EXERCISE

13.0 : Introduction

Q.1. What is electric current?

Ans: Electric current:

i. The rate of flow of electric charges through a conductor is called electric current.

ii. An electric current which does not depend upon time is known as steady current.

iii. Unit: ampere (A) in SI system

iv. Smaller units are milliampere (mA), microampere (μA) etc.
$1 \text{ mA} = 10^{-3}$ A, $1 \mu\text{A} = 10^{-6}$ A

Q.2. Explain the mechanism of flow of electric current through a conductor.

Ans: i. When an electric charge is set in motion through a coriductor, it constitutes an electric cufrent.

ii. A conductor contains large number of free electrons which are in the state of random motion. So the net charge crossing any cross-section of conductor is zero.

iii. However, when a source of e.m.f is connected to the conductor, an electric field is developed at every point of conductor. Therefore, the electrons being negatively charged particles, travel in a direction opposite to the electric field and so the electric current flows through a conductor.

iv. The direction of flow of electric current is conventionally opposite to the direction of flow of electron.

13.1 : Kirchhoff's laws

Q.3. State and explain Kirchhoff's laws in electric circuit. State the sign conventions for each statement.

Ans: Kirchhoff's first law (Current law or junction law):

Statement:

The algebraic sum of electric currents at any junction is always equal to zero.

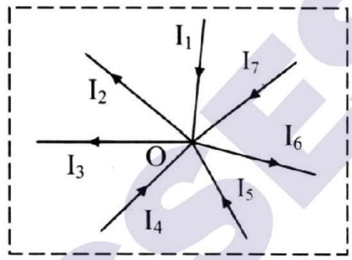
i.e., $\sum I = 0$

Sign conventions:

i. The currents approaching. a junction point in the circuit are taken positive.

ii. Currents flowing away from the junction point are taken negative.

Explanation:



i. Consider O as a point in the electric circuit which is a junction point. Currents of magnitude I_1, I_2, I_3, I_4, I_5, I_6 and I_7 are flowing in two directions, such that I_1, I_4, I_5 and I_7 are flowing towards junction point O whereas I_2, I_3 and I_6 are flowing away from the junction.

ii. According to Kirchhoff's first law
$I_1 - I_2 - I_3 + I_4 + I_5 - I_6 + I_7 = 0$
$\therefore$ $I_1 + I_4 + I_5 + I_7 = I_2 + I_3 + I_6$
Thus, the total current flowing towards a junction is equal to the total current flowing away from that junction.

iii. This law is based on the law of conservation of charge.

iv. When the current in a circuit is steady, there cannot be accumulation (gain) or loss of charge at any junction in the circuit.

Kirchhoff's second law (Voltage law or loop theorem):

Statement:

In a closed loop of electrical network, the algebraic sum of potential differences for all components plus the algebraic sum of all e.mf's is equal to zero.

$\Sigma IR + \Sigma E = 0$

Sign conventions:

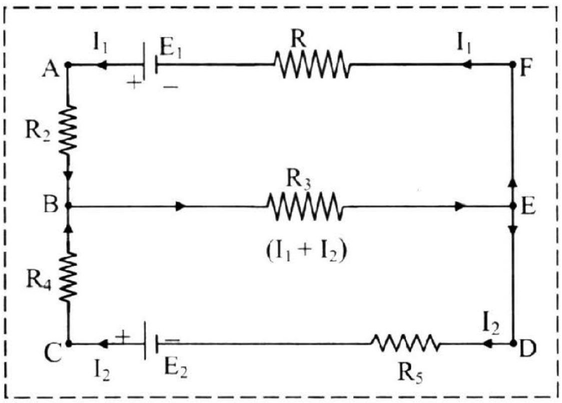
i. While tracing a circuit, potential difference taken in the direction of conventional current is negative and P.D taken against the direction of conventional current is positive.

HENRY CLASSES

ii. If the direction of tracing is same as that of flow of conventional current then potential difference across the resistances is considered as negative otherwise it is positive.

iii. E.M.F is positive if we traverse from negative terminal to the positive' terminal inside the cell and e.m.f is negative if we traverse from the positive terminal to the negative terminal.

Explanation:



i. Consider a closed electrical circuit ABCDEF A containing two cells of e.m.f's E_1 and E_2, resistances R_1, R_2, R_3, R_4 and R_5 as shown in figure.

ii. Current flows from A to B i.e., from higher potential point A to lower potential point B.

iii. Applying Kirchhoff's second law for loop 'ACDFA',

$-I_1 R_2 + I_2R_4 - E_2 + I_2R_5 - I_1R_1 + E_1 = 0$

$\therefore$ $E_1 - E_2 - I_1 (R_2 + R_1) + I_2(R_4 + R_5) = 0$

iv. Applying Kirchhoff's law for loop 'ABEFA',

$-I_1R_2 - (I_1 + I_2) R_3 - I_1R_1 + E_1 = 0$

$\therefore$ $E_1 - I_1 (R_2 + R_1 + R_3) - I_2R_3 = 0$

v. Applying Kirchhoff's law for the loop 'BCDEB',

$I_2R_4 - E_2 + I_2R_5 + (I_1 + I_2) R_3 = 0$

vi. Kirchhoff s second law is in accordance with the law of conservation of energy.

Note:

1. Junction is the point in electric circuit where the current can split.
2. Electric network is a combination of various electric circuit elements and sources of e.m.f connected in complicated manner

13.2 : Wheatstone's network

Q.4. Obtain the balancing condition in case of Wheatstone's network. [Oct 08]

OR

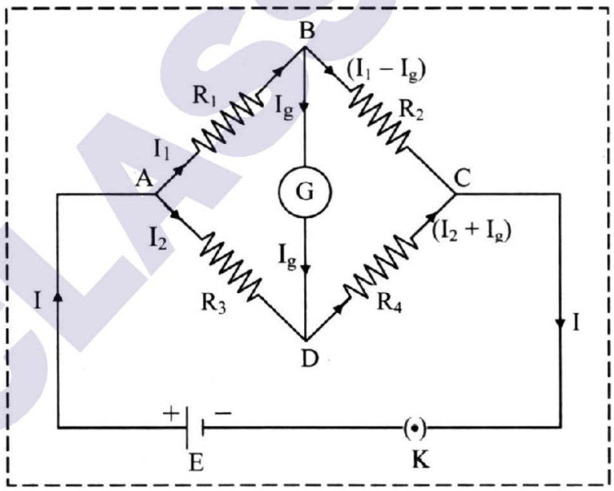
With the help of a neat circuit diagram, obtain the balancing condition of Wheatstone's network. [Mar 97, 11]

Ans: Construction of Wheatstone's bridge:

i. Wheatstone's bridge consists of four resistances R_1, R_2, R_3 and R_4 which are connected to form the four sides of quadrilateral ABCD.

ii. A cell of e.m.f (E) and plug key (K) is connected in series across A and C.

iii. A galvanometer (G) is connected between Band D as shown in figure.



Balance condition of bridge:

i. The network is said to be balanced, if points B and D are at equipotential, i.e., $V_B = V_D$. If it is so, $I_g = 0$, i.e., current flowing through galvanometer must be zero.

ii. Thus, in a balanced condition even though current flows in the rest of the circuit, galvanometer will not show any deflection, i.e. it shows a null point. In this position $\frac{R_1}{R_2} = \frac{R_3}{R_4}$. This is called balanced condition of bridge.

Proof:

i. The current entering at point A is I.
Let I_1 be the current through R_1 and I_2 be the current through R_2 and I_g be the current through the galvanometer.
Applying Kirchhoff's first law,

HENRY CLASSES

$I = I_1 + I_2$

ii. Network is said to be balanced, if B and D are at equipotential,
i.e., $V_B = V_D$

$\therefore$ $I_g = 0$

$\therefore$ Current through $R_2 = I_1 - I_g = I_1$ and current through $R_4 = I_2 + I_g = I_2$

iii. Applying Kirchhoff's second law in loop ABGDA, we get,
$-I_1R_1 - I_gG + I_2R_3 = 0$
But $I_g = 0$

$\therefore$ $-I_1R_1 + I_2R_3 = 0$

$\therefore$ $I_2R_3 = I_1R_1$ ....(i)

iv. Applying Kirchhoff's second law in loop BCDGB, we get,
$-(I_1 - I_g)R_2 + (I_2 + I_g)R_4 + I_g G = 0$
But, $I_g = 0$

$\therefore$ $-I_1R_2 + I_2R_4 = 0$

$\therefore$ $I_2R_4 = I_1R_2$ ....(ii)

v. Dividing equation (i) by (ii), we have,

$$\frac{I_2R_3}{I_2R_4} = \frac{I_1R_1}{I_1R_2}$$

$\therefore$ $\frac{R_3}{R_4} = \frac{R_1}{R_2}$ $\therefore$ $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Alternate method:

i. Balancing condition in Wheatstone's bridge can also be found out by using Ohm'slaw.

ii. From figure, $V_B = V_D$
$V_A - V_B = V_A - V_D$
$V_B - V_C = V_D - V_C$
where V_A, V_B, V_C and V_D are the potentials at points A, B, C and D respectively.

iii. By applying Ohm's law to the resistances R_1, R_2 and R_3, R_4, we get,
$V_A - V_B = I_1R_1$, $V_B - V_C = I_1R_2$ and
$V_A - V_D = I_2R_3$, $V_D - V_C = I_2R_4$

iv. Substituting these values in equation (i) and (ii), we get, $I_1R_1 = I_2R_3$ .....(iii)
and $I_1R_2 = I_2R_4$ .....(iv)
Dividing equation (iii) by (iv), we get,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Note:

1. Measurement of resistance by Wheatstone's bridge method is not suitable for measuring very low and very high resistance in the circuit.
2. By interchanging the position of galvanometer and cell the balanced position of Wheatstone's bridge remains unchanged. Hence branches AC and BD are called conjugate arms.
3. Accuracy of Wheatstone's bridge is maximum when each arm has equal resistance.
4. The measurement of resistance by Wheatstone's bridge is not affected by the internal resistance of the cell.
5. Metrebridge works on the principle of Wheatstone's bridge.

13.3 : Metrebridge

Q.5. Explain with neat circuit diagram, how will you determine the unknown resistance by using a metrebridge experiment. [Mar 12]

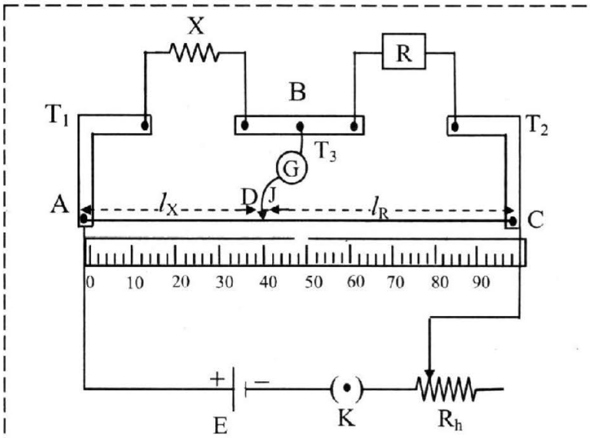
Ans: Construction:

i. It consists of a 1 metre long homogeneous, conducting wire of uniform cross section area made of manganin stretche.d on a wooden board.

ii. There are two L-shaped strips T_1 and T_2 which are also fitted from the ends of the wire on the top side.

iii. These strips are made up of copper. There is another straight strip T_3 fitted in between T_1 and T_2. This gives rise to formation of two gaps, a left gap and a right gap.

iv. A metre scale is fitted along the wire which measures the length of the wire.



AC	:	**One metre long uniform wire**
X	:	**Unknown resistance**
R	:	**Resistance from resistance box**
G	:	**Galvanometer**
T_1, T_2, T_3	:	**Metal strips**
D	:	**Null Point**
J	:	**Sliding key (jockey)**
R_h	:	**Rheostat**

HENRY CLASSES

Determination of unknown resistance:

i. Unknown resistance X is connected in the left gap and a resistance box R in right gap.

ii. A galvanometer is connected between points B and D through a Jockey (1). A battery is connected between A and C.

iii. A suitable resistance is introduced in the circuit from the resistance box and the jockey is tapped on the wire till a point D is located such that the galvanometer deflection is zero.

iv. The distance of the point D from A is measured on the scale say lx.
The distance of the point D from C is measured on the scale say IR.
By adjusting the value of R, the neutral point is obtained in the middle of the Wire.

v. In the balanced condition of bridge,

$$\frac{X}{R} = \frac{\text{Resistance of length } l\text{x}}{\text{Resistance of length } l\text{R}}$$

since, $R = \rho\frac{l}{A}$

where, ρ is specific resistance of the material of wire

$$\therefore \quad \frac{X}{R} = \frac{\frac{\rho l_x}{A}}{\frac{\rho l_g}{A}} = \frac{l\text{x}}{l\text{g}}$$

$\therefore \quad l\text{x} + l\text{g} = 100 \text{ cm}$

$\therefore \quad l\text{g} = 100 - l\text{x}$

$$\therefore \quad X = R\left(\frac{l\text{x}}{100 - l\text{x}}\right)$$

Hence the value of unknown resistance 'X' can be determined.

Q.6. State the sources of error in the metrebridge experiment. How they can be minimised?

Ans: Sources of error and their minimisation in metrebridge:

i. Error due to non-uniformity of wire:
If the wire is non-uniform, the resistance per unit length of the wire does not remain the same and the null point obtained would not be correct.
To minimise this error wire used must be uniform i.e., of same cross section.

ii. Error due to contact resistance:
It affects the null point and introduces an error in unknown resistance (X). To minimise this error, unknown resistance (X) and known resistance (R) are interchanged. The null point is found out again and X is calculated.

iii. Error due to non exact coincidence with zero and 100 cm mark of scale: To minimise this error, the value of R should be so chosen that null point is obtained near middle one third portion of the wire.

iv. Error due to sliding of jockey on the wire:
Due to sliding of the jockey, heat is produced due to friction. Thus the area of wire can be deformed and resistance of the wire may change. To minimise this error, jockey is tapped on the wire.

v. Error due to heating effect of the cell current:
Heating effect of the wire leads to thermal expansion in the wire. Due to thermal expansion, resistance of wire increases.
To minimise this error, circuit is switched off after every reading.

