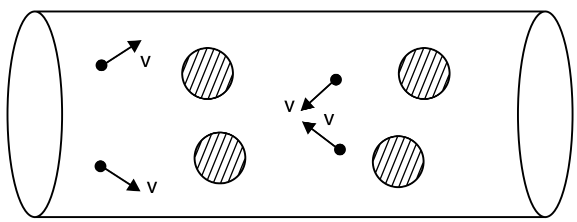
3 Current Electricity

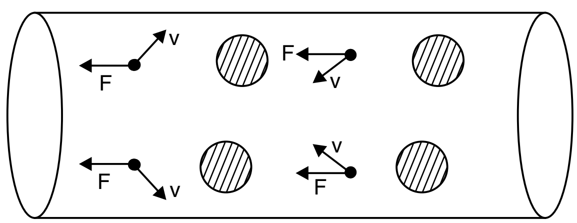
Facts that Matter

• Motion of Free Electrons in a Conductor

In a conductor free electrons move randomly in all possible directions with all possible velocities. If an electric field is applied across a conductor the free electrons experience a force in the opposite direction of electric field and move in the direction of force.



(a) Motion of free electrons in the absence of electric field



(b) Motion of free electrons in presence of electric field

Fig. 3.1

When free electrons move, they collide with core of atoms elastically and lose their velocity. Again the free electrons acquire velocity and the influence of force of the electric field. Thus, the velocity of free electrons just after the collision becomes zero and just before the collision remains maximum. If velocity of free electrons just after the collision is $u = 0$, then the velocity just before the collision

$$v = u + a\tau$$

$$= 0 + \frac{eE}{m}\tau \qquad \left[\because \begin{array}{r} F = qE \\ ma = eE \end{array}\right]$$

or $$v = \frac{eE}{m}.\tau$$

where τ is the time between two sucessive collisions called relaxation time.

- The average velocity of free electrons in preserve of electric field in a conductor is called **drift velocity.** For n number of free electrons drift velocity can be given as

$$v_d = \frac{V_1 + V_2 + \ldots V_n}{n} = \frac{n\left(\frac{eE}{m}.\tau\right)}{n} \qquad [v_1 \simeq v_2 \simeq \ldots v_n]$$

or
$$\boxed{v_d = \frac{eE}{m}.\tau}$$

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

$\therefore$
$$\boxed{V_d = \frac{eV}{ml}.\tau}$$

- When **temperature increases** the amplitude of vibration of the atoms about their equilibrium position increases. Hence the mean free path decreases and the relaxation time $\tau = \frac{\text{mean free path}}{\text{velocity of free electrons}}$ decreases, correspondingly the **drift velocity decreases.**

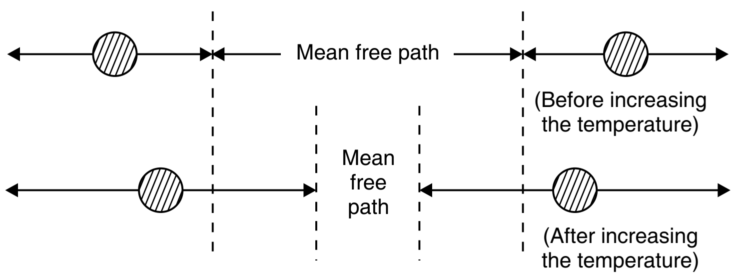


Fig. 3.2

- **Electric Current**

If potential difference V is applied across a conductor of area of cross-section A and length l having n of free electrons per unit volume, then the rate of flow of charge, called electric current, is given by

$$I = \frac{q}{t} = \frac{nAle}{l} = neAv_d \quad \left(v_d = \frac{l}{t}\right)$$

or
$$\boxed{I = neAv_d}$$

This is the relation between electric current and drift velocity.

- Electric current per unit area of cross-section is called **current density** (J)

Thus,
$$J = \frac{I}{A} = nev_d$$

or
$$J = ne\frac{eE}{m}.\tau$$

$$\boxed{J = \frac{ne^2E}{m}.\tau}$$

- Resistivity is the property of the conductor, due to which they offer, resistance to the current flowing through the conductor.

$\because \quad I = neAv_d = neA \dfrac{eV}{ml} . \tau$

or $\quad \dfrac{V}{I} = \left(\dfrac{m}{ne^2\tau}\right)\dfrac{l}{A}$

or $\quad R = \int \dfrac{l}{A} \qquad \left[\dfrac{V}{I} = R \text{ (resistance)}\right]$

where $\boxed{\rho = \dfrac{m}{ne^2C}}$ is called resistivity of the conductor.

Also, $\quad \rho = \dfrac{RA}{l}$

If A = 1 m² and l = 1 m, then $\rho = R$

Thus, resistivity is defined as the resistance offered by a conductor of unit length and unit area of cross-section. The unit of resistance is ohm (Ω) and the unit of resistivity is ohm metre (Ωm).

- When **temperature increases** the relaxation time decreases and the resistivity $\rho = \dfrac{m}{ne^2e}$ increases. Correspondingly the **resistance increases.**
- The increase in resistance is directly proportional to the increase in temperature and the original resistance.

$$\Delta R \propto R_0$$
$$\propto \Delta\theta$$

or $\quad \Delta R \propto R_0\Delta\theta$

or $\quad \Delta R = \alpha R_0\Delta\theta$

$\therefore$ New resistance, $\quad R = R_0 + \Delta R$

$$= R_0 + \alpha R_0\Delta\theta$$

or $\quad \boxed{R = R_0 (1 + \alpha\, \Delta\theta)}$

where α in the temperature coefficient of resistance.

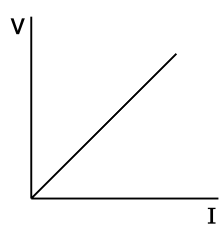
- The ratio of potential difference and current flowing through a conductor is constant provided all physical conditions are uncharged.

$$\frac{V}{I} = \text{Constant} - (R)$$

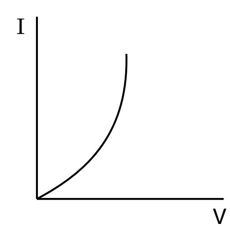
or $\quad \dfrac{V}{I} = R$

This statement is called Ohm's law.

- The $V - I$ graph for conductor is a straight line and it is called an **Ohmic conductors**.
- If the $V - I$ graph is not a straight line, the conductor or device is called a **non-ohmic conductor**.



(a) Ohmic conductor



(b) Non-ohmic conductor

Fig. 3.3

- A conducting device obeys Ohm's law only and only if under steady physical conditions of temperature, etc., its resistance is independent of magnitude and polarity of the applied potential difference. In the situation shown in Fig. 3.3 (*a*) the graph between V and I is a straight line passing through the origin, the slope of the graph gives the resistance, *i.e.*,

$$R = \frac{V}{I} = \tan\theta = \text{constant.}$$

  Silver, copper, mercury, nichrome, carbon, silicon, sulphur and mica, etc, can be cited as examples of substances which obey Ohm's law.
- Ohm's law is not universal as it does not hold good in cases of gases, crystal-rectifiers, thermonic valves, etc.
- $\because$ $$I = \frac{V}{R} = \frac{El}{\rho\frac{l}{A}}$$

$$\Rightarrow \quad \frac{I}{A} = \frac{E}{\rho} \quad \text{or} \quad J = \sigma E.$$

- The relation $V = IR$ is same as $J = \sigma E$ or $\vec{E} = \rho\vec{J}$. However the former is for a body in terms of scalar macroscopic quantities V, I and R while the later is at a point of the body in terms of corresponding microscopic quantities. The later can be called vector term of Ohm's law.
- Cell is a device which converts chemical energy into electrical energy. It consists of two electrodes of different materials and an electrolyte.

• Electro Motive Force (EMF)

The electro motive force (emf) is the work done by the cell in moving unit positive charge in the whole circuit including the cell once. So, if W is the work done by a cell in moving a charge q once round a circuit including the cell, then

$$\text{emf, } E = \frac{W}{q}$$

- The emf of the cell depends only on the nature of electrodes and electrolyte. It is constant for a given type of cell.

• Internal Resistance

The resistance offered by a cell is called internal resistance. It depends upon the surface area of the electrodes $\left(r \propto \frac{1}{A}\right)$, distance between the electrodes ($r \propto d$), the temperature of electrolyte (it decreases with increase in temperature), concentration and nature of the electrolyte.

It is more for more concentration and less for less concentration.

- If a resistor R is connected between positive and negative terminals of a cell of emf ε and internal resistance r as shown in figure, the current in the circuit will be

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

or $$\varepsilon = IR + Ir$$

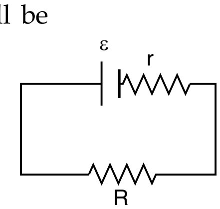


Fig. 3.4

- In terms of terminal voltage ($V = IR$) and internal drop ($X = Ir$),

$$E = V + X,$$

i.e., $$\frac{\varepsilon}{V} = \left[1 + \frac{X}{V}\right] = \left(1 + \frac{Ir}{IR}\right)$$

or $$\boxed{r = R\left[\frac{\varepsilon}{V} - 1\right]}$$

- When the cell is **discharging**, *i.e.,* current inside the cell is from negative terminal to the positive terminal. $V = \varepsilon - Ir$ or $\boxed{I = \frac{\varepsilon}{(R + r)}}$
- When cell is charging, *i.e.,* current inside the cell is from positive terminal to the negative terminal. $V = \varepsilon + Ir$ or $\boxed{I = \frac{(V - \varepsilon)}{r}}$
- When cell is in the open circuit, *i.e.,* external resistance between negative terminal and positive terminal is infinity, *i.e.,* $R = \infty$

$\therefore$ $$I = \frac{\varepsilon}{r + \infty} = 0 \quad \text{or} \quad Ir = 0$$

So $$V = \varepsilon - Ir = \varepsilon$$

- In open circuit emf and terminal voltage are same and equal to the maximum value of voltage which a cell can provide.
- When the cell is short-circuited, *i.e.,* external resistance between the negative and positive terminals is zero.

$\therefore$ $$I = \frac{\varepsilon}{r} \quad \text{or} \quad V = 0$$

i.e., short circuit current of a cell is maximum while terminal voltage is zero

- **Combination of Resistors**

(*i*) **Series combination.** When resistors are connected one by one and equal current is passed through all, the combination is called series combination as shown in the figure. Let R_1, R_2 and R_3 resistors are connected in series. The potential drop across R_1, R_2 and R_3 respectively is given by

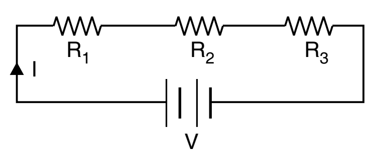


Fig. 3.5

$$V_1 = IR_1, \quad V_2 = IR_2 \quad \text{and} \quad V_3 = IR_3$$

but $$V = V_1 + V_2 + V_3$$

If R be the equivalent resistance of the combination, then $V = IR$

or $$IR = IR_1 + IR_2 + IR_3$$

or $$\boxed{R = R_1 + R_2 + R_3}$$

(*ii*) **Parallel combination.** When resistors are connected across two same points and kept at the same potential difference, the combination is called parallel combination. Let resistors R_1, R_2 and R_3 are connected in parallel as shown in the figure. The current in resistors R_1, R_2 and R_3 respectively can be given as

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

and $$I_3 = \frac{V}{R_3}$$

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

If R be the equivalent resistance, then

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

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

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

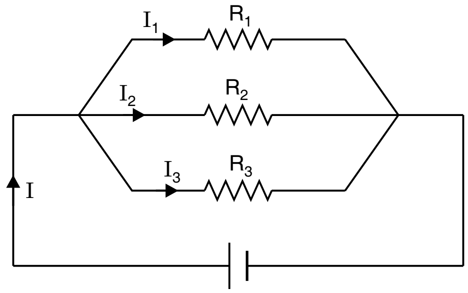


Fig. 3.6

- **Combination of Cells**

(*i*) **Series Combination.** Let n identical cells each of emf ε and internal resistance r are connected in series.

The net emf $= \varepsilon + \varepsilon + \ldots\ \varepsilon$

$= n\varepsilon$

and net internal resistance $= nr$

The total resistance of the circuit

$= nr + R$

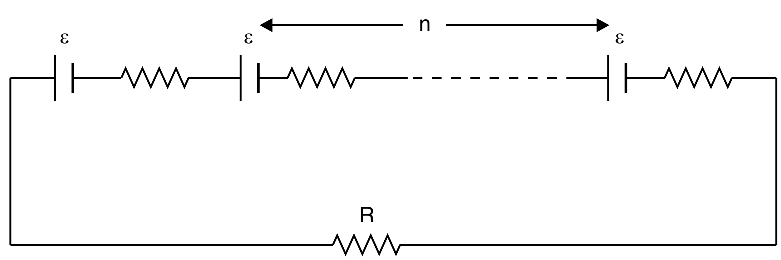


Fig. 3.7

Current in the circuit,

$$\boxed{I = \frac{n\varepsilon}{nr + R}}$$

If $r << R$, then nr can be neglected and $I = \frac{n\varepsilon}{R}$.

The current will be n times the current of a single cell.

(*ii*) **Parallel combination of cells.** Let m cells each of emf ε and internal resistance r are connected in parallel as shown in the figure.

The net emf = ε

The net internal resistance

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

The total resistance of the circuit,

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

∴ The current in the circuit,

$$I = \frac{m\varepsilon}{r + mR}$$

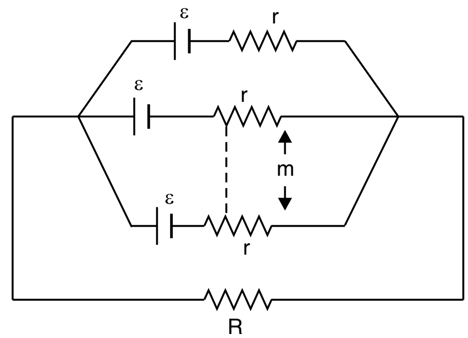


Fig. 3.8

If, $R << r$, mR can be neglected and

$$I = m\frac{\varepsilon}{r}$$

The current will be m times the current of a single cell.

(*iii*) **Mixed grouping of the cell.** When $r \nless R$ and $r \ngtr R$, then mix grouping of the cells is preferred. Let n cells each of emf ε and internal resistance r are connected in series and such m series are connected in parallel as shown in the following figure.

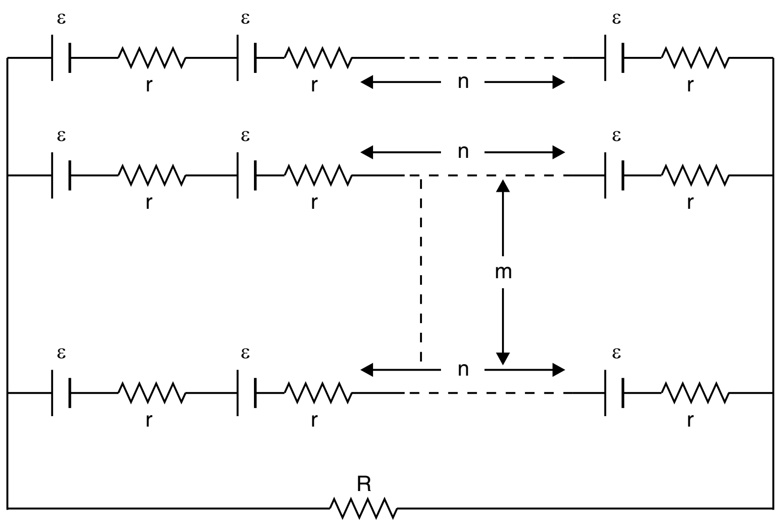


Fig. 3.9

The total emf = $n\varepsilon$

and total internal resistance

$$= \frac{nr}{m}$$

and the net resistence= $\frac{nr}{m} + R + \frac{nr + mR}{m}$

∴ The current,

$$I = \frac{n\varepsilon}{(nr + mR)/m} = \frac{mn\varepsilon}{nr + mR}$$

or

$$I = \frac{mn\varepsilon}{nr + mR}$$

- For maximum current, $nr + mR$ must be minimum

$\because \quad (nr + mR)^2 = (nr - mR)^2 + 4\,mnrR$

$\because \quad m, n, r \text{ and } R \neq 0$

$\therefore$ for $(nr + mR)^2$ is equal to zero the $(nr - mR)^2 = 0$

$\Rightarrow \quad nr - mR = 0$

or $\quad r = \dfrac{mR}{n}$

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

$\Rightarrow$ internal resistance = external resistance.

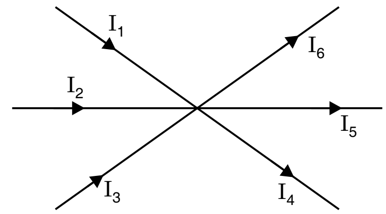


Fig. 3.10

- **Kirchhoff's Rules of Electricity**

(*i*) **Junction rule or point rule.** It states that algebraic sum of all currents meeting at a point is zero.

$$\Sigma I = 0$$

The current coming towards I_3 the point are taken as positive and the current going away from the point are taken as negative. In Fig.

$$I_1 + I_2 + I_3 - I_4 - I_5 - I_6 = 0$$

or $\quad I_1 + I_2 + I_3 = I_4 + I_5 + I_6$

i.e., current coming = current going.

(*ii*) **Loop rule.** It states that the algebraic sum of the emfs in a closed circuit is equal to the algebraic sum of the product of current and respective resistances.

$$\Sigma \varepsilon = \Sigma IR$$

In Fig. for loop ABCDA

$$\varepsilon_1 = (I_1 + I_2)\, R_2 + I_1 R_1$$

and for closed loop ABCDFEA

$$\varepsilon_1 - \varepsilon_2 = I_1 R_1 - I_2 R_3$$

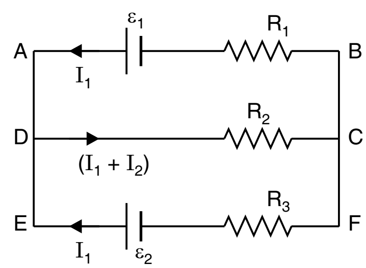


Fig 3.11

- **Wheatstone Bridge**

Wheatstone bridge is a network of four resistors say *P*, *Q*, *R* and *S* in the form of an quadrilateral having a galvanometer in one diagonal and the battery in another diagonal as shown in the figure.

In the given circuit, the current is following as shown in the figure.

Applying the Kirchhoff's loop rule for closed loop ABDA, BDCB and EABCE respectively.

$$I_1 P + I_g G - (I - I_1)\, R = 0 \qquad ...(i)$$

$$I_g G + (I - I_1 + I_g)\, S - (I_1 - I_g)\, Q = 0 \qquad ...(ii)$$

and $\quad I_1 P + (I_1 - I_g)\, Q = \varepsilon$

These equations can be solved for I, I_1 and I_g and hence quantities of interest may be evaluated. If potential of *B* and *D* points are same,

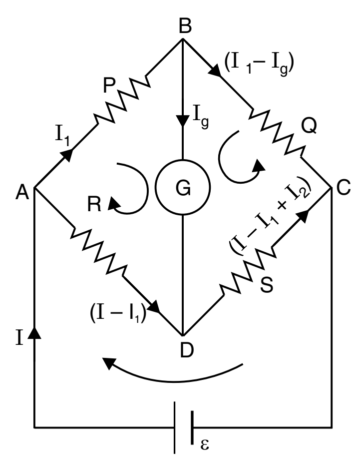


Fig. 3.12

no current will flow through galvanometer ($I_g = 0$) and bridge is said to be balanced. The above equations (*i*) and (*ii*) can be written as

$$I_1P - (I - I_1)\, R = 0 \quad \text{or} \quad I_1P = (I - I_1)\, R$$

and $$(I - I_1)\, S - I_1Q = 0 \quad \text{or} \quad I_1Q = (I - I_1)\, S$$

$\Rightarrow$ $$\frac{I_1P}{I_1Q} = \frac{(I - I_1)\, R}{(I - I_1)\, S} \Rightarrow \frac{P}{Q} = \frac{R}{S}$$

- **Meter Bridge**

It is a device used to measure the resistance and resistivity of the given wire. It has a a one metre long wire fastened on a wooden plank. Two L shaped metallic strips are attached to the end of a wire and an *I* shaped strip between the *L* shaped strips with small gaps on both sides as shown in Fig. 3.13. A resistance box and unknown resistance *S* is connected between the two gaps as shown in the Fig. 3.13.

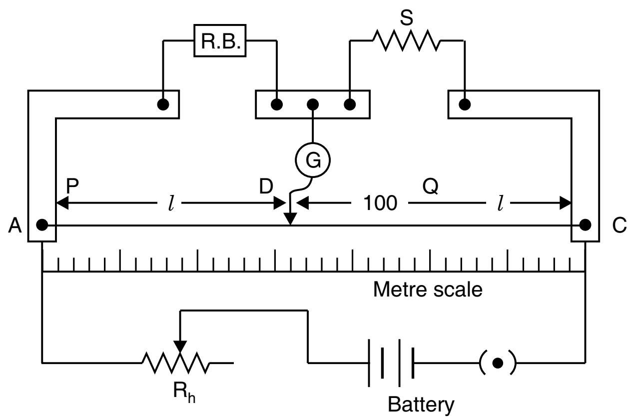


Fig. 3.13

The jockey connected to the galvanometer between *B* and *D* can be shifted on wire *AC* in such a way that galvanometer shows null deflection. For $I_g = 0$, the bridge becomes balanced and

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

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

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

where *R* is the resistance from resistance box and *S* is the unknown resistance *P* and *Q* be the resistances of *AD* and *DC* part of the wire.

