Current Electricity

Introduction

The flow of electric charges in a conductor constitutes an electric current in the circuit.

The charged particles which constitute an electric current in solids, liquids or gases are known as current carriers.

(a) Solids

In conductors (e.g. metals like Copper, Silver, Aluminium etc.), *free electrons constitute an electric current.* In *semi–conductors,* the current carriers are free **electrons** and **holes.**

(b) Liquids

Positive and negative ions are the current carriers in the liquids.

(c) Gases

Positive ions and electrons are the current carriers in gases.

Electric Current

Electric current can be defined as the amount of charge flowing through any cross–section of a conductor in unit time.

OR

Electric current is defined as the rate of flow of charge through any cross–section of a conductor. Let charge Q crosses through a cross–section of a conductor in time t, then

$$\text{Electric current,} \qquad I = \frac{\text{Total charge flowing (Q)}}{\text{Time taken (t)}}$$

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

Direction of electric current

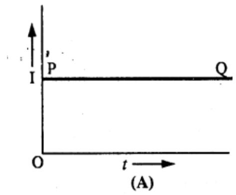
The direction of **conventional current** is positive to –ve or opposite to the direction of flow of negative charges i.e., electrons. The S.I. unit of current is ampere (A).

Electric current through a conductor is said to be one ampere if one coulomb charge flows through any cross–section of the conductor in one second. It is a **scalar** quantity.

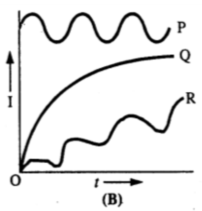
Types of Current

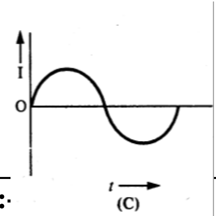
Different types of electric current are discussed below:

(i) **Steady Direct Current:** An electric current is said to be steady direct current if its magnitude and direction do not change with time.



(ii) **Varying or Variable Direct Current:** An electric current is said to be varying direct current if its magnitude changes with time and polarity remains same.



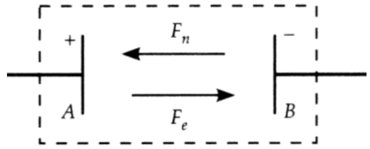


(iii) **Alternating Current (A.C.):** An electric current is said to be alternating current if its magnitude changes with time and polarity (i.e. + or –) reverses periodically.

Electromotive Force : EMF

A battery is a device which maintains a potential difference between its two terminals A and B

The work done per unit charge is $\xi = \frac{W}{q} = \frac{F_n d}{q}$



The quantity ξ = W/q is called the electromotive force or emf of the battery or any other source.

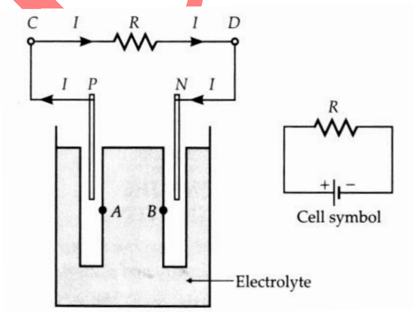
The electromotive force of a source may be defined as the work done by the source in taking a unit positive charge from lower to the higher potential.

If the two terminals of the battery are not connected externally, then

$$F_n = F_e = qE \qquad \therefore \qquad F_n d = F_e d = q\,Ed = qV$$

where V = Ed is the p.d. between the two terminals. Thus,

$$\xi = \frac{F_n d}{q} = \frac{qV}{q} = V$$



Hence the emf of a source is equal to the maximum potential difference between its terminals when it is in the open circuit i.e., when it is not sending any current in the circuit.

Basically, an electrochemical cell consists of two electrodes P and N immersed in an electrolyte, as shown in figure.

The emf of a source may be defined as the energy supplied by the source in taking a unit positive charge once round the complete circuit. Again, we note that $\text{emf} = \frac{\text{Work done}}{\text{Charge}}$ or $\xi = \frac{W}{Q}$ *Unit = volt*

Subjective Assignment – I

Q.1 10^{20} electrons, each having a charge of 1.6×10^{-19} C, pass from a point A towards another point B in 0.1 S. What is the current in ampere? What is it s direction?

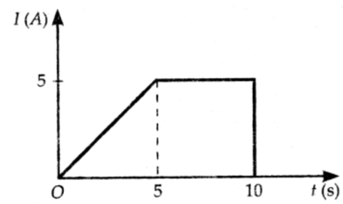
Q.2 Show that one ampere is equivalent to a flow of 6.25×10^{18} elementary charges per second.

Q.3 How many electrons pass through a lamp in one minute, if the current is 300 mA?

Q.4 How many electrons per second flow through a filament of a 120 V and 60 W electric bulb? Given electric power is the product of voltage and current.

Q.5 In the Bohr model of hydrogen atom, the electron revolves around the nucleus in a circular path of radius 5.1×10^{-11} m at a frequency of 6.8×10^{15} revolutions per second. Calculate equivalent current.

Q.6 In a hydrogen atom, an electron moves in an orbit of radius 5.0×10^{-11} m with a speed of 2.2×10^{6} ms^{-1}. Find the equivalent current. (Electronic charge = 1.6×10^{-19} coulomb).



Q.7 Figure shows a plot of current I through the cross–section of a wire over a time interval of 10 s. Find the amount of charge that flows through the wire during this time period.

Q.8 The amount of charge passing through cross–section of a wire is

$$q(t) = at^2 + bt + c$$

(i) Write the dimensional formulae for a, b and c.

(ii) If the values of a, b and c in SI units are 5, 3 and 1 respectively, find the value of current at t = 5 second.

Q.9 A solution of sodium chloride discharges 6.1×10^{16} Na^+ ions and 4.6×10^{16} Cl^- ions in 2s. Find the current passing through the solution.

Q.10 In a hydrogen discharge tube, the number of protons drifting across a cross–section per second is 1.1×10^{18}, while the number of electrons drifting in the opposite direction across another cross–section is 3.1×10^{18} per second. Find the current flowing in the tube.

Answers

1.	160 A	3.	1.125×10^{20}		
4.	3.125×10^{18}	5.	1.088×10^{-3} A	6.	1.12×10^{-3} A
7.	37.5 C	8.	(i) $[AT^{-1}]$, [A], [AT], (ii) 53 A		
9.	8.56×10^{-3} A	10.	0.672 A		

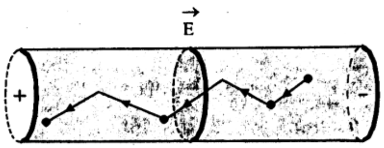
Electric Current in Conductors

In the absence of external electric field, the motion of the electrons in the conductor is random such that the *average thermal velocity* of electrons becomes zero i.e. $\vec{u} = 0$.

A metal conductor has large number of free electrons or conduction electrons, whose number density (i.e., no. of electrons per unit volume) is about 10^{29} m^{-3}. These electrons at room temperature move at random within the body of the conductor, like the molecules of a gas. The average thermal speed of the free electrons in random motion at room temperature is of the order of 10^5 ms^{-1}.

If $\overrightarrow{u_1}, \overrightarrow{u_2}, \overrightarrow{u_3}, ...\overrightarrow{u_n}$ are random thermal velocities of n free electrons in the metal conductor, then the average thermal velocity of electrons is $\dfrac{\overrightarrow{u_1} + \overrightarrow{u_2} + \overrightarrow{u_3} + ...+\overrightarrow{u_n}}{n} = \vec{0}$

Drift Velocity



When an electric field is applied across the conductor, the free electrons accelerate in a direction opposite of the applied field (figure). Due to this acceleration, the electrons gain extra velocity but for a short time because the accelerated electrons collide with other free electrons or the ions in the conductor and during this collision, the extra velocity gained is destroyed.

Again, the electron is accelerated and come to rest after collision. Therefore, the motion of electrons in a conductor under the influence of electric field is like a stop and go. As a net result, the electrons acquire a small velocity called ***drift velocity*** $(\vec{v}_d)$ in the direction opposite to that of the applied electric field. The flow of electrons with drift velocity from one end to another end of the conductor constitutes an electric current.

Drift velocity is defined as the average velocity with which free electrons in a conductor get drifted in a direction opposite to the direction of the applied electric field.

Consider a conductor under the influence of electric field $\vec{E}$. The force experienced by a free electron in the conductor placed in the electric field is given by $\vec{F} = -e\vec{E}$,

Negative sign shows that the directions of $\vec{F}$ and $\vec{E}$ are opposite to each other.
The acceleration produced in the electron is given by,

$$\vec{a} = \frac{\vec{F}}{m}, \text{ where m is the mass of the electron} \quad \text{or} \quad \vec{a} = \frac{-e\vec{E}}{m}$$

Small interval of time between two successive collisions between electron and ion in the conductor is called **relaxation time or mean free time (τ).**
Therefore, the drift velocity is given by

$$\vec{v}_d = \vec{u} + \vec{a}\,\tau$$

or $\vec{v}_d = 0 + \frac{-e\vec{E}}{m}\tau$ $\left(\because \vec{u} = 0 \text{ and } \vec{a} = \frac{-e\vec{E}}{m}\right)$

or $\vec{v}_d = \frac{-e\vec{E}}{m}\tau$ i.e. $|\vec{v}_d| = v_d = \frac{eE\tau}{m}$

Note:

(1) The order of relaxation time is 10^{-14} second
(2) Drift velocity is of the order of 10^{-5} to 10^{-4} m/s.
(3) Average relaxation time = mean free path of electron/drift speed of electron.

Mobility (μ)

Mobility of a current carrier is the ratio of the drift velocity (v_d) of current carrier in a material to the applied electric field (E) across the material i.e.

$$\mu = \frac{v_d}{E} \qquad \text{Since } v_d = \frac{eE\tau}{m} \qquad \therefore \qquad \mu = \frac{v_d}{E} = \frac{e\tau}{m}$$

Thus, mobility of a current carrier is inversely proportional to the mass of the current carrier. For example, in a semiconductor, mobility of an electron is more than mobility of a hole because electron is lighter than the hole.

Relation Between Current and Drift Velocity

Consider a conductor of length l and uniform cross–sectional area A. Let V be the applied potential difference across the ends of the conductor (figure). The magnitude of electric field set up across the conductor is given by

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

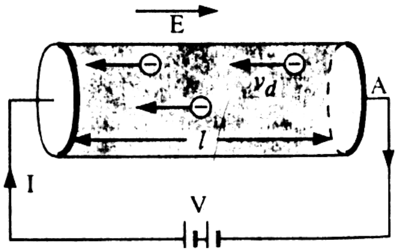
Let n be the number of free electrons per unit volume of the conductor. Then, total number of free electrons in the conductor = n × volume of the conductor = n × Al.

If e is the magnitude of charge on each electron, then the total charge in the conductor,

$$Q = (nAl)e$$

The time taken by the charge to cross the conductor length is given by

$t = \frac{l}{v_d}$, where v_d is drift velocity of electrons.



According to the definition of electric current,

$$I = \frac{Q}{t} = \frac{nAle}{l/v_d} = neA\ v_d$$

or $I = neA\ v_d$

or $I \propto v_d$ (as n, e and A are constants)

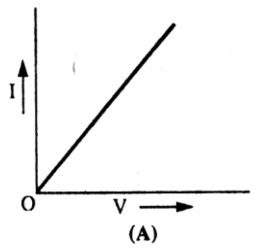
Again from equation $v_d = \frac{I}{neA}$

Note:

When we close the circuit, the electric field is set up in the entire closed circuit instantly with the speed of electromagnetic wave which causes electron drift at every portion of the circuit. Due to it, the current is set up in the entire circuit instantly. The current so set up does not wait for the electrons to flow from one end of the conductor to other end. It is due to this reason, the *electric bulb glows immediately when switched on.*

OHM's Law

According to Ohm's law, the current (I) flowing through a conductor is directly proportional to the potential difference (V) across the ends of the conductor provided the physical conditions (like temperature, pressure, strain etc.) of the conductor remain unchanged.



i.e. $I \propto V$ or $V \propto I$

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

where R is constant of proportionality and is known as ***electric resistance*** or ***resistance*** of the conductor.

The value of R depends upon the *nature* of *the material, its dimensions and its temperature.* It does not depend on the values of V or I.

Derivation of Ohm's Law from First Principles

Let v_d be the drift velocity of electrons through a section of the conductor of length l and cross–sectional area A. V is the potential difference across the section of the conductor, and E is electric field.

Resulting current in the conductor is given by, $I = neAv_d$,

where n is number of electrons per unit volume in the conductor.

But magnitude of drift velocity,

$$v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml} \qquad \left(\because E = \frac{V}{l}\right)$$

$$\therefore \quad I = neA\left(\frac{eV\tau}{ml}\right) = ne^2\frac{A\tau}{ml}V$$

or $$\frac{V}{I} = \frac{ml}{ne^2A\tau} = \text{constant} = R \text{ (resistance of the conductor)}$$

$$\therefore \quad V \propto I$$

where $R = \frac{ml}{ne^2A\tau} = \left(\frac{m}{ne^2\tau}\right)\frac{l}{A}$ Also $R = \rho\frac{l}{A}$ $\therefore$

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

Electrical Resistance

Resistance of a conductor is basically the opposition offered to the flow of electric charge in the conductor. It is defined as the ratio of the potential difference across the ends of the conductor to the current flowing through it.

i.e. $R = \frac{V}{I}$

S.I. unit of resistance is ohm (Ω)

$$1 \text{ ohm } (\Omega) = \frac{1 \text{ volt(V)}}{1 \text{ ampere(A)}} = 1 \text{ VA}^{-1}$$

Resistance of a conductor is said to be 1 ohm, if current of 1A flows through it, when potential difference of 1V is applied across it.

Dimensional formula of resistance

$$[R] = \frac{[V]}{[I]} = \frac{[\text{Work}]}{[\text{Charge}] \times [\text{Current}]} = \frac{[\text{Work}]}{[\text{Current}][\text{Time}].[\text{Current}]}$$

$$\therefore \quad [R] = \frac{[ML^2T^{-2}]}{[A^2T]} = [ML^2T^{-3}A^{-2}]$$

Factors on which resistance depends

Resistance of a conductor depends upon:

(i) Nature of material of the conductor and its (ii) **dimensions** i.e.

(a) Length: The resistance R of a conductor is directly proportional to its length l i.e.

i.e. $R \propto l$

(b) Area of cross–section: The resistance of a conductor is inversely proportional to its area of cross–section A.

i.e. $R \propto \frac{1}{A}$ Hence $R \propto \frac{l}{A}$ or $R = \rho\left(\frac{l}{A}\right)$

Resistivity or specific resistance of the material of a conductor is defined as the resistance of a unit length with unit area of cross section of the material of the conductors, i.e., it is also defined as the resistance of unit cube of a material of the given conductor.

We known that, $R \propto \frac{l}{A}$ or $R = \rho\left(\frac{l}{A}\right)$

where, ρ is known as *specific resistance or resistivity* of the substance/material.

Thus $\rho = R\left(\frac{A}{l}\right)$

If $A = 1, l = 1$, then $\rho = R$

Unit of Resistivity

Since $\rho = R\left(\frac{A}{l}\right)$, Therefore, S. I. unit of ρ is $\left(\frac{\text{ohm metre}^2}{\text{metre}}\right)$ or ohm–metre i.e. Ω m.

Dimensional Formula of Resistivity

Resistivity, $[\rho] = \frac{[R]\times[A]}{[L]}$ $\therefore$ $[\rho] = \frac{[ML^2T^{-3}A^{-2}][L^2]}{[L]} = [ML^3T^{-3}A^{-2}]$

Conductance

Conductance of a substance is equal to the inverse of its resistance i.e.

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

S.I. unit of conductance is ohm^{-1} or Ω^{-1} or mho or siemen (S).

Electrical conductivity or conductivity of a substance is equal to the inverse of its resistivity i.e. $\sigma = \frac{1}{\rho}$

S.I. unit of conductivity is $\Omega^{-1}\ m^{-1}$ or mho m^{-1} or Sm^{-1}.

Dimensions of conductivity, $[\sigma] = \frac{1}{[\rho]} = [M^{-1}L^{-3}T^{3}A^{2}]$

Current Density

The current density at any point inside a conductor is defined as the amount of charge flowing per second through a unit area held normal to the direction of the flow of charge at that point. It is a vector quantity having the same direction as that of the motion of the positive charge.

As shown in figure (a), if a current I is flowing uniformly and normally through an area of cross–section A of a conductor, then the magnitude of current density at any point of this cross–section will be

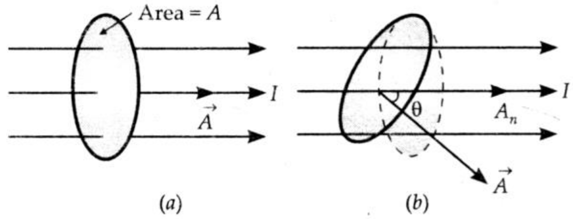
$$j = \frac{q/t}{A} = \frac{I}{A}$$

If the area A is not perpendicular to the direction of current and normal to this area makes angle θ with the direction of current as shown in figure (b), then the component of A parallel to the direction of current flow will be

$$A_n = A\cos\theta$$

∴ Current density,

$$j = \frac{I}{A_n} = \frac{I}{A\cos\theta} \quad \text{or} \quad I = jA\cos\theta = \vec{j}.\vec{A}$$



This equation again shows that electric current, being scalar product of two vectors, is a scalar quantity. The SI unit of current density is ***ampere per square metre*** **(Am^{-2})** and its dimensions are $[AL^{-2}]$

Note: The current I through a particular surface S in a conductor is the flux of $\vec{j}$ through that surface and is given by the surface integral

$$I = \int_S \vec{j}\,.\,\vec{dS} \qquad \text{where } \vec{dS} \text{ is a small element of the given surface area.}$$

Vector form of Ohm's Law

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

$$V = El$$

Also from Ohm's law, we can write $\quad V = IR = \frac{I\rho l}{A}$

$$\therefore \quad El = \frac{I}{A}\rho l \quad \text{or} \quad E = j\rho$$

As the direction of current density $\vec{j}$ is same as that of electric field $\vec{E}$, we can write the above equation as

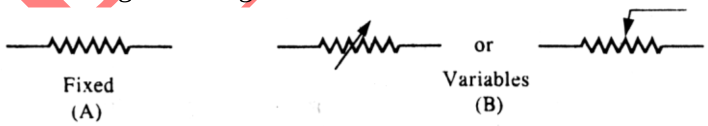
$$\vec{E} = \rho\,\vec{j} \quad \text{or} \quad \vec{j} = \sigma\vec{E}$$

This above equation is the ***vector form of Ohm's law***. It is equivalent to the scalar form V = RI.

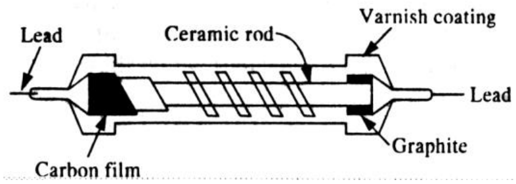
Carbon Resistor and Colour Code

Resistor is a component of an electrical circuit offering certain opposition to the flow of current in that circuit.

Pictorial Symbols of resistors are given in figure.



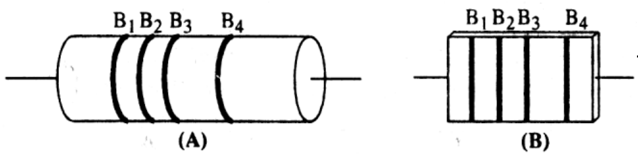
To make a **carbon resistors** of fixed resistance, carbon with a suitable binding materials is moulded into a cylinder. Wire leads are attached to this cylinder and the whole resistor is encased in a ceramic jacket.



Wire wound resistors are made inductance free. They are reliable and stable. They are bigger than carbon resistances. Their value varies from 0.1 to 4 MΩ. They have low power consumption. There is no noise. They have poor response at high frequency because they have large distributed capacitance.

The values of the resistances of the carbon resistors are indicated by *four colour bands* painted on the bodies of the carbon resistor. These coloured bands can be translated into a number by using the standard **colour code** given below:

The first coloured band B_1 represents the first figure and the second band B_2 represents the second figure of the



number (figure). The third band B_3 represents the number of *zeros* to be added to the right side after the second figure to get the total resistance. The fourth band gives the ***tolerance*** known as the limit of accuracy of ***permitted variation*** in the value of the resistance.

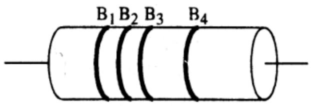
Colour code can be remembered

BB ROY Great Britain Very Good Wife wearing Gold Silver

Colour	Letter As in Aide to Memory	Number	Multiplier	Colour	Tolerance
Black	B	0	10^0	Gold	5%
Brown	B	1	10^1	Silver	10%
Red	R	2	10^2	No colour	20%
Orange	O	3	10^3		
Yellow	Y	4	10^4		
Green	G	5	10^5		
Blue	B	6	10^6		
Violet	V	7	10^7		
Grey	G	8	10^8		
While	W	9	10^9		
Gold			10^{-1}		
Silver			10^{-2}		

Illus.1 Suppose the colour band sequence of a resistor is (B_1) green, (B_2) brown, (B_3) yellow and (B_4) gold. Then, what is the effective resistance of the resistor as per colour code?

Ans: $(51 \pm 2.55) \times 10^4\ \Omega$



(A)

Subjective Assignment – II

Q.1 In a discharge tube, the number of hydrogen ions (i.e., protons) drifting across a cross–section per second is 1.0×10^{18}, while the number of electrons drifting in the opposite direction across another cross–section is 2.7×10^{18} per second. If the supply voltage is 230 V, what is the effective resistance of the tube?

Q.2 An electron beam has an aperture of 1.0 mm^2. A total of 6×10^{16} electrons flow through any perpendicular cross–section per second. Calculate (i) the current and (ii) the current density in the electron bream.

Q.3 A copper wire of radius 0.1 mm and resistance 1 kΩ is connected across a power supply of 20 V. (i) How many electrons are transferred per second between the supply and the wire at one end? (ii) Write down the cur rent density in the wire?

Q.4 A current of 2 mA is passed through a colour coded carbon resistor with first, second and third rings of yellow, green and orange colours. What is the voltage drop across the resistor?

Q.5 An arc lamp operates at 80 V, 10 A. Suggest a method to use it with a 240 V d.c. source. Calculate the value of the electric component required for this purpose.

Q.6 Calculate the resistivity of a material of a wire 10 m long, 0.4 mm in diameter and having a resitance of 2.0 Ω.

Q.7 The external diameter of a 5 metre long hollow tube is 10 cm and the thickness of its wall is 5 mm. If the specific resistance of copper be 1.7×10^{-5} ohm–metre, then determine its resistance.

Q.8 Find the resistivity of a conductor in which a current density of 2.5 Am^{-2} is found to exist, when an electric field of 15 Vm^{-1} is applied on it.

Q.9 Calculate the electrical conductivity of the material of a conductor of length 3m, area of cross–section 0.02 mm^2 having a resistance of 2Ω.

Q.10 A wire of resistance 4Ω is used to wind a coil of radius 7 cm. The wire has a diameter of 1.4 mm and the specific resistance of its material is 2×10^{-7} Ωm. Find the number of turns in the coil.

Q.11 A wire of 10 ohm resistance is stretched to thrice its original length. What will be its (i) new resistivity, and (ii) new resistance?

Q.12 A wire has a resistance of 16 Ω. It is melted and drawn into a wire of half its length. Calculate the resitance of the new wire. What is the percentage change in its resistance?

Q.13 A cylindrical wire is stretched to increase its length by 10%. Calculate the percentage increase in resistance.

Q.14 Two wires A and B of equal mass and of the same metal are taken. The diameter of the wire A is half the diameter of wire B. If the resistance of wire A is 24Ω, calculate the resistance of wire B.

Q.15 A piece of silver has a resistance of 1Ω. What will be the resistance of a constantan wire of one–third length and one–half diameter, if the specific resistance of constantan is 30 times that of silver?

Q.16 Calculate the conductance and conductivity of a wire of resistance 0.01 Ω, area of cross–section 10^{-4} m^2 and length 0.1 m.

Q.17 A rheostat has 100 turns of a wire of radius 0.4 mm having resistivity 4.2×10^{-7} Ωm. The diameter of each turn is 3 cm. What is the maximum value of resistance that it can introduce?

Q.18 Given that resistivity of copper is 1.68×10^{-8} Ωm. Calculate the amount of copper required to draw a wire 10 km long having resistance of 10 Ω. The density of copper is 8.9×10^3 kg m^{-3}.

Q.19 Two wires A and B of the same material have their lengths in the ratio 1 : 5 and diameters in the ratio
3 : 2. If the resistance of the wire B is 180 Ω, find the resistance of the wire A.

Q.20 A uniform wire is cut into four segments. Each segment is twice as long as the earlier segment. If the shortest segment has a resistance of 4Ω, find the resistance of the original wire.

Answers

1.	3.9×10^2 Ω	2.	(i) 9.6×10^{-3} A, (ii) 9.6×10^3 Am^{-2}		
3.	(i) 1.25×10^{17}, (ii) 6.37×10^5 Am^{-2}	4.	90 v		
5.	16 Ω	6.	2.513×10^{-8} Ωm	7.	5.7×10^{-5} Ω
8.	6 Ωm	9.	75×10^6 $Ω^{-1}$ m^{-1}	10.	70
11.	90 Ω	12.	4 Ω, 75%	13.	21%
14.	1.5 Ω	15.	40 Ω	16.	100 S, 10^5 Sm^{-1}
17.	7.875 Ω	18.	1495.2 kg	19.	16 Ω
20.	60 Ω				

Subjective Assignment – III

Q.1 Assuming that there is one free electron per atom in copper, determine the number of free electrons in 1 $metre^3$ volume of copper. Density of copper is 8.9×10^3 kgm^{-3} and atomic weight 63.5. (Avogadro's number, $N = 6.02 \times 10^{26}$ per kg–atom).

Q.2 A copper wire has a resistance of 10Ω and an area of cross–section 1 mm^2. A potential difference of 10V exists across the wire. Calculate the drift speed of electrons if the number of electrons per cubic metre in copper is 8×10^{28} electrons.

Q.3 (a) Estimate the average drift speed of conduction electrons in a copper wire of cross–sectional area 1.0×10^{-7} m^2, carrying a current of 1.5 A. Assume that each copper atom contributes roughly one conduction electron. The density of copper is 9.0×10^3 kg m^{-3}, and its atomic mass is 63.5 u. take Avogadro's number = 6.0×10^{23} mol^{-1}.

(b) Compare the drift speed obtained above with (i) thermal speeds of copper atoms at ordinary temperatures, (ii) speeds of electrons carrying the current and (iii) speed of propagation of electric field along the conductor which causes the drift motion.

Q.4 Calculate the electric field in a copper wire of cross–sectional area 2.0 mm^2 carrying a current of 1A. The conductivity of copper = 6.25×10^7 Sm^{-1}.

Q.5 A potential difference of 100 V is applied to the ends of a copper wire one metre long. Calculate the average drift velocity of the electrons. Compare it with the thermal velocity at 27°C. Given conductivity of copper, $\sigma = 5.81 \times 10^7$ Ω^{-1} m^{-1} and number density of conduction electron, $n = 8.5 \times 10^{28}$ m^{-3}.

Q.6 Find the time of relaxation between collision and free path of electrons in copper at room temperature. Given resistivity of copper = 17×10^{-8} Ωm, number density of electrons in copper = 8.5×10^{28} m^{-3}, charge on electron = 1.6×10^{-19} C, mass of electron 9.1×10^{-31} kg and drift velocity of free electrons = 1.6×10^{-4} ms^{-1}.

Q.7 An aluminium wire of diameter 0.24 cm is connected in series to a copper wire of diameter 0.16 cm. The wires carry an electric current of 10 ampere. Find (i) current–density in the aluminium wire (ii) drift velocity of electrons in the copper wire. Given: Number of electrons per cubic metre volume of copper = 8.4×10^{28}.