Q.7. State any two sources of errors in metrebridge experiment. Explain how they can be minimised. [Oct 99]

Ans: i. Error due to non-uniformity of wire:
If the wire is non-uniform, the resistance per unit length of the wire does not remain the same and the null point obtained would not be correct.
To minimise this error wire used must be uniform i.e., of same cross section.

ii. Error due to contact resistance:
It affects the null point and introduces an error in unknown resistance (X). To minimise this error, unknown resistance (X) and known resistance (R) are interchanged. The null point is found out again and X is calculated.

iii. Error due to non exact coincidence with zero and 100 cm mark of scale: To minimise this error, the value of R should be so chosen that null point is obtained near middle one third portion of the wire.

iv. Error due to sliding of jockey on the wire:
Due to sliding of the jockey, heat is produced

due to friction. Thus the area of wire can be deformed and resistance of the wire may change. To minimise this error, jockey is tapped on the wire.

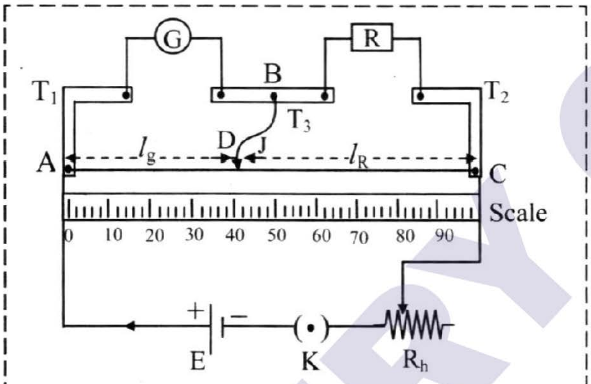
v. **Error due to heating effect of the cell current:**
Heating effect of the wire leads to thermal expansion in the wire. Due to thermal expansion, resistance of wire increases.
To minimise this error, circuit is switched off after every reading.

Q.8. Describe Kelvin's method to determine the resistance of a galvanometer by using a metrebridge. [Oct 06, Feb 01, 09]

Ans: Kelvin's method to determine the resistance of a galvanometer:

i. In Kelvin's method, the galvanometer (G) whose resistance is to be determined is connected in the left gap of a metrebridge and a known resistance R is connected in the right gap.

ii. A jockey (J) is connected directly to the point B and it can slide along the wire.



G : Galvanometer
R : Resistance from resistance box
AC : Metal wire one metre long
R_h : Rheostat
E : Cell
K : Plug key
J : Jockey

iii. A cell of e.m.f 'E' is connected between points A and C of the wire in series with a high resistance box.

iv. The rheostat is used to adjust the deflection in the galvanometer to half of its maximum value. Hence, this method is also called half current method or half scale method.

v. First the deflection in the galvanometer is adjusted at half of its original value and the reading is noted. It acts as null position.

vi. The value of R is adjusted, so that the galvanomter gives a fairly large deflection, i.e., full scale deflection. If the jockey is touched to different points on the wire then galvanometer shows increase or decrease in the deflection.

vii. A point D is located on the wire so that when the jockey is touched at that point, galvanometer shows the same deflection as before. It means that point D and B are at the same potential, i.e., bridge is balanced.

viii. Let,
l_g = length of wire corresponding to left gap
l_R = length of wire corresponding to right gap
G = resistance of galvanometer

ix. In the balanced condition,

$$\frac{G}{R} = \frac{\text{Resistance of wire of length } l_g}{\text{Resistance of wire of length } l_g}$$

$$\frac{G}{R} = \frac{\sigma l_g}{\sigma l_g} = \frac{l_g}{l_R}$$

where,
σ = resistance per unit length of wire

$$G = R.\ \frac{l_g}{l_g}$$

x. Since $l_g + l_R = 100$ cm
$l_g = (100 - l_g)$

$$G = R\left(\frac{l_g}{100 - l_g}\right)$$

Measuring l_g and R, value of G can be determined.

Q.9. Draw a neat labelled circuit diagram to determine resistance of a galvanometer using Kelvin's method. [Oct 08,11]

Ans: Refer Q.8 (Diagram)

Q.10. What precautions should be taken in Kelvin's method to determine resistance of. a galvanometer?

Ans: Precautions to be taken in Kelvin's method:

i. Select suitable resistance R so that the balance point is near the centre of wire. It reduces percentage error and effect of end resistance.

ii. Observations are to be repeated by

HENRY CLASSES

interchanging the position of galvanometer and resistance box in the gaps.

iii. Jockey should not be pressed on the wire or dragged over the wire.

iv. Do not pass current continuously through the circuit, it may cause heating and hence change its resistance.

Note:

1. Null point is the point in the metrebridge experiment where galvanometer shows no deflection.
2. In Kelvin's method to determine resistance of a galvanometer null point is not obtained.

Q.11. Does the value of resistance of a conductor depend upon the potential difference applied across it or the current passed through it?

Ans: The value of resistance of a conductor is independent of potential difference applied to it or the current passed through it.

Q.12. You know that voltmeter measures P.D. Do you know an instrument which can measure terminal P.D as well as e.m.f?

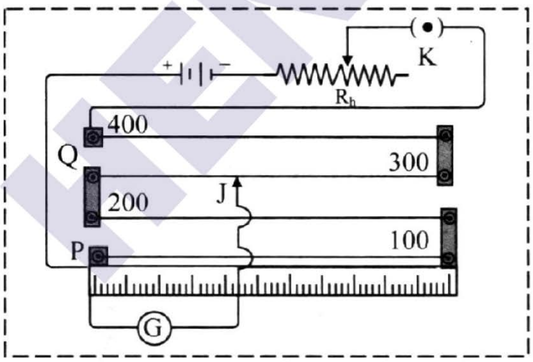
Ans: Potentiometer is an instrument which can measure terminal P.D. as well as e.m.f (after calibration)

13.4 : Potentiometer

Q.13. What is a potentiometer?

Ans: i. A potentiometer is an ideal instrument which is based on null deflection method to measure unknown e.m.f by comparing it with known e.m.f in the electric circuit.

ii. It consists of a number of segments of wire 2 m to 10m of uniform area of cross-section stretched over a wooden board between two thick copper strips as shown in figure.



iii. Each segment of wire is 100 cm long. The wire is made of constantan or manganin.

iv. A metre scale is fixed parallel to its length. A battery is connected across two end terminals which send current through the wire.

v. Current 'through potentiometer is kept constant by using a rheostat.

Note:

The potentiometer is almost an ideal voltmeter.

Q.14. State and explain principle of potentiometer.

Ans: Principle [Oct 2000, Mar 11, Oct 13)

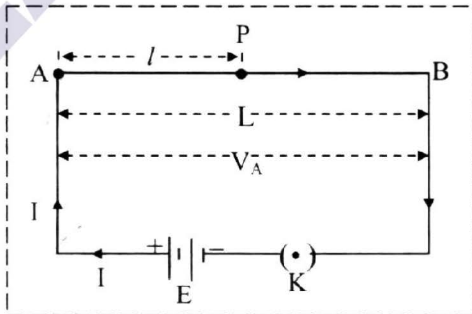
The potential difference between any two points of the potentiometer wire is directly proportional to the length of wire between these two points.

OR

The fall of potential per unit length of potentiometer wire (potential gradient of wire) is constant.

Explanation:

i. Suppose a potentiometer wire AB of length L and resistance R is stretched on the rectangular wooden board. The source of e.m.f E and negligible internal resistance is connected to the wire AB through a key K as shown in figure.



ii. Resistance per unit length of wire AB is given by,

$$\sigma = \frac{R}{L}$$

$\therefore$ $R = \sigma L$

iii. Let 'V AB' be the P.D across the wire. There is uniform fall of potential along the wire from A to B.

iv. By Ohm's law, the current 'I' passing through the wire is given by,

$$I = \frac{V_{AB}}{R} = \frac{V_{AB}}{\sigma L}$$

v. Let 'P' be any point on the wire, such that AP = 'l'. The resistance of wire AP of length 'l' is $R_{AP} = \sigma l$. So the potential difference

'V'$_{AP}$ between points A and P is given by,

$$V_{AP} = IR_{AP} = I\sigma l = \frac{V_{AB}}{\sigma L} \times \sigma l$$

$$V_{AP} = \left(\frac{V_{AB}}{L}\right).l$$

vi. But, V_{AB} and L are constant,

$V_{AP} \propto L$

$$\frac{V_{AB}}{L} = K = \text{constant}$$

where, K is called potential gradient of wire.

Note:

1. The potential gradient is given by,

$$K = \frac{V_{AB}}{l} = \frac{V_{AB}}{L}$$

$$= I\sigma = \frac{IR}{L}$$

$$\therefore \quad K = \frac{I\rho L}{LA} = \frac{I\rho}{A}$$

where 'p' is resistivity of material of wire AB.

2. Potential gradient of potentiometer remains unchanged either by changing diameter of the wire and material of the wire.
3. The value of potential gradient does not change with any change affected in the secondary circuit.
4. Value of potential gradient changes with change in primary circuit containing cell, rheostat and key.
5. In a potentiometer, the potential gradient is not uniform, if the cross-section of the wire is nonuniform.
6. If 'r' is the internal resistance of source 'E' and 'RE' is the external resistance of rheostat connected in the circuit, then the current through the circuit is given by,

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

Q.15. Describe the use of a potentiometer to compare the e.m.f of two cells by the direct method (individual cell method).

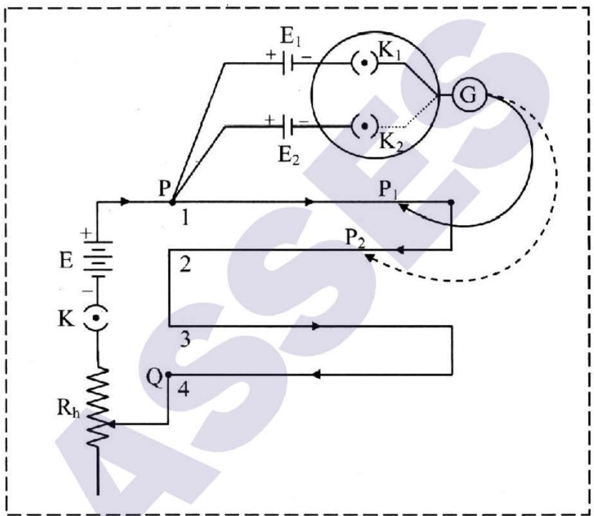
OR

Describe how a potentiometer is used to compare the emfs of two cells by connecting them separately. [Oct 09]

Ans: Comparision of e.m.f of cells by individual method:

Experimental arrangement:

i. An electric circuit consists of potentiometer, cells, two-way keys K_1, K_2, plug key K, rheostat, galvanometer etc. as shown in the figure. For simplicity one single wire is taken between P and Q.



ii. The uniform wire PQ of the potentiometer is connected in series with a battery of constant e.m.f E, a plug key K and a rheostat R_h.

iii. Let E_1 and E_2 be the e.m.f's of the two given cells such that $E > E_1 > E_2$.

iv. The positive terminals of the cell E_1 and E_2 are connected to end P of the wire where positive terminal of E is connected. Negative terminals of cells E_1 and E_2 are connected to K_1 and K_2 of the two-way keys respectively. Common terminal of K_1 and K_2 is connected to galvanometer and jockey. The negative terminal of the cell is connected to a jockey through a centre-zero galvanometer. The jockey can slide on the wire.

Working:

i. Current is allowed to pass through the wire PQ by connecting E_1 in the circuit. Check the deflections of the galvanometer by contacting the jockey at the ends P and Q of the wire. If necessary, adjust the rheostat to obtain the deflections on both sides of the zero of the galvanometer.

ii. Now, K_1 is closed, keeping K closed. Jockey is slided at different points on the wire till a point P_1 is obtained for which the galvanometer shows no deflection. This point is known as the balance point

iii. Let the balancing length $PP_1 = l_1$.
Since no current flows through E, therefore, its e.m.f (E_1) is balanced by the fall of potential from P to P_1.
In this case $E_1 = V_{PP1}$

iv. According to the principle of potentiometer,
$V_{PP1} \propto l_1$
$\therefore$ $V_{PP1} = Kl_1$ where,
K = potential gradient
$\therefore$ $E_1 = Kl_1$ .... (i)

v. Now, key K_1 is removed thus disconnecting E_1 and key K_2 is closed.
Find the balancing length $PP_2 = l_2$.
In this case, $V_{PP2} = Kl_2$
$\therefore$ $E_2 = Kl_2$ .... (ii)

vi. Dividing equation (i) by (ii), we get

$$\frac{E_1}{E_2} = \frac{Kl_1}{Kl_2}$$

$$\therefore \quad \frac{E_1}{E_2} = \frac{l_1}{l_2}$$

Thus, knowing the balancing lengths l_1 and l_2 the e.m.f of two cells can be compared. If the e.m.f of one cell is known, then e.m.f of the other cell can be determined.

Q.16. Explain the use of potentiometer to compare the e.m.f of two cells by sum and difference method.

[Oct 97, 02, Mar 08]

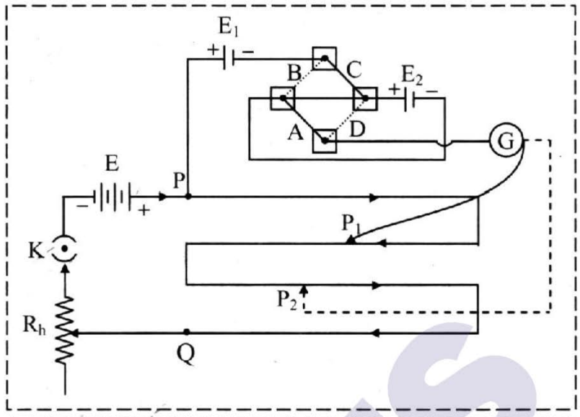
Ans: Comparison of e.m.f's of two cells by sum and difference method:

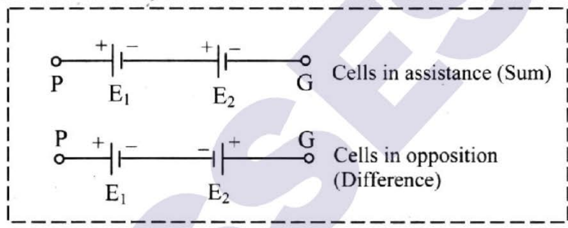
Experimental arrangement:

i. Uniform wire PQ of the potentiometer is connected in series with a battery of constant e.m.f E, a plug key K and a rheostat R_h as shown in figure.

ii. Let E_1 and E_2 be the e.m.f.s of the two given cells such that $E_1 > E_2$.
Also $E > (E_1 + E_2)$

iii. Now the negative terminal of the cell E_1 is connected to the positive terminal of the cell E_2. The cells are in assisting mode or in sum stable. The combination behaves as a new cell of e.m.f $E_1 + E_2$.





iv. When the negative terminal of E_1 is connected to negative terminal of E_2 then combination behaves as a new cell of e.m.f ($E_1 - E_2$).

