Kirchhoff's Laws & Electric Devices

1 Mark Questions

1.A heating element is marked 210 V, 630 What is the value of the current drawn by the element when connected to a 210 V DC Source? [Delhi 2013]

Ans.

Given that $P = 630$ W and $V = 210$ V. In DC source $P = VI$. Therefore, $I = \frac{P}{V} = \frac{630}{210} = 3$ A. **(1)**

2.In an experiment on meter bridge, if the balancing length AC is X, what would be its value, when the radius of the meter bridge wire AB is doubled? Justify your answer.[All India 2011 C]

Ans.

The balancing length continue to be X even on doubling the radius of meter bridge wire as it does not affect the ratio of length of two parts of meter bridge wire. **(1)**

NOTE $\because$ Resistance of wire $= \left(\frac{\rho}{A}\right) l$

For uniform wire, $\left(\frac{\rho}{A}\right)$ is constant even on doubling the radius of meter bridge wire.

$\therefore$ Resistance of wire $\propto l$.

3.In a meter bridge, two unknown resistances R and S when connected in the two gaps, give a null point at 40 cm from one end. What is the ratio of R and S?[Delhi 2010]

Ans.

∵ Null point is obtained at 40 cm from one end

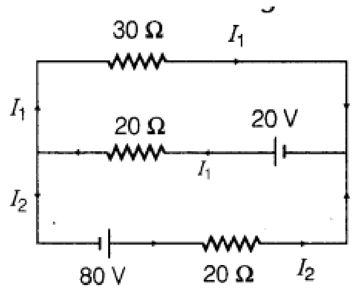
$$l = 40 \text{ cm},$$
$$100 - l = 60 \text{ cm}.$$

∵ For meter bridge ratio of unknown resistances

$$\frac{R}{S} = \frac{l}{(100 - l)} = \frac{40}{60} = \frac{2}{3}$$

$\Rightarrow R:S = 2:3$ **(1)**

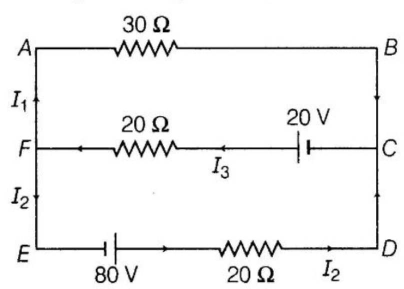
4.Use Kirchhoff's rules to determine the value of the current I_x flowing in the circuit shown in the figure.



[Delhi 2013C]

Ans.

According to the question,



Applying Kirchhoff's junction rule at *F* node

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

Applying Kirchhoff's second rule in loop *ABCF*,

$$-30I_1 + 20 - 20I_3 = 0$$
$$3I_1 + 2I_3 = 2 \quad \text{...(ii)}$$

In loop *ABDE*, **(1)**

$$-30I_1 + 20I_2 - 80 = 0$$
$$-3I_1 + 2I_2 = 8 \quad \text{...(iii)}$$

From Eq. (i) put the value of I_3 in Eq. (ii),

$$3I_1 + 2I_1 + 2I_2 = 2$$
$$5I_1 + 2I_2 = 2 \quad \text{...(iv)}$$
$$\underset{+}{-3I_1} + \underset{-}{2I_2} = \underset{-}{8} \quad \text{...(v)}$$

subtract $8I_1 = -6, \; I_1 = -\frac{3}{4}$ A

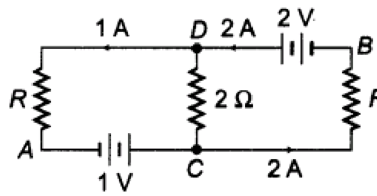
Put I_1 in Eq. (iv)

$$-5 \times \frac{3}{4} + 2I_2 = 2, \; 2I_2 = \frac{23}{4}, \; I_2 = \frac{23}{8} \text{ A}$$

From Eq. (i)

$$I_3 = -\frac{3}{4} + \frac{23}{8} = \frac{-6 + 23}{8} \text{ or } I_3 = \frac{17}{8} \text{ A.}$$ **(1)**

5.In the given circuit, assuming point A to be at zero potential, use Kirchhoff's rules to determine the potential at point B

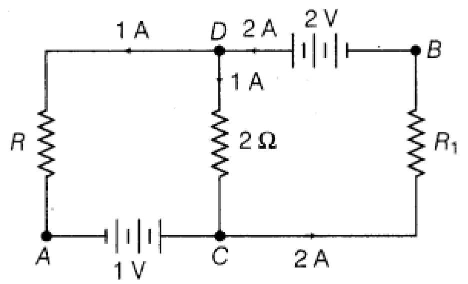


[All India 2011]

Ans.

By Kirchhoff's first law at D

$$I_{DC} = 1\text{A} \qquad (I_{DC} + 1 = 2)$$



(1)

Along $ACDBA$,

$$V_A + 1\text{V} + 1 \times 2 - 2 = V_B$$

But $V_A = 0,$

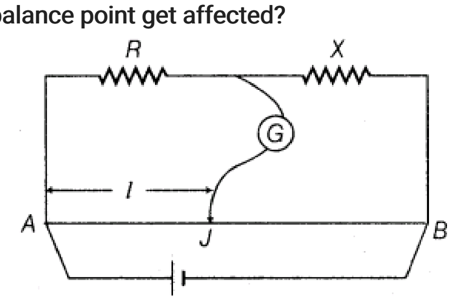
$$V_B = 1 + 2 - 2 = 1\text{V}$$

$$V_B = 1\text{ V}$$ **(1)**

6.In the meter bridge experiment, balance point was observed at J with AJ =l.

(i)The values of R and X were doubled and then interchanged. What would be the new position of balance point?

(ii)If the galvanometer and battery are interchanged at the balanced position, how will the balance point get affected?



[All India 2011]

Ans.

(*i*) The balancing condition state that

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

When X and R both are doubled, then

$$\frac{2X}{2R} = \frac{X}{R} = \frac{100 - l}{l}$$

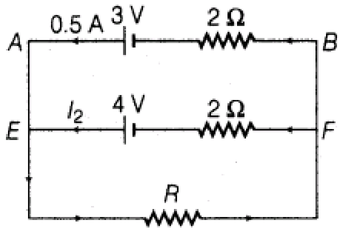
Balancing length would be at $(100 - l)$ cm. **(1)**

(*ii*) On changing the position of galvanometer and battery, the meter bridge continue to be balanced and hence, no change occur in the balance point. **(1)**

7.Using Kirchhoff's rules in the given circuit, determine

(i)the voltage drop across the unknown resistor R and

(ii)the current I_2 in the arm EF



[All India 2011]

Ans.

(*i*) Applying Kirchhoff's second rule in the closed mesh *ABFEA*

$$V_B - 0.5 \times 2 + 3 = V_A \quad \Rightarrow \quad V_B - V_A = -2$$

$$V = V_A - V_B = +2\,\text{V}$$

Potential drop across *R* is 1 V as *R*, *EF* and upper row are in parallel. **(1)**

or

Potential across *AB* = potential across *EF*

$$3 - 2 \times 0.5 = 4 - 2I_2$$

$$2I_2 = 2\ I_2\ \text{A}$$

Potential across *R* = potential across *AB* = potential accross *EF*

$$= 3 - 2 \times 0.5 = 2\ \text{V}$$

(*ii*) Applying Kirchhoffs first rule at *E*

$$0.5 + I_2 = I$$

where, I is current through *R*.