Q.8 A current of 1.0 ampere is flowing through a copper wire of length 0.1 metre and cross–section 1.0×10^{-6} m^2. (i) If the specific resistance of copper be 1.7×10^{-8} Ωm, calculate the potential difference across the ends of the wire. (ii) Determine current density in the wire. (iii) If there be one free electron per atom in copper, then determine the drift velocity of electrons.

Given: atomic wt. = 63.5, density of copper = 8.9×10^3 kgm^{-3}, N = 6.02×10^{26} per kg–atom.

Answers

1. 8.4×10^{28} m^{-3}
2. 0.078 mm s^{-1}
3. (a) 1.1×10^{-3} ms^{-1}, (b) (i) 3.21×10^{-6}, (ii) 1.74×10^6 ms^{-1}, 10^{-9}, 10^{-11} (iii) 3×10^8 m s^{-1}, 10^{-11}
4. 8×10^{-3} Vm^{-1}
5. 0.43 ms^{-1}, 1.17×10^5 ms^{-1}, 3.67×10^{-6}
6. 2.5×10^{-14} s, 4.0×10^{-18} m
7. (i) 2.2×10^6 Am^{-2}, (ii) 3.7×10^{-4} ms^{-1}
8. (i) 1.7×10^{-3} V, (ii) 1.0×10^6 Am^{-2}, (iii) 7.4×10^{-5} ms^{-1}

Temperature Dependence of Resistivity

Resistivity of a material is given by,

$$\rho = \frac{m}{ne^2\tau} \quad \text{or} \quad \rho \propto \frac{1}{n\tau} \qquad \text{(m and e are constants)}$$

(i) Metal: As n (number of electrons per unit volume) *does not change with temperature*, so variation in ρ with temperature depends only on the relaxation time τ. With increase in temperature, the collisions between free electrons and ions of a metallic conductor become more frequent. As a result of this, relaxation time decreases and hence the resistivity $\left(\rho \propto \frac{1}{\tau}\right)$ increases. Thus, *resistivity of a metallic conductor increases with increase in temperature and vice–versa.*

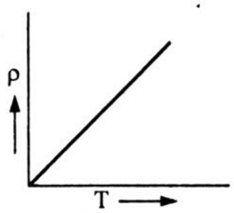
The variation of ρ with temperature (T) is expressed by the relation

$$\rho = \rho_0 [1 + \overline{\alpha}\ (T - T_0)]$$

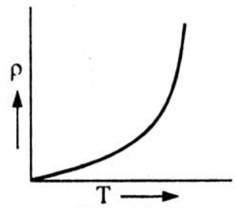
where ρ_0 is the resistivity at temperature T_0 (say 273 K or 0^oC), ρ is resistivity at temperature T and $\overline{\alpha}$ is the ***temperature coefficient of resistivity.***

$\overline{\alpha}$ is different for different materials.

$\overline{\alpha}$ is **positive,** i.e. their resistivity increase with increase in temperature.



Nichrome



Aluminium

(ii) **Semi–conductors:** $\overline{\alpha}$ is **negative.** Germanium and Silicon are the examples of semi–conductors. At 0 K, semi–conductors behave as insulators but at room temperature, they behave as conductors.

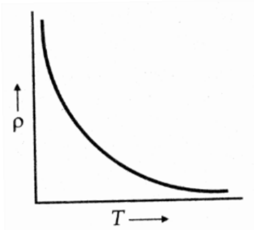
The resistivity of semiconductors depends on two factors: (i) the temperature variation and (ii) the suitable impurities added in the semi–conductor.

The variation of resistivity of a semi–conductor with temperature is given by $\rho = \rho_0\, e^{E/2kT}$, where E is energy gap between *conduction band and valence band, k* is **Boltzmann's constant** and T is the absolute temperature of the semiconductor.

At room temperature k_BT = 0.03 eV. Whether the non–conducting substance is an insulator or a semi–conductor, depends on the size of the energy gap, E_g:

(i) If $E_g \le 1$ eV, the resistivity at room temperature is not very high and the substance is a ***semiconductor.***

(ii) If $E_g > 1$ eV, the resistivity at room temperature is very high (~ 10^3 Ω m) and the substance is an ***insulator.***



The coefficient of resistivity (α) is negative for carbon and semiconductors i.e., their resistivity decreases with temperature, as shown in figure.

(iii) Electrolytes: As the temperature increases, the interionic attractions (solute–solute, solvent–solute and solvent–solvent types) decrease and also the viscous forces decrease, the ions move more freely. Hence conductivity increases or the resistivity decreases as the temperature of an electrolytic solution increases.

Use of alloys in making standard resistors

Alloys like constantan or manganin are used for making standard resistance coils because of the following reasons:

(i) These alloys have high value of resistivity.

(ii) They have very small temperature coefficient. So their resistance does not change appreciably even for several degrees rise of temperature.

(iii) They are least affected by atmosphere conditions like air, moisture, etc.

(iv) Their contact potential with copper is small.

Subjective Assignment – IV

Q.1 (i) At what temperature would the resistance of a copper conductor be double its resistance at 0^oC?

(ii) Does this temperature hold for all copper conductors regardless of shape and size?

Given α for Cu = $3.9 \times 10^{-3}\ {}^oC^{-1}$.

Q.2 The resistance of the platinum wire of a platinum resistance thermometer at the ice point is 5Ω and at steam point is 5.39Ω. When the thermometer is inserted in a hot both, the resistance of the platinum wire is 5.975 Ω. Calculate the temperature of the bath.

Q.3 A nichrome heating element connected to a 220V supply draws an initial current of 2.2 A which settles down after a few seconds to a steady value of 2.0 A. Find the steady temperature of the heating element. The room temperature is 30°C and the average temperature coefficient of resistance of nichrome is 1.7×10^{-4} per °C.

Q.4 An electric toaster uses nichrome (an alloy of nickel and chromium) for its heating element. When a negligibly small current passes through it, its resistance at room temperature (27.0°C) is found to be 75.3 Ω. When the toaster is connected to a 230 V supply, the current settles after a few seconds to a steady value of 2.68 A. What is the steady temperature of the nichrome element? The temperature coefficient of resistance of nichrome averaged over the temperature range involved is 1.70×10^{-4} $^{o}C^{-1}$.

Q.5 The resistance of a tungsten filament at 150°C is 133 ohm. What will be its resistance at 500°C? The temperature coefficient of resistance of tungsten is 0.0045 per °C.

Q.6 The resistance of conductor at 20°C is 3.15 Ω and at 100°C is 3.75Ω. Determine the temperature coefficient of resistance of the conductor. What will be the resistance of the conductor at 0°C?

Q.7 The resistances of iron and copper wires at 20°C are 3.9 Ω and 4.1Ω respectively. At what temperature will the resistance be equal? Temperature coefficient of resistivity for iron is 5.0×10^{-3} K^{-1} and for copper it is 4.0×10^{-3} K^{-1}. Neglect any thermal expression.

Q.8 A metal wire of diameter 2 mm and length 100 m has a resistance of 0.5475Ω at 20° C and 0.805Ω at 150°C. Find (i) temperature coefficient of resistance (ii) resistance at 0°C (iii) resistivities at 0° & 20°C.

Q.9 A potential difference of 6 V is applied across a conductor of length 0.12 m. Calculate the drift velocity of electrons, if the electron mobility is 5.6×10^{-6} $m^2 V^{-1} s^{-1}$.

Q.10 The number density of electrons in copper is 8.5×10^{28} m^{-3}. Determine the current flowing through a copper wire of length 0.2 m, area of cross–section 1 mm^2, when connected to a battery of 3V. Given the electron mobility = 4.5×10^{-6} $m^2 V^{-1} s^{-1}$ and charge on electron = 1.6×10^{-19} C.

Q.11 A semiconductor has the electron concentration 0.45×10^{12} m^{-3} and hole concentration 5×10^{20} m^{-3}. Find its conductivity. Given: electron mobility = 0.135 $m^2V^{-1}s^{-1}$ and hole mobility = 0.048 $m^2V^{-1}s^{-1}$;
e = 1.6×10^{-19} coulomb.

Answers

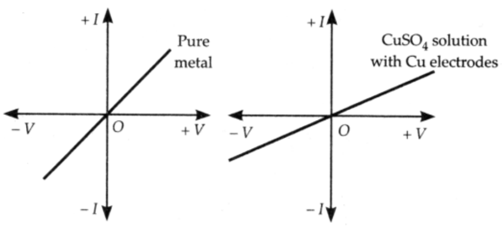
2.	250°C	3.	618°C	4.	847°C
5.	258 Ω	6.	$0.0025°C^{-1}$, 3.0 Ω	7.	84.5°C
8.	(i) 3.6×10^{-3} $^{o}C^{-1}$, (ii) 0.5107 Ω, (iii) 1.60×10^{-8} Ωm, 1.72×10^{-8} Ωm				
9.	2.8×10^{-4} ms^{-1}	10.	0.918 A	11.	3.84 Sm^{-1}

Limitations of Ohm's Law: Ohmic and Non–ohmic Conductors

Ohm's law is obeyed by many substances under certain conditions but it is not a fundamental law of nature.

Ohmic conductor: *The conductors which obey Ohm's law are called Ohmic conductors.* For these conductors, the linear relationship between voltage and current (V ∝ I) holds good.

The V–I graph for ohmic conductors is a straight line passing through the origin. A metallic conductor for small currents and the electrolyte like copper sulphate solution with copper electrodes are ohmic conductors, as shown in figure (a) and (b) respectively.



Non–ohmic conductors: *The conductors which do not obey Ohm's law are called non–ohmic conductors.* The resistance of such conductors is not constant even at a given temperature, rather it is current dependent. Non–ohmic situations may be of the following types:

(i) The straight line V–I graph does not pass through the origin.

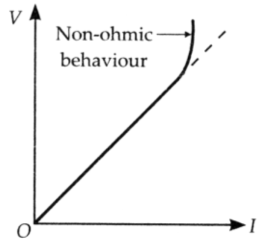
(ii) V–I relationship is non–linear.

(iii) V–I relationship depends on the sign of V for the same absolute value of V, and

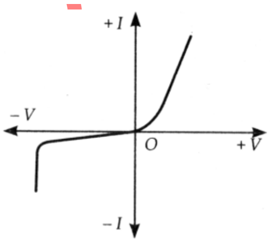
(iv) V–I relationship is non–unique.

Examples of non–ohmic conductors:

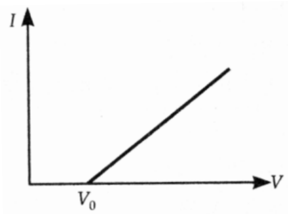
(i) Metallic conductor: For small currents, a metallic conductor obeys Ohm's law and its V–I graph is a straight line. But when large currents are passed through the same conductor, it gets heated up and its resistance increases. V–I graph no longer remains linear, i.e., conductor becomes non–ohmic at higher currents, as shown in figure.



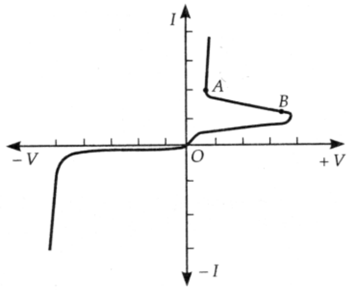
(ii) Water Voltameter: Here a back e.m.f. is set up due to the liberation of hydrogen at the cathode and oxygen at the anode. No current flows through the voltameter until the applied p.d. exceeds the back e.m.f. V_0 (1.67 V for water voltameter). So V–I graph is a straight line but not passing through the origin, as shown in figure. Hence the electrolyte (water acidified with dil. H_2SO_4) is a non–ohmic conductor.



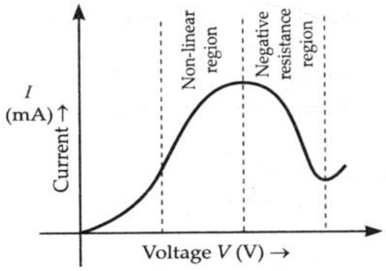
(iii) p–n junction diode: It consists of a junction of p–type and n–type semiconductors. A voltage V is applied across the junction. The resulting current I is shown in figure. Obviously, I is not proportional to V. The junction diode allows (current to flow only in one direction i.e., it acts as a rectifier (converts a.c. into d.c.)



(iv) Thyristor: It consists of four alternate layers of p and n–type semiconductors. Its V–I relationship is as shown in figure.



(v) Gallium arsenide: Figure shows the V–I graph for the semiconductor GaAs. It exhibits non–linear behaviour. Moreover, after a certain voltage, the current decreases as the voltage increases. That is, if ΔI is negative and hence the effective resistnce (=ΔV/ΔI) is negative.



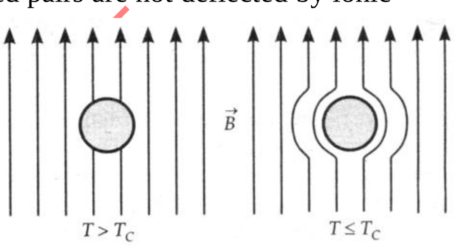
Superconductivity

Prof. Kammerlingh Onnes at the University of Leiden (Holland), observed that the resistivity of mercury suddenly drops to zero at a temperature of about 4.2 K and it becomes a superconductor.

The phenomenon of complete loss of resistance metals and alloys when they are cooled below a certain temperature is called **superconductivity.** The temperature at which a substance undergoes a transition from normal conductor to superconductor in a zero magnetic field is called **transition** or **critical temperature** (T_c)

A current once set up in a superconductor persists for a very long time without any apparent change in its magnitude.

Cause of superconductivity: It is believed that near the transition temperature, a weak attractive force acts on the electrons which bring them closer to form coupled pairs. Such coupled pairs are not deflected by ionic vibrations and so move without collisions.



Messener effect: In 1933, *Meissener* and *Ochsenfeld* observed that if a conductor is cooled in a magnetic field to a temperature below the transition temperature, then at this temperature, the lines of magnetic induction B are pushed out of the specimen, as shown in figure. Thus B becomes zero inside a superconducting specimen.

The expulsion of the magnetic flux from a superconducting material when it is cooled to a temperature below the critical temperature in a magnetic field is called Meissner effect.

Meissner effect indicates that as the superconductivity appears in a material, it becomes perfectly *diamagnetic.*

Application of superconductors: The possible applications of superconductors are

1. For producing high magnetic fields required for research work in high energy physics.
2. For storage of memory in high speed computers.
3. In the construction of very sensitive galvanometers.
4. In levitation transportation (trains which move without rails)
5. In long distance power transmission without any wastage of power.

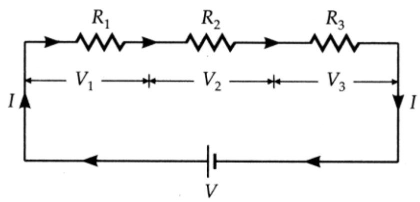
Resistances in Series

If a number of resistances are connected end to end so that the same current flows through each one of them in succession, then they are said to be connected in series. Figure shows three resistances R_1, R_2 and R_3 connected in series.

When a potential difference V is applied across the combination, the same current I flows through each resistance.

By Ohm's law, the potential drops across the three resistances are

$V_1 = IR_1,\ V_2 = IR_2,\ V_3 = IR_3$



If R_s is the equivalent resistance of the series combination, then we must have

$V = IR_s$

But V = Sum of the potential drops across the individual resistances

or $V = V_1 + V_2 + V_3$

or $IR_s = IR_1 + IR_2 + IR_3$ or $Rs = R_1 + R_2 + R_3$

The equivalent resistance of n resistances connected in series will be

$R_s = R_1 + R_2 + R_3 + \ldots\ldots + R_n$

Thus when a number of resistances are connected in series, their equivalent resistance is equal to the sum of the individual resistances.

Laws of resistances in series

(i) *Current through each resistance is same.*

(ii) *Total potential drop = Sum of the potential drops across the individual resistances.*

(iii) *Individual potential drops are directly proportional to individual resistances.*

(iv) *Equivalent resistance = Sum of the individual resistances.*

(v) *Equivalent resistance is larger than the largest individual resistances.*

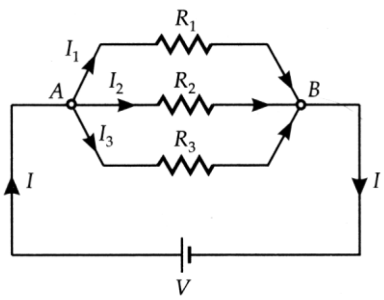
Resistances in parallel

If a number of resistances are connected in between two common points so that each of them provides a separate path for current, then they are said to be connected in parallel. Figure shows three resistances R_1, R_2 and R_3 connected in parallel between points A and B. Let V be the potential difference applied across the combination.

Let I_1, I_2 and I_3 be currents through the resistances R_1, R_2 and R_3 respectively. Then the current in the main circuit must be $I = I_1 + I_2 + I_3$

Since all the resistances have been connected between the same two points A and B, therefore, potential drop V is same across each of them. By Ohm's law, the currents through the individual resistances will be

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



If R_p is the equivalent resistance of the parallel combination, then we must have

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

But $\quad I = I_1 + I_2 + I_3$

or $\quad \frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad$ or $\quad \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

The equivalent resistance R_p of n resistances connected in parallel is given by

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

Thus when a number of resistances are connected in parallel, the reciprocal of the equivalent resistances of the parallel combination is equal to the sum of the reciprocals of the individual resistances.

Laws of resistances in parallel

(i) *Potential drop across each resistance is same.*

(ii) *Total current = Sum of the currents through individual resistances.*

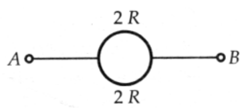
(iii) *Individual currents are inversely proportional to the individual resistances.*

(iv) *Reciprocal of equivalent resistance = Sum of the reciprocals of the individual resistances.*

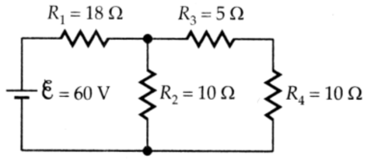
(v) *Equivalent resistance is less than the smallest individual resistances.*

Subjective Assignment – V

Q.1 A wire of resistance 4 R is bent in the form of a circle (figure). What is the effective resistance between the ends of the diameter?



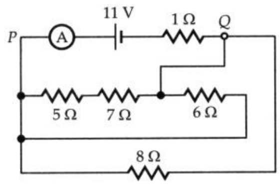
Q.2 Determine the voltage drops across the resistor R_1 in the circuit given below with $\xi = 60V$.



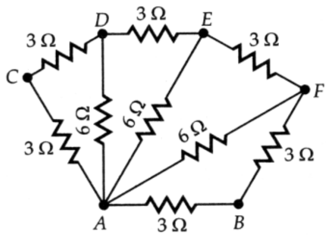
Q.3 A letter A consists of a uniform wire of resistance 1 ohm per cm. The sides of the letter are each 20cm long and the cross–piece in the middle is 10 cm long while the apex angle is 60°. Find the resistance of the letter between the two ends of the legs.

Q.4 When a current of 0.5 A is passed through two resistances in series, the potential difference between the ends of the series arrangement is 12.5 V. On connecting them in parallel and passing a current of 1.5A, the potential difference between their ends is 6 V. Calculate the two resistances.

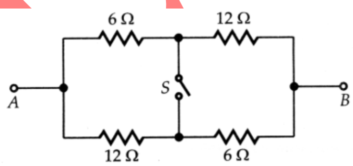
Q.5 Find the ammeter reading in the circuit shown in figure.



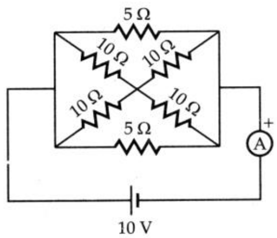
Q.6 Find the effective resistance between points A and B for the network shown in figure.



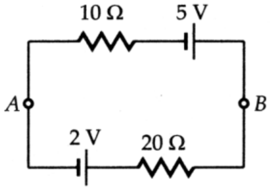
Q.7 Find the effective resistance of the network shown in figure between the points A and B when (i) the switch S is open (ii) switch S is closed.



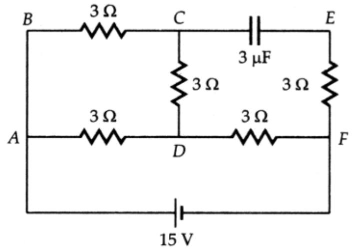
Q.8 Calculate the current shown by the ammeter A in the circuit shown in figure.



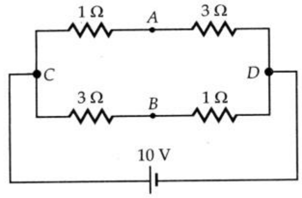
Q.9 Find the potential difference between the points A and B in the circuit shown in figure. Internal resistances of the cells are negligible.



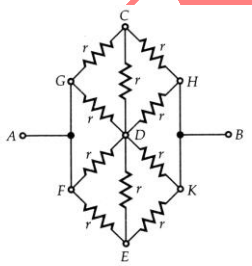
Q.10 In the circuit shown in figure, find the potential difference across the capacitor.



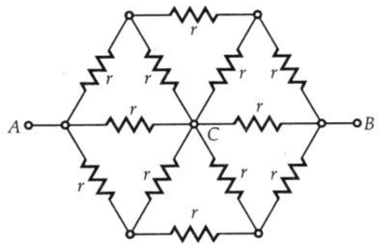
Q.11 A battery of emf 10 V is connected to resistances as shown in figure. Find the potential difference between the points A and B.



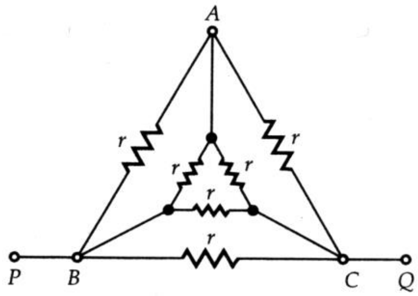
Q.12 Find the effective resistance between points A and B of the network of resistors shown in figure.



Q.13 A regular hexagon with diagonals is made of identical wires, each having same resistance r, as shown in figure. Find the equivalent resistance between the points A and B.



Q.14 Find the equivalent resistance of the circuit shown in figure between the points P and Q. Each resistor has a resistance r.

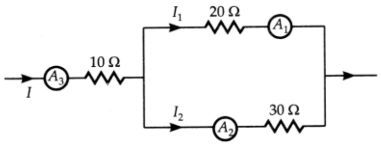


Q.15 How can the resistances of 2Ω, 3Ω and 6Ω be connected to give an effective resistance of 4Ω?

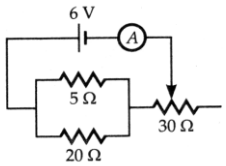
Q.16 A uniform wire of resistance 2.20Ω has a length of 2m. Find the length of the similar wire which connected in parallel with the 2m long wire, will give a resistance of 2.0Ω.

Q.17 A wire of 15 Ω resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 3.0 volt battery. Find the current drawn from the battery.

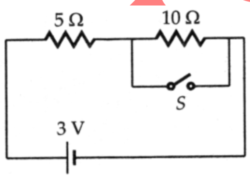
Q.18 If the reading of the ammeter A_1 in figure is 2.4A, what will the ammeters A_2 and A_3 read? Neglect the resistances of the ammeters.



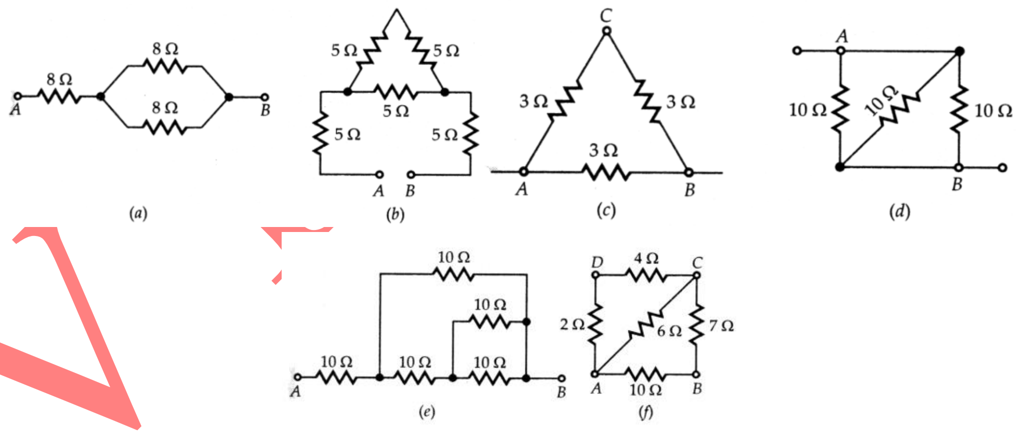
Q.19 The resistance of the rheostat shown in figure is 30Ω. Neglecting the meter resistance, find the minimum and maximum current through the ammeter as the resistance of the rheostat is varied.



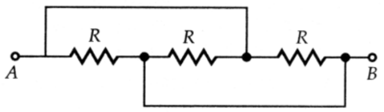
Q.20 Find the current through the 5Ω resistor in the circuit shown in figure, when the switch S is (i) open and (ii) closed.



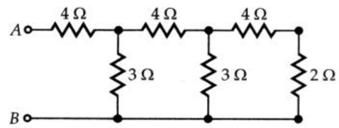
Q.21 Calculate the equivalent resistance between points A and B in each of the following networks of resistors:



Q.22 Calculate the resistance between points A and B for the following networks:

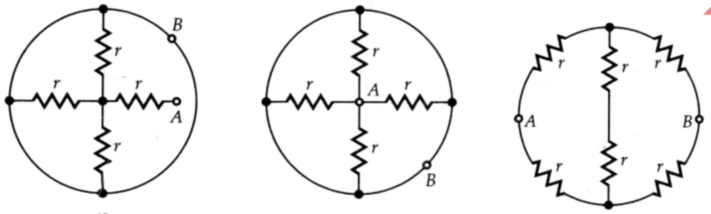


(c)



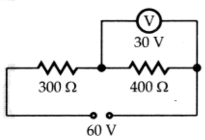
(d)

Q.23 Find the equivalent resistance of the networks shown in figure between the points A and B.

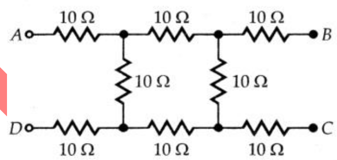


(i) (ii) (iii)

Q.24 In the circuit diagram shown in figure, a voltmeter reads 30V when connected across 400Ω resistance. Calculate what the same voltmeter reads when it is connected across 300Ω resistance.



Q.25 Find the resistance between the points (i) A and B and (ii) A and C of the network shown in figure.



Answers

1.	R	2.	45 V	3.	26.67 Ω
4.	5 Ω & 20 Ω	5.	3 A	6.	2Ω
7.	9 Ω, 8 Ω	8.	5 A	9.	– 4 V
10.	12 V	11.	5.0 V	12.	0.5 r
13.	0.8 r	14.	$\frac{r}{3}$		

15. 2Ω resistance should be connected in series with parallel combination of 3Ω and 6Ω resistances

16.	20 m	17.	0.2 A	18.	1.6A, 4.0 A
19.	0.18A, 1.5A	20.	(i) 0.2A, (ii) 0.6A		

21. (a) 12 Ω, (b) 40/3Ω, (c) 2Ω, (d) 10/3Ω, (e) 16Ω, (f) 5Ω

22 (a) $\frac{2}{3}\Omega$, (b) $\frac{4}{3}\Omega$, (c) $\frac{R}{3}\Omega$, (d) 6Ω 23. (a) $\frac{4}{3}$r, (b) $\frac{r}{4}$, (c) r

24. 22.5 V 25. (i) 27.5Ω, (ii) 30Ω

Internal Resistance of a Cell

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

The internal resistance of a cell depends on following factors:

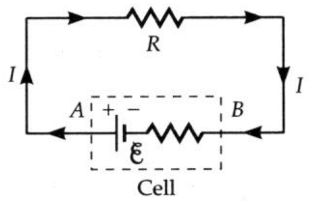
1. Nature of the electrolyte.
2. It is directly proportional to the concentration of the electrolyte.
3. It is directly proportional to the distance between the two electrodes.
4. It varies inversely as the common area of the electrodes immersed in the electrolyte.
5. It increases with the decrease in temperature of the electrolyte.

