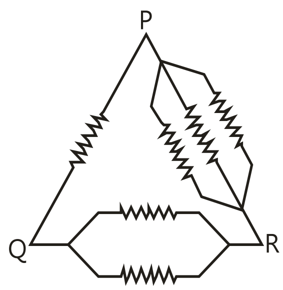
Q.31 Electrons are emitted by a hot filament and are accelerated by an electric field as shown in figure. The two stops at the left ensure that the electron beam has a uniform cross-section. Match the entries of column-I with column-II as electron move from A to B:



Column-I	Column-II
(A) Speed of an electron	(p) Increase
(B) Number of free Per unit Volume electrons	(q) Decrease
(C) current density	(r) Remains same
(D) Electric potential	(s) any of the above is possible

Previous Years' Questions

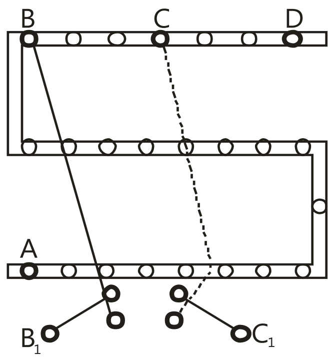
Q.1 Six equal resistance are connected between points P, Q and R as shown in the figure. Then, the net resistance will be maximum between ***(2004)***



(A) P and Q (B) Q and R

(C) P and R (D) Any two points

Q.2 For the post office box arrangement to determine the value of unknown resistance, the unknown resistance should be connected between ***(2004)***



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

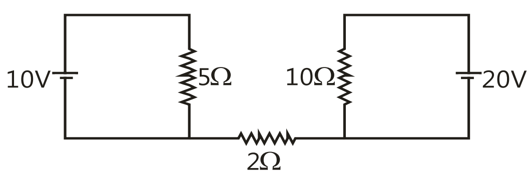
(C) A and D (D) B_1 and C_1

Q.3 A moving coil galvanometer of resistance 100 Ω is used as ammeter using a resistance 0.1 Ω. The maximum deflection current in the galvanometer is 100μA. Find the current in circuit, so that the ammeter shown maximum deflection ***(2005)***

(A) 100.1 mA (B) 1000.1 mA

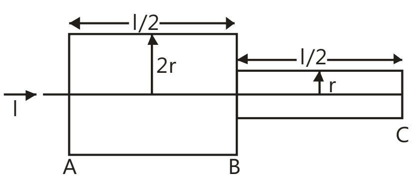
(C) 10.01 mA (D) 10.1 mA

Q.4 Find out the value of current through 2 Ω resistance for the given circuit. ***(2005)***



(A) 5A (B) 2A (C) Zero (D) 4A

Q.5 Two bars of radius r and 2r are kept in contact as shown figure. An electric current I is passed through the bars. Which one of following is correct? ***(2006)***



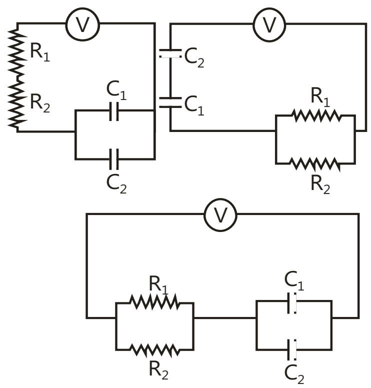
(A) Heat produced in bar BC is 4 times the heat produced in bar AB

(B) Electric field in both halves is equal

(C) Current density across AB is double that of across BC

(D) Potential difference across AB is 4 times that of across BC

Q.6 Find the time constant for the given RC circuits in correct (in μs). ***(2006)***

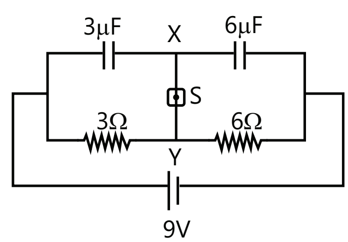


$R_1 = 1\Omega, R_2 = 2\Omega, C_1 = 4\,\mu F, C_2 = 2\mu F.$

(A) 18,4,8/9 (B) 18, 8/9, 4

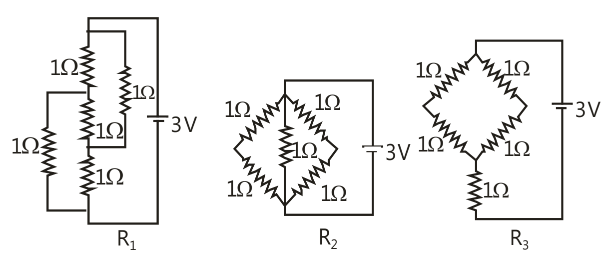
(C) 4, 18,8/9 (D) 4, 8/9,18

Q.7 A circuit is connected as shown in the figure with the switch S open. When the switch is closed, the total amount of charge that flows from Y to X is ***(2007)***



(A) Zero (B) 54 μC (C) 27 μC (D) 81 μC

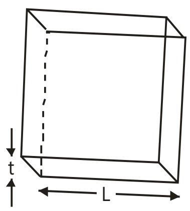
Q.8 Figure shows resistor circuit configuration R_1, R_2 and R_3 connected to 3V battery. If the power dissipated configuration $R_1 R_2$ and R_3 is P_1, P_2 and P_3 respectively, then ***(2008)***



(A) $P_1 > P_2 > P_3$ (B) $P_1 > P_3 > P_2$

(C) $P_2 > P_1 > P_3$ (D) $P_3 > P_2 > P_1$

Q.9 Consider 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 area in the figure is ***(2010)***



(A) Directly proportional to L.

(B) Directly proportional to t

(C) Independent of L

(D) Independent of t

Assertion Reasoning Type

(A) If statement-I is true, statement-II is true: statement-II is the correct explanation for statement-I

(B) If statement-I is true, statement-II is true: statement-II is the not a correct explanation for statement-I

(C) If statement-I is true: statement-II is false

(D) If statement-I is false: statement-II is true

Q.10 Statement-I: In a meter bridge experiment, null point for an unknown resistance is measured. Now, the unknown resistance is put inside an enclosure maintained at a higher temperature. The null point can be obtained at the same point as before by decreasing the value of the standard resistance.

Statement-II: Resistance of a metal increase with increase in temperature. ***(2008)***

Q.11 Capacitor C_1 of capacitance $1\mu F$ and capacitor C_2 of capacitance $2\mu F$ are separately charged fully by a common battery. The two capacitors are then separately allowed to discharge through equal resistor at time t = 0 ***(1989)***

(A) The current in each of the two discharging circuit is zero at t = 0

(B) The current in the two discharging at circuits at t = 0 are equal but not zero

(C) The current in the two discharging circuit at t = 0 are unequal

(D) Capacitor C_1, loses 50% of its initial charge sooner than C_2 loses 50% of its initial charge

Q.12 A micrometre has a resistance of 100Ω and full scale range of $50\mu F$. If can be used as a voltmeter or as a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combination (S) ***(1991)***

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

(B) 10V range with200 kΩ resistance in series

(C) 5mA range with 1Ω resistance in parallel

(D) 10mA range 1Ω resistance in parallel

Q.13 When a potential difference is applied across. The current passing through ***(1999)***

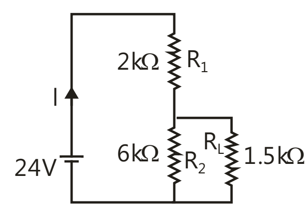
(A) An insulator at 0 K is zero

(B) A semiconductor at 0 K is zero

(C) A metal at 0 K finite

(D) A p-n diode at 300 K is finite, if it is reverse biased

Q.14 For the circuit shown in the figure. ***(2009)***



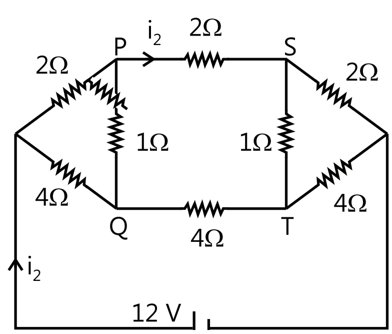
(A) The current I through the battery is 7.5 mA

(B) The potential difference across R_L is 18V

(C) Ratio of powers dissipated in R_L and R_2 is 3

(D) If $R_1$and R_2 are interchanged, magnitude of the power dissipated in R_L will decrease by a factor of 9

Q.15 For the resistance network shown in the figure, choose the correct option(s). ***(2012)***



(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 = 2A

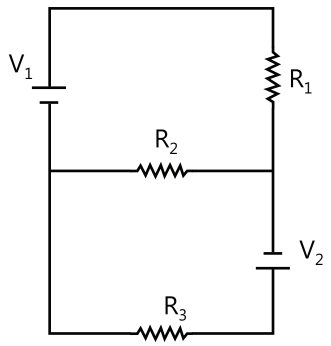
Q.16 The ideal batteries of emf V_1 and V_2 and three resistances R_1, R_2 and R_3 are connected as shown in the figure. The current in resistance R_2 would be zero if ***(2014)***

(A) $V_1 = V_2$ and $R_1 = R_2 = R_3$

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

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

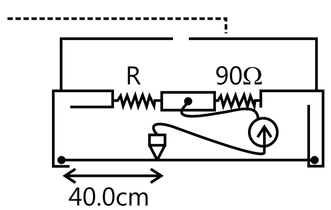
(D) $2V_1 = 2V_2$ and $2R_1 = R_2 = R_3$



Q.17 During an experiment with a metre bridge, the galvanometer shows a null point when the jockey is pressed at 40.0 cm using a standard resistance of 90 Ω, as shown in the figure. The least count of the scale used in the metre bridge is 1 mm. The unknown resistance is ***(2014)***

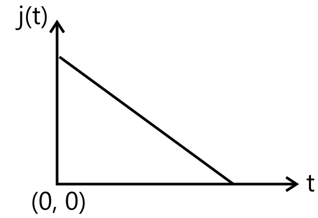
(A) $60 \pm 0.15\ \Omega$ (B) $135 \pm 0.56\ \Omega$

(C) $60 \pm 0.25\ \Omega$ (D) $135 \pm 0.23\ \Omega$

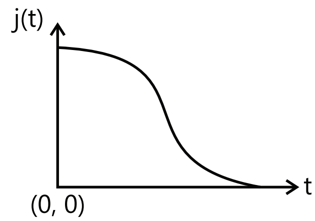


Q.18 An infinite line charge of uniform electric charge density λ lies along the axis of an electrically conducting infinite cylindrical shell of radius R. At time t = 0, the space inside the cylinder is filled with a material of permittivity ε and electrical conductivity σ. The electrical conduction in the material follows Ohm's law. Which one of the following graphs best describes the subsequent variation of the magnitude of current density j(t) at any point in the material? ***(2016)***

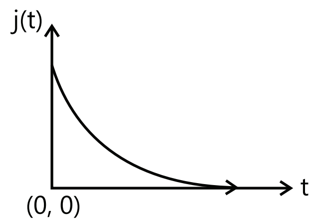
(A)



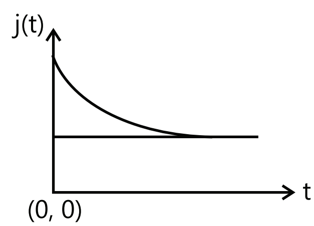
(B)



(C)



(D)



Q.19 Consider the 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 ? ***(2016)***

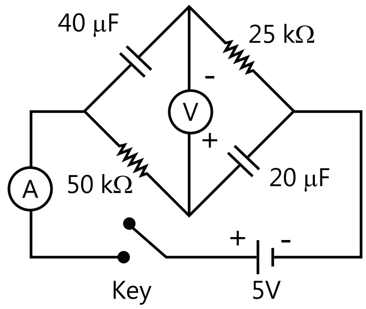
(A) The maximum voltage range is obtained when all the components are connected in series

(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

Q.20 In the circuit shown below, the key is pressed at time t = 0. Which of the following statement(s) is (are) true? ***(2016)***



(A) The voltmeter displays – 5 V as soon as the key is pressed, and displays +5 V after a long time

(B) The voltmeter will display 0 V at time t = ln 2 seconds

(C) The current in the ammeter becomes 1/e of the initial value after 1 second

(D) The current in the ammeter becomes zero after a long time

PlancEssential Questions

JEE Main/Boards

Exercise 1

Q. 8 Q.9 Q.11

Q.19 Q.20 Q.24

Q.28

Exercise 2

Q. 2 Q.4 Q.8

Q.14

JEE Advanced/Boards

Exercise 1

Q.1 Q.2 Q.13

Q. 23 Q.24

Exercise 2

Q.5 Q.9 Q.14

Q.15 Q.17 Q.18

Q.21

Comprehension – 1 (Q.24-26),

Comprehension – 2 (Q.27-30)

Answer Key

JEE Main/Boards

Exercise 1

Q.1 30 A

Q.2 17 Ω , 8.5V

Q.3 (a) 6 Ω (b) 2 V,4V ,6V

Q.4 (a) (20/19) Ω ,(b) 10A, 5A, 4A; 19A

Q.5 1027 ^{0}C

Q.6 2.0 × 10^{-7} Ω m

Q.7 0.0039 °C^{-1}

Q.8 867 ^{0}C

Q.9 current in branch AB = (4/17)A, in BC = (6/17)A, in CD = (-4/17)A, in AD(6/17)A, in BD = (-2/17)A, total current (10/17)A.