Working:

i. Pass the current in the wire PQ by using the plug key K. Check the deflections of the G by contacting the jockey at the ends of the wire. If necessary, adjust the rheostat to obtain the deflections on both the sides of the zero of the galvanometer. This means the P.D. applied across the wire is greater than the e.m.f ($E_1 + E_2$) of the cell.

ii. Now, keys A and C are closed and keys C and D are kept open. Cells E_1 and E_2 are said to assist each other. Now contact the jockey at different points on the wire till a point PI is obtained for which (G) shows no deflection. Such a point is known as the balance point.

iii. Let the balancing length PP_1 be l_1. Since no current flows through the cells, therefore, its e.m.f ($E_1 + E_2$) is balanced by the fall of potential from P to P_1.
$E_1 + E_2 = V_{pp1}$

iv. According to the principle of potentiometer,
$V_{pp1} \propto l_1$,
$V_{pp1} = Kl_1$
$E_1 + E_2 = Kl_1$ .... (i)

v. Keeping the same potential gradient, keys C and D are closed and keys A and B are

HENRY CLASSES

kept open. Cells EI and E2 are said to oppose each other. Now experiment is repeated for opposing cell of e.m.f ($E_1 - E_2$) and balance point P_2 is obtained.
Let, balancing length $PP_2 = l_2$
By the same considerations:
$E_1 - E_2 = Kl_2$ .... (ii)

vi. Dividing equation (i) by (ii), we get,

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{Kl_1}{Kl_2}$$

$$\therefore \quad \frac{E_1 + E_2}{E_1 - E_2} = \frac{l_1}{l_2} \quad ...(iii)$$

vii. Applying componendo and dividendo in equation (iii), we get,

$$\frac{E_1 + E_2 + E_1 - E_2}{E_1 + E_2 - E_1 + E_2} = \frac{l_1 + l_2}{l_1 - l_2}$$

$$\therefore \quad \frac{2E_1}{2E_2} = \frac{l_1 + l_2}{l_1 - l_2}$$

$$\therefore \quad \frac{E_1}{E_2} = \frac{l_1 + l_2}{l_1 - l_2} \quad ....(iv)$$

Thus knowing the balancing lengths l_1 and l_2 the e.m.f of two cells can be compared. If the e.m.f of one cell is known, e.m.f of other cell can be calculated.

Note:
For $E_1 >> E_2$, sum and difference method is preferred over direct method. If direct method is used then $l_1 >> l_2$, may introduce an error whereas for sum and difference method respective balancing lengths will be close.

Q.17. State the precautions which must be taken while performing experiment with potentiometer.

Ans: Precautions:

i. The wire used in potentiometer should be of uniform cross sectional area.
ii. The positive terminal of the source battery and positive terminal of cells to be measured or to be compared should be connected to one common end of potentiometer wir
iii. Balancing .length should be measured from high potential end of potentiometer wrre.
iv. The resistance of potentiometer wire should be high.
v. The e.m.f of driver cell must be greater than e.m.fs to be compared i.e., $E > E_1$, $E > E_2$ and for combination $E > E_1 + E_2$.

Q.18. Describe with the help of a neat circuit diagram how will you determine the internal resistance of a cell by using potentiometer. Derive the necessary formula. [Oct 05]

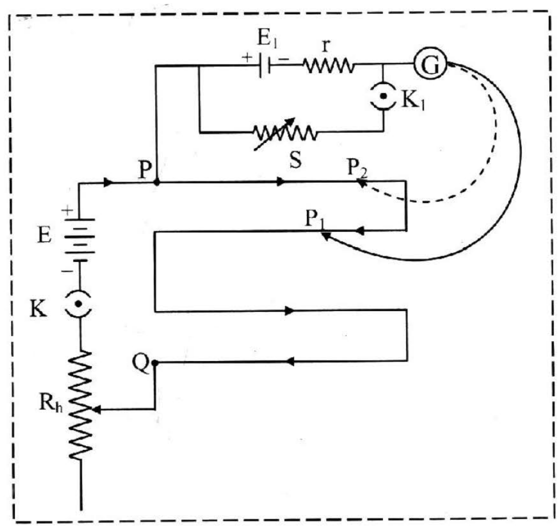
OR

Draw neat labelled circuit diagram to determine internal resistance of cell by using potentiometer. [Feb 13 old course]

Ans: Determination of internal resistance of a cell by using potentiometer:

Construction:

i. The uniform wire, PQ of the potentiometer is connected in series with a battery of constant e.m.f E, a plug key K and a rheostat R_h.
ii. Let E_1 be the e.tn.f of the given cell whose internal resistance 'r' is to be found.
iii. The positive terminal of the cell E_1 is connected to the positive end P of the wire. The negative terminal of the cell is connected to a jockey through a centrezero galvanometer.
iv. The jockey can slide on the wire. A resistance box (S) with a plug key (K_1) is connected parallel to the cell (E_1) as shown in the figure.



Working:

i. Current is passed through the potentiometer wire PQ by using the plug key K. The key K_1 is kept open, so that there is no current through S.
ii. Deflections of the galvanometer is checked

HENRY CLASSES

by contacting the jockey at the ends P and Q of the wire. If necessary, rheostat is adjusted to obtain the deflections on both sides of the zero of the galvanometer. This means the P.D. applied across the wire is greater than the e.m.f (E_1) of the cell.

iii. Now the jockey is moved at different points on the wire till the balance point P_1 is obtained for which the galvanometer shows no deflection.

iv. Let the balancing length PP_1 be l_1. Since no current flows through E_1, therefore, we conclude that its e.m.f E_1 is balanced by the fall of potential from P to P_1

$\therefore$ $E_1 = V_{PP1}$

v. According to the principle of potentiometer,

$V_{PP1} \propto l_1$

$\therefore$ $V_{PP1} = Kl_1$

where, K = potential gradient

$\therefore$ $E_1 = Kl_1$ .... (i)

vi. Now introduce a suitable resistance R in the S and close the key K_1. A current I begins to flow through the cell E_1. Therefore the. potential difference between the positive and negative terminals of the cell is its terminal voltage.

vii. Now find the balance point P_2 for which the galvanometer shows no deflection. Since no part of the current i flowing through E_1 and R is diverted by the galvanometer, therefore fall of the potential from P to P_2 balances the terminal voltage V of the cell.

$PP_2 = l_2$

Let $V = V_{pp2}$

But $V_{pp2} \propto l_2$

$V_{pp2} = Kl_2$

$V = Kl_2$ .... (ii)

viii. Dividing equation (i) by (ii), we get,

$$\frac{E_1}{V} = \frac{Kl_1}{Kl_2}$$

$$\therefore \frac{E_1}{V} = \frac{l_1}{l_2} \qquad \text{....(ii)}$$

ix. Current I through the cell of e.m.f E_1 is given by,

$$I = \frac{E_1}{R + r}$$

$\therefore$ $E_1 = (R + r)I$ ....(iv)

Also $V = RI$ ....(v)

x. From equation (iv) and (v), we have,

$$\frac{E_1}{V} = \frac{(R+r)I}{RI}$$

$$\therefore \frac{E_1}{V} = \frac{R+r}{R} \qquad \text{...(vi)}$$

xi. Equating equation (iii) and (vi), we get,

$$\frac{R+r}{R} = \frac{l_1}{l_2}$$

$$\therefore R + r = R\frac{l_1}{l_2}$$

$$\therefore r = R\frac{l_1}{l_2} - R$$

$$\therefore r = R\left[\frac{l_1}{l_2} - 1\right] \qquad \text{...(vii)}$$

$$\therefore r = R\left(\frac{l_1 - l_2}{l_2}\right) \qquad \text{...(viii)}$$

From equation (iii) and (vii), we have,

$$r = R\left(\frac{E_1}{V} - 1\right) \qquad \text{....(ix)}$$

Equation (vii), (viii) and (ix) represent internal resistance of cell.

Q.19. State the advantages of potentiometer over voltmeter.

Ans: Advantages of potentiometer over voltmeter:

i. The, voltmeter is used to measure terminal P.D of cell while potentiometer is used to measure small terminal P.D as well as e.m.f of the cell.

ii. The accuracy of potentiometer can be easily increased by increasing the length of wire.

iii. A small P.D can be measured accurately with the help of potentiometer. The resistance of voltmeter is high but not infinity to work as an ideal voltmeter.

iv. The internal resistance of a cell can be measured with the help of potentiometer.

v. Potential difference across the wire is greater than E_1 or E_2 or $E_1 + E_2$.

Q.20. State the disadvantages of potentiometer over voltmeter.

Ans: Disadvantages of potentiometer over

HENRY CLASSES

voltmeter:

i. Voltmeter is portable whereas potentiometer is not portable and compact.

ii. Voltmeter can be used to measure very high value of terminal potential difference but potentiometer cannot be used for higher values of potential difference.

iii. Voltmeter gives direct readings but potentiometer does not give direct readings.

Q.21. Distinguish between potentiometer and voltmeter.

Ans:

No.	Potentiometer	Voltmeter
i.	Its resistance is infinite.	Its resistance is high but finite.
ii.	It does not draw any current from the source of known e.m.f.	It draws some current from the source of e.m.f.
iii.	The potential difference measured by it is equal to actual potential difference.	The potential difference measured by it is less than the actual potential difference.
iv.	It has high sensitivity.	It has low sensitivity.
v.	It measures e.m.f as well as p.d.	It measures only p.d.
vi.	It is used to measure internal resistance of a cell.	It cannot be used to measure the internal resistance of a cell.
vii.	It is more accurate	It is less accurate
viii.	It does not give direct reading.	It gives direct reading.
ix.	It is not portable.	It is portable.
x.	It is used to measure lower voltage values only.	It is used to measure lower as well as higher voltage values.

Note:

1. A potentiometer is said to be more sensitive, if it measures a small potential difference more accurately.
2. Sensitivity of potentiometer can be increased by decreasing potential gradient, increasing resistance of primary circuit and increasing length of wire.
3. If the e.m.f of driver cell of potentiometer is less than e.m.fs of other cells connected in the circuit, then the null point is obtained beyond the length of potentiometer wire.
4. The terminal potential difference across a cell decreases as more current is drawn from the cell.
5. The internal resistance of the cell depends on the area of the plates, separation between the plates, concentration of the electrolyte and temperature.

Q.22. Do you know how to measure internal resistance-of a cell?

Ans: Internal resistance of a cell can be found out by using potentiometer.

Q.23. Why is there no way to separate the internal resistance from the e.m.f. of a cell?

Ans: i. When the current flows through the cell, it's electrolyte offers resistance to the flow of current.

ii. Ions have to move against background of other ions and neutral ions.

iii. This creates opposition to the flow of current in the cell and appears as internal resistance. This resistance cannot be avoided.

Q.24. On what factors does the internal resistance of a cell depend?

Ans: Internal resistance of a cell depends upon following factors:

i. Nature of electrolyte

ii. Nature of electrodes

iii. Distance between the electrodes

iv. The area of electrodes inside the electrolyte.

Q.25. Is internal resistance a defect of cell? Explain.

Ans: i. Internal resistance of a cell is not a defect of cell.

ii. It depends upon nature of electrolyte, nature, of electrodes, distance between the electrodes and area of electrodes inside the electrolyte.

iii. In the construction of the cell, these factors need to be considered. Hence internal resistance is accompanied by the construction and working of the cell.

Summary :

1. Kirchhoff explained two laws for explanation of flow of current in an electric network.

i. Junction law: Algebraic sum of electric current meeting at a point in a circuit is zero.

i.e. $\sum I = 0 = 0$

ii. Voltage law: The algebraic sum of the e.m.f is equal to the algebraic sum of the product of the resistance and current flowing through them.

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

2. Wheatstone's network is used to find unknown resistance accurately and quickly. Balancing condition of Wheatstone's network is

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

3. Metrebridge is the practical form of Wheatstone's network. The unknown resistance can be determined by using formula,

$$X = R\frac{l_x}{l_R} = \frac{lx}{100 - lx}$$

4. Kelvin's method is used to determine resistance of a galvanometer conveniently and accurately. Resistance of galvanometer is given by,

$$G = R.\frac{l_x}{l_R} = R\frac{lx}{100 - lx}$$

5. Potential drop per unit length of a wire is called potential gradient.

$$K = \frac{V}{L} = \frac{IR}{L} = \frac{ER}{(R + r)L}$$

where 'R' is the resistance of potentiometer wire, 'r' is the internal resistance of driver cell and 'L' is the length of potentiometer wire.

6. Potentiometer experiment is used for various purposes i.e. comparing e.m.f of cells, to find internal resistance of cell etc.

7. For comparison of e.m.f of two cells, two methods are used:

i. Individual method, $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

ii. Sum and difference method,

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{l_1 + l_2}{l_1 - l_2}$$

8. When ammeter or voltmeter is connected in the circuit, the current or voltage indicated by them is less than the actual values in their absence.