Now, Kirchhoff's second rule in closed mesh *AEFB*, $\Sigma E + \Sigma IR = 0$

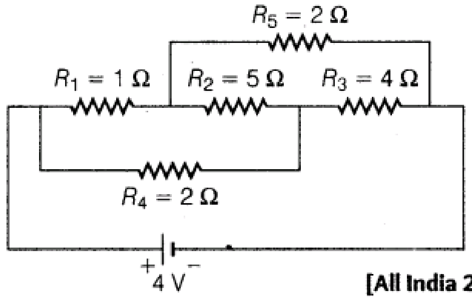
$$-4 + 2I_2 - 0.5 \times 2 + 3 = 0$$

$$2I_2 - 2 = 0$$

$$I_2 = 1\,\text{A}$$

The current in arm $EF = 1\,\text{A}$ **(1)**

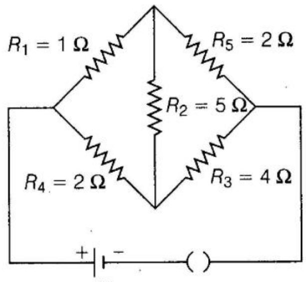
8.Calculate the current drawn from the battery in the given network



[All India 2009]

Ans.

The given circuit can be redrawn as given below.



Here, $\dfrac{R_1}{R_5} = \dfrac{R_4}{R_3} \Rightarrow \dfrac{1}{2} = \dfrac{2}{4}$

Wheatstone bridge is balanced. So, there will no current in the diagonal resistance R_2 or it can be withdrawn from the circuit.

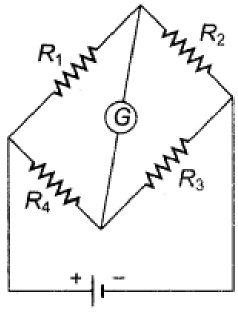
The equivalent resistance would be equivalent to a parallel combination of two rows which consists of series combination of R_1 and R_5 and R_4 and R_3, respectively.

$$\frac{1}{R} = \frac{1}{1+2} + \frac{1}{2+4} = \frac{1}{3} + \frac{1}{6}$$

$$R = \frac{18}{9} = 2\,\Omega$$

$$\therefore\ I = \frac{V}{R} = \frac{4}{2} = 2\text{ A or } I = 2\text{ A}$$

9. For the circuit diagram of a Wheatstone bridge shown in the figure, use Kirchhoff's laws to obtain its balance condition.

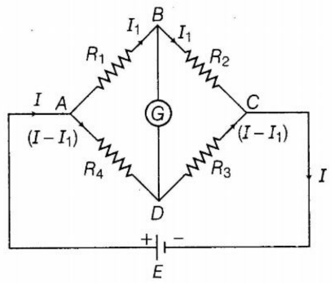


[Delhi 2009]

Ans.

In balanced Wheatstone bridge to current flow through galvanometer, that means while applying Kirchhoff's law, we can neglect this path.

No current flows through the galvanometer G when circuit is balanced.



(1)

On distributing currents as per Kirchhoff's first rule.
Applying Kirchhoff's second rule

(*i*) In mesh *ABDA*,

$\therefore -I_1R_1 + (I - I_1)R_4 = 0$

$\Rightarrow \quad I_1R_1 = (I - I_1)R_4 \quad$ ...(i)

(*ii*) In mesh *BCDB*,

$-I_1R_2 + (I - I_1)R_3 = 0$

$\Rightarrow \quad I_1R_2 = (I - I_1)R_3 \quad$ ...(ii)

On dividing Eq. (i) by Eq. (ii), we get

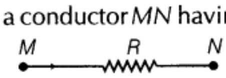
$$\frac{I_1R_1}{I_1R_2} = \frac{(I - I_1)R_4}{(I - I_1)R_3}; \quad \frac{R_1}{R_2} = \frac{R_4}{R_3}$$

This is necessary and required balanced condition of balanced Wheatstone bridge.
(1)

10.Obtain the formula for the power loss (i.e. power dissipated) in a conductor of resistance R, carrying a current.[Delhi 2009 C]

Ans.

Consider a conductor *MN* having resistance *R*.



The potentials of the two terminals are suppose V_M and V_N.

Such that, $V_M - V_N = V \quad (As, V_M > V_N)$

At any time interval Δt, current through the conductor will be

$$I = \frac{\Delta q}{\Delta t} \quad \textbf{(1)}$$

where, Δq = charge drifted through the conductor.

The electrical potential energies of the charge Δq at *M* and *N* are $\Delta U_m = \Delta q V_M$ and $\Delta U_N = \Delta q V_N$, respectively.

$\therefore$ Change in potential energy

$$\Delta U = \Delta U_N - \Delta U_M$$

As loss of potential energy = gain in kinetic energy.

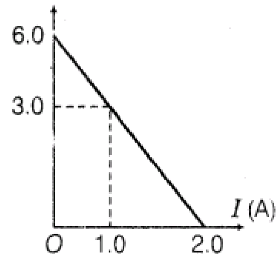
$\Rightarrow \quad \Delta K = -\Delta U = IV\Delta t \quad$ **(1)**

$\therefore$ Energy dissipated per unit time (called power loss) is,

$$P = \frac{IV\Delta t}{\Delta t} = VI = I^2R$$

$(\because V = IR)$

11.The adjoining graph shows the variation of terminal potently difference V, across a combination o three cells in series to a resistor vers[1] the current I.



(i)Calculate the emf of each cell.
(ii)For what current I, will the power dissipation of the circuit be maximum? [All India 2008]
Ans.

(i) As, terminal potential,

$$V = \varepsilon_0 - Ir$$

When current drawn through the cell is zero (i.e. $I = 0$)
then voltage is 6 V.
The battery is a combination of three cells.
Thus, in open circuit its terminal potential is equal to its emf.

$\therefore$ The emf of each cell, $\varepsilon = \frac{6.0}{3} = 2$ V

(ii) From the graph,
$V = 0$ when $I_s = 2$ A

$\therefore \quad 0 = \varepsilon_0 - I_s r$

where, r_2 is internal resistance of the cell combination

$\Rightarrow \quad r = \frac{\varepsilon_0}{I_s} = \frac{6}{2} = 3\,\Omega$ **(1)**

Power is maximum when internal resistance is equal to the external resistance and the current drawn,

$I = \frac{\varepsilon}{r+R} = \frac{\varepsilon}{2r} = \frac{6}{2 \times 3} = 1$ A **(1)**

3 Marks Questions

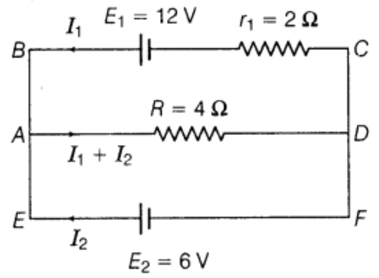
12.Answer the following
(i)Why are the connections between the resistor in a meter bridge made of thick copper strips?
(ii)Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire?
(iii)Which material is used for the meter bridge wire and why?[All India 2014]
Ans.(i)The connections between the resistors in a meter bridge are made of thick copper strips because of their negligible resistance.

(ii) It generally preferred to obtain the balance point in the middle of the meter bridge wire because meter bridge is most sensitive when all four resistances are of same order

(iii)Alloy, magnanin or constantum are used for making meter bridge wire due to low temperature coefficient of resistance and high resistivity

13. In the electric network shown in the figure, use Kirchhoff 's rules to calculate the power consumed by the resistance $R = 4\ \Omega$.

[Delhi 2014 C]



Ans.

According to Kirchhoff's rule in loop *ABCDA*.

$$+12 - 2I_1 - 4(I_1 + I_2) = 0$$

$$3I_1 + 2I_2 = 6 \quad \text{...(i)}$$

For loop *ADFEA*

$$+4(I_1 + I_2) - 6 = 0$$

$$\therefore \quad 2I_1 + 2I_2 = 3 \quad \text{...(ii)}$$

On solving Eqs. (i) and (ii), we get

$$I_1 = 3\text{A}$$

$$I_2 = -1.5\text{ A}$$

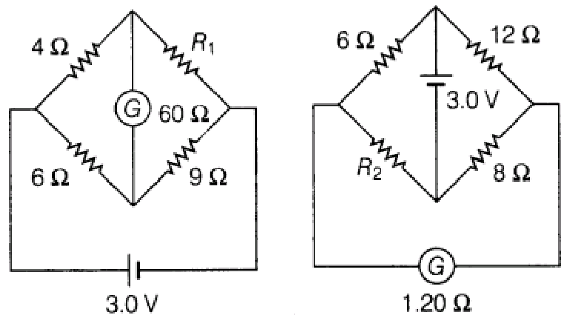
Hence, power consumed by resistor R

$$= (I_1 + I_2)^2 R = (3 - 1.5)^2 \times 4$$

$$= (1.5)^2 \times 4$$

$$= 9$$

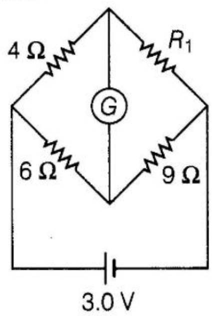
14.Define the current sensitivity of a galvanometer. Write its SI unit.Figure shows two circuits each having a galvanometer and a battery of 3 V.When the galvanometer in each arrangement do not show any deflection, obtain the ratio R_1 / R_2.