Q.10 11.5V

Q.11 2.25V

Q.12 2.7×10^4 s (7.5 h)

Q.13 $\approx$ 238 s.

Q.14 (a) 1.4A, 11.9V, (b) 0.005 A

Q.15 $\approx$ 22 Aluminium is lighter, it is preferred for long suspensions of cables

Q.16 (a) Only current (because it is given to be steady). The rest depends on the area of cross-section inversely.

(b) No, examples of non-ohmic elements; vacuum diode, semiconductor diode.

(c) Because the maximum current drawn a source = ε/r.

(d) Because, if the circuit is shorted (accidentally), the current drawn will exceed safety limits, if internal resistance is not large

Q.17 (a) greater, (b) lower, (c) nearly independent of, (d) 10^{22}.

Q.18 Hint: Let X be the equivalent resistance of the infinite network. Clearly, 2+X(X+1) =X which given X= $(1+\sqrt{3})\ \Omega$; therefore the current is 3.7 A

Q.19 (a) ε = 1.24V, (b) To reduce current through the galvanometer when the movable contact is far from the balance point, (c) No. (d) N truncated. (e) No

Q.20 $1.7\,\Omega$

Q.21 Resistance in series =$5988\,\Omega$

Q.22 Shunt resistance=10 mΩ

Q.23 0.12 volt

Q.24 (a) 0.9 A, (b)(b) Yes we can do it. It is called The venin theorem. It can be represented as equivalent resistance and equivalent voltage.

Q.25 (a) shunt resistance = 400×10^{-3} which is also nearly its net resistance, reads slightly less. (b) Series resistance = $3988\,\Omega$; net resistance = $4000\,\Omega$; read slightly less

Q.26 $2\,\Omega$,$4\,\Omega$

Q.27 3.6 volt

Exercise 2

Single Correct Choice Type

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

Previous Years' Questions

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

JEE Advanced/Boards

Exercise 1

Q.1 $1\,\Omega$	**Q.2** I = 2.5A, V= 2.5 V	**Q.3** $\frac{22}{35}\Omega$
Q.4 12A-20W	**Q.5** $\sqrt{R_1R_2}$	**Q.6** $\frac{3r}{5}\Omega$

Q.7 $4\,\Omega$ **Q.8** $1\,\Omega$ **Q.9** $600\,\Omega$

Q.10 20/3V **Q.11** 7.5 A **Q.12** 1V

Q.13 46.67 cm **Q.14** 4 ohm **Q.15** $\frac{10}{3}\Omega, 5\Omega$

Q.16 20 ohm **Q.17** 7.5 m,8.7 m, 6.125 m **Q.18** (a) $J_0A\backslash 3$; (b) $2J_0A\backslash 3$

Q.19 $\frac{R_1}{R_2}=\frac{5}{3}$ **Q.20** (i) $10.52\,\Omega$; (ii) $0.3125\,\Omega$

Q.21 (i) $\frac{(k-1)^2}{k};\frac{k}{(k-1)}$ (ii) $\frac{\left((k-1)\backslash k^2\right)V_0}{R^3}$ **Q.22** 4/9kgs^{-1}, 450 sec

Q.23 (i) V_{ab} = –12 V (ii) 3 amp from b to a

Q.24 $R=\frac{\rho_0 L}{A}\left(1-\frac{1}{e}\right); I=\frac{V_0 A}{\rho_0 L}\left(\frac{e}{e-1}\right); V\frac{V_0(e^{-x\backslash L}-e^{-1})}{1-e^{-1}}$ **Q.25** 7.2 m

Exercise 2

Single Correct Choice Type

Q.1 D **Q.2** B **Q.3** B **Q.4** A **Q.5** B **Q.6** B

Q.7 A **Q.8** C **Q.9** C **Q.10** C **Q.11** B **Q.12** D

Q.13 A **Q.14** C

Multiple Correct Choice Type

Q.15 A, B, C, D **Q.16** A, D **Q.17** B, C **Q.18** A, B, C **Q.19** A, D **Q.20** A, D

Assertion Reasoning type

Q.21 D **Q.22** D **Q.23** A

Comprehension Type

Q.24 B **Q.25** B **Q.26** A **Q.27** A **Q.28** A **Q.29** D

Q.30 C

Match the Columns

Q.31 $A\rightarrow p$, $B\rightarrow q$, $C\rightarrow r$, $D\rightarrow p$

Previous Years' Questions

Q.1 A **Q.2** C **Q.3** A **Q.4** C **Q.5** A **Q.6** B

Q.7 C **Q.8** C **Q.9** C **Q.10** D **Q.11** B, D **Q.12** B, C

Q.13 A, B, D **Q.14** A, D **Q.15** A, B, C, D **Q.16** A, B, D **Q.17** C **Q.18** C

Q.19 A, C **Q.20** A, B, C, D

Solutions

JEE Main/Boards

Exercise 1

Sol 1: $i = \frac{V}{R} = \frac{12}{0.4} = 30$ A

Sol 2: $i = \frac{V}{r+R}$ (let R be resistor)

$0.5 = \frac{10}{3+R}$

R = 17 Ω

$V_0 = V - ir = 10 - 3\,(0.5) = 8.5$ V

∴ Terminal voltage = 8.5 V

Sol 3: (a) $r = r_1 + r_2 + r_3 = 1 + 2 + 3 = 6\,\Omega$

(B) $i = \frac{V}{r} = \frac{12}{6} = 2$A

V = ir = i [1, 2, 3] = 2 [1, 2, 3] = [2, 4, 6]

∴ Potential drops are 2V, 4V, 6V

Sol 4: $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{1}{2}+\frac{1}{4}+\frac{1}{5}$

$\frac{1}{R} = \frac{19}{20}$

$\Rightarrow R = \frac{20}{19}\Omega$

$i = V\left(\frac{1}{r}\right) = 20\left[\frac{1}{2}\frac{1}{4}\frac{1}{5}\right] = [10\ 5\ 4]$

∴ Current is 10A, 5A, 4A

Total current = $\frac{V}{R} = \frac{20}{\frac{20}{19}} = 19$ A

Sol 5: $r_t = r_0 + \alpha(t - t_0)$

$117 = 100 + 1.7 \times 10^{-4}\Delta t$

$\Rightarrow \Delta t = 10^3$ °C

$\Rightarrow t_0 = t_0 + \Delta t = 27 + 10^3$

t = 1027°C

Sol 6: $R = \frac{\rho L}{A}$

$\rho = \frac{RA}{L} = \frac{5\times6\times10^{-7}}{15} = 2 \times 10^{-7}\,\Omega$m

Sol 7: $\alpha = \frac{\Delta r}{\Delta t} = \frac{2.7-2.1}{100-27.5} = 0.0039°C^{-1}$

Sol 8: $\alpha = \frac{\Delta r}{\Delta t} = \frac{\frac{V}{i_1}-\frac{V}{i_2}}{\Delta t} = \frac{V}{\Delta t}\left(\frac{1}{i_1}-\frac{1}{i_2}\right)$

$t = t_0 + \frac{V}{\alpha}\left(\frac{1}{i_1}-\frac{1}{i_2}\right) = 27 + \frac{230}{1.7\times10^{-4}}\left(\frac{1}{2.8}-\frac{1}{3.2}\right)$

= 867°C

Sol 9: By symmetry $i_{AB} = i_{DC}$

$i_{BC} = i_{AD}$

Let current in circuit be i

Let $i_{AB} = i_1$

$(i - i_1)_5 = 10(i_1) + 5(i_1-(i-i_1))$

(from ABD)

$Si - Si_1 = 10i_1 + 10i_1 - 5i$

$\Rightarrow 25i_1 = 10i$

$\Rightarrow i_1 = \frac{2}{5}i$

Now, $10 = 10i + 10i_1 + 5(i - i_1)$

$= 15i + 5i_1 = 15i + \frac{2}{5}i_1(5)$

10 = 17i

$i = \frac{10}{17}$ A

$i_{AB} = i_{OC} = \frac{2}{3}i = \frac{4}{17}$ A

$i_{AD} = i_{BC} = i - i_1 = \frac{6}{17}$ A

$i_{CD} = 2i_1 - i = \frac{-4}{17}$ A

Sol 10: $i = \frac{V_1 - V_2}{R + r} = \frac{120-8}{15.5+0.5}$

i = 7 A

$\Delta V_{battery} = V + ir = 8 + 7(0.5) = 11.5$ V

Sol 11: $\frac{V_1}{V_2} = \frac{\ell_1}{\ell_2}$

$\Rightarrow V_2 = V_1 \times \frac{\ell_2}{\ell_1} = 1.25 \times \frac{63}{35} = 2.25$ V

So 12: $\frac{I}{A} = neV_d$; $V_d = \frac{I}{Ane}$

$t = \frac{\ell}{V_d} = \frac{Ane\ell}{I} = \frac{2\times10^{-6}\times8.5\times10^{28}\times1.6\times10^{-19}\times3}{3}$

= 27200 sec

Sol 13: $Q = \sigma A = \sigma . \frac{4}{3}\pi r_e^3$

$t = \frac{Q}{i} = \frac{4}{3}\frac{\pi\sigma r_e^3}{i} = \frac{4}{3}\frac{\pi\times10^{-9}\times(6.37\times10^6)^3}{1800}$

≈ 238 s

Sol 14: (a) $i = \frac{nV}{R+nr} = \frac{6\times2}{8.5+6(0.015)} = 1.4$ A

Terminal voltage = iR= 1.4 (8.5)= 11.9 V

(b) $i_{max} = \frac{V}{r} = \frac{1.9}{380} = 0.005$ A

It can't start a car as its current is very less.

Sol 15: $R = \frac{\rho\ell}{A}$; $R \propto \frac{\rho}{A}$

m = d.Al

$A \propto \frac{m}{d}$; $\frac{1}{A} \propto \frac{d}{m}$

$\Rightarrow R \propto \frac{\rho d}{m}$ R = constant

$\Rightarrow m \propto \rho d$

$\frac{m_{a\ell}}{m_{cu}} = \frac{2.63\times10^{-8}\times2.7}{1.72\times10^{-8}\times8.9} = 0.464$

$\Rightarrow m_{Al} < m_{Cu}$

Aluminium is lighter

For long suspension cables, Al is used as it is lighter.

Sol 16: (a) Only current is constant. Rest depends on area of cross-section inversely.

(b) Ohm's law is non-universal for example non-ohmic conductors like semi-conductors.

(c) $i = \frac{E}{r} \Rightarrow i \propto \frac{1}{r}$

So low resistance is necessary.

(d) Because the circuit is shorted accidentally, the current drawn will exceed safely limits.

Sol 17: (a) Alloys have greater resistance than their constitutional metals.

(b) Alloys have lower temperature coefficient of resistance than pure metals.

(c) It is nearly independent

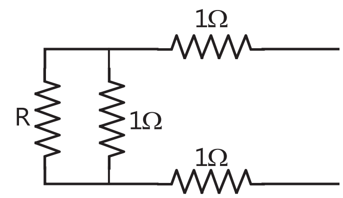
(d) $r = \frac{\rho\ell}{A} \Rightarrow \frac{r_1}{r_2} = \frac{\rho_1}{\rho_2}$

$r >>> r_2 \Rightarrow \rho_1 >>> \rho_2$

$\Rightarrow 10^{22}$ is the correct answer.

Note: (a), (b), (c) are all theoretical. Perfect reasoning will be learnt in engineering. You may refer to energy bands to understand it.

Sol 18: Let the resistance of circuit be R.



$\Rightarrow R = \frac{1}{\frac{1}{R}+\frac{1}{1}} + 2 \Rightarrow R = \frac{R}{R+1} + 2$

$\Rightarrow R = \sqrt{3} + 1$; $(R > 0 \Rightarrow R \neq -\sqrt{3} + 1)$

$i = \frac{V}{r+R} = \frac{12}{\sqrt{3}+1+0.5} \approx 3.7$ A

Sol 19: (a) Let length of potentiometer be ℓ

⇒ Standard cell voltage

$V_s = \frac{\ell_2}{\ell}E$

Assume ℓ = 100 cm

For standard potentiometer

$\Rightarrow \xi = \dfrac{1.02 \times 100}{82.3} = 1.24$ V

(b) 600 kΩ is used to reduce the galvanometer current, when the movable content is far from the balance point.