The internal resistance of a freshly prepared cell is usually low but its value increases as we draw more and more current from it.

Terminal potential difference: *The potential drop across the terminals of a cell when a current is being drawn from it is called its terminal potential difference (V).*

Relation between r, ξ and V. Consider a cell of emf ξ and internal resistance r connected to an external resistance R, as shown in figure. Suppose a constant current I flows through this circuit.

By definition of emf,



ξ = Work done by the cell in carrying a unit charge along the closed circuit.

= Work done in carrying a unit charge from A to B against external resistance R

+ Work done in carrying a unit charge from B to A against internal resistance r

or $\xi = V + V'$

By Ohm's law,

$V = IR$ and $V' = Ir$ $\therefore$ $\xi = IR + Ir = I(R + r)$

Hence the current in the circuit is $I = \dfrac{\xi}{R+r}$

Thus to determine the current in circuit, the internal resistance r combines in series with external resistance R.

The terminal p.d. of the cell that sends current I through the external resistance R is given by

$V = IR = \dfrac{\xi R}{R+r}$ Also $V = \xi - V' = \xi - Ir$

or terminal p.d. = emf – potential drop across the internal resistance

Again, from the above equation, we get $r = \dfrac{\xi - V}{I} = \dfrac{\xi - V}{V/R} = \left(\dfrac{\xi - V}{V}\right)R$

Special Cases

(i) When cell is on open circuit, i.e., I = 0, we have

$V_{open} = \xi$

Thus the potential difference across the terminals of the cell is equal to its emf when no current is being drawn from the cell.

(ii) A real cell has always some internal resistance r, so when current is being drawn from cell, we have

$V < \xi$

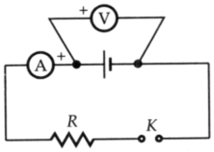
Thus the potential difference across the terminals of cell in a closed circuit is always less than its emf.

Subjective Assignment – VI

Q.1 For driving a current of 3 A for 5 minutes in an electric circuit, 900 J of work is to be done. Find the emf of the source in the circuit.

Q.2 A voltmeter of resistance 998 Ω is connected across a cell of emf 2V and internal resistance 2Ω. Find the p.d. across the voltmeter, that across the terminals of the cell and percentage error in the reading of the voltmeter.

Q.3 In the circuit shown in figure, the voltmeter reads 1.5 V, when the key is open. When the key is closed, voltmeter reads 1.35 V and ammeter reads 1.5 A. Find the emf and the internal resistance of the cell.



Q.4 A battery of e.m.f. ξ, and internal resistance 'r', gives a current of 0.5 A with an external resistor of 12 ohm and a current of 0.25 A with an external resistor of 25 ohm. Calculate (i) internal resistance of the cell and (ii) emf of the cell.

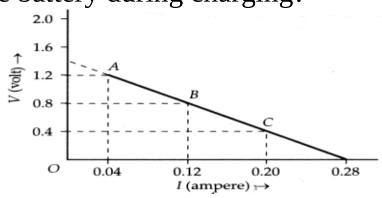
Q.5 (a) A car has a fresh storage battery of emf 12 V and internal resistance 5.0×10^{-2} Ω. If the starter motor draws a current of 90 A, what is the terminal voltage of the battery when the starter is on?

(b) After long use, the internal resistance of the storage battery increases to 500 Ω. What maximum current can be drawn from the battery? Assume the emf of the battery to remain unchanged.

(c) If the discharged battery is charged by an external emf source, is the terminal voltage of the battery during charging greater or less than its emf 12 V?

Q.6 A battery of emf 12.0 V and internal resistance 0.5Ω is to be charged by a battery charger which supplies 110 V d.c. how much resistance must be connected in series with the battery to limit the charging current to 5.0 A? What will be the p.d. across the terminals of the battery during charging?

Q.7 Potential differences across terminals of a cell were measured (in volt) against different current (in ampere) flowing through the cell. A graph was drawn which was a straight line ABC, as shown in figure. Determine from the graph



(i) emf of the cell

(ii) maximum current obtained from the cell, and

(iii) internal resistance of the cell

Q.8 The emf of a cell is 1.5V. On connecting a 14Ω resistance across the cell, the terminal p.d. falls to 1.4 V. Calculate the internal resistance of the cell.

Q.9 The potential difference between the terminals of a 6.0V battery is 7.2V when it is being charged by a current of 2.0. What is the internal resistance of the battery?

Q.10 The potential difference across the terminals of a battery is 8.5V, when a current of 3A flows through it from its negative terminal to +ve terminal. When a current of 2A flows through it in the opposite direction, the terminals potential difference is 11V. Find the internal resistance of battery and its emf.

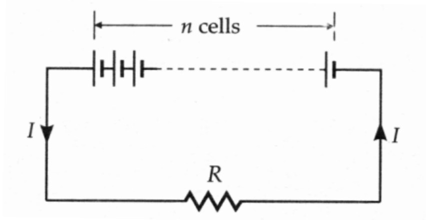
Answers

1.	1.0 V	2.	1.996 V, 0.2%	3.	1.5V, 0.1Ω
4.	1 Ω, 6.5 V	5.	(a) 7.5 V, (b) 24 mA (c) greater		
6.	14.5 V, 19.1 Ω	7.	(i) 1.4 V, (ii) 0.28 A, (iii) 5Ω		
8.	1Ω	9.	0.6Ω	10.	0.5Ω, 10 V

Combinations of Cells in Series and Parallel

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

As shown in figure, suppose n similar cells each of emf ε and internal resistance r be connected in series. Let R be the external resistance.



Total emf of n cells in series

= Sum of emfs of all cells = $n\xi$

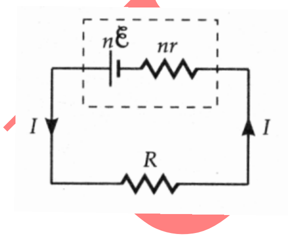
Total internal resistance of n cells in series

= r + r + r + ….n terms = nr

Total resistance in the circuit = R + nr

The current in the circuit is

$$I = \frac{\text{Total emf}}{\text{Total resistance}} = \frac{n\xi}{R + nr}$$



Special Cases

(i) If R > > nr, then $I = \frac{n\xi}{R}$

= n times the current (ξ/R) that can be drawn from one cell.

(ii) If R < < nr, then

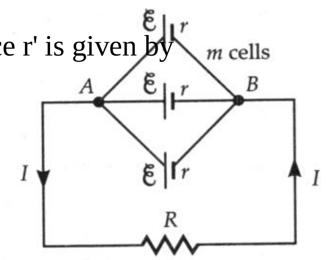
$$I = \frac{n\xi}{nr} = \frac{\xi}{r} = \text{the current given by a single cell}$$

Thus, *when external resistance is much higher than the total internal resistance, the cells should be connected in series to get maximum current.*

Cells in parallel: *When the positive terminals of all cells are connected to one point and all their negative terminals to another point, the cells are said to be connected in parallel.*

As shown in figure, suppose m cells each of emf ξ and internal resistance r be connected in parallel between points A and B. Let R be the external resistance.

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

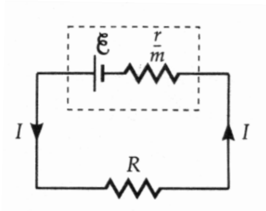


$$\frac{1}{r'} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \text{.......... m terms} = \frac{m}{r}$$

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

Total resistance in the circuit

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



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

Total emf of parallel combination = emf due to single cell = ξ

∴ The current in the circuit is $I = \frac{\xi}{R + r/m} = \frac{m\xi}{mR + r}$

Special Cases

(i) If $R << \frac{r}{m}$, then $I = \frac{m\xi}{r} = m$ times the current due to a single cell.

(ii) If $R >> \frac{r}{m}$, then $I = \frac{\xi}{R} =$ the current given by a single cell.

Thus, *when external resistance is much smaller than the net internal resistance, the cells should be connected in parallel to get maximum current.*

Mixed grouping of cells

In this combination, a certain number of identical cells are joined in series, and all such rows are then connected in parallel with each other.

As shown in figure, suppose n cells, each of emf ξ and internal resistance r, are connected in series in each row and m such rows are connected in parallel across the external resistance R.

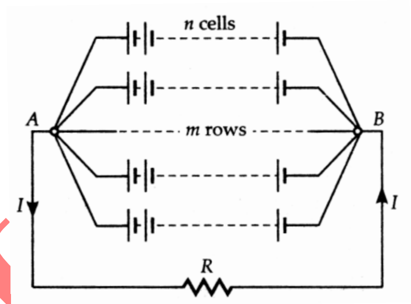
Total number of cells = mn

Net emf of each row of n cells in series = $n\xi$

As m such rows are connected in parallel, so net emf of the combination = $n\xi$

Net internal resistance each row of n cells = nr

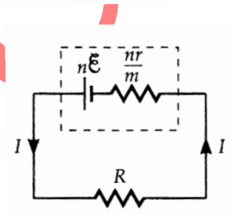
As m such rows are connected in parallel, so the total internal resistance r' of the combination is given by



$$\frac{1}{r'} = \frac{1}{nr} + \frac{1}{nr} + \frac{1}{nr} + \ldots\ldots m \text{ terms} = \frac{m}{nr}$$

or Total resistance of the circuit $= R + r' = R + \dfrac{nr}{m}$

The current through the external resistance R,



$$I = \frac{\text{Total emf}}{\text{total resistance}} = \frac{n\xi}{R + nr/m} = \frac{mn\xi}{mR + nr}$$

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

Now

$$mR + nr = \left(\sqrt{mR}\right)^2 + \left(\sqrt{nr}\right)^2$$

$$= \left(\sqrt{mR}\right)^2 + \left(\sqrt{nr}\right)^2 - 2\sqrt{mR}\,\sqrt{nr} + 2\sqrt{mR}\,\sqrt{nr} = \left(\sqrt{mR} - \sqrt{nr}\right)^2 + 2\sqrt{mnRr}$$

As the perfect square cannot be negative, so mR + nr will be minimum if

i.e., $\sqrt{mR} - \sqrt{nr} = 0$

or mR = nr or $R = \dfrac{nr}{m}$

or External resistance = Total internal resistance of the cells.

Thus, *in a mixed grouping of cells, the current through the external resistance will be maximum if the external resistance is equal to the total internal resistance of the cells.*

Subjective Assignment – VII

Q.1 (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 emf and internal resistance (independent of external circuit)? If not, how will you obtain currents in different branches?

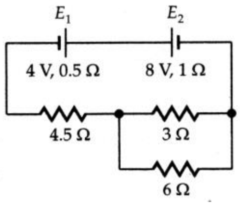
Q.2 Two identical cells of emf 1.5V each joined in parallel provide supply to an external circuit consisting of two resistances of 17Ω each joined in parallel. A very high resistance voltmeter reads the terminal voltage of cells to be 1.4V. Calculate the internal resistance of each cell.

Q.3 Four identical cells, each of emf 2V, are joined in parallel providing supply of current to external circuit consisting of two 15Ω resistors joined in parallel. The terminal voltage of the cells, as read by an ideal voltmeter is 1.6 volt. Calculate the internal resistance of each cell.

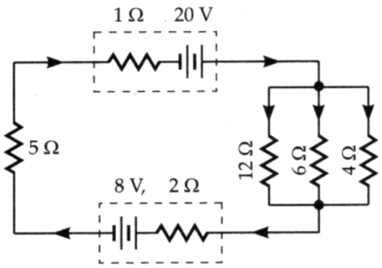
Q.4 Two cells E_1 and E_2 of emfs 4V and 8V having internal resistances 0.5Ω and 1.0Ω respectively are connected in opposition to each other. This combination is connected in series with resistances of 4.5Ω and 3.0Ω. Another resistance 6Ω is connected in parallel across the 3Ω resistor.

(a) Draw the circuit diagram (b) Calculate the total current flowing through the circuit.

Q.5 In the circuit diagram given in figure, the cells E_1 and E_2 have emfs 4V and 8V and internal resistances 0.5Ω and 1.0Ω respectively. Calculate the current in each resistance.



Q.6 A 20V battery of internal resistance 1Ω is connected to three coils of 12 Ω, 6Ω and 4 Ω in parallel, as shown in figure. Calculate the current in each resistor and the terminal potential difference across each battery.



Q.7 36 cells each of internal resistance 0.5Ω and emf 1.5V each are used to send current through an external circuit of 2Ω resistance. Find the best mode of grouping them and the current through the external circuit.

Q.8 How would you arrange 64 similar cells each having an emf of 2.0 V and internal resistance 2Ω so as to send maximum current through an external resistance of 8Ω.

Answers

1.	(a) 0.92 A, (b) No	2.	1.2Ω	3.	7.5Ω
4.	(b) 0.5 A	5.	$\frac{1}{3}$A, $\frac{1}{6}$A		
6.	0.2 A, 0.4 A, 0.6 A, 18.8 V, 10.4 v	7.	4.5 A, 3 × 12		
8.	n = 16, m = 4, 2.0 A				

Kirchhoff's Laws

1. **Electric network:** *The term electric network is used for a complicated system of electrical conductors.*
2. **Junction:** *Any point in an electric circuit where two or more conductors are joined together is a junction.*
3. **Loop or Mesh:** *Any closed conducting path in an electric network is called a loop or mesh.*
4. **Branch:** *A branch is any part of the network that lies between two junctions.*

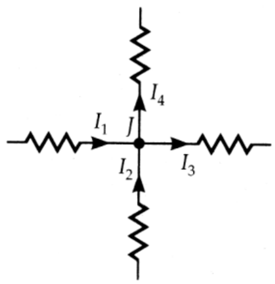
Kirchhoff's First Law or Junction Rule

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

Mathematically, this law may be expressed as

$$\sum I = 0$$

Sign convention for applying function rule:



1. The currents flowing towards the junction are taken as positive.
2. The currents flowing away from the junction are taken as negative.

Figure, represents a junction J in a circuit where four currents meet. The currents I_1 and I_2 flowing towards the junction are positive, while the currents I_3 and I_4 flowing away from the junction are negative, therefore, by *junction rule:*

$\sum I = 0$

or $I_1 + I_2 - I_3 - I_4 = 0$ or $I_1 + I_2 = I_3 + I_4$ i.e., Incoming current = Outgoing current

First law is also called *Kirchhoff's current law* (KCL). It is based on the law of conservation of charge.

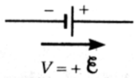
Kirchhoff's second law or loop rule

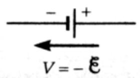
Around any closed loop of a network, the algebraic sum of changes in potential must be zero. Or, the algebraic sum of the emfs in any loop of a circuit is equal to the sum of the products of currents and resistances in it.

Mathematically, the loop rule may be expressed as $\sum \Delta V = 0$ or $\sum \xi = \sum IR$

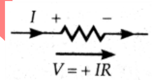
Sign convention for applying loop rule:

1. We can take any direction (clockwise or anticlockwise) as the direction of traversal.
2. The emf of cell is taken as positive if the direction of traversal is from its negative to the positive terminal (through the electrolyte).

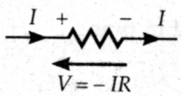




3. The emf of a cell is taken as negative if direction of traversal is from its positive to negative terminal.
4. The current–resistance (IR) product is taken as positive if the resistor is traversed in the same direction of assumed current.

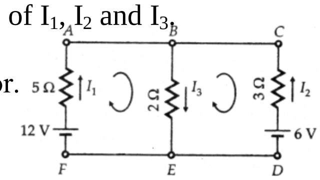


5. The IR product is taken as negative if the resistor is traversed in the opposite direction of assumed current.

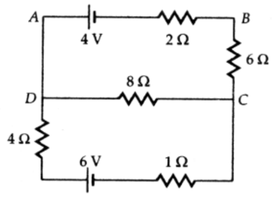


Subjective Assignment – VIII

Q.1 Using Kirchhoff's laws in the electrical network shown in figure, calculate values of I_1, I_2 and I_3.



Q.2 Using Kirchhoff's laws, calculate the potential difference across the 8 ohm resistor.



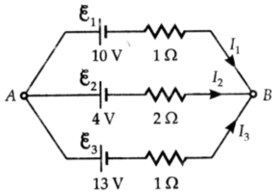
Q.3 Two cells of emfs 1.5V and 2.0 V and internal resistances 1Ω and 2Ω respectively are connected in parallel so as to send current in the same direction through an external resistance of 5Ω.

(i) Draw the circuit diagram (ii) Using Kirchoff's calculate

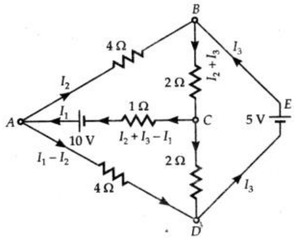
(a) current through each branch of the circuit.

(b) p.d. across the 5Ω resistance.

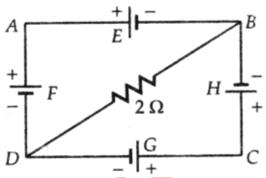
Q.4 Find the current flowing through each cell in the circuit shown in figure. Also calculate the potential difference across the terminals of each cell.



Q.5 Determine the current in each branch of the network shown in figure.

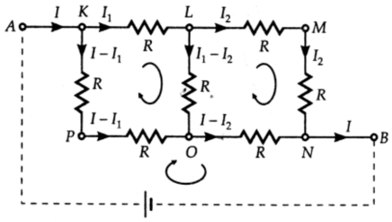


Q.6 In the circuit shown in figure, E, F, G and H are cells of emf 2V, 1V, 3V and 1V, and their internal resistances are 2Ω, 1Ω, 3Ω and 1Ω, respectively. Calculate (i) the potential difference between B and D and (ii) potential difference across the terminals of each of the cells G and H.



Q.7 In a Wheatstone bridge, P = 1Ω, Q = 2Ω, R = 2Ω, S = 3Ω and R_g = 4Ω. Find the current through the galvanometer in the unbalanced position of the bridge, when a battery of 2V and internal resistance 2Ω is used.

Q.8 Find the equivalent resistance between the terminals A and B in the network shown in figure. Given each resistor R is of 10Ω



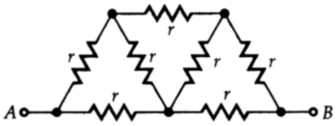
Q.9 A battery of 10V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistance 1Ω. Determine the equivalent resistance of the network and the current along each edge of the cube.

Q.10 Twelve wires each having a resistance of rΩ are connected to form a skeleton cube; find the resistance of the cube between the two corners of the same edge.

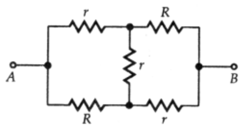
Q.11 Eleven equal wires each of resistance r form the edges of an incomplete cube. Find the total resistance from one end of the vacant edge of the cube to the other.

Q.12 Twelve wires each having a resistance of 1Ω are connected to form a cube. Find the resistance of the cube between two corners of a diagonal of one face of a cube.

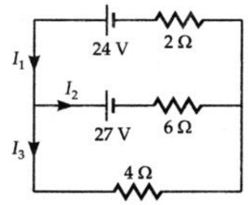
Q.13 In the network as shown in figure, each resistance r is of 2Ω. Find the effective resistance between points A and B.



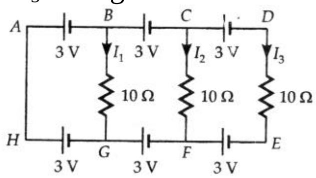
Q.14 Calculate the equivalent resistance between the points A and B in the network shown in figure.



Q.15 Using Kirchhoff's laws, determine the currents I_1, I_2 and I_3 for the network shown in figure.



Q.16 Find the currents I_1, I_2 and I_3 through the three resistors of the circuit shown in figure.



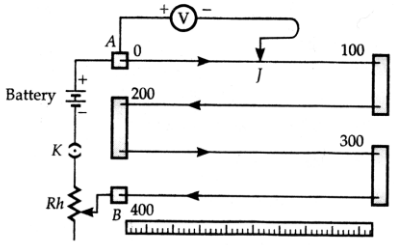
Answers

1. $I_1 = \frac{48}{31}A,\ I_2 = \frac{18}{31}A,\ I_3 = \frac{66}{31}A$
2. 34/9 V
3. $\frac{1}{34}A, \frac{9}{34}A, \frac{10}{34}A, 1.47\ V$
4. $I_4 = 3A$, $I_{10} = 0$, $I_{13} = 3A$, 10 V
5. $I_{AB} = 5/8$ A, $I_{BC} = 5/2$A, $I_{CA} = 5/2$A, $I_{DEB} = 15/8$ A, $I_{AD} = 15/8$ A, $I_{CD} = 0$
6. $\frac{2}{13}V$, 1.615V, 1.46V
7. $\frac{1}{91}A$
8. 14 Ω
9. 5/6 Ω, 2A
10. $\frac{7}{12}r\Omega$
11. 1.4 rΩ
12. $\frac{3}{4}\Omega$
13. $\frac{16}{7}\Omega$
14. $\frac{r(3R+r)}{R+3r}$
15. 3A, –1.5A, 4.5A
16. Zero in each resistor

Potentiometer

Potentiometer: An ideal voltmeter which does not change the original potential difference, needs to have infinite resistance. But a voltmeter cannot be designed to have an infinite resistance. Potentiometer is one such device which does not draw any current from the circuit and still measures the potential difference. So it acts as an ideal voltmeter. *A potentiometer is a device used to measure an unknown emf or potential difference accurately.*

Construction: A potentiometer consists of a long wire AB of uniform cross–section for material having high resistivity and low temperature coefficient of resistivity such as constantan or manganin. The wires are joined in series by thick copper strips. A metre scale is fixed parallel to the wires. The ends A and B are connected to a strong battery, a plug key K and a rheostat Rh. This circuit, called *driving or auxiliary circuit,* sends a constant current I through the wire AB. Thus, the potential gradually falls from A to B. A jockey can slide along the length of the wire.



Principle: *The basic principle of a potentiometer is that when a constant current flows through a wire of uniform cross–sectional area and composition, the potential drop across any length of the wire is directly proportional to that length.*

If we connect a voltmeter between the end A and the jockey J, it reads the potential difference V across the length l of the wire AJ. By Ohm's law,

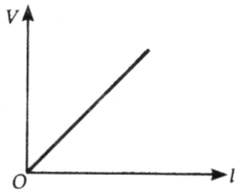
$$V = IR = I.\frac{\rho l}{A} \qquad \left[\because R = \rho\frac{l}{A}\right]$$

For a wire of uniform cross–section and uniform composition, resistivity ρ and area of cross–section A are constants. Therefore, when a steady current I flows through the wire,

$$\frac{I\rho}{A} = \text{a constant, } k$$

Hence $V = k\,l$ or $V \propto l$

This is the principle of a potentiometer. A graph drawn between V and l will be a straight line passing through the origin O, as shown in figure.



Potential gradient: *The potential drop per unit length of the potentiometer wire is known as potential gradient. It is given by*

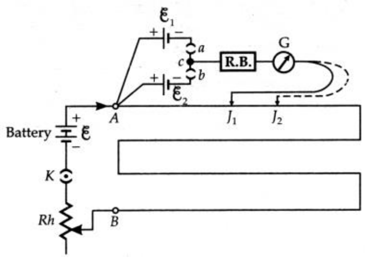
$$k = \frac{V}{l}$$

SI unit of potential gradient = Vm^{-1}

Practical unit of potential gradient = $V\ cm^{-1}$

Applications of a Potentiometer

Comparison of emfs of two primary cells: Figure shows the circuit diagram for comparing the emfs of two cells. A constant current is maintained in the potentiometer wire AB by means of a battery of the potentiometer wire AB by means of a battery of emf ξ through a key K and rheostat Rh. Let ξ_1 and ξ_2 be the emfs of the two primary cells which are to be compared. The positive terminals of these cells are connected to the end A of the potentiometer wire and their negative terminals are connected to a high resistance box R.B., a galvanometer G and a jockey J through a two way key. A high resistance R is inserted in the circuit from resistance box R.B to prevent excessive currents flowing through the galvanometer.



As the plug is inserted between a and c, the cell ξ_1 gets introduced in the circuit. The jockey J is moved along the wire AB till the galvanometer shows no deflection. Let the position of the jockey be J_1 and length of wire. $AJ_1 = l_1$. If k is the potential gradient along the wire AB, then at null point,

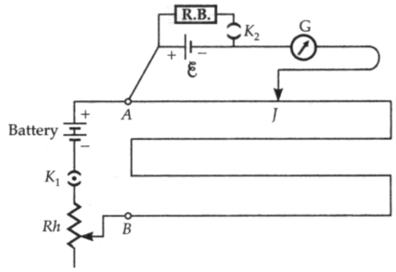
$$\xi_1 = kl_1$$

By inserting the plug between b and c, the null point is again obtained for cell ξ_2. Let the balancing length be $AJ_2 = l_2$. Then

$$\xi_2 = kl_2$$

Hence, $\frac{\xi_2}{\xi_1} = \frac{l_2}{l_1}$

Internal resistance of a primary cell by a potentiometer: As shown in the figure, the +ve terminal of the cell whose emf ξ is to be measured is connected to the end A of the potentiometer wire and its negative terminal to a galvanometer G and jockey J. A resistance box R.B. is connected across the cell through a key K_2.



Close the key k_1. A constant current flows through the potentiometer wire. With key K_2 kept open, move the jockey along AB till it balances the emf ξ of the cell. Let l_1 be the balancing length of the wire. If k is the potential gradient, then emf of the cell will be

$$\xi = kl_1$$

With the help of resistance box R.B., introduce a resistance R and close key K_2. If l_2 is the balancing length, then

$$V = kl_2 \qquad \therefore \qquad \frac{\xi}{V} = \frac{l_1}{l_2}$$

Let r be the internal resistance of the cell. If current I flows through cell when it is shunted with resistance R, then from Ohm's law we get

$$\xi = I(R + r) \quad \text{and} \quad V = IR$$

$$\therefore \quad \frac{\xi}{V} = \frac{R+r}{R} = \frac{l_1}{l_2} \qquad 1 + \frac{r}{R} = \frac{l_1}{l_2} \qquad \text{or} \qquad \frac{r}{R} = \frac{l_1 - l_2}{l_2}$$

$\therefore$ Internal resistance, $r = R\left[\frac{l_1 - l_2}{l_2}\right]$

Superiority of a potentiometer to a voltmeter: Potentiometer is a null method device. At null, it does not draw any current from the cell and thus there is no potential drop due to the internal resistance of the cell. It measures the p.d. in an open circuit which is equal to the actual emf of the cell.

On the other hand, a voltmeter draws a small current from the cell for its operation. So it measures the terminal p.d. in a closed circuit which is less than the emf of a cell. That is why a potentiometer is preferred over a voltmeter for measuring the emf of a cell.

Sensitiveness of a Potentiometer

A potentiometer is sensitive if

(i) it is capable of measuring very small potential differences, and

(ii) it shows a significant change in balancing length for a small change in th potential difference being measured.

The sensitivity of a potentiometer depends on the potential gradient along its wire. *Smaller the potential gradient, greater will be the sensitivity of the potentiometer.*

The sensitivity of a potentiometer can be increased by reducing the potential gradient. This can be done in two ways:

(i) For a given potential difference, the sensitivity can be increased by increasing the length of the potentiometer wire.

(ii) For a potentiometer wire of fixed length, the potential gradient can be decreased by reducing the current in the circuit with the help of a rheostat.

NOTE

- A potentiometer can be regarded as an *ideal voltmeter with infinite resistance* because it does not draw any current from the source of emf at the null point.
- The principle of potentiometer requires that (i) the potentiometer wire should be of uniform cross–section and (ii) the current through h the wire should remain constant.
- The emf of the auxiliary battery must be greater than the emf of the cell to be measured.
- The balance point cannot be obtained on the potentiometer if the fall of potential along the potentiometer wire due to the auxiliary battery is less than the emf of the cell to be measured.
- The positive terminals of the auxiliary battery and the cell whose emf is to be determined must be connected to the zero end of the potentiometer.

Subjective Assignment – IX

Q.1 A potentiometer wire is 10 m long and has a resistance of 18Ω. It is connected to a battery of emf 5V and internal resistance 2Ω. Calculate the potential gradient along the wire.