[All India 2013]

Ans.

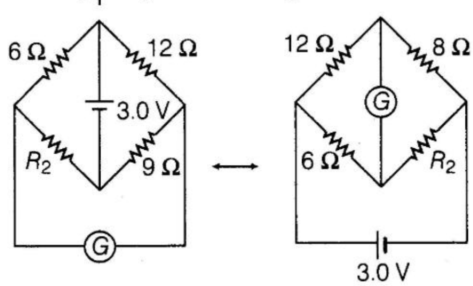
Current sensitivity of a galvanometer is defined as the deflection produed in galvanometer per unit current flowing through it. Its SI unit is radian/ampere.



(1)

For balanced Wheatstone bridge, there will be no deflection in the galvanometer.

$$\frac{4}{R_1} = \frac{6}{9} \Rightarrow R_1 = \frac{4 \times 9}{6} = 6\Omega$$



(1)

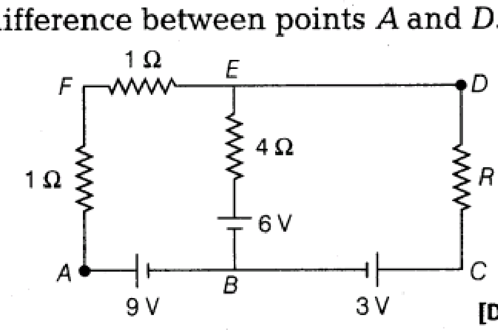
For the equivalent circuit, when the Wheatstone bridge is balanced, there will be no deflection in the galvanometer.

$$\therefore \quad \frac{12}{8} = \frac{6}{R_2}$$

$$\Rightarrow \quad R_2 = \frac{6 \times 8}{12} = 4\,\Omega$$

$$\therefore \quad \frac{R_1}{R_2} = \frac{6}{4} = \frac{3}{2}$$

15. Using Kirchhoff's rules, determine the value of unknown resistance R in the circuit, so that no current flows through 4 Ω resistance. Also, find the potential difference between points A and D.



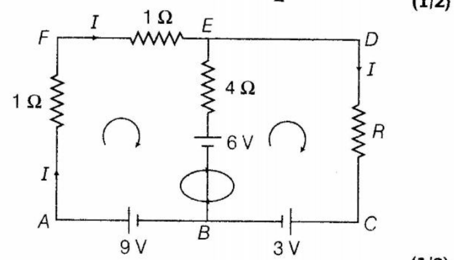
[Delhi 2012]

Ans.

Applying Kirchhoff's second law in mesh *AFEBA*

$$-1 \times I - 1 \times I - 6 + 9 = 0$$
$$-2I + 3 = 0$$
$$I = \frac{3}{2}\text{ A} \quad \text{...(i)}$$

(1/2)



(1/2)

Applying Kirchhoff's IInd law in mesh *AFDCA*

$$-1 \times I - 1 \times I - I \times R - 3 + 9 = 0$$
$$-2I - IR + 6 = 0 \quad \textbf{(1/2)}$$
$$2I + IR = 6 \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

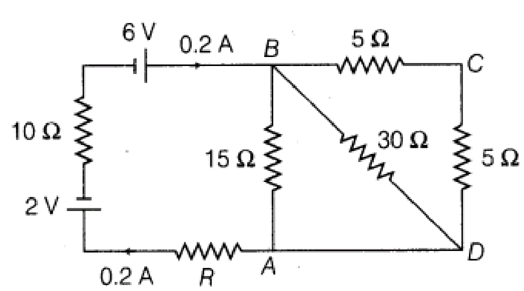
$$\left(2 \times \frac{3}{2}\right) + \frac{3}{2}R = 6$$

$$\Rightarrow \quad R = 2\ \Omega \quad \textbf{(1/2)}$$

For potential difference across *A* and *D* along *AFD*

$$V_A - \frac{3}{2} \times 1 - \frac{3}{2} \times 1 = V_D$$
$$V_A - V_D = 3\text{ V} \quad \textbf{(1)}$$

16.Calculate the value of the resistance R in the circuit shown in the figure, so that the current in the circuit is 0.2A. What would be the potential difference between points A and B ?



[All India 2012]

Ans.

For *BCD*, equivalent resistance

$$R_1 = 5\Omega + 5\Omega = 10\ \Omega \quad \textbf{(1/2)}$$

Across *BA*, equivalent resistance R_2

$$\frac{1}{R_2} = \frac{1}{10} + \frac{1}{30} + \frac{1}{15}$$
$$= \frac{3+1+2}{30} = \frac{6}{30} = \frac{1}{5} \quad \textbf{(1/2)}$$

$$\Rightarrow \quad R_2 = 5\Omega$$

Potential difference,

$$V_{BA} = I \times R_2$$
$$= 0.2 \times 5$$
$$V_{BA} = 1\text{V}$$
$$\Rightarrow \quad V_{AB} = -1\text{V}$$

17.Two heating elements of resistances R1 and R_2 when operated at a constant supply of voltage V, consume powers P1 and P_2, respectively. Deduce the expressions for the power of their combination when they are, in turn, connected in

(i)series and

(ii)parallel across their same voltage supply.[All India 2011]

Ans.

To deduce the expression for the power of the combination, first find the equivalent resistance of the combination in the given conditions.

$$\because \quad P_1 = \frac{V^2}{R_1} \Rightarrow R_1 = \frac{V^2}{P_1}$$

$$P_2 = \frac{V^2}{R_2}$$

$$\Rightarrow \quad R_2 = \frac{V^2}{P_2}$$

(1/2 × 2 = 1)

(*i*) In series combination,

$$R_s = R_1 + R_2 = \frac{V^2}{P_1} + \frac{V^2}{P_2}$$

$$R_s = R_1 + R_2 = V^2\left(\frac{1}{P_1} + \frac{1}{P_2}\right) = V^2\left(\frac{P_1 + P_2}{P_1 P_2}\right)$$

Now, let the power of heating element in series combination be P_s.

$$\therefore \quad P_s = \frac{V^2}{R_1 + R_2} = \frac{V^2}{V^2\left(\frac{P_1 + P_2}{P_1 P_2}\right)} = \frac{P_1 P_2}{P_1 + P_2}$$

$$P_s = \frac{P_1 P_2}{P_1 + P_2}$$

(1)

(*ii*) In parallel combination,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{\frac{V^2}{P_1}} + \frac{1}{\frac{V^2}{P_2}} = \frac{P_1}{V^2} + \frac{P_2}{V^2}$$

$$\frac{1}{R_p} = \frac{1}{V^2}(P_1 + P_2)$$

Now, power consumption in parallel combination

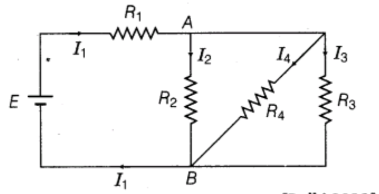
$$P_p = \frac{V^2}{R_p} = V^2\left(\frac{1}{R_p}\right)$$

$$P_p = V^2\left[\frac{1}{V^2}(P_1 + P_2)\right]$$

$$P_p = P_1 + P_2$$

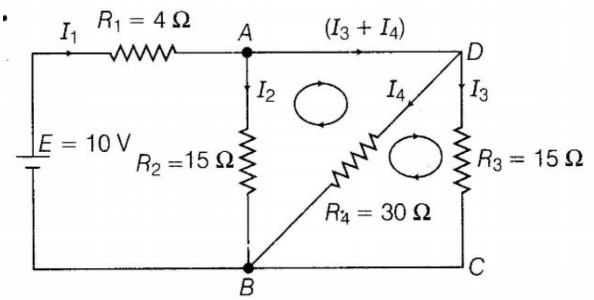
(1)

18. In the circuit shown, $R_1 = 4\,\Omega$, $R_2 = R_3 = 15\,\Omega$, $R_4 = 30\,\Omega$ and $E = 10$ V. Calculate the equivalent resistance of the circuit and the current in each resistor.