(c) No, the balance point where voltage of standard cell equals voltage difference or potentiometer. Hence current is zero so high resistance doesn't affect it.

(d) Not much if the driver cell has small resistance compared to potentiometer. Else it affects

(e) No, as emf of driver cell is less than standard cell, current through galvanometer is in opposite direction.

(f) No, if doesn't work well as the gradation on potentiometer is low. To measure it keep a high resistance in series to battery, to reduce voltage across potentiometer.

Sol 20: For ℓ_1 = 76.3 cm, V_1 = 1.5V

$\Rightarrow V_2 = \dfrac{\ell_2}{\ell_1} \times V_1 = \dfrac{64.8}{76.3} \times 1.5 = 1.274$ V

Let current in 9.5Ω be i

$\Rightarrow$ (9.5) (i) = 1.27 Ω $\Rightarrow$ i = 0.134 A

$\Rightarrow$ 1.274 = 1.5 – i(r)

$\Rightarrow$ r = 1.7 Ω

Sol 21: Voltage across galvanometer

(V) = ir= 3 × 10^{-3} × 12= 36 mV

To convert it into a voltmeter of maximum value V_0, resistance R should be add in series.

V_0 = 18V

$\therefore V_0 >> V \Rightarrow R >> r$

$\Rightarrow R = \dfrac{V_0}{i} = \dfrac{1.8}{3 \times 10^{-3}} \approx 6$ kΩ

For accurate result, use

$V_0 = i(r + R) \Rightarrow R = 5988\ \Omega$

Sol 22: $i_1R_1 = i_2R_2$

$\Rightarrow R_2 = \dfrac{i_1R_1}{i_2} = \dfrac{4 \times 10^{-3} \times 15}{6} = 10^{-2}\Omega = 10$ mΩ

Sol 23: Potential gradient = $\dfrac{\Delta V_P}{\ell}$

(ΔV_P = Potential a cross potentiometer)

$\Delta V_P = \dfrac{r_P \times \varepsilon}{r_P + R} = \dfrac{20 \times 5}{20 \times 480} = 0.2$ V

Potential gradient = $\dfrac{0.2}{10}$ = 2 × 10^{-2} V/m

E = Potential gradient × length

= 2 × 10^{-2} × 6= 0.12 V

Sol 24: (a) $i = \dfrac{V_1 + V_2 + V_3}{r_1 + r_2 + r_3 + R}$

$= \dfrac{2 + 1.8 + 1.5}{0.05 + 0.71 + 1 + 4} = 0.9$ A

(b) Yes we can do it. It is called theorem. It can be represented as equivalent resistance and equivalent voltage.

Sol 25: (a) The resistance to be added in parallel

$r_s = \dfrac{r.i}{i_A} = \dfrac{12 \times 2.5 \times 10^{-3}}{7.5}$ = 4 × 10^{-3} Ω = 4 mΩ

$\therefore$ Shunt resistance is 4 mΩ

(b) The resistance to be added in series

$R = \dfrac{V}{i} = \dfrac{10}{2.5 \times 10^{-3}}$ = 4kΩ

$\therefore r_{series} = r - r_g$= 4000 – 12= 3988 Ω

Ammeter reads slightly less as all of i_A doesn't pass through shunt. In derivation we assume i_A passes through shunt only for full deflection. Hence it reads slightly less. Voltmeter reads less as some current passes through it, which reduces current in the measuring element, which leads to reduced reading.

Sol 26: $\dfrac{R_1}{R_2} = \dfrac{\frac{1}{3}}{1 - \frac{1}{3}} = \dfrac{1}{2} \Rightarrow R_2 = 2R_1$

$\dfrac{R_1 + 6}{R_2} = \dfrac{\frac{2}{3}}{1 - \frac{2}{3}} = 2$

$\Rightarrow \dfrac{R_1 + 6}{2R_1} = 2 \Rightarrow R_1 = 2\Omega,\ R_2 = 4\Omega,$

Sol 27: Let current in each branch be i

Current in 10Ω is 2i by symmetry

$\Rightarrow$ 2 + 2 = 10(2i) + 2 × 1.05 (i)

$i = \dfrac{4}{22.1} = 0.181$ A

$V_{10\Omega} = 20i = 3.6$ V

Sol 28: Let $V_D = 0$

$3V - 1V = i_1(3 + 1) + 2I$ (for loop BDC)

$1V - 2V = i_2(2 + 1) + 2I$ (for loop BDA)

$I = i_1 + i_2$

$\Rightarrow 2V = i_1(4) + 2(i_1 + i_2)$

$\Rightarrow 6i_1 + 2i_2 = 2$ ... (i)

$\Rightarrow -1V = 3i_1 + 2(i_1 + i_2)$

$\Rightarrow 2i_1 + 5i_2 = -1$ ... (ii)

$\Rightarrow i_2 = \frac{-5}{13}$ A (from (i) and (ii)) $i_1 = \frac{6}{13}$

$V_D - V_B = -2(I) = -2(i_1 + i_2)$

$= -2\left(\frac{6}{13} - \frac{5}{13}\right) = \frac{-2}{13}$ V

$\Delta V_G = E_G - i_1 R_G = 3V - \frac{6}{13}$ (iii) $= \frac{21}{13}$ V

$\Delta V_H = E_H + i_1 R_H = 1 + \frac{16}{13}$ (i) $= \frac{19}{13}$ V

Exercise 2

Single Correcr Choice Type

Sol 1 : (D) $i = neVA$

$\frac{i_1}{i_2} = \frac{V_1 A_1}{V_2 A_2}$

$i_1 = i_2$

$\Rightarrow V_1 A_1 = V_2 A_2$

$V_1(\pi d^2) = V_2\left(\frac{\pi d^2}{4}\right)$; $V_2 = 4V$

Sol 2 : (C) $i = neVA$

$\therefore$ For constant n and e;

$\Rightarrow V_1 A_1 = V_2 A_2$

$\frac{V_P}{V_Q} = \frac{A_Q}{A_P}$; $A_Q > A_P$

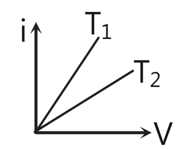
$\therefore \frac{V_P}{V_Q} > 1; \Rightarrow V_P > V_Q$

Sol 3 : (B) $i = neVA$

$V = \frac{i}{neA} = \frac{i}{pqs}$

Sol 4 : (B) $V = iR$

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



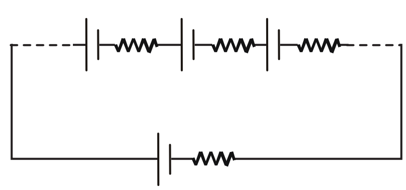
Here slope of the graph is $\left(\frac{i}{V}\right) = \left(\frac{1}{R}\right)$

We know that as temperature increases, Resistance of the metal increases.

$\therefore \left(\frac{1}{R_1}\right) > \left(\frac{1}{R_2}\right)$ [From graph]

$\Rightarrow R_1 < R_2 \therefore T_1 < T_2$

Sol 5 : (D)

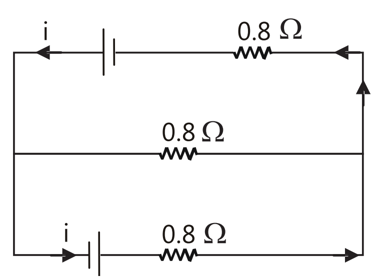


$i = \left(\frac{E_1 + E_2 + ...E_n}{r_1 + r_2 + r_3 + ...R}\right)$

$i = \frac{nE}{nr}$ (for no R)

$i = \frac{E}{r}$

Sol 6 : (C) On simplifying



Current flowing through R is zero.

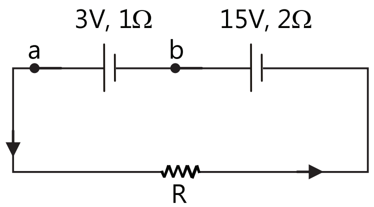
'i' in the circuit is $\frac{8}{1.6} = 5$ amp.

Potential difference between each cell is E – ir

1 – 5(0.2) = 0V

Sol 7 : (C) $i = \left(\frac{3+15}{1+2+R}\right)$

$i = \left(\frac{18}{3+R}\right)$

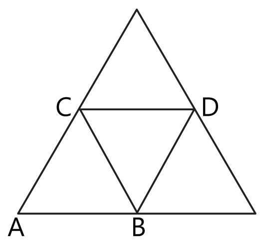


Now writing the potential drop ab;

$3 - (1)\left(\frac{18}{3+R}\right) = 0$

$\Rightarrow 3 = \frac{18}{3+R}$;R = 3 Ω

Sol 8 : (D)



$R_{CD} = \frac{1}{\frac{1}{2R}+\frac{1}{R}} = \frac{2R}{3}$

Similarly $R_{DB} = \frac{4^2R}{3}$

$R_{CB} = \frac{1}{\frac{1}{R}+\frac{1}{\frac{2R}{3}+\frac{2R}{3}}}$;$R_{CB} = \frac{4R}{7}$

$R_{AB} = \frac{1}{\frac{1}{R}+\frac{1}{\frac{4R}{7}+R}}$; $R_{AB} = \frac{11R}{18}$

Sol 9 : (C) $R = \frac{V^2}{P} \Rightarrow R \propto V^2$

∵ Connected in series, they have same current i

Power consume (P_C) = i^2R

$P_C \propto R \Rightarrow P_C \propto V^2$

Sol 10 : (A) (i) $i_1 = \frac{P_1}{V_1} = \frac{25}{220} \approx 0.1136$ A

$i_2 = \frac{P_2}{V_2} = \frac{100}{220V} \approx 0.4545$ A

$r_1 = \frac{V_1^2}{P_1} = \frac{200^2}{25} = 1936\ \Omega$

$r_2 = \frac{V_2^2}{P_2} = \frac{200^2}{100} = 484\ \Omega$

$i = \frac{V}{r_1+r_2} = \frac{440}{1936+484} = 182Å$

∴ 25 W bulb fuses.

(ii) Alternative solution

$r \propto \frac{1}{P}$

$r_1 : r_2 = P_2 : P_1 = 700 : 25 = 4 : 1$

$V_1 : V_2 = r_1 : r_2 = 4 : 1$

$V_1 = \frac{4V}{4+1} = \frac{4}{5}V = 352$ V

$V_2 = \frac{V}{4+1} = \frac{V}{5} = 88$ V

$V_1 > V_{rated}$, $V_2 < V_{rated}$

Hence 25W bulb fuses.

Sol 11: (D) $V = \frac{RV}{r+R}$

Sol 12 : (C) Let resistance be r

$i = \frac{V_G - V}{r+R}$

$10 = \frac{120-100}{r+1}$

$\Rightarrow r = 1\Omega$

Sol 13: (D) Let voltage across galvanometer be V, resistance r

$i_1 = \frac{V}{r}$

Now after shunning

$i_2 = \frac{V}{r+20}$

given $i_2 = \frac{i_1}{2}$

$\Rightarrow \frac{1}{2}\left(\frac{1}{r}\right) = \frac{1}{r+20}$

$\Rightarrow r = 20\ \Omega$

Sol 14: (B) To convert galvanometer to ammeter, we need to connect resistance across it. Let it be r max current through galvanometer

$I = \frac{V}{R} = \frac{0.2}{20} = 10^{-2}$ A

$ir = I_0R_0$

$10(r) = 10^{-2} \times 20$

$\Rightarrow r = 2 \times 10^{-2}\,\Omega$

$\therefore$ 0.02Ω resistor is connected across it.

Sol 15: (C) Total voltage $(V_0) = i(r + R)$

$= 10(90 + 910)$mV = 10 V

$\therefore$ Number of divisions

$= \frac{V_0}{\text{least count}} = \frac{10}{0.1} = 100$

Sol 16: (D) $V = i(r + R)$

$12 = 0.1(20 + r) \Rightarrow r = 100\ \Omega$

Sol 17: (D) Resistance of galvanometer,

$R_g >> r, R$

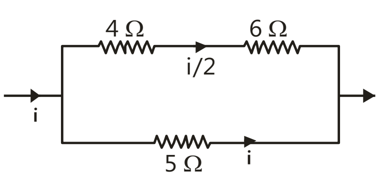
$\therefore V_g \approx 12$ V

$\therefore$ It reads 12 V

Sol 18 : (C) On increase in temperature, number of free electrons increase. But also the collisions will increase. Hence conductivity decreases.