If *r* be the radius and *n* the length of the resistance wire, then the resistivity of the unknown resistance wire

$$\rho = \frac{SA}{n} = \frac{R\,(100 - l)\,\pi r^2}{n\,.\,l}$$

- **Potentiometer**

It is a device used to compare the emfs of primary cells and to determine the internal resistance of the cell. It consists of resistance R through which a steady flows as shown in Fig. 3.14. When a source of precisely emf E_S is connected between points A and B and the jockey is adjusted till no current flows in the galvanometer by 'loop rule'.

$$E_s = IR_s$$

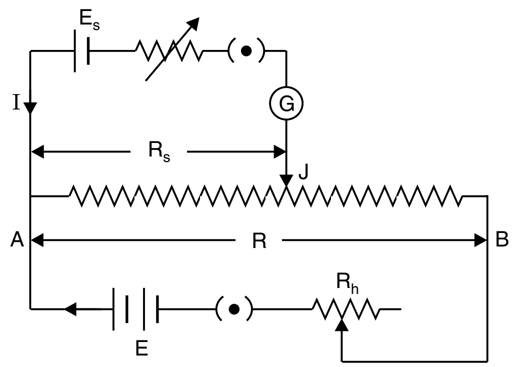


Fig. 3.14

Now replacing the source E_s by unknown potential difference V (to be measured), the balance point is achieved by shifting the jockey for value R_x so that $V = IR_x$ and hence

$$V = \frac{R_x}{R_s} E_s = \frac{L_x}{L_s} E_s \qquad [\text{as } R \propto L]$$

or $$V = KL_x \text{ with } K = \frac{E_s}{L_s} = \text{Potential gradient}$$

- Though the deriving emf ε and resistances r and R do not need to be known, they must remain same during the whole experiment from the time the first balance is obtained (otherwise) I will not remain same.
- Usually the first balance (called standardisation is obtained by fixing the jockey at point B at a given length L_s and adjusting I by means of r so that $K = (E_s/L_s)$ becomes a simple ratio.
- A balance point will be obtained only if the source of potential difference V is connected between A and B with the same polarity and its potential difference V is lesser than that across R.
- In this method, no current is drawn from the source of potential difference V, the potentiometer acts like a voltmeter of infinite resistance (*i.e.,* open circuit voltage) hence it acts as an ideal voltmeter and can measure emf or potential difference more accurately.
- The sensitivity of potentiometer can be increased by decreasing potential gradient K, *i.e.,* by increasing the length L_s of potentiometer wire for a given E_s. Modern potentiometer can measure potentials in steps of 1 MV with an accurancy of 10^{-3}%.
- In the given circuit of potentiometer to measure the internal resistance of cell ε_s.

  The balance point of length l is obtained without applying any resistance from resistance box.

  ∴ $\varepsilon \propto l$ ...(*i*)

  Now balance point obtained again for a resistance R applying from resistance box for length l'

  ∴ $V \propto l'$ ...(*ii*)

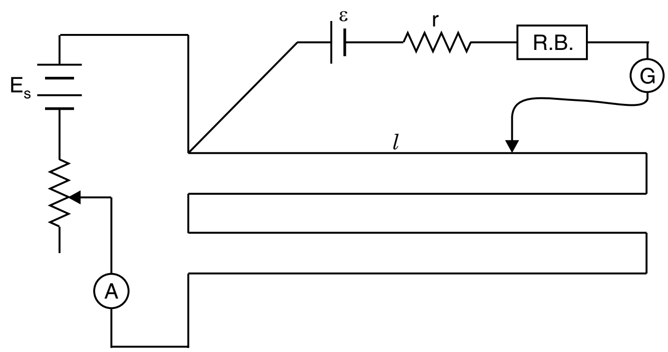


Fig. 3.15

From Eqs. (*i*) and (*ii*)

$$\frac{\varepsilon}{V} = \frac{l}{l'}$$

or
$$\frac{V + Ir}{V} = \frac{l}{l'}$$

or
$$1 + \frac{Ir}{V} = \frac{l}{l'}$$

or
$$\frac{r}{R} = \frac{l}{l'} - 1$$

or
$$r = R\frac{(l - l')}{l'}$$

- To compare the emfs of two primary cells ε_1 and ε_2 in the given circuit of potentiometer first balance point is obtained for ε_1 cell in the circuit only for length l_1.

  ∴ $$\varepsilon_1 \propto l_1 \quad ...(i)$$

  Now balance point obtained again for the cell of emf ε_2 only for length l_2.

  ∴ $$\varepsilon_2 \propto l_2 \quad ...(ii)$$

  From Eqs. (*i*) and (*ii*)

  $$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

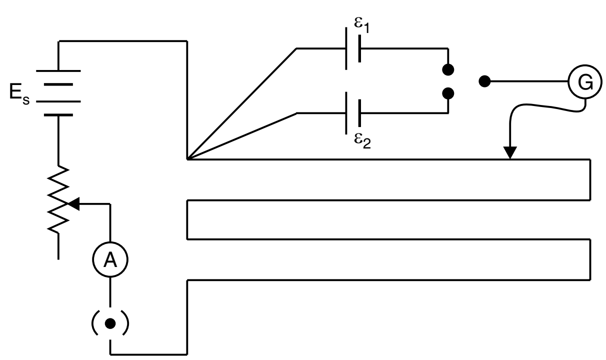


Fig. 3.16

• Heating Effect of Electric Current

When potential difference is applied across a conductor of resistance *R*, the free electrons in a conductor moves from lower potential to higher potential and strike with the atoms of the conductor inelastically. In these inelastic collisions the energy is released in the form of heat. This heat released is equal to the amount of work done

∴ $$H = \text{Work done}$$

$$= V_q$$

$$\boxed{H = VIt}$$

or $$H = I^2Rt$$

or $$H = \frac{V^2}{R}t$$

- The electric power is the rate of doing work,

$$P = \frac{W}{t} = \frac{VIt}{t}$$

or $$\boxed{P = VI}$$

or $$P = I^2R$$

or $$P = \frac{V^2}{R}$$

The S.I. unit of electric power is watt.

- Kilowatt hour is the electrical energy consumed by a device of power one kilowatt in one hour.

$$1 \text{ KWH} = 3.6 \times 10^6 \text{ J}$$

- If an electric bulb of power P rated at voltage V is operated at voltage V', then power consumed by the bulb,

$$\boxed{P' = \left(\frac{V'}{V}\right)P}$$

- If bulbs of power P_1 and P_2 are connected in parallel, the equivalent power of the combination will be

$$\boxed{P = P_1 + P_2}$$

- If bulbs of power P_1 and P_2 are connected in series, then equivalent power of the combination P is given by

$$\boxed{\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2}}$$

- Power transfer to the load by the cell will be

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

i.e., P will be minimum when $R = 0$ or ∞

and will be maximum when $\frac{dP}{dR} = 0$

i.e., $$\frac{d}{dR}\left[\frac{\varepsilon^2 R}{(R+r)^2}\right] = 0$$

i.e., $$\frac{d}{dR}[R(R+r)^{-2}] = 0 \qquad (\because \quad \varepsilon \neq 0)$$

$\Rightarrow \quad (R + r)^{-2} + R(-2)(R + r)^{-3} = 0$

or $\quad (R + r)^{-3}(r - R) = 0$

i.e., $\quad r = R \quad \text{as} \quad (R + r)^{-3} \neq 0$

Thus power transfer to the load by a cell is maximum

When $\quad R = r$

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

This is called maximum '**power transfer theorem**'.

The variation of power with external resistance R is shown in Fig. 3.17

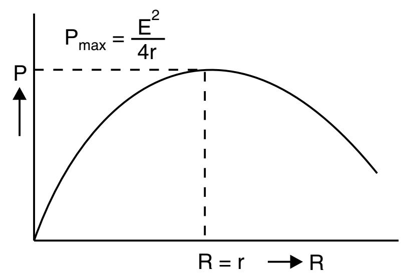


Fig. 3.17

QUESTIONS FROM TEXTBOOK

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

Sol. When the external resistance in the circuit is zero *i.e.,* $R = 0$ then the maximum current is drawn from a battery.

Given, $\quad \varepsilon = 12 \text{ V}, \quad r = 0.4$

$$\boxed{I_{max} = \frac{\varepsilon}{r}} = \frac{12}{0.4} = 30 \text{ A}$$

3.2. *A battery of emf 10 V and internal resistance 3 Ω 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?*

Sol. Since, $\quad \boxed{I = \frac{\varepsilon}{R + r}}$

or $\quad R = \frac{\varepsilon}{I} - r$

Putting given values $\varepsilon = 10$ V, $r = 3\ \Omega$ and

$I = 0.5$ A

$$R = \frac{10}{0.5} - 3 = 17\ \Omega$$

Terminal voltage, $\quad V = IR = 0.5 \times 17 = 8.5$ V

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

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

Sol. (*a*) Resistance of series combination

$$\boxed{R = R_1 + R_2 + R_3}$$

$$= 1 + 2 + 3 = 6\ \Omega$$

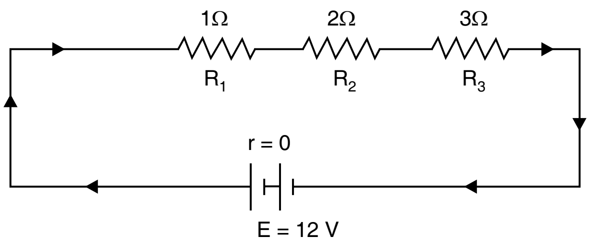


Fig. 3.18

(b) Current through the circuit,

$$I = \frac{E}{R+r} = \frac{12}{6+0} A = 2\text{A}$$

Potential drop across R_1 = 2 × 1 V = 2 V
Potential drop across R_2 = 2 × 2 V = 4 V
Potential drop across R_3 = 2 × 3 V = 6 V

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

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

Sol. (a) Total resistance of parallel combination,

$$\boxed{\frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} \text{ or } \frac{1}{R} = \frac{1}{2}+\frac{1}{4}+\frac{1}{5} = \frac{10+5+4}{20} = \frac{19}{20}\,\Omega$$

or $$R = \frac{20}{19}\,\Omega$$

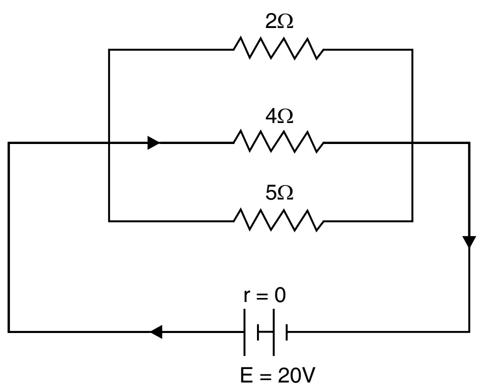


Fig. 3.19

(b) Given, voltage across the parallel

Combination V = 20 volt

Let the current through resistances 2Ω, 4Ω and 5Ω are I_1, I_2 and I_3 respectively.

Now, $$I_1 = \frac{V}{R_1} = \frac{20}{2} = 10\text{ A}$$

$$I_2 = \frac{V}{R_2} = \frac{20}{4} = 5\text{ A}$$

$$I_3 = \frac{V}{R_3} = \frac{20}{5} = 4 \text{ A}$$

Total current, $I = I_1 + I_2 + I_3 = 10 + 5 + 4 = 19$ A.

3.5. *At room temperature (27.0 °C) the resistance of a heating element is 100 Ω. What is the temperature of the element if the resistance is found to be 117 Ω, given that the temperature co-efficient of the material of the resistor is 1.70×10^{-4} °C^{-1}.*

Sol. Given, $R_t = 117, \quad R_{27} = 100$

Since, $\boxed{R_t = R_{27} [1 + \alpha (t - 27)]}$

Putting values,

$$117 = 100 [1 + 1.70 \times 10^{-4} (t - 27)]$$

$$t = 1000 + 27 = 1027 \text{ °C}$$

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

Sol. Given, $R = 5$ W

$l = 15$ m

$A = 6 \times 10^{-7}$ m^2 (Area of cross-section of wire)

Resistivity $\boxed{P = \frac{RA}{l}} = \frac{5 \times 6.0 \times 10^{-7}}{15}$

$= 2.0 \times 10^{-7}$ Ωm.

3.7. *A silver wire has a resistance of 2.1 Ω at 27.5 °C, and a resistance of 2.7 Ω at 100 °C. Determine the temperature co-efficient of resistivity of silver.*

Sol. Given, $R_1 = 2.1$ Ω, $t_1 = 27.5$ °C, $R_2 = 2.7$ Ω

$t_2 = 100$ °C

Since, $\boxed{R_2 = R_1 [1 + \alpha (t_2 - t_1)]}$

or,
$$\alpha = \frac{R_2 - R_1}{R_1 (t_2 - t_1)} = \frac{2.7 - 2.1}{2.1 (100 - 27.5)}$$

$$= \frac{0.6}{2.1 \times 72.5}$$

$$= \frac{0.6}{152 \cdot 25} = 0.0039 \text{ °C}^{-1}$$

3.8. *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 2.8 A. What is the steady temperature of the heating element if the room temperature is 27.0°C? Temperature co-efficient of resistance of nichrome averaged over the temperature range involved is 1.70×10^{-4} °C^{-1}.*

Sol. Here,
$$R_1 = \frac{230}{3.2} = 71.87 \text{ Ω}$$

$$R_2 = \frac{230}{2.8} = 82.14 \text{ Ω}$$

$$\alpha = 1.7 \times 10^{-4} \text{ °C}^{-1}$$

$$t_1 = 27°$$

Since, $\boxed{R_2 = R_1 [1 + \alpha (t_2 - t_1)]}$

Thus, $t_2 = \dfrac{R_2 - R_1}{R_1 \cdot \alpha} + t_1$

or, $t_2 = \dfrac{82.14 - 71.87}{71.87 \times 1.7 \times 10^{-4}} + 27$

$= 840.56 + 27$

$= 867.56\ °C$

$= 867\ °C.$

3.9. *Determine the current in each branch of the network shown in figure.*

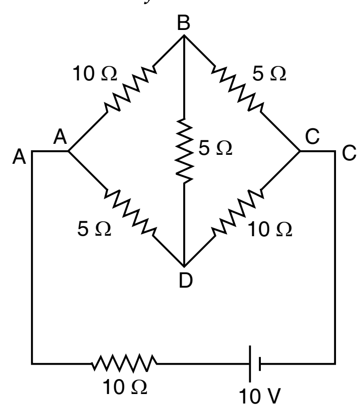


Fig. 3.20

Sol. Applying Kirchhoff's second law to the mesh *ABDA*,

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

or $$3I_1 - I + I_g = 0 \qquad ...(i)$$

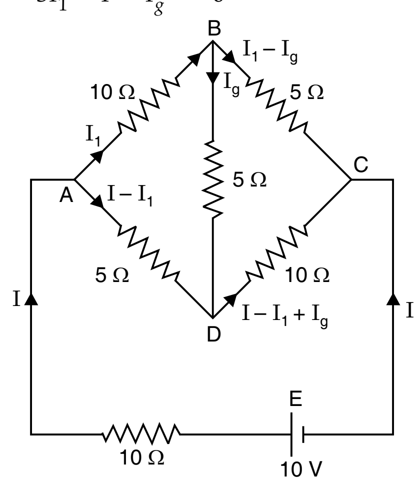


Fig. 3.21

Again, applying Kirchhoff's second law to the mesh *BDCB*,

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

or $$3I_1 - 2I - 4I_g = 0 \qquad ...(ii)$$

Applying Kirchhoff's second law to the mesh *ABCEA*,

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

or $$3I_1 + 2I - I_g = 2 \quad ...(iii)$$

Adding (*i*) and (*iii*), we get

$$6I_1 + I = 2 \quad ...(iv)$$

Multiplying (*i*) by 4 and adding in (*ii*), we get

$$15I_1 - 6I = 0 \quad ...(v)$$

Solving equations (*iv*) and (*v*), we get

$$I_1 = \frac{4}{17} A = 0.235 \text{ A}$$

So, current in branch *AB* is 0.235 A.

Putting the value of I_1 in equation (*v*) and simplifying, we get

Total current, $$I = \frac{10}{17} = 0.588 \text{ A}$$

Putting the values of *I* and I_1 in equation (*iii*) and simplifying, we get

$$I_g = \frac{2}{17} A = -0.118 \text{ A}$$

The negative sign indicates that the direction of current is opposite to that shown in Fig. above.

So, current in branch *BD* is "– 0.118 A".

Current in branch *BC* is $(I_1 - I_g)$ *i.e.,* $\frac{4}{17} - \left(-\frac{2}{17}\right)$

i.e., $\frac{6}{17}$ or 0.353 A.

Current in branch *AD* is $(I - I_1)$

i.e., $\left(\frac{10}{17} - \frac{4}{17}\right)A$ *i.e.,* $\frac{6}{17}A$ or 0.353 A

Current in branch *DC* is $(I_1 - I_1 + I_g)$

i.e., $\frac{6}{17} + \left(-\frac{2}{17}\right)A$ or $\frac{4}{17}A$ or 0.235 A

3.10. *(a) In a metre bridge, the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5 Ω. Determine the resistance of X. Why are the connections between resistors in a Wheatstone or Meter bridge made of thick copper strips?*

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

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

Sol. (a) Here, $l = 39.5$ cm, $R = X = ?$, $S = Y = 12.5\ \Omega$

$$S = \frac{100 - l}{l} \times R$$

$$\therefore \quad 12.5 = \frac{100 - 39.5}{39.5} \times X$$

or $$X = \frac{12.5 \times 39.5}{60.5} = 8.16\,\Omega$$

Thick copper strips are used to minimise resistance of the connections which are not accounted in the formula.

(*b*) As X and Y are interchanged, therefore, l_1 and l_2 (*i.e.*, lengths) are also interchanged.

Hence, $l = 100 - 39.5 = 60.5$ cm

(*c*) The galvanometer will show no current.

3.11. *A storage battery of emf 8.0 V and internal resistance 0.5 Ω is being charged by a 120 V dc supply using a series resistor of 15.5 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?*

Sol. Charging current,

$$I = \frac{V_a - E}{R + r} \quad \left[\begin{array}{l} V_a \rightarrow \text{supply voltage} \\ E \rightarrow \text{E.m.f of battery} \\ R \rightarrow \text{External resistance} \\ r \rightarrow \text{internal resistance} \end{array}\right.$$

or, $$I = \frac{120 - 8}{15.5 + 0.5}$$

$$= \frac{112}{16} = 7A$$

Terminal voltage, $V = E + I\,r = 8 + 7 \times 0.5 = 11.5$ V

The series resistor limits the current from the external source. In its absence, the current may be dangerously high.

3.12. *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?*

Sol. $$\boxed{\frac{E_2}{E_1} = \frac{l_1}{l_2}}.$$ substituting values,

$$\frac{E_2}{1.25} = \frac{63}{35} \quad \text{or} \quad E_2 = 1.25 \times \frac{63}{35} \text{ volt} = 2.25 \text{ volt}$$

3.13. *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 3.0 m long to its other end? The area of cross-section of the wire is 2.0 × 10^{-6} m^2 and it is carrying a current of 3.0 A.*

Sol. $n = 8.5 \times 10^{28}$ m^{-3}, $I = 3.0$ A,

$A = 2.0 \times 10^{-6}$ m^2, $l = 3.0$ m, $e = 1.6 \times 10^{-19}$ C

Drift velocity, $$\boxed{v_d = \frac{I}{neA}}$$

$$= \frac{3}{8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.0 \times 10^{-6}} \text{ m s}^{-1}$$

$$= 1.103 \times 10^{-4} \text{ m s}^{-1}$$

Time taken by electron to drift from one end to another,

$$t = \frac{l}{v_d} = \frac{3.0}{1.103 \times 10^{-4}} \text{ s} = 2.72 \times 10^4 \text{ s } (\approx 7.5 \text{ h}).$$

3.14. *The earth's surface has a negative surface charge density of 10^{-9} C m^{-2}. The potential difference of 400 kV between the top of the atmosphere and the surface results (due to the low 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 neutralise the earth's surface? (This never happens in practice because there is a mechanism to replenish electric charges, namely the continual thunderstorms and lightning in different parts of the globe.)*

(Radius of earth = 6.37×10^6 m).

Sol. Given charge per unit area of surface of earth = 10^{-9} coulomb per sq. metre.

$$\text{Current } I = 1800 \text{ A}$$

The radius of earth 6370 km = 6.37×10^6 m

Charge on entire surface of the earth

$$= 4\pi (6.37 \times 10^6)^2 \times 10^{-9} \text{ C}$$

As the rate of flow of charge is 1800 C per second, time required for the flow of entire charge

$$= \frac{4 \times 3.14 \times \left(6.37 \times 10^6\right)^2 \times 10^{-9}}{1800} = 283 \text{ seconds.}$$

3.15. *(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 8.5 Ω. What are the current drawn from the supply and its terminal voltage?*

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

Sol. (*a*) Here, $E = 2.0$ V, $n = 6$, $r = 0.015$ Ω

and $R = 8.5$ Ω

Current, $$\boxed{I = \frac{nE}{R + nr}} = \frac{6 \times 2.0}{8.5 + 6 \times 0.015} = 1.4\text{A}$$

Terminal voltage $V = IR = 1.4 \times 8.5 = 11.9$ V

(*b*) Given, $E = 1.9$ V, $r = 380$ Ω

$$\boxed{I_{max} = \frac{E}{r}} = \frac{1.9}{380}$$

or $I_{max} = 0.005$ A

This amount of current cannot start a car because to start the motor, the current required is 100 A for few second.