[Delhi 2011]

Ans.



According to figure 15Ω, 30Ω and 15Ω are in parallel, their equivalent resistance (R_{eq}) is

$$\frac{1}{R_{eq}} = \frac{1}{15} + \frac{1}{30} + \frac{1}{15} = \frac{2+1+2}{30} = \frac{5}{30}$$

$$\frac{1}{R_{eq}} = \frac{1}{6}$$

$$R_{eq} = 6\,\Omega$$

Now, $R_{eq} = 6\Omega$ and 4Ω are in series their equivalent resistance R'_{eq} is

$$R'_{eq} = R_{eq} + 4\Omega = 6\Omega + 4\Omega = 10\Omega$$

By junction rule at node A

$$I_1 = I_2 + I_3 + I_4 \qquad \text{...(i)} \quad \textbf{(1/2)}$$

Applying Kirchhoff's second rule in

(*i*) In mesh ADB,

$$-I_4 \times 30 + 15I_2 = 0$$

$$I_2 = 2I_4$$

$$\Rightarrow \quad I_4 = \frac{I_2}{2}$$ **(1/2)**

(*ii*) In mesh BDC,

$$30\,I_4 - 15I_3 = 0$$

$$\Rightarrow \quad I_3 = 2I_4 \Rightarrow I_4 = \frac{I_3}{2}$$

(*iii*) In mesh ABE (containing battery), **(1/2)**

$$-4I_1 - 15\,I_2 + 10 = 0$$

$$4I_1 + 15I_2 = 10 \qquad \text{...(ii)}$$

(*iv*) In mesh $ABCD$, **(1/2)**

$$-15I_2 + 15\,I_3 = 0$$

$$I_2 = I_3$$

$$I_1 = I_2 + I_2 + \frac{I_2}{2}$$

$$I_1 = \frac{5}{2}I_2$$

From Eq. (ii), we get

$$4\left(\frac{5}{2}I_2\right)+15I_2=10$$

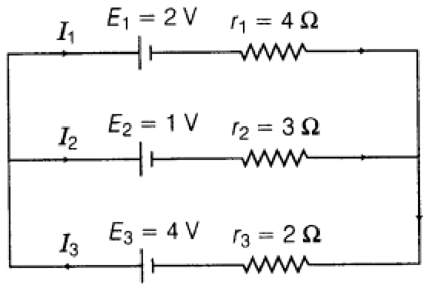
$$I_2=\frac{10}{25}\text{ A}=\frac{2}{5}\text{ A}=I_3$$

$$\Rightarrow \quad I_2=I_3=\frac{2}{5}\text{ A}$$

$$I_4=\frac{I_2}{2}=\frac{1}{5}\text{ A}$$

$$\therefore \quad I_1=\frac{5}{2}I_2=\frac{5}{2}\times\frac{2}{5}=1\text{ A}$$

19. State Kirchhoff's rules. Use these rules to write the expressions for the currents I_{1t} I_2 and I_3 in the circuit diagram shown in figure below.



[All India 2010]

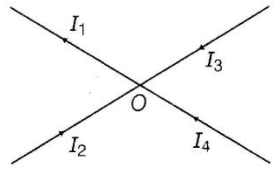
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$$\Rightarrow \quad \Sigma I=0$$

At junction O,

$$I_1+I_2=I_3+I_4$$



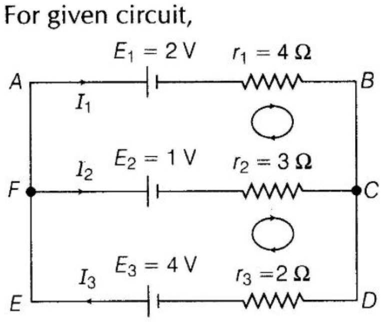
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\Sigma E+\Sigma IR=0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3=I_1+I_2 \quad \text{...(i)}$$

In mesh *ABCFA*,

$$-2-4I_1+3I_2+1=0$$

$$4I_1-3I_2=-1$$

In mesh *FCDEF*,

$$-1-3I_2-2I_3+4=0$$

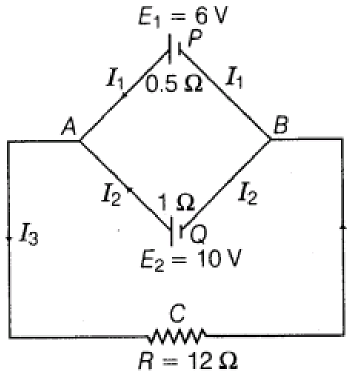
$$3I_2+2I_3=3$$

On solving, we get I_1, I_2 and I_3.

$$I_1=\frac{2}{13}\text{A} \quad \text{or} \quad I_2=\frac{7}{13}\text{A}$$

$$I_3=\frac{9}{13}\text{A}$$

20.State Kirchhoff's rules. Apply Kirchhoff's rules to the loops ACBPA and ACBQA to write the expressions for the currents I_1, I_2 and I_3 in the network.



[All India 2010]

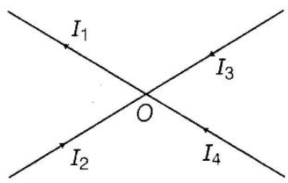
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$$\Rightarrow \quad \Sigma I = 0$$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



(1)

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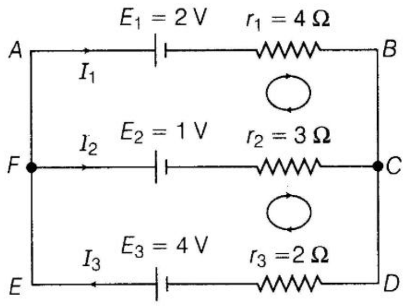
Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

In mesh $ABCFA$,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$

$$4I_1 - 3I_2 = -1$$

In mesh $FCDEF$,

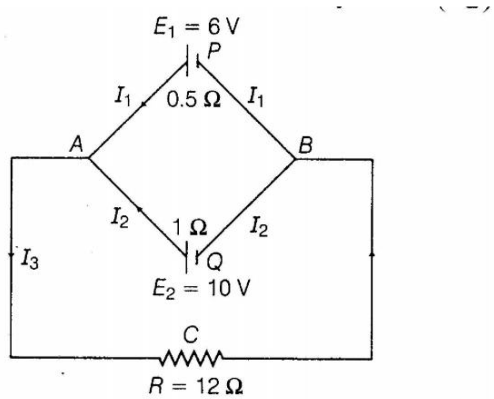
$$-1 - 3I_2 - 2I_3 + 4 = 0$$

$$3I_2 + 2I_3 = 3$$

On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$

$$I_3 = \frac{9}{13}\text{ A}$$



Applying Kirchhoff's second rule in loop $ACBPA$,

$$-12I_3 + 6 - 0.5\,I_1 = 0$$

$$5I_1 + 120\,I_3 = 60 \quad \text{...(i)}$$

In loop $ACBQA$,

$$-12\,I_3 + 10 - I_2 \times 1 = 0$$

$$12I_3 + I_2 = 10 \quad \text{...(ii)}$$ **(1/2)**

Also Kirchhoff's junction rule,

$$I_1 + I_2 = I_3 \quad \text{...(iii)}$$ **(1/2)**

(Here, three equations are the expressions for I_1, I_2 and I_3)

On solving Eqs. (i), (ii) and (iii), we get

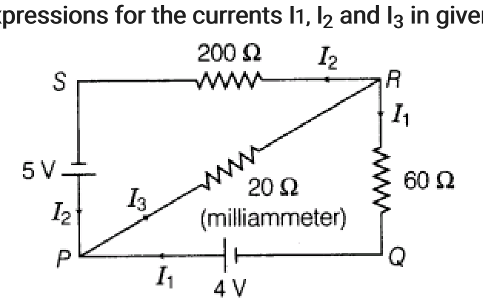
$$I_1 = -\frac{84}{37}\text{ A}$$

$$I_2 = \frac{106}{37}\text{ A}$$

$$I_3 = \frac{22}{37}\text{ A}$$

(1/2)

21.State Kirchhoff's rules. Apply these rules to the loops PRSP and PRQP to write the expressions for the currents I_1, I_2 and I_3 in given circuit.