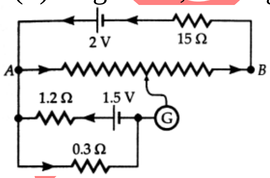
Q.2 A potentiometer wire is supplied a constant voltage of 3 V. A cell of emf 1.08 V is balanced by the voltage drop across 216 cm of the wire. Find the total length of the potentiometer wire.

Q.3 In a potentiometer, a standard cell of emf 5V and of negligible resistance maintains a steady current through the potentiometer wire of length 5m. Two primary cells of emfs ξ_1 and ξ_2 are joined in series with (i) same polarity, and (ii) opposite polarity. The combination is connected through a galvanometer and a jockey to the potentiometer. The balancing lengths in the two cases are found to be 350 cm and 50 cm respectively.

(i) Draw the necessary circuit diagram. (ii) Find the value of the emfs of the two cells

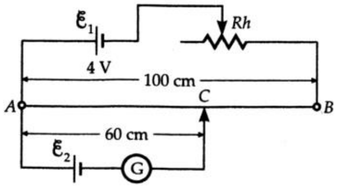
Q.4 A potentiometer wire of length 100 cm has a resistance of 100Ω. It is connected in series with a resistance and a battery of emf 2 V and of negligible internal resistance. A source of emf 10 mV is balanced against a length of 40 cm of the potentiometer wire. What is the value of the external resistance?

Q.5 AB is 1 metre long uniform wire of 10Ω resistance. Other data are as shown in figure. Calculate (i) potential–gradient along AB and (ii) length AO, when galvanometer shows no deflection.



Q.6 A cell gives a balance with 85cm of a potentiometer wire. When the terminals of the cell are shorted through a resistance of 7.5Ω, the balance is obtained at 75 cm. Find the internal resistance of the cell.

Q.7 A battery ξ_1 of 4V and a variable resistance Rh are connected in series with wire AB of the potentiometer. The length of wire of potentiometer is 1 metre. When a cell ξ_2 of emf 1.5 volt is connected between points A and C, no current flows through ξ_2. Length of AC = 60 cm.



(i) Find the potential difference between the ends A and B of the potentiometer.

(ii) Would the method work, if the battery ξ_1 is replaced by a cell of emf of 1 V?

Answers

1. 0.45 V m^{-1} 2. 600 cm 3. (i) 2.0 V, (ii) 1.50 V

4.	790 Ω	5.	37.5 cm, 0.008 V/cm	6.	1Ω
7.	(i) 2.5 V, (ii) No				

Wheatstone Bridge

It is an arrangement of four resistances used to determine one of these resistances quickly and accurately in terms of the remaining three resistances. This method was first suggested by a British physicist Sir Charles F. Wheatstone in 1843.

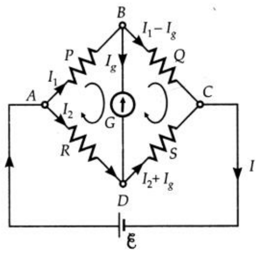
A Wheatstone bridge consists of four resistance P, Q, R and S; connected to form the arms of a quadrilateral ABCD. A battery of emf ξ is connected between points A and C and a sensitive galvanometer between B and D, as shown in figure.

The resistance R is so adjusted that there is no deflection in the galvanometer. The *bridge is said to balanced when* the potential difference across the galvanometer is zero so that there is no current through the galvanometer. In the balanced condition of the bridge, $\frac{P}{Q} = \frac{R}{S}$

Unknown resistance, $S = \frac{Q}{P}.R$

Knowing the ratio of resistance P and Q, and the resistance R, we can determine the unknown resistance S. That is why the arms containing the resistance P and Q are called *ratio arms*, the arm AD containing R *standard arm* and the arm CD containing S the *unknown arm.*

Derivation of balance condition from Kirchhoff's laws: In accordance with Kirchhoff's first law, the currents through various branches are as shown in figure.



Applying Kirchhoff's second law to the loop ABDA, we get

$$I_1P + I_gG - I_2R = 0$$

where G is the resistance of the galvanometer. Again applying Kirchhoff's second law to the loop BCDB, we get

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

In the balanced condition of the bridge, $I_g = 0$. The above equations become

$$I_1P - I_2R = 0 \quad \text{or} \quad I_1P = I_2R \qquad \dots \text{(i)}$$

and $$I_1Q - I_2S = 0 \quad \text{or} \quad I_1Q = I_2S \qquad \dots \text{(ii)}$$

On dividing equation (i) by (ii), we get $\frac{P}{Q} = \frac{R}{S}$

This proves the condition for the balanced Wheatstone bridge.

Sensitivity of a Wheatstone bridge

A Wheatstone bridge is said to be sensitive if it shows a large deflection in the galvanometer for a small change of resistance in the resistance arm.

The sensitivity of the Wheatstone bridge depends on two factors:

(i) Relative magnitudes of the resistances in the four arms of the bridge. The bridge is most sensitive when all the four resistances are of the same order.

(ii) Relative positions of battery and galvanometer.

According to *Callender* for the greater sensitivity of the Wheatstone bridge, *the battery should be so connected that the resistance in series with the resistance to be measured is greater than the resistance in parallel with it.*

According to *Maxwell* for the greater sensitivity of the Wheatstone bridge, *out of the battery and the galvanometer, the one having the higher resistance should be connected between the junction of the two highest resistances and the junction of the two lowest resistances.*

NOTE

- When the Wheatstone bridge is balanced, the potential difference between the points B and D is zero.
- The Wheatstone bridge is most sensitive when the resistances in the four arms are of the same order.
- Wheatstone bridge method is not suitable for the measurement of very low and very high resistances.

- In the balanced Wheatstone bridge, the resistance in arm BD is ineffective. The equivalent resistance of the balanced Wheatstone bridge between the points A and C will be

$$R_{eq}=\frac{(P+Q)(R+S)}{P+Q+R+S}$$

- If the bridge is balanced, then on interchanging the positions of the galvanometer and the battery there is no effect on the balance of the bridge. That is why the arms BD and AC are called *conjugate arms* of the bridge.
- The Wheatstone bridge is the simplest example of an arrangement, the variants of which are used for a large number of electrical measurements. The important applications of Wheatstone bridge are metre bridge, Carey–Foster's bridge and post office box.

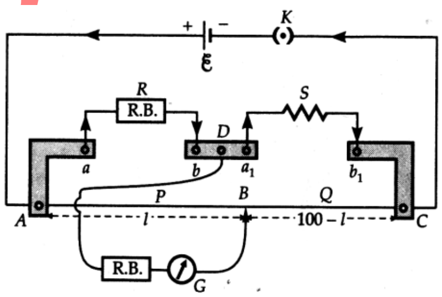
Metre Bridge or Slide Wire Bridge

It is the simplest practical application of the Wheatstone bridge that is used to measure an unknown resistance.

Principle: Its working is based on the principle of Wheatstone bridge.

When the bridge is balanced, $\frac{P}{Q}=\frac{R}{S}$

Construction: It consists of usually one metre long magnanin wire of uniform cross–section, stretched along a metre scale fixed over a wooden board and with its two ends soldered to two L–shaped thick copper strips A and C. Between these two copper strips, another copper strip is fixed so as the provide two gaps ab and a_1b_1. A resistance box R.B. is connected in the gap ab and the unknown resistance S is connected in the gap a_1b_1. A source of emf ξ is connected across AC. A movable jockey and a galvanometer are connected across BD, as shown in figure.



Working: After taking out a suitable resistance R from the resistance box, the jockey is moved along the wire AC till there is no deflection in the galvanometer. This is the balanced condition of the Wheatstone bridge. If P and Q are the resistances of the parts AB and BC of the wire, then for the balanced condition of the bridge, we have

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

Let total length of wire AC = 100 cm and AB = *l* cm, then BC = (100 – *l*) cm. Since the bridge wire is of uniform cross–section, therefore,

resistance of wire ∝ length of wire

or $$\frac{P}{Q}=\frac{\text{resistance of AB}}{\text{resistance of BC}}=\frac{\sigma l}{\sigma(100-l)}=\frac{l}{100-l}$$

where σ is the resistance per unit length of the wire. Hence

$$S=\frac{R(100-l)}{l}$$

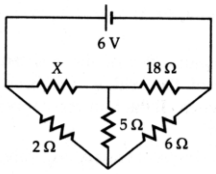
Knowing *l* and R, unknown resistance S can be determined.

Determination of resistivity: If r is the radius of the wire and *l*' its length, resistivity of its material will be

$$\sigma=\frac{SA}{l'}=\frac{S\times\pi r^2}{l'}$$

Subjective Assignment – X

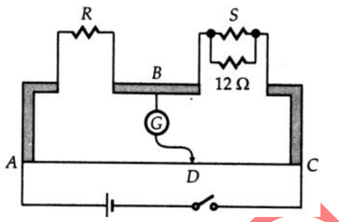
Q.1 Find out the magnitude of resistance X in the circuit shown in figure, when no current flows through the 5Ω resistor.



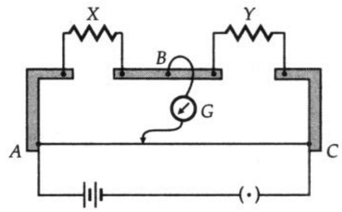
Q.2 P, Q, R and S are four resistance wires of resistances 2, 2, 2 and 3 ohms respectively. Find out the resistance with which S must be shunted in order that bridge may be balanced.

Q.3 In a metre bridge, the length of the wire is 100 cm. At what position will the balance point be obtained if the two resistances are in the ratio 2 : 3.

Q.4 In a metre bridge (figure), the null point is found at a distance of 33.7 cm from A. If now a resistance of 12Ω is connected in parallel with S, the null point occurs at 51.9 cm. Determine the values of R and S.



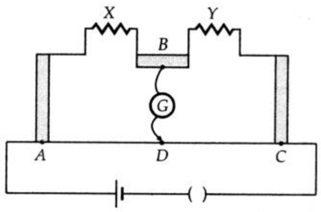
Q.5 The given figure shows the experimental setup of a metre bridge. The null point is found to be 60 cm away from the end A with x and Y in position as shown. When a resistance of 15Ω is connected in series with Y, the null point is found to shift by 10 cm towards the end A of the wire. Find the position of null point if a resistance of 30Ω were connected in parallel with Y.



Q.6 In a metre–bridge experiment, two resistances P and Q are connected in series in the left gap. When the resistance in the right gap is 50Ω, the balance point is at the centre of the slide wire. If P and Q are connected in parallel in the left gap, the resistance in the right gap has to be changed to 12Ω so as to obtain the balance point at the same position. Find P and Q.

Q.7 In a metre bridge when the resistance in the left gap is 2Ω and an unknown resistance in the right gap, the balance point is obtained at 40 cm from the zero end. On shunting the unknown resistance with 2Ω, find the shift of the balance point on the bridge wire.

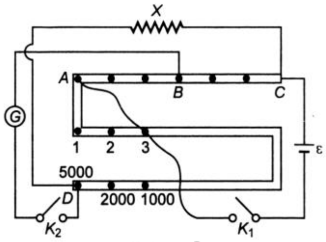
Q.8 Figure shows experimental set up of a metre bridge. When the two unknown resistances X and Y are inserted the null point D is obtained 40 cm from the end A. When a resistance of 10Ω is connected in series with X, the null point shifts by 10 cm. Find the position of the null point when the 10Ω resistance is instead connected in series with resistance 'Y'. Determine the values of the resistances X and Y.



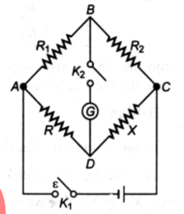
Answers

1.	6Ω	2.	6Ω	3.	40 cm
4.	R = 6.64 Ω, S = 13.1 Ω	5.	75 cm	6.	P = 30Ω, Q = 20Ω
7.	22.5 cm	8.	X = 20Ω, Y = 30Ω, l' = 33.3 cm		

Post Office Box



This is a device to measure an unknown resistance by using the principle of balanced Wheatstone bridge. It is a compact form of Wheatstone bridge to have three arms AB, BC and AD with many resistors. The arms AB and BC have three resistances $10, 10^2$ and 10^3 Ω respectively. The arm AD has a complete set of resistances ranging from 1 to 5000Ω . The key K_2 is internally connected between B and D. The key K_1 is fitted between A and C through a battery of emf ε. The unknown resistance X is connected between C and D which can be found by adjusting the circuit to a balanced Wheatstone bridge condition. Then, X can be given as



$$X = R\left(\frac{R_2}{R_1}\right)$$

where R_1/R_2 can vary from 100 : 1 to 1 : 100 and R is the resistance adjusted (fitted) in the branch AD within the limit of $1 \rightarrow 5000$ Ω.

Heating Effect of Current

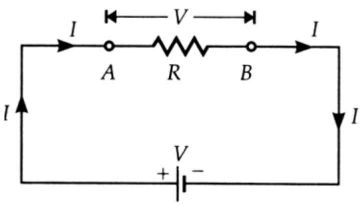
The phenomenon of the production of heat in a resistor by the flow of an electric current through it is called heating effect of current or Joule heating.

Cause of Heating Effect of Current

When a potential difference is applied across the ends of a conductor, its free electrons get accelerated in the opposite direction of the applied field. But the speed of the electrons does not increase beyond a constant drift speed. This is because during the course of their motion, the electrons collide frequently with the positive metal ions. The kinetic energy gained by the electrons during the intervals of free acceleration between collisions is transferred to the metal ions at about their mean positions more and more violently. The average kinetic energy of the ions increases. This increases the temperature of the conductor. Thus the conductor gets heated due to the flow of cur rent. Obviously, the electrical energy supplied by the source of emf is converted into heat.

Heat Produced by Electric Current: Joule's Law

Consider a conductor AB of resistance R, shown in figure. A source of emf maintains a potential difference V between its ends A and B and sends a steady current I from A to B. Clearly,



$V_A > V_B$ and the potential difference across AB is $V = V_A - V_B > 0$

The amount of charge that flows from A to B in time t is q = It

As the charge q moves through a decrease of potential of magnitude V, its potential energy decreases by the amount,

$$U = \text{final P.E. at B} - \text{Initial P.E. at A}$$
$$= qV_B - qV_A = -q(V_A - V_B) = -qV < 0$$

If the charges move through the conductor without suffering collisions, their kinetic energy would change so that the total energy is unchanged. By conservation of energy, the change in kinetic energy must be

$$K = -U = qV = It \times V = VIt > 0$$

Thus, in case, charges were moving freely through the conductor under the action of the electric field, their kinetic energy would increase as they move. However, we know that on the average, the charge carriers or electrons do not move with any acceleration but with a steady drift velocity. This is because of the collisions of electrons with ions and atoms during the course of their motion. The kinetic energy gained by the electrons is shared with the metal ions. These ions vibrate more vigorously and the conductor gets heated up.

The amount of energy dissipated as heat in conductor in time t is $H = VIt \text{ joule} = I^2 Rt \text{ joule} = \frac{V^2 t}{R} \text{ joule}$

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

The above equations are known as **Joule's law of heating.** According to this law, heat produced in a resistor is

1. directly proportional to the square of current for a given R,
2. directly proportional to the resistance R for a given I,
3. inversely proportional to the resistance R for a given V, and
4. directly proportional to the time for which the current flows through the resistor.

NOTE:

- The equation: W = VIt is applicable to the conversion of electrical energy into any other form, but the equation: $H = I^2 Rt$ is applicable only to the conversion of electrical energy into heat energy in an ohmic resistor.
- Joule's law of heating holds good even for a.c. circuits. Only current and voltage have to be replaced by their rms values.
- If the circuit is purely resistive, the energy expended by the source entirely appears as heat. But if the circuit has an active element like a motor, then a part of the energy supplied by the source goes to do useful work and the rest appears as heat.

Electric Power

The rate at which work is done by a source of emf in maintaining an electric current through a circuit is called electric power of the circuit. Or, the rate at which an appliance converts electric energy into other forms of energy is called its electric power.

If a current I follows through a circuit for time t at a constant potential difference V, then the work done or energy consumed is given by

W = VIt joule

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

Electric Energy

The total work done (or the energy supplied) by the source of emf in maintaining an electric current in a circuit for a given time is called electric energy consumed in the circuit. It depends upon the power of the appliance used in the circuit and the time for which this power is maintained.

Electric energy,

$W = P.t = VIt \text{ joule} = I^2 Rt \text{ joule}$

The SI unit of electric energy is **joule** (J).

1 joule = 1 volt × 1 ampere × 1 second = 1 watt × 1 second

Commercial unit of electric energy

The commercial unit of electric energy is ***kilowatt hour*** or ***board of Trade*** (B.O.T.) ***unit.*** One kilowatt hour is defined as the electric energy consumed by an appliance of 1 kilowatt in one hour.

1 kilowatt hour = 1 kilowatt × 1 hour

= 1000 watt × 3600 s = 3,600,000 joules or $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$

The electric metres installed in our houses measure the electric energy consumed in kilowatt hours. Another common unit of electric energy is watt hour. *It is the electric energy consumed by an appliance of one watt in one hour.*

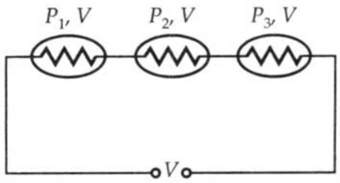
$1 \text{ watt hour} = 1 \text{ watt} \times 1 \text{ hour} = 3.6 \times 10^3 \text{ J}$

Power rating

The power rating of an electric appliance is the electrical energy consumed per second by the appliance when connected across the marked voltage of the mains. If a voltage V applied a across a circuit element of resistance R sends current I through it, then power rating of the element will be

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

Power consumed by a series combination of appliances



As shown in figure, consider a series combination of three bulbs of powers P_1, P_2 and P_3; which have been manufactured for working on the same voltage V.

The resistances of the three bulbs will be

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

As the bulbs are connected in series, so their equivalent resistance is

$$R = R_1 + R_2 + R_3$$

If P is the effective power of the combination, then

$$\frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3} \quad \text{or} \quad \frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}$$

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

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

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

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

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

The brightness of the three bulbs will be

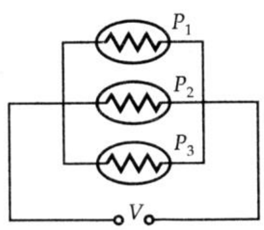
$$P_1' = I^2 R_1, \; P_2' = I^2 R_2, P_3' = I^2 R_3$$

As $R \propto \frac{1}{P}$, the bulb of lowest wattage (power) will have maximum resistance and it will glow with maximum brightness. When the current in the circuit exceeds the safety limit, the bulb of lowest wattage will be fused first.

Power consumed by a parallel combination of appliances

As shown in figure, consider a parallel combination of three bulbs of powers P_1, P_2 and P_3, which have been manufactured for working on the same voltage V.

The resistances of the three bulbs will be



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

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

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

Multiplying both sides by V^2, we get $\frac{V^2}{R} = \frac{V^2}{R_1} + \frac{V^2}{R_2} + \frac{V^2}{R_3}$ or $P = P_1 + P_2 + P_3$

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

If N bulbs, each of power P, are connected in parallel, then

$$P_{eff} = NP$$

The brightness of the three bulbs will be $P_1 = \frac{V^2}{R_1}, P_2 = \frac{V^2}{R_2}, P_3 = \frac{V^2}{R_3}$

As the resistance of the highest wattage (power) bulb is minimum, it will glow with maximum brightness. If the current in the circuit exceeds the safety limit, the bulb with maximum wattage will be fused first. For this reason, the appliances in houses are connected in parallel.

Efficiency of a source of emf

The efficiency of a source of emf is defined as the ratio of the output power to the input power. Suppose a source of emf ξ and internal resistance r is connected to an external resistance R.

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{VI}{\xi I} = \frac{V}{\xi} = \frac{IR}{I(R+r)} \quad \text{or} \quad \eta = \frac{R}{R+r}$$

Maximum power theorem

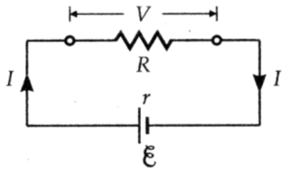
It states that the output power of a source of emf is maximum when the external resistance in the circuit is equal to the internal resistance of the source.

Let emf of the battery $= \xi$

Internal resistance $= r$

Resistance of the device $= R$

$\therefore$ Current through the device,



$$I = \frac{\text{Total emf}}{\text{Total resistance}} = \left(\frac{\xi}{R+r}\right)$$

$\therefore$ Power output of the resistive device will be

$$P = I^2R = \left(\frac{\xi}{R+r}\right)^2 R = \frac{\xi^2 R}{(R+r)^2} = \frac{\xi^2 R}{(R-r)^2 + 4Rr} \quad \text{...(i)}$$

Obviously, the power output will be maximum when $R - r = 0$ or $R = r$

Thus, the power output of the device is maximum when there is a perfect matching between the external resistance and the resistance of the source, i.e., when R = r. This proves maximum power theorem.

Maximum power output of the source is

$$P_{max} = \frac{\xi^2 r}{(r+r)^2} = \frac{\xi^2}{4r} \quad \text{[Putting R = r in Equ. (i)]}$$

(b) When the battery is shorted, R becomes zero, therefore, power output = 0. In this case, entire power of the battery is dissipated as heat inside the battery due to its internal resistance.

Power dissipation inside the battery

$$= I^2 r = \left(\frac{\xi}{r}\right)^2 r = \frac{\xi^2}{r}$$

Maximum efficiency of a source of emf

For a source of emf,

Input power $= \xi I$

Output power $= VI$

$\therefore$ Efficiency $\eta = \frac{VI}{\xi I} = \frac{V}{\xi} = \frac{IR}{I(R+r)} = \frac{R}{R+r}$

When the source delivers maximum power, R = r

$\therefore \quad \eta = \frac{r}{r+r} = \frac{1}{2} = 50\%$

Thus the efficiency of a source of emf is just 50% when it is delivering maximum power.

Applications of Heating Effect of Current

1. Household Heating Appliances

Many electrical appliances used in daily life are based on the heating effect of current such as room heater, electric toaster, electric iron, electric oven, electric kettle, geyser, etc. The designing of these devices requires the selection of a proper resistor. The resistor should have high resistance so that most of the electric power is converted into heat. In most of the household heating appliances, *nichrome element* is used because of the following reasons:

(i) Its melting point is high (ii) Its resistivity is large

(iii) It is tensile, i.e., it can be easily drawn into wires.

(iv) It is not easily oxidized by the oxygen of the air when heated

2. Incandescent Electric Bulb

It is an important application of Joule heating in producing light. It consists of a filament of fine metallic wire enclosed in a glass bulb filled with chemically inactive gases like nitrogen and argon. The filament material should have high resistivity and high melting point. Therefore, tungsten (melting point 3380^{o}C) is used for bulb filament.

3. Effective Fuse

It is safety device used to protect electrical appliances from strong currents. A fuse wire must have high resistivity and low melting point. It is usually made from an alloy of tin (63%) and lead (37%). It is put in series with the live wire of the circuit. When the current exceeds the safety limit, the fuse wire melts and breaks the circuit. The electric installations are thus saved from getting damaged.

4. Electric arc

It consists of two carbon rods with a small gap between their pointed ends. When a high potential difference of 40–60 V is applied between the two rods, very intense light is emitted by the gap. We know that E = –dV/dr. Clearly, E will be large if the gap is small. When the electric field exceeds the dielectric strength of air, ionization of air occurs. This causes a big spark to pass across the gap.

High voltage power transmission

Electric power is transmitted from power stations to homes and factories through transmission cables. These cables have resistance. Power is wasted in them as heat. Let us see how can we minimize this power loss.

Suppose power P is delivered to a load R via transmission cables of resistance R_t. If V is the voltage across load R and I the current through it, then P = VI

The power wasted in transmission cables is

$$P_t = I^2R_t = \frac{P^2R_t}{V^2}$$

Thus the power wasted in the transmission cables is inversely proportional to the square of voltage. Hence to minimize the power loss, electric power is transmitted to distant places at high voltages and low currents. These voltages are stepped down by transformers before supplying to homes and factories.

NOTE

- The emission of light by a substance when heated to a high temperature is called incandescence

- A heater wire is made from a material of large resistivity and high melting point while a fuse wire is made from a material of large resistivity and low melting point.
- The load in an electric circuit refers to the current drawn by the circuit from the supply line. If the current in a circuit exceeds the safe limit then the circuit is overloaded.
- The temperature upto which a wire gets heated (i.e., steady state temperature θ) is directly proportional to the square of the current and is inversely proportional to the cube of its radius but is independent of its length.

$$\theta \propto \frac{I^2}{r^3}$$

- When the resistances are connected in series, the current I through each resistance is same. Consequently,

$$P \propto R \qquad (\because P = I^2R)$$

and $$V \propto R \qquad (\because V = IR)$$

Hence in a series combination of resistances, the potential difference, power consumed and hence heat produced will be larger in the higher resistance.

- When the resistances are connected in parallel, the potential difference V is same across resistance. Consequently,

$$P \propto \frac{I}{R} \qquad \left(\because P = \frac{V^2}{R}\right) \qquad \text{and} \qquad I \propto \frac{1}{R} \qquad \left(\because I = \frac{V}{R}\right)$$

Hence in a parallel combination of resistances, the current, power consumed and hence heat produced will be larger in the smaller resistance.

Subjective Assignment – XI

Q.1 An electric current of 4.0 A flows through a 12Ω resistor. What is the rate at which heat energy is produced in the resistor?

Q.2 A heating element is marked 210 V, 630W. What is the current drawn by the element when connected to a 210 V d.c. mains? What is the resistance of the element?

Q.3 A 10V storage battery of negligible internal resistance is connected across a 50Ω resistor made of alloy manganin. How much heat energy is produced in the resistor in 1 h? What is the source of this energy?

Q.4 (a) A nichrome heating element across 230V supply consumes 1.5 kW of power and heats up to a temperature of 750°C. A tungsten bulb across the same supply operates at a much higher temperature of 1600°C in order to be able to emit light. Does it mean that the tungsten bulb necessarily consumes greater power? (b) Which of the two has greater resistance: a 1kW heater or a 100 W tungsten bulb, both marked for 230 V?

Q.5 An electric power station (100 MW) transmits power to a distant load through long and thin cables. Which of the two modes of transmission would result in lesser power wastage: power transmission of : (i) 20,000 V or (ii) 200 V?

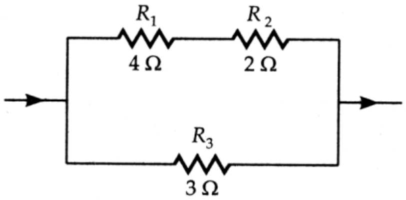
Q.6 A heater coil is rated 100W, 200V. It is cut into two identical parts. Both parts are connected together in parallel, to the same source of 200V. Calculate the energy liberated per second in the new combination.

Q.7 An electric bulb is marked 100W, 230V. If the supply voltage drops to 115 V, what is the heat and light energy produced by the bulb in 20 min? Calculate the current flowing through it.

Q.8 An electric bulb rated for 500 W at 100 V is used in circuit having a 200 V supply. Calculate the resistance R that must be put in series with the bulb, so that the bulb delivers 500 W.

Q.9 An electric heater and an electric bulb are rated 500W, 220V and 100W, 220V respectively. Both are connected in series to a 220 V d.c. mains. Calculate the power consumed by (i) the heater and (ii) electric bulb.

Q.10 In a part of the circuit shown in the figure, the rate of heat dissipation in 4Ω resistor is 100 J/s. Calculate the heat dissipated in the 3Ω resistor in 10 seconds.



Q.11 A house is fitted with 20 lamps of 60W each, 10 fans consuming 0.5A each and an electric kettle of resistance 110 Ω. If the energy is supplied at 220 V and costs 75 paise per unit, calculate the monthly bill for running appliances for 6 hours a day. Take 1 month = 30 days.

Q.12 There are two electric bulbs rated 60W, 110V and 100W, 110V. They are connected in series with a 220 V d.c. supply. Will any bulb fuse? What will happen if they are connected in parallel with the same supply?

Q.13 A thin metallic wire of resistance 100Ω is immersed in a calorimeter containing 250g of water at 10°C and a current of 0.5 ampere is passed through it for half an hour. If the water equivalent of the calorimeter is 10g, find the rise of temperature.