3.16. *Two wires of equal length, one of aluminium and the other of copper have the same resistance. Which of the two wires is lighter? Hence explain why aluminium wires are preferred for overhead power cables. ($\rho_{Al} = 2.63 \times 10^{-8}$ Ω m, $\rho_{Cu} = 1.72 \times 10^{-8}$ Ω m, Relative density of Al = 2.7, of Cu = 8.9).*

Sol. $$R = \rho\frac{l}{A} = \rho\frac{l^2}{Al} = \frac{\rho l^2}{V} = \frac{\rho l^2 d}{m} \quad V = \frac{m}{d}$$

where V = volume of wire = Al

m = mass of wire

d = density of wire material

mass = volume × density = Ald

For aluminium wire, $$R_{Al} = \frac{\rho_{Al} l_{Al}^2 d_{Al}}{m_{Al}}$$

For copper wire, $$R_{cu} = \frac{\rho_{Cu} l_{Cu}^2 d_{Cu}}{m_{Cu}}$$

Since, $R_{Al} = R_{Cu}$ and $l_{Al} = l_{Cu}$

$$\therefore \quad \frac{\rho_{Al} l_{Al}^2 d_{Al}}{m_{Al}} = \frac{\rho_{Cu} l_{Cu}^2 d_{Cu}}{m_{Cu}}$$

or $$\frac{m_{Cu}}{m_{Al}} = \frac{\rho_{Cu} d_{Cu}}{\rho_{Al} d_{Al}} = \frac{0.72 \times 10^{-8} \times 8.9}{2.63 \times 10^{-8} \times 2.7} = 2.2.$$

It indicates that aluminium wire is lighter than copper wire. Therefore, aluminium wires are preferred in overhead cables.

3.17. *What conclusion can you draw from the following observations on a resistor made of alloy manganin?*

Current *A*	*Voltage* *V*	*Current* *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*	*138.2*
2.0	*39.4*	*8.0*	*158.0*

Sol.

$\frac{3.94}{0.2} = 19.7\ \Omega$ $\qquad \frac{59.2}{3.0} = 19.7\ \Omega$

$\frac{7.87}{0.4} = 19.67\ \Omega$ $\qquad \frac{78.8}{4.0} = 19.7\ \Omega$

$\frac{11.8}{0.6} = 19.66\ \Omega$ $\qquad \frac{98.6}{5.0} = 19.72\ \Omega$

$\frac{15.7}{0.8} = 19.62\ \Omega$ $\qquad \frac{118.5}{6.0} = 19.75\ \Omega$

$\frac{19.7}{1.0} = 19.7\ \Omega$ $\qquad \frac{138.2}{7.0} = 19.74\ \Omega$

$\frac{39.4}{2.0} = 19.7\ \Omega$ $\qquad \frac{158.0}{8.0} = 19.75\ \Omega$

Since the ratio of voltage and current for different readings is same so Ohm's law is valid to high accuracy. The *resistivity of alloy is nearly independent of temperature.*

3.18. *Answer the following questions:*

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

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

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

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

Sol. (*a*) Only current because it is given to be steady. The rest depends on the area of cross-section inversely.

(*b*) Ohm's law is not applicable for non-ohmic elements. For example; vacuum tubes, semi-conducting diode, liquid electrolyte etc. (see text).

(*c*) Maximum current drawn from a source = $\frac{E}{r}$.

(*d*) If accidently the circuit is shorted, the current drawn will exceed safety limit and will cause damage to circuit. Therefore, a high tension supply must have a large internal resistance.

3.19. *Choose the correct alternative:*

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

(b) Alloys usually have much (lower/higher) temperature co-efficients 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 ($10^{22}/10^{3}$).

Sol. (*a*) Greater

(*b*) lower

(*c*) nearly independent of

(*d*) 10^{22}

3.20. *(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 1 Ω, 2 Ω, 3 Ω, how will be combine them to get an equivalent resistance of (i) (11/3) Ω (ii) (11/5) Ω, (iii) 6 Ω, (iv) (6/11) Ω?

(c) Determine the equivalent resistance of networks shown in the figures (a) and (b) below.

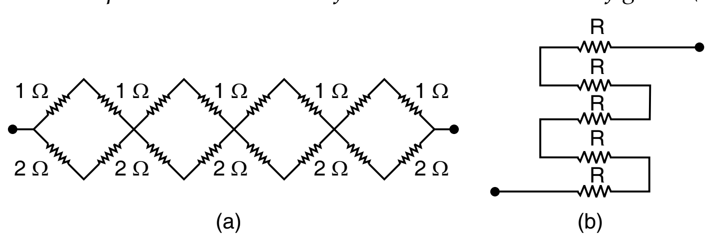


Fig. 3.22

Sol. (*a*) (*i*) all in series, (*ii*) all in parallel; n^2 $\because$ $\frac{R_S}{R_b} = \frac{nR}{\frac{R}{n}} = n^2$

(*b*) (*i*) Join 1 Ω, 2 Ω in parallel and the combination in series with 3 Ω. (*ii*) parallel combination of 2 Ω and 3 Ω in series with 1 Ω. (*iii*) all in series (*iv*) all in parallel.

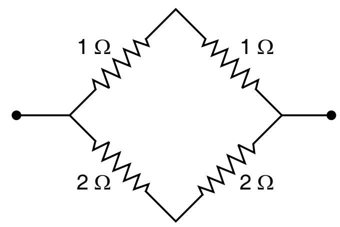


Fig. 3.23

(*c*) **Equivalent resistance of network in figure (*a*).** The given network is a series combination of four identical units. Let us consider one such unit shown in Fig. It is equivalent to a parallel combination of 2 Ω and 4 Ω. Its equivalent resistance is

$$R_p = \frac{2 \times 4}{2+4}\,\Omega \;\; i.e., \;\; \frac{8}{6}\,\Omega \;\; i.e., \;\; \frac{4}{3}\,\Omega$$

So, the given electrical network is a series combination of four resistors, each equal to $\frac{4}{3}\,\Omega$.

Thus, the combined resistance is $\frac{16}{3}\,\Omega$ or 5.33 Ω.

Equivalent resistance of network in fig. (*b*). Suppose a battery is connected between *A* and *B*. Same current will flow through all the resistors. So, all the resistors are connected in series.

$\therefore$ Equivalent resistance,

$$R_s = R + R + R + R + R = 5R$$

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

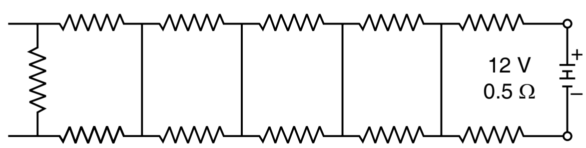


Fig. 3.24

Sol. Let *x* be the equivalent resistance of the infinite network. This network consists of infinite sets of three resistors of 1 Ω, 1 Ω and 1 Ω. Adding one more set across *AB* to the infinite network will not affect the equivalent resistance.

Resistance between *A* and *B*

$$R_p = \frac{x}{x+1} \qquad \left(\because \frac{1}{R} = \frac{1}{x} + \frac{1}{1}\right)$$

Resistance between *P* and *Q*

$$R_s = 1 + \frac{x}{x+1} + 1 = 2 + \frac{x}{x+1}$$

This must be equal to the initial resistance *x*

$$\therefore \qquad x = 2 + \frac{x}{x+1}$$

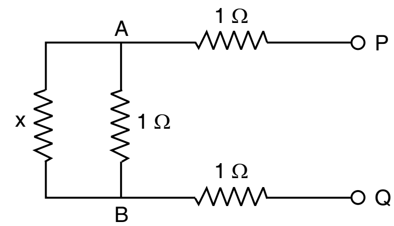


Fig. 3.25

$$\text{or} \qquad x + x^2 = 2 + 2x + x$$

$$x^2 - 2x - 2 = 0$$

$$x = \frac{2 \pm \sqrt{4+8}}{2} = 1 \pm \sqrt{3}$$

$$\text{But} \qquad x \neq 1 - \sqrt{3}$$

$$\therefore \qquad x = \left(1 + \sqrt{3}\right)\Omega = 2.732\ \Omega$$

$$\text{Current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{12}{2.732 + 0.5}$$

$$\text{or} \qquad I = 3.7 \text{ A.}$$

3.22. *Figure shows a potentiometer with a cell of 2.0 V and internal resistance 0.4 Ω 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 up to a few mA) 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 kΩ is put in series with it, which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf ε and the balance point found similarly, turns out to be at 82.3 cm length of the wire.*

(a) What is the value of ε?

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

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

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

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

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

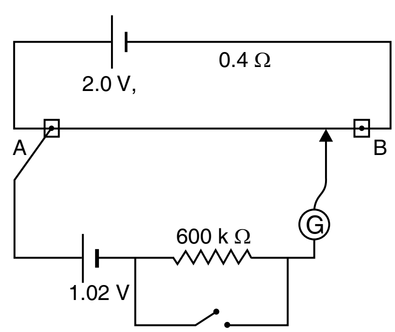


Fig. 3.26

Sol. (*a*) Here, $E_1 = 1.02$ V; $l_1 = 67.3$ cm; $E_2 = E = ?$; $l_2 = 82.3$ cm

Since, $\boxed{\dfrac{E_2}{E_1} = \dfrac{l_2}{l_1}}$ $\therefore\ E = \dfrac{l_2}{l_1} \times E_1 = \dfrac{82.3}{67.3} \times 1.02 = 1.247$ V.

(*b*) The purpose of using high resistance of 600 kΩ is to allow very small current through the galvanometer when the movable contact is far from the balance point.

(*c*) No, the balance point is not affected by the presence of this resistance.

(*d*) No, the balance point is not affected by the internal resistance of the driver cell.

(*e*) No, it is necessary that the emf of the driver cell is more than the emf of the cells.

(*f*) For measurement of small emf, this circuit will not work well.

The number of potentiometer wires is increased to 11 or 15 to get a potential gradient of 0.1 Vm^{-1}. The purpose discussed above will be served by a single 1 metre long wire with series resistance euqal to 10 or 14 wires.

3.23. *Figure shows a potentiometer circuit for comparison of two resistors. The balance point with a standard resistor R = 10.0 Ω is found to be 58.3 cm, while that with the unknown resistor 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 of emf ε?*

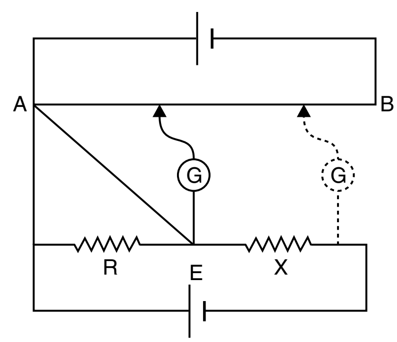


Fig. 3.27

Sol. Here, $\boxed{\dfrac{R}{X} = \dfrac{l_1}{l_2}}$

or, $X = R\dfrac{l_1}{l_2} = \dfrac{10 \times 68.5}{58.3} = 11.75\ \Omega$

The potential drop across *R* and *X* are greater than the potential drop across the potentiometer wire *AB* if there is no balance point. The obvious thing to do is to reduce the current in the outside circuit (hence the potential drop across *R* and *X*) suitably by putting a series resistor.

3.24. *Figure shows a 2.0 V potentiometer used for the determination of internal resistance of a 1.5 V cell. The balance point of the cell in open circuit is 76.3 cm. When a resistor of 9.5 Ω 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.*

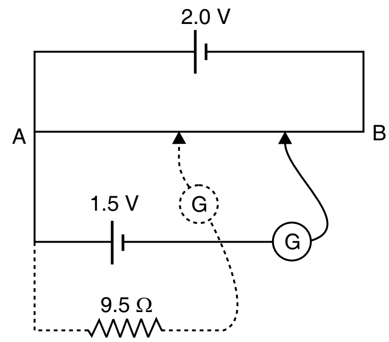


Fig. 3.28

Sol. $$r = \frac{R(E-V)}{V} = \frac{R(l_1 - l_2)}{l_2} = \frac{9.5(76.3-64.8)}{64.8} \text{ ohm} \qquad \left[\frac{E}{V} = \frac{l_1}{l_2}\right]$$

$$= \frac{9.5 \times 11.5}{64.8} \text{ ohm } = 1.686 \text{ ohm} \sim 1.7\ \Omega$$

MORE QUESTIONS SOLVED

I. VERY SHORT ANSWER TYPE QUESTIONS

Q. 1. *Write an expression for the resistivity of a metallic conductor showing its variation over a limited range of temperatures.*

Ans. The resistivity of a metallic conductor is given by

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

Where P_T be the resistivity at temperature T and ρ_0 be the resistivity at temperature T_0 and α be the temperature co-efficient.

Q. 2. *A (i) series (ii) parallel combination of two given resistors is connected, one-by-one, across a cell. In which case will the terminal potential difference, across the cell, have a higher value?*

Ans. Terminal potential difference of the cell is

$$V = \varepsilon - Ir$$

Terminal potential difference is higher in parallel combination as compared in series combination.

Q. 3. *State the reason, why Ga As is most commonly used in making of a solar cell.*

Ans. *Ga As* (gallium arsenide) is most commonly used in making of a solar cell because it absorbs relatively more energy from the incident solar radiations being of relatively higher absorption co-efficient.

Q. 4. *Define electromotive force of a cell.*

Ans. The potential difference between two poles of a cell, when no current is drawn from it, is called electromotive force (e.m.f.) of the cell.

Q. 5. *Explain how does the resistivity of a conductor depend upon (i) number density n of free electrons, and (ii) relaxation time τ.*

Ans. Resistivity ρ of a metal conductor is related with n and τ as

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

i.e., $$\rho \propto \frac{1}{n} \quad \text{and} \quad \rho \propto \frac{1}{\tau}$$

Q. 6. *Calculate the conductivity of a wire of length 2 m, area of cross-section 2 cm^2 and resistance 10^{-4} Ω.*

Ans. Electrical conductivity,

$$\boxed{\sigma = \frac{1}{\rho}} = \frac{l}{RA} = \frac{2}{10^{-4} \times \left(2 \times 10^{-4}\right)}$$

$$= 10^8 \text{ Sm}^{-1}$$

Q. 7. *Three identical cells each of e.m.f. 2 V and unknown internal resistance are connected in parallel. This combination is connected to a 5 ohm resistor. If the terminal voltage across the cells is 1.5 volt, what is the internal resistance of each cell?*

Ans. Effective emf of three cells in parallel. ε = 2 V; Effective internal resistance of each three cells in parallel, when internal resistance of each cell is $r \approx r/3$; Total resistance of circuit $= \frac{r}{3} + R$.

$$\boxed{V = \frac{\varepsilon R}{r + R}}$$

Terminal voltage, $$V = \frac{\varepsilon \times R}{(r/3) + R} \quad \text{or} \quad 1.5 = \frac{2 \times 5}{(r/3) + 5} \quad \text{or} \quad r = 5\ \Omega$$

Q. 8. *A resistance coil develops heat of 800 cal/sec when 20 volt is applied across its ends. Find the resistance of the coil (1 cal. = 4.2 joule). ∴ 1 cal = 4.2 J*

ρ = 800 cal/sec = 800 × 4.2 J/s

ρ = 800 × 4.2 Watt.

Ans. $$P = \frac{V^2}{R} \quad \text{or} \quad R = \frac{V^2}{P} = \frac{(20)^2}{800 \times 4.2} = \mathbf{0.12}\ \Omega.$$

Q. 9. *A 60 watt bulb carries a current of 0.5 ampere. Find the total charge passing through it in 1 hour.*

Ans. Charge, $q = It$ = 0.5 × (60 × 60) = **1800 coulomb.**

Q. 10. *Two electric bulbs A and B are marked 220 V, 40 W and 220 V, 60 W respectively. Which one of these bulbs has higher resistance?*

Ans. 40 W bulb; $P = V^2/R$ or $R = V^2/P$ *i.e.,* $R \propto 1/P$.

Q. 11. *Which of the two has greater resistance: a 2 kilowatt heater or a 200 watt tungsten bulb, both marked for 250 volts?*

Ans. Resistance of heater, $$R_1 = \frac{V^2}{P_1} = \frac{(250)^2}{2000} = 31.25\ \Omega;$$

Resistance of bulb, $$R_2 = \frac{V^2}{P_2} = \frac{(250)^2}{200} = 312.5\ \Omega$$

So, the resistance of bulb is greater than that of heater.

Q. 12. *Sketch a graph showing variation of resistivity of carbon with temperature.*

Ans. The resistivity of carbon decreases with increasing temperature as shown in the figure below.

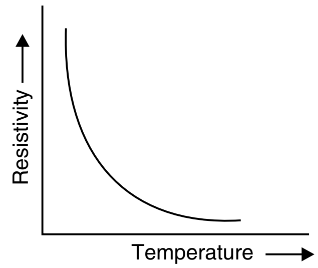


Fig. 3.29

Q. 13. *A wire of 'resistivity' ρ is stretched to twice its length. What will be its new resistivity ?*

Ans. Resistivity ρ remains unaffected.

Q. 14. *A carbon resistor has three strips of red colour on its surface and a gold strip at one end of it. What is the value of this resistance?*

Ans. $22 \times 10^2 \pm 5\% \ \Omega$.

Q. 15. *What are the units of conductance and conductivity?*

Ans. Siemen and Siemen metre^{-1}.

Q. 16. *Define electrical conductivity of a conductor and give its S.I. unit.*

Ans. The reciprocal of resistivity of the material of a conductor is called its conductivity *i.e.*

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

S.I. unit of σ is $\Omega^{-1}m^{-1}$. or Siemen per metre

Q. 17. *The coil of a heater is cut into two equal halves and only one of them is used into heater. What is the ratio of the heat produced by this half coil to that by the original coil?*

Ans. The resistance of half part of a coil = $R/2$

∴ Heat produced $\quad H' = \dfrac{V^2 t}{R/2}$

Original heat produced,

$$H = \frac{V^2 t}{R}$$

$$\therefore \qquad \frac{H'}{H} = 2.$$

Q. 18. *Write the condition under which the potential difference between the terminals of a battery and its emf are equal.*

Ans. When the internal resistance of battery is zero, the potential difference is equal to emf.

Q. 19. *A carbon resistance is marked in red, green and orange bands. What is the approximate resistance of the resistor?*

Ans. $25 \times 10^3 \ \Omega \pm 20\%$

Q. 20. *If the temperature of a good conductor decreases, how does the relaxation time of electrons in the conductor change?*

Ans. If the temperature of a good conductor decreases, its resistance decreases. Since $R = \frac{m}{ne^2\tau}\frac{l}{A}$ ≤ 0, $R \propto 1/\tau$ or $\tau \propto 1/R$; so time of relaxation increases.

Q. 21. *A current flowing in a copper wire is passed through another copper wire of the same length but of double the radius of the first one. How would the drift velocity of free electrons change?*

Ans. Drift velocity, $\boxed{v_d = \frac{I}{n\,Ae}} = \frac{I}{n\,\pi\,r^2 e}$ *i.e.,* $v_d \propto \frac{1}{r^2}$

$$\therefore \quad \frac{v_{d_2}}{v_{d_1}} = \frac{r^2}{(2r)^2} = \frac{1}{4}$$

$$\text{or} \quad v_{d_2} = \frac{1}{4} v_{d_1}$$

So, the drift velocity becomes one-fourth when radius of the conductor is doubled.

Q. 22. *A carbon resistor has colour code as blue, yellow and red respectively. What will be the resistance?*

Ans. $64 \times 10^2\ \Omega \pm 20\%$.

Q. 23. *A carbon resistor is marked in coloured bands in the sequence blue, green, orange and gold. What is the resistance and tolerance value of resistance?*

Ans. $65 \times 10^3\ \Omega \pm 5\%$.

Q. 24. *How does the drift velocity of electrons in a metallic conductor vary with increase in temperature?*

Ans. Drift velocity of electrons in a metallic conductor decreases as the temperature increases as number of collissions increases on increasing temperature.

Q. 25. *The given graph shows the variation of resistance of mercury in the temperature range $0 < T < 4$ kelvin. Name the phenomenon shown by the graph.*

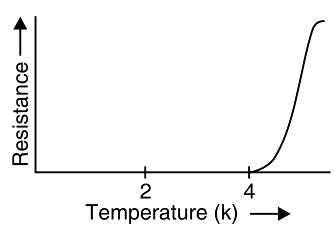


Fig. 3.30

Ans. Superconductivity.

Q. 26. *What is the significance of the direction of electric current?*

Ans. The direction of conventional electric current is opposite to the direction of flow of electron or (–) ve ions or in the direction of (+) ve ions.

Q. 27. *Suppose balance point is not obtained on the potentiometer wire. Give one possible cause for this.*

Ans. If the emf of the auxiliary battery is less than the emf of the cell to be measured, then the balance point will not be obtained on the potentiometer wire.

Q. 28. *It is possible to generate a 1,00,000 volt potential difference by rubbing a pocket comb with wool. Why is this voltage not dangerous when the much lower voltage provided by ordinary electric outlet is very dangerous?*

Ans. This is because the insulator (comb) has high resistance. So, the current is extremely small. Consequently, power is small.

Q. 29. *Would the galvanometer show any current if the galvanometer and cell are interchanged at the balance point of the bridge?*

Ans. No. The galvanometer will not show any current.

Q. 30. *Why is it easier to start a car engine on a warm day than on a chilly day?*

Ans. The internal resistance of a car battery decreases with increase in temperature.