Formulae :

1. **Resistance of a wire:**

$$R = \frac{\rho l}{A}$$

2. **Kirchhoff's law:**

i. $\sum I = 0$ (current rule)

ii. $\sum IR + \sum E = 0$ (voltage rule)

3. **Voltage across an external resistance:**

$$V = \frac{ER}{R + r}$$

4. **In balance position of Wheatstone's bridge:**

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

5. **Metrebridge:**

Unknown res:stance, $X = R.\frac{l_1}{l_2}$

6. **Resistance of galvanometer:**

$$G = R\frac{l_g}{l_R} = R\frac{l_g}{(100 - l_g)}$$

7. **Potentiometer:**

i. Current through driver cell,

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

ii. Current through driver cell,

$$I = \frac{E}{R + R_E} \text{ (If r is not given)}$$

iii. Resistance per unit length,

$$\sigma = \frac{R}{l}$$

iv. Potential gradient,

$$K = \frac{V}{L}$$

v. Comparison between the e.m.f of two cells,

a. $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ (individual method)

b. $\frac{E_1}{E_2} = \frac{l_1 + l_2}{l_1 - l_2}$

(sum and difference method)

8. **Internal resistance of a cell:**

i. $r = R\left(\frac{l_1}{l_2} - 1\right)$

HENRY CLASSES

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

Solved Problems :

Example 1

In an electric circuit, the currents 2 A, 1.5 A and 3 A the flow towards the junction while a current of' magnitude 2.5 A and an unknown current leave the junction. Find the magnitude of unknown current.

Solution:

Let, $I_1 = 2$ A, $I_2 = 1.5$ A, $I_3 = 3$ A, $I_4 = 2.5$ A

Let, $I_5 = x$ A

According to Kirchhoff s first law,

$\Sigma I = O$

$\therefore \quad I_1 + I_2 + I_3 - I_4 + (-x) = 0$

Negative sign indicates that current leaves the junction.

$\therefore \quad 2 + 1.5 + 3 - 2.5 - x = 0$

$\therefore \quad 4 - x = 0$

$\therefore \quad x = 4A$

Ans: The magnitude of unknown current is **4 A**.

Example 2

A battery of e.m.f 8 V and internal resistance 2Ω is connected to a resistor. If the current in the circuit is 0.4 A, what is the resistance of the resistor? Calculate the terminal voltage of the battery when the circuit is closed.

Solution:

Given : $E = 8$ V, $r = 2\ \Omega$, $1 = 0.4$ A

To find : Resistance (R), terminal voltage (V)

Formula : i. $I = \frac{E}{R + r}$

ii. $V = IR$

Calculation : From formula (i),

$$R = \frac{E}{I} - r$$

$$\therefore \quad R = \frac{8}{0.4} - 2$$

$$\therefore \quad R = 18\Omega$$

From formula (ii),

$V = 0.4 \times 18$

$\therefore \quad V = \mathbf{7.2\ volt}$

Ans: i. The resistance of the resistor is **18Ω**.

ii. The terminal voltage of battery is **7.2 V**.

Example 3

A voltmeter has a resistance of $100\ \Omega$. What will be its reading when it is connected across a cell of e.m.f. 2 V and internal resistance 20Ω?

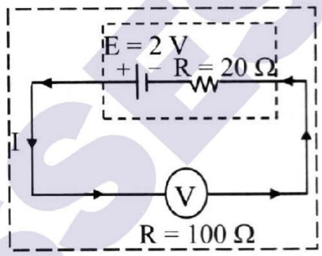
Solution:

Given : $R = 100\ \Omega$, $r = 20\ \Omega$, $E = 2$ V

To find : Reading of voltmeter (V)

Formula : $V = E - Ir$

Calculation : Current through the circuit is given by



$$I = \frac{E}{R + r} = \frac{2}{100 + 20} = \frac{2}{120}$$

$$\therefore \quad I = \frac{1}{60}\ A$$

From formula,

$$V = 2 - \left(\frac{1}{60} \times 20\right) = 2 - 0.3333$$

$\therefore \quad V = \mathbf{1.667\ V}$

Ans: The reading on the voltmeter is **1.667 V**.

Example 4

The current of 1 A is flowing through an external resistance of 10Ω when it is connected to the terminals of a cell. This current reduces to 0.5 A when the external resistance is 25Ω. Find the internal resistance of the cell.

Solution:

Given : $I_1 = 1$ A, $R_1 = 10\Omega$, $I_2 = 0.5$ A, $R_2 = 25\Omega$

To find : Internal resistance (r)

Formula : $\Sigma\ I(R + r) = E$

Calculation : From first condition,

$E = I_1\ (R_1 + r)$ ...(i)

From second condition,

$E = I_2(R_2 + r)$ .... (ii)

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

HENRY CLASSES

$I_1 (R_1 + r) = I_2(R_2 + r)$

$\therefore$ $1 (10 + r) = 0.5 (25 + r)$

$\therefore$ $10 + r = 12.5 + 0.5 r$

$\therefore$ $r - 0.5 r = 12.5 - 10$

$\therefore$ $0.5 r = 2.5$

$\therefore$ $r = \frac{2.5}{0.5} = \mathbf{5\Omega}$

Ans: The internal resistance of the cell is $\mathbf{5\Omega}$.

Example 5

A battery of e.m.f 6 V and internal resistance 2Ω is connected in parallel with another battery of emf 5 V and internal resistance 2Ω. The combination is used to send current through an external resistance of 8Ω. Calculate the current through the external resistance.

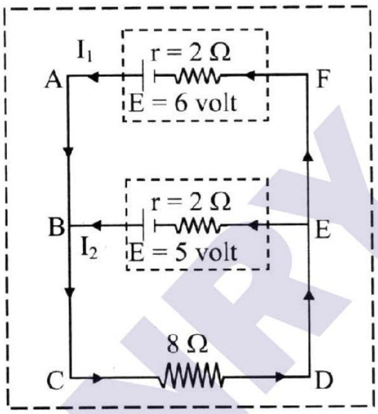
Solution:

Given : $E_1 = 6$ V, $r_1 = 2\Omega$, $E_2 = 5$ V, $r_2 = 2\Omega$, $R = 8\Omega$

To find : Current (I)

Formula : $\Sigma\ I(R + r) = E$

Calculation : Let current through 6 volt battery be I_1 and 5 volt battery be I_2.



Applying Kirchhoffs second law to loop ABCDEF A, we get,

$8 (I_1 + I_2) + 2 I_1 = 6$

$\therefore$ $10 I_1 + 8 I_2 = 6$

$\therefore$ $5 I_1 + 4 I_2 = 3$ .... (i)

Applying Kirchhoffs second law to loop BCDEB, we get,

$8 (I_1 + I_2) + 2 I_2 = 5$

$8 I_1 + 10 I_2 = 5$ .... (ii)

Multiplying equation (i) by 5 and equation (ii) by 2 then subtracting, we get,

$25 I_1 + 20 I_2 = 15$

$16 I_1 + 20 I_2 = 10$

$-\quad -\quad\quad -$

$9 I_1 = \quad = 5$

$\therefore$ $I_1 = \frac{5}{9}$ A

From equation (i),

$I_2 = \frac{3 - 5 \times \frac{5}{9}}{4} = \frac{2}{36} = \frac{1}{18}$ A

$\therefore$ $I_1 = \frac{5}{9}$ A and $I_2 = \frac{1}{18}$ A

Current through external resistance,

$I = I_1 + I_2 = \frac{5}{9} + \frac{1}{18} = \mathbf{\frac{11}{18}}$ A

Ans: The current through the external resistance is $\mathbf{\frac{11}{18}}$ A.

Example 6

Two cells of e.m.f 1.5 V and 2 V and internal resistances 1Ω and 2Ω respectively are connected in parallel so as to send current in the same direction through an external resistance of 5 Ω. Calculate current through each branch of the circuit. Also find potential across the 5Ω resistance.

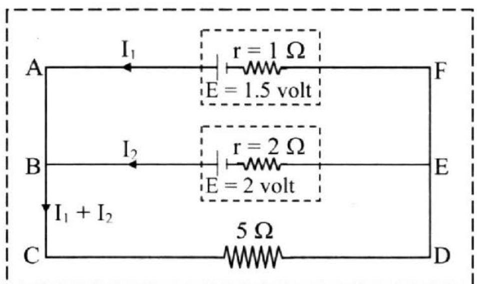
Solution:

Given : $E_1 = 1.5$ V, $E_2 = 2$ V, $r_1 = 1\Omega$, $r_2 = 2$, Ω, $R = 5\Omega$

To find : Current through each branch $(I_1 I_2)$, Potential across resistance (V)

Formula : $E = \Sigma\ I (R + r)$

Calculation :



Applying Kirchhoff's second law

HENRY CLASSES

in loop ABCDEF A, we get,

$5(I_1 + I_2) + 1 \times I_1 = 1.5$

$\therefore$ $6 I_1 + 5 I_2 = 1.5$ ....(i)

Applying Kirchhoffs second law to loop BCDEB, we get,

$5 (I_1 + I_2) + 2I_2 = 2$

$\therefore$ $5 I_1 + 7I_2 = 2$ ....(ii)

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

$\mathbf{I_1 = 0.0294\ A,\ I_2 = 0.2647\ A}$

Potential difference across $5\,\Omega$ resistance,

$V = (I_1 + I_2) R$

$\therefore$ $V = (0.0294 + 0.2647)\,5$

$\therefore$ $V = \mathbf{1.4705\ V}$

Ans: i. The current through branch AF is **0.0294 A.**

ii. The current through branch BE is **0.2647 A.**

iii. The potential across the resistance is **1.4705 V**.

Example 7

A cell of e.m.f. 3 V and internal resistance 4Ω is connected to two resistances of 10 0 and 24Ω joined in parallel. Find the current through each resistance and total current in the circuit using Kirchhoff's laws.

Solution:

Given : $E = 3\ V, r = 4\,\Omega, R_1 = 10\,\Omega, R_2 = 24\ \Omega$

To find : Current through each branch (I_1 and I_2), Total current (1)

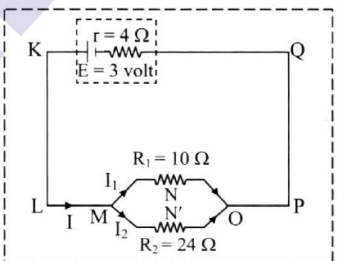
Formula : i. $\Sigma I = 0$ (Kirchhoff s Junction law)

ii. $\Sigma IR + \Sigma E = 0$ (Kirchhoff's voltage law)

Calculation : From Kirchhoffs junction law,

$I - I_1 - I_2 = 0$

$\therefore$ $I = I_1 + I_2$



Applying Kirchhoff's voltage law for loop in the circuit containing KLMNOPQK, we get,

$-I_1R_1 - Ir + E = 0$

$\therefore$ $-I_1R_1 - (I_1 + I_2)r + E = 0$

$\therefore$ $-10 I_1 - 4 (I_1 + I_2) + 3 = 0$

$\therefore$ $-10 I_1 - 4 I_1 - 4 I_2 + 3 = 0$

$\therefore$ $-14 I_1 - 4 I_2 + 3 = 0$

$\therefore$ $14 I_1 + 4 I_2 = 3$ .... (i)

Applying Kirchhoff's voltage law for loop MN'ONM, we get,

$-I_2 R_2 + I_1 R_1 = 0$

$-24 I_2 + 10 I_1 = 0$

$\therefore$ $I_1 = 2.4 I_2$ .... (ii)

From equations (i) and (ii), we get,

$14 (2.4 I_2) + 4 I_2 = 3$

$\therefore$ $33.6 I_2 + 4 I_2 = 3$

$\therefore$ $37.6 I_2 = 3$

$\therefore$ $I_2 = \dfrac{3}{37.6}$

$\therefore$ $I_2 = \mathbf{0.07979\ A}$ .... (iii)

From equations (ii) and (iii), we get,

$I_1 = 2.4 \times 0.07979$

$\therefore$ $I_1 = \mathbf{0.1915\ A}$ .... (iv)

$I = I_1 + I_2 = 0.1914 + 0.07979$

$\therefore$ $I = \mathbf{0.2713\ A}$

Ans: i. The current through branch R_1 is 0.1915 A and that through branch R_2 is **0.07979 A.**

ii. The total current in the circuit is **0.2713 A.**

Example 8

The current flowing through an external resistance of 2Ω is 0.5 A when it is connected to the terminals of a cell This current reduces to 0.25 A when the external resistance is 5 Ω. Use Kirchhoff's laws to find e.m.f of cell.

Solution:

Given : $R_1 = 2\,\Omega, R_2 = 5\,\Omega, I_1 = 0.5\ A, I_2 = 0.25\ A$

To find : E.M.F. (E)

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

Calculation :

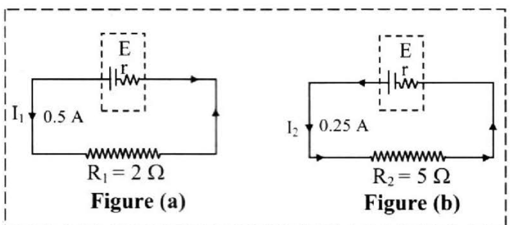


Figure (a) **Figure (b)**

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Let 'r' be the internal resistance of cell E.

Applying Kirchhoff's voltage law to figure (a), we get,

$- I_1 (R_1 + r) + E = 0$

$\therefore \quad E = I_1 (R_1 + r)$

$E = 0.5 (2 + r) \quad .... (i)$

Applying Kirchhoff's voltage law to figure (b), we get,

$- I_2 (R_2 + r) + E = 0$

$\therefore \quad E = I_2 (R_2 + r)$

$E = 0.25 (5 + r) \quad .... (ii)$

From equations (i) and (ii), we get,

$0.5 (2 + r) = 0.25 (5 + r)$

$\therefore \quad 2 (2 + r) = (5 + r)$

$\therefore \quad 4 + 2r = 5 + r$

$\therefore \quad r = 1 \Omega \quad .... (iii)$

From equations (i) and (iii), we get,

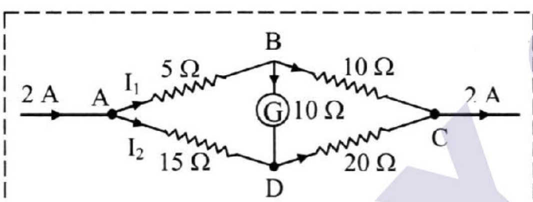
$E = 0.5 (2 + 1) = 1.5$ volt

$E =$ **1.5 V**

Ans: The e.m.f. of the cell is **1.5 V**.

Example 9

Determine the current flowing through the galvanometer (G) as shown in the figure.



Solution:

Let I_1 and I_2 be the current through AB and AD.