Q.14 A copper electric kettle weighing 1000g contains 900g of water at 20°C. It takes 12 minutes to raise the temperature to 100°C. If electric energy is supplied at 210 V, calculate the strength of the current, assuming that 10% heat is wasted. Specific heat of copper is 0.1.

Q.15 A coil of enameled copper wire of resistance 50Ω is embedded in a block of ice and a potential difference of 210 V applied across it. Calculate the rate at which ice metals. Latent heat of ice is 80 cal per gram.

Q.16 An electric kettle has two heating coils, when one of the coils is switched on, the kettle begins to boil in 6 minutes and when the other is switched on, the boiling begins in 8 minutes. In what time will the boiling begin if both the coils are switched on simultaneously (i) in series and (ii) in parallel?

Q.17 The heater coil of an electric kettle is rated at 2000W, 200V. How much time will it take in raising the temperature of 1 litre of water from 20°C to 100°C, assuming that only 80% of the total heat energy produced by the heater coil is used in raising the temperature of water. Density of water = 1g cm^{-3} and specific heat of water = 1 cal g^{-1} $°C^{-1}$.

Q.18 One kilowatt electric heater is to be used with 220 V d.c. supply. (i) What is the current in the heater? (ii) What is its resistance? (iii) What is the power dissipated in the heater? (iv) How much heat in calories is produced per second? (v) How many grams of water at 100°C, will be converted per minute into steam at 100°C, with the heater? Assume that heat losses due to radiation are negligible. Latent heat of stream = 540 cal per gram.

Q.19 The walls of a closed cubical box of edge 50 cm are made a material of thickness 1 mm and thermal conductivity 4×10^{-4} cal s^{-1} cm^{-1} $°C^{-1}$. The interior of the box maintained at 100°C above the outside temperature by heater placed inside the box and connected across a 400 V d.c. source. Calculate the resistance of the heater.

Q.20 A 10V battery of negligible internal resistance is charged by a 200 V d.c. supply. If the resistance in the charging circuit is 38Ω, what is the value of charging current?

Q.21 A dry cell of emf 1.6V and internal resistance 0.10 ohm is connected to a resistor of resistance R ohm. If the current drawn from the cell is 2 A, then

(i) what is the voltage drop across R?

(ii) what is the energy dissipation in the resistor?

Q.22 A dry cell of emf 1.5 V and internal resistance 0.10 Ω is connected across a resistor in series with a very low resistance ammeter. When the circuit is switched on, the ammeter reading settles to a steady value of 2.0A. What is the steady

(a) rate of chemical energy consumption of the cell, (b) rate of energy dissipation inside the cell,

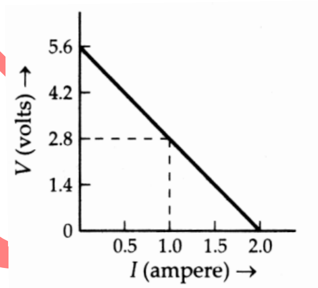
(c) rate of energy dissipation inside the resistor

(d) power output of the source?

Q.23 A series battery of 10 lead accumulators, each of emf 2 V and internal resistance 0.25 ohm, is charged by a 220 V d.c. mains. To limit the charging current, a resistance of 47.5 ohm is used in series in the charging circuit. What is (a) the power supplied by the mains and (b) power dissipated as heat? Account for the difference of power in (a) and (b).

Q.24 A 24 V battery of internal resistance 4.0 Ω is connected to a variable resistor. At what value of the current drawn from the battery is the rate of heat produced in the resistor maximum?

Q.25 4 cells of identical emf ξ, internal resistance r, are connected in series to a variable resistor. The following graph shows the variation of terminal voltage of the combination with the current output.



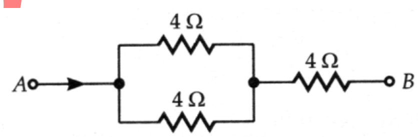
(i) What is the emf of each cell used?

(ii) For what current from the cells, does maximum power dissipation occur in the circuit?

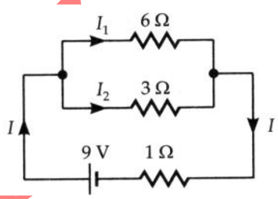
(iii) Calculate the internal resistance of each cell

Q.26 A fuse with a circular cross–sectional radius of 0.15 mm blows at 15 A. What should be the radius of cross–section of a fuse made of the same material which will blow at 30A?

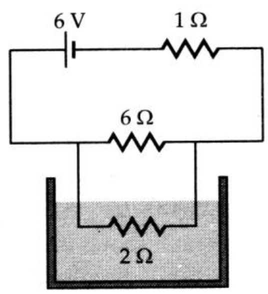
Q.27 In the circuit shown in figure, each of the three resistors of 4Ω can have a maximum power of 20 W (otherwise it will melt). What maximum power can the whole circuit take?



Q.28 Find the heat produced per minute in each of the resistors shown in figure.



Q.29 The 2.0Ω resistor shown in figure is dipped into a calorimeter containing water. The heat capacity of the calorimeter together with water is 2000 JK^{-1}. (a) If the circuit is active for 30 minutes, what would be the rise in the temperature of the water? (b) Suppose the 6.0Ω resistor gets burnt. What would be the rise in the temperature of the water in the next 30 minutes?

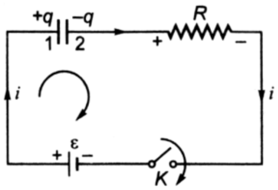


Answers

1.	192 W	2.	3A, 70 Ω	3.	7200 J
4.	(a) No, (b) 52.9Ω, 529Ω	5.	20,000 V	6.	400 J
7.	30 kJ, 5/23 A	8.	20Ω		
9.	(i) 13.8 W, (ii) 69.89W	10.	3000 J	11.	Rs. 369.90
12.	60 W, both will fuse	13.	41.2°C	14.	2.469 A
15.	2.62 g s^{-1}	16.	14 min, 3.43 min	17.	210 s
18.	(i) 4.55 A, (ii) 48.4Ω, (iii) 1000 W, (iv) 240 cal s^{-1}, (v) 26.67 g			19.	6.35Ω
20.	5 A	21.	(i) 1.4 V, (ii) 2.8 W		
22.	(a) 3.0W, (b) 0.40W, (c) 2.6W, (d) 2.6W			23.	(a) 880 W, (b) 800 W

24.	3.0 A	25.	1.4 V, 0.7 Ω, 1 A	26.	0.24 mm
27.	30 W	28.	360 J, 720 J, 540 J	29.	5.8°C, 7.2°C

Charging of the Capacitor



A circuit containing only resistors and capacitors is called R-C circuit. For the sake of simplicity, let us take a single loop R-C circuit comprising a resistor R and a capacitor C connected in series with a battery of emf ε through a key K After we close the key at t = 0, let the battery circulate a charge q during time t. If the capacitor is initially uncharged, its plates 1 and 2 receive charges +q and –q respectively during the time t. So, the instantaneous current at time t is

$$i = \frac{dq}{dt}$$

If you move in clockwise sense, the potential difference across the capacitor, resistor and battery can be given as $\Delta V_C = -\frac{q}{C}$, $\Delta V_R = -iR$ and $\Delta V_b = +\varepsilon$ respectively.

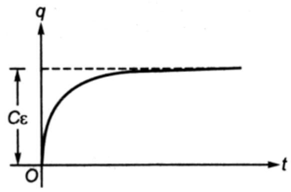
Applying KCL,

$$\Delta V_C + \Delta V_R + \Delta V_b = 0 \qquad \text{or,} \qquad -\frac{q}{C} - iR + \varepsilon = 0$$

Putting $i = \frac{dq}{dt}$ and separating the variables, we have $\frac{dq}{C\varepsilon - q} = \frac{1}{RC}dt$

Since a charge q flows during time t, integrating both sides,

$$\int_0^q \frac{dq}{C\varepsilon - q} = \frac{1}{RC}\int_0^t dt \qquad \text{or,} \qquad \ln\,(C\varepsilon - q)\Big|_0^q = -\frac{t}{RC}$$



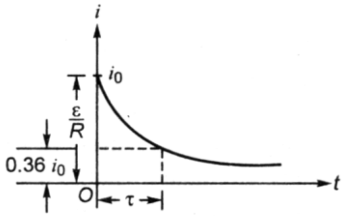
$$\text{or,} \qquad \ln\left(\frac{C\varepsilon - q}{C\varepsilon}\right) = -\frac{t}{RC} \qquad \text{or,} \qquad q = C\varepsilon\left(1 - e^{-\frac{1}{RC}}\right)$$

where RC is time constant of R – C circuit denoted by τ (tau)

If $t \to \infty$, $q \to C\varepsilon\ (= q_0)$

This tells us that the charge on each plate builds up from zero to its maximum exponentially (but not abruptly) after closing the key.

The current i at time t is given as



$$i = \frac{dq}{dt} = \frac{d}{dt}C\varepsilon(1 - e^{-t/RC})$$

$$\text{or} \qquad i = \frac{\varepsilon}{R}e^{-t/RC}$$

At $t = 0$, $i = \frac{\varepsilon}{R}\ (= i_0)$; at $t \to \infty$, $i \to 0$

Time Constant

The term "RC" is called time constant τ of RC circuit. $\tau = RC$

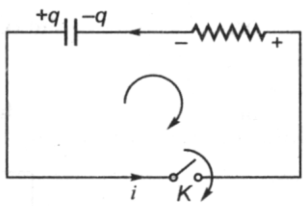
If $t = \tau$, $i = \frac{i_0}{e}$. Hence, the time constant of RC circuit is defined as the time after which the current drops by a factor e (to 36% of the maximum current).

It means that the current in the circuit decays exponentially from its maximum value $i_0\left(=\frac{\varepsilon}{R}\right)$ to zero after closing the key and the capacitor is fully charged to V (= ε) after a long time (practically within a time period of few time constants).

In the charging R-C circuit charge increases and current decreases exponentially.

Discharging of the Capacitor

Let us open the key, remove the battery and then close the key. You can see that a current i flows in the circuit from +ve to –ve plate. Since the charge q of the capacitor plates decreases with time, the current in the circuit is given as $i = -\frac{dq}{dt}$



Applying KCL in clockwise sense,

$$\Delta V_C + \Delta V_R = 0$$

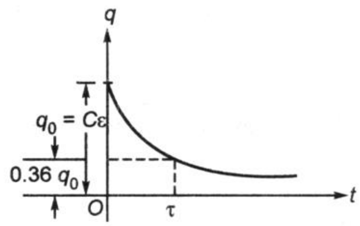
or, $$-\frac{q}{R}+(iR)=0$$ or,

$$-\frac{q}{R}+\left(-\frac{dq}{dt}\right)R=0 \qquad \left(\because\ i=-\frac{dq}{dt}\right)$$

or, $$-\frac{dq}{dt}=\frac{q}{RC}$$ or, $$\frac{dq}{q}=-\frac{1}{RC}dt$$

Since, the charge on the capacitor plates decreases from O to q during time t, integrating both sides,

$$\int_0^q \frac{dq}{q}=-\frac{i}{RC}\int_0^t dt$$

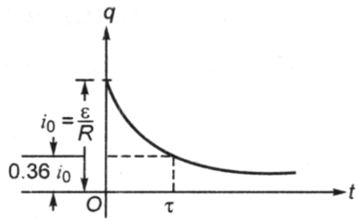


or, $$\ln q\Big|_{C\varepsilon}^{q}=-\frac{t}{RC}$$ or, $$\ln\frac{q}{C\varepsilon}=-\frac{t}{RC}$$

or, $$q = C\varepsilon\ e^{-\frac{t}{RC}}$$

The current in the circuit is

$$i=-\frac{dq}{dt}=-\frac{d}{dt}\left(C\varepsilon e^{-\frac{t}{RC}}\right)$$



or $$i = \frac{\varepsilon}{R}e^{-\frac{t}{RC}}$$

The above discussion tells us that,

In discharging RC circuit both charge and current in the circuit decreases exponentially from their maximum values to zero. At t = τ (= RC), both charge and current decreases by 64%.

Solved Examples

Ex.1 What will be the charge of a capacitor C = 1 μF connected to an ideal battery of emf ε = 100 volt through an external resistor R = 100Ω. After a time t = 2 ms in a single lop R–C circuit?

Sol. The charge of the capacitor at time t is

$$q = C\varepsilon\left(1-e^{-\frac{t}{RC}}\right)$$

$$= (10^{-6})\ (100)\left(1-e^{\frac{-2\times10^{-3}}{(100)\ (10^{-6})}}\right) = \left(1-\frac{1}{e^2}\right)\times 10^{-4}\ \text{coulomb}$$

Ex.2 After how many time constants the charge of a discharging R–C circuit decreases by 50%?

Sol. The charge of the capacitor at time t is

$$q = C\varepsilon e^{-\frac{t}{RC}}$$

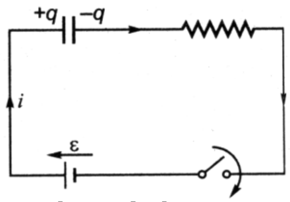
Putting $q = \frac{C\varepsilon}{2}$, we have $\frac{1}{2} = e^{-\frac{t}{RC}}$ or, $-\ln 2 = -\frac{t}{RC}\ln e$ or, $\frac{t}{RC} = \ln 2 = 0.693$

Energy Consideration and heat Dissipated in R–C Circuits

Work done by the Battery (W_b)

The battery sends a charge $q = \int_0^\infty i\ dt$ during charging of the capacitor, where $i = \frac{\varepsilon}{R}e^{-\frac{t}{RC}}$. This gives

$$q_{flown} = C\varepsilon$$



Then, the total work done (or energy supplied) by the battery is

$$W_b = \varepsilon q$$
$$= \varepsilon (C\varepsilon)$$

or, $$W_b = C\varepsilon^2$$

Increase in Potential Energy (ΔU)

As the final charge of the capacitor is $q_0 = C\varepsilon$ and initially the capacitor is uncharged, the increase (change) in potential energy of the capacitor is

$$\Delta U = \frac{q_0^2}{2C} = \frac{(C\varepsilon)^2}{2C} \quad \text{or,} \quad \Delta U = \frac{C\varepsilon^2}{2}$$

Total Heat Dissipated (Q)

The total heat dissipated in the resistor is $Q = \int_0^\infty P\ dt = \int_0^\infty i^2\ Rdt = \int_0^\infty \left(\frac{\varepsilon}{R}e^{-\frac{t}{RC}}\right) Rdt$ or, $Q = \frac{1}{2}C\varepsilon^2$

From the above discussion we understand that half of the total energy supplied by the battery is utilized in increasing the potential energy of the capacitor and rest of the energy is dissipated in the form of heat, light, sound, etc. This is called 50%-50% rule. This is in accordance with the conservation of total energy (or work-energy theorem) given as $W_b = \Delta U + Q$

The above expression is useful for finding total heat dissipated in any complicated RC circuit.

Solved Examples

Ex.1 In charging single loop RC circuit, after how many time constant the potential energy in the capacitor will be 25% of its maximum value.

Sol. The potential energy of the capacitor at time t is

$$U = \frac{q^2}{2C}, \quad \text{where } q = C\varepsilon\left(1 - e^{-\frac{t}{RC}}\right)$$

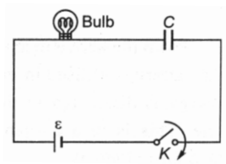
Then, $$U = \frac{C\varepsilon^2}{2}\left(1 - e^{-\frac{t}{RC}}\right)^2, \quad \textit{where } \frac{C\varepsilon^2}{2} = U_0$$

Putting $U = \frac{U_0}{4} = \frac{C\varepsilon^2}{8}$, we have

$$\left(1 - e^{-\frac{t}{RC}}\right)^2 = \frac{1}{4} \quad \text{or,} \quad \left(1 - e^{-\frac{t}{RC}}\right)^2 = \frac{1}{4} \quad \text{or,} \quad 1 - e^{-\frac{t}{RC}} = \frac{1}{2}$$

or, $$e^{-\frac{t}{RC}} = \frac{1}{2} \quad \text{or,} \quad -\frac{t}{RC}\ln e = -\ln 2 \quad \text{or,} \quad \frac{t}{RC} = \ln 2$$

Ex.2 In this circuit, how does the illumination of the bulb changes after closing the key?

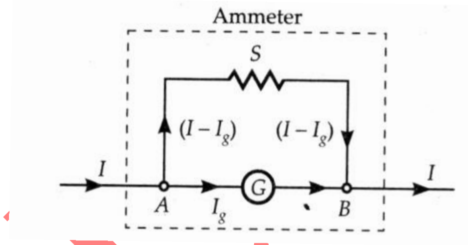


Sol. As the current decreases exponentially, the illumination I which is directly proportional to the square of the current can be given as

$$P = P_0 e^{-\frac{2t}{RC}}$$

This tells us that illumination of the bulb goes out gradually as the current decreases exponentially. As the final current is zero, the bulb will be extinguished after a long time (practically after few seconds). This example tells us that in the RC circuits the capacitors get discharged releasing its stored energy slowly which will appear in the form of heat and light, etc.

Conversion of a Galvanometer Into An Ammeter



At ammeter is a device used to measure current through a circuit element. To measure current through a circuit element, ammeter is connected in *series* with the element so that the current which is to be measured actually passes through it. *An ideal ammeter should have zero resistance.*

To measure large currents with it, a small resistance is connected in parallel with the galvanometer coil. The resistance connected in this way is called a ***shunt.***

Let G = resistance of the galvanometer

I_g = the current with which galvanometer give full scale deflection

0 – I = the required current range of the ammeter

S = shunt resistance

I – I_g = current through the shunt.

As galvanometer and shunt are connected in parallel, so

P.D. across the galvanometer = P.D. across the shunt

$$I_g G = (1 - I_g)S \qquad \text{or} \qquad S = \frac{I_g}{I - I_g} \times G$$

So by connecting a shunt of resistance S across the given galvanometer, we get an ammeter of desired range. Moreover,

$$I_g = \frac{S}{G+S} \times I$$

The deflection in the galvanometer is proportional to I_g and hence to I. So the scale scan can be graduated to read the value of current I directly.

Hence *an ammeter is a shunted or low resistance galvanometer*. Its effective resistance is $R_A = \frac{GS}{G+S} < S$

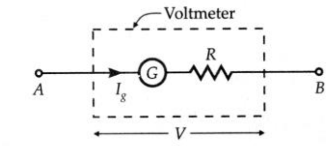
NOTE

- Since an ammeter is a parallel combination of the galvanometer and the shunt resistance, so its resistance is even less than that of the shunt resistance. Moreover, $R_A << G$.
- Because of its very small resistance, an ammeter placed in a series circuit does not practically change the current in the circuit to be measured.
- The resistance of an ideal ammeter is zero.
- Higher the range of ammeter to be prepared from a given galvanometer, lower is the value of the shunt resistance required for the purpose.
- The ammeter of lower range has a higher resistance than the ammeter of higher range.
- The range of an ammeter can be increased but it cannot be decreased.

Conversion of a Galvanometer into a Voltmeter

A voltmeter is a device for measuring potential difference across any two points in a circuit. It is connected in parallel with the circuit element across which the potential difference is intended to be measured.

The voltmeter should be designed to have very high resistance. In fact, *an ideal voltmeter should have infinite resistance.*



A galvanometer can be converted into a voltmeter by connecting a high resistance in series with it. The value of this resistance is so adjusted that only current I_g which produces full scale deflection in the galvanometer, passes through the galvanometer. Let

G = resistance of the galvanometer

I_g = the current with which galvanometer gives full scale deflection

0 – V = required range of the voltmeter, and

R = the high series resistance which restricts the current of safe limit I_g.

∴ Total resistance in the circuit = R + G

By Ohm's law,

$$I_g = \frac{\text{Potential difference}}{\text{Total resistance}} = \frac{V}{R+G} \quad \text{or} \quad R + G = \frac{V}{I_g} \quad \text{or} \quad R = \frac{V}{I_g} - G$$

So by connecting a high resistance R in series with the galvanometer, we get a voltmeter of desired range. Moreover, the deflection in the galvanometer is proportional to current I_g and hence to V. The scale can be graduated to read the value of potential difference directly.

Hence a voltmeter is a high resistance galvanometer. Its effective resistance is $R_V = R + G >> G$

NOTE

- Since a voltmeter is a series combination of a galvanometer and a high resistance R, so its resistance is much higher than that of the galvanometer.
- An ideal voltmeter should have infinite resistance.
- A voltmeter is placed in parallel with the circuit element across which the voltage is to be measured. Because of its high resistance, it draws a very small current and hence the potential difference across the element remains practically unaffected.
- Higher the range of voltmeter to be prepared from a given galvanometer, higher is the value of series high resistance required for the purpose.
- The voltmeter of lower range has a lower resistance than the voltmeter of higher range.
- The range of voltmeter can be both increased or decreased.

Subjective Assignment – XII

Q.1 A galvanometer with a coil of resistance 12.0Ω shows full scale deflection for a current of 25 mA. How will you convert the meter into:

(i) an ammeter of range 0 to 7.5 A, (ii) a voltmeter of range 0 to 10.0 V

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 across a part of the circuit, does it read (slightly) less or more than the original voltage drop? Explain.

Q.2 A galvanometer with a scale divided into 100 equal divisions has a current sensitivity of 10 divisions per mA and a voltage sensitivity of 2 divisions per mV. What adoptions are required to read (i) 5A for full scale and (ii) 1 division per volt?

Q.3 An ammeter of resistance 0.80Ω can measure currents upto 1.0 A. (i) What must be the shunt resistance to enable the ammeter to measure current upto 5.0A? (ii) What is the combined resistance of the ammeter and the shunt?

Q.4 In a galvanometer there is a deflection of 10 divisions per mA. The internal resistance of the galvanometer is 60 Ω. If a shunt of 2.5Ω is connected to the galvanometer and there are 50 divisions in all, on the scale of galvanometer, what maximum current can this galvanometer read?

Q.5 A galvanometer having a resistance of 50Ω gives a full deflection for a current of 0.05 A. Calculate the length of the shunt wire of 2 mm diameter required to convert the galvanometer to an ammeter reading current upto 5A. Specific resistance for the material of wire is 5×10^{-7}Ω m.

Q.6 A copper conductor of length 10 cm and radius 1.5 mm is connected in parallel to an ammeter having a resistance of 0.03Ω. Find the current in the circuit if the ammeter indicates 0.4A. The resistivity of copper is 1.78×10^{-8} Ω.

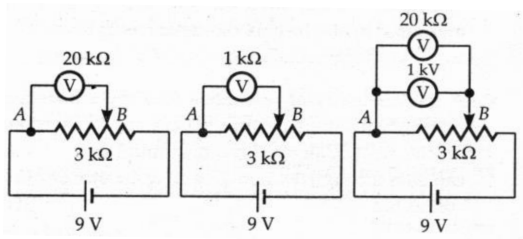
Q.7 When a galvanometer having 30 divisions scale and 100Ω resistance is connected in series to a battery of emf 3 V through a resistance of 200 Ω, shows full scale deflection. Find the figure of merit of the galvanometer in μA.

Q.8 The deflection produced in a galvanometer is reduced in a galvanometer is reduce to 45 divisions from 55 when a shunt of 8Ω is used. Calculate the resistance of the galvanometer.

Q.9 A voltmeter reads 5.0V at full scale deflection and is graded according to its resistance per volt at full deflection as 5000 Ω V^{-1}. How will you convert it into a voltmeter that reads 20 V at full scale deflection? Will it still be graded as 5000ΩV^{-1}? Will you prefer this voltmeter to one that is graded as 2000Ω V^{-1}?

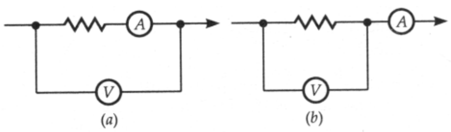
Q.10 A d.c. supply of 120 V is connected to a large resistance X. A voltmeter of resistance 10k Ω placed in series in the circuit reads 4V. What is the value of X? What do you think is the purpose in using a voltmeter, instead of an ammeter, to determine the large resistance X?

Q.11 (a) A battery of emf 9V and negligible internal resistance is connected to a 3 kΩ resistor. The potential drop across a part of the resistor (between points A and B in figure) is measured by (i) a 20 kΩ voltmeter; (ii) a 1 kΩ voltmeter. In (iii) both the voltmeter are connected across AB. In which case would you get the (1) highest, (2) lowest reading?



(b) Do your answers to this problem alter if the potential drop across the entire is measured? What if the battery has non–negligible resistance?

Q.12 You are given two resistors X and Y whose resistances are to be determined using an ammeter of resistance 0.5Ω and a voltmeter of resistance 20kΩ. It is known that X is in the range of a few ohms, while Y is the range of several thousand ohms. In each case, which of the two connections shown in figure would you choose for resistance measurement? Justify your answer quantitatively.



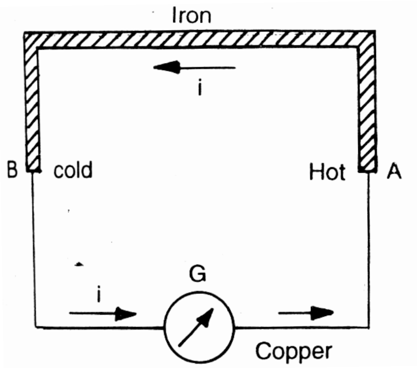
Q.13 A galvanometer has a resistance of 96Ω and it is desired to pass 4% of the total current through it. Calculate the value of shunt resistance.

Answers

1.	4.0×10^{-3} Ω, 4.0×10^{-3} Ω, 3988 Ω, 4000 Ω			2.	5/499Ω, 9995 Ω
3.	0.2 Ω, 0.16Ω	4.	125 mA	5.	3.17 m
6.	50.4A	7.	333.3 μA div^{-1}	8.	36Ω

9.	75000 Ω, same change	10.	290 kΩ	11.	(a) (i),(ii),(b)	No
12.	(a) y, (b) x	13.	4Ω			

Thermoelectric effects of current (Thermoelectricity)



Seebeck effect : Seebeck effect is the phenomenon of production of an electric current or e.m.f. in a thermocouple when the two junctions are kept at two different temperature. Suppose two wires of different materials (let copper and iron) are connected together at the two ends as shown in fig. A sensitive galvanometer is also connected in the circuit. When two junctions *A* and *B* are maintained at different temperatures, galvanometer show some deflection, and a current begins to flow from copper to iron at hot junction. Hence an e.m.f. appear which is known as thermoelectric e.m.f. and the current produced due to this e.m.f. is known as thermoelectric current. Such arrangement as shown in figure is called thermoelectric couple or thermocouple.

When hot and cold junctions are interchanged, the e.m.f. changes sign, or the circulating current reverses direction. Obviously the effect is reversible.

The thermo–electric e.m.f. (*E*) of a number of thermocouples is given by a simple form –

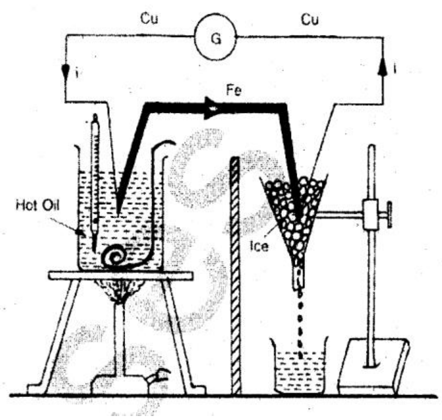
$$E = V_{AB} = \alpha T + \frac{1}{2}\beta T^2 \quad \text{(Equation of parabola)}$$

where T is the temperature difference between junctions and α , β called thermoelectric coefficients whose values depend on the metals chosen for thermocouple.

The pair of metals forming the thermocouple : Seebeck arranged a number of metals in the form of a series which is called thermoelectric series or seebeck series.

