CURRENT ELECTRICITY

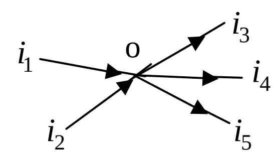
3. KIRCHOFF'S LAW

POINTS TO REMEMBER

1. Kirchoff's Laws :

Ist Law: Node (or) Junction theorem.

It states that the algebraic sum of the currents meeting at any Junction in an electric circuit is zero (or)
The sum of the currents flowing towards a Junction is equal to the sum of the currents flowing away from the Junction.



$i_1 + i_2 - i_3 - i_4 - i_5 = 0$ (or) $\sum i = 0$

IInd Law (or) loop theorem :

It states that in any closed mesh (loop) of a circuit, the algebraic sum of the products of the current and resistance in each part of the loop is equal to the algebraic sum of the emf's in that loop
(or)
In any closed mesh (loop) algebraic sum of potential difference in zero.

2. Wheatstone bridge:

Wheat stones bridge is used to compare the resistances, to determine unknown resistance and to measure small strain in hard materials. This works on the principle of Kirchoff's laws.

$\frac{P}{Q} = \frac{R}{S}$ This is the wheatstone's bridge balancing condition.

3. Meter Bridge : $X = \left(\frac{\ell_1}{100 - \ell_1}\right) R$

Unknown resistance X can be calculated by knowing the value of R i. e. the resistance in the right gap and the balancing length ℓ_1.

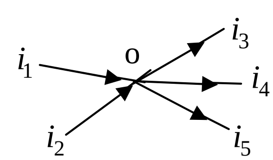
LONG ANSWER QUESTIONS

1. **State and explain Kirchhoff's laws in electricity and apply them to Wheatstone bridge to obtain its balancing condition. (March2011,June2010)**

A. **Ist Law** : **Node (or) Junction theorem.**

It states that the algebraic sum of the currents meeting at any Junction in an electric circuit is zero (or)
The sum of the currents flowing towards a Junction is equal to the sum of the currents flowing away from the Junction.

Explanation : Consider the Junction (Node) 'O' of an electric circuit where five conductors are meeting. Let i_1 and i_2 be the currents flowing towards the Junction and i_3, i_4 and i_5 flowing from the Junction .



$i_1 + i_2 = i_3 = i_4 + i_5$ (or) $i_1 + i_2 - i_3 - i_4 - i_5 = 0$ (or) $\sum i = 0$

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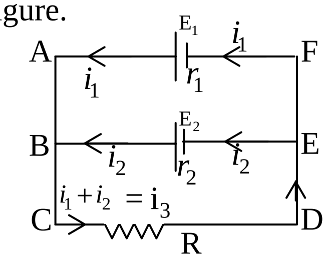
It states that in any closed mesh (loop) of a circuit, the algebraic sum of the products of the current and resistance in each part of the loop is equal to the algebraic sum of the emf's in that loop

(or)

In any closed mesh (loop) algebraic sum of potential difference in zero.

Explanation: Consider the circuit as shown in the figure.



According to 1st law, $i_1 + i_2 = i_3$

According to 2nd law,

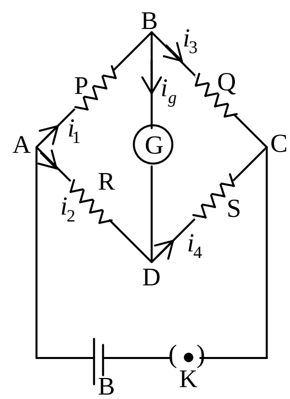
In the closed loop ACDFA, $E_1 = i_1 r_1 + i_3 R$

In the closed loop BCDEB, $E_2 = i_2 r_2 + i_3 R$

In the closed loop ABEFA, $E_1 - E_2 = i_1 r_1 - i_2 r_2$

Wheatstone bridge:

Wheat stones bridge is used to compare the resistances, to determine unknown resistance and to measure small strain in hard materials. This works on the principle of Kirchoff's laws.



Description :

Wheatstone bridge consists of four resistance PQR and S connected in the four arms of a square to form four Junctions. ABC and D. A Galvanometer G is connected between the Junction B and D. A battery of emf E is connected across the Junction A and C through a plug key K.

Principle : (Theory)

When the key K is pressed, Let i_1, i_2, i_3 and i_4 be the currents passing through P,Q,R and S respectively. Let i_g be the current passing through the galvanometer and G be its resistance.

By applying Kirchoff's first law to the Junction B and D.

$i_1 = i_3 + i_g$ – (1) and $i_2 + i_g = i_4 - (2)$

By applying Kirchoff's 2nd law to the closed loop ABDA,

$i_1 P + i_g G - i_2 R = 0$ - (3)

By applying Kirchoff's 2nd law to the closed loop BCDB,

$i_3 Q - i_4 s - i_g G = 0$ - (4)

From equation (3) and (4)

$i_1 P = i_2 R$ and $i_3 Q = i_4 S$

Dividing the above $\boxed{\frac{P}{Q} = \frac{R}{S}}$

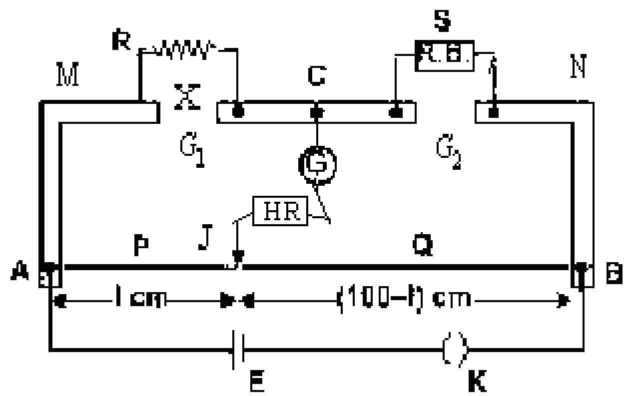
This is the wheat stone's bridge balancing condition.

2. Explain the principle of Meter Bridge. Describe an experiment for the determination of unknown resistance of a wire.

A. **Meter Bridge :**

Meter Bridge works on the principle of wheat stone Bridge.

Description : A meter Bridge consists of a manganine wire of uniform cross-section one meter in length, which is fixed on a wooden board between A and B. Two L shaped copper strips M and N are arranged on the wooden bard so that two gaps G_1 and G_2 are formed between the two strips by means of another strip C. A meter scale is fixed on the wooden board parallel to the length of the wire.



Measurement of unknown resistance : A battery of emf E is connected between A and B through a plug key K. An unknown resistance X is connected in the left gap G_1 and a resistance box R.B. is connected in the right gap. A high resistance HR and a galvanometer G and a Jockey J are connected in series to central terminal C as shown.

Procedure : A suitable resistance R is introduced in the R.B and the plug key K is closed. When the Jockey J is pressed at the two ends of the wire, the deflection of the galvanometer should be in opposite directions.

Now the Jockey is pressed along the length of the wire with high resistance in the circuit. At certain position of the Jockey the deflection of the galvanometer becomes zero. The high resistance is now removed and the exact null point is obtained. The balancing length AJ for null deflection is measured. Let it be ℓ_1. Let the resistance per unit length of the wire be ρ.

$\therefore$ The resistance of wire of length $\ell_1 = \ell_1\rho$.

The resistance of JB $= (100-\ell)\rho$.

From the wheat stone's bridge principle $\frac{P}{Q} = \frac{R}{S}$

$$\frac{X}{R} = \frac{\ell_1\rho}{(100-\ell_1)\rho} \quad \text{(or)} \quad X = \left(\frac{\ell_1}{100-\ell_1}\right)R$$

Thus unknown resistance