To find current through galvanometer I_g,

Applying Kirchhoff's 2nd law to loop ABDA,

$- 5 I_1 - 10 I_g + 15 I_2 = 0$

$\therefore \quad - I_1 - 2 I_g + 3 I_2 = 0 \quad .... (i)$

Applying Kirchhoff's 2nd law to loop BCDB,

$- 10 (I_1 - I_g) + 20 (I_2 + I_g) + 10 I_g = 0$

$\therefore \quad - 10 I_1 + 10 I_g + 20 I_2 + 20 I_g + 10 I_g = 0$

$\therefore \quad - 1.0 I_1 + 20 I_2 + 40 I_g = 0$

$\therefore \quad - I_1 + 2 I_2 + 4 I_g = 0 \quad .... (ii)$

Subtract equation (ii) from (i), we have,

$- I_1 + 3I_2 - 2I_g = 0$

$-I_1 + 2I_2 + 4I_g = 0$

$+ \quad - \quad -$

$I_2 - 6I_g = 0$

$\therefore \quad I_2 = 6I_g \quad .... (iii)$

From equations (ii) and (iii), we have,

$-I_1 + 2(6I_g) + 4I_g = 0$

$\therefore \quad -I_1 + I_2 I_g + 4I_g = 0$

$\therefore \quad I_1 = 16I_g \quad .... (iv)$

Adding equations (iii) and (iv), we have,

$I_1 + I_2 = 6I_g + 16I_g$

$\therefore \quad I_1 + I_2 = 22I_g$

$\therefore \quad 2 = 22 I_g \quad [\because I_1 + I_2 = 2]$

$\therefore \quad I = \frac{2}{22} = \frac{1}{11}$

$\therefore \quad I_g = \mathbf{\frac{1}{11}}$ A

Ans: The current through the galvanometer is $\mathbf{\frac{1}{11}}$ A.

Example 10

A skeleton cube is made of 12 wires each of resistance R Ω, connected to a cell of e.m.f. E and of negligible internal resistance. Use Kirchhoff's laws to find the resistance between (a) adjacent corners of the cube i.e. between two ends of any wire or across anyone edge (b) the diagonally opposite corners of same face of cube. i.e. across face diagonal.

Solution:

a. Let a current (x + 2y) enter the junction A of the cube ABCDEFGH. From the symmetry of the parallel paths, current distribution will be as shown in figure (a).

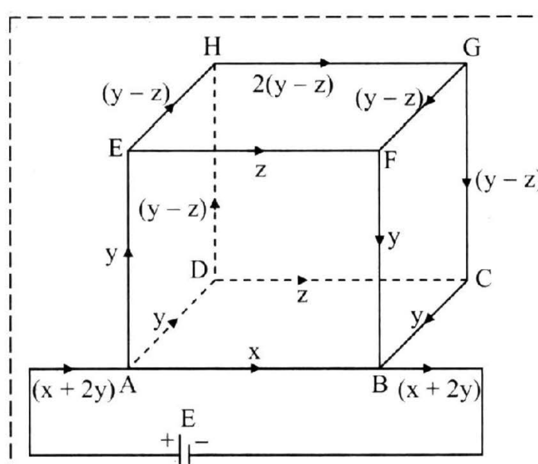


Figure (a)

Applying Kirchhoffs second law to the loop

HENRY CLASSES

DHGCD, we get,

$(y - z)R + 2(y - z)R + (y - z)R - zR = 0$

$\therefore \quad 4yR - 5zR = 0$

$\therefore \quad 5z = 4y \Rightarrow z = \frac{4}{5}y$

Applying Kirchhoffs second law to the loop ABCDA, we get,

$xR - yR - zR - yR = 0$ or $x - 2y - z = 0$

$\therefore \quad x - 2y - \frac{4}{5}y = 0 \quad .... [\because z = \frac{4}{5}y]$

$\therefore \quad x = \frac{14}{5}y;\ y = \frac{5}{14}x$

Let RAB be the resistance across AB.

Then P.D. across AB = xR

i.e., $(x + 2y)R_{AB} = xR$

$\therefore \quad \left(x + \frac{10}{14}x\right)R_{AB} = xR$

b. Let a battery be connected between points A and F so that a current of 1 A enters junction A. This current is divided equally along AB and AD. The distribution of current in various branches is shown in figure. These currents finally add so that a current of I A flows out of junction F.

Applying Kirchoffs second law to the loop ADHEA, we get

$-(1 - 2x)R - zR + yR + xR = 0$

$\therefore \quad -(1 - 2x) - z + y + x = 0 \quad .... (i)$

Similarly, from the loop BCGFB, we have

$-yR - (1 - 2x - z + y)R - (1 - 2x + 2y)R + (x - y)R = 0$

$\therefore \quad -y - (1 - 2x - z + y) - (1 - 2x + 2y) + (x - y) = 0 \quad .... (ii)$

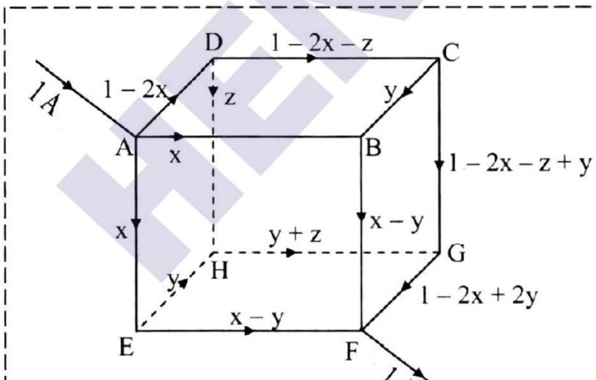


Figure (b)

Now, from the loop HGFEH, we have

$-(y + z)R - (1 - 2x + 2y)R + (x - y)R - yR = 0$

$\therefore \quad -(y + z) - (1 - 2x + 2y) + (x - y) - y = 0 \quad .... (iii)$

On solving equations (i), (ii) and (iii), we get

$x = \frac{3}{8}A,\ y = 0,\ z = \frac{1}{8}A$

Now, $V_{AF} = V_{AB} + V_{BF} = R \times \frac{3}{8} + R \times \frac{3}{8}$

$= \frac{6}{8}R = \left(\frac{3}{4}R\right)V$

Equivalent resistance between A and F,

$\therefore \quad R = \frac{V_{AF}}{I} = \frac{3R/4}{1} = \frac{3}{4}R\Omega$

Ans: i. The resistance between adjacent corners is $\mathbf{\frac{7}{12}R\Omega}$.

ii. The resistance between diagonally opposite corners is $\mathbf{\frac{3}{4}R\Omega}$

Example 11

Find the radius of the wire of length 25 m needed to prepare a coil of resistance 25 Ω (Resistivity of material of wire is 3.142 × 10^{-7} Ω m).

Solution:

Given : $L = 25$ m, $R = 25\ \Omega$, $\rho = 3.142 \times 10^{-7}\ \Omega$ m

To find : Radius of wire (r)

Formula : $R = \frac{\rho l}{A}$

Calculation: From formula,

$R = \frac{\rho l}{\pi r^2}$

$r^2 = \frac{3.142 \times 10^{-7} \times 25}{3.142 \times 25}$

$\therefore \quad r^2 = 10^{-7}$

$\therefore \quad r = 0.3162 \times 10^{-3}$ m

$=$ **0.3162mm**

Ans: The radius of the wire is **0.3162 mm.**

Example 12

Resistances in Wheatstone's bridge are 30

HENRY CLASSES

Ω, 60 Ω, 15 Ω and a series combination of 5 Ω and XΩ. If the bridge is balanced, calculate value of X.

Solution:

Given: $R_1 = 30\ \Omega$, $R_2 = 60\,\Omega$, $R_3 = 15\ \Omega$, $R_4 = (X + 5)\,\Omega$

($\because$ X Ω and 5 Ω resistances connected in series)

To find: Unknown resistance (X)

formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: From formula,

$$\frac{30}{36} = \frac{15}{X+5}$$

$$\therefore \quad \frac{1}{2} = \frac{15}{X+5}$$

$$\therefore \quad X + 5 = 30$$

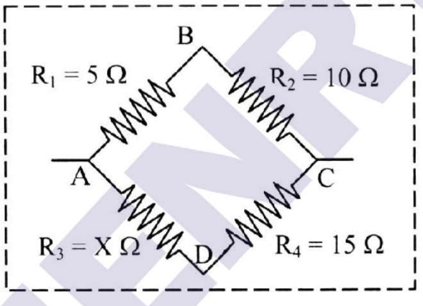
$$\therefore \quad X = \mathbf{25\,\Omega}$$

Ans: The unknown resistance is **25 Ω**.

Example 13

Four resistances 5Ω, 10Ω, 15Ω and an unknown XΩ are connected in series so as to form Wheatstone's network. Determine the unknown resistance X, if the network is balanced with these numerical values of resistances.

Solution:



Given: $R_1 = 5\,\Omega$, $R_2 = 10\,\Omega$, $R_4 = 15\,\Omega$,

To find: Unknown resistance (X)

Formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: From formula,

$$R_3 = \frac{R_1}{R_2} \times R_4$$

$$R_3 = \frac{5}{10} \times 15 = 7.5$$

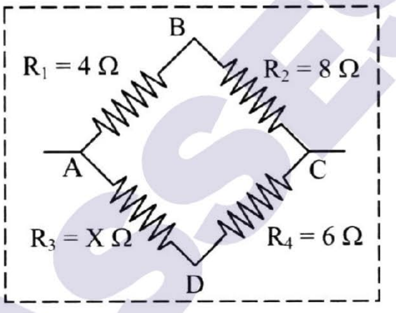
$$X = 7.5\,\Omega$$

Ans: The unknown resistance is **7.5 Ω**.

Example 14

Four resistances 4 Ω, 8 Ω, XΩ and 6Ω are connected in a series so as to form Wheatstone's network. If the network is balanced, find the value of 'X'. [Oct 13]

Solution:



Given: $R_1 = 4\ \Omega$, $R_2 = 8\,\Omega$, $R_4 = 6\,\Omega$.

To find: Unknown resistance (X).

Formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: From formula,

$$R_3 = \frac{R_1}{R_2} \times R_4$$

$$= \frac{4}{8} \times 6 = 3\,\Omega$$

$$\therefore \quad X = 3\,\Omega$$

Ans: The unknown resistance is **3 Ω**.

Example 15

Four resistances 4Ω, 4Ω, 4 nand 12Ω form a Wheatstone's network. Find the resistance which when connected across the 12Ω resistance, will balance the network.

Solution:

Given: $R_1 = R_2 = R_3 = 4\ \Omega$

To find: Resistance (X)

Formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: Let resistance connected across 12 Ω be X.

Equivalent resistance for 12 Ω

HENRY CLASSES

and X in parallel is given by,

$$X = \frac{12 \times X}{12 + X}$$

$$X' = R_4 = \frac{12X}{12 + X}$$

From formula,

$$\frac{4}{4} = \frac{\left(\frac{4}{12X}\right)}{12 + X}$$

$$\therefore \quad I = \frac{4(12 + X)}{12X}$$

$\therefore$ $12X = 48 + 4X$

$\therefore$ $8X = 48$

$\therefore$ $X = 6\,\Omega$

Ans: The resistance connected across 12 Ω resistance to balance the network is 6 Ω.

Example 16

In a balanced metrebridge, the segment of wire opposite to $20\,\Omega$ is 40 cm. Calculate the unknown resistance.

Solution:

Given : Let the unknown resistance be X.
$R = 20\,\Omega$, $l_R = 40$ cm $= 0.4$ m
lx = I – 0.4 = 0.6 m

To find : Unknown resistance (X)

Formula : $X = R\,\frac{l_X}{l_R}$

Calculation : From formula,

$$X = 20 \times \frac{0.6}{0.4}$$

$\therefore$ $X = 30\,\Omega$

Ans: The unknown resistance is 30 Ω.

Example 17

In an electric circuit, the currents 2 A, 1.5 A and 3 A the flow towards the junction while a current of' magnitude 2.5 A and an unknown current leave the junction. Find the magnitude of unknown current.

Solution:

Let, $I_1 = 2$ A, $I_2 = 1.5$ A, $I_3 = 3$ A, $I_4 = 2.5$ A

Let, $I_5 = x$ A

According to Kirchhoff s first law,

ΣI =O

$\therefore$ $I_1 + I_2 + I_3 - I_4 + (-x) = 0$

Negative sign indicates that current leaves the junction.

$\therefore$ $2 + 1.5 + 3 - 2.5 - x = 0$

$\therefore$ $4 - x = 0$

$\therefore$ $x = 4$A

Ans: The magnitude of unknown current is **4 A**.

Example 18

A battery of e.m.f 8 V and internal resistance $2\,\Omega$ is connected to a resistor. If the current in the circuit is 0.4 A, what is the resistance of the resistor? Calculate the terminal voltage of the battery when the circuit is closed.

Solution:

Given : E = 8 V, r = 2 Ω, 1 = 0.4 A

To find : Resistance (R), terminal voltage (V)

Formula : i. $I = \frac{E}{R + r}$

ii. $V = IR$

Calculation : From formula (i),

$$R = \frac{E}{I} - r$$

$$\therefore \quad R = \frac{8}{0.4} - 2$$

$\therefore$ $R = 18\,\Omega$

From formula (ii),

$V = 0.4 \times 18$

$\therefore$ V = **7.2 volt**

Ans: i. The resistance of the resistor is **18 Ω**.

ii. The terminal voltage of battery is **7.2 V**.

Example 19

A voltmeter has a resistance of 100 Ω. What will be its reading when it is connected across a cell of e.m.f. 2 V and internal resistance $20\,\Omega$?

Solution:

Given : R = 100 Ω, r = 20 Ω, E = 2 V

To find : Reading of voltmeter (V)

Formula : V = E – Ir

Calculation : Current through the circuit is given by

$$I = \frac{E}{R + r} = \frac{2}{100 + 20} = \frac{2}{120}$$

$$\therefore \quad I = \frac{1}{60}\ \text{A}$$

HENRY CLASSES

From formula,

$$V = 2 - \left(\frac{1}{60}\times 20\right) = 2 - 0.3333$$

$\therefore$ $V = \mathbf{1.667\ V}$

Ans: The reading on the voltmeter is **1.667 V**.

Example 20

The current of 1 A is flowing through an external resistance of $10\,\Omega$ when it is connected to the terminals of a cell. This current reduces to 0.5 A when the external resistance is $25\,\Omega$. Find the internal resistance of the cell.