Q. 31. *The resistivities of semiconductors and insulators decrease with increase of temperature. Why?*

Ans. As $\rho_t = \rho_0 (1 + \alpha_r t)$; α_r for semiconductor and insulator is negative.

Thus $\rho_t < \rho_0$.

II. SHORT ANSWER TYPE QUESTIONS

Q. 1. *Six resistors, each of value 4 Ω, are joined together in a circuit as shown in the figure. Calculate equivalent resistance across the points A and B. If a cell of emf 2V is connected across AB, compute the current through the arms AB and DF of the circuit.*

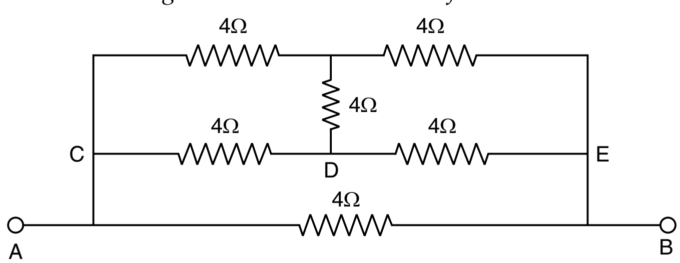


Fig. 3.31

Ans. The equivalent circuits are shown as arms ratio of resistances of Wheatstone bridge are equal. So, no current flows (current = 0) in resistor R_g.

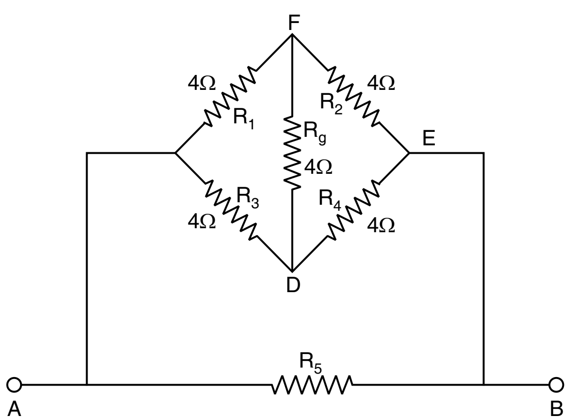


Fig. 3.32

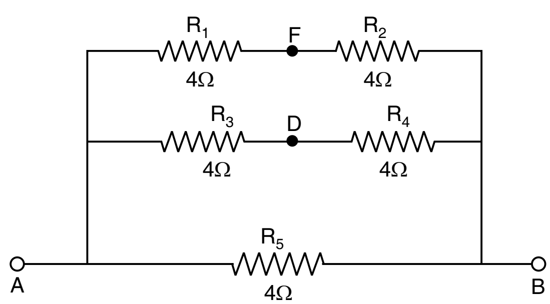


Fig. 3.33

$$R_{12} = R_1 + R_2 = 4 + 4 = 8\ \Omega$$

$$R_{34} = R_3 + R_4 = 8\ \Omega$$

Equivalent resistance across AB is given by

$$\frac{1}{R} = \frac{1}{R_{12}} + \frac{1}{R_{34}} + \frac{1}{R_5}$$

$$\frac{1}{R} = \frac{1}{8}+\frac{1}{8}+\frac{1}{4} = \frac{4}{8} = \frac{1}{2}$$

or $$R = 2\ \Omega$$

Current through arm $AB = \frac{V}{R} = \frac{2V}{2\Omega} = 1\text{A}$

Current through arm $DF = 0$ (Balanced Wheatstone Bridge)

Q. 2. *Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons.*

Ans. Consider a conductor of length l and area of cross-section A having n electrons per unit length, as shown in the figure.

Volume of the conductor = Al

$\therefore$ Total number of electrons in the

$$\text{Conductor} = \text{Volume} \times \text{electron density} = Aln$$

If C is the charge of an electron, then total charge contained in the conductor.

$$Q = en\ Al$$

Let the potential difference V is applied across the conductor. The resulting electric field in the conductor is given by

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

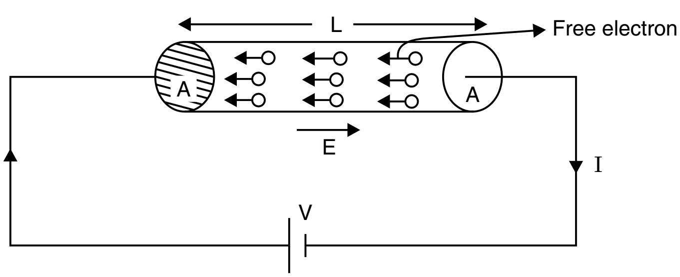


Fig. 3.34

Under the influence this field E, free electrons begin to drift in a direction opposite to that of the field. Time taken by electrons to cross-over the conductor is

$$t = \frac{l}{v_d}$$

Where v_d is the drift velocity of electrons. Therefore, current through the conductor is given by

$$I = \frac{Q}{t} = \frac{en\ Al}{l/v_d}$$

or $$I = ne\ A\ v_d \quad \Rightarrow \quad \frac{I}{A} = n_e v_d \text{ or } J = n_e v_d$$

$\Rightarrow$ $$I \propto v_d$$ [$\because$ n, e, A are all constant]

Thus, current density is proportional to drift velocity.

Q. 3. *Find the equivalent resistance of the circuit given across ab.*

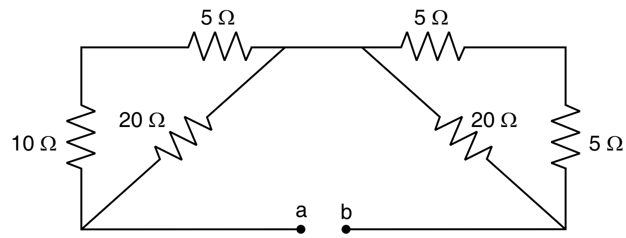


Fig. 3.35

Ans. As a first step the circuit may be redrawn as follows.

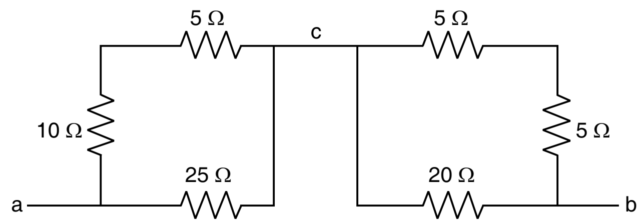


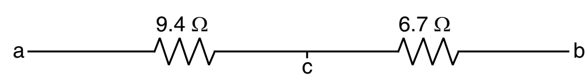
Fig. 3.36

The left block is equivalent to 15 ohm and 25 ohm in parallel

i.e., $$\frac{25 \times 15}{25 + 15} = 9.4 \ \Omega$$

The right block is equivalent to 10 ohm and 20 ohm in parallel

i.e., $$\frac{10 \times 20}{10 + 20} = \frac{200}{30} = 6.7 \ \Omega$$



The circuit now reduces as two resistors in series *i.e.,* 9.4 + 6.7 = **16.1 Ω**

Q. 4. *When a resistor of 20 Ω is connected in series with a battery, the current is 0.5 A. When a resistor of 10 Ω is connected, the current becomes 0.8 A. Calculate the emf and the internal resistance of the battery.*

Ans. Let E be the emf of the battery and r its internal resistance.

$$\boxed{E = I[R + r]}$$

Then $E = 0.5\ (20 + r)$ ...(1)

Also $E = 0.8\ (10 + r)$ ...(2)

$$0.5\ (20 + r) = 0.8\ (10 + r)$$

or $10 + 0.5\ r = 8 + 0.8\ r$

or $0.3\ r = 2, \quad r = 6.67\ \Omega$

Hence $E = 0.5 \times 26.67 = 13.34$ V

Q. 5. *(i) State the principle of working of a meter bridge.*

(ii) In a meter bridge balance point is found at a distance l_1 with resistors R and S as shown in the figure.

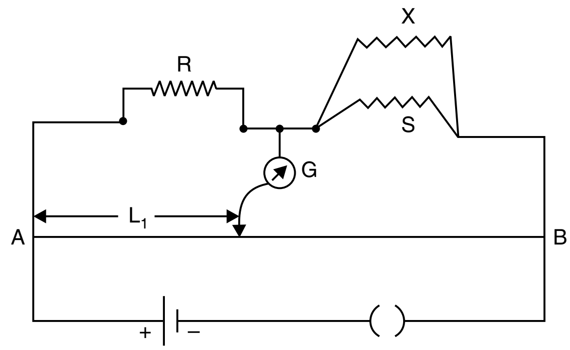


Fig. 3.37

When an unknown resistor X is connected in parallel with the resistor S, the balance point shift to a distance l_2. Find the expression for X in terms of l_1, l_2 and S.

Ans. (*i*) A slide wire bridge is known as meter bridge. It is constructed on the principle of balanced Wheatstone bridge, when a Wheatstone bridge is balanced then

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

(*ii*) **When resistors *R* and *S* are connected.** Since balance point is found at a distance l_1 from the zero and

$$\therefore \quad \frac{R}{S} = \frac{l_1}{100-l_1} \quad ...(i)$$

When unknown resistance X is connected in parallel to S.

$\therefore$ total resistance in the right h and gap is

$$S_1 = \frac{SX}{S+X} \qquad \left[\because \frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2} \Rightarrow R = \frac{R_1R_2}{R_1+R_2}\right]$$

Since the balance point is obtained at a distance l_2 from the zero end

$$\therefore \quad \frac{R}{S_1} = \frac{l_2}{100-l_2}$$

putting the value of S_1, we get

$$\frac{R}{\frac{SX}{S+X}} = \frac{l_2}{100-l_2}$$

$$\frac{R\left(S+X\right)}{SX} = \frac{l_2}{100-l_2} \quad ...(ii)$$

Dividing equation (*ii*) by (*i*), we get

$$\frac{R\left(S+X\right)}{SX}\cdot\frac{S}{R} = \frac{l_2}{100-l_2}\times\frac{100-l_1}{l_1}$$

$$\text{or,} \quad \frac{S+X}{X} = \frac{l_2\left(100-l_1\right)}{l_1\left(100-l_2\right)}$$

or, $\frac{S}{X}+\frac{X}{X} = \frac{l_2(100-l_1)}{l_1(100-l_2)}$

or, $\frac{S}{X}+1 = \frac{l_2(100-l_1)}{l_1(100-l_2)}$

or, $\frac{S}{X} = \frac{l_2(100-l_1)}{l_1(100-l_2)}-1$

$= \frac{100\,l_2 - l_1\,l_2 - 100\,l_1 + l_1\,l_2}{l_1(100-l_2)}$

or, $\frac{S}{X} = \frac{100(l_2-l_1)}{l_1(100-l_2)}$

Hence, $X = \frac{l_1(100-l_2)}{100(l_2-l_1)} - S$

Q. 6. *Three resistors of values 4 ohm, 6 ohm and 7 ohm are in series and a potential difference of 34 V is applied across the grouping. Find the potential drop across each resistor.*

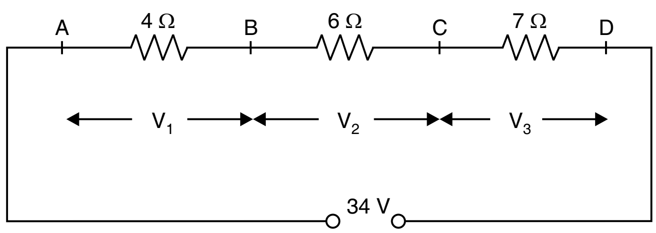


Fig. 3.38

Ans. The current through the circuit = $\frac{34V}{(4+6+7)\,\text{ohm}}$ = 2 A

potential difference across 4 ohm resistor = IR = 2 A × 4 ohm = **8 V**
potential difference across 6 ohm resistor = 2 A × 6 ohm = **12 V**
potential difference across 7 ohm resistor = 2 A × 7 ohm = **14 V**

Q. 7. *A wire of 20 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 4.0 volt battery. Find the current drawn from the battery.*

Ans. When any resistor is stretched to double its original length. The new resistance becomes four times of its original resistance as $R \propto \frac{1}{A}$ or $R \propto \frac{1}{\pi\left(\frac{d}{2}\right)^2}$

Here, R = 20 Ω and V = 4.0 volt

$\therefore$ New resistance = 4 R = 4 × 20 = 80Ω $R \propto \frac{4}{\pi d^2}$

Resistance of each part $\frac{80}{2}$ = 40 Ω (as divided in two parts)

$\therefore \quad R_1 = 40\ \Omega, \quad R_2 = 40\ \Omega$

Effective resistance in parallel combination R_P is

$$\frac{1}{R_P} = \frac{1}{40} + \frac{1}{40} = \frac{2}{40} = \frac{1}{20} \qquad \left[\because \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}\right]$$

$\therefore \quad R_P = 20\ \Omega$

$$\text{Current } I = \frac{V}{R_P} = \frac{4.0}{20} = 0.2 \text{ A.}$$

Q. 8. *Calculate the steady-state current in the 2 Ω resistor shown in Fig. The internal resistance of the battery is negligible and capacitance of the condenser is 0.2 μ F.*

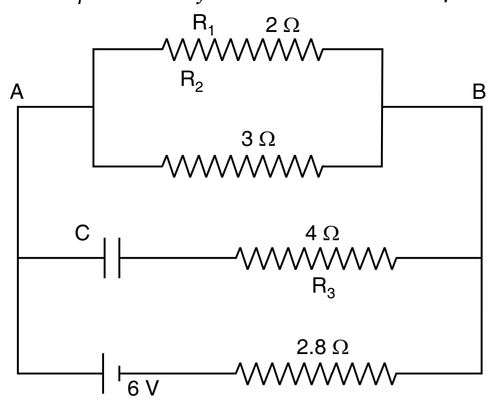


Fig. 3.39

In the steady state, no current flows through the capacitor *C* and hence no current passes through the 4 Ω resistor which is in series with the capacitor.

Ans. The resistance of the parallel combination of 2 Ω and 3 Ω resistors is given by

$$\frac{1}{R_{12}} = \frac{1}{2} + \frac{1}{3} = \frac{5}{6}$$

which gives $\quad R_{12} = 1.2\ \Omega$

This resistance is in series with 2.8 Ω giving a total effective resistance = 1.2 + 2.8 = 4.0 Ω. Thus, the current through the circuit = 6/4 = 1.5 A. Hence, the P.D. across *AB* = 1.5 × 1.2 = 1.8 V and the current through 2 Ω resistor = $\frac{1.8}{2}$ = 0.9 A.

Q. 9. *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 double at constant temperature.*

Ans. Electron mobility of a conductor,

$$\boxed{\mu = \frac{e\tau}{m}} \text{ and } \boxed{\tau \propto T}$$

(*i*) When the temperature of the conductor increases, the relaxation time τ of free electrons increases, so mobility μ increases.

(*ii*) Mobility μ is independent of applied potential difference.

Q. 10. *State the principle of potentiometer. Draw a circuit diagram used to compare the emf of two primary cells. Write the formula used. How can the sensitivity of a potentiometer be increased?*

Ans. **Principle of potentiometer:** The fall of potential along any length of the wire is directly proportional to that length. When a constant current flows through a wire of uniform cross-section and composition.

$$V \propto l$$

Comparison of emfs of two primary cells: The circuit diagram is shown in the figure.

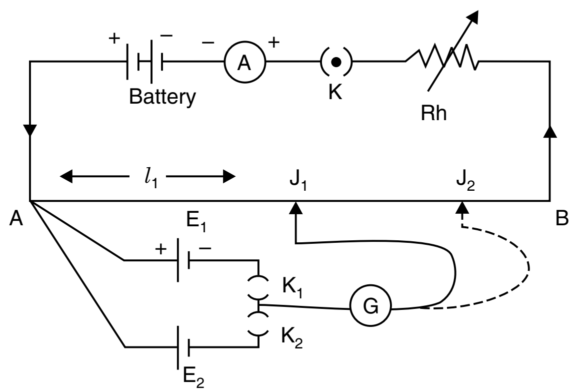


Fig. 3.40

When the key K is closed, a constant current flows the potentiometer wire. By closing key K_1, the cell E_1 is included in the circuit. The jockey is adjusted till galvanometer shows no deflection. Suppose $AJ_1 = l_1$ is the balancing length for cell E_1. Then

$$E_1 = kl_1$$

where k is the potential gradient. Now the null point is obtained for cell E_2 by closing key K_2. Let $AJ_2 = l_2$ be the balancing length in this case. Then

$$E_2 = kl_2$$

$$\therefore \qquad \boxed{\frac{E_2}{E_1} = \frac{l_2}{l_1}}$$

by increasing the length of a potentiometer's wire the sensitivity of a potentiometer can be increased.

Q. 11. *What is the resistance of the filament of a bulb rated at (100 W – 250 V)? What is the current through it when connected to 250 V line? What will be power if it is connected to a 200 V line?*

Ans. Power, $P = VI = \dfrac{V^2}{R}$

Resistance, $R = \dfrac{V^2}{P} = \dfrac{250 \times 250}{100} = 625\ \Omega$

The current through the lamp $\boxed{I = \dfrac{P}{V}} = \dfrac{100\text{ W}}{250\text{ V}} = 0.8\text{ A}$

The power of the lamp when it is connected to a 200 V line is

$$\boxed{P = \frac{V^2}{R}} = \frac{200 \times 200}{625} = 64\text{ W}$$

Q. 12. *In a power station, a copper bar designed to carry many amperes of current is 2 m long and 10 cm² in cross-section. Determine the resistance of the bar at 0 °C. What potential difference is needed to cause a current of 5000 A through the bar? The resistivity of copper at 0°C is 1.59 × 10⁻⁸ Ω m. Also compute the resistance of the bar if it is stretched to form a long and uniform wire of 1 mm² cross-section.*

Ans. The cross-section of the bar = 10 cm² = $10 \times 10^{-4} = 10^{-3}$ m²

The resistance of the bar is

$$\boxed{R = \frac{\rho l}{A}} = \frac{1.59 \times 10^{-8} \times 2}{10^{-3}} = 3.18 \times 10^{-5}\ \Omega$$

Using Ohm's law, the potential difference across its ends is

$$\boxed{V = I R} = 5000 \times 3.18 \times 10^{-5} = 0.159\ \text{V}$$

Volume of the bar = 2×10^{-3} m³

Area of cross-section of the wire = 1 mm² = 10^{-6} m²

$$\text{Length of the wire } l = \frac{\text{volume}}{\text{area}} = \frac{2 \times 10^{-3}}{1 \times 10^{-6}} = 2 \times 10^{3}\,\text{m}$$

The wire has the same amount of copper as the bar, but it is 2000 m long. The resistance of the wire is

$$\boxed{R = \frac{\rho l}{A}} = \frac{1.59 \times 10^{-8} \times 2000}{10^{-6}}$$

$$= 31.8\ \Omega$$

Q. 13. *Write the mathematical relation for the resistivity of a material in terms of relaxation time, number density and mass and charge of charge carriers in it. Explain, using this relation, why the resistivity of a metal increases and that of a semi-conductor decreases with rise in temperature.*

Ans. Resistivity $\boxed{\rho = \frac{m}{ne^2\tau}}$

(*i*) The thermal speed of electrons increases as the temperature increases. Free electrons collide more frequently with the positive metal ions. The relaxation time τ decreases. Consequently, the resistivity ρ of the metal increases.

(*ii*) The relaxation time τ does not change with temperature in semiconductor. But the number density (n) of free electrons increases exponentially with temperature. As a result, the resistivity of semiconductor decreases exponentially with the increase in temperature.

Q. 14. *Two cells of emf 1.5 V and 2 V and internal resistance 1 ohm and 2 ohm respectively are connected in parallel to pass a current in the same direction through an external resistance of 5 ohm.*

(a) Draw the circuit diagram.

(b) Using Kirchhoff's laws, calculate the current through each branch of the circuit and potential difference across the 5 ohm resistor.