Previous Years' Questions

Sol 1: (B) Sing, resistance in upper branch of the circuit is twice the resistance in low lower branch. Hence, current there will be half.

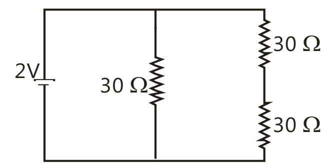


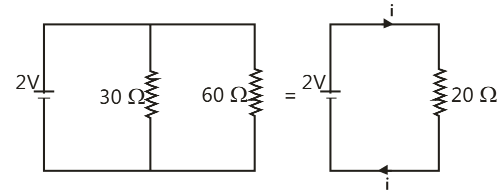
Now $P_4 = (i \backslash 2)(4)(p = i^2R)$

$p_5 = (i)^2(5)$

or $\frac{p_4}{p_5} = \frac{1}{5}$ $\qquad P_4 = \frac{P_5}{5} = \frac{10}{5} = 2$ cal / s

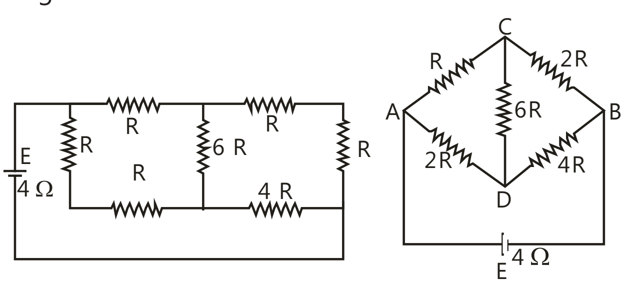
Sol 2: (C) The simplified circuit is shown in the figure



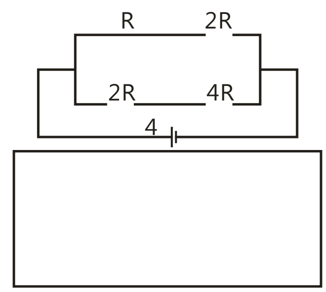


Therefore current I = $I = \frac{2}{20} = \frac{1}{10}$ A

Sol 3: (B) The given circuit is a balanced Whetstone's bridge



Thus no current will flow across 6R of the side CD. The given circuit will now be equivalent to



For maximum power net external resistance

= Total internal resistance

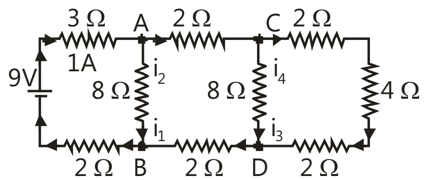
or 2R = 4 or R = 2Ω

Sol 4: (D) Net resistance of the circuit is 9 Ω.

∴ Current drawn from the battery.

$= \frac{9}{9} = 1A$ = current though $3\,\Omega$ resistor

$$\frac{P_{R_1}}{P_{R_2}} = \frac{(I_{R_1}^2)R_1}{(I_{R_2}^2)R_2} = \frac{(7.5)^2(2)}{(1.5)} = \frac{25}{3}$$



Potential difference between A and B is

$V_A - V_B = 9 - (3+2) = 4V - 8i_1$

∴ $i_1 = 0.5$ A

∴ $i_2 = 1 - 1_1 = 0.5$ A

Similarly potential difference between C and D

$V_C - V_D = (V_A - V_B) - i_2(2+2)$
$= 4 - 4i_2 = 4 - 4(0.5) = 2V = 8i_3$
$i_3 = 0.25\,A$

$i_4 = i_2 - i_3 = 0.5 - 0.25$

$i_4 = 0.25\,A$

Sol 5: (A) As there is no change in the reading of galvanometer with switch S open or closed. It implies that bridge is balanced. Current though S is zero and

$I_R = I_G, I_P = I_Q$

Sol 6: (C) The statement indicates a balanced Wheatstone bridge formed by R_3, R_4, R_2 and R_1.

$\Rightarrow \frac{R_3}{R_4} = \frac{R_1}{R_2}$

i.e. $R_1R_4 = R_3R_2$

Sol 7: (B) In the first case $\frac{(3E)^2}{R}t = ms\,\Delta T$ ... (i)

$$\left[H = \frac{V^2}{R}t\right]$$

When length of the wire is doubled, resistance and mass both are doubled.

Therefore, in the second case,

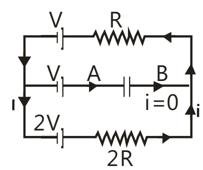
$\frac{(NE)^2}{2R}t = (2m)s\,\Delta T$ ... (i)

Dividing Eq. (ii) by (i), we get

$\frac{N^2}{18} = 2$ or $N^2 = 36$ or $N = 6$

Sol 8 (C) In steady state condition, no current will flow though the capacitor C, current in the outer circuit,

$i = \frac{2V - V}{2R + R} = \frac{V}{3R}$



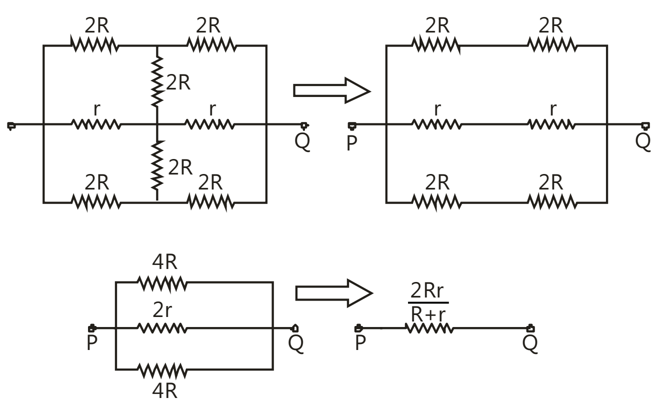
Potential difference between A and B

$V_A - V + V + ir = V_B$

∴ $V_B - V_A = iR = \left(\frac{V}{3r}\right)R = \frac{V}{3}$

Note: In this problem charge stored in the capacitor can also be asked. Which is equal to $q = C\frac{V}{3}$ with positive change on B side and negative on A side because $V_B > V_A$

Sol 9: (A) The circuit can be drawn as follows:



Sol 10: (A) The ratio $\frac{AC}{CB}$ will remain unchanged.

Sol 11: (A) $P = i^2R$

Current is same, so $P \propto R$.

In the first case it is 3r, in second case it is $\frac{2}{3}r$ in third case it is $\frac{r}{3}$ and in fourth case the net resistance is $\frac{3r}{2}$.

$R_{III} < R_{II} < R_{IV} < R_I \therefore P_{III} < P_{II} < P_{IV} < P_I$

Sol 12: (D) For discharging of an RC circuit,

$$V = V_0 e^{-t/\tau}$$

So, when $V = \frac{V_0}{2}$

$$\frac{V_0}{2} = V_0 e^{-t/\tau}$$

$$\ln\frac{1}{2} = -\frac{t}{\tau} \Rightarrow \tau = \frac{t}{\ln 2}$$

From graph when $V = \frac{V_0}{2}$, t – 100 s

$$\therefore \quad \tau = \frac{100}{\ln 2} = 144.3 \text{ sec}$$

Sol 13: (C) Resistances of both the bulbs are

$$R_1 = \frac{V^2}{P_1} = \frac{220^2}{25}$$

$$R_2 = \frac{V^2}{P_2} = \frac{220^2}{100}$$

Hence $R_1 > R_2$

When connected in series, the voltages divide in them in the ratio of their resistances. The voltage of 440 V divides in such a way that voltage across 25 W bulb will be more than 220 V.

Sol 14: (C) Resistance of bulb $= \frac{120 \times 120}{60} = 240\ \Omega$

Resistance of Heater $= \frac{120 \times 120}{240} = 60\ \Omega$

Voltage across bulb before is switched on,

$$V_1 = \frac{120}{246} \times 240$$

Voltage across bulb after heater is switched on,

$$V_2 = \frac{120}{54} \times 48$$

Decrease in the voltage is $V_1 - V_2 = 10.04$ V (approximately).

Note: Here supply voltage is taken as rated voltage.

Sol 15: (C) For ammeter, $S = \frac{I_g G}{I - I_g}$

So for I to increase, S should decrease, so additional S can be connected across it.

Sol 16: (A)

Item	No.	Power
40 W bulb	15	600 Watt
100 W bulb	5	500 Watt
80 W fan	5	400 watt
1000 W heater	1	1000 Watt

Total Wattage = 2500 Watt

So current capacity

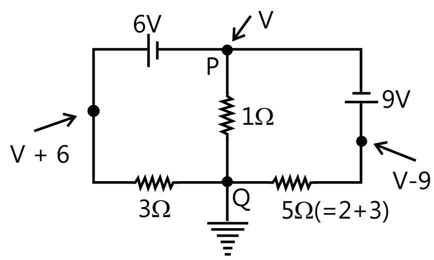
$$i = \frac{P}{V} = \frac{2500}{220} = \frac{125}{11} = 11.36 \cong 12 \text{ Amp}$$

Sol 17: (B) Taking the potential at Q to be 0 and at P to be V, we apply Kirchhoff's current law at Q :

$$\frac{V+6}{3} + \frac{V}{1} + \frac{V-9}{5} = 0$$

$$V = -\frac{3}{23} = -0.13 \text{ volt}$$

The current will flow from Q to P.



Sol 18: (C) $J = ne\, v_d$

$$\frac{A\Delta V}{\rho \ell A} = nev_d$$

$$\therefore \quad \rho = \frac{\Delta v}{\ell nev_4}$$

$$= \frac{5}{0.1 \times 8 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.5 \times 10^{-4}} = 1.56 \times 10^{-4}$$

$$\approx 1.6 \times 10^{-5}\ \Omega\text{m}$$

Sol 19: (D) For full scale deflection

$$100 \times i_g = (i - i_g)S$$

Where 'S' is the required resistance

$$S = \frac{100 \times 1 \times 10^{-3}}{(10 - 10^{-3})}$$

$$S \approx 0.01\ \Omega$$

JEE Advanced/Boards

Exercise 1

Sol 1: Let voltage at A be V_A

Let current from A to B be i_{AB}. Similarly define i_{AC} by the symmetry of circuit, $i_{AB} = i_{AC}$

$V_B = V_A - i_{AB}(R_{AB})$

$= V_A - i_{AB}(1)$

$= V_A - i_{AB}$

Similarly $V_C = V_A - i_{AC}$

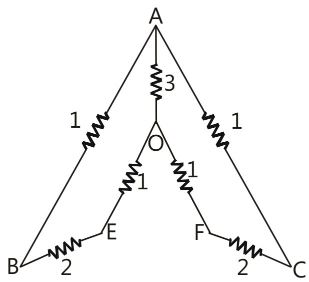
$\therefore i_{AC} = i_{AB}$

$\Rightarrow V_B = V_C$

$\Rightarrow i_{BC} = 0$

$\Rightarrow$ We can ignore R_{BC}.

Similarly we can ignore R_{ef}. Resultant circuit.

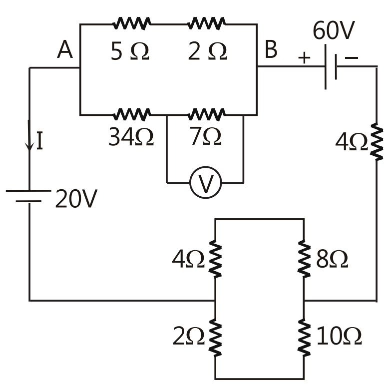


$$\Rightarrow \frac{1}{R_{eff}} = \frac{1}{2} + \frac{1}{1+2+1} + \frac{1}{1+2+1}$$

$$\frac{1}{R_{eff}} = 1$$

$\Rightarrow$ Equivalent resistance between AD = 1Ω

Sol 2:



Let effective resistance across A, B be R_{AB}

$$\Rightarrow \frac{1}{R_{AB}} = \frac{1}{5+2} + \frac{1}{34+7}$$

$\Rightarrow R_{AB} = 6\ \Omega$

Similarly $\frac{1}{R_{CD}} = \frac{1}{4+8} + \frac{1}{2+10}$

$\Rightarrow R_{CD} = 6\ \Omega$

Let current be I

Writing RVL (Kirchhoff Voltage law) equation

$60 = 20 + IR_{AB} + IR_{CD} + I(4)$

$40 = I(6 + 6 + 4)$

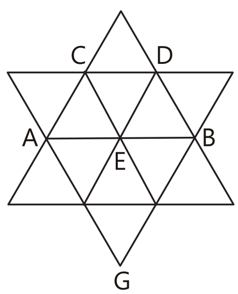
$\Rightarrow I = 2.5$ A

$V_{BA} = IR_{AD} = 2.5\ (6) = 15$ V

Voltage across 7Ω = $\frac{7 \times V_{BA}}{7+34}$

$= \frac{15 \times 7}{42} = 2.5$ V

Sol 3:



By symmetry, $i_{CE} = i_{ED}$

$\Rightarrow$ Point E can be detached to your CED branch.