Solution:

Given : $I_1 = 1$ A, $R_1 = 10\,\Omega$, $I_2 = 0.5$ A, $R_2 = 25\,\Omega$

To find : Internal resistance (r)

Formula : $\Sigma\ I(R + r) = E$

Calculation : From first condition,

$E = I_1 (R_1 + r)$ ...(i)

From second condition,

$E = I_2(R_2 + r)$ .... (ii)

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

$I_1 (R_1 + r) = I_2(R_2 + r)$

$\therefore$ $1 (10 + r) = 0.5 (25 + r)$

$\therefore$ $10 + r = 12.5 + 0.5\ r$

$\therefore$ $r - 0.5\ r = 12.5 - 10$

$\therefore$ $0.5\ r = 2.5$

$$\therefore\ r = \frac{2.5}{0.5} = \mathbf{5\Omega}$$

Ans: The internal resistance of the cell is 5Ω.

Example 21

A battery of e.m.f 6 V and internal resistance $2\,\Omega$ is connected in parallel with another battery of cmf 5 V and internal resistance $2\,\Omega$. The combination is used to send current through an external resistance of $8\,\Omega$. Calculate the current through the external resistance.

Solution:

Given : $E_1 = 6$ V, $r_1 = 2\,\Omega$, $E_2 = 5$ V, $r_2 = 2\,\Omega$, $R = 8\,\Omega$

To find : Current (I)

Formula : $\Sigma\ I(R + r) = E$

Calculation : Let current through 6 volt battery be I_1 and 5 volt battery be I_2.

Applying Kirchhoffs second law to loop ABCDEF A, we get,

$8\ (I_1 + I_2) + 2\ I_1 = 6$

$\therefore$ $10\ I_1 + 8\ I_2 = 6$

$\therefore$ $5\ I_1 + 4\ I_2 = 3$ .... (i)

Applying Kirchhoffs second law to loop BCDEB, we get,

$8\ (I_1 + I_2) + 2\ I_2 = 5$

$8\ I_1 + 10\ I_2 = 5$ .... (ii)

Multiplying equation (i) by 5 and equation (ii) by 2 then subtracting, we get,

$25\ I_1 + 20\ I_2 = 15$

$16\ I_1 + 20\ I_2 = 10$

$-\quad -\quad -$

____

$9\ I_1 = \quad = 5$

$$\therefore\ I_1 = \frac{5}{9}\text{A}$$

From equation (i),

$$I_2 = \frac{3 - 5\times\frac{5}{9}}{4} = \frac{2}{36} = \frac{1}{18}\text{A}$$

$$\therefore\ I_1 = \frac{5}{9}\text{ A and } I_2 = \frac{1}{18}\text{ A}$$

Current through external resistance,

$$I = I_1 + I_2 = \frac{5}{9} + \frac{1}{18} = \mathbf{\frac{11}{18}}\text{A}$$

Ans: The current through the external resistance is $\mathbf{\frac{11}{18}}$ A.

Example 22

Two cells of e.m.f 1.5 V and 2 V and internal resistances $1\,\Omega$ and $2\,\Omega$ respectively are connected in parallel so as to send current in the same direction through an external resistance of $5\ \Omega$. Calculate current through each branch of the circuit. Also find potential across the $5\,\Omega$ resistance.

Solution:

Given : $E_1 = 1.5$ V, $E_2 = 2$ V, $r_1 = 1\,\Omega$, $r_2 = 2,\ \Omega$, $R = 5\,\Omega$

To find : Current through each branch ($I_1\ I_2$), Potential across resistance

HENRY CLASSES

(V)

Formula : $E = \Sigma I(R + r)$

Calculation :

Applying Kirchhoff's second law in loop ABCDEF A, we get,

$5(I_1 + I_2) + 1 \times I_1 = 1.5$

$\therefore$ $6I_1 + 5I_2 = 1.5$ ....(i)

Applying Kirchhoffs second law to loop BCDEB, we get,

$5(I_1 + I_2) + 2I_2 = 2$

$\therefore$ $5I_1 + 7I_2 = 2$ ....(ii)

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

$\mathbf{I_1 = 0.0294\ A,\ I_2 = 0.2647\ A}$

Potential difference across $5\,\Omega$ resistance,

$V = (I_1 + I_2)R$

$\therefore$ $V = (0.0294 + 0.2647)\,5$

$\therefore$ $V = \mathbf{1.4705\ V}$

Ans: i. The current through branch AF is **0.0294 A.**

ii. The current through branch BE is **0.2647 A.**

iii. The potential across the resistance is **1.4705 V**.

Example 23

A cell of e.m.f. 3 V and internal resistance 4Ω is connected to two resistances of 10 0 and 24Ω joined in parallel. Find the current through each resistance and total current in the circuit using Kirchhoff's laws.

Solution:

Given : $E = 3\ V$, $r = 4\,\Omega$, $R_1 = 10\,\Omega$, $R_2 = 24\,\Omega$

To find : Current through each branch (I_1 and I_2), Total current (1)

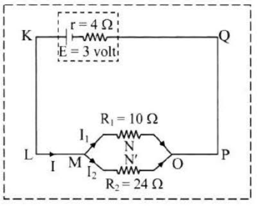
Formula : i. $\Sigma I = 0$ (Kirchhoff s Junction law)

ii. $\Sigma IR + \Sigma E = 0$ (Kirchhoff's voltage law)

Calculation : From Kirchhoffs junction law,

$I - I_1 - I_2 = 0$

$\therefore$ $I = I_1 + I_2$



Applying Kirchhoff's voltage law for loop in the circuit containing KLMNOPQK, we get,

$-I_1R_1 - Ir + E = 0$

$\therefore$ $-I_1R_1 - (I_1 + I_2)r + E = 0$

$\therefore$ $-10I_1 - 4(I_1 + I_2) + 3 = 0$

$\therefore$ $-10I_1 - 4I_1 - 4I_2 + 3 = 0$

$\therefore$ $-14I_1 - 4I_2 + 3 = 0$

$\therefore$ $14I_1 + 4I_2 = 3$ .... (i)

Applying Kirchhoff's voltage law for loop MN'ONM, we get,

$-I_2R_2 + I_1R_1 = 0$

$-24I_2 + 10I_1 = 0$

$\therefore$ $I_1 = 2.4I_2$ .... (ii)

From equations (i) and (ii), we get,

$14(2.4I_2) + 4I_2 = 3$

$\therefore$ $33.6I_2 + 4I_2 = 3$

$\therefore$ $37.6I_2 = 3$

$\therefore$ $I_2 = \dfrac{3}{37.6}$

$\therefore$ $I_2 = \mathbf{0.07979\ A}$ .... (iii)

From equations (ii) and (iii), we get,

$I_1 = 2.4 \times 0.07979$

$\therefore$ $I_1 = \mathbf{0.1915\ A}$ .... (iv)

$I = I_1 + I_2 = 0.1914 + 0.07979$

$\therefore$ $I = \mathbf{0.2713\ A}$

Ans: i. The current through branch R_1 is 0.1915 A and that through branch R_2 is **0.07979 A**.

ii. The total current in the circuit is **0.2713 A.**

Example 24

The current flowing through an external resistance of 2Ω is 0.5 A when it is connected to the terminals of a cell This current reduces to 0.25 A when the external resistance is 5 Ω. Use Kirchhoff's laws to find e.m.f of cell.

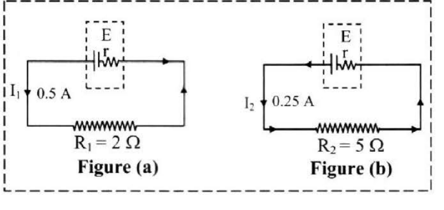
Solution:

Given : $R_1 = 2\,\Omega$, $R_2 = 5\,\Omega$, $I_1 = 0.5\ A$, $I_2 = 0.25\ A$

To find : E.M.F. (E)

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

Calculation :



Let 'r' be the internal resistance

HENRY CLASSES

of cell E.

Applying Kirchhoff's voltage law to figure (a), we get,

$-I_1 (R_1 + r) + E = 0$

$\therefore \quad E = I_1 (R_1 + r)$

$E = 0.5 (2 + r) \quad .... (i)$

Applying Kirchhoff's voltage law to figure (b), we get,

$-I_2 (R_2 + r) + E = 0$

$\therefore \quad E = I_2 (R_2 + r)$

$E = 0.25 (5 + r) \quad .... (ii)$

From equations (i) and (ii), we get,

$0.5 (2 + r) = 0.25 (5 + r)$

$\therefore \quad 2 (2 + r) = (5 + r)$

$\therefore \quad 4 + 2r = 5 + r$

$\therefore \quad r = 1\,\Omega \quad .... (iii)$

From equations (i) and (iii), we get,

$E = 0.5 (2 + 1) = 1.5$ volt

E = **1.5 V**

Ans: The e.m.f. of the cell is **1.5 V**.

Example 25

Determine the current flowing through the galvanometer (G) as shown in the figure.

Solution:

Let I_1 and I_2 be the current through AB and AD.

To find current through galvanometer I_g,

Applying Kirchhoff's 2nd law to loop ABDA,

$-5 I_1 - 10 I_g + 15 I_2 = 0$

$\therefore \quad -I_1 - 2 I_g + 3 I_2 = 0 \quad .... (i)$

Applying Kirchhoff's 2nd law to loop BCDB,

$-10 (I_1 - I_g) + 20 (I_2 + I_g) + 10 I_g = 0$

$\therefore \quad -10 I_1 + 10 I_g + 20 I_2 + 20 I_g + 10 I_g = 0$

$\therefore \quad -1.0 I_1 + 20 I_2 + 40 I_g = 0$

$\therefore \quad -I_1 + 2 I_2 + 4 I_g = 0 \quad .... (ii)$

Subtract equation (ii) from (i), we have,

$-I_1 + 3I_2 - 2I_g = 0$

$-I_1 + 2I_2 + 4I_g = 0$

$+ \quad - \quad -$

$I_2 - 6I_g = 0$

$\therefore \quad I_2 = 6I_g \quad .... (iii)$

From equations (ii) and (iii), we have,

$-I_1 + 2(6I_g) + 4I_g = 0$

$\therefore \quad -I_1 + I_2 I_g + 4I_g = 0$

$\therefore \quad I_1 = 16I_g \quad .... (iv)$

Adding equations (iii) and (iv), we have,

$I_1 + I_2 = 6I_g + 16I_g$

$\therefore \quad I_1 + I_2 = 22I_g$

$\therefore \quad 2 = 22 I_g \qquad [\because I_1 + I_2 = 2]$

$\therefore \quad I = \frac{2}{22} = \frac{1}{11}$

$\therefore \quad I_g = \mathbf{\frac{1}{11}}$ A

Ans: The current through the galvanometer is $\mathbf{\frac{1}{11}}$ A.

Example 26

A skeleton cube is made of 12 wires each of resistance R Ω, connected to a cell of e.m.f. E and of negligible internal resistance. Use Kirchhoff's laws to find the resistance between (a) adjacent corners of the cube i.e. between two ends of any wire or across anyone edge (b) the diagonally opposite corners of same face of cube. i.e. across face diagonal.

Solution:

a. Let a current (x + 2y) enter the junction A of the cube ABCDEFGH. From the symmetry of the parallel paths, current distribution will be as shown in figure (a).

Applying Kirchhoffs second law to the loop DHGCD, we get,

$(y - z) R + 2(y - z) R + (y - z) R - z R = 0$

$\therefore \quad 4yR - 5z R = 0$

$\therefore \quad 5z = 4y \Rightarrow z = \frac{4}{5} y$

Applying Kirchhoffs second law to the loop ABCDA, we get,

$xR - yR - zR - yR = 0$ or $x - 2y - z = 0$

$\therefore \quad x - 2y - \frac{4}{5} y = 0 \qquad .... [\because z = \frac{4}{5} y]$

$\therefore \quad x = \frac{14}{5} y; \; y = \frac{5}{14} x$

Let RAB be the resistance across AB.

Then P.D. across AB = xR

i.e., $(x + 2y) R_{AB} = xR$

$\therefore \quad \left(x + \frac{10}{14} x\right) R_{AB} = xR$

b. Let a battery be connected between points A and F so that a current of 1 A enters junction A. This current is divided equally along AB and AD. The distribution of current in various branches is shown in figure. These

HENRY CLASSES

currents finally add so that a current of I A flows out of junction F.

Applying Kirchoffs second law to the loop ADHEA, we get

$-(1-2x)R - zR + yR + xR = 0$

$\therefore \quad -(1-2x) - z + y + x = 0 \quad .... (i)$

Similarly, from the loop BCGFB, we have

$-yR - (1-2x-z+y)R - (1-2x+2y)R + (x-y)R = 0$

$\therefore \quad -y - (1-2x-z+y) - (1-2x+2y) + (x-y) = 0 \quad .... (ii)$

Now, from the loop HGFEH, we have

$-(y+z)R - (1-2x+2y)R + (x-y)R - yR = 0$

$\therefore \quad -(y+z) - (1-2x+2y) + (x-y) - y = 0 \quad .... (iii)$

On solving equations (i), (ii) and (iii), we get

$$x = \frac{3}{8}A,\ y = 0,\ z = \frac{1}{8}A$$

$$\text{Now, } V_{AF} = V_{AB} + V_{BF} = R \times \frac{3}{8} + R \times \frac{3}{8}$$

$$= \frac{6}{8}R = \left(\frac{3}{4}R\right) V$$

Equivalent resistance between A and F,

$$\therefore \quad R = \frac{V_{AF}}{I} = \frac{3R/4}{1} = \frac{3}{4}R\,\Omega$$

Ans: i. The resistance between adjacent corners is $\mathbf{\frac{7}{12}R\Omega}$.

ii. The resistance between diagonally opposite corners is $\mathbf{\frac{3}{4}R\Omega}$

Example 27

Find the radius of the wire of length 25 m needed to prepare a coil of resistance 25 Ω (Resistivity of material of wire is 3.142 × $10^{-7}\,\Omega$ m).