Ans. (*i*) The circuit diagram is shown below:

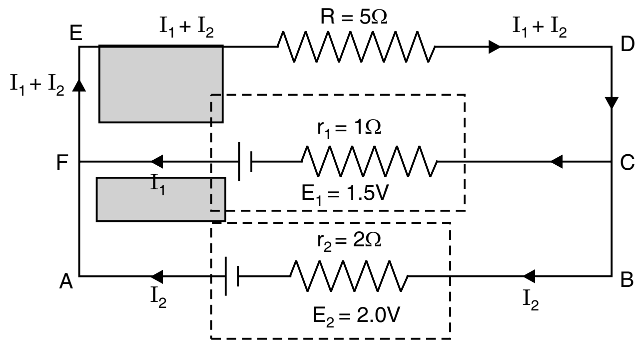


Fig. 3.41

(*ii*) (*a*) Let I_1, I_2 and $I_1 + I_2$ be the currents flowing through the resistors r_1, r_2 and R respectively. Applying Kirchhoff's law to the closed circuit *CBAFC*, we have

$$-2I_2 + 1I_1 = 2.0 - 1.5 = 0$$

or, $2I_2 - I_1 = 0.5$ ...(*i*)

Again applying Kirchhoff's law for closed circuit *CFEDC*, we have

$$-1I_1 - 5(I_1 + I_2) + 1.5 = 0$$

or, $6I_1 + 5I_2 = 1.5$

solving (*i*) and (*ii*), we get

$$I_2 = \frac{4.5}{17} = \frac{9}{34}\text{ A}$$

$$\therefore \quad I_1 = \frac{5}{170}\text{ A}$$

$$\text{Current through } CF = I_1 = \frac{5}{170}\text{ A}$$

$$\text{Current through } BA = I_2 = \frac{9}{34}\text{ A}$$

$$\therefore \text{ Current through } DE = I_1 + I_2 = \frac{5}{170} + \frac{9}{34}$$

$$= \frac{150}{170}\text{ A} = \frac{5}{17}\text{ A}$$

(*b*) Potential difference across 5 Ω resistor

$$= (I_1 + I_2) \times 5$$

$$= \frac{5}{17} \times 5 = 1.47\text{ V.}$$

Q. 15. *The following circuit diagram shows the set up for measurement of emf generated in a thermocouple connected between X and Y. The cell E of emf 2 V has negligible internal resistance. The potentiometer wire of length 1 m has a resistance of 10 Ω. The balance point S is found to be 400 mm from point P. Calculate the emf generated by the thermocouple.*

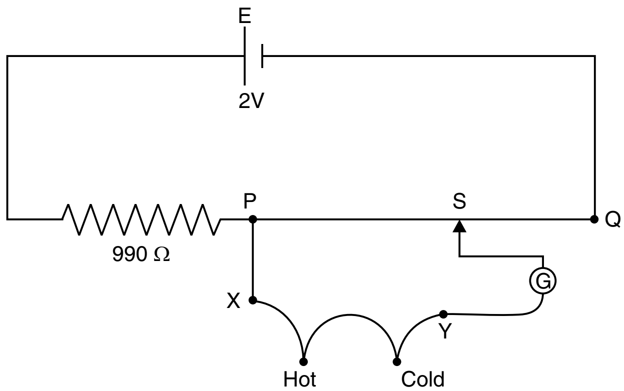


Fig. 3.42

Ans. Resistance of wire *PQ*, $r = 10\ \Omega$

Current through the wire *PQ* is

$$I = \frac{2V}{(990+10)\,\Omega} = \frac{2}{1000} = 2\times 10^{-3}\,\text{A}$$

Potential drop across the wire $PQ = V_r = I_r r$

$$V_r = 2 \times 10^{-3} \times 10 = 0.02\ \text{V}$$

Potential gradient along the wire *PQ* is $= \dfrac{V_r}{L}$

$$k = \frac{0.02V}{1m} = \frac{0.02V}{1000\ mm}$$

Potential drop across the wire $PS = Pd$ across *XY*

$$= \frac{0.02\ \text{V}}{1000\ \text{mm}} \times 400\ \text{mm} = 0.008\ \text{V}.$$

Thus, emf generated by thermocouple

$$= 0.008\ \text{V}.$$

Q. 16. *A battery of emf 2 V and internal resistance 0.1 Ω is being charged with a current of 5 A. In what direction will the current flow inside the battery? What is the potential difference between the two terminals of the battery?*

Ans. The positive terminal of the battery is connected to the positive terminal of the charger in order to charge the battery. Hence, inside the battery, the direction of the current is from the positive terminal to the negative terminal (see fig. below)

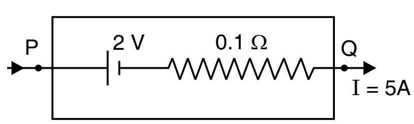


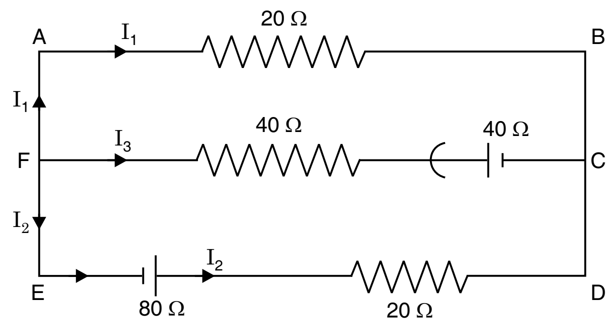
Fig. 3.43

The emf between the terminals of the battery is $(V_P - V_Q)$.

Now, $V_P - 2.0 - (0.1 \times 5) = VQ$

$$V_{PQ} = V_P - V_Q = 2 + 0.5 = 2.5\ \text{V}$$

Q. 17. *State Kirchhoff's rules of current distribution in an electrical network.*
Using these rules determine the value of the current I_1 in the electric circuit given below.



Ans. For electrical network, Kirchhoff's rules are as follows:

(*i*) Junction rule: At any junction, the sum of the currents entering the function is equal to the sum of currents leaving the junction

$\therefore \quad \Sigma I = 0$

(*ii*) Loop rule: The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.

$\therefore \quad \Sigma IR + \Sigma E = 0$

According to Kirchhoff's rule, $I_1 + I_2 = I_3$

Applying loop rule to both the lower and upper loops, we get

$40 I_3 + 20 I_1 = 40$ (In loop *ABCF*)

$40 I_3 + 20 I_2 = 80 + 40$ (In loop *CDEF*)

By addition of two equations, we get

$$80 I_3 + 20 (I_1 + I_2) = 160$$

or $$80 I_3 + 20 I_3 = 160$$

or $$I_3 = \frac{160}{100} = 1.6 \text{ A}$$

Again, $$40 \times 1.6 + 20 I_1 = 40$$

or, $$20 I_1 = 40 - 64 = -24$$

or, $$I_1 = -\frac{24}{20} = -1.2 \text{ A}.$$

Q. 18. *We have 30 watt, 6 volt bulb which we want to glow by a supply of 120 V. What will have to be done for it?*

Ans. Given, $P = 30$ W, V = 6 V

$\therefore$ Resistance of the bulb,

$$R = \frac{V^2}{P} = \frac{(6)^2}{30} = 1.2\,\Omega$$

Current capacity of the bulb,

$$I = \frac{P}{V} = \frac{30}{6} = 5 \text{ A}$$

Supply voltage, $V' = 120$ V

Let R' be the resistance used in series with the bulb to have a current of 5 A in the circuit.

$$\text{Total resistance} = R' + R = (R' + 1.2)$$

$$\therefore \quad \text{Current, } I = V'/(R' + 1.2)$$

or, $$5 = \frac{120}{R'+1.2}$$

or, $$R' = \frac{120}{5} - 1.2 = 22.8\ \Omega \text{ in series.}$$

Q. 19. *A potentiometer wire of length 1 m is connected to a driver cell of emf 3 V as shown in the figure. When a cell of 1.5 V emf is used in the secondary circuit, the balance point is found to be 60 cm. On replacing this cell and using a cell of unknown emf, the balance point shifts to 80 cm.*

(i) Calculate unknown emf of the cell.

(ii) Explain with reason, whether the circuit works, if the driver cell is replaced with a cell of emf 1 V.

(iii) Does the high resistance R, used in the secondary circuit affect the balance point? Justify your answer.

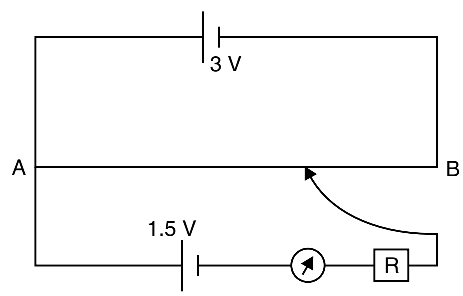


Fig. 3.44

Ans. (*i*) Given, $E_1 = 1.5$ V, $l_1 = 60$ cm $= 0.60$ m

$E_2 = ?$, $l_2 = 80$ cm $= 0.80$ m

By using the formula

$$\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}} \Rightarrow E_2 = \frac{l_2}{l_1} \times E_1$$

$$\therefore \quad E_2 = \frac{0.80}{0.60} \times 1.5 = \frac{80 \times 1.5}{60} = 2\text{ V}$$

(*ii*) The circuit will not work.

Reason: Because there will be smaller fall of potential across the potentiometer wire than the emf of the cell in secondary circuit to be determined and hence the balance point will not be obtained on the potentiometer wire. Thus the emf of the driver cell should be greater than the emf of the cell to be determined.

(*iii*) High resistance R, used in the secondary circuit shift the balance point towards right.

Q. 20. *Calculate the steady state current in the 2 Ω resistor shown in the figure below. The internal resistance of the battery is negligible and the capacitance of the capacitor is 0.2 μF.*

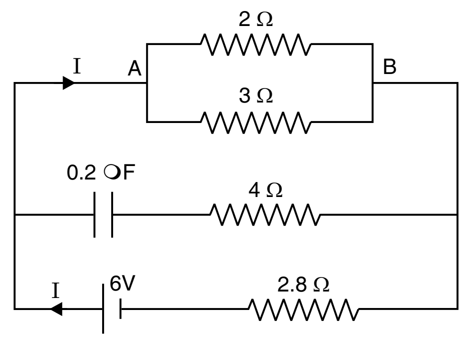


Fig. 3.45

Ans. Equivalent resistance of 2 Ω and 3 Ω in parallel will be

$$R_p = \frac{2 \times 3}{2+3} = \frac{6}{5} = 1.2\,\Omega$$

Since capacitor provides infinite resistance to direct current, hence no current flows in capacitor arm. Therefore, total resistance of current carrying arms

$$R = 1.2 + 2.8 = 4\,\Omega$$

Hence current from battery will be

$$I = \frac{6}{4} = 1.5\text{ A}$$

∴ Potential difference across A and $B = IR_p$

$$= 1.5 \times 1.2 = 1.80\text{ V}$$

∴ Current through 2 Ω resistor

$$= \frac{\text{potential difference}}{\text{resistance}}$$

$$= \frac{1.8}{2} = 0.9\text{ A}.$$

Q. 21. *Study the following circuit. Values of r_1, r_2 and r_3 are 1 ohm, 2 ohm and 3 ohm respectively. A resistor R is connected across the points C and D. What should be the value of R for which the resistance of the network across AB is R?*

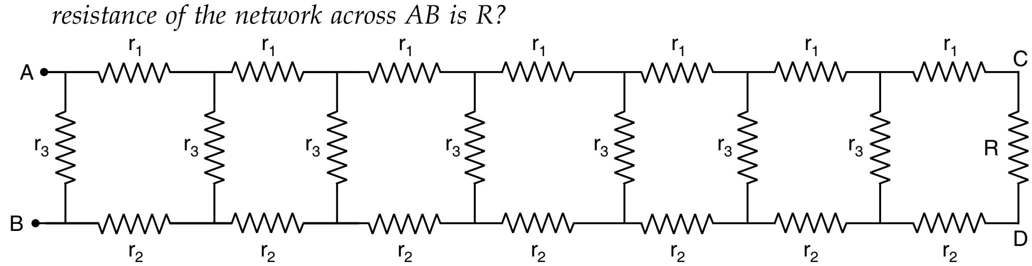


Fig. 3.46

Ans. Let us consider the extreme right square of the loop.

Resistance across $EF = (r_1 + R + r_2)$ and r_3 in parallel

$$= \frac{r_3(r_1 + r_2 + R)}{(r_1 + r_2 + r_3 + R)}$$

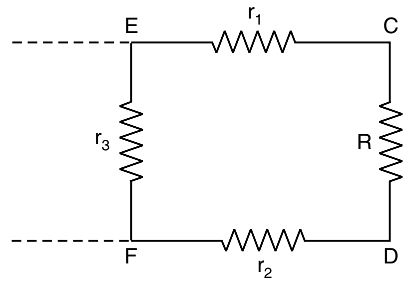


Fig. 3.47

This value should be equal to R, so that by the repeated operation of this type will be left with only one square which will be the left extreme one and it will have a value R

i.e., $$\frac{r_3(r_1 + r_2 + R)}{(r_1 + r_2 + r_3 + R)} = R$$

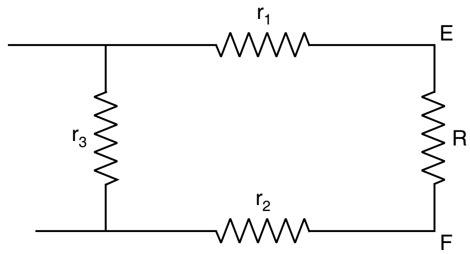


Fig. 3.48

Substituting the numerical values

$$\frac{3(1+2+R)}{(1+2+3+R)} = R$$

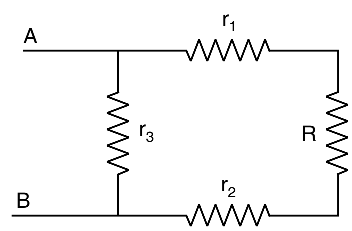


Fig. 3.49

or, $$\frac{3(3+R)}{(6+R)} = R$$

$$9 + 3R = 6R + R^2$$

or, $$R^2 + 3R - 9 = 0$$

$$R = \frac{-3 \pm \sqrt{9+36}}{2}$$

$$= \frac{-3 \pm 3\sqrt{5}}{2}$$

$\therefore$ $$R = \frac{3(\sqrt{5}-1)}{2}\ \Omega$$

III. LONG ANSWER TYPE QUESTIONS

Q. 1. *A battery of 24 cells, each of emf 1.5 V and internal resistance 2 Ω, is to be connected in order to send the maximum current through a 12 Ω resistor. How are they to be connected? Find the current in each cell and the potential difference across the external resistance.*

Ans. Let x be the number of cells in series in each row and let there be y such rows in parallel.

Total number of cells = xy = 24

Resistance of each row in series = $2x$ ohms

Total internal Resistance due to all xy batteries = R

$$\frac{1}{R} = \frac{1}{2x} + \frac{1}{2x} + \dots y \text{ times } \frac{1}{R} = \frac{y}{2x}$$

Total internal resistance = $\frac{2x}{y}$ ohms (because there are y rows in parallel)

The maximum current passes through the circuit when the internal resistance of the battery of cells equals the external resistance.

Thus, $\frac{2x}{y} = 12$

or, $\frac{x}{y} = 6$

But $xy = 24$

Hence $x = 12$ and $y = 2$

i.e., there should be two rows of 12 cells in series (see the figure below).

The current in the circuit is

$$I = \frac{\text{Total emf}}{\text{Total resistance}}$$

$$= \frac{1.5 \times 12}{12 + 12} = \frac{18}{24} = 0.75 \text{ A}$$

Because of two rows have the same resistance, the current in each arm must be

$= \frac{0.75}{2} = 0.375$ A.

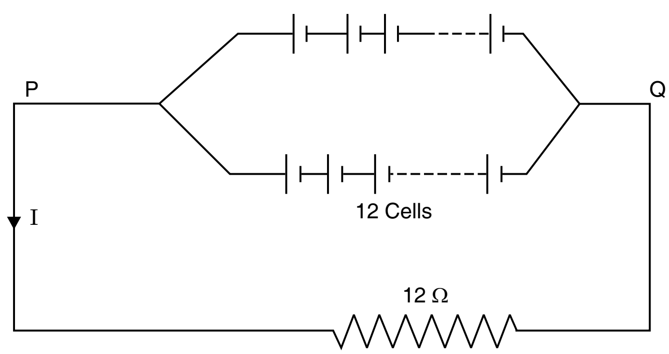


Fig. 3.50

Therefore, current through each cell = 0.375 A

The potential difference across the external resistance is

$$= 12 \text{ x } 0.75 = 9 \text{ V}$$

Q. 2. *Deduce the condition for balance in a Wheatstone bridge. Using the principle of Wheatstone bridge, describe the method to determine the specific resistance of a wire in the laboratory. Draw the circuit diagram and write the formula used. Write any two important precautions you would observe while performing the experiment.*

Ans. Four resistances P, Q, R and S are connected to form quadrilateral $ABCD$. A galvanometer G is connected between B and D. A battery is connected between A and C. The resistances are so adjusted that no current flows in the galvanometer G. The same current I_1 will flow in arms AB and BC. Similarly current I_2 flows in arms AD and DC.

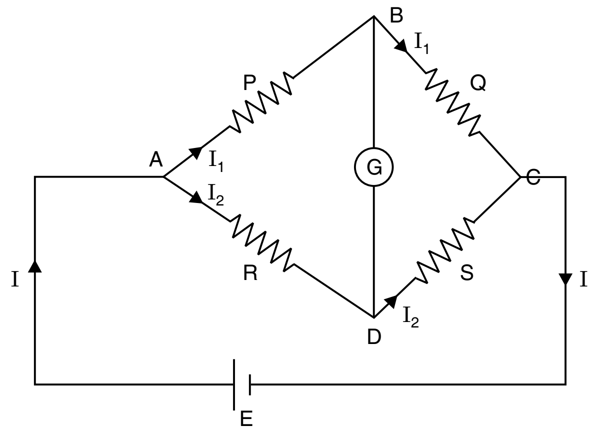


Fig. 3.51

Applying Kirchhoff's second law for mesh *ABCD*,

$$I_1P - I_2R = 0$$

or, $$I_1P = I_2R \quad ...(i)$$

For mesh *BCDB*,

$$I_1Q - I_2S = 0$$

or, $$I_1Q = I_2S \quad ...(ii)$$

Dividing (*i*) by (*ii*), we get

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

This is the balanced condition of the Wheatstone bridge.

Measurement of specific resistance: Slide wire or meter bridge is a practical form of Wheatstone bridge.

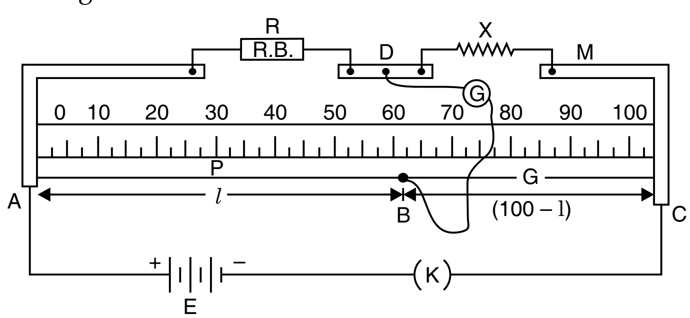


Fig. 3.52

In the figure *X* is unknown resistor and *R.B* is resistance box. After inserting the key *k*, jockey is moved on wire *AC* till galvanometer shows no deflection (point *B*). If *k* is the resistance per unit length of wire *AC*.

$$P = \text{resistance of } AB = kl$$

$$Q = \text{resistance of BC} = k(100 - l)$$

$$\therefore \quad \frac{R}{X} = \frac{P}{Q} = \frac{kl}{k(100-l)}$$

or, $$X = \frac{(100-l)\,R}{l}$$

If r is the radius of wire and l be its length, then its resistivity will be

$$\rho = \frac{XA}{l'} = \frac{\pi r^2 X}{l'}$$

Precautions: (*i*) The null point should lie in the middle of the wire.

(*ii*) The current should not be allowed to flow in the wire for a long time.

Q. 3. *Three pieces of copper wires of lengths in the ratio 2:3:4 and with diameters in the ratio 4:5:6 are connected in parallel. Find the current in each branch if the main current is 5 A.*

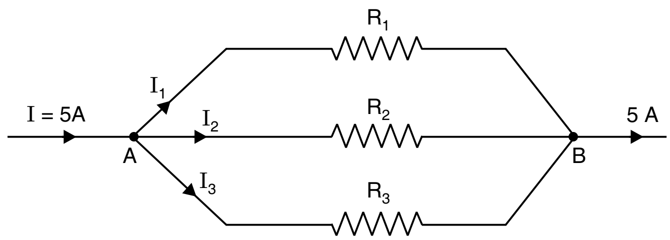


Fig. 3.53

Ans. Let l_1, l_2, l_3 be lengths of three copper wires and D_1, D_2 and D_3 be their diameters and A_1, A_2, A_3 be their area of cross section.

Given, $l_1 : l_2 : l_3 = 2 : 3 : 4$

$\therefore$ $l_1 = 2\,l$, $l_2 = 3\,l$ and $l_3 = 4\,l$.

Also given, $D_1 : D_2 : D_3 = 4 : 5 : 6$

$\therefore$ $A_1 : A_2\ A_3 = (4)^2 : (5)^2 : (6)^2 = 16 : 25 : 36$

$A_1 = 16$ A, $A_2 = 25$ A and $A_3 = 36$ A

If ρ is the resistivity of copper, then

$$R_1 = \frac{\rho l_1}{A_1} = \frac{\rho \times 2\,l}{16\,A} = \frac{1}{8}\frac{\rho l}{A}$$

$$R_2 = \frac{\rho l_2}{A_2} = \frac{\rho \times 3l}{25A} = \frac{3}{25}\frac{\rho l}{A}$$

and, $$R_3 = \frac{\rho l_3}{A_3} = \frac{\rho 4l}{36A} = \frac{1}{9}\frac{\rho l}{A}$$

$\therefore$ $$R_1 : R_2 : R_3 = \frac{1}{8} : \frac{3}{25} : \frac{1}{9}$$

$$= 25 \times 9 : 3 \times 8 \times 9 : 8 \times 25$$

or, $R_1 : R_2 : R_3 = 225 : 216 : 200$

$\therefore$ $R_1 = 225\ R$, $R_2 = 216\ R$ and $R_3 = 200\ R$

Let I_1, I_2 and I_3 be the currents through the wires of resistances R_1, R_2 and R_3 respectively. (see figure given above). Then,

$$I_1 + I_2 + I_3 = 5 \qquad ...(i)$$

and, $I_1 \times 225\ R = I_2 \times 216\ R = I_3 \times 200\ R$

or, $I_1 \times 225 = I_2 \times 216 = I_3 \times 200$

$\therefore$ $I_2 = \dfrac{225\,I_1}{216} = 1.04\,I_1$

and, $I_3 = \dfrac{225\,I_1}{200} = 1.125\,I_1$

Putting values in equation (*i*) we get

$I_1 + 1.04\,I_1 + 1.125\,I_1 = 5$

on solving, $I_1 = 1.58$ A

$\therefore$ $I_2 = 1.04 \times 1.58 = 1.64$ A

and, $I_3 = 1.125 \times 1.58 = 1.78$ A.