Let resistance across CD be R_{CD}

$$\Rightarrow \frac{1}{R_{CD}} = \frac{1}{2} + \frac{1}{2} + \frac{1}{1} \Rightarrow R_{CD} = \frac{1}{2}\Omega$$

$$\frac{1}{R_{AC}} = \frac{1}{1} + \frac{1}{2}$$

$$R_{AC} = \frac{2}{3}\Omega$$

$$R_{DB} = \frac{2}{3}\Omega$$

$\Rightarrow R_{ACDB} = R_{AC} + R_{CD} + R_{DB}$

$$= \frac{1}{2} + \frac{2}{3} + \frac{2}{3}$$

$$R_{ACDB} = \frac{11}{6}\Omega$$

By symmetry, $R_{AGB} = R_{ACDB} = \frac{11}{6}\Omega$

$R_{AEB} = 1 + 1 = 2\,\Omega$

Let effective resistance be $_{Reff.}$

$$\frac{1}{R_{eff.}} = \frac{1}{R_{ACDB}} + \frac{1}{R_{AEB}} + \frac{1}{R_{AGB}}$$

$$= \frac{6}{11} + \frac{6}{11} + \frac{1}{2}$$

$$= \frac{35}{22} \Rightarrow R_{eff} = \frac{22}{35}\Omega$$

Sol 4: Let current through 11 Ω be i_1

$$i_1 = \frac{25+30}{11} = 5\text{ A}$$

Similarly $i_2 = \frac{25-20}{5} = 1\text{A}$

$$i_3 = \frac{25+5}{10} = 3\text{ A}$$

$$i_4 = \frac{25-10}{5} = 3\text{ A}$$

$i = i_1 + i_2 + i_3 + i_4 = 5 + 1 + 3 + 3 = 12\text{ A}$

Power supplied = V × i

$= -20 \times i_2 = -20 \times 1 = -20\text{ W}$

Note: here V is taken – 20V as it opposes the direction of current.

Sol 5: Let internal resistance of battery be R

Current flown when R_1 is connected

$$i_1 = \frac{V}{R_1 + R}$$

Power consumed

$$P_1 = i_1^2 R_1 = \frac{V^2 R_1}{(R+R_1)^2}$$

Similarly $P_2 = \frac{V^2 R_2}{(R+R_2)^2}$

Given $P_1 = P_2$

$$\Rightarrow \frac{V^2 R_1}{(R_1+R)^2} = \frac{V^2 R_2}{(R+R_2)^2}$$

$\Rightarrow R_1R_2^2 + 2R_1R_2R + R_1R^2$

$= R_1^2R_2 + 2R_1R_2R + R_2R^2$

$\Rightarrow R^2(R_1 - R_2) = R_1R_2(R_1 - R_2)$

$\Rightarrow R = \sqrt{R_1R_2}$

Sol 6: Path ADCB is similar to path AFEB

$\Rightarrow i_{AD} = i_{ET}$

Where i_{AD} is current trough R_{AD}.

$\Rightarrow V_D = V_F$

$\Rightarrow V_{FD} = D$

$\Rightarrow$ Resistor FD can be removed

Similar EC can be removed

$R_{ADCB} = 3r$

$R_{DFEB} = 3r$

$R_{AB} = r$

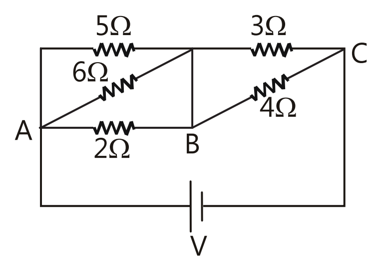
Let effective resistance be $R_{eff.}$

$$\Rightarrow \frac{1}{R_{eff.}} = \frac{1}{R_{ADCB}} + \frac{1}{R_{AB}} + \frac{1}{R_{AFEB}}$$

$$= \frac{1}{3r} + \frac{1}{r} + \frac{1}{3r}$$

$$\Rightarrow R_{eff.} = \frac{3r}{5}\Omega$$

Sol 7:



$$\frac{1}{R_{AB}} = \frac{1}{2} + \frac{1}{6} + \frac{1}{5}$$

$$R_{AB} = \frac{15}{13}\Omega$$

$$R_{BC} = \frac{20}{9}\Omega$$

Let current trough circuit be i

$$\Rightarrow V_{AB} = iR_{AB} = \frac{15i}{13}$$

$$V_{BC} = \frac{20i}{13}$$

Power in 4Ω is more than 5Ω across it as

$4\Omega < 5\Omega\left(\frac{V^2}{r_1} > \frac{V^2}{r_2} \text{ if } r_1 < r_2\right)$

Similarly $P_{2\Omega}$ is greater than 6Ω, 5Ω across it

$$P_{2\Omega} = \frac{(V_{AB})^2}{2\Omega} = \left(\frac{15i}{13}\right)^2 . \frac{1}{2}$$

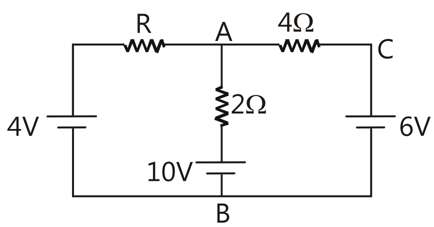
$$P_{2\Omega} = \frac{225\, i^2}{338}\Omega$$

$$P_{4\Omega} = \frac{(V_{BC})^2}{4\Omega} = \left(\frac{20i}{9}\right)^2 \frac{1}{4} = \frac{100\, i^2}{81}$$

$$\frac{100}{81} > \frac{225}{338}$$

⇒ 4Ω produces maximum power.

Sol 8:



$i_{4\Omega} = 0$

Given, ⇒ $V_{AB} = 6V$

But $V_{AB} = V_R + 4V$

⇒ $V_R = 2V$ (V_R = Voltage across R)

$$i_{AB} = \frac{10V - 6V}{2} = 2A$$

$i_{AB} = i_R = 2A$ (∵ $i_{4\Omega} = 0$)

$$\Rightarrow R = \frac{V_R}{iR} = \frac{2V}{2A} = 1\Omega$$

Sol 9 : When both switches open,

$$i = \frac{1.5}{300+100+50} \text{ A}$$

$$i = \frac{1}{3} \times 10^{-2} \text{ A}$$

When both switches closed,

Voltage across R,

$$V_R = 1000 \times i = \frac{1}{3} \text{ V}$$

Current in 200 Ω (i_0)

$$= \frac{1.5 - V_R}{300} = \frac{1.5 - \frac{1}{3}}{300} = \frac{7}{18} \times 10^{-2} \text{A}$$

Current through R $i_R = i_0 - i$

$$= \frac{7}{18}\times 10^{-2} - \frac{1}{3}\times 10^{-2} = \frac{1}{18}\times 10^{-2} \text{ A}$$

$$R = \frac{V_R}{i_R} = \frac{\frac{1}{3}}{\frac{1}{18}\times 10^{-2}} = 600\ \Omega$$

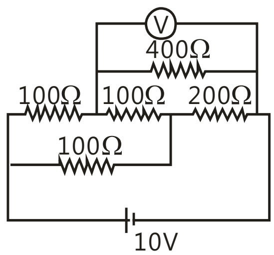
Sol 10 : Since resistance of voltage is 400 Ω, resistance viewed by voltmeter R_0

$$\frac{1}{R_0} = \frac{1}{R} + \frac{1}{R_V}$$

$R_V = 400\ \Omega$, $R = 400\ \Omega$

⇒ $R_0 = 200\ \Omega$

Now we see there is a wheat stone bridge formed.



Hence the middle 100 Ω can be ignored

$$\Rightarrow V_{200\Omega} = \frac{200}{200+100} \times 10 = \frac{20}{3} \text{ V}$$

∴ Voltmeter resonances $\frac{20}{3}$ V

Sol 11: Resistance of circuit

$$R = 2\left(\frac{1}{\frac{1}{1}+\frac{1}{2}}\right) = \frac{4}{3}\Omega$$

$$\text{Current } i = \frac{V}{R} = \frac{30}{\frac{4}{3}} = \frac{45}{2} \text{ A}$$

$$\text{Voltage across } 2\Omega = \frac{V}{2} = \frac{30}{2} = 15 \text{ V}$$

$$i_{2\Omega} = \frac{V}{r} = \frac{15}{2}\text{A}$$

$$i_{1\Omega} = i - i_{2\Omega} = \frac{45}{2} - \frac{15}{2} = 15 \text{ A}$$

Current through AB = $i_{1R} - i_{2R}$

$= 15 - \frac{15}{2} = 7.5$ A

Sol 12: Since current is minimum, resistance should be maximum.

⇒ All switches should be open to present short circuit.

$R_{AB} = \frac{1}{1+1} = \frac{1}{2}\Omega$

Resistance across switch S_2:

$R_1 = \frac{1}{\frac{1}{9}+\frac{1}{6+3}} = \frac{9}{2}\Omega$

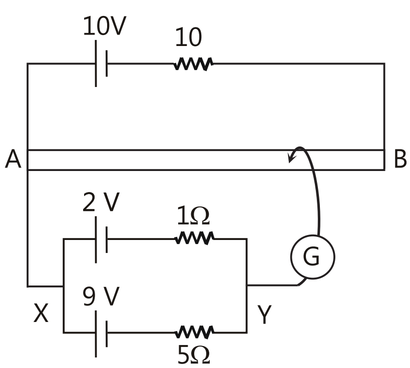
Resistance of circuit

$R = 1 + 6 + R_1 + R_{AB} = 7 + \frac{1}{2} + \frac{9}{2} = 12\ \Omega$

Current in circuit $i = \frac{V}{R} = \frac{24}{12} = 2$ A

$V_{AB} = i\,.\,R_{AB} = 2\left(\frac{1}{2}\right) = 1$V

Sol 13:



$i_G = 0$

$\Rightarrow i_{AX} = 0$

Note: here we should see XY as a system since current leaving is zero.

⇒ Current entering is zero

$V_{AB} = V_{xy}$

Current in XY system

$i_{xy} = \frac{4-2}{5+1} = \frac{1}{3}$ A

$V_{xy} = 2 + 1\left(\frac{1}{3}\right) = \frac{7}{3}$ V

$\Rightarrow V_{AP} = \frac{7}{3}$ V

$R_{AB} = 10\frac{R}{m} \times 1\text{m} = 10\ \Omega$

Let A_P = xm

$R_{AP} = 10x\Omega$

$V_{AP} = \frac{10x}{R_{AB}+10\Omega} \times V = \frac{10x}{10+10} \times 10$

$V_{AP} = 5x$

But $V_{AP} = \frac{7}{3}$ V

$\Rightarrow 5x = \frac{7}{3} \Rightarrow x = \frac{7}{15}$ m = 46.67 cm

Sol 14: Potential drop across the 40 cm wire

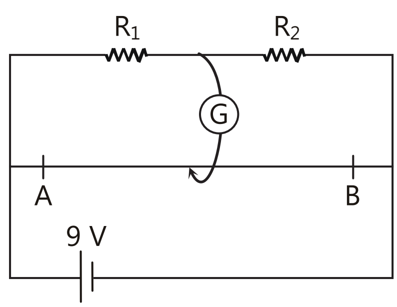
$= \frac{40}{100} \times 10$ v = 4 v

Now, $5 - i\,r = i\,r = 4$

$\Rightarrow 5 - i = i\,r = 4$

$\Rightarrow i = 1$ A & $R = 4\ \Omega$

Sol 15:



$\frac{R_1}{R_2} = \frac{40}{60} \Rightarrow 3R_1 = 2R_2$ ... (i)

$\frac{R_1}{\frac{1}{\frac{1}{R_2}+\frac{1}{10}}} = 1$

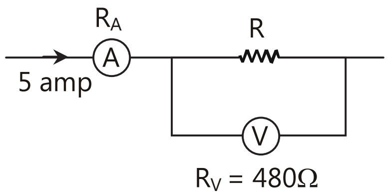
$R_1 = \frac{R_2(10)}{10+R_2}$

$R_1R_2 = 10(R_2 - R_1)$ ... (ii)

From (i) and (ii)

$R_1 = \frac{10}{3}\ \Omega;\ R_2 = 5\Omega$

Sol 16:



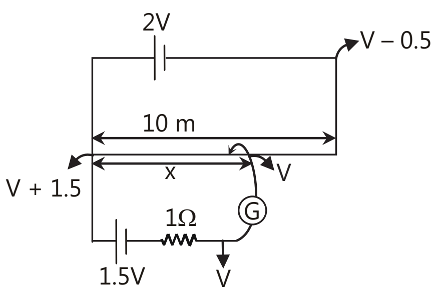
I = 5 ampere, V = 96 V

Voltage diff. at R= $5\left(\frac{480}{R+480}\right)R = 96$

25R = R + 480

R = 20 Ω

Sol 17:

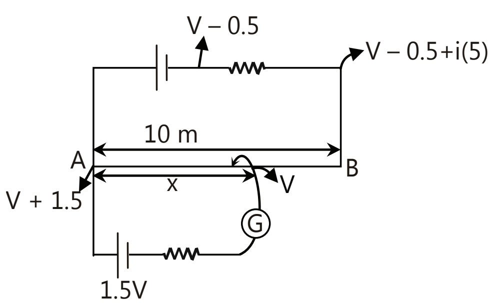


Hence $x_i = 1.5$

(v – x)i = 0.5

X = 7.5 m

(a)



$1.5 = i\left(\frac{x}{10}\right)(30)$ ... (i)

$0.5 - i(5) = i\left(\frac{10-x}{10}\right)30$

5 – 50i = i(350 – 30x)

5 = i (350 – 30x) ... (ii)

From (i) and (ii)

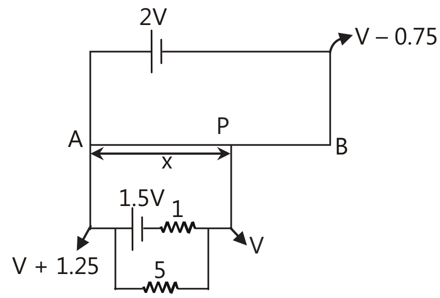
5 = 350 i – 15

$i = \frac{2}{35}$

Putting in (i)

$1.5 = \frac{2}{35}(x)(3)$; x = 8.75 m

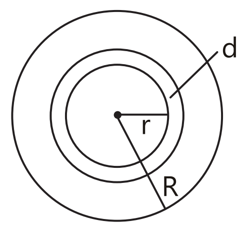
(b)



x(3)i = 1.25

(10 – x) 3i = 0.75; x = 6.125m

Sol 18: (a)



Consider a small circular strip of width dr.

Area of strip dA = 2ρrdr

Current through strip di = 5 .dA

$= J_0\left(1-\frac{r}{R}\right)2\pi r.dr$

$i = \int di = \int_0^R J_0\left(1-\frac{r}{R}\right)2\pi r dr$

$= 2\pi J_0\int_0^R (r - \frac{r^2}{R}).dr = 2\pi J_0 (\frac{r^2}{2} - \frac{r^3}{3R})\Big|_0^R$

$= 2\pi J_0\left(\frac{R^2}{2} - \frac{R^3}{3R}\right) = \frac{\pi J_0 R^2}{3}$

$i = \frac{AJ_0}{3}$ $(\pi R^2 = A)$

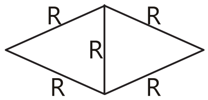
(b) Here $J = J_0\frac{r}{R}$

$\Rightarrow i = \int di = \int_0^R J_0\frac{r}{R}2\pi r dr = \frac{2\pi}{3}\frac{J_0}{R}r^3\Big|_0^R = \frac{2}{3}\pi J_0 R^2$

$i = \frac{2AJ_0}{3}$

Sol 19: Initial resistance $R_1 = 5R$

Suppose two new similar resistance are added, we get a wheat stone bridge



Resistance of bridge $R_{eff.} = \dfrac{1}{\dfrac{1}{2R}+\dfrac{1}{2R}} = R$

$\therefore$ Total resistance $R_2 = 3R$

Change in resistance = 5R – 3R = 2R

$R_1 : R_2 = 5 : 3$

Sol 20: Let resistance be r

(i) $\Rightarrow V = V_0 - ir$

$\Rightarrow i = 0.2\,(V_0 - ir)^{5/2}$

Given i = 0.44

$\Rightarrow 0.44 = (6 - 0.44r)^{5/2} \times 0.2$

$\left(\dfrac{0.44}{0.2}\right)^{\frac{2}{5}} = 6 - 0.44r$

$r = \dfrac{6-\left(\dfrac{0.44}{0.2}\right)^{\frac{2}{5}}}{0.44} = \dfrac{6-1.37}{0.44} = 10.52\ \Omega$

(ii) $I = 0.2\ V^{\frac{5}{2}}$

$\Rightarrow V = \left(\dfrac{I}{0.2}\right)^{\frac{2}{5}}$

Power dissipated in rod $P_1 = VI$

$P_1 = \dfrac{I^{\frac{7}{5}}}{(0.2)^{\frac{2}{5}}}$

Total power dissipated $P = \dfrac{3}{2}P_1$

Power supplied by battery $P_b = V_0 I$

$\therefore P_b = P$

$\Rightarrow V_o I = \dfrac{3}{2} \cdot \dfrac{I^{\frac{7}{5}}}{(0.2)^{\frac{2}{5}}} \Rightarrow 6 = \dfrac{3}{2} \cdot \dfrac{I^{\frac{2}{5}}}{(0.2)^{\frac{2}{5}}}$

$\Rightarrow I = 0.2\,.\,(4)^{\frac{5}{2}} = 6.4$ A

$P_1 = \dfrac{\left(0.2(4)^{\frac{5}{2}}\right)^{\frac{7}{5}}}{(0.2)^{\frac{2}{5}}}$

$P_1 = 0.2(4)^{\frac{7}{2}}$

$P_1 = \dfrac{P_1}{2} = 0.1(4)^{\frac{7}{2}}$

$P_r = I^2 r = (0.2)^2\,.\,(4)^5\,.r$

$\Rightarrow 6.1\,(4)^{\frac{7}{2}} = (0.2)^2\,(4)^5\,.r$

$\Rightarrow r = \dfrac{1}{0.4}\,.\,(4)^{-\frac{3}{2}}$

$r = 0.3125\Omega$

Sol 21: $R_3 = \dfrac{V_N}{V_N - 1}$

$R_1 = \dfrac{V_{N-1} - V_N}{V_N - 1}$

$\dfrac{R_1}{R_3} = \dfrac{V_{N-1} - V_N}{V_N}$

$\dfrac{R_1}{R_3} = k - 1$

Now $R_1 = \dfrac{V_0 - V_1}{i} = \dfrac{(k-1) - V_1}{i}$

$\Rightarrow \dfrac{V_1}{R_1} = \dfrac{i}{(k-1)}$

$R_2 = \dfrac{V_1}{i_1} \Rightarrow i_1 = \dfrac{V_1}{R_2}$

$R_1 = \dfrac{V_1 - V_2}{i - i_1} = \dfrac{\left(\dfrac{k-1}{k}\right)V_1}{i - i_1}$

$i - \dfrac{V}{R_2} = \dfrac{\left(\dfrac{k-1}{R}\right)V_1}{R_1}$

$i - \dfrac{V}{R_2} = \left(\dfrac{k-1}{k}\right)\dfrac{i}{R-1_1}$

$\dfrac{V}{R_2} = i\left(\dfrac{k-1}{k}\right)$

$\Rightarrow R_2 = \dfrac{VR}{i(k-1)}$

$\Rightarrow \dfrac{R_1}{R_2} = \dfrac{(k-1)^2}{k}$

$\dfrac{R_2}{R_3} = \dfrac{R_2}{R_1} \times \dfrac{R_1}{R_3} = \dfrac{k}{(k-1)}$

Sol 22: Power dissipated P_d = 40 watt

Power generate $P_g = n.\frac{dm}{dt}\times g\times h$

h = efficiency

$= 0.9 \times \frac{dm}{dt} \times 10 \times 10 = 90\ \frac{dm}{dt}$

But $P_g = P_d$

$\Rightarrow 40 = 90\ \frac{dm}{dt}$

$\Rightarrow \frac{dm}{dt} = \frac{4}{9}$ kg/s

Mass of water = V × d

= 200 × 1 (1 litre = 1 kg)= 200 kg

$\frac{200}{T} = \frac{4}{9}$

T = 450 s = 7.5 minute

Sol 23: (i) $V_a = \frac{3}{3+6} \times 36 = 12$ V

$V_b = \frac{6}{3+6} \times 36 = 24$ V

(ii) $V_a = \frac{V}{2} = \frac{36}{2} = 18$ V

$i_{6\Omega} = \frac{18}{6} = 3A$

$i_{3\Omega} = \frac{18}{3} = 6A$

$i_{ab} = i_{3\Omega} - i_{6\Omega} = 6 - 3 = 3A$

Sol 24 : (a) $dr = \frac{\rho d\ell}{A}; dr = \frac{\rho_0 e^{-\frac{x}{2}}}{A}.dx$

$$r = \int r = \int_0^L \frac{\rho_0 e^{-\frac{x}{L}} dx}{A} = \frac{\rho_0}{A}\frac{\left. e^{-\frac{x}{L}}\right|_0^L}{-\frac{1}{L}}$$

$$r = \frac{\rho_0 L}{A}.(1-e^{-1}) = \frac{L\rho_0}{A}\left(\frac{e-1}{e}\right)$$

$$I = \frac{V}{r} = \frac{V_0}{\frac{L\rho_0}{A}\left(\frac{e-1}{e}\right)} = \frac{V_0 Ae}{L\rho_0(e-1)}$$

(b) $r_x = \int_0^x \frac{\rho_0 e^{-\frac{x}{L}}}{A} dx$

(r_x = resistance till a distance x)

$$= \frac{\rho_0 L}{A}\left(1-e^{-\frac{x}{L}}\right)$$

$\Delta V = r_x . I$

$$= \frac{\rho_0 L}{A}\left(1-e^{-\frac{x}{L}}\right).\frac{\rho_0 A}{L\rho_0}\frac{1}{(1-e^{-1})}$$

$$= \frac{V_0\left(1-e^{-\frac{x}{L}}\right)}{(1-e^{-1})}$$

$\Delta V = V_0 - V_{(R)}$ (V(x) = Potential at x)

$\Rightarrow V_{(R)} = V_0 - \Delta V$

$$= V_0 - \frac{V_0\left(1-e^{-\frac{x}{L}}\right)}{1-e^{-1}}$$

$$V_{(R)} = V_0\left(\frac{e^{-\frac{x}{L}} - e^{-1}}{1-e^{-1}}\right)$$

Sol 25 : Voltage at 6.9 m

$V_1 = \frac{6.9}{10} \times 2 = 1.38$ V

But V_1 is voltage of another cell

$\Rightarrow V_{cell} = 1.38$ V

The null point is V = 1.38 V

Resistance of wire $r_w = \rho \times l = 11.5 \times 10 = 115$ W

Resistance at a distance R,

$r_x = 11.5$ x

Voltage at x

$V_x = \frac{r_x}{r_w + 5}\times V = \frac{11.5\times x}{120}(ii) = \frac{11.5x}{60}$

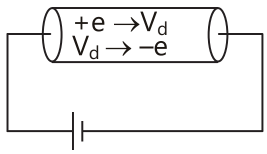
But $V_x = V_{cell}$

$\Rightarrow 1.38 = \frac{11.5x}{60} \Rightarrow x = 7.2$ m

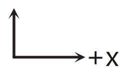
Exercise 2

Single Correct Choice Type

Sol 1: (D) We have two types of charges –e and +2e



When a potential different is applied both the charges drift in opposite directions.



$\therefore i = neV_dA$

$i_{(+ve)} = (n)\ (2e)\ \dfrac{(V_d)}{4} A = \dfrac{neV_dA}{2}$

$i_{(-e)} = n(-e)\ (-V_d)\ .\ A = n_eV_dA$

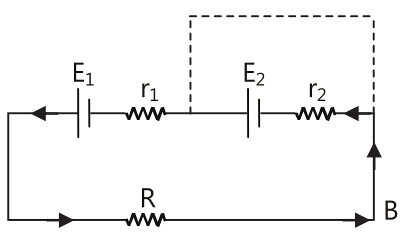
$i_{total} = i_{+2e} + i_{-e}$

$i = \dfrac{3}{2} neV_dA$

Try to understand why they are getting summed up!