[All India 2010]

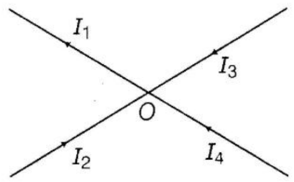
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$$\Rightarrow \quad \Sigma I = 0$$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



(1)

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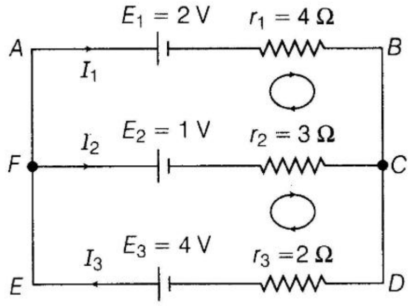
i.e. $\Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

In mesh $ABCFA$,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$

$$4I_1 - 3I_2 = -1$$

In mesh $FCDEF$,

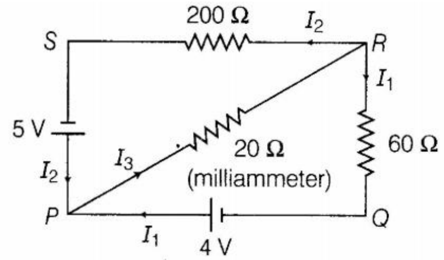
$$-1 - 3I_2 - 2I_3 + 4 = 0$$

$$3I_2 + 2I_3 = 3$$

On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$

$$I_3 = \frac{9}{13}\text{ A}$$



Applying Kirchhoff's second rule to the loop *PRSP*,

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

$$-I_3 \times 20 - I_2 \times 200 + 5 = 0$$

$$4I_3 + 40I_2 = 1 \quad \text{...(i)}$$

For loop *PRQP*,

$$-20I_3 - 60I_1 + 4 = 0$$

$$5I_3 + 15I_1 = 1 \quad \text{...(ii)}$$

Applying Kirchhoff's first rule at *P*

$$I_3 = I_1 + I_2 \quad \text{...(iii)}$$

(1)

From Eqs. (i) and (iii), we have

$$4I_1 + 44I_2 = 1 \quad \text{...(iv)}$$

From Eqs. (ii) and (iii), we have

$$20I_1 + 5I_2 = 1 \quad \text{...(v)}$$

On solving the above equations, we get

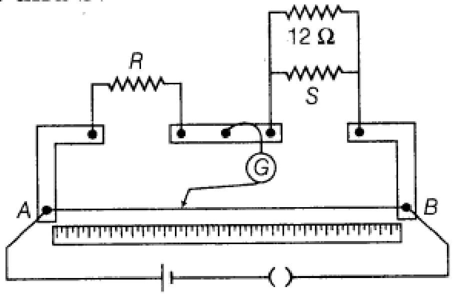
$$I_3 = \frac{11}{172} \text{ A} = \frac{11000}{172} \text{ mA}$$

$$I_2 = \frac{4}{215} \text{ A} = \frac{4000}{215} \text{ mA}$$

$$I_1 = \frac{39}{860} \text{ A} = \frac{39000}{860} \text{ mA}$$

(1)

22. In a meter bridge, the null point is found at a distance of 40 cm from *A*. If a resistance of 12 Ω is connected in parallel with *S*, then null point occurs at 50.0 cm from *A*. Determine the values of *R* and *S*.



[HOTS; Delhi 2010]

Ans.

In case of meter bridge at null point condition, the bridge is balanced, i.e. we can apply the condition of balanced Wheatstone bridge.

Applying the condition of balanced Wheatstone bridge,

$$\frac{R}{S} = \frac{l}{100 - l} = \frac{40}{100 - 40} = \frac{40}{60} = \frac{2}{3}$$

$$\frac{R}{S} = \frac{2}{3} \quad \text{...(i)}$$

(1)

The equivalent resistance of 12 Ω and S Ω in parallel is $\frac{12S}{12+S}$ Ω.

(1/2)

Again, applying the condition

$$\frac{R}{\left(\frac{12S}{12+S}\right)} = \frac{50}{50} = 1$$

(1/2)

$$\Rightarrow \quad R = \frac{12S}{12+S} \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{2}{3}S = \frac{12S}{12+S}$$

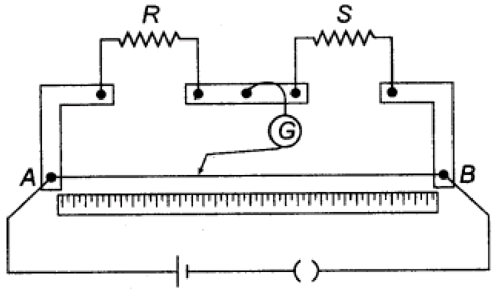
$$12 + S = 18 \quad \text{or} \quad S = 6\,\Omega$$

$$R = \frac{2}{3}S = \frac{2}{3} \times 6 = 4\,\Omega$$

$$R = 4\,\Omega$$

(1/2 × 2 = 1)

23. In a meter bridge, the null point is found at a distance of 60 cm from A. If a resistance of 5 Ω is connected in series with S, then null point occurs at 50.0 cm from A. Determine the values of R and S.



[Delhi 2010]

Ans.

The condition of balanced meter bridge

$$\frac{R}{S}=\frac{60}{100-60}=\frac{60}{40}=\frac{3}{2}$$

$$\frac{R}{S}=\frac{3}{2} \qquad \ldots(i)$$

(1)

Again, applying the condition, when S and $5\ \Omega$ are connected in series

$$\frac{R}{S+5}=\frac{50}{50} \Rightarrow \frac{R}{S+5}=1 \qquad \ldots(ii)$$

(1)

From Eqs. (i) and (ii), we get

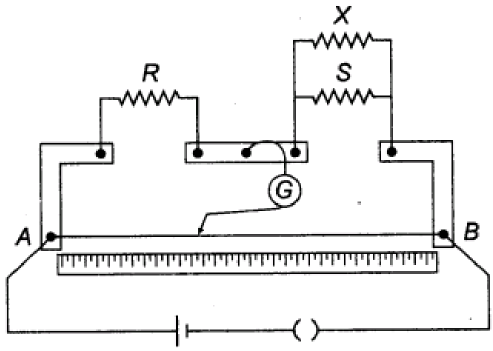
$$\frac{3}{2}S=S+5 \quad \Rightarrow \frac{3}{2}S-S=5$$

$$S=10\ \Omega$$

$$R=\frac{3}{2}S=\frac{3}{2}\times 10=15\ \Omega$$

$$R=15\ \Omega, S=10\ \Omega$$ **(1)**

24.In a meter bridge, the null point is found at a distance of l1 cm from A. If a resistance of X is connected in parallel with S, then null point occurs at a distance l2 cm from A Obtain the formula for X in terms of l1,l2 and S.



[Delhi 2010]

Ans.