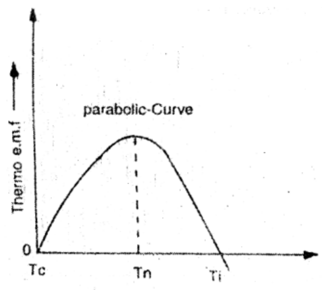
Bi, Ni, Co, Pd, Pt, U, Cu, Mn, Ti, Hg, Pb, Sn, Cr, Mo, Rh, Ir, Au, Ag, Zn, W, Cd, Fe, As, Sb

For large separation between the two metals, greater value of thermo e.m.f. is obtained.



Temperature difference between the two junction : Plot a graph between the hot junction temperature and their corresponding thermo e.m.f. keeping the cold junction temperature constant i.e., 0°C. When the graph is drawn initially e.m.f. increases with the increase of temperature of hot junction and becomes maximum for a particular temperature T_n and then start decreasing. The temperature of hot junction at which the thermo e.m.f. produced in the thermocouple becomes maximum is called neutral temperature (T_n). On increasing more temperature of the hot junction a stage comes when thermo e.m.f. becomes zero and then changes direction (becomes reverse). The temperature of the hot junction for which thermo e.m.f. reduced to zero is called the temperature of inversion T_i. It depends on the temperature of cold junction. If the temperature of cold junction is T_C then

$$T_i - T_n = T_n - T_c \quad \Rightarrow \quad T_n = \frac{T_i + T_c}{2}$$



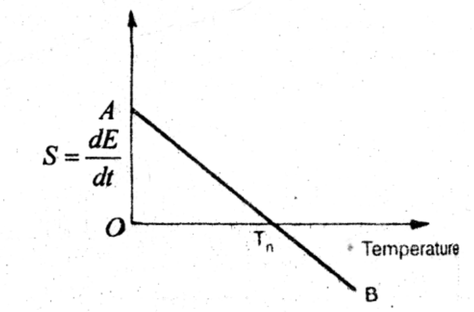
Hence the neutral temperature is the arithmetic mean of the inversion temperature and the temperature of cold junction. **Seebeck coefficient of thermo-electric Power (*S*)**

The rate of change of thermoelectric e.m.f. with temperature (i.e., $\frac{dE}{dT}$) is called the thermopower or the seebeck co-efficient (*S*)

$$s = \frac{dE}{dT}$$

Also , $\quad E = \alpha T + \frac{1}{2}\beta T^2$

$$\therefore \quad S = \frac{dE}{dT} = \frac{d}{dT}\left(\alpha T + \frac{1}{2}\beta T^2\right) \quad \Rightarrow \quad S = \alpha + \beta T$$



Thermoelectric power is independent of cold junction temperature. The graph between thermoelectric power and temperature is a straight line, known as thermoelectric line. Neutral temperature (T_n) and Temperature of inversion (T_i) in terms of α and β.

$$\frac{dE}{dT} = \alpha + \beta T \quad \text{at} \quad T = T_n \; ; \; \frac{dE}{dT} = 0$$

$$\therefore \quad 0 = \alpha + \beta T_n \quad \Rightarrow \quad T_n = -\frac{\alpha}{\beta}$$

Again from curve of fig. At $T = T_i$; $E = 0$

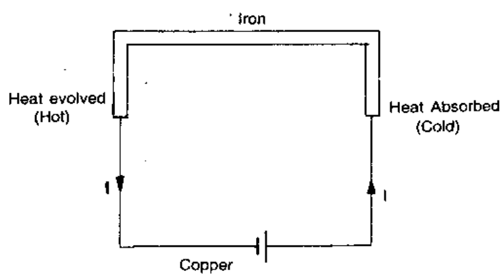
$$E = \alpha T + \frac{1}{2}\beta T^2 \quad \Rightarrow \quad 0 = \alpha T_i + \frac{1}{2}\beta T_i^2$$

$$\Rightarrow \quad T_i = -2\frac{\alpha}{\beta} \quad \Rightarrow \quad T_i = 2\left(-\frac{\alpha}{\beta}\right) = 2T_c \quad \Rightarrow \quad T_i = 2T_c$$

Peltier Effect

When an electric current is passed through two dissimilar metals connected as a point (thermocouple), heat is evolved at one junction and absorbed at the other junction; this effect is called peltier effect. It is also reversible.

Peltier coefficient (π)



The heat absorbed when a charge q coulomb passes from metal A to metal B is $q\pi$ joules. The amount of heat absorbed or evolved at junction of a thermocouple when one coulomb of charge passed through junction is called Peltier co–efficient (π).

Let q coulomb charge passes through a junction having peltier e.m.f. E volt, then

Energy absorbed or evolved = πq joule

also; work done = qE joule

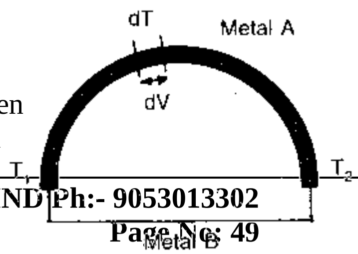
$$\therefore \quad \pi q = qE \quad \Rightarrow \quad \pi = E$$

Unit of peltier co–efficient is joule/coulomb.

Thomson Effect

The absorption or evolution of heat along the length of a wire when a current is passed through a wire, whose one end is hot and other is kept cold, is known as Thomson effect. It is also reversible phenomenon.

Thomson coefficient (σ)



The amount of heat energy absorbed or evolved when a unit charge is passed between two points of a conductor having a unit temperature difference is known as Thomson coefficient (σ) for the material of the conductor. Specifically if two points in a metal *A* having a small temperature difference *dT*, the electric potential difference (*dV*) is proportional to *dT*.

$$dV \propto dT \quad \Rightarrow \quad dV = \sigma\, dT \quad \Rightarrow \quad V = \sigma \int_{T_1}^{T_2} dT$$

$$\Rightarrow \quad \sigma = \frac{dV}{dT}$$

This co-efficient of proportionality is known as "Thomson coefficient". Let *I* ampere current flows through the conductor for *t* seconds in between the two points of the conductor having temperature difference 1*K*. The heat energy evolved or absorbed between the two points of the conductor is $H = \sigma I t$

Relation between Seebeck, Peltier and Thomson co–efficient

he Peltier coefficient π *S* by the equation.

$$\pi = TS = \frac{TdE}{dT}$$

The Thomson coefficient σ is related to *S* by the equation $\sigma = -T\frac{dS}{dT} = -T\frac{d^2E}{dT^2}$

Applications of Thermoelectric Effects :

(i) **Thermoelectric refrigerator :** Thermoelectric refrigerator works on the principle of Peltier effect.

(ii) **Thermoelectric generator :** Seebeck effect can be used to generate electric power in remote areas.

(iii) **Thermoelectric Thermometers :** Thermometer used to measure low temperature are called Thermoelectric theoremometer. It is based on Seebeck effect.

(iv) **Thermopile :** Thermopile is used to measure the very–high temperature (e.g. temperature of an electric arc furnace) with the help of heat radiation falling on its hot junction. It is based on Seebeck effect.

Solved Examples

Ex.1 The neutral temperature for a copper-iron thermocouple is 275^0C. Find the temperature of inversion when the cold junction is kept at 10^0C.

Sol. Temperature of cold junction = $T_c = 10^0 C$

Neutral temperature = $T_n = 275^0 C$

Temperature of inversion = T_i

$$T_n = \frac{T_i + T_c}{2} \Rightarrow T_i = 2T_n - T_c = (2\times 275 - 10)^0 C \quad \Rightarrow \quad T_i = 540^0 C$$

Ex.2 The e.m.f. of a *Cu–Fe* thermocouple varies with the temperature θ of the hot junction (cold junction at 0^0C) as $E(\mu V) = 14\theta - 0.02\theta^2$ Determine the neutral temperature.

Sol. $E = 14\theta - 0.02\theta^2$

$$\frac{dE}{d\theta} = 14 - 2\times .02\times\theta$$

For maximum e.m.f. of thermocouple $\frac{dE}{d\theta} = 0$ and $\theta = \theta_n$

$$\therefore \quad 14 - 2\times 0.02\times\theta_n = 0 \quad \Rightarrow \quad \theta_n = 350^0 C.$$

Ex.3 The thermoelectric e.m.f. E of a copper constantan thermocouple and the temperature θ of the hot junction (with cold junction at 0^oC) are found to satisfy approximately the following relation: $E = a\theta + \frac{1}{2}b\theta^2$ where E is in μV, θ in ^0C and $a = 41\mu V^0c^{-1}$, $b = 0.041\mu V^0c^{-2}$. What is the temperature of the hot junction when the thermoelectric e.m.f. is measured to be 5.5mV.?

Sol. Substituting the given values in the equation

$E = a\theta + \frac{1}{2}b\theta^2$; we get

$5500\times10^{-6} = 41\times10^{-6}\,\theta + 0.5\times0.041\times10^{-6}\,\theta^2 \quad\Rightarrow\quad 0.0205\theta^2 + 41\theta - 5500 = 0$

Solving, we get, $\theta = 126.18^0C$ or $\theta = -2126.2^0C$

Neglecting –ve value ; $\theta \approx 126^0C$.

Ex.4 A sensitive microphone can not withstand currents greater than 0.05A. When connected across a thermocouple of e.m.f. 8.5 mV, the current in a very low resistance ammeter placed in series in the circuit reads 34 mA. Calculate the resistance of the microphone.

Sol. Let R be the resistance of the microphone and r is the resistance of the ammeter, then

Current flowing = $I = \dfrac{\text{Net e.m.f.}}{\text{Net Resistance}}$

$\Rightarrow \quad I = \dfrac{E}{R+r} \quad\Rightarrow\quad 34\times10^{-3}A = \dfrac{8.5\times10^{-3}V}{(R+r)\Omega}$

For $R >> r$ $\quad 34 = \dfrac{8.5}{R} \quad\Rightarrow\quad R = 0.25\Omega$

Board Oriented Questions

Q.1 Is a wire carrying current charged?

Q.2 A steady current is flowing in a cylindrical conductor. Is there any electric field within the conductor?

Q.3 For the flow of electricity through gases, they should be better exposed to some high energy radiations like X–rays. Why?

Q.4 What is the cause of resistance of a conductor?

Q.5 A large number of free electrons are present in metals. Why is there no current in the absence of electric field across it?

Q.6 Two wires of equal lengths, one of copper and the other of manganin have the same resistance. Which wire will be thicker.

Q.7 Two wires of equal cross–sectional area, one of copper and other of manganin have the same resistance. Which one will be longer?

Q.8 Two wires A and B of the same metal and of the same length have their areas of cross–section in the ratio of 2 : 1. If the same potential difference is applied across each wire in turn, what will be the ratio of the currents flowing in A and B?

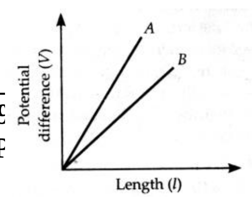
Q.9 When we switch on an electric bulb, it lights up almost instantaneously though velocity of electrons in copper wires is very small. Given reason.

Q.10 A car battery has an emf of 12 V. Eight ordinary cells connected in series can also supply 12 V. But we do not use such an arrangement of cells in the car. Why?

Q.11 Why should the potentiometer wire be of uniform cross–section and composition?

Q.12 Of which material is a potentiometer wire normally made and why?

Q.13 What type of cell should be used in the main circuit of the potentiometer and why?



Q.14 The variation of potential difference with length in case of two potentiometers A and B is shown in figure. Which of the two is preferred to find emf of a cell? Give reason for your answer.

Q.15 What is the end error in a metre bridge?

Q.16 Two wires A and B of same material and having same length, have their cross–sectional areas in ratio 1:4. What would be ratio of heat produced in these wires when same voltage is applied across each?

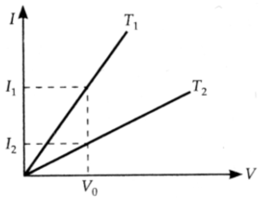
Q.17 Heat is generated continuously in an electric heater but its temperature becomes constant after some time. Why?

Q.18 A current is passed through a steel wire heating it to red hot. The half of the wire is immersed in cold water. Which half of the wire will heat up more and why?

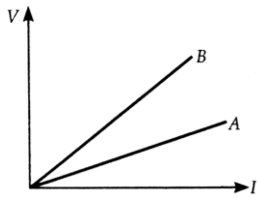
Q.19 Why an electric bulb becomes dim when an electric heater in parallel circuit is switched on? Why dimness decreases after some time?

Q.20 Nichrome and copper wires, having same length and same area of cross–section, are connected across a battery in turn. In which case the rate of production of heat will be higher?

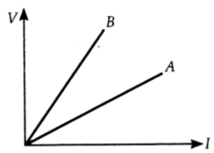
Q.21 The current voltage graphs for a given metallic wire at difference temperatures T_1 and T_2 are shown in figure. Which of the temperatures T_1 and T_2 is greater?



Q.22 V–I graphs for parallel and series combination of two metallic resistors are as shown in figure. Which graph represents parallel combination? Justify your answer.



Q.23 The voltage–current graphs for two resistors of the same material and the same radii with lengths L_1 and L_2 are shown in figure. If $L_1 > L_2$, state with reason, which of these graphs represents voltage–current change for L_1.

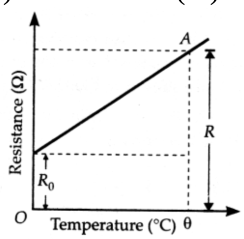


Q.24 A potential difference V is applied to a conductor of length l, diameter D. How are the electric field E, the drift velocity v_d and the resistance R affected when (i) V doubled (ii) l is doubled (iii) D is doubled?

Q.25 The variation of the resistance of a metallic conductor with temperature is shown in figure.

(i) Calculate the temperature coefficient of resistance from the graph.

(ii) State why the resistance of the conductor increases with the rise in temperature.



Q.26 What happens to drift velocity (v_d) of electrons and the resistance R if the length of a conductor is doubled (keeping potential difference unchanged)?

Q.27 A potential difference V is applied to a conductor of length L, diameter D. How are the electric field E, the drift velocity v_d and the resistance R affected when (i) V is doubled (ii) L is doubled (iii) d is doubled?

Q.28 Explain why bending a wire does not affect its electrical resistance?

Q.29 A non–conducting ring of radius r has charge q distributed unevenly over it. What will be the equivalent current if it rotates with an angular velocity ω?

Q.30 A cell of emf E and internal resistance r is connected across a variable resistor R. Plot a graph showing the variation of terminal potential V with resistance R. Predict from the graph the condition under which V becomes equal to E.

Q.31 A battery has an emf E and internal resistance r. A variable resistance R is connected across the terminals of the battery. Find the value of R such that (a) the current in the circuit is maximum (b) the potential difference across the terminals is maximum.

Q.32 Two cells each of emf E and internal resistances r_1 and r_2 are connected in series to an external resistance R. Can a value of R be selected such that the potential difference at the first cell be zero?

Q.33 When we switch on the lights one after the other, what is the effect on the resistance of the electric circuit of the house? On the current flowing in the main circuit?

Q.34 What do you mean by a linear resistor?

Q.35 What is the effect of rise in temperature on the electrical resistivity of semiconductor?

Q.36 If the radius of the copper wire is doubled, what will be the effect on its specific resistance?

Q.37 A 4Ω non insulated resistance wire is bent in the middle by 180^o and both the halves are twisted with each other. What will be its new resistance?

Q.38 If the electric current is passed through a nerve, the man is excited, why?

Q.39 Is it possible that there is no potential difference between the plates of a cell? If yes, under what condition?

Q.40 What will be the bands of colours in sequence on carbon resistor, if its resistance is 0.1Ω ± 5%.

Q.41 What is the most probable cause of super–conductivity?

Q.42 Two different wires X and Y of same diameter but different materials are joined in series across a battery. If the number density of electrons in X is twice that in Y, find the ratio of drift velocity of electrons in the two wires.

Q.43 What are thermistors? Explain their use in brief.

Q.44 Why is it unsafe to turn a light switch on or off while taking bath?

Q.45 While making a standard resistance, the coil is made of manganin. The coil is double folded and is wound over non–conducting frame. Why?

Q.46 To reduce the brightness of a light bulb, should an auxiliary resistance be connected in series with it or in parallel?

Q.47 If the current flowing in a copper wire be allowed to flow in another copper wire of same length but of double the radius, then what will be the effect on the drift velocity of the electrons. If the same current be allowed to flow in an iron wire of the same thickness, then?

Q.48 Draw V – I graph for ohmic and non–ohmic materials. Give one example for each.

Q.49 Define the term temperature coefficient of resistivity. Show graphically the variation of resistivity with temperature for nichrome.

Q.50 Define the term temperature coefficient of resistivity. Write its SI unit. Plot a graph showing the variation of resistivity of copper with temperature.

Q.51 Explain how electron mobility changes for a good conductor, when (i) the temperature of the conductor is decreased at constant potential difference and (ii) applied potential difference is doubled at constant temperature.

Q.52 Describe the phenomenon of current flow in a conductor and derive the relation between current and drift velocity.

Q.53 What do you understand by resistance of a conductor? Define its SI unit. Show that resistance of a conductor is given by $R = \frac{ml}{ne^2 \tau A}$, where the symbols have their usual meanings.

Q.54 Define specific resistance and express it in terms of mass, charge, number density and relaxation time.

Q.55 What is drift velocity of electrons and relaxation time of free electrons in a metallic conductor carrying a current? Establish a relation between them.

Q.56 Are Kirchhoff's laws applicable to both a.c. and d.c.?

Q.57 Can metre bridge be used for finding the resistance of (i) moderate values (ii) high values (iii) low values? Explain.

Q.58 Why do we prefer a potentiometer to measure emf of a cell rather than a voltmeter?

Q.59 The emf of the driver cell in the potentiometer experiment should be greater than the emf of the cell to be determined. Why?

Q.60 Why should the current not be passed through a potentiometer wire for long time?

Q.61 Why the jockey should not be rubbed against the potentiometer wire?

Q.62 Why do we prefer potentiometer of longer length for accurate measurements?

Q.63 Using metre bridge, it is advised to obtain the null point in the middle of the wire. Why?

Q.64 What do you understand by sensitiveness of a potentiometer and how can you increase the sensitiveness of a potentiometer?

Q.65 What is the principle of working of metre–bridge?

Q.66 When is a Wheatstone bridge said to be balanced?

Q.67 Some times balance point may not be obtained on the potentiometer wire. Why?

Q.68 What are two practical forms of Wheatstone bridge?

Q.69 Whether electric field inside potentiometer wire is constant or variable?

Q.70 If the emf of the driving cell be decreased, what will be effect on the position of zero deflection in a potentiometer? Explain.

Q.71 If the length of the wire be (i) doubled and (ii) halved, what will be effect on the position of zero deflection in a potentiometer? Explain.

Q.72 Give the circuit diagram of potential divider.

Q.73 State the principle of potentiometer. Draw a circuit diagram used to compare the *emfs* of two primary cells. Write the formula used. How can the sensitivity of a potentiometer be increased.

Q.74 State the principle of potentiometer. With the help of circuit diagram describe a method to find the internal resistance of a primary cell.

Q.75 State and explain Kirchhoff's laws.

NCERT Questions

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

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

Q.3 (i) Three resistors of 1Ω, 2Ω and 3Ω are combined in series. What is the total resistance of the combination?

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

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

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

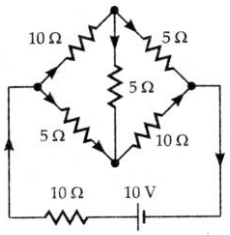
Q.5 At room temperature (27°C), the resistance of a heating element is 100Ω. What is the temperature of the element if the resistance is found to be 117Ω, given that temperature coefficient of the resistor material is $1.70 \times 10^{-4}\,°C^{-1}$.

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 at the temperature of the experiment?

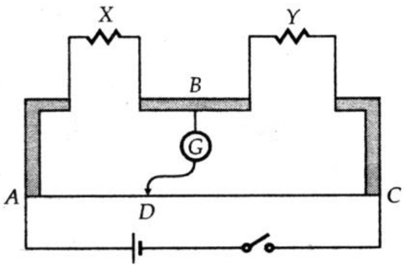
Q.7 A silver wire has a resistance of 2.1Ω at 27.5°C, and a resistance of 2.7 Ω at 100°C. Determine the temperature coefficient of resistivity of silver.

Q.8 A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A 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°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 (i) In a metre bridge (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 connections between resistors in a Wheatstone or metre bridge made of thick copper strips?



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

(iii) What happens if the galvanometer and cell are interchanged at the balance point of the bridge? Would the galvanometer show any current?

Q.11 A storage battery of emf 8.0 V and internal resistance 0.5Ω is being charged by a 120 V dc supply using a series resistor of 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.12 In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell?

Q.13 The number density of free electrons in a copper conductor is 8.5×10^{28} m^{-3}. How long does an electron take to drift from one end of a wire 3.0m long to its to 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 A.

Q.14 The earth's surfaced has a negative surface charge density of 10^{-9} Cm^{-2}. The potential difference of 400 kV between the top of the atmosphere and the surface results (due to the law conductivity of the lower atmosphere) in a current of only 1800 A over the entire globe. If there were no mechanism of sustaining atmospheric electric field, how much time (roughly) would be required to neutralize the earth's surface? (Radius of the earth = 6.37×10^6 m)

Q.15 (a) Six lead–acid type of secondary cells each of emf 2.0 V and internal resistance 0.015 Ω are joined in series to provide a supply to a resistance of 8.5Ω. What are the current drawn from the supply and its terminal voltage?

(b) A secondary cell after long use has an emf 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.16 Two wires of equal length, one of aluminium and the other of copper have the same resistance. Which of two wires is lighter? Hence explain why aluminium wires are preferred for overhead power cables.

Q.17 What conclusion can you draw from the following observations on a resistor made of alloy manganin:

Current I(A)	Voltage (V)	Current I (A)	Voltage V
0.2	3.94	3.0	59.2
0.4	7.87	4.0	78.8
0.6	11.8	5.0	98.6
0.8	15.7	6.0	118.5
1.0	19.7	7.0	138.5
2.0	39.4	8.0	158.0

Q.18 Answer the following questions:

(a) A steady current flows in a metallic conductor of non–uniform cross–section. Say which of these quantities is constant along the conductor: current, current density, electric field, drift speed.

(b) In Ohm's law universally applicable for all conducting elements? If not, give examples of elements which do not obey Ohm's law.

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

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

Q.19 Choose the correct alternative:

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

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

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

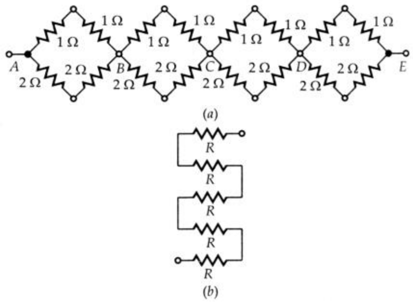
(d) The resistivity of a typical insulator (e.g., amber) is greater than that of a metal by a factor of the order of ($10^{22}/10^{3}$)

Q.20 (a) Given n resistors each of resistance R, how will you combine them to get the (i) maximum, (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?

(b) Given the resistance of 1Ω, 2Ω, 3Ω, how will you combine them to get an equivalent resistance of;

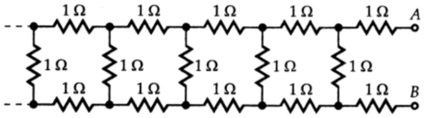
(i) $\frac{11}{3}\Omega$ (b) $\frac{11}{5}\Omega$ (iii) 6Ω (iv) $\frac{6}{11}\Omega$

(c) Determine the equivalent resistance of the following networks:

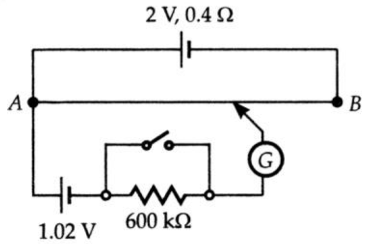


(a)
(b)

Q.21 Determine the current drawn from a 12V supply with internal resistance 0.5Ω by the following infinite network. Each resistor has 1Ω resistance.



Q.22 Figure shows a potentiometer with a cell of 2.0 V and internal resistance 0.40Ω maintaining a potential drop across the resistor wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents upto a few A) gives a balance point at 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600 k Ω 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 ξ and the balance point found similarly turns out to be at 82.3 cm length of the wire.



(a) What is the value of ξ?

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

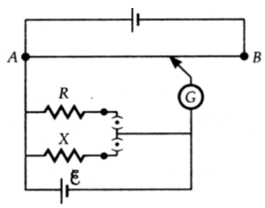
(c) Is the balance point affected by this high resistance?

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

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

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

Q.23 Figure shows a potentiometer circuit for comparison of two resistances. The balance point with a standard resistor R = 10.0Ω is found to be 58.3 cm, while that with the unknown resistance X is 68.5 cm. Determine the value of X. What might you do if you failed to find a balance point with the given cell ξ?



Q.24 Figure shows a 2.0V potentiometer used for the determination of internal resistance of a 1.5V cell. The balance point of the cell in open circuit is 76.3 cm. When a resistor of 9.5Ω 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.

Answers

1.	30 A	2.	8.5 V	3.	(i) 6 Ω, (ii) 2V, 4V, 6V
4.	(i) $\frac{20}{19}\Omega$, (ii) 10A,5A, 4A, 19A	5.	$1027^{\circ}C$	6.	$2.0 \times 10^{-7}\ \Omega$ m
7.	$0.00394^{\circ}C^{-1}$	8.	$867.35^{\circ}C$		

9. $I_{AB}=\frac{4}{17}A, I_{BC}=\frac{6}{17}A, I_{DC}=\frac{4}{17}A, I_{AD}=\frac{6}{17}A, I_{BD}=\frac{-2}{17}A, I=\frac{10}{17}A$

10. (i) 8.16Ω, (ii) 60.5 cm, (iii) galvanometer will not show any current

11. 11.5 V | 12. 2.25 V | 13. 7.57 h

14. 283 s | 15. (a) 1.4 A, 11.9 V, (b) 0.005 A, No

16. Al

18. (a) Only current is const ant, (b) No, (c) I_{max} will be large if r is small
(d) If the internal resistance is not very large, then the current will exceed the safety limits in case the circuit is short–circuited accidentally.

19. (a) greater, (b) lower (c) is nearly independent of (d) 10^{22}

20. (a) (i) nR, (ii) R/n, (iii) n^2 : 1, (b) (i) 1 Ω // 2Ω in series with 3Ω, (ii) 2Ω // 3Ω in series with 1 Ω, (iii) 1 Ω, 2 Ω and 3 Ω are in series, (iv) 1 Ω // 2Ω // 3 Ω, (c) (i) 16/ 3Ω, (ii) 5R

22. (a) 1.25 V, (b) High resistance of 600kΩ protects the galvanometer for positions far away from the balance point, by decreasing current through it. (c) No, (d) No, (e) No, (f) the circuit is modified by putting a suitable resistor R in series with the wire AB.