Sol 2: (B) Initially

Writing the KVL;



$-E_1 + ir_1 - E_2 + ir_2 + iR = 0$

$\Rightarrow i = \left(\dfrac{E_1 + E_2}{r_1 + r_2 + R}\right)$ amp

Now when E_2 is short circuited;

$-E_1 + i_1r_1 + i_1R = 0$

$\Rightarrow i_1 = \left(\dfrac{E}{r_1 + R}\right)$

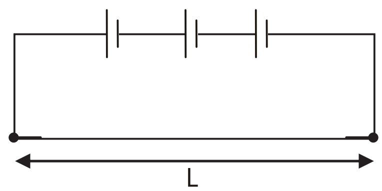
Now given that $i_1 > i$

$\therefore \dfrac{E_1}{r_1 + R} > \dfrac{E_1 + E_2}{r_1 + R + r_2}$

$E_1r_1 + E_1R + E_1r_2 > E_1r_1 + E_1R + E_2r_1 + E_2R$

$E_1r_2 > E_2(R + r_1)$

Sol 3: (B) Power initially = $\dfrac{V^2}{R} = \dfrac{(3)^2}{R}$



Now when length is doubled,

$P_{final} = 2\ P_{initial}$,

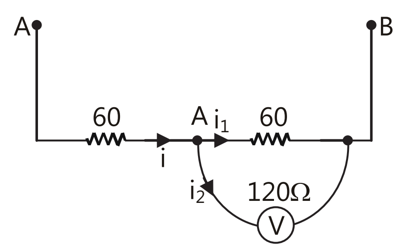
$P_{final} = 2\ P_{initial}$, $\left[R = \dfrac{3L}{A}\right]$

$\therefore \dfrac{V_1^2}{R_f} = 2\ .\dfrac{(3)^2}{R}$

$\because V = \sqrt{4 \times (3)^2} = 2 \times 3$

N = 6

Sol 4: (A)



$R_{eff} = 60\ \Omega + (60 \parallel 120) = 60\ \Omega + 40\ \Omega$

$R_{eff} = 100\ \Omega$

$i = \dfrac{120 \text{ Volt}}{100\Omega} = 1.2$ amp

$60\ i_1 = 120\ i_2$

$i_1 = 2i_2$ .....(i)

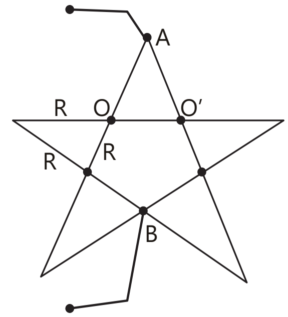
and also at junction A; $i = i_1 + i_2$

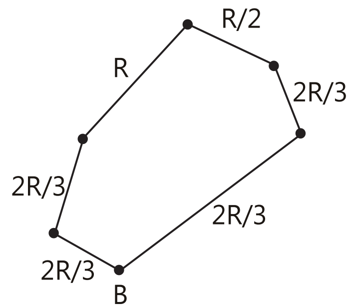
$i = 2i_2 + i_2$

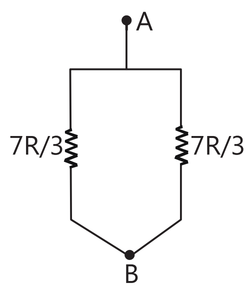
$i_2 = \dfrac{i}{3} = 0.4$ amp

$\therefore$ V across voltmeter = (0.4) (120) = 48 V

Sol 5: (B) Now we can remove resister OO′ because of symmetry property.

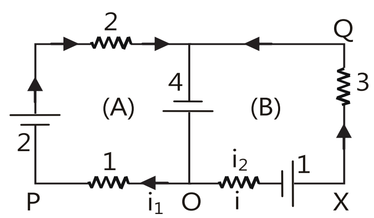






= (7R/6)

Sol 6: (B) In Mesh A, Applying KVL;



$i_1 - 4 + 2i_1 - 2 = 0$

$3i_1 = 6$

$\Rightarrow i_1 = 2$ amp

Now same for mesh 2;

$-2i_2 + 1 - 3i_2 + 4 = 0$

$\Rightarrow i_2 = 1$ amp

Now applying voltage drop along POXQ;

$V_P + i_1(1) - 2i_2 + 1 - 3i_2 = V_Q$

$V_P - V_Q = 5i_2 - i_1 - 1 = 5 - 2 - 1$

$V_{PQ} = 2V$

Sol 7: (A)

$R_1 = \frac{\rho.2L}{A}\ R_2 = \frac{\rho.2L}{2A}$

$R_1 = 2\left(\frac{\rho L}{A}\right);\ R_2 = \frac{1}{2}R_x \left[\therefore R = \frac{\rho L}{A}\right]$

$R_1 = 2R$

$i = \frac{V_A - V_B}{R_1 + R_2} = \frac{8-1}{2R + \frac{R}{2}} = \frac{7}{\frac{5R}{2}} = \left(\frac{14R}{5R}\right)$

$V_A - iR_1 = V_0$

$8 - \left(\frac{14}{5R}\right)(2R) = V_0$

$V_0 = 8 - \frac{28}{5} = 2.4\ V$

Sol 8: (C) $\frac{P}{V} = \frac{EeVd}{V}$

$J = neV_d \quad \Rightarrow \frac{P}{V} = EJ$

Sol 9: (C) IR = ir

I = 10 mA

R = 9Ω + 0.9 Ω = 9.9 Ω

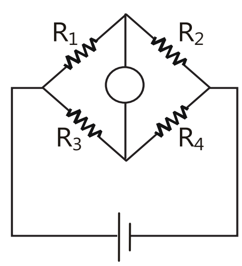
r = 0.1 Ω

$\Rightarrow i = \frac{10 \times 9.9}{0.1} = 990$ mA

Total current = i + I = 990 + 10 = 1A

Sol 10: (C) For wheatstone bridge,

$R_1R_4 = R_2R_3$



It is independent of emf

Let r = KR

$\Rightarrow r_1r_4 = K^2(R_1R_4) = K^2(R_2R_3) = r_2r_3$

So it is still balance

Even if battery and galvanometer are interchanged, still it is balanced.

Sol 11: (B) 625(P) = QS

(625 + 51) = PS

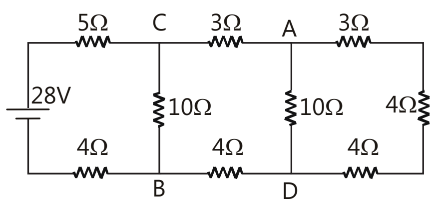
$\Rightarrow 625 \cdot \frac{P}{Q} = 676\left(\frac{Q}{P}\right); \Rightarrow \frac{P}{Q} = \sqrt{\frac{676}{625}}$

$\frac{P}{Q} = \frac{26}{25}$

$S = 625\ \frac{P}{Q} = 625 \times \frac{26}{25} = 650\ \Omega$

Sol 12: (D) Number of free electrons is constant for ohmic resistor.

Sol 13: (A)



$R_{AD} = \frac{1}{\frac{1}{10} + \frac{1}{3+4+3}} = 5\Omega$

$R_{CB} = \frac{1}{\frac{1}{10} + \frac{1}{3+5+2}} = 5\Omega$

$i = \frac{28}{5+5+4} = 2A$

Current through 5Ω is 2A

$R_{CADB} = 3+5+2 = 10\Omega$

$\because R_{CADB} = R_{CB}$

$\Rightarrow i_{CA} = i_{CB} = \frac{i}{2} = 1A$

$V_{CA} = 1 \times 3 = 3V$

$V_{CB} = 1 \times 10 = 10V$

$V_{AB} = V_{CB} - V_{CA} = 10 - 3$

$V_A - V_B = 7V$

Sol 14: (C) 1f V was ideal, $R = \frac{V_0}{i_0} = \frac{20}{4} = 5\Omega$

$\therefore$ V is not ideal, $i < i_0$

$\Rightarrow R > R_0$

$\Rightarrow R > 5\Omega$

Multiple Correct Choice Type

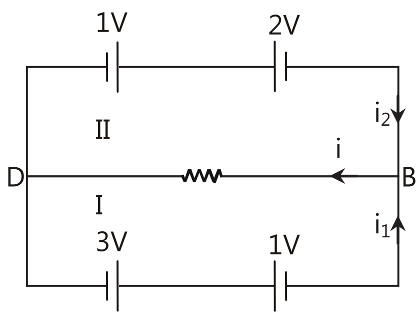
Sol 15: (A, B, C, D) Current is constant across the cross-section.

$E \propto \frac{1}{A}$; $r \propto \frac{1}{A}$

$\Rightarrow i^2 r \propto \frac{1}{A}$

$\therefore$ Heat at Q > heat a P

Sol 16: (A, D)



Let $V_D = 0$

$3V - 1\ V = i_1\ (3 + 1) + 2I$ (for loop I)

$1V - 2\ V = i_2\ (2 + 1) + 2I$ (for loop II)

$I = i_1 + i_2$

$\Rightarrow 2V = i_1(4) + 2(i_1 + i_2)$

$\Rightarrow 6i_1 + 2i_2 = 2$ ... (i)

$-1V = 3i_2 + 2\ (i_1 + i_2)$

$\Rightarrow 2i_1 + 5i_2 = -1$ ... (ii)

$\Rightarrow i_2 = \frac{-5}{13}$ A (from i and ii)

$i_1 = \frac{6}{13}A$

$V_B - V_D = 2(I) = 2(i_1 + i_2)$

$= 2\left(\frac{6}{13} - \frac{5}{13}\right) = \frac{2}{13}\ V$

$\Rightarrow V_D - V_B = \frac{-2}{13}\ V$

$\Delta V_G = E_G - i_1 B_G = 3V - \frac{6}{13}(3)\,V = \frac{21}{13}V$

$\Delta' V_H = E_H + i_1 R_H = 1 + \frac{6}{13}(1) = \frac{19}{13}\ V$

Sol 17 : (B, C) Let range of voltage be V

Let resistance added be R

$V = i(R + r)$

For $R >> r$,

$V = iR; i = 50\mu A = 50 \times 10^{-6} A$

For 200 kΩ, V = 10V

For 10 kΩ, V = 0.5V

Let range of ammeter be I

Let resistance in series be R

Voltage $V = 50 \times 10^{-6} \times 100 = 5$ mV

For $i = \frac{V}{R}$ $(R << r)$

For R = 1Ω, I = 5mA

For R = 1 kΩ, R >> r, so cannot be ammeter

Sol 18 : (A, B, C) For R = 120 Ω

Potential across potentiometers

$$\Delta V_P = \frac{75(20)}{75+5+120} = \frac{75(20)}{200} = 7.5\ V$$

For $V < \Delta V_P$

V can be measured

Sol 19 : (A, D) Current is constant, hence charge crossing cross section

J = nevd

J is not constant $\Rightarrow v_d$ variable

Sol 20: (A, D) Ammeter should have small resistance and voltmeters large

Assertion Reasoning Type

Sol 21: (D) $JE = \frac{iR^2}{V}$ (V = volume)

$\Rightarrow E \propto R^2$

∴ Statement-I is false

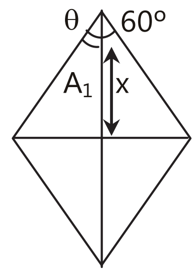
Sol 22: (D) If a battery of higher emf is placed across it, e.m.f. of given battery < potential difference across it

Sol 23: (A) Statement-II explains statement-I

Comprehension type

Paragraph 1

Sol 24: (B) $E = B\frac{dA}{dt}$



$A = 4A_1$

$A = \frac{1}{2} . x\,(x \tan\theta)$

$= \frac{x^2}{2}\tan\theta \left(\theta = \frac{60^\circ}{2} = 30^\circ\right)$

$\frac{dA_1}{dt} = x\tan\theta - \frac{dx}{dt} = xv\tan\theta$

$x = a\cos\theta$

$\Rightarrow \frac{dA_1}{dt} = av\sin\theta$

$\frac{dA}{dt} = 4av\sin\theta$

$\Rightarrow E = B\frac{dA}{dt} = 4avB\sin\theta = 4avB\sin 30^\circ = 2avB$

Sol 25: (B) $i = \frac{E}{R} = \frac{2BaV}{R}$

Sol 26: (A) $i = \frac{B\frac{dA}{dt}}{R}$

$\frac{dQ}{dt} = \frac{B}{R}.\frac{dA}{dt}$

$\Rightarrow \Delta Q = \frac{B}{R}\Delta A = \frac{B}{R}(a^2)$

$\Delta Q = \frac{a^2 B}{B}$

Paragraph 2

Sol 27: (A) Just after pressing switch, $I_2 = 0$ as inductor doesn't pass current through it initially.

$$\therefore I_1 = I_3 = \frac{V}{R_1 + R_2} = \frac{10}{2+6} = \frac{10}{8}\ \text{A}$$

Sol 28: (A) After long time, inductor acts as short circuit.

$$\therefore I_2 = \frac{R_3 I_1}{R_3 + R_2}$$

$$I_1 = \frac{E}{R_1 + \frac{R_2 \times R_3}{R_2 + R_3}} = \frac{10}{2 + \frac{3\times 6}{3+6}} = 2.5\ \text{A}$$

Sol 29 : (D) $I_2 = \frac{6 \times 2.5}{9}\left(I_2 = \frac{R_3 I_1}{R_2 + R_3}\right)$

$$I_2 = \frac{5}{3}\ \text{A}$$

Sol 30: (C) Even after releasing switch, inductor still tries to continue the same current

$$\Rightarrow I_2 = \frac{10}{6}\ \text{A}$$

Match the Columns

Sol 31 : $A \rightarrow p;\ B \rightarrow q;\ C \rightarrow r;\ D \rightarrow p$

Previous Years' Questions

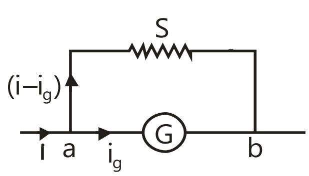
Sol 1: (A) $R_{PQ} = \frac{5}{11}r,\ R_{QR} = \frac{4}{11}r$ and $R_{PR} = \frac{3}{11}r$

$\therefore$ R_{PQ} is maximum.