Solution:

Given: $L = 25$ m, $R = 25\ \Omega$, $\rho = 3.142 \times 10^{-7}\ \Omega$ m

To find: Radius of wire (r)

Formula: $R = \frac{\rho l}{A}$

Calculation: From formula,

$$R = \frac{\rho l}{\pi r^2}$$

$$r^2 = \frac{3.142 \times 10^{-7} \times 25}{3.142 \times 25}$$

$\therefore \quad r^2 = 10^{-7}$

$\therefore \quad r = 0.3162 \times 10^{-3}$ m

$= \mathbf{0.3162mm}$

Ans: The radius of the wire is **0.3162 mm.**

Example 28

Resistances in Wheatstone's bridge are 30 Ω, 60 Ω, 15 Ω and a series combination of 5 Ω and XΩ. If the bridge is balanced, calculate value of X.

Solution:

Given: $R_1 = 30\ \Omega$, $R_2 = 60\,\Omega$, $R_3 = 15\ \Omega$, $R_4 = (X+5)\,\Omega$

($\because$ X Ω and 5 Ω resistances connected in series)

To find: Unknown resistance (X)

formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: From formula,

$$\frac{30}{36} = \frac{15}{X+5}$$

$$\therefore \quad \frac{1}{2} = \frac{15}{X+5}$$

$\therefore \quad X + 5 = 30$

$\therefore \quad X = \mathbf{25\,\Omega}$

Ans: The unknown resistance is **25Ω**.

Example 29

Four resistances 5Ω, 10Ω, 15Ω and an unknown XΩ are connected in series so as to form Wheatstone's network. Determine the unknown resistance X, if the network is balanced with these numerical values of resistances.

Solution:

Given: $R_1 = 5\,\Omega$, $R_2 = 10\,\Omega$, $R_4 = 15\,\Omega$,

To find: Unknown resistance (X)

Formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: From formula,

HENRY CLASSES

$$R_3 = \frac{R_1}{R_2} \times R_4$$

$$R_3 = \frac{5}{10} \times 15 = 7.5$$

$$X = 7.5\,\Omega$$

Ans: The unknown resistance is **7.5** Ω.

Example 30

Four resistances 4 Ω, 8 Ω, XΩ and 6Ω are connected in a series so as to form Wheatstone's network. If the network is balanced, find the value of 'X'. [Oct 13]

Solution:

Given: $R_1 = 4\,\Omega$, $R_2 = 8\,\Omega$, $R_4 = 6\,\Omega$.

To find: Unknown resistance (X).

Formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: From formula,

$$R_3 = \frac{R_1}{R_2} \times R_4$$

$$= \frac{4}{8} \times 6 = 3\,\Omega$$

$$\therefore \quad X = 3\,\Omega$$

Ans: The unknown resistance is **3** Ω.

Example 31

Four resistances 4Ω, 4Ω, 4 nand 12Ω form a Wheatstone's network. Find the resistance which when connected across the 12Ω resistance, will balance the network.

Solution:

Given: $R_1 = R_2 = R_3 = 4\,\Omega$

To find: Resistance (X)

Formula: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Calculation: Let resistance connected across 12 Ω be X.

Equivalent resistance for 12 Ω and X in parallel is given by,

$$X = \frac{12 \times X}{12 + X}$$

$$X' = R_4 = \frac{12X}{12 + X}$$

From formula,

$$\frac{4}{4} = \frac{\left(\frac{4}{12X}\right)}{12 + X}$$

$$\therefore \quad I = \frac{4(12 + X)}{12X}$$

$$\therefore \quad 12X = 48 + 4X$$

$$\therefore \quad 8X = 48$$

$$\therefore \quad X = 6\,\Omega$$

Ans: The resistance connected across 12 Ω resistance to balance the network is 6 Ω.

Example 32

In a balanced metrebridge, the segment of wire opposite to 20Ω is 40 cm. Calculate the unknown resistance.

Solution:

Given: Let the unknown resistance be X.

$R = 20\,\Omega$, $l_R = 40$ cm $= 0.4$ m

lx $= I - 0.4 = 0.6$ m

To find: Unknown resistance (X)

Formula: $X = R\,\frac{l_X}{l_R}$

Calculation: From formula,

$$X = 20 \times \frac{0.6}{0.4}$$

$$\therefore \quad X = 30\,\Omega$$

Ans: The unknown resistance is 30 Ω.

EXERCISE :

Section A: Practice problcms

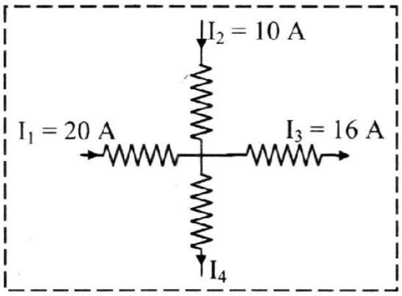
1. An unknown resistance X and a resistance of 50 ohm are placed in the gaps of a metre bridge and the null point is found to be 50 cm from one end of the wire. Find the value of the unknown resistance.

2. A potentiometer wire has a length 1.5 m and a resistance of 10 ohm. It is connected in series with a cell of e.m.f 4 V and internal resistance 5Ω. Calculate the potential gradient of the Wire.

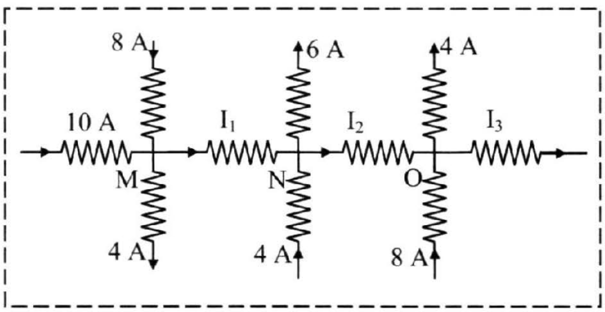
3. A potentiometer wire of length 5 m has a resistance of 4Ω. What resistance must be connected in series with this wire and an accumulator of e.m.f 4 V, so as to get a potential gradient of 10^{-3} V/cm on the wire?

HENRY CLASSES

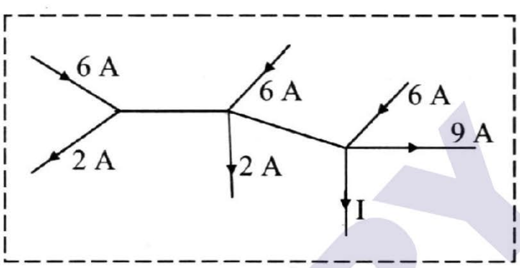
4. Find out the value of current I_4 in the circuit shown below.



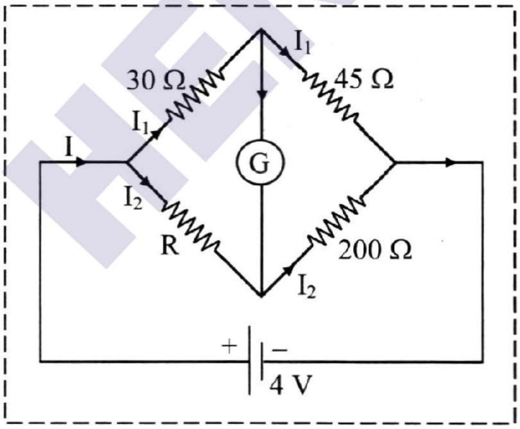
5. In the circuit shown below, calculate the value of currents I_1, I_2 and I_3.



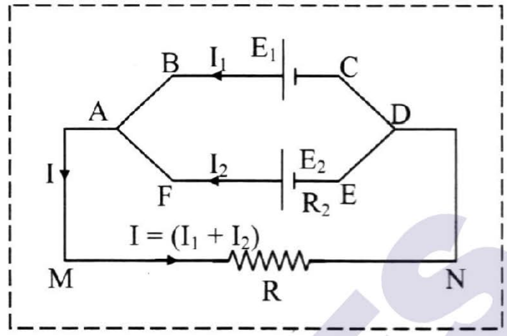
6. In the circuit shown below calculate the value of the current 1.



7. Calculate the current in each arm of the Wheatstone's bridge if galvanometer shows no deflection.



8. Calculate the value of currents I'' hand in the given figure if $E_1 = 2$ V, $E_2 = 1$ V, $r_1 = r_2 = 2\Omega$ and $R = 6\Omega$.



9. A potentiometer consists of a wire of length 8 m and it has resistance of 10 ohm. It is connected to a cell of e.m.f 2 volt having negligible internal resistance. What would be the e.m.f of a cell for which the balance point is obtained at 2 metre?

10. The resistance of a potentiometer wire is 10 ohm and its length is 10 metre. A resistance box and a cell of e.m.f 2 volt is connected in series with the wire. Calculate the value of the resistance in the box in order to have a potential drop of one micro volt per millimetre.

11. Two cells of e.m.f E_1 and E_2 are connected in series. Their effective e.m.f is balanced across a length of 400 cm of a potentiometer wire. When the two cells are oppositely connected then the balance point is obtained at 200 cm. Compare e.m.f if $E_1 > E_2$.

12. Four resistances 10Ω, 10Ω, 10Ω and 20Ω form a Wheatstone's network. Calculate the value of shunt needed across 20Ω resistor to balance the network.

13. Two resistances, P and Q are connected in the left and right gaps of a Wheatstone's metrebridge. The null point is 60 cm from the end where P is connected. When Q is increased by 10 ohm the null point is at 40 cm from the same end. Determine P and Q.

14. A 1.9 m length of potentiometer wire balances the e.m.f of a cell on open circuit and a 1.75 m length balances the p.d between the terminals of the same cell when a conductor of 15 Ω is connected between its terminals. Calculate the internal resistance of the cell.

15. In metrebridge experiment, two resistance R_1 and

HENRY CLASSES

R_2 are connected in the left and right gaps respectively. The balance point is at 60 cm from the left end. When R_1 is reduced by 5 Ω, the balance point is at 50 cm from the left end. Find R_1 and R_2.

16. Resistance of a potentiometer wire is 1Ω per metre. A Daniel cell of e.m.f. 1.08 volt balances at 216 cm on this potentiometer. Calculate current through the wire. Also calculate balancing length for another cell of cmf 1.5 V on the same potentiometer.

17. A potentiometer wire is of length 5 m. It is connected across a battery of negligible internal resistance. The cmf of the cell is balanced against a length 250 cm of the potentiometer. If the length of the potentiometer wire is increased by 1 m, determine the new balancing length for the same cell.

18. A steady p.d. of 2.5 V is maintained between the ends of a potentiometer wire 5 m long. The cmf of a cell balances against a length of 216 cm of the wire. When the cell is shunted by a resistance of 15 Ω, the balance point is obtained at a distance of 200 cm from the high potential end. Find the internal resistance of the cell.

19. The length of the potentiometer wire is 4 m and has a resistance of 8 Ω. An accumulator of 2 V and of internal resistance 2 Ω is connected in series with an external resistance R which in turn also connected in series with potentiometer. Find the value of R so that the potential drop per cm will be 2×10^{-4} V/cm.

20. A potentiometer wire of length 5 m has a resistance 2 ohm. What resistance must be connected in series with the wire and an accumulator of e.m.f 6 V, so as to get a potential gradient of 10^{-3} V/cm of the wire?

Section B: Theoretical Board Questions

1. Describe how two unknown e.m.f.s can be compared by using a potentiometer. **[Mar 98, Feb 03]**

2. State Kirchhoff's laws in electricity. Describe with a neat diagram Wheatstone's network. Obtain the balance condition. **[Mar 99]**

3. State and explain Kirchhoff's law for steady currents. **[Oct 99]**

4. State and explain principle of potentiometer. What are the advantages of potentiometer over voltmeter? **[Feb 04, Oct 04]**

5. Explain the use of Wheatstone's meter-bridge to determine an unknown resistance. **[Mar 05]**

6. Explain the principle of a potentiometer, and describe a method to compare the e.m.f.s of two cells using a potentiometer. **[Feb 06]**

7. State Kirchhoff's law of electricity. **[Mar 10]**

Section C: Numerical Board Problcms

1. The e.m.f of a cell is balanced by the length of 1.812 m of a potentiometer wire, III the potentiometer experiment. When a resistor of 5 ohm is connected across the cell, the balancing length is found to be 1.51 m. Find the internal resistance of the cell. **[Mar 96]**

2. A metrebridge is balanced 'by putting 20 ohm resistance in the left gap and 40 ohm in right gap. If 40 ohm resistance is now shunted with 40 ohm resistance find the shift in the null point. **[Oct 96]**

3. An unknown resistance is placed in the left gap of a metre bridge and a resistance 'R' is placed in the right gap. The null point is obtained at a distance of 40 cm. from the left end. When the resistance of 10 ohm is connected in series with the unknown resistance and the same resistance 'R' is kept in right gap, the null point is obtained at the centre of the wire. Calculate the unknown resistance. **[Oct 98]**

4. A wire of uniform cross-section is bent in the shape of a complete ring. Two diametrically opposite points on the wire are connected to the two terminals of left gap of a mete bridge. The resistance of 15 Ω is connected in the right gap. If the null point is obtained at 70 cm from the left end of the bridge wire, find the resistance of the wire before bending it to a nng. **[Oct 2000]**

5. In a potentiometer experiment, e.m.f of a cell is balanced by a length of 150 cm on the potentiometer wire. When the cell is shunted by a ion resistance, the balancing length reduces to 90 cm. What is the internal resistance of the cell? **[Feb 01]**

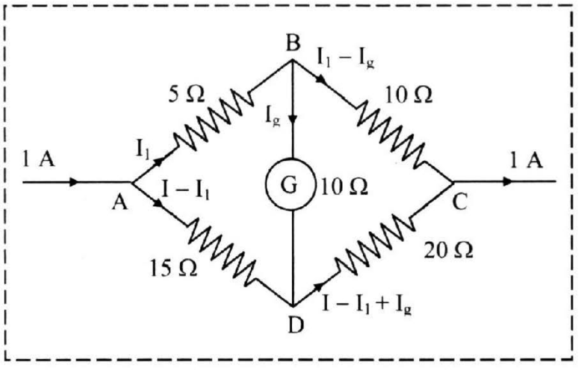
6. A' potentiometer wire has a length 10m and resistance 20 ohm. Its terminals are connected to a cell of e.m.f 5 V and internal resistance 5