23. 11.75Ω | 24. 1.7 Ω

Objective Assignment – [AIIMS]

Q.1 Dimension of electrical resistance is
(a) $[ML^2T^{-3}A^{-1}]$ (b) $[ML^2T^{-3}A^{-2}]$ (c) $[ML^3T^{-3}A^{-2}]$ (d) $[ML^2T^{-3}A^{-1}]$

Q.2 Dimension of resistivity is
(a) $ML^2T^{-2}I^{-1}$ (b) $ML^3T^{-3}I^{-2}$ (c) $ML^3T^{-2}I^{-1}$ (d) $ML^3T^{-2}I^{-2}$

Q.3 Which of the following relations is called as current density?
(a) I/A (b) A/I (c) I^2/A (d) I^3/A^2

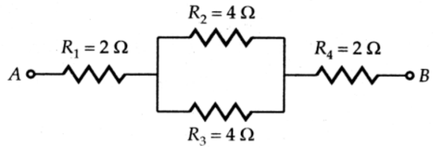
Q.4 Given a current carrying wire of non–uniform cross section, which of the following is constant throughout the length of the wire?
(a) current, electric field and drift speed (b) drift speed only
(c) current and drift speed (d) current only

Q.5 A wire of radius r has resistance R. If it is stretched to the wire of r/2 radius, then the resistance becomes
(a) 2R (b) 4 R (c) 16 R (d) zero

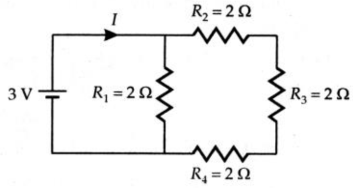
Q.6 A wire of length L is drawn such that its diameter is reduced to half of its original diameter. If the initial resistance of the wire were 10Ω, its new resistance would be
(a) 40 Ω (b) 80 Ω (c) 120Ω (d) 160 Ω

Q.7 Ten identical wires each having a resistance of 1Ω are connected in parallel. The combination will have a resistance of
(a) 10 Ω (b) 1 Ω (c) 0.1 Ω (d) 0.01 Ω

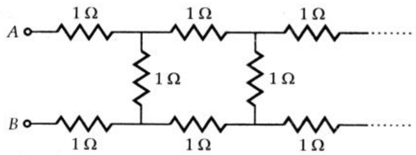
Q.8 In the given figure the equivalent resistance between the points A and B is
(a) 8 Ω
(b) 6 Ω
(c) 4 Ω
(d) 2 Ω



Q.9 What is the current I in the circuit as below?
(a) 1 A
(b) 0.5 A
(c) 1.2 A (d) 2 A



Q.10 The resistance between the terminal points A and B of the given infinitely long circuit will be



(a) $\sqrt{3}-1$

(b) $1-\sqrt{3}$

(c) $1+\sqrt{3}$ (d) $2+\sqrt{3}$

Q.11 The voltage of clouds is 4×10^6V with respect to the ground. In a lightning strike lasting 100ms, a charge of 4C is delivered to the ground. The power of the lightning strike is

(a) 160 MW (b) 80 MW (c) 20 MW (d) 500 MW

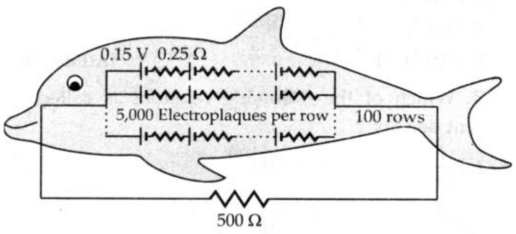
Q.12 A 60 W incandescent lamp operates at 120 V. The number of electrons passing through the filament per second will be

(a) 1.61×10^{12} (b) 3.12×10^{18} (c) 7.21×10^{12} (d) 12.40×10^{13}

Q.13 The internal resistance of a cell of emf 2V is 0.1Ω. It is connected to a resistance of 3.9Ω. The voltage across the cell will be

(a) 0.5 V (b) 1.9 V (c) 1.95 V (d) 2 V

Q.14 Eels are able to generate current with biological cells called electro-plaques. The electro-plaques in an eel are arranged in 100 rows, each row stretching horizontally along the body of the fish containing 5000 electro-plaques. The arrangement is suggestively shown below. Each electro-plaque has an emf of 0.15V and internal resistance of 0.25Ω. The water surrounding the eel completes a circuit between the head and its tail. If the water surrounding it has a resistance of 500Ω, the current an eel can produce in water is about



(a) 1.5 A (b) 3.0 A (c) 15 A (d) 30 A

Q.15 The instrument for the accurate measurement of the emf of a cell is

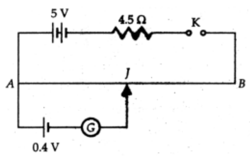
(a) a slide wire bridge (b) an ammeter (c) a potentiometer (d) a voltmeter

Q.16 When a balance point is obtained in a potentiometer for finding the internal resistance of a cell, the current through the potentiometer wire is due to

(a) the cell, whose internal resistance is to be found (b) the auxiliary battery

(c) both cell and the auxiliary battery (d) neither the cell nor the battery

Q.17 In figure, the potentiometer wire AB has a resistance of 5Ω and length 10m. The balancing length AJ for the emf of 0.4 V is



(a) 4 m (b) 1.5 m (c) 0.8 m (d) 0.4 m

Answers

1	b	2	b	3	a	4	d	5	c
6	d	7	c	8	b	9	d	10	c
11	a	12	b	13	c	14	a	15	c
16	b	17	b						

Objective Assignment – [AIEEE]

Q.1 The length of a given cylindrical wire is increased by 100%. Due to the consequent decrease in diameter, the change in the resistance of the wire will be

(a) 200% (b) 100% (c) 50% (d) 300%

Q.2 An electric current is passed through a circuit containing two wires of the same material, connected in parallel. If the lengths and radii of the wires are in the ratio of 4/3 and 2/3, then the ratio of the currents passing through the wire will be

(a) 3 (b) 1/3 (c) 8/9 (d) 2

Q.3 The resistance of the series combination of two resistance is S. When they are joined in parallel, the total resistance is P. If S = nP, then the minimum possible value of n is

(a) 4 (b) 3 (c) 8/9 (d) 2

Q.4 The difference in the variation of resistance with temperature in a metal and a semiconductor arises essentially due to the difference in the

(a) crystal structure (b) type of bonding

(c) variation of scattering mechanism with temperature

(d) variation of the number of charge carriers with temperature

Q.5 A piece of copper and another of germanium are cooled from room temperature to 77 K. Resistance of

(a) copper decreases and germanium increases (b) copper increases and germanium decreases

(c) each of them increases (d) each of them decreases

Q.6 The thermistors are usually made of

(a) metals with low temperature coefficient of resistivity

(b) metals with high temperature coefficient of resistivity

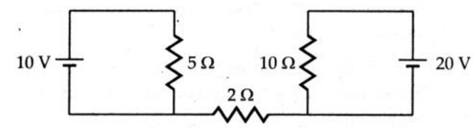
(c) metals oxides with high temperature coefficient of resistivity

(d) semi conducting materials having low temperature coefficient of resistivity

Q.7 The resistance of a wire is 5Ω at 50°C and 6Ω at 100°C.The resistance of the wire at 0°C will be

(a) 3 Ω (b) 2 Ω (c) 1 Ω (d) 4 Ω

Q.8 What will be the value of current through 2Ω resistance for the circuit shown in the figure.



(a) 5 A (b) 2 A (c) zero (d) 4 A

Q.9 An energy source will supply a constant current into the load, if its internal resistance is

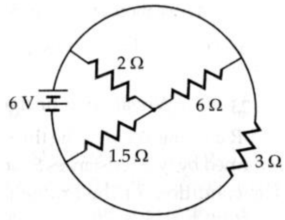
(a) zero (b) non–zero but less than the resistance of the load

(c) equal to the resistance of the load (d) very large as compared to the load resistance

Q.10 Two sources of equal emf are connected to an external resistance R. The internal resistances of the two sources are R_1 and R_2($R_2 > R_1$). If the potential difference across the source having internal resistance R_2 is zero, then

(a) $R = R_2 \times \frac{(R_1 + R_2)}{(R_2 - R_1)}$ (b) $R = \frac{R_1 R_2}{(R_1 + R_2)}$ (c) $R = \frac{R_1 R_2}{(R_2 - R_1)}$ (d) $R = R_2 - R_1$

Q.11 The total current supplied to the circuit by the battery wire is



(a) 1A (b) 2 A (c) 4 A (d) 6 A

Q.12 A material B has twice the specific resistance of the material A. A circular wire made of B has twice the diameter of the wire made of A. Then, for the two wires to have the same resistance, the ratio l_A/l_B of their respective lengths must be
(a) 1/4 (b) 2 (c) 1 (d) 1/2

Q.13 By increasing the temperature, the specific resistance of a conductor and a semiconductor
(a) increases for both (b) decreases for both
(c) increases, decreases respectively (d) decreases, increases respectively

Q.14 The resistance of bulb filament is 100Ω at a temperature of 100°C. If its temperature coefficient of resistance be 0.005°C^{-1}, its resistance will become 200Ω at a temperature of
(a) 500°C (b) 200°C (c) 300°C (d) 400°C

Q.15 The resistance of hot tungsten filament is about 10 times the cold resistance. What will be the resistance of 100W – 200V lamp, when not in use?
(a) 40 Ω (b) 20 Ω (c) 400Ω (d) 2 Ω

Q.16 An electric bulb is rated 220V – 100W. The power consumed by it, when operated on 110 V, will be
(a) 25 W (b) 50 W (c) 75 W (d) 40 W

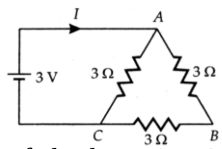
Q.17 A 220 volt– 1000 watt bulb is connected across a 110 V mains supply. The power consumed will be
(a) 750 watt (b) 500 watt (c) 250 watt (d) 1000 watt

Q.18 A heater coil is cut into two equal parts and only one part is now used in the heater. The heat generated will now be
(a) doubled (b) four times (c) one fourth (d) halved

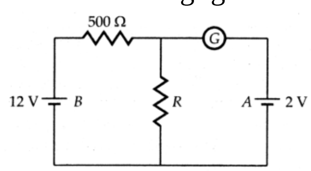
Q.19 A wire, when connected to 220V main supply, has power dissipation P_1. Now the wire is cut into two equal pieces which are connected in parallel to the same supply. Power dissipation in this case is P_2. Then P_2:P_1 is
(a) 1 (b) 4 (c) 2 (d) 3

Q.20 If in the circuit, power dissipation is 150W, then R is
(a) 2Ω (b) 6Ω (c) 5Ω (d) 4Ω

Q.21 A 3V battery with negligible internal resistance is connected in a circuit as shown in the figure. The current I in the circuit will be
(a) 1 A
(b) 1.5 A
(c) 2 A (d) 1/3 A



Q.22 In the circuit, the galvanometer G shows zero deflection. If the batteries A and B have negligible internal resistance, the value of the resistor R will be
(a) 200 Ω
(b) 100 Ω
(c) 500 Ω (d) 1000Ω



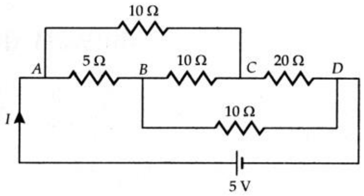
Q.23 The Kirchhoff's first law (∑I = 0) and law (∑IR = ∑ξ), are respectively based on
(a) conservation of momentum, conservation of charge
(b) conservation of charge, conservation of energy
(c) conservation of charge, conservation of momentum

(d) conservation of energy, conservation of charge

Q.24 In a Wheatstone bridge, three resistances P, Q and R are connected in the three arms and the fourth arm is formed by two resistances S_1 and S_2 connected in parallel. The condition for bridge to be balanced will be

(a) $\frac{P}{Q}=\frac{R(S_1+S_2)}{2S_1S_2}$ (b) $\frac{P}{Q}=\frac{R}{S_1+S_2}$ (c) $\frac{P}{Q}=\frac{2R}{S_1+S_2}$ (d) $\frac{P}{Q}=\frac{R(S_1+S_2)}{S_1S_2}$

Q.25 The current I drawn from the 5V source will be



(a) 0.67 A
(b) 0.17 A
(c) 0.33 A
(d) 0.5 A

Q.26 In a metre bridge experiment, null point is obtained at 20 cm from one end of the wire when resistance X is balanced against another resistance Y. If X < Y, then where will be the new position of the null point from the same end, if one decides to balance a resistance of 4X against Y?

(a) 50 cm (b) 80 cm (c) 40 cm (d) 70 cm

Q.27 In a potentiometer experiment, the balancing with a cell is at length 240 cm. On shunting the cell with a resistance of 2Ω, the balancing length becomes 120 cm. The internal resistance of the cell is

(a) 1 Ω (b) 0.5 Ω (c) 4 Ω (d) 2 Ω

Q.28 The length of a wire of a potentiometer is 100 cm and the emf of its standard cell is ξ volt. It is employed to measure the emf of a battery, whose internal resistance is 0.5Ω. If the balance point is obtained at l = 30 cm from the positive end, the emf of the battery is

(a) $\frac{30\xi}{100.5}$ (b) $\frac{30\xi}{99.5}$ (c) $\frac{30\xi}{100}$ (d) $\frac{30(\xi-0.5I)}{100}$

where I is the current in the potential wire.

Q.29 Statement – 1.The temperature dependence of resistance is usually given as $R = R_0(1 + \alpha\Delta t)$. The resistance of a wire changes from 100Ω to 150Ω when its temperature is increased from 27°C to 227°C. This implies that $\alpha = 2.5 \times 10^{-3}/^\circ C$.

Statement – 2. $R = R_0(1 + \alpha\Delta T)$ is valid only when the change in the temperature ΔT is small and $\Delta R = (R - R_0) << R_0$.

(a) Statement – 1 is true, Statement – 2 is false
(b) Statement – 1 is true, Statement – 2 is true, Statement – 2 is correct explanation of Statement –1
(c) Statement – 1 is true, Statement – 2 is true; Statement – 2 is not the correct explanation of Statement– 1.
(d) Statement – 1 is false, Statement – 2 is true

Answers

1.	d	2.	b	3.	a	4.	d	5.	a
6.	c	7.	d	8.	c	9.	d	10.	d
11.	c	12.	d	13.	c	14.	c	15.	c
16.	a	17.	c	18.	a	19.	b	20.	b
21.	b	22.	b	23.	b	24.	d	25.	d
26.	a	27.	d	28.	c	29.	d		

Objective Assignment [IIT–JEE]

One Option Correct

Q.1 A steady current flows in a metallic conductor of non–uniform cross–section. The quantity/ quantities constant along the length of conductor is/are

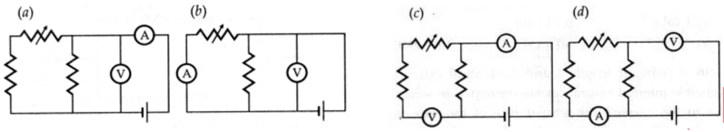
(a) current, electric field and drift speed (b) drift speed only

(c) current and drift speed (d) current only

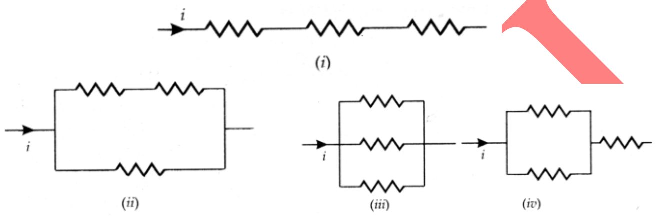
Q.2 The potential difference applied to an X–ray tube is 5 kV and the current through it is 3.2 mA. Then the number of electrons striking the target per second is

(a) 2×10^{16} (b) 5×10^{6} (c) 1×10^{17} (d) 4×10^{15}

Q.3 Express which of the following set up can be used to verify Ohm's law?



Q.4 The three resistances of equal value are arranged in the different combinations shown below. Arrange them in increasing order of power dissipation.



(a) III < II < IV < I (b) II < III < IV < I (c) I < IV < III < II (d) I< III < II < IV

Q.5 A piece of copper and another of germanium are cooled from room temperature to 80 K. Resistance of

(a) copper increases, germanium decreases (b) copper decreases and germanium increases

(c) each of them increases (d) each of them decreases

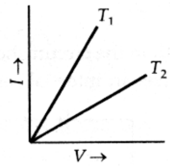
Q.6 The current I and voltage V curves for a given temperatures T_1 and T_2 are shown in the figure. Then,

(a) $T_1 > T_2$

(b) $T_1 < T_2$

(c) $T_1 = T_2$

(d) $T_1 = 2T_2$



Q.7 The temperature coefficient of resistance of wire is 0.00125 $^{\circ}C^{-1}$. At 300 K, its resistance is 1Ω. The resistance of the wire will be 2Ω at

(a) 1154 K (b) 1100 K (c) 1400 K (d) 1127 K

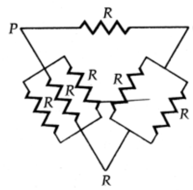
Q.8 Six identical resistors are connected as shown in the figure. The equivalent resistance will be

(a) Maximum between P and R

(b) Maximum between Q and R

(c) Maximum between P and Q

(d) all are equal



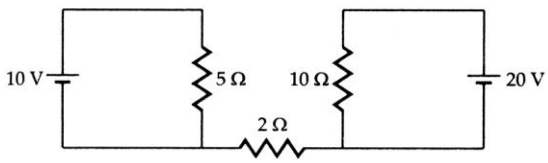
Q.9 Find out the value of current through 2Ω resistance for the given circuit.

(a) zero

(b) 2A

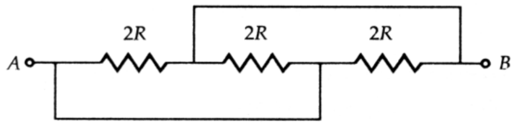
(c) 5 A

(d) 4 A

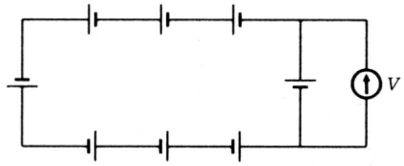


Q.10 The equivalent resistance between points A and B of the circuit shown in the figure

(a) 2R
(b) 5 R
(c) 2R/3
(d) R/5



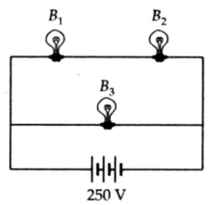
Q.11 In the circuit shown below, each battery is of 5 V and has an internal resistance of 0.2 Ω The reading in the ideal voltmeter V is
(a) zero
(b) 5 V
(c) 7.5 V
(d) 10 V



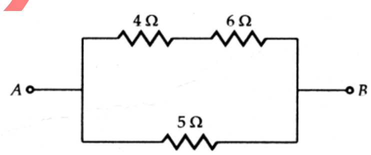
Q.12 A constant voltage is applied between the two ends of a uniform metallic wire. Some heat is developed in it. The heat developed is doubled, if
(a) both the length and radius of wire are halved (b) both length and radius of wire are doubled
(c) the radius of wire is doubled (d) the length of the wire is doubled

Q.13 A 25 W–220 V bulb and a 100 W–220 bulb are joined in series and connected to the mains. Which bulb will glow brighter?
(a) 25 W bulb (b) 100 W bulb
(c) First 25 W bulb and then 100 W bulb (d) Both will glow with same brightness

Q.14 A 100 W bulb B_1, and two 60 W bulbs B_2 and B_3, are connected to a 250 V source as shown in the figure. Now W_1, W_2 and W_3 are the output powers of the bulbs B_1, B_2 and B_3 respectively. Then
(a) $W_1 > W_2 = W_3$
(b) $W_1 > W_2 > W_3$
(c) $W_1 < W_2 = W_3$
(d) $W_1 < W_2 < W_3$



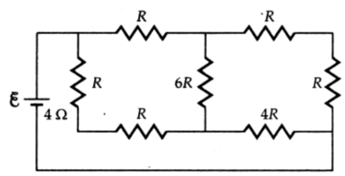
Q.15 In the circuit as shown in figure, the heat produced in the 5Ω resistor due to the current flowing in it is 10 cal s^{-1}. The heat generated in 4Ω is:
(a) 1 cal s^{-1}
(b) 2 cal s^{-1}
(c) 3 cal s^{-1} (d) 4 cal s^{-1}



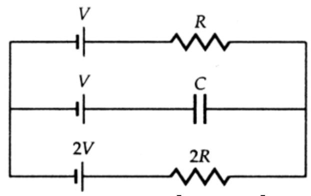
Q.16 A wire of length L and 3 identical cells of negligible internal resistances are connected in series. Due to the current, the temperature of the wire is raised by ΔT in time t. A number N of similar cells is now connected in series with a wire of the same material and cross–section but of length 2L. The temperature of the wire is raised by the same amount ΔT in the same time. The value of N is
(a) 4 (b) 6 (c) 8 (d) 9

Q.17 An ideal gas is filled in a closed rigid and thermally insulated container. A coil of 100 Ω resistor carrying current 1A for 5 minutes supplies heat to the gas. The change in internal energy of the gas is
(a) 10 kJ (b) 30 kJ (c) 20 kJ (d) 0 kJ

Q.18 A battery of internal resistance 4Ω is connected to the network of resistances as shown as shown. In order that the maximum power can be delivered to the network, the value of R in Ω should be
(a) 4/9
(b) 2
(c) 8/3
(d) 18

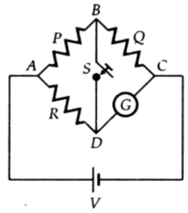


Q.19 In the given circuit, the potential drop across the capacitor must be



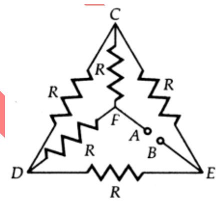
(a) V
(b) V/2
(c) V/3
(d) 2V/3

Q.20 In the circuit shown in the figure, $P \neq R$. The reading of the galvanometer is same with switch S open or closed. Then,



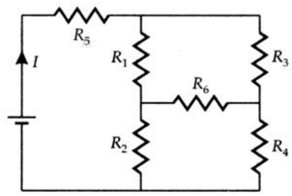
(a) $I_R = I_C$
(b) $I_P = I_C$
(c) $I_Q = I_C$ (d) $I_Q = I_R$

Q.21 Each of the resistances in the network shown in the figure is equal to R. The resistance between the terminals A and B is



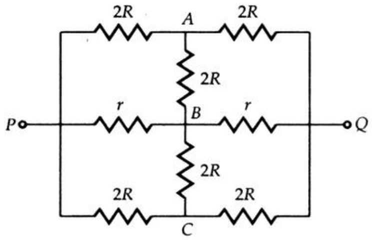
(a) R
(b) 5 R
(c) 3 R
(d) 6 R

Q.22 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



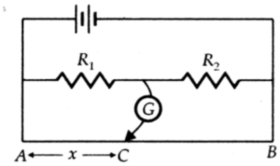
(a) $R_1 R_2 R_3 = R_3 R_4 R_6$
(b) $\frac{1}{R_5} + \frac{1}{R_6} = \frac{1}{R_1 + R_2} + \frac{1}{R_3 + R_4}$
(c) $R_1R_4 = R_2R_3$
(d) $R_1R_3 = R_2R_4 = R_5R_6$

Q.23 The effective resistance between points P and Q of the electrical circuit shown in the figure is



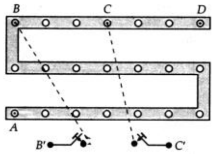
(a) $\frac{2Rr}{R+r}$
(b) $\frac{8R(R+r)}{3R+r}$
(c) $2r + 4R$ (d) $\frac{5R}{2} + 2r$

Q.24 In the shown arrangement of the experiment of the metre 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?



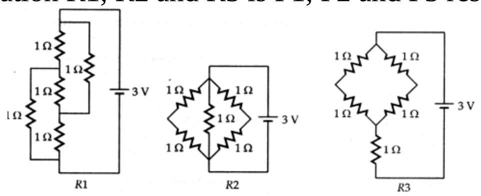
(a) x
(b) x/4
(c) 4x
(d) 2 x

Q.25 A post office box is shown in the figure. In order to calculate the value of an external resistance, it should be connected between



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

Q.26 Figure shows three resistor configurations R1, R2 and R3 connected to 3 V battery. If the power dissipated by the configuration R1, R2 and R3 is P1, P2 and P3 respectively, then



(a) P1 > P2 > P3 (b) P1 > P3 > P2 (c) P2 > P1 > P3 (d) P3 > P2 > P1

Multiple Choice Questions

Q.27 Read the following statements carefully:

Y The resistivity of a semiconductor decreases with increase of temperature

Z In a conducting solid, the rate of collisions between free electrons and ions increases with increase of temperature.

Select the correct statement(s) from the following:

(a) Y is true but Z is false (b) Y is false but Z is true

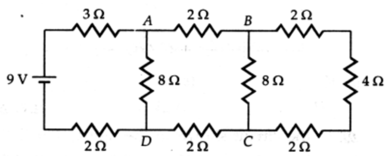
(c) Both Y and Z are true (d) Y is true and Z is the correct reason for Y

Q.28 When a potential difference is applied across, the current passing through

(a) an insulator at 0 K is zero (b) a semiconductor at 0 K is zero

(c) a metal at 0 K is finite (d) a p–n diode at 300 K is finite, if it is reverse biased

Q.29 In the circuit shown in figure, the current through the

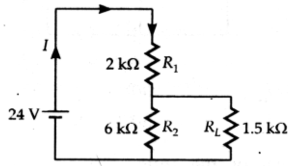


(a) 3Ω resistor is 0.50 A

(b) 3Ω resistor is 0.25 A

(c) 4Ω resistor is 0.50 A (d) 4Ω resistor is 0.25 A

Q.30 For the circuit shown in the figure



(a) the current I through the battery is 7.5 mA

(b) the potential difference across R_L is 18 V

(c) ratio of powers dissipated in R_1 and R_2 is 3

(d) if R_1 and R_2 are interchanged, magnitude of power dissipated in R_L, will decrease by a factor of 9

Answers

1	d	2	a	3	a	4	a	5	b
6	b	7	b	8	c	9	a	10	c
11	a	12	b	13	a	14	d	15	b
16	b	17	b	18	b	19	c	20	a
21	a	22	c	23	a	24	a	25	c
26	c	27	c	28	a, b, d	29	d	30	a, d

Higher Order Assignment

Q.1 The amount of charge passed in time t through a cross–section of a wire is $Q(t) = At^2 + Bt + C$.

(a) Write the dimensional formulae for A, B and C.

(b) If the numerical values of A, B and C are 5, 3 and 1 respectively in SI units, find the value of the current at t = 5s.

Q.2 An electron gun emits 2.0×10^{16} electrons per second. What electric current does this correspond to?

Q.3 The electric current existing in a discharge tube is 2.0 μA. How much charge is transferred across a cross–section of the tube in 5 minutes?

Q.4 The current through a wire depends on time as $i = i_0 + \alpha t$, where $i_0 = 10A$ and $\alpha = 4A\ s^{-1}$. Find the charge crossed through a section of the wire in 10 seconds.

Q.5 A current of 1.0 A exists in a copper wire of cross–section 1.0 mm^2. Assuming one free electron per atom calculate the drift speed of the free electrons in the wire. The density of copper is 9000 kg m^{-3}.

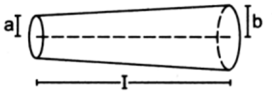
Q.6 A wire of length 1m and radius 0.1mm has a resistance of 100Ω. Find the resistivity of the material.

Q.7 A uniform wire of resistance 100Ω is melted and recast in a wire of length double that of the original. What would be the resistance of the wire?

Q.8 Consider a wire of length 4m and cross–sectional area 1 mm^2 carrying a current of 2 A. If each cubic metre of the material contains 10^{29} free electrons, find the average time taken by an electron to cross the length of the wire.

Q.9 What length of a copper wire of cross–sectional area 0.01 mm^2 will be needed to prepare a resistance of 1 kΩ? Resistivity of copper = 1.7×10^{-8} Ωm.

Q.10 Figure shows a conductor of length l having a circular cross section. The radius of cross section varies linearly from a to b. The resistivity of the material is ρ. Assuming that b – a < < l, find the resistance of the conductor.



Q.11 A copper wire of radius 0.1mm and resistance 1 kΩ is connected across a power supply of 20 V. (a) How many electrons are transferred per second between the supply and the wire at one end? (b) Write down the current density in the wire.

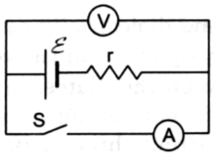
Q.12 Calculate the electric field in a copper wire of cross–sectional area 2.0 mm^2 carrying a current of 1A. The resistivity of copper = 1.7×10^{-8} Ωm.

Q.13 A wire has a length of 2.0m and a resistance of 5.0 Ω. Find the electric field existing inside the wire if it carries a current of 10 A.

Q.14 The resistances of an iron wire and a copper wire at 20^{o}C are 3.9 Ω and 4.1Ω respectively. At what temperature will the resistances be equal? Temperature coefficient of resistivity for iron is 5.0×10^{-3} K^{-1} and for copper it is 4.0×10^{-3} K^{-1}. Neglect any thermal expansion.

Q.15 The current in a conductor and the potential difference across its ends are measured by an ammeter and a voltmeter. The meters draw negligible currents. The ammeter is accurate but the voltmeter has a zero error (that is, it does not read zero when no potential difference is applied). Calculate the zero error if the readings for two different conditions are 1.75 A, 14.4 V and 2.75 A, 22.4 V.