Sol 2: (C) BC, CD and BA are known resistance.

The unknown resistance is connected between A and D.

Sol 3: (A)



$$V_{ab} = i_g.G = (i - i_g)$$

$$\therefore \qquad i = \left(1 + \frac{G}{S}\right) i_g$$

Substituting the values, we get, i = 100.1 m A

Sol 4: (C) Current in the respective loop will remain confined in the loop itself.

Therefore, current through 2Ω resistance=0

Sol 5: (A) Current flowing through the bars is equal. Now, the heat produced is given by

$H = I^2Rt$ or $H \propto R$

or $\frac{H_{AB}}{H_{BC}} = \frac{R_{AB}}{R_{BC}} = \frac{(1\backslash 2r)^2}{(1\backslash r)}$ (as $R \propto \frac{1}{A} \propto \frac{1}{r^2}$)

$= \frac{1}{4}$ or $H_{BC} = 4H_{AB}$

Sol 6: (B) . $\tau = CR$

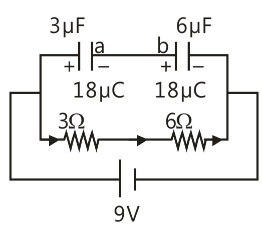
$$\tau = (C_1 + C_2)(R_1 + R_2) = 18\ \mu s$$

$$\tau_2 = \left(\frac{C_1C_2}{C_1 + C_2}\right)\left(\frac{R_1R_2}{R_1 + R_2}\right) = \frac{8}{6} \times \frac{2}{3} = \frac{8}{9}\mu s$$

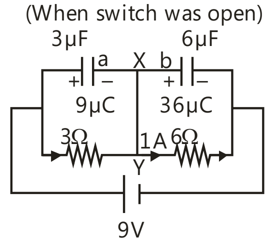
$$\tau_3 = (C_1 + C_2)\left(\frac{R_1R_2}{R_1 + R_2}\right) = (6)\left(\frac{2}{3}\right) = 4\mu s$$

Sol 7: (C) From Y to X charge flows to plates a and b.

$(q_a + q_b)_i = 0,\ (q_a + q_b)_f = 27\mu C$



Initial Figure
(When switch was open)



Final Figure
(When switch is closed)

$\therefore$ 27 μC charge flows from Y to X.

Sol 8: (C) Applying $P = \frac{V^2}{R}$, $R_1 = 1\,\Omega$, $R_2 = 0.5\,\Omega$

and $R_3 = 2\,\Omega$

$V_1 = V_2 = V_3 = 3V$

$$\therefore \quad P_1 = \frac{(3)^2}{1} = 9\ \text{W}$$

$P_2 = \frac{(3)^2}{0.5} = 18\text{ W}$ and $P_3 = \frac{(3)^2}{2} = 4.5\text{W}$

$\therefore P_2 > P_1 > P_3$

Sol 9: (C) $R = R = \frac{\rho(L)}{A} = \frac{\rho L}{tL} = \frac{\rho}{t}$

i.e. R is independent of L.

Sol 10: (D) With increase in temperature, the value of unknown resistance will increases.

In balanced Wheat stone bridge condition, $\frac{R}{X} = \frac{l_1}{l_2}$

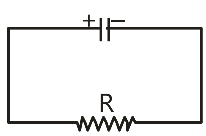
Hence R = Value of standard resistance

X = value of unknown resistance

To take null point at same point or $\frac{l_1}{l_2}$ to remain unchanged $\frac{R}{X}$ should also remain unchanged.

Therefore, if X is increasing R, should also increase.

Sol 11: (B, D) The discharging current in the circuit is, $i = i_0 e^{-\tau/CR}$



Hence, i_0 = initial current = $\frac{V}{R}$

Here, V is the potential with which capacitor was charged.

Since, V and R for both the capacitors are same, initial discharging current will be same, but non-zero.

Further, τ_c = CR

$C_1 < C_2$ or $\tau_{C_1} < \tau_{C_2}$

or C_1 loses its 50% of initial charge sooner the C_2.

Sol 12: (B, C) To increase the range of ammeter a parallel resistance (called shunt) is required which is given by

$$S = \left(\frac{i_x}{i - i_g}\right)G$$

For option (C)

$$S = \left(\frac{50 \times 10^{-6}}{5 \times 10^{-3} - 50 \times 10^{-6}}\right)(100) = 1\Omega$$

To change it in voltmeter, a high resistance R is put in series where R is given by $R = \frac{V}{i_g} - G$

For option (B) $R = \frac{10}{50 \times 10^{-6}} - 100 \approx 200\text{ k}\Omega$

Sol 13: (A, B, D) At 0 K, a semiconductor becomes a perfect insulator. Therefore, at 0 K, if some potential difference is applied across an insulator or semiconductor, current is zero. But a conductor will become a super conductor at 0 K. Therefore, current will be infinite. In reverse biasing at 300 K through a p-n junction diode, a small finite current flows due to minority charge carriers.

Sol 14: (A, D) $R_{total} = 2 + \frac{6 \times 1.5}{6 + 1.5} = 3.2\text{ k}\Omega$

(a) $I = \frac{24\text{ V}}{3.2\text{k}\Omega} = 7.5\text{mA} = I_{R_1}$

$$I_{R_2} = \left(\frac{R_L}{R_L + R_2}\right)I$$

$$I = \frac{1.5}{7.5} \times 7.5 = 1.5\text{ mA}$$

$$I_{R_L} = 6\text{mA}$$

(b) $V_{R_L} = (I_{R_L})(R_L) = 9\text{V}$

(c) $\frac{P_{R_1}}{P_{R_2}} = \frac{I_{R_1}^2 R_1}{I_{R_2}^2 R_2} = \frac{(7.5)^2(2)}{(1.5)^2(6)} = \frac{25}{3}$

(d) When R_1 and R_2 are inter changed then

$$\frac{R_2 R_L}{R_2 + R_L} = \frac{2 \times 1.5}{3.5} = \frac{6}{7}\text{k}\Omega$$

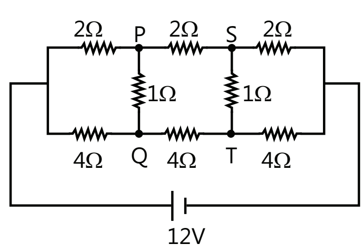
Now potential difference across R_L will be

$$V_L = 24\left[\frac{6/7}{6 + 6/7}\right] = 3\text{V}$$ Earlier it was 9V

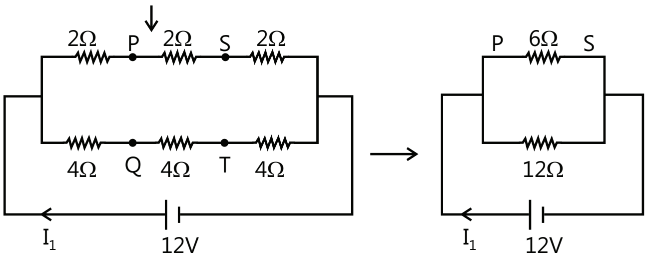
Since, $P = \frac{V^2}{R}$ or $P \propto V^2$

In new situation potential difference has been decreased three times. Therefore, power dissipated will decrease by a factor of 9.

Sol 15: (A, B, C, D) The circuit can be simplified as



Because of symmetry no current through 1Ω



$$R_{eq} = \frac{12\times6}{12+6} = 4\,\Omega$$

$$I_1 = \frac{12}{4} = 3A \quad ; \quad I_2 = \frac{2}{3}\times3 = 2A$$

Here we have

$$V_S - V_Q = -4 \quad \text{i.e.,} \quad V_S < V_Q$$

Sol 16: (A, B, D) $V_1 = \frac{R_1(V_1+V_2)}{R_1+R_3} \Rightarrow V_1R_3 = V_2R_1$

$$V_2 = \frac{R_3(V_1+V_2)}{R_1+R_3} \Rightarrow V_2R_1 = V_2R_3$$

Sol 17: (C) $R = \frac{x}{100-x}90$

$$\therefore \quad R = 60\ \Omega$$

$$\frac{dR}{R} = \frac{100}{(x)(100-x)}dx$$

$$\therefore \quad dR = \frac{100}{(40)(60)}\,0.1\times60 = 0.25\ \Omega$$

Sol 18: (C) For infinite the,

$$E = \frac{\lambda}{2\pi\varepsilon r}$$

$$\Rightarrow \ dV = \frac{-\lambda}{2\pi\varepsilon r}dr$$

Current through an elemental shell ;

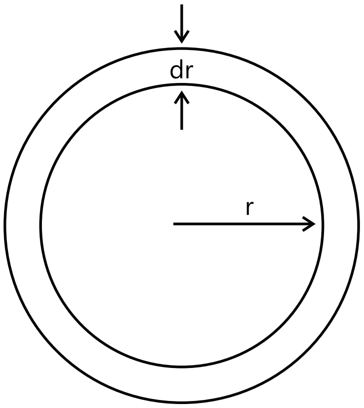
$$I = \frac{|dV|}{dR} = \frac{\frac{\lambda}{2\pi\varepsilon r}dr}{\frac{1}{\sigma}\times\frac{dr}{2\pi r\ell}} = \frac{\lambda\sigma\ell}{\varepsilon}$$

This current is radially outwards so ;

$$\frac{d}{dt}(\lambda\ell) = \frac{-\lambda\sigma\ell}{\varepsilon} \Rightarrow \frac{d\lambda}{\lambda} = -\left(\frac{\sigma}{\varepsilon}\right)dt$$

$$\Rightarrow \lambda = \lambda_{0e^{-(\sigma/\varepsilon)t}}$$

So, $j = \frac{I}{2\pi r\ell} = \frac{\lambda\sigma}{2\pi\varepsilon r} = \left(\frac{\lambda_0\sigma}{2\pi\varepsilon r}\right)e^{-(\sigma/\varepsilon)t}$



Sol 19: (A, C) For maximum voltage range across a galvanometer, all the elements must be connected in series.

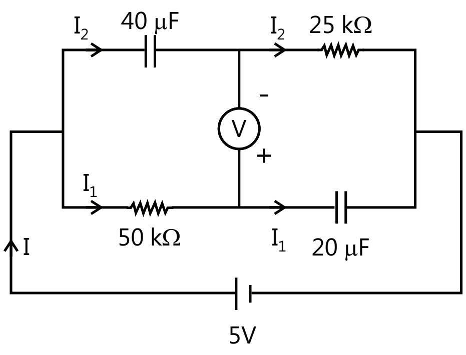
For maximum current range through a galvanometer, all the elements should be connected in parallel.

Sol 20: (A, B, C, D) At t = 0 voltage across each capacitor is zero, so reading of voltmeter is -5 Volt.

At $t=\infty$, capacitors are fully charged. So for ideal voltmeter, reading is 5 Volt.

At transient state.

$$I_1 = \frac{5}{50}e^{-\frac{t}{\tau}}mA,\ I_2 = \frac{5}{25}e^{-\frac{t}{\tau}} \text{ and } I = I_1 + I_2$$



Where τ = 1 sec

So I becomes 1/e times of the initial current after 1 sec.

The reading of voltmeter at any instant

$$\Delta V_{40\mu f} - \Delta V_{50k\Omega} = 5\left(1-e^{-\frac{t}{\tau}}\right) - 5e^{-\frac{t}{\tau}}$$

So at t = log2 sec, reading of voltmeter is zero.