Initially, for balanced Wheatstone bridge,

$$\frac{R}{S}=\frac{l_1}{100-l_1}$$

$$\Rightarrow \qquad R=\frac{l_1}{100-l_1}S \qquad \ldots(i)$$

(1)

When X is connected in parallel with S, then

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

(1)

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

$$= \left(\frac{100-l_2}{l_2}\right) \times \left(\frac{l_1}{100-l_1}\right)S$$

(from Eq. (i))

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

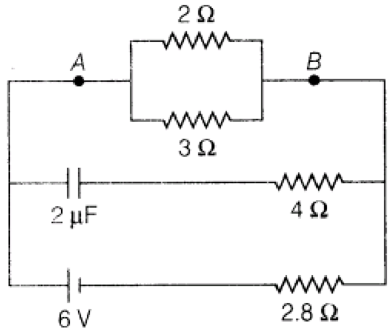
$$\frac{S+X}{X} = \left(\frac{l_2}{l_1}\right)\left(\frac{100-l_1}{100-l_2}\right)$$

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

$$\frac{S}{X} = \frac{l_2}{l_1}\left(\frac{100-l_1}{100-l_2}\right)-1$$

$$\frac{S}{X} = \frac{100(l_2-l_1)}{l_1(100-l_2)} \Rightarrow X = \frac{l_1(100-l_2)}{100(l_2-l_1)}S$$ **(1)**

25. Calculate the steady current through the $2\,\Omega$ resistor in the circuit shown in the figure below.



[Foreign 2010]

Ans.

No current flows through 4 Ω resistor as capacitor offers infinite resistance in DC circuits.

Also, 2 Ω and 3 Ω are in parallel combination

$$\therefore \quad R_{AB} = \frac{2 \times 3}{2+3} = \frac{6}{5} = 1.2 \text{ A}$$

Applying Kirchhoff's second rule in outer loop AB and cell.

Let I current flow through outer loop in clockwise direction.

$$-1.2I - 2.8I + 6 = 0$$
$$4I = 6$$
$$I = \frac{3}{2} \text{ A} \qquad \left(1\frac{1}{2}\right)$$

$\therefore$ Potential difference across AB

$$V_{AB} = IR_{AB} = \frac{3}{2} \times 1.2$$
$$V_{AB} = 1.8 \text{ V}$$

$\therefore$ 3 Ω and 2 Ω are in parallel combination.

$\therefore$ Potential difference across 2 Ω resistor is 1.8 V.

$\therefore$ Current I' through 2 Ω resistor is given by

$$I' = \frac{V}{R} = \frac{1.8}{2} = 0.9 \text{ A}$$
$$I' = 0.9 \text{ A} \qquad \left(1\frac{1}{2}\right)$$

The current through 2 Ω resistor is 0.9 A.

26. (*i*) State Kirchhoff's rules.

(*ii*) A battery of 10 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of 1 Ω resistance. Use Kirchhoff's rules to determine

(*a*) the equivalent resistance of the network and

(*b*) the total current in the network.

[All India 2010]

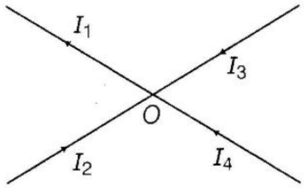
Ans.(i)

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \qquad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



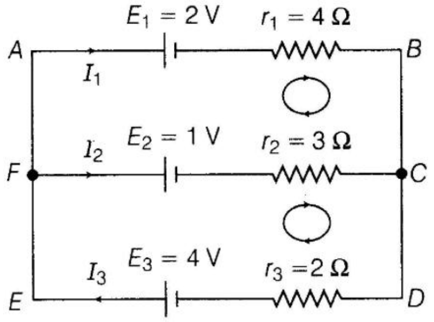
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\qquad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,

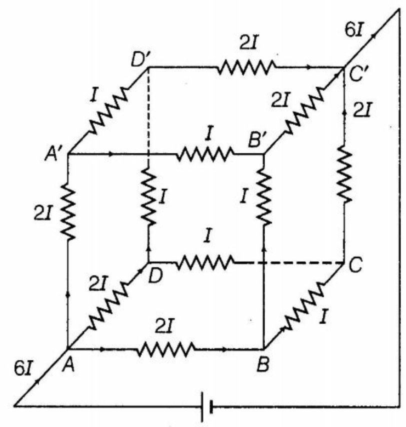


At F, applying junction rule

$$I_3 = I_1 + I_2 \qquad \text{...(i)}$$

(*ii*) Let $6I$ current be drawn from the cell. Since, the paths AA', AD and AB are symmetrical, current through them is same. **(1)**

As per Kirchhoff's junction rule, the current distribution is shown in the figure. **(1)**



Let the equivalent resistance across the combination be R.

$$E = V_A - V_B = (6I)R$$

$\Rightarrow$ $6IR = 10$ $(\because E = 10 \text{ V})$ ...(i)

Applying Kirchhoff's second rule in loop $AA'B'C'A$

$$-2I \times 1 - I \times 1 - 2I \times 1 + 10 = 0$$

$\Rightarrow$ $5I = 10$

$$I = 2 \text{ A}$$

Total current in the network $= 6I$

$$= 6 \times 2 = 12 \text{ A}$$

From Eq. (i), $6IR = 10$

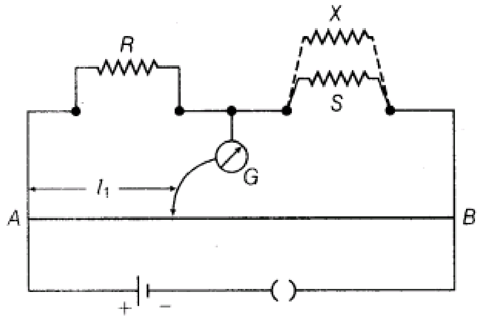
$$6 \times 2 \times R = 10$$

$$R = \frac{10}{12} = \frac{5}{6} \Omega$$

$$R = \frac{5}{6} \Omega$$

27.(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 resistances R and S as shown in the figure. When an unknown resistance X is connected in parallel with the resistance S, the balance point shifts to a distance l_2. Find expression for X in terms of l_1, l_2 and S. [All India 2009]



Ans.

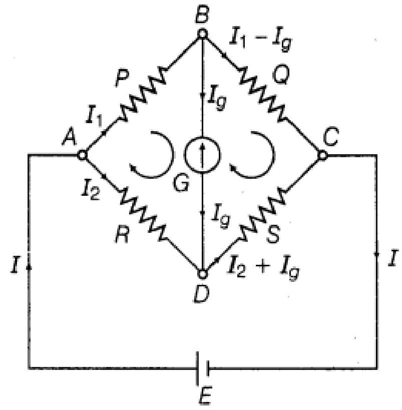
(i) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

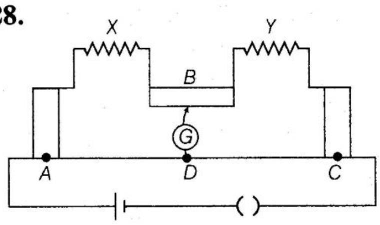
(a) no current flow through the galvanometer.

(b) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.
R = known resistance and
S = unknown resistance.



28.



The figure 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 shifts by 10 cm.

Find the position of the null point when the 10Ω resistance is instead connected in series with resistance Y. Determine the values of the resistances X and Y.
[Delhi 2009]

Ans.

Applying the condition of balanced Wheatstone bridge $\frac{X}{Y} = \frac{l}{100 - l}$, where l is the balancing length from end A.

Initially, $l = 40$ cm

$$\Rightarrow \quad \frac{X}{Y} = \frac{40}{100 - 40} = \frac{40}{60} = \frac{2}{3}$$

$$X = \frac{2}{3}Y \quad \text{...(i)}$$

(1/2)

When 10 Ω resistance connected in series with X, null points shift to $40 + 10 = 50$ cm.

$$\therefore \quad \frac{X + 10}{Y} = \frac{50}{50} = 1$$

$$\Rightarrow \quad X + 10 = Y$$

$$\Rightarrow \quad Y - X = 10 \quad \text{...(ii)}$$

(1/2)

From Eqs. (i) and (ii), we get

$$\frac{Y}{3} = 10\ \Omega$$

$$\Rightarrow \quad Y = 30\ \Omega$$

$$X = 20\ \Omega$$

(1)

Now, 10 Ω resistance connected in series with Y and let null point is obtained at length l cm.

$$\frac{X}{Y + 10} = \frac{l}{100 - l}$$

$$\frac{20}{30 + 10} = \frac{l}{100 - l}$$

$$(\because X = 20\ \Omega, Y = 30\ \Omega)$$

$$\frac{1}{2} = \frac{l}{100 - l}$$

$$100 - l = 2l$$

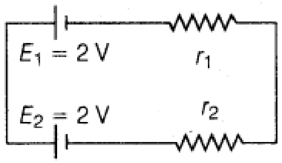
$$3l = 100$$

$$l = \frac{100}{3}\ \text{cm} = 33.33\ \text{cm}$$

(1)

So, null point is obtained at length 33.33 cm.