Q.16 Figure shows an arrangement to measure the emf ε and internal resistance r of a battery. The voltmeter has a very high resistance and the ammeter also has some resistance. The voltmeter reads 1.52 V when the switch S is open. When the switch is closed the voltmeter reading drops to 1.45 V and the ammeter reads 1.0 A. Find the emf and the internal resistance of the battery.

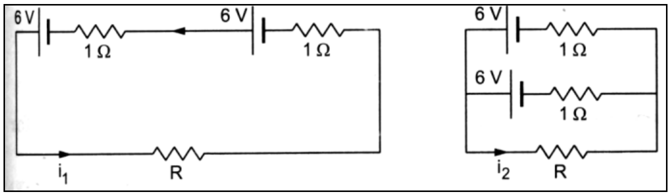


Q.17 The potential difference between the terminals of a battery of emf 6.0 V and internal resistance 1Ω drops to 5.8 V when connected across an external resistor. Find the resistance of the external resistor.

Q.18 The potential difference between the terminals of a 6.0 V battery is 7.2 V when it is being charged by a current of 2.0 A. What is the internal resistance of the battery?

Q.19 The internal resistance of an accumulator battery of emf 6V is 10Ω when it is fully discharged. As the battery gets charged up, its internal resistance decreases to 1Ω. The battery in its completely discharged state is connected to a charger which maintains a constant potential difference of 9 V. Find the current through the battery (a) just after the connections are made and (b) after a long time when it is completely charged.

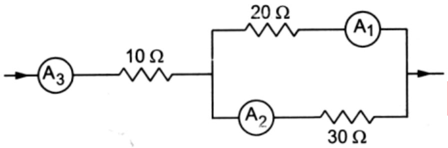
Q.20 Find the value of i_1/i_2 in figure if (a) R = 0.1Ω, (b) R = 1 Ω (c) R = 10 Ω.



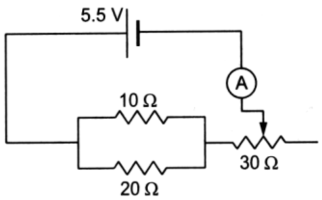
Q.21 Consider N = n_1n_2 identical cells, each of emf E and internal resistance r. Suppose n_1 cells are joined in series to form a line and n_2 such lines are connected in parallel. The combination drives a current in an external resistance R. (a) Find the current in the external resistance. (b) Assuming that n_1 and n_2 can be continuously varied, find the relation between n_1, n_2, R and r for which the current in R is maximum.

Q.22 A battery of emf 100 V and a resistor of resistance 10 kΩ and joined in series. This system is used as a source to supply current to an external resistance R. If R is not greater than 100Ω, the current through it is constant up to two significant digits. Find its value. This is the basic principle of a *constant–current source.*

Q.23 If the reading of ammeter A_1 in figure is 2.4 A, what will the ammeters A_2 and A_3 read? Neglect the resistance of the ammeters.



Q.24 The resistance of the rheostat shown in figure is 30 Ω. Neglecting the meter resistance, find the minimum and maximum currents through the ammeter as the rheostat is varied.

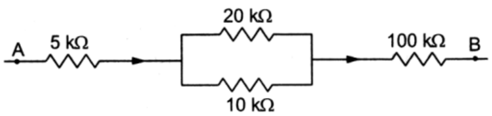


Q.25 Three bulbs, each having a resistance of 180 Ω, are connected in parallel to an ideal battery of emf 60 V. Find the current delivered by the battery when (a) all the bulbs are switched on, (b) two of the bulbs are switched on and (c) only one bulb is switched on.

Q.26 Suppose you have three resistors of 20Ω, 50Ω and 100Ω. What minimum and maximum resistances can you obtain from these resistors?

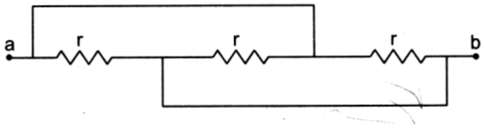
Q.27 A bulb is made using two filaments. A switch selects whether the filaments are used individually or in parallel. When used with a 15 V battery, the bulb can be operated at 5 W, 10 W or 15 W. What should be the resistances of the filaments?

Q.28 Figure shows a part of a circuit. If a current of 12 mA exists in the 5 kΩ resistor, find the currents in the other three resistors. What is the potential difference between the points A and B?



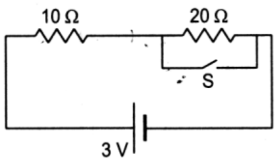
Q.29 An ideal battery sends a current of 5 A in a resistor. When another resistor of value 10Ω is connected in parallel, the current through the battery is increased to 6 A. Find the resistance of the first resistor.

Q.30 Find the equivalent resistance of the network shown in figure between the points a and b.

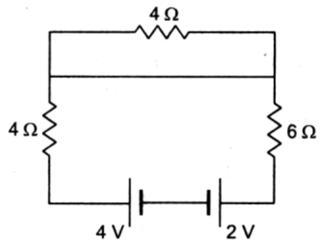


Q.31 A wire of resistance 15.0 Ω is bent to form a regular hexagon ABCDEFA. Find the equivalent resistance of the loop between the points (a) A and B, (b) A and C and (c) A and D.

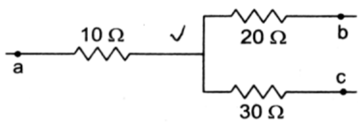
Q.32 Consider the circuit shown in figure. Find the current through the 10Ω resistor when the switch S is (a) open, (b) closed.



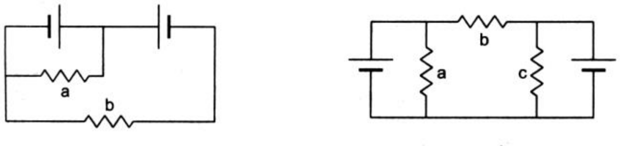
Q.33 Find the currents through the three resistors shown in figure.



Q.34 Figure shows a part of an electric circuit. The potentials at the points a, b and c are 30 V, 12 V and 2V respectively. Find the currents through the three resistors.

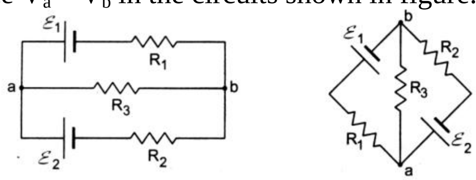


Q.35 Each of the resistors shown in figure has a resistance of 10Ω and each of the batteries has an emf of 10V. Find the currents through the resistors a and b in the two circuits.



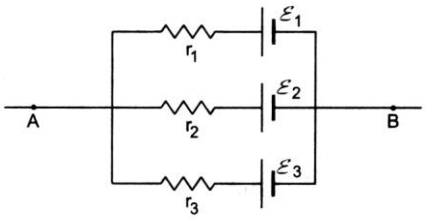
(a) (b)

Q.36 Find the potential difference $V_a - V_b$ in the circuits shown in figure.

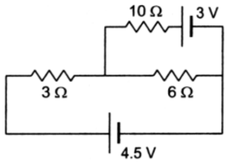


(a) (b)

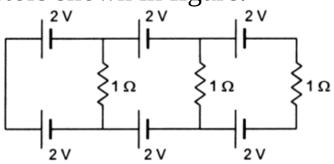
Q.37 In the circuit shown in figure, $\mathcal{E}_1 = 3V$, $\mathcal{E}_2 = 2V$, $\mathcal{E}_3 = 1V$ and $r_1 = r_2 = r_3 = 1\Omega$. Find the potential difference between the points A and B and the current through each branch.



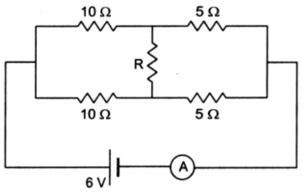
Q.38 Find the current through the 10Ω resistor shown in figure.



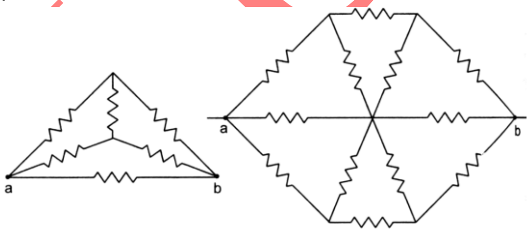
Q.39 Find the current in the three resistors shown in figure.



Q.40 What should be the value of R in figure for which the current in it is zero?

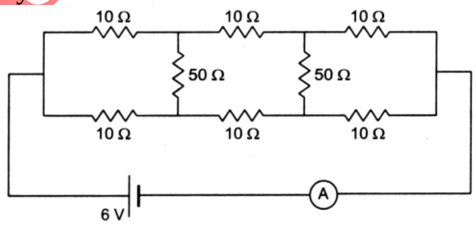


Q.41 Find the equivalent resistance of the circuits shown in figure between the points a and b. Each resistor has a resistance r.



(a) (b)

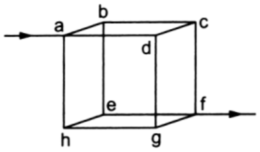
Q.42 Find the current measured by the ammeter in the circuit shown in figure.



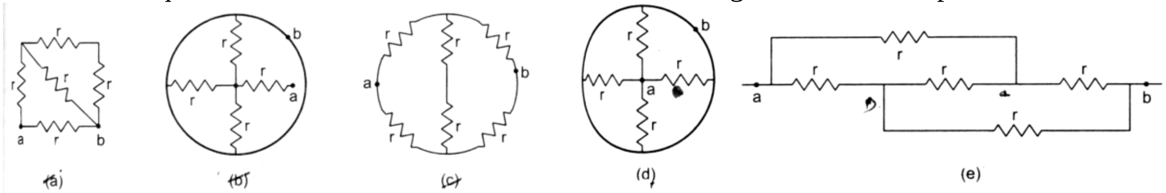
Q.43 Consider the circuit shown in figure. Find (a) the current in the circuit, (b) the potential drop across the 5Ω resistor, (c) the potential drop across the 10Ω resistor. (d) Answer the parts (a), (b) and (c) with reference to figure.

(a) (b)

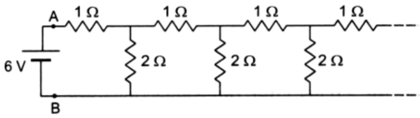
Q.44 Twelve wires, each having equal resistance r, are joined to form a cube as shown in figure. Find the equivalent resistance between the diagonally opposite points a and *f*.



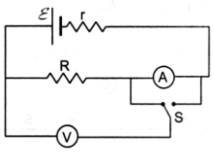
Q.45 Find the equivalent resistances of the networks shown in figure between the points a and b.



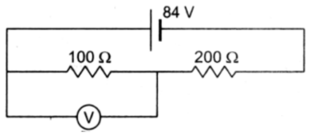
Q.46 An infinite ladder is constructed with 1 Ω and 2 Ω resistors as shown in figure. (a) Find the effective resistance between the points A and B. (b) Find the current that passes through the 2Ω resistor nearest to the battery.



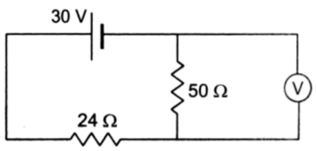
Q.47 The emf $\mathcal{E}$ and the internal resistance r of the battery shown in figure are 4.3 V and 1.0 Ω respectively. The external resistance R is 50Ω. The resistances of the ammeter and voltmeter are 2.0Ω and 200Ω respectively. (a) Find the readings of the two meters. (b) The switch is thrown to the other side. What will be the readings of the two meters now?



Q.48 A voltmeter of resistance 400 Ω is used to measure the potential difference across the 100Ω resistor in the circuit shown in figure. (a) What will be the reading of the voltmeter? (b) What was the potential difference across 100Ω before the voltmeter was connected?



Q.49 The voltmeter shown in figure reads 18 V across the 50 Ω resistor. Find the resistance of the voltmeter.

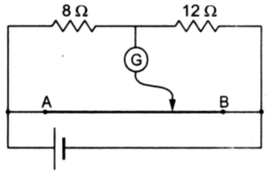


Q.50 A voltmeter consists of a 25 Ω coil connected in series with a 575Ω resistor. The coil takes 10 mA for full scale deflection. What maximum potential difference can be measured on this voltmeter?

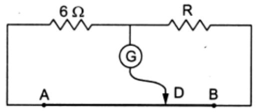
Q.51 An ammeter is to be constructed which can read currents upto 2.0 A. If the coil has a resistance of 25Ω and takes 1 mA for full scale deflection, what should be the resistance of the shunt used?

Q.52 A voltmeter coil has resistance 50.0 Ω and a resistor of 1.15 KΩ is connected in series. It can read potential differences upto 12 volts. If this same coil is used to construct an ammeter which can measure currents upto 2.0 A, what should be the resistance of the shunt used?

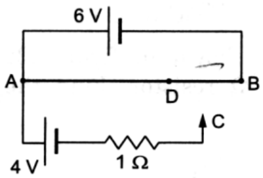
Q.53 The potentiometer wire AB shown in figure is 40 cm long. Where should the free end of the galvanometer be connected on AB so that the galvanometer may show zero deflection?



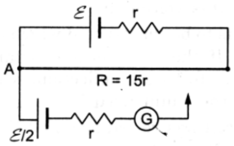
Q.54 The potentiometer wire AB shown in figure is 50 cm long. When AD = 30 cm, no deflection occurs in the galvanometer. Find R.



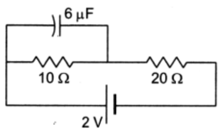
Q.55 A 6–volt battery of negligible internal resistance is connected across a uniform wire AB of length 100cm. The positive terminal of another battery of emf 4 V and internal resistance 1Ω is joined to the point A as shown in figure. Take the potential at B to be zero. (a) What are the potentials at the points A and C? (b) At which point D of the wire AB, the potential is equal to the potential at C? (c) If the points C and D are connected by a wire, what will be the current through it? (d) If the 4 V battery is replaced by 7.5 V battery, what would be the answers of parts (a) and (b)?



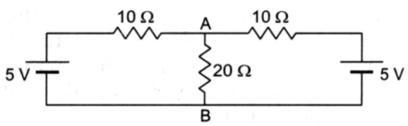
Q.56 Consider the potentiometer circuit arranged as in figure. The potentiometer wire is 600 cm long. (a) At what distance from the point A should the jockey touch the wire to get zero deflection in the galvanometer? (b) If the jockey touches the wire at a distance of 560 cm from A, what will be the current in the galvanometer?



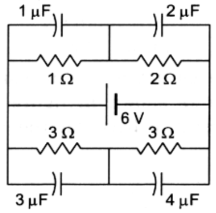
Q.57 Find the charge on the capacitor shown in figure.



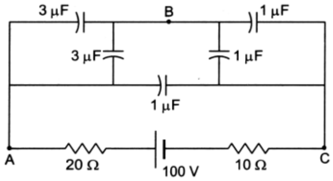
Q.58 (a) Find the current in the 20Ω resistor shown in figure. (b) If a capacitor of capacitance 4 μF is joined between the points A and B, what would be the electrostatic energy stored in it in steady state?



Q.59 Find the charges on the four capacitors of capacitances 1 μF, 2μF, 3μF and 4μF shown in figure.



Q.60 Find the potential difference between the points A and B and between the points B and C of figure in steady state.



Q.61 A capacitance C, a resistance R and an emf $\mathcal{E}$ are connected in series at t = 0. What is the maximum value of (a) the potential difference across the resistor, (b) the current in the circuit, (c) the potential difference across the capacitor, (d) the energy stored in the capacitor, (e) the power delivered by the battery and (f) the power converted into heat.

Q.62 A parallel–plate capacitor with plate area 20 cm^2 and plate separation 1.0 mm is connected to a battery. The resistance of the circuit is 10 kΩ. Find the time constant of the circuit.

Q.63 A capacitor of capacitance 10μF is connected to a battery of emf 2V. It is found that it takes 50 ms for the charge on the capacitor to become 12.6 μC. Find the resistance of the circuit.

Q.64 A 20 μF capacitor is joined to a battery of emf 6.0 V through a resistance of 100 Ω. Find the charge on the capacitor 2.0 ms after the connections are made.

Q.65 The plates of a capacitor of capacitance 10 μF, charged to 60 μC, are joined together by a wire of resistance 10Ω at t = 0. Find the charge on the capacitor in the circuit at (a) t = 0, (b) t = 30 μs, (c) t = 120 μs and (d) t = 1.0 ms.

Q.66 A capacitor of capacitance 8.0 μF is connected to a battery of emf 6.0 V through a resistance of 24Ω. Find the current in the circuit (a) just after the connections are made and (b) one time constant after the connections are made.

Q.67 A parallel–plate capacitor of plate area 40 cm^2 and separation between the plates 0.10 mm is connected to a battery of emf 2.0 V through a 16Ω resistor. Find the electric field in the capacitor 10 ns after the connections are made.

Q.68 A parallel–plate capacitor has plate area 20 cm^2, plate separation 1.0 mm and a dielectric slab of dielectric constant 5.0 filling up the space between the plates. This capacitor is joined to a battery of emf 6.0 V through a 100 kΩ resistor. Find the energy of the capacitor 8.9 μs after the connections are made.

Q.69 A 100 μF capacitor is joined to a 24 V battery through a 1.0 MΩ resistor. Plot qualitative graphs (a) between current and time for the first 10 minutes and (b) between charge and time for the same period.

Q.70 How many time constants will elapse before the current in a charging RC circuit drops to half of its initial value? Answer the same question for a dischanging RC circuit.

Q.71 How many time constants will elapse before the charge on a capacitor falls to 0.1% of its maximum value in a discharging RC circuit?

Q.72 How many time constants will elapse before the energy stored in the capacitor reaches half of its equilibrium value in a charging RC circuit?

Q.73 How many time constants will elapse before the power delivered by the battery drops to half of its maximum value in an RC circuit?

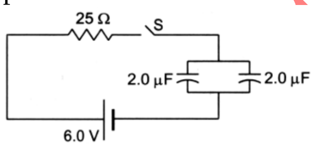
Q.74 A capacitor of capacitance C is connected to a battery of emf $\mathcal{E}$ at t = 0 through a resistance R. Find the maximum rate at which energy is stored in the capacitor. When does the rate has this maximum value?

Q.75 A capacitor of capacitance 12.0 μF is connected to a battery of emf 6.00 V and internal resistance 1.00Ω through resistanceless leads. 12.0 μs after the connections are made, what will be (a) the current in the circuit, (b) the power delivered by the battery, (c) the power dissipated in heat and (d) the rate at which the energy stored in the capacitor is increasing.

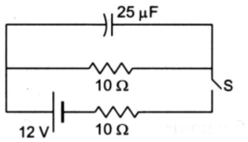
Q.76 A capacitance C charged to a potential difference V is discharged by connecting its plates through a resistance R. Find the heat dissipated in one time constant after the connections are made.

Q.77 A parallel–plate capacitor is filled with a dielectric material having resistivity ρ and dielectric constant K. The capacitor is charged and disconnected from the charging source. The capacitor is slowly discharged through the dielectric. Show that the time constant of the discharge is independent of all geometrical parameters like the plate area or separation between the plates. Find this time constant.

Q.78 Find the charge on each of the capacitors 0.20 ms after the switch S is closed of figure.

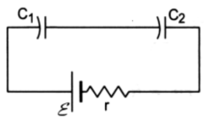


Q.79 The switch S shown in figure is kept closed for a long time and is then opened at t = 0. Find the current in the middle 10Ω resistor at t = 1.0 ms.



Q.80 A capacitor of capacitance 100μF is connected across a battery of emf 6.0 V through a resistance of 20 kΩ for 4.0s. The battery is then replaced by a thick wire. What will be the charge on the capacitor 4.0 s after the battery is disconnected?

Q.81 Consider the situation shown in figure. The switch is closed at t = 0 when the capacitors are uncharged. Find the charge on the capacitor C_1 as a function of time t.



Q.82 A capacitor of capacitance C is given a charge Q. At t = 0, it is connected to an uncharged capacitor of equal capacitance through a resistance R. Find the charge on the second capacitor as a function of time.

Q.83 A capacitor of capacitance C is given a charge Q. At t = 0, it is connected to an ideal battery of emf E through a resistance R. Find the charge on the capacitor at time t.

Answers

1.	IT^{-1}, I, IT, (b) 53 A	2.	3.2×10^{-3} A	3.	6.0×10^{-4} C
4.	300 C	5.	0.074 mm s^{-1}	6.	$\pi \times 10^{-6}$ Ω m
7.	400 Ω	8.	3.2×10^{4} s ≈ 8.9 hours	9.	0.6 km
10.	$\frac{\rho l}{\pi ab}$	11.	(a) 1.25×10^{17}, (b) 6.37×10^{5} A/m^2		
12.	8.5 mV m^{-1}	13.	25 V m^{-1}	14.	84.5°C
15.	0.4 V	16.	1.52 V, 0.07 Ω	17.	29 Ω

18. 0.6 Ω
19. (a) 0.3 A, (b) 3 A
20. (a) 0.57, (b) 1, (c) 1.75
21. (a) $\frac{nE}{R+\frac{n_1 r}{n_2}}$, (b) $rn_1 = Rn_2$
22. 10 mA
23. 1.6 A, 4.0 A
24. 0.15 A, 0.83 A
25. (a) 1.0 A, (b) 0.67 A, (c) 0.33 A
26. 12.5 Ω, 170 Ω
27. 45 Ω, 22.5 Ω
28. 4 mA in 20 kΩ resistor, 8 mA in 10 kΩ resistor and 12 mA in 100 kΩ resistor, 1340 V
29. 2 Ω
30. r/3
31. (a) 2.08Ω, (b) 3.33Ω, (c) 375Ω
32. (a) 0.1A, (b) 0.3 A
33. zero in the upper 4Ω resistor and 0.2 A in the rest two
34. 1 A through 10Ω, 0.4Ω through 20Ω and 0.6 A through 30Ω
35. 1 A in a and zero in b in both the circuits
36. $(a)\ \frac{\frac{\varepsilon_1}{R_1}+\frac{\varepsilon_2}{R_2}}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$
37. 2V, $i_1 = 1$ A, $i_2 = 0$, $i_3 = -1$ A
38. zero
39. zero
40. any value of R will do
41. (a) r/2, (b) 4r/ 5
42. 0.4 A
43. (a) 1.2 A, (b) 6 V, (c) 12 V, (d) same as the parts (a), (b) and (c)
44. $\frac{5}{6}r$
45. $(a)\ \frac{5}{8}r,\ (b)\ \frac{4}{3}r,\ (c)\ r,\ (d)\ \frac{r}{4},\ (e)\ r$
46. (a) 2 Ω, (b) 1.5 A
47. (a) 0.1 A, 4.0 V, (b) 0.08 A, 4.2 V
48. (a) 24 V, (b) 28 V
49. 130 Ω
50. 6 V
51. 1.25×10^{-2} Ω
52. 0.251 Ω
53. 16 cm from A
54. 4 Ω
55. (a) 6 V, 2V, (b) AD = 66.7 cm, (c) zero, (d) 6V, – 1.5 V, no such point D exists
56. $(a)\ 320\ cm,\ (b)\ \frac{3\varepsilon}{22\ r}$
57. 4 μC
58. (a) 0.2 A, (b) 32 μJ
59. 2 μC, 8μC, 9μC and 12 μC
60. 25 V, 75 V
61. $(a)\ \varepsilon,\ (b)\ \frac{\varepsilon}{R},\ (c)\ \varepsilon,\ (d)\ \frac{1}{2}C\varepsilon^2,\ (e)\ \frac{\varepsilon^2}{R},\ (f)\ \frac{\varepsilon^2}{R}$
62. 0.18 μs
63. 5 kΩ
64. 76 μC
65. (a) 60 μC, (b) 44 μC, (c) 18 μC, (d) 0.003 μC
66. (a) 0.25 A, (b) 0.09 A
67. 1.7×10^{-4} V m^{-1}
68. 6.3×10^{-10} J
70. 0.69 in both cases
71. 6.9
72. 1.23
73. 0.69
74. $\frac{\varepsilon^2}{4R},\ CR\ \ln 2$
75. (a) 2.21 A, (b) 13.2 W, (c) 4.87 W, (d) 8.37 W
76. $\frac{1}{2}(1-1/e^2)\ CV^2$
77. $\varepsilon_0 \rho K$
78. 9.2 μC
79. 11 mA
80. 70 μC
81. $q = EC(1^{-e-t/rc}),\ where\ C = \frac{C_1 C_2}{C_1 + C_2}$
82. $\frac{Q}{2}(1^{-e-2t/RC})$
83. $CE\ (1-e^{-t/CR}) + Qe^{-t/CR}$

Thermal and Chemical Effects of Electric Current

Q.1 An electric current of 2.0 A passes through a wire of resistance 25Ω. How much heat will be developed in 1 minute?

Q.2 A coil of resistance 100Ω is connected across a battery of emf 6.0 V. Assume that the heat developed in the coil is used to raise its temperature. If the heat capacity of the coil is 4.0 J K^{-1}, how long will it take to raise the temperature of the coil by 15°C?

Q.3 The specification on a heater coil is 250 V, 500 W. Calculate the resistance of the coil. What will be the resistance of a coil of 1000 W to operate at the same voltage?

Q.4 A heater coil is to be constructed with a nichrome wire ($\rho = 1.0 \times 10^{-6}$ Ωm) which can operate at 500W when connected to a 250 V supply. (a) What would be the resistance of the coil? (b) If the cross–sectional area of the wire is 0.5 mm^2, what length of the wire will be needed? (c) If the radius of each turn is 4.0 mm, how many turns will be there in the coil?

Q.5 A bulb with rating 250 V, 100 W is connected to a power supply of 220 V situated 10 m away using a copper wire of area of cross section 5 mm^2. How much power will be consumed by the connecting wires? Resistivity of copper = 1.7×10^{-8} Ωm.

Q.6 An electric bulb, when connected across a power supply of 220 V, consumes a power of 60 W. If the supply drops to 180 V, what will be the power consumed? If the supply is suddenly increased to 240 v, what will be the power consumed?

Q.7 A servo voltage stabilizer restricts the voltage output to 220 V $\pm$ 1%. If an electric bulb rated at 220 V, 100W is connected to it, what will be the minimum and maximum power consumed by it?

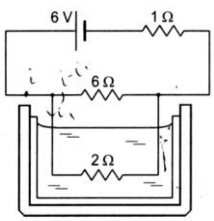
Q.8 An electric bulb marked 220 V, 100W will get fused if it is made to consume 150 W or more. What voltage fluctuation will the bulb withstand?

Q.9 An immersion heater rated 1000W, 220 V is used to heat 0.01 m^3 of water. Assuming that the power is supplied at 220 V and 60% of the power supplied is used to heat the water, how long will it take to increase the temperature of the water from 15°C to 40°C?

Q.10 An electric kettle used to prepare tea, takes 2 minutes to boil 4 cups of water (1 cup contains 200 cc of water) if the room temperature is 25°C. (a) If the cost of power consumption is Re 1.00 per unit (1 unit = 1000 watt–hour), calculate the cost of boiling 4 cups of water. (b) What will be the corresponding cost if the room temperature drops to 5°C?

Q.11 The coil of an electric bulb takes 40 watts to start glowing. If more than 40W is supplied, 60% of the extra power is converted into light and the remaining into heat. The bulb consumes 100W at 220 V. Find the percentage drop in light intensity at a point if the supply voltage changes from 220 V to 200 V.

Q.12 The 2.0 Ω resistor shown in figure is dipped into a calorimeter containing water. The heat capacitor of the calorimeter together with water is 2000 J K^{-1}. (a) If the circuit is active for 15 minutes, what would be the rise in the temperature of the water? (b) Suppose the 6.0Ω resistor gets burnt. What would be the rise in the temperature of the water in the next 15 minutes?



Answers

1. 6.0×10^3 J
2. 2.8 min
3. 125 Ω, 62.5 Ω
4. (a) 125 Ω, (b) 62.5 m, (c) ≈ 2500 turns
5. 8.4 mW

6.	40 W, 71 W	7.	98 W, 102 W	8.	up to 270 V
9.	29 minutes	10.	(a) 7 paise, (b) 9 paise	11.	29%
12.	(a) 2.9^{o}C, (b) 3.6^{o}C				