Q. 4. *State the two rules that serve as general rules for analysis of electric circuit.*
Use these rules to write the three equations that may be used to obtain the values of the three unknown currents in the branches (shown) of the circuit given below.

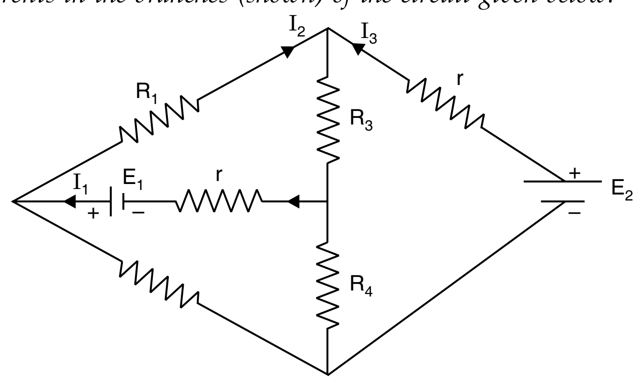


Fig. 3.54

Ans. Two rules of Kirchhoff are used for analysis of electrical circuit (discussed in Q. no. 18, Short Answer Type).

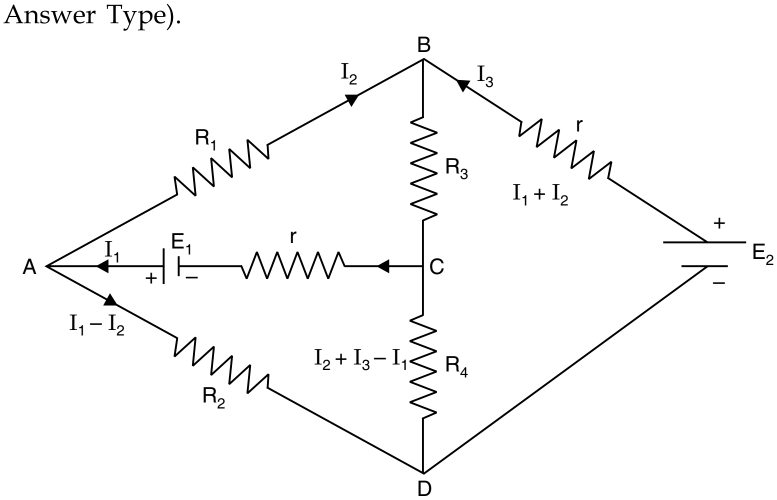


Fig. 3.55

In loop *ABCA*

$$-I_2R_1 - (I_1 + I_2)\,R_3 - I_1\,r + E_1 = 0$$

$\therefore$ $I_2R_1 + (I_1 + I_2)\,R_3 + I_1r = E_1$ ...(*i*)

In loop *ACDA*

$$I_1 r - (I_2 + I_3 - I_1)\, R_4 + (I_1 - I_2)\, R_2 - E_1 = 0$$

$$I_1 r - (I_2 + I_3 - I_1)\, R_4 + (I_1 - I_2)\, R_2 = E_1 \qquad ...(ii)$$

In loop *ABCDA*

$$-I_2 R_1 - (I_1 + I_2)\, R_3 - (I_2 + I_3 - I_1)\, R_4 + (I_1 - I_2)\, R_2 - E_1 = 0$$

$$I_2 R_1 + (I_1 + I_2)\, R_3 + (I_2 + I_3 - I_1)\, R_4 - (I_1 - I_2)\, R_2 = E_1 \qquad ...(iii)$$

Q. 5. *An infinite ladder network of resistances is constructed with 1 ohm and 2 ohm resistors as shown in figure below. The 6 volt battery between A and B has negligible internal resistance.*

(i) Show that effective resistance between A and B is 2 ohms.

(ii) What is the current that passes through the 2 ohm resistance nearest to the battery?

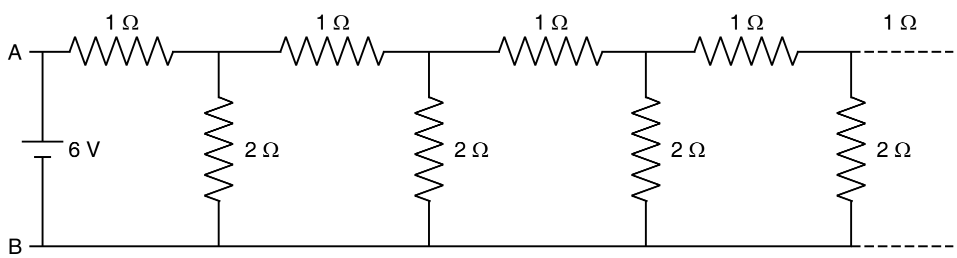


Fig. 3.56

Ans. Let circuit be broken as shown in fig. (*a*) and (*b*).

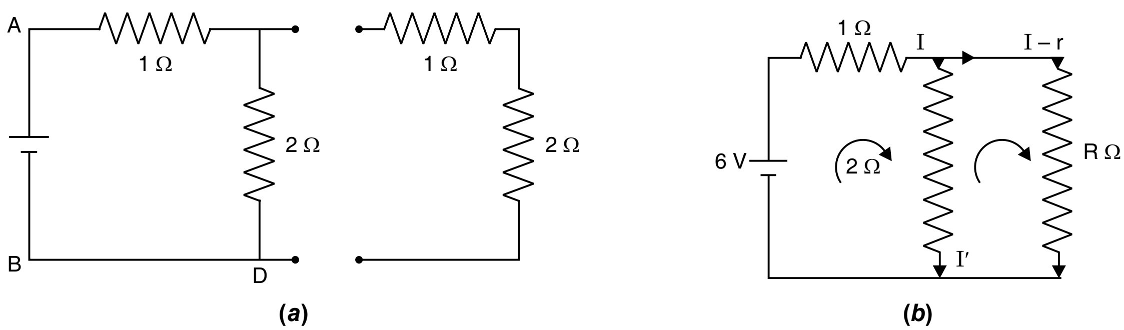


Fig. 3.57

Since the circuit is infinitely long, its total resistance remains unaffected by removing one mesh from it. Let the effective resistance of the infinite network be *R*. The effective resistance of the remaining part of the circuit beyond *CD* is also *R*. The circuit can be recombined as shown in fig. (*b*). The resistance *R* and 2 Ω are in parallel. Their combined resistance is

$$R' = \frac{2R}{R+2}$$

R′ is in series with remaining 1 Ω resistance. The total combined resistance is

$$\frac{2R}{R+2} + 1$$

which must be equal to the total resistance of the infinite network. Therefore

$$R = \frac{2R}{R+2} + 1 = \frac{3R+2}{R+2}$$

$$\text{or,} \quad R^2 + 2R = 3R + 2$$
$$\text{or,} \quad R^2 - R - 2 = 0$$
$$\therefore \quad R = \frac{1 \pm \sqrt{1+8}}{2} = 2\,\Omega$$

since R can not be negative. Applying Kirchhoff's second law to the two neighbouring meshes in fig. (b), we get

$$1 \times 1 + 2\,I' = 6 \quad (R = 2\,\Omega)$$
$$2\,(I - I') - 2\,I' = 0$$

From second equation $I = 2\,I'$

$$\therefore \quad 4\,I' = 6 \text{ or } I' = 1.5 \text{ A}$$

Q. 6. *Eight identical resistors r, each are connected along the edges of a pyramid having square base ABCD as shown in figure below. Calculate equivalent resistance between A and B. Solve the problem (i) without using Kirchhoff's laws (ii) by using Kirchhoff's laws.*

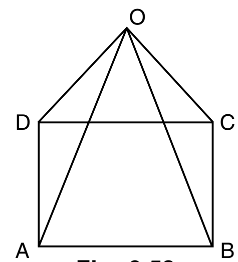


Fig. 3.58

Ans. (*i*) **Without using Kirchhoff's laws**

Consider a battery connected between A and B. The circuit now has a plane of symmetry. This plane of symmetry passes through the mid-points of AB and CD and the vertex O. So, the currents are same in (*i*) AO and OB (*ii*) DO and OC. Now, OA and OB can be treated as a series combination which gives resistance $2r$. Also, DO and OC are in series combination. This gives $2r$. It is in parallel with DC. This gives a resistance of $\frac{2r \times r}{2r + r}$ or $\frac{2r^2}{3r} = \frac{2r}{3}$. This is in series with resistances AD and CB. This gives $\frac{2r}{3} + 2r$ *i.e.,* $\frac{8r}{3}$.

Now, $\frac{8r}{3}$, resistor AB and combination of AO and BO *i.e.,* $2r$ are in parallel. If R is the equivalent resistance, then

$$\frac{1}{R} = \frac{3}{8r} + \frac{1}{r} + \frac{1}{2r} = \frac{3+8+4}{8r} = \frac{15}{8r}$$
$$\text{or,} \quad R = \frac{8r}{15}$$

(*ii*) **By using Kirchhoff's laws**

Using Kirchhoff's second law in loop $DOCD$, we get

$$-I_3r - I_3r + (I_2 - I_3)r = 0$$
$$\text{or,} \quad -3I_3r + I_2r = 0$$
$$\text{or,} \quad I_3 = \frac{I_2}{3} \qquad \text{...(i)}$$

Again, using Kirchhoff's second law to loop $AOBA$, we get

$$-I_1r - I_1r + (I - I_1 - I_2)\,r = 0$$
$$\text{or,} \quad 3\,I_1 + I_2 = I \qquad \text{...(ii)}$$

Considering loop $ADCBA$, we get

$$-I_2r - (I_2 - I_3)\,r - I_2r + (I - I_1 - I_2)\,r = 0$$
$$\text{or,} \quad Ir - I_1r - 4I_2r + I_3r = 0$$
$$\text{or,} \quad I = I_1 + 4I_2 - I_3 \text{ or } I = I_1 + 4I_2 - \frac{I_2}{3}$$

Using equation (i),

or, $$I = I_1 + \frac{11}{3} I_2$$

Using equation (ii),

$$3\,I_1 + I_2 = I_1 + \frac{11}{3}\,I_2 \text{ or } I_2 = \frac{3}{4} I_1$$

From equation (ii),

$$I = 3\,I_1 + \frac{3}{4} I_1 = \frac{15}{4} I_1$$

Considering circuit $ABEA$,

$$E - (I - I_1 - I_2)\,r = 0$$

or, $$E = (I - I_1 - I_2)\,r$$

$$= \left(\frac{15}{4} I_1 - I_1 - \frac{3}{4} I_1\right) r$$

or, $$E = 2\,I_1 r \qquad ...(iii)$$

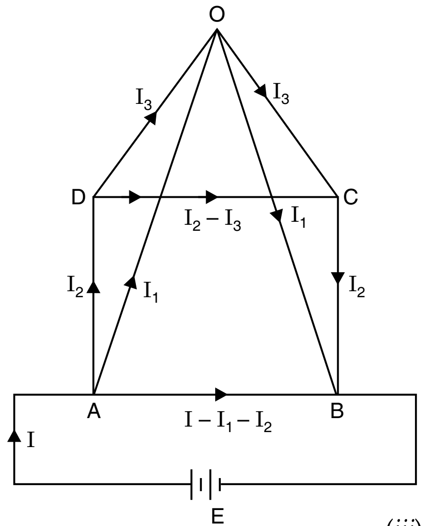


Fig. 3.59

If R is the total resistance, then $E = I\,R$

or, $$E = \frac{15}{4} I_1 R$$

$$2I_1 r = \frac{15}{4} I_1 R \text{ (from (}iii\text{))}$$

$$\therefore \quad \frac{15}{4} R = 2r \text{ or } R = \frac{8\,r}{15}.$$

Q. 7. *State the working principle of a potentiometer with the help of a circuit diagram. Describe a method to find the internal resistance of a primary cell.*
In a potentiometer arrangement, a cell of emf 1.20 volt gives a balance point at 30 cm length of the wire. This cell is now replaced by another cell of unknown emf. If the ratio of the emfs of the two cells is 1.5. Calculate the difference in the balancing length of the potentiometer wire in the two cases.

Ans. The working principle of potentiometer is discussed in the text (see the text).
The connections are made as shown in the figure. E is the cell whose internal resistance r is to be determined. A resistance R is connected across the cell through a key k.
The key k' is closed and k is kept open. The balance point is found out. Let the balancing length be l_1. Then,

$$E \propto l_1 \qquad ...(i)$$

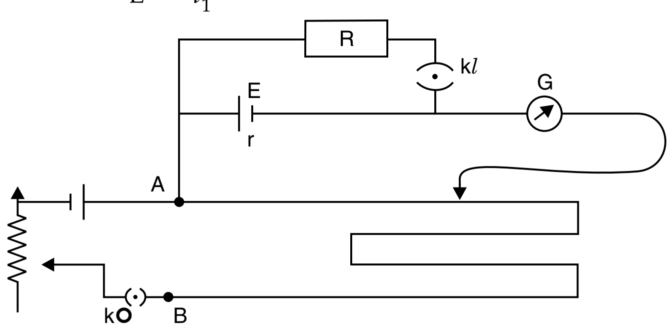


Fig. 3.60

A suitable resistance R is introduced in the resistance box R and with the key k' closed, the balancing length l_2 is found out. When the circuit is closed, the potential difference across the cell falls to $\frac{E\,R}{R+r}$. Then,

$$\frac{E\,R}{R+r} = \propto l_2 \qquad \text{...}(ii)$$

Dividing equation (*i*) by (*ii*), we get

$$\frac{E\,(R+r)}{E\,R} = \frac{l_1}{l_2} \quad \Rightarrow \quad \frac{E+r}{R} = \frac{l_1}{l_2}$$

or, $$\frac{R+r}{R} - 1 = \frac{l_1}{l_2} - 1 = \frac{l_1 - l_2}{l_2}$$

or, $$r = \frac{l_1 - l_2}{l_2} \times R.$$

Given, $$E_1 = 1.20 \text{ V}, \; l_1 = 30 \text{ cm}$$

$$\frac{E_1}{E_2} = \frac{l_1}{l_2} = 1.5$$

or $$l_2 = \frac{l_1}{1.5} = \frac{30}{1.5} = 20 \text{ cm}$$

Difference in the balancing length,

$$l_1 - l_2 = 30 - 20 = 10 \text{ cm}.$$

Q. 8. *A potentiometer wire of length 100 cm has a resistance of 10 Ω. It is connected in series with a resistance and an accumulator of emf 2V 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?*

Ans. Let AB be the potentiometer wire and R, the external resistance, as shown in the figure.

Potential drop across the wire AB = current × resistance

$$= \left(\frac{2}{R+10}\right) \times 10 = \frac{20}{R+10}$$

Therefore, the potential drop per cm of the wire is

$$\frac{20}{100\,(R+10)} \text{ V cm}^{-1}$$

The fall of potential across 40 cm of the wire

is $$= \frac{40 \times 20}{100\,(R+10)} = \frac{8}{R+10} \text{ V}$$

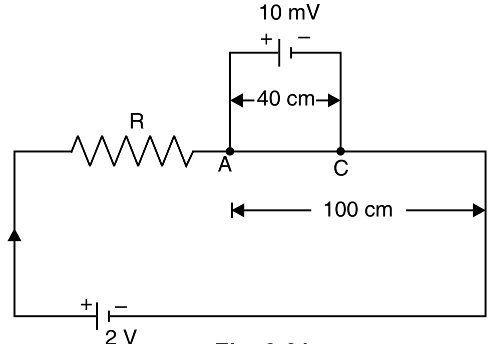


Fig. 3.61

which must be equal to the emf of the source when the balance is achieved.

Thus, $$\frac{8}{R+10} = 10 \times 10^{-3} = \frac{1}{100}$$

$$R + 100 = 800 \text{ or } R = 790 \; \Omega.$$

Q. 9. *A network of resistors is connected to a 16 V battery with internal resistance of 1 Ω as shown in fig. (a) Compute the equivalent resistance of the network. (b) Obtain the current in each resistor. (c) Also obtain the voltage drops* V_{AB}, V_{BC} *and* V_{CD}.

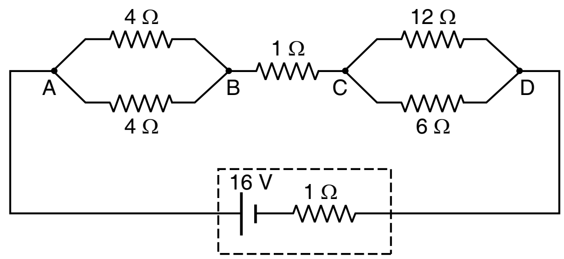


Fig. 3.62

Ans. (*a*) Equivalent resistance of two 4 Ω resistors in parallel is $\frac{4 \times 4}{4+4}$ Ω *i.e.,* 2 Ω. Equivalent resistance of 12 Ω and 6 Ω resistors in parallel is $\frac{12 \times 6}{12+6}$ Ω *i.e.,* $\frac{72}{18}$ Ω or 4 Ω.

Now 2 Ω, 1 Ω and 4 Ω (equivalent of 12 Ω and 6 Ω) are in series. So, total resistance is (2 + 1 + 4) Ω, *i.e.,* 7 Ω,.

(*b*)
$$I = \frac{E}{R+r} = \frac{16}{7+1} \text{ A} = 2 \text{ A}$$

Consider the resistors between *A* and *B*. It is a case of two equal resistors connected in parallel. So, current in each resistor is 1 A. Current through 1 Ω is clearly 2 A. Let us now consider resistors between *C* and *D*. It is a parallel combination of two resistances. Current would be divided in the inverse ratio of resistances. If I_1 is the current through 12 Ω and I_2 is the current through 6 Ω, then $\frac{I_1}{I_2} = \frac{6}{12} = \frac{1}{2}$. So, current through 12 Ω resistor is $\frac{2}{3}$ A.

Similarly, current through 6 Ω resistor is $\frac{4}{3}$ A.

(*c*) The voltage V_{AB} between *A* and *B* is the product of total current between *A* and *B* and the equivalent resistance between *A* and *B*.

∴ $V_{AB} = 2 \times 2\text{V} = 4\text{V}$

Similarly $V_{BC} = 2 \times 1\text{V} = 2\text{V}$; $V_{CD} = 2 \times 4\text{V} = 8\text{V}$

Note that the terminal voltage is 14V. The loss of 2V is due to internal resistance of battery.

Q. 10. *Describe the formula for the equivalent EMF and internal resistance for the parallel combination of two cells with EMF* E_1 *and* E_2 *and internal resistances* r_1 *and* r_2 *respectively. What is the corresponding formula for the series combination? Two cells of EMF 1 V, 2 V and internal resistances 2 Ω and 1 Ω respectively are connected in (i) series (ii) parallel. What should be the external resistance in the circuit so that the current through the resistance be the same in the two cases? In which case more heat is generated in the cells?*

Ans. **In parallel combination**

Let combined emf is E_{eq} and combined internal resistance be r_{eq} in the parallel combination

$$\therefore \quad r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

and $$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

In series combination

Let E_{eq} and r_{eq} respectively be the combined emf and resistance in series combination, then

$$E_{eq} = E_1 + E_2$$
$$r_{eq} = r_1 + r_2$$

Numerical:

Given,

$$E_1 = 1 \text{ V}, E_2 = 2 \text{ V}, r_1 = 2\ \Omega, r_2 = 1\ \Omega$$

Let the external resistance be R

$\therefore$ In series combination,

$$E_S = 1 + 2 = 3 \text{ V}$$
$$R_S = R + 2 + 1 = R + 3\ \Omega$$
$$\therefore \quad I_S = \frac{3}{R+3}$$

Now, in parallel combination

$$E_P = 2 - 1 = 1 \text{ V}$$
$$R_P = R + \frac{r_1 r_2}{r_1 + r_2}$$
$$R_P = R + \frac{2 \times 1}{2+1}$$
$$R_P = R + \frac{2}{3} = \frac{3R+2}{3}$$
$$\therefore \quad I_P = \frac{1}{\frac{3R+2}{3}} = \frac{3}{3R+2}$$
$$\because \quad I_S = I_P$$
$$\frac{3}{R+3} = \frac{3}{3R+2}$$
$$\therefore \quad 3R + 2 = R + 3$$
$$3R - R = 3 - 2 \Rightarrow 2R = 1 \Rightarrow R = \frac{1}{2}\ \Omega$$
$$\therefore \quad E_S = 3V \text{ and } R_S = \frac{1}{2} + 3 = 3.5$$
$$\text{Heat generated} = \frac{E_S^2}{R_S} = \frac{9}{3.5}$$

and, $E_P = 1 \text{ V}, R_P = \frac{3 \times 0.5 + 2}{3} = \frac{3.5}{3}$

$\therefore$ Heat generated $= \frac{E_P^2}{R_P} = \frac{1}{3.5/3} = \frac{3}{3.5}$

Therefore, heat generated in the series combination will be more than the heat generated in parallel combination.

QUESTIONS ON HIGH ORDER THINKING SKILLS (HOTS)

Q. 1. (a) *Find the emf E_1 and E_2 in the circuit of the following diagram and the potential difference between the points a and b.*

(b) *If in the above circuit, the polarity of the battery E_1, be reversed, what will be the potential difference between a and b?*

Ans. (*a*) It is clear that 1 A current flows in the circuit from *B* to *A*.