29.State Kirchhoff's rules. Use Kirchhoff's rules to show that no current flows in the given circuit



[Foreign 2009]

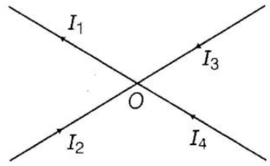
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



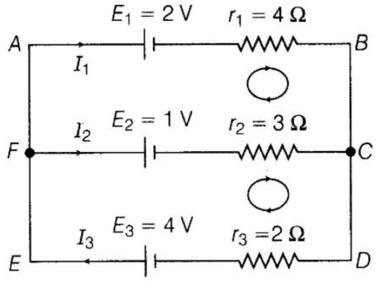
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\quad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

In mesh $ABCFA$,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$
$$4I_1 - 3I_2 = -1$$

In mesh $FCDEF$,

$$-1 - 3I_2 - 2I_3 + 4 = 0$$
$$3I_2 + 2I_3 = 3$$

On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$
$$I_3 = \frac{9}{13}\text{ A}$$

Let I current flows clockwise in the circuit.
Applying Kirchhoff's voltage rule

$$-2 - Ir_1 - Ir_2 + 2 = 0 \quad \textbf{(1/2)}$$
$$Ir_1 + Ir_2 = 0$$
$$I(r_1 + r_2) = 0$$

$\therefore \quad r_1 + r_2 \neq 0$

$\Rightarrow \quad I = 0$ **(1/2)**

Thus, no current flows through the circuit.

30. A battery of five lead acid accumulators, each of emf 4 V and internal resistance 1 Ω, connected in series is charged by 100 V DC source.

Calculate the following.

(*i*) The series resistance to be used in the circuit to have a current of 5 A.

(*ii*) Power supplied by the source.

(*iii*) Chemical energy stored in the battery in 10 min. **[Foreign 2008]**

Ans.

(*i*) Net emf $= 100 - 5 \times 4 = 80$ V

Net resistance = Net internal resistance + External resistance (R)

Net resistance $= 5 \times 1 + R = (5 + R)\ \Omega$

$$\therefore \quad I = \frac{V}{R} \quad \text{(Ohm's law)}$$

$$\Rightarrow \quad 5 = \frac{80}{5 + R}$$

$$\Rightarrow \quad 5 + R = \frac{80}{5} = 16$$

$$\text{or} \quad R = 11\Omega$$

(*ii*) As, $P = VI$ **(1)**

$= 100 \times 5 = 500$ W **(1)**

(*iii*) Chemical energy stored

= Net energy consumed by external battery – Energy loss in resistance

$= 500 \times (10 \times 60) - (5)^2 \times 16 \times (60 \times 10)$

$= 100 \times 10 \times 60 = 6 \times 10^4$ J

or $W = EIt = (5 \times 4) \times (5) \times (10 \times 60)$

$= 6 \times 10^4$ J **(1)**

31.Draw a circuit showing a Wheatstone bridge. Use Kirchhoff's rule to obtain the balance condition in terms of the values of the four resistors for the galvanometer to give null deflection. [Delhi 2008 CI

Ans.

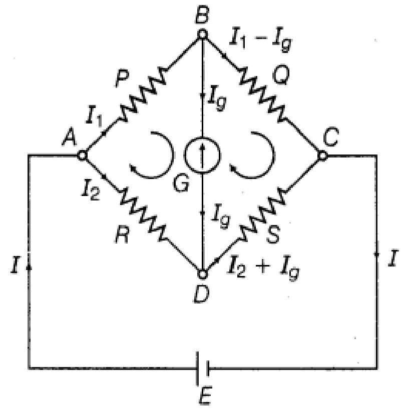
(*i*) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

(*a*) no current flow through the galvanometer.

(*b*) $V_B = V_D$ (*c*) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.
R = known resistance and
S = unknown resistance.



32.Draw a circuit diagram for a Wheatstone bridge. Explain briefly how the balance condition for the galvanometer to give null deflection provides a practical method for the determination of an unknown resistance? [Delhi 2008]

Ans.

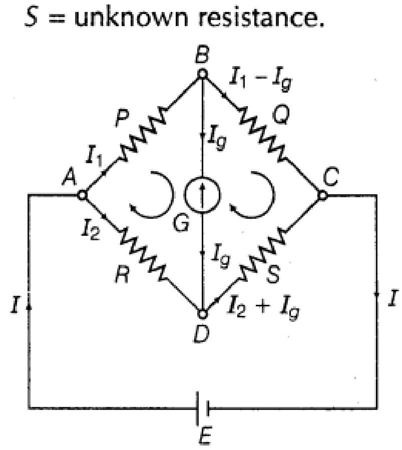
(i) Meter bridge works on the principl... balanced Wheatstone bridge.

In balanced Wheatstone bridge,

(a) no current flow through the galvanometer.

(b) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.
R = known resistance and
S = unknown resistance.



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

where, S is unknown resistance.

$$S = \frac{Q}{P} \times R = \frac{l}{(100 - l)} \times R \qquad \textbf{(1)}$$

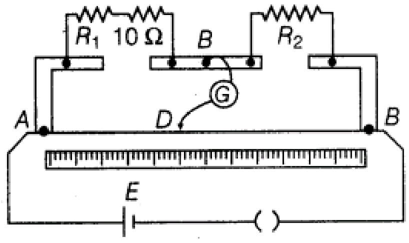
(using meter bridge)

5 Marks Questions

33.(i) State Kirchhoff's rules for an electric network. Using Kirchhoff's rules, obtain the balance condition in terms of the resistances of four arms of Wheatstone bridge.

(ii) In the meter bridge experimental set up, shown in the figure, the null point D is obtained at a distance of 40 cm from end A of the meter bridge wire.

If a resistance of $10\,\Omega$ is connected in series with R_1, null point is obtained at $AD = 60$ cm. Calculate the values of R_1 and R_2.



[Delhi 2013]

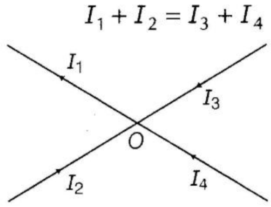
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



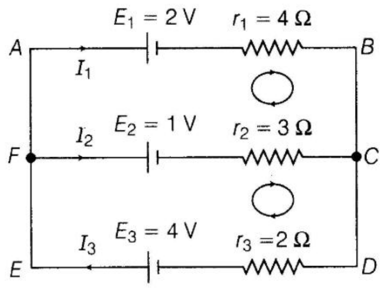
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\quad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

In mesh $ABCFA$,

$$-2-4I_1+3I_2+1=0$$

$$4I_1-3I_2=-1$$

In mesh $FCDEF$,

$$-1-3I_2-2I_3+4=0$$

$$3I_2+2I_3=3$$

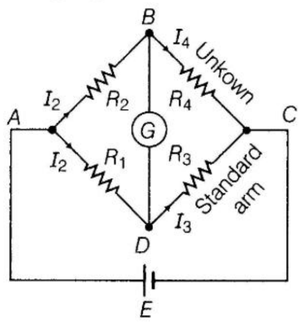
On solving, we get I_1, I_2 and I_3.

$$I_1=\frac{2}{13}\text{ A} \quad \text{or} \quad I_2=\frac{7}{13}\text{ A}$$

$$I_3=\frac{9}{13}\text{ A}$$

Wheatstone Bridge

The Wheatstone bridge is an arrangement of four resistances as shown in the following figure.