HENRY CLASSES

ohm. What are the distances at which null points are obtained when two cells of e.m.f.s 1.5 V and I.3V are connected so as to (i) assist (ii) oppose each other. **[Feb 02]**

7. Two resistances X and Y are connected in the left and right gap of metrebridge. A null point is measured from left end and the ratio of balancing lengths is found to be 2 : 3. When the value of X is changed by 20 ohm the ratio of balancing length is found to be 1 : 4. Determine X and y. **[Oct 02]**

8. Determine the current flowing through the galvanometer (G) from the figure given below. **[Feb 03]**



9. The current flowing through an external resistance of 5 ohm is 1 ampere when it is connected to the terminals of a cell. This current reduces to 0.6 ampere when the external resistance is 10 ohm. Find the internal resistance of a cell using Kirchhoff's law. **[Oct 04]**

10. A potentiometer wire of length 2 m has resistance of 10 ohm. It is connected in series with cell of e.m.f 4 V and internal resistance 6 ohm. Calculate potential gradient. Find the length of potentiometer wire to balance the cell of e.m.f 1 V. **[Mar 05]**

11. A resistance of ion is connected in the left gap of metre bridge. Two resistances 20 Ω and 16 Ω are connected in parallel in the right gap. Find the position of the null points. **[Oct 05]**

12. Resistances P = 10 Ω, Q = 15 Ω, S = 50 Ω and R = 25 Ω are connected in order in the arms AB, BC, CD and DA respectively of a Wheatstone's network ABCD. The cell is connected between A and C. What resistance has to be connected in parallel with S to balance the network? **[Feb 06]**

13. The potentiometer wire has length 10m and resistance ion. If the current flowing through it is 0.4 A, what are the balancing lengths when two cells of e.m.f's 1.3 V and 1.1 V are connected so as to (a) assist and (b) oppose each other? **[Mar 10]**

14. The length of potentiometer wire is 4m and its resistance is 18 Ω. A battery of e.m.f. 2 V and internal resistance 2 Ω is connected across the wire. Calculate the potential gradient. If the balancing length for a cell of e.m.f. E, is 200 cm, calculate E_1. **[Oct 10]**

15. In a potentiometer the balancing length of the string is found to be 2.5 m for a cell of e.m.f. 1.5 V. Find the balancing length of the string for another cell of e.m.f. 1.2 V on the same potentiometer.

2015

Multipal Choice Questions

1. Two wires of same material have length in the ratio 1 : 2. The ratio of their specific resistances will be ______
   a) 2 : 1 b) 1 : 2
   c) 1 : 4 d) 1 : 1
2. The algebraic sum of current at junction in any electric circuit is equal to ______
   a) zero
   b) ∞
   c) a positive integer
   d) potential difference
3. Which of the following instruments is generally used with a galvanometer to show nil reading?
   a) Ammeter b) Voltameter
   c) Voltmeter d) A metrebridge
4. The e.m.f of a cell is 'E' volts and internal' resistance is 'r' ohm. The resistance in external circuit is also 'r' ohm. The p.d across the cell will be
   a) E/2 b) 2E
   c) 4E d) E/9
5. A 2 Ω and a 2/3 Ω resistor are connected in parallel across a 3 V battery. What energy is given out per minute?

HENRY CLASSES

a) 4080 J b) 3080 J
c) 2080 J d) 1080 J

6. A high resistance, voltmeter connected across a cell reads 1.5 V. When 4 Ω resistance is connected across its terminal, the reading falls to 1.2 V. What is the internal resistance of the cell?
a) 0.5 Ω b) 1.0 Ω
c) 1.5 Ω d) 2.0 Ω

7. When a resistor of 20 Ω is connected in series with a battery, a current of 0.5 A flows through it. When a resistor of 10 Ω is connected, the current is 0.8 A. The internal resistance of the battery is ______
a) 6.0 Ω b) 5.67 Ω
c) 6.67 Ω d) 5.0 Ω

8. Kirchhoffs voltage law and current law are respectively in accordance with the conservation of _____
a) charge and momentum
b) charge and energy
c) energy and charge
d) energy and momentum

9. Kirchhoffs junction law is equivalent to _____
OR
Kirchhoff's first law is
a) conservation of energy
b) conservation of charge
c) conservation of electric potential
d) conservation of electric flux

10. A battery having e.m.f 5 V and internal resistance 0.5 Ω is connected with a resistance of 4.5 Ω, then the voltage at the terminals of battery is
a) 4.5 V b) 4 V
c) 0 V d) 2 V

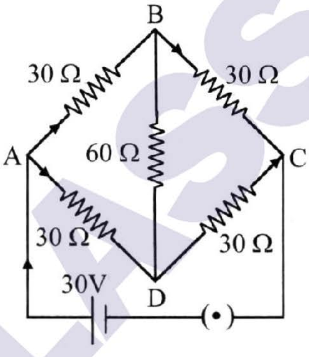
11. A cell supplies a current of 0.9 A through a 2 Ω resistor. The same cell supplies a current of 0.3 A through a 7 Ω resistor. The internal resistance of the cell is
a) 0.1 Ω b) 0.3 Ω
c) 0.5 Ω d) 0.7 Ω

12. A voltmeter having a resistance of 50 Ω is connected across a cell of e.m.f 2 V and internal resistance 10 Ω. The reading of voltmeter is
a) 1.667 V b) 16.7 V
c) 167 V d) 0.167 V

13. A Wheatstone's bridge ABCD is balanced with a galvanometer between the points B and D. At balance, the resistance between the points B and D is _____
a) zero
b) undeterminable
c) between zero and infinite
d) arbitrary

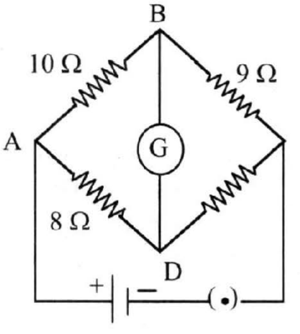
14. The Wheatstone's bridge is balanced for four resistors R_1, R_2, R_3 and R_4 with a cell of emf 1.46 V. The cell is now replaced by another cell of emf 1.08 V. To obtain a balance again,
a) only resistance R_4 should be changed.
b) both the resistance R_1 and R_4 should be changed.
c) all the four resistances should be changed.
d) no resistance needs to be changed.

15. The current between B and D in the given B figure is



a) 1 A b) 2A
c) 0.5 A d) zero

16. Three resistances of 10 ohm, 9 ohm and 8 ohm are connected in a Wheatstone's network. The fourth resistance to be connected between C and D to balance the bridge is B



a) 8.8 Ω b) 9 Ω
c) 10 Ω d) 7.2 Ω

17. Ratio of lengths and diameters of two resistance wires of the same material are 4 : 1 and 2 : 1 respectively. The two wires are connected in the left and right gaps of Wheatstone's metrebridge. Find the distance of the null point from the left end of the wire.

HENRY CLASSES

a) 60 cm b) 10 cm
c) 90 cm d) 50 cm

18. A metrebridge cannot be used to determine
a) resistance of a wire.
b) specific resistance.
c) conductivity.
d) e.m.f of a cell.

19. Kelvin's method of determination of resistance of galvanometer by metrebridge is
a) equal deflection method.
b) null deflection method.
c) equal distance method.
d) equal length method.

20. The current density is
a) the rate of flow of charge per unit area.
b) the rate of flow of charge per unit area in a normal direction.
c) the charge flowing per unit area.
d) the charge flowing per unit area in normal direction.

21. The length and cross-section of the wire of a metrebridge are _____
a) 1 m and non uniform
b) 1 m and uniform
c) 0.5 m and non uniform
d) 0.5 m and uniform

22. In a metre bridge experiment, unknown resistance X and known resistance of 60 Ω is connected in left and right gap of a metrebridge respectively. If the null point is obtained at 40 cm from the left end then the unknown resistance is
a) 20 Ω b) 40 Ω
c) 60 Ω d) 80 Ω

23. If the balancing point is obtained at 35 cm in a metrebridge, then the ratio of resistance in the gap is
a) 13 : 7 b) 11 : 9
c) 7 : 13 d) 2 : 3

24. In a metre bridge experiment, a resistance R and a 20 Ω resistance are connected in the left and right gap respectively and the null point is obtained at 75 cm from the left end. Determine the value of resistance to be connected in parallel with R, without changing the right gap resistance so that the null point is obtained at 50 cm from the left end.
a) 20 Ω b) 30 Ω
c) 40 Ω d) 42 Ω

25. In a metrebridge, an unknown resistance P is connected in the left gap and a 50 Ω resistance in the right gap. Null point is obtained at x cm from the left end. The unknown resistance is now shunted with an equal resistance. Find the value of the resistance in the right gap so that the null point is not shifted.
a) 60 Ω b) 38 Ω
c) 25 Ω d) 50 Ω

26. The length of the potentiometer wire is kept larger so that the value of potential gradient may
a) increase.
b) decrease.
c) remain uniform all over the length of its wire.
d) none of these.

27. For the same potential difference, a potentiometer wire is replaced by another one of a high specific resistance. The potential gradient then ($r = R_h = 0$)
a) decreases. b) remains same.
c) increases. d) data inadequate.

28. S. 1. unit of potential gradient is _
a) V cm b) V/cm
c) Vm d) V/m

29. Sensitivity of a potentiometer is increased by
a) increasing the emf of the cell.
b) increasing the length of potentiometer wire.
c) decreasing the length of potentiometer wire.
d) none of these.

30. The material of Wire of potentiometer is
a) copper b) steel
c) manganm d) aluminium

31. A cell of internal resistance 'r' is connected to an external resistance R. The current will be maximum in 'R', if
a) $R = r$ b) $R < r$
c) $R > r$ d) $R = r/2$

32. The e.m.f of the same cell measured by a potentiometer and a good voltmeter are E_1 and E_2 respectively, then
a) $E_1 = E_2$ b) $E_1 > E_2$
c) $E_1 < E_2$ d) $E_1 \leq E_2$

33. When null point is obtained in the potentiometer, the current is drawn from
a) cell only.
b) main battery.
c) both the cell and main battery.
d) neither cell nor main battery.

34. Accuracy of potentiometer can increased by ______
a) increasing resistance of wire
b) decreasing resistance of wire

HENRY CLASSES

c) increasing the length of wire
d) decreasing the length of wire

35. If 'V' is p.d across the potentiometer of length 'l', then the potential drop per unit length of wire is given by

a) Vl b) $I\sigma$

c) IRl d) $\frac{I}{Rl}$

36. The length of a potentiometer wire is 10m and a potential difference of 2 volt is applied to its ends. If the length of wire is increased by 1 m, the value of potential gradient in volt/m will be

a) 0.18 b) 0.22
c) 1.3 d) 0.9

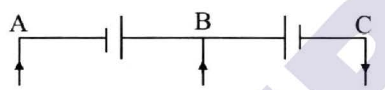
37. The potentiometer wire 10m long and 20 ohm resistance is connected to a 3 volt e.m.f battery and a 10 ohm resistance. The value of potential gradient in volt/m of the wire will be

a) 1.0 b) 0.2
c) 0.1 d) 0.02

38. In a potentiometer experiment, balancing length for first cell and second cell are 2.5 m and 2 m respectively, when cells are used separately. Hence E_1/E_2 is

a) 0.8 b) 1
c) 1.1 d) 1.25

39. A potentiometer is connected across AB and the balance is obtained at 64 cm. When the variable lead is moved to C, a balance is found at 8 cm. If potentiometer is connected across BC, the balance is obtained at



a) 8 cm b) 56 cm
c) 64 cm d) 72 cm

40. A cell has internal resistance of one ohm and its e.m.f is balanced across a length of 250 cm. When the cell is shunted by a resistance R, the balancing length is 200 cm. The shunting resistance R is

a) $\frac{4}{5}\Omega$ b) $\frac{5}{4}\Omega$

c) 4 Ω d) 1/4 Ω

41. In a potentiometer experiment, 2 Ω resistance is connected across a cell. It is balanced by 120 cm of a potentiometer wire. Now 20 Ω resistance is connected across the cell and is balanced by 240 cm of the same potentiometer wire. Determine internal resistance of the cell and the balancing length when the cell is on open circuit.

a) r = 2.5 Ω, 270 cm
b) r = 5.8 Ω, 820 cm
c) r = 0.5 Ω, 180 cm
d) r = 1.12 Ω, 210 cm

42. In a potentiometer experiment, a cell balances against length of 350 of the potentiometer wire when it is shunted by a resistance of 40 Ω. The balancing length reduces to 280 cm when it is shunted by a resistance of 15 Ω. Find the internal resistance of the cell.

a) 7.06 Ω b) 16.8 Ω
c) 17.10 Ω d) 18.6 Ω

Answer Keys

1. d)	2. a)	3. d)	4. a)	5. d)	6. b)	7. c)	8. c)	9. b)	10. a)
11. c)	12. a)	13. b)	14. d)	15. d)	16. d)	17. d)	18. d)	19. a)	20. b)
21. b)	22. b)	23. c)	24. b)	25. c)	26. b)	27. b)	28. d)	29. b)	30. c)
31. a)	32. b)	33. b)	34. c)	35. b)	36. a)	37. b)	38. d)	39. b)	40. c)
41. a)	42. a)								

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Answers :

Section A

1. 50 Ω
2. 1.78 V/m
3. 28 Ω
4. 14 A
5. 14 A, 12 A and 16 A
6. 5 A, away from the point
7. 0.053 A, 0.012 A
8. $\frac{5}{14}$ A, $-\frac{1}{7}$ A, $\frac{3}{14}$ A 3
9. 0.5V
10. 1990 Ω
11. 3 : 1
12. 20 Ω
13. 12 Ω, 8 Ω
14. 1.29 Ω
15. 15 Ω, 10 Ω
16. 0.5 A, 3 m
17. 300 cm
18. 1.2 Ω
19. 190 Ω
20. 22 Ω

Section C

1. 1 Ω
2. 16.67 cm to right
3. 20 Ω
4. 140 Ω
5. 6.67 Ω
6. i. 7 m
   ii. 0.5 m
7. 32 Ω, 48 Ω
8. 1/22 A
9. 2.5 Ω
10. 1.25V/m, 0.8 m
11. 52.94 cm
12. 150 Ω
13. 6 m, 0.5 m
14. 0.5 V/m, 1 V
15. 2 m

HENRY CLASSES