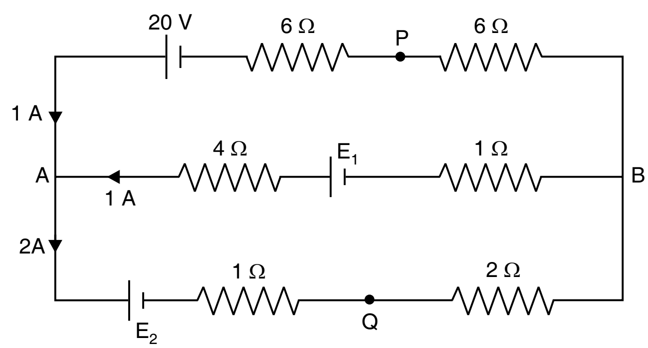
Applying Kirchhoff's law to the loop *PAQBP*,

$$20 - E_2 = 12 \times 1 + (1 \times 2) + (2 \times 2) = 18$$

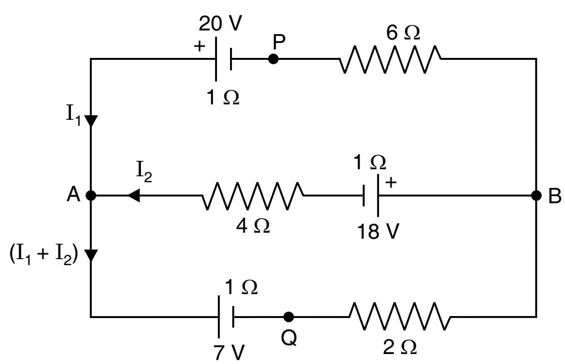
Hence, $E_2 = 2 \text{ V}$

Thus the potential difference between the points *a* and *b* is

$$V_{ab} = 18 - 1 - 4 = 13 \text{ V}.$$



(*b*) On reversing the polarity of the battery E_1, the current distributions will be changed. Let the currents be I_1 and I_2 as shown in the following figure.



Applying Kirchhoff's law for the loop *PABP*,

$$20 + E_1 = (6 + 1) I_1 - (4 + 1) I_2$$

or $$38 = 7 I_1 - 5 I_2 \quad ...(i)$$

Similarly for the loop *ABQA*,

$$4I_2 + I_2 + 18 + 2 (I_1 + I_2) + (I_1 + I_2) + 7 = 0$$

or, $$3 I_1 + 8 I_2 = - 25 \quad ...(ii)$$

Solving equation (*i*) and (*ii*) for I_1 and I_2, we get

$$I_1 = 2.52 \text{ and } I_2 = - 4.07 \text{ A}$$

Hence, $$V_{ab} = - 5 \text{ x } (4.07) + 18$$
$$= - 20.35 + 18$$
$$= - 2.35 \text{ V.}$$

Q. 2. *Twelve cells each having the same emf are connected in series and are kept in a closed box. Some of the cells are wrongly connected. This battery of cells is connected in series with an ammeter and two cells identical with the others of previous cells. The current is 3 A when the cells and the battery add each other and is 2 A when the cells and the battery oppose each other. How many cells in the battery are wrongly connected?*

Ans. If m cells are connected correctly and n cells are connected wrongly, we have

$$m + n = 12$$

If E is the emf of each cell, the total emf of the battery is $(m - n) E$.

When the battery and the cells add each other, the net emf

$$= (m - n) E + 2 E$$

If R is the total resistance of the circuit, the current is given by

$$I = \frac{(m-n)E+2E}{R} = 3 \quad .(1)$$

When the battery and the cells oppose each other, the net emf is $(m - n) E - 2 E$. Therefore, the current is

$$\frac{(m-n)E-2E}{R} = 2 \quad (2)$$

The division of equation (1) by equation (2) gives

$$m - n = 10$$

But $$m + n = 12$$

Hence $m = 11$ and $n = 1$. Thus, one cell is wrongly connected.

Q. 3. *A battery of emf E and internal resistance r gives a current of 0.5 A with an external resistor of 12 Ω, and a current of 0. 25 A with an external resistor of 25 Ω. Calculate (a) internal resistance and (b) emf of battery.*

Ans. As we know

$$\boxed{I = \frac{E}{R+r}}$$

Now, $$0.5 = \frac{E}{12+r} \text{ and } 0.25 = \frac{E}{25+r}$$

(*a*) Dividing, $\frac{0.5}{0.25} = \frac{25+r}{12+r}$

or, $2 = \frac{25+r}{12+r}$ or $r = 1\ \Omega$

(*b*) $0.5 = \frac{E}{12+1} \Rightarrow E = 6.5$ V.

Q. 4. *Voltmeters V_1 and V_2 are connected in series across a D.C. line. V_1 reads 80 V and has a per volt resistance of 200 Ω. V_2 has a total resistance of 32 kΩ. What is the line voltage?*

Ans. The resistance R_1 of voltmeter V_1 is given by

$$R_1 = 80 \times 200 = 16000\ \Omega = 16\ k\ \Omega$$

Current in the circuit,

$$I = \frac{V_1}{R_1} = \frac{80}{16000} = 5 \times 10^{-3}\ \text{A}$$

Reading of voltmeter, $V_2 = IR_2 = (5 \times 10^{-3}) \times (32 \times 10^3)$
$= 160$ V.

∴ Line voltage, $V = V_1 + V_2 = 80 + 160$
$= 240$ V.

Q. 5. *For the network shown in fig. below. Calculate the equivalent resistance between points A and B.*

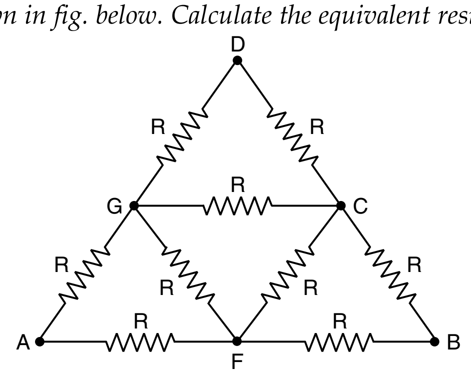


Fig. 3.63

Ans. The distribution of current in the circuit will be as shown in fig. below, following Kirchhoff's first law. Here point *F* is not a true junction, hence shown separate. If *R*′ is the effective resistance of circuit between *A* and *B*, then

$$E = I R' \quad \text{...}(i)$$

In a closed circuit *EABE*

$$E = (I - I_1) R + (I - I_1) R$$
$$= 2 (I - I_1) R \quad \text{... }(ii)$$

In a closed circuit *GDCG*,

$$I_2 R/2 + R I_2/2 - (I_1 - I_2) R = 0$$

or, $I_2 = I_1/2$ ...(*iii*)

In a closed circuit *AGCBA*, we have

$$I_1 R + (I_1 - I_2) R + I_1 R - (I - I_1) R - (I - I_1) R = 0$$

or, $5 I_1 - I_2 = 2 I$

or, $5\, I_1 - \dfrac{I_1}{2} = 2\, I$ [from (*iii*)]

or, $9\, I_1 = 4\, I$ or $I_1 = \dfrac{4}{9} I$

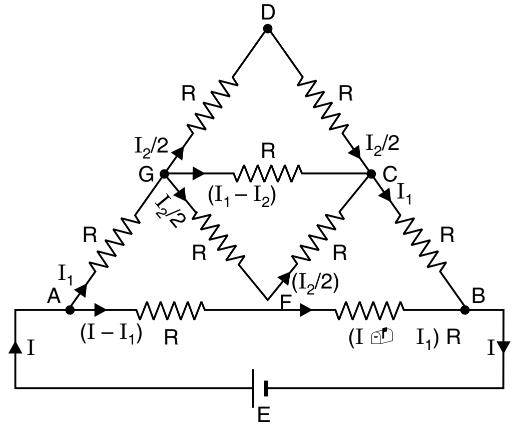


Fig. 3.64

Putting this value in (*ii*) we get

$$E = 2\left(I - \frac{4}{9} I\right) R = \frac{10}{9} I\, R \qquad ...(iv)$$

Comparing (*i*) and (*iv*) we get $R' = \dfrac{10}{9} R$

Q. 6. *The figure shows a cube made of wires each having a resistance R. The cube is connected into a circuit across a body diagonal AB as shown. Find the equivalent resistance of the network in this case.*

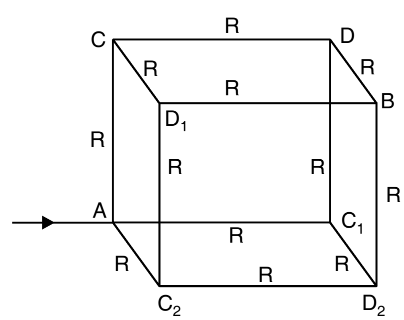


Fig. 3.65

Ans. Let us search the points of same potential. Since the three edges of the cube from A viz., AC, AC_1 and AC_2 are identical in all respects the circuit points C, C_1 and C_2 are at the same potential. Similarly for the point B the sides BD, BD_1 and BD_2 are symmetrical and the points D, D_1 and D_2 are at the same potential.

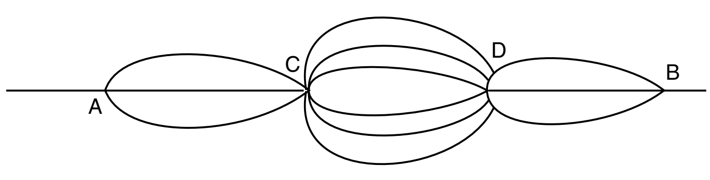


Fig. 3.66

Next let us bring together the points C, C_1 and C_2 and also D, D_1 and D_2. Then, the cube will look as shown above.

The resistance between A and $C = \frac{R}{3}$

The resistance between C and $D = \frac{R}{6}$

The resistance between D and $B = \frac{R}{3}$

The circuit is equivalent to $\frac{R}{3}, \frac{R}{6}$ and $\frac{R}{3}$ in series which is equal to $\frac{5}{6}R$.

Q. 7. *A homogeneous poorly conducting medium of resistivity ρ fills up the space between two thin coaxial ideally conducting cylinders. The radii of the cylinders are equal to a and b with a < b, the length of each cylinder is l. Neglecting the edge effects, find the resistance of the medium between the cylinders.*

Ans. The current will be conducted radially outwards from the inner conductor (say) to the outer. The area of cross-section for the conduction of the current is, therefore, the area of an elementary cylindrical shell and which varies with radius. The length of the conducting shell is measured radially from radius a to radius b.

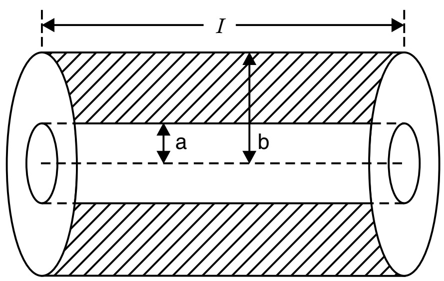


Fig. 3.67

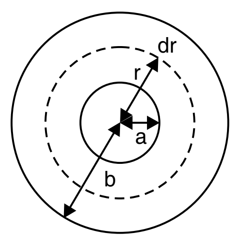


Fig. 3.68

Consider an elementary cylindrical shell of radius r and thickness dr. Its area of cross-section (normal to flow of current) = $2\pi rl$ and its length = dr.

Hence, the resistance of the elementary cylindrical shell of the medium is

$$dR = \frac{\rho dr}{2\pi rl} = \frac{\rho}{2\pi l}\left[\frac{dr}{r}\right]$$

The resistance of the medium is obtained by integrating for r from a to b.

Hence required resistance

$$R = \frac{\rho}{2\pi l}\int_a^b \frac{dr}{r} = \frac{\rho}{2\pi l}\left[\log_e r\right]_a^b = \left(\frac{\rho}{2\pi l}\right)\log_e \frac{b}{a}$$

Q. 8. *A wire carries a current of 1.5 A, when a potential difference of 2.1 V is applied across it. What is its conductance? If the wire is of length 3 m and area of cross-section 5.4 × 10^{-6} m^2, calculate its conductivity.*

Ans. Given, $I = 1.5$ A, $V = 2.1$ V, $l = 3$ m

$A = 5.4 \times 10^{-6}$ m^2

Conductance, $\boxed{G = \frac{1}{R}} = \frac{I}{V} = \frac{1.5}{2.1} = 0.714\ S$

Conductivity, $\boxed{\sigma = \frac{1}{\rho}} = \frac{l}{RA} = \frac{I\,l}{VA} = \frac{1.5 \times 3}{2.1 \times 5.4 \times 10^{-6}}$

$= 3.97 \times 10^5 \text{ Sm}^{-1}$

Q. 9. *What is the net resistance between points A and F in the circuit shown in above figures?*

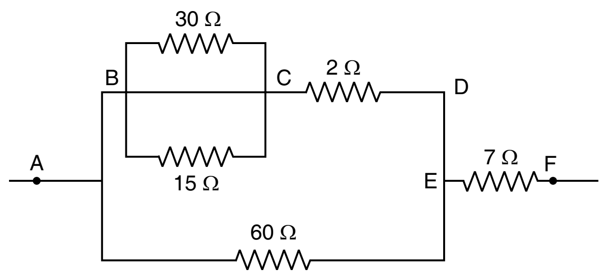


Fig. 3.69

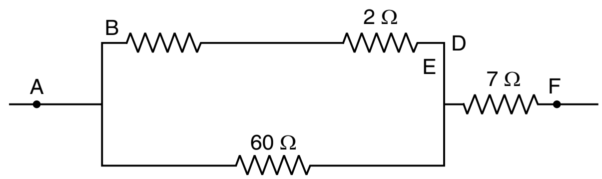


Fig. 3.70

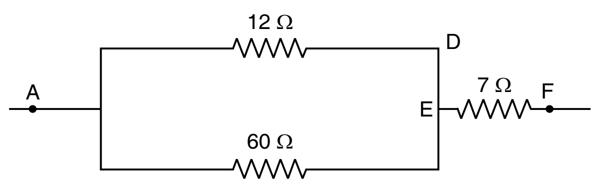


Fig. 3.71

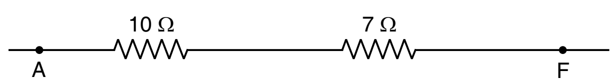


Fig. 3.72

Ans. First consider the parallel combination *BC*. The resistance of this combination is given by

$$\frac{1}{R} = \frac{1}{30} + \frac{1}{15} = \frac{3}{30} \text{ or } R = 10\ \Omega$$

Substitute 10 Ω for the combination and redraw the circuit as shown in fig. 3.70. Now, the series combination *BD* can be replaced by a single resistor of resistance

$$R = 10 + 2 = 12\ \Omega$$

Now the circuit can be redrawn as in fig. 3.71. Combination *AE* in the parallel arrangement can be replaced by a single resistor of resistance given by

$$\frac{1}{R} = \frac{1}{12} + \frac{1}{60} = \frac{6}{60} \text{ or } R = 10\ \Omega$$

The circuit can again redrawn as shown in fig. 3.72. The resistance between points A and F is given by

$$R = 10 + 7 = 17\ \Omega.$$

Q. 10. *Prove that when a current is divided between two resistors in accordance with Kirchhoff's laws, the heat produced is minimum.*

Ans. Consider two resistors R_1 and R_2 connected in parallel and the current through the various arms of the circuit be as shown in the figure below.

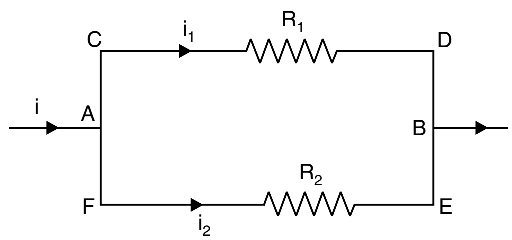


Fig. 3.73

According to Kirchhoff's first law, at junction A,

$$i = i_1 + i_2 \text{ or } i_2 = i - i_1 \quad ...(i)$$

Let H be the heat produced in the circuit in t seconds, then

$$H = i_1^2 R_1 t + i_2^2 R_2 t$$

$$= i_1^2 R_1 t + (i - i_1)^2 R_2 t \quad \text{[from } (i)\text{]}$$

In case the heat produced in the circuit is minimum, then $\frac{dH}{di_1} = 0$; therefore,

$$2i_1R_1t + 2(i - i_1)(-1) R_2t = 0$$

or, $$2i_1R_1t - 2i_2R_2t = 0$$

or, $$i_1R_1 - i_2R_2 = 0$$

which is according to Kirchhoff's second law in a closed circuit $ACDEFA$.

Q. 11. *A fuse made of lead wire has an area of cross-section 0.2 mm^2. On short circuiting, the current in the fuse wire reaches 30 amp. How long after the short circuiting will the fuse begin to melt?*

Specific heat capacity of lead = 134.4 Jkg^{-1} k^{-1}

Melting point of lead = 327 °C

Density of lead = 11340 kg/m^3

Resistivity of lead = 22 × 10^{-8} ohm-m

Initial temperature of the wire = 20°C

Neglect heat loss.

Ans. If L be the length of the wire, its resistance

$$\boxed{R = \frac{\rho L}{A}} = \frac{(22 \times 10^{-8}) L}{(0.2 \times 10^{-6})\ \text{m}^2} \quad ...(i)$$

Heat produced in the wire in one second

$$= I^2R = (30)^2\ R\text{J}.$$

Heat required to raise the temperature of the wire to 327°C

$$Q = ms\ \Delta T \qquad ...(ii)$$

$$= (LAd)\ (134.4)\ (307)\ \text{J}.$$

Time required to melt the wire

$$\Delta T = \frac{Q}{I^2 R} = \frac{L\ Ad \times 134.4 \times 307}{I^2 \times \rho\ L} \times A \qquad \text{[from } (i) \text{ and } (ii)\text{]}$$

$$= \frac{A^2 d}{I^2 \rho} \times 134.4 \times 307$$

$$= \frac{\left(0.2 \times 10^{-6}\right)^2}{900} \times \frac{11340}{22 \times 10^{-8}} \times 134.4 \times 307$$

$$= 0.0945\ \text{S}.$$

Q. 12. *Is current density a vector quantity or scalar quantity? Deduce the relation between current density and potential difference across a current carrying conductor of length l, area of cross-section A and number density of free electrons n. How does the current density in a conductor vary with*

(a) increase in potential gradient,

(b) increase in temperature,

(c) increase in area of cross-section?

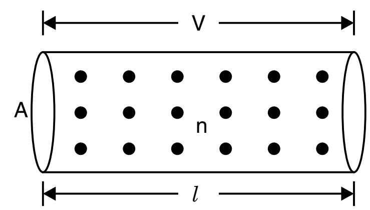


Fig. 3.74

Ans. Current-density is a vector quantity. If potential difference V is applied across a conductor of length d and area of cross-section A having number of free electrons per unit volume n. Then, the charge in the conductor

$$q = neAl$$

and current,

$$I = \frac{q}{t}$$

$$= neA\left(\frac{l}{t}\right)$$

or current per unit area *i.e.*, current density

$$J = \frac{I}{A} = nev_d \qquad \left(\frac{l}{t} = v_d \text{ drift speed}\right)$$

or

$$J = ne\frac{eV}{ml}.\tau$$

or

$$J = \frac{ne^2 V\tau}{m.l}$$

where m is mass of an electron and τ is relaxation time.

(*a*) current density increases with increase in potential gradient $\left(\frac{V}{l}\right)$.

(*b*) when temperature increases, relaxation time (τ) decreases and current density decreases.

(*c*) when area of cross-section increases the current density $J = \frac{I}{A}$ decreases.

Q. 13. *In the given Wheatstone bridge, the current 3R is zero. Find the value of R, if carbon resistor, connected in one arm of the bridge has the colour sequence of red, red and, orange.*

The resistance of BC and CD arm are now interchanged and another carbon resistor is connected in place of R so that the current through arm BD is again zero. Write the sequence of colour bands of the carbon resistor. Also find the current through it.

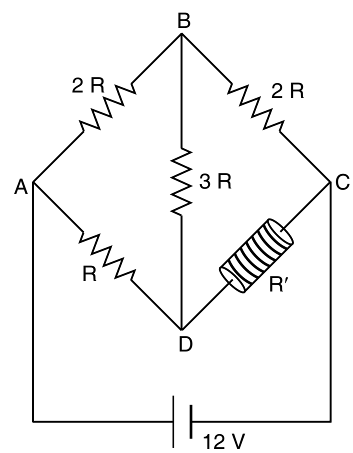


Fig. 3.75

Ans. For no current through BD, the Wheatstone bridge is balanced and the resistance of carbon resistor is

$$R' = R.$$
$$= 22000\ \Omega$$

when resistance of BC and CD arms are interchanged and another carbon resistor is connected in place of *R*, the current through *BD* is again zero. Therefore, again for balanced Wheatstone bridge

$$R' = 4R$$
$$= 4 \times 22000\ \Omega$$
$$= 88000\ \Omega$$

For 88000 Ω the sequence of colour bands is gray, orange.

Now net resistance of arm *ADC*,

$$= 88000 + 44000$$
$$= 132000\ \Omega$$

$\therefore$ current through carbon resistor,

$$I = \frac{12}{132000}\ \text{A}$$
$$= \frac{12}{132} \times 10^{-3}\ \text{A}.$$

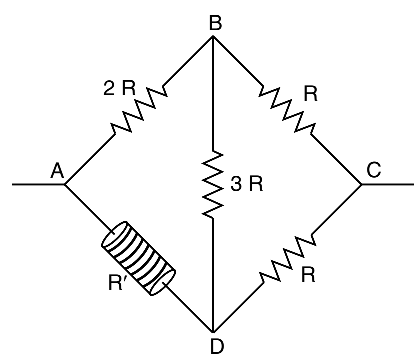


Fig. 3.76

Q. 14. *In a meter bridge experiment students observe a balance point at the point J, where AJ = l. Draw the equivalent Wheatstone bridge for this set up. The value of R and X are both doubled and then interchanged. What will be the new position of the balance point? How will the balance point get affected?*

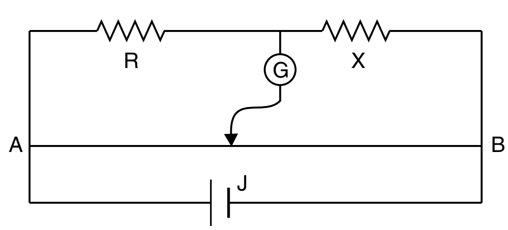


Fig. 3.77

Ans. The equivalent Wheatstone bridge is shown in Fig. For balance bridge

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

If R and X both are doubled, the ratio will remain same and there will be no change in position of balance point. Position of balance point gets affected if R and B or X and Q are interchanged.

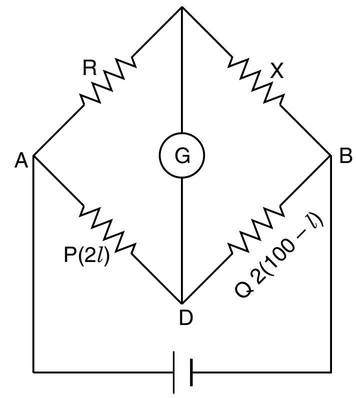


Fig. 3.78

Q. 15. *Find the potential difference across each cell and the rate of energy dissipation in R*

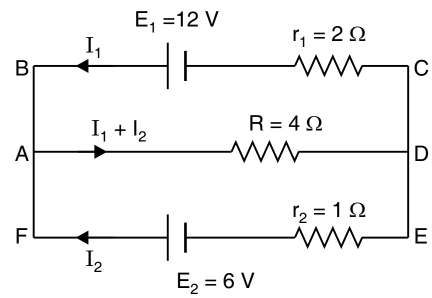


Fig. 3.79

Ans. Applying Kirchhoff's rule for loop *ABCDA,*

$$12 = 4(I_1 + I_2) + 2I_1$$

or $$12 = 6I_1 + 4I_2 \quad ...(i)$$

For loop *DEFAD*

$$6 = 4(I_1 + I_2) + I_2$$

or $$6 = 4I_1 + 5I_2 \quad ...(ii)$$

Eqs. (*i*) and (*ii*) can be written as

$$12 = 6I_1 + 4I_2$$

and $$9 = 6I_1 + 7.5I_2$$

or $$3 = -3.5\, I_2$$

or $$I_2 = -\frac{3}{3.5}\, A$$

Putting the value I_2 in equation (*i*)

$$12 = 6I_1 - \frac{4 \times 3}{3.5}$$

or $$12 \times 3.5 = 6 \times 3.5I_1 - 12$$

or $$12\,(4.5) = 210\, I_1$$

or $$I_1 = \frac{12 \times 4.5}{21}\text{ A}$$

$$= \frac{180}{7} = 25.7\text{ A}$$

$\therefore$ Current in R, $$I = 25.7 - \frac{3}{3.5}$$

or rate of energy dissipation = $2R$

Q. 16. *A potentiometer circuit is set up as shown. The potential gradient across the potentiometer wire is 0.025 Vcm^{-1} and the ammeter present in the circuit reads 0.1 A, when the two way key is completely switched off. The balance point when the key between the terminals (i) 1 and 2 (ii) 1 and 3 is pluged in are found to be at length 40 cm and 100 cm respectively. Find the value of R and X.*

Ans.

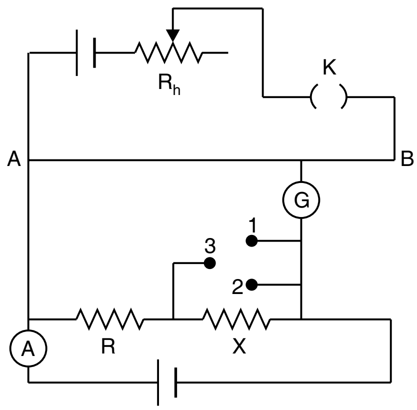


Fig. 3.80

MULTIPLE CHOICE QUESTIONS

1. Which of the following is not the cause of low conductivity of electrolysis?

(*a*) low drift velocity of ions

(*b*) high resistance offered by the solution to the motion of ions.

(*c*) low number density of charge carriers.

(*d*) ionisation of salt.

2. How many coulombs of electricity must pass through acidulated water to liberate 22.4 litres of hydrogen at N.T.P.?

(*a*) 1C (*b*) 1.6×10^{-19} C (*c*) 96500 C (*d*) 19300 C

3. If the electric current in a lamp decreases by 5%, then the power output decreases by

(*a*) 25% (*b*) 5% (*c*) 10% (*d*) 20%.

4. Two similar head lamps are connected in parallel to each other. Together, they consume 48W from a 6V battery, the resistance of each filament is

(*a*) 1.5 Ω (*b*) 3 Ω (*c*) 4 Ω (*d*) 6 Ω.

5. Fuse wire should have

(*a*) low resistance, high melting point (*b*) low resistance, low melting point

(*c*) high resistance, low melting point (*d*) high resistance, high melting point.

6. Time taken by an 836 W water heater to heat one litre of water from 0°C to 40°C is

(*a*) 50 S (*b*) 100 S (*c*) 150 S (*d*) 200 S.

7. A certain charge liberates 0.8 g of oxygen. The same charge will liberate how many gram of silver?

(*a*) 108 g (*b*) 10.8 g (*c*) 0.8 g (*d*) (108/0.8) g.

8. A thermoelectric refrigerator works on

(*a*) Joule effect

(*b*) seebeck effect

(*c*) Peltier effect

(*d*) Thermionic effect

9. Amount of charge in coulomb required to deposit one gram equivalent of substance by electrolysis is

(a) 9.6×10^4 (b) 4.8×10^{-4}

(c) 96500 (d) 6500.

10. If the cold junction of a thermocouple is lowered, then the neutral temperature

(a) increases (b) decreases

(c) approaches inversion temperature (d) remains the same.

11. If the electric current in a lamp decreases by 5%, then the power output decreases by

(a) 25% (b) 10%

(c) 5% (d) 20%.

12. Masses of three wires are in the ratio of 1 : 3 : 5. Their lengths are in the ratio of 5 : 3 : 1. When connected in series with a battery the ratio of heat produced in them will be

(a) 1 : 3 : 5 (b) 5 : 3 : 1

(c) 1 : 15 : 125 (d) 125 : 15 : 1.

13. An electric kettle taking 3A at 200 V brings one litre of water from 20°C to the boiling point in 10 minute. Its efficiency is

(a) 33.3% (b) 66.6%

(c) 87.7% (d) 93.3%.

14. Thermo emf set up in thermocouple varies as $E = aT - \frac{1}{2} bT^2$, where a, b are constant and T is temperature in kelvin. If $a = 16.3\ \mu V/°C$ and $b = 0.042\ \mu V/(°C)^2$, then inversion temperature is

(a) 776 °C (b) 388 °C

(c) 279 °C (d) none of these.

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

(a) free electron density (b) current density

(c) drift speed (d) the charge crossing in a given time interval.

Answers

1. (d)	**2.** (d)	**3.** (c)	**4.** (a)	**5.** (c)
6. (c)	**7.** (b)	**8.** (c)	**9.** (c)	**10.** (d)
11. (b)	**12.** (d)	**13.** (d)	**14.** (b)	**15.** (a, d).

TEST YOUR SKILLS

1. Why is a voltmeter always connected in parallel with a circuit element across which voltage is to be measured?

2. If the length of a conductor wire is doubled by stretching it, keeping the p.d. across it constant, by what factor does the drift velocity of electrons change?

3. What will be the change in the resistance of Eureka wire, when its radius is halved and length is reduced to one-fourth of its original length?

4. Define the term electrical resistivity of a material. How is it related to its electrical conductivity? Of the factors, length area of cross-section, nature of material and temperature, which one controls the resistivity value of a conductor?

5. Are the paths of electrons straight lines between successive collisions (with positive ions of the metal) in the (*i*) absence of electric field? (*ii*) presence of electric field? Establish a relation between drift velocity 'v_d' of an electron in a conductor of cross-section '*A*' carrying current '*I*' and concentration '*n*' of free electrons per unit volume of conductor. Hence, obtain the relation between current density and drift velocity.

6. V-I graph for a metallic wire at two different temperatures T_1 and T_2 is shown in the figure 3.81. Which of the two temperatures is the higher and why?

7. A resistance of a wire is 5 Ω at 50°C and 6 Ω at 100°C. What will be the resistance of the wire at 0°C?

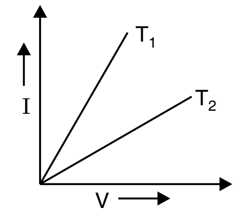


Fig. 3.81

8. State Kirchhoff' rules of current distribution in an electrical network. Using these rules determine the value of current in *R* = 20Ω resistance in the electric circuit given in the figure 3.82.

9. A cylindrical metallic wire is stretched to increase its length by 5%. Calculate the percentage change in its resistance.

10. Write the mathematical relation for the resistivity of a material in terms of relaxation time, number density, mass and charge of charge carriers in it. Explain, using this relation, why the resistivity of metal increases and that of a semi-conductor decreases with rise in temperature.

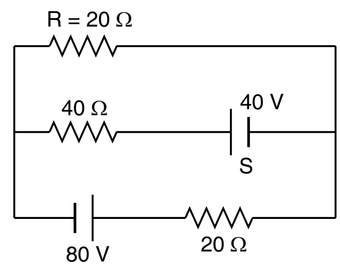


Fig. 3.82

11. Two wire of equal lengths, one of copper and the other of maganin have the same resistance. Which wire is thicker?

12. Explain the principle of Wheatstone bridge for determining an unknown resistance. How is it realised in actual practice in the laboratory?

13. Obtain an expression for the potential gradient '*k*' of potentiometer whose wire of length *l* has a resistance *r*. The driving cells has an emf *E,* is connected in series with an external resistance *R*.

14. It is observed that the deflection in a potentiometer setup is in the same sense at both the starting end as well as at the other extreme end of the potentiometer. However, the value of this deflection is more at the other extreme end than at the starting end. What could be the reason for this? How can it be corrected?

15. Explain the working principle of a potentiometer. How will you find the value of the emf of an electric cell using a potentiometer?

16. *V-I* graphs for parallel and series combination of two metallic resistors are as shown in the figure 3.83. Which graph represents the parallel combination? Justify you answer.

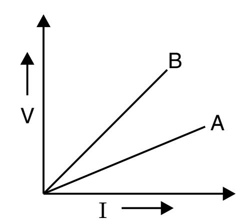


Fig. 3.83

17. Calculate the equivalent resistance of the resistance network between the point *A* and *B* as shown in the figure 3.84, when switch *S* is closed.

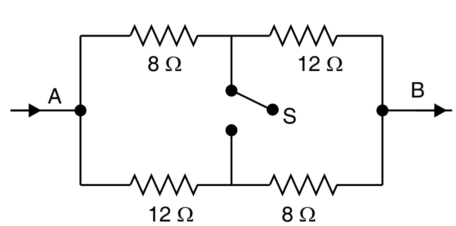


Fig. 3.84

18. A volmeter V of resistance 400 Ω is used to measure the potential difference across a 100 Ω resistor in the circuit shown in figure 3.85. (*i*) What will be reading of the voltmeter? (*ii*) Calculate the *p.d.* across 100 Ω resistor before the voltmeter is connected.

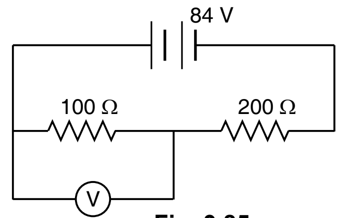


Fig. 3.85

19. On a given resistor, the colour bands are in the sequence; green violet and red. What is its resistance?

20. Calculate the current drawn from the battery in the following network.

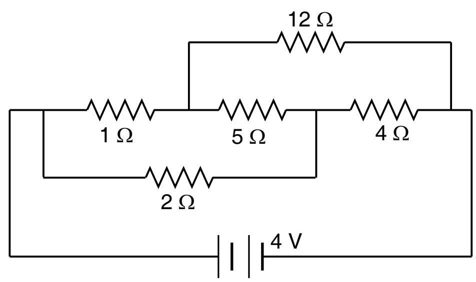


Fig. 3.86

21. (*a*) In a meter bridge, the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5 Ω. Determine the resistance of X.

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

(*c*) What happens, if the galvanometer and cell are interchanged at the balance point of the bridge? Would galvanometer show any current?

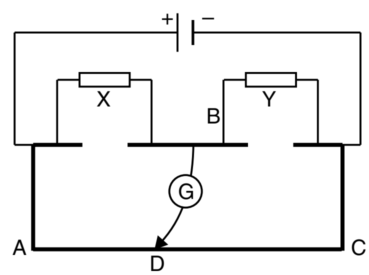


Fig. 3.87

22. A potentiometer wire has a length of 10 m and resistance 4Ω. An accumulator of emf 2 V and a resistance box are connected in series with it. Calculate the resistance to be introduced in the box so as to get a potential gradient of (*i*) 0.1 V/m, and (*ii*) 0.001 V/m.

23. A potentiometer wire of length 100 cm has a resistance of 10 Ω. It is connected in series with a resistance and a cell of emf 2V and of negligible internal resistace. A source of emf 10 mV is balanced by a length of 40 cm of the potentiometer wire, What is the value of external resistance?

24. Why is a potentiometer preferred over a voltmeter to measure emf of a cell? The potentiometer wire AB shown in the figure is 400 cm long. Where should the free end of the galvanometer be connected on AB, so that the galvanometer shows zero deflection?

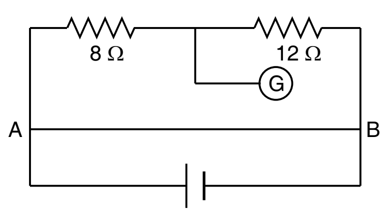


Fig. 3.88

25. A 10 m long wire AB of uniform area of cross-section and 20 Ω resistance is used as a potentiometer wire. This wire is connected in series with a battery of 5 V and a resistor of 480 Ω. An unknown emf is balanced at 600 cm of the wire as shown in the following figure. Calculate (*i*) the potential gradient for the potentiometer wire. (*ii*) the value of unknown emf E.

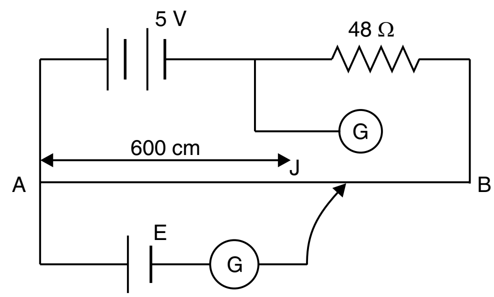


Fig. 3.89

26. Two metallic wires of the same material have same length but cross-sectional area is in the ratio 1 : 2. They are connected (*i*) in series and (*ii*) in parallel. Compare the drift velocities of electrons in the two wires in both the cases (*i*) and (*ii*).

27. (*i*) Calculate the equivalent resistances of the given electrical network between points A and B.

(*ii*) Also calculate the current through CD and ACB, if a 10 V d.c. source is connected between A and B, and the value of R is assummed as 2 Ω.

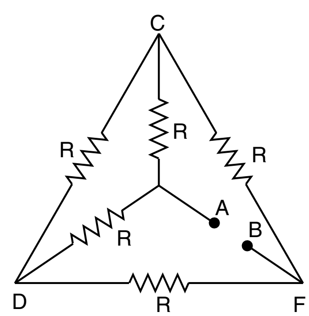


Fig. 3.90

28. Derive an expression for the resistivity of a good conductor, in terms of the relaxation time of electrons.

29. The plot of variation of potential difference across a combination of three identical cells in series, versus current is as shown in figure 3.91. What is the emf of each cell?

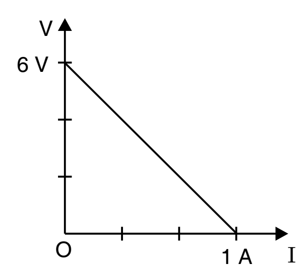


Fig. 3.91

30. Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons through the conductor.

31. Define resistivity of a conductor. Plot a graph showing the variation of resistivity with temperature for a metallic conductor. How does one explain such a behaviour, using the mathematical expression of the resistivity of a material?

32. A potentiometer wire of length 1 m is connected to a driver cell of emf 3V as shown in the figure 3.92. When a cell of 1.5 V emf is used in the secondary circuit, the balance point is found to be 60 cm. On replacing this cell and using a cell of unknown emf, the balance point shifts to 80 cm.

(*i*) Calculate unknown emf of the cell.

(*ii*) Explain with reason, whether the circuit works, if the driver cell is replaced with a cell of emf 1 V.

(*iii*) Does the high resistance *R*, used in secondary circuit affect the balance point? Justify your answer.

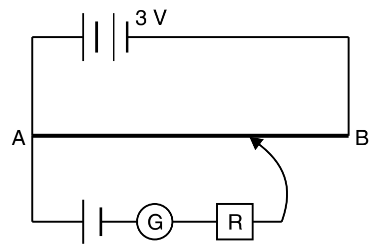


Fig. 3.92

33. Draw the circuit diagram of a potentiometer which can be used to determine the internal resistance (*r*) of a given cell of emf (E). Explain briefly how the internal resistance of the cell is determined.

34. A cell of emf 'E' and internal resistance '*r*' is connected to a variable resistance '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'.

35. The figure 3.93 shows experimental set up of a meter bridge when the two unknown resistances X and *Y* are inserted, the null point D is obtained 40 cm from the end A. When a resistance of 10 Ω is connected in series with X, the null point D is obtained 10 cm. Find the position of the null point when the 10 Ω resistance is inserted in series with resistance *Y*. Determine the value of the resistances X and Y.

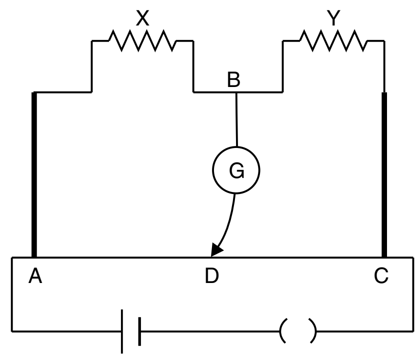


Fig. 3.93

36. 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.

37. In a meter bridge balance point is found at a distance l_1 with resistors *R* and *S* as shown in the figure 3.94. When an unknown resistor X is connected in parallel with the resistor S, the balance point shifts to a distance l_2. Find the expression for X in terms of l_1, l_2 and S.

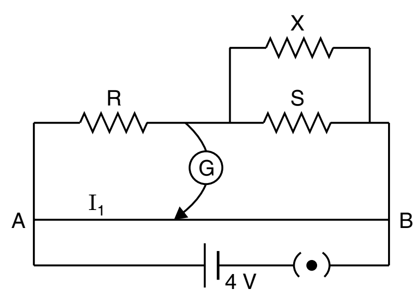


Fig. 3.94

In the figure 3.95, the resistances, of BC and CD arms are now interchanged and another carbon resistance is connected in place of R so that the current through the arm BD is again zero. Write the sequence of colour bands of the carbon resistor. Also find the value of current through it.

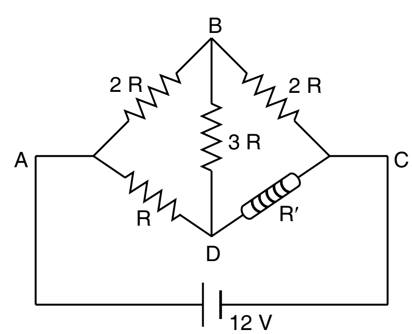


Fig. 3.95

38. A resistance R is connected across a cell, of emf E_x and internal resistance r_x. A potentiometer now measures the p.d. between the terminals of the cell, as V, state the expression for r in terms of E, V and R.

39. A parallel combination of two cells of emfs E_1 and E_2 and internal resistance r_1 and r_2 is used to supply current to a load of resistance R. Write the expression for the current through the load in terms of E_1, E_2, r_1 and r_2.

40. Write the nature of path of free electrons in a conductor in the

(*i*) presence of electric field

(*ii*) absence of electric field.

Between two successive collisions each free electron acquire a velocity 0 to ν where $v = eE/m\tau$. What is the average velocity of a free electron in the presence of an electric field? Do all electrons have the same average velocity? How does the average velocity of free electron in the presence of electric field vary with temperature? A potentiometer circuit set up is shown. The potential gradient across the potentiometer wire is 0.025 V cm^{-1} and the ammeter present in a circuit reads 0.1 A, when the two way key is completely switched off. The balance point when the key between the terminals (*i*) 1 and 2 (*ii*) 1 and 3 is pluged in are found to be at lengths 40 cm and 100 cm respectively. Find the value of R and X.

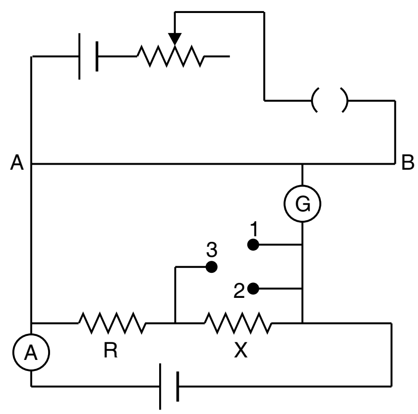


Fig. 3.96

❑❑❑