(1)

R_1, R_2, R_3 and R_4 are the four resistances. Galvanometer (G) has a current I_g flowing through it at balanced condition,

$$I_g=0$$

Applying junction rule at B,

$$\therefore \quad I_2=I_4$$

Applying junction rule at D,

$$\therefore \quad I_1=I_3$$

Applying loop rule to closed loop $ADBA$,

$$-I_1R_1+0+I_2R_2=0$$

$$\therefore \quad \frac{I_1}{I_2}=\frac{R_2}{R_1}$$

...(i)

Applying loop rule to closed loop $CBDC$,

$$I_2R_4+0-I_1R_3=0$$

$$\because \quad I_3=I_1$$

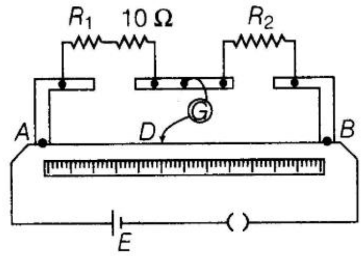
$$I_4=I_2$$

$$\therefore \quad \frac{I_1}{I_2}=\frac{R_4}{R_3} \qquad \text{...(ii)}$$

From Eqs. (i) and (ii), $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

This is the required balanced condition of Wheatstone bridge.

(*ii*) Considering both the situations and writing them in the form of equations



Let R' be the resistance per unit length of the potential meter wire

$$\frac{R_1}{R_2} = \frac{R' \times 40}{R'(100-40)} = \frac{40}{60} = \frac{2}{3}$$

$$\frac{R_1+10}{R_2} = \frac{R' \times 60}{R'(100-60)}$$

$$= \frac{60}{40} = \frac{3}{2}$$

$$\frac{R_1}{R_2} = \frac{2}{3} \quad \text{...(i)}$$

$$\frac{R_1+10}{R_2} = \frac{3}{2} \quad \text{...(ii)}$$

Putting the value of R_1 from Eq. (i) and substituting in Eq. (ii).

$$\frac{2}{3} + \frac{10}{R_2} = \frac{3}{2}$$

$\Rightarrow$ $R_2 = 12\ \Omega$

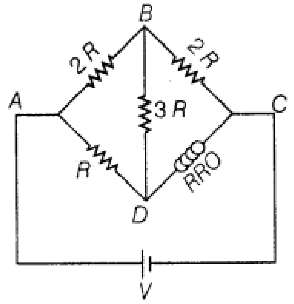
Recalling Eq. (i) again

$$\frac{R_1}{12} = \frac{2}{3}$$

$\Rightarrow$ $R_1 = 8\ \Omega$ **(3)**

34.(i) Use Kirchhoff's rules to obtain the balance condition in a Wheatstone bridge.

(ii) Calculate the value of R in the balance condition of the Wheatstone bridge, if the carbon resistor connected across the arm CD has the colour sequence red, red and orange, as shown in the figure.



(iii) If now the resistance of the arms BC and CD are interchanged, to obtain the balance condition, another carbon resistor is connected in place or R. What would now be sequence of colour bands of the carbon resistor?[Delhi 2012]

Ans.

(i) The balance condition is

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

$$\Rightarrow \quad \frac{P}{R} = \frac{Q}{S} \quad \textbf{(1)}$$

(ii) Let a carbon resistor S is given to the bridge

$$\Rightarrow \quad \frac{R}{S} = 1 \Rightarrow R = S = 22 \times 10^3\ \Omega \quad \textbf{(1)}$$

(iii) After interchanging the resistances the balanced bridge would be

$$\frac{2R}{X} = \frac{2 \times 10^3}{2 \times 22 \times 10^3} = \frac{1}{2}$$

$$\Rightarrow X = 4R = 4 \times 22 \times 10^3 = 88\,\text{k}\Omega \quad \textbf{(1)}$$

Thus, equivalent resistances of Wheatstone bridge

$$\frac{1}{R_{eq}} = \frac{1}{3R} + \frac{1}{6R} = \frac{3}{6R} \quad \textbf{(1)}$$

$$\Rightarrow \quad R_{eq} = 2R \quad \textbf{(1)}$$

$\therefore$ Current through it $I = \frac{1}{3} \times \frac{V}{2R} = \frac{V}{6R}$ A

35.(i) State with the help of a circuit diagram, the working principle of a meter bridge. Obtain the expression used for determining the unknown resistance.

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

(iii)Why is it considered important to obtain the balance point near the mid-point of the wire? [Delhi 2011 c]

Ans.(i)

(i) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

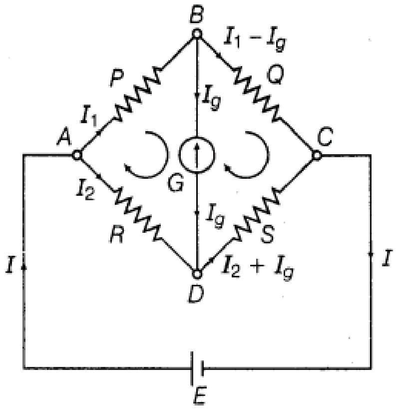
(a) no current flow through the galvanometer.

(b) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.

R = known resistance and

S = unknown resistance.



(ii)

(*i*) The balancing condition state that

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

When X and R both are doubled, then

$$\frac{2X}{2R} = \frac{X}{R} = \frac{100 - l}{l}$$

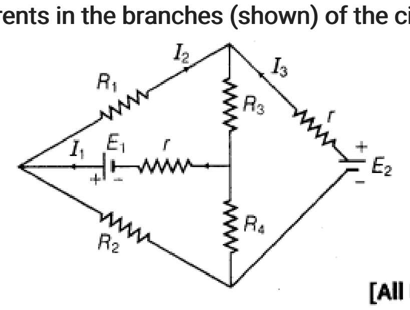
Balancing length would be at $(100 - l)$ cm.

(1)

(*ii*) On changing the position of galvanometer and battery, the meter bridge continue to be balanced and hence, no change occur in the balance point. **(1)**

(iii)It is because of the fact that meter bridge is most sensitive when null point occur nc the mid-point of wire and all the four resistances are of same order.

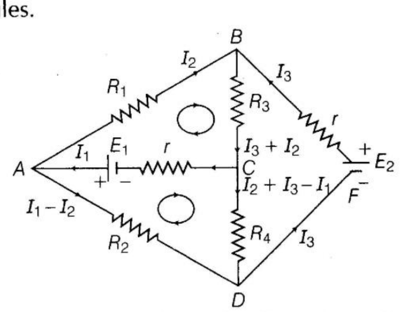
36.State the two rules that serves as general rules for analysis of electrical circuits.Use these rules to write the three equations that may be used to obtain the values of the three unknown currents in the branches (shown) of the circuit given below. [All India 2008 C]



[All India 2008C]

Ans.

The two rules that serves as general rules for analysis of electrical circuits are Kirchhoff's rules.



For statement of Kirchhoff's rule refer to ans. 19. **(2)**

In loop *ABCA* (clockwise),

$$-I_2R_1 - (I_2 + I_3)R_3 - I_1r + E_1 = 0$$

$$I_1r + I_2(R_1 + R_3) + I_3R_3 = E_1 \quad \text{...(i)}$$

(1)

In loop *ACDA* (clockwise),

$$-(I_1 - I_2)R_2 - I_1r + E_1 + (I_2 + I_3 - I_1)R_1 = 0$$

$$\Rightarrow I_1(r + R_2 + R_4) - I_2(R_2 + R_4) - I_3R_4 = E_1$$

(1)

In loop *ABFDA* (anti-clockwise)

$$-I_2R_1 + I_3r_1 - E_2 + (I_1 - I_2)R_2 = 0$$

$$I_1R_2 - I_2(R_1 + R_2) + I_3r_1 = E_2 \quad \text{...(iii)}$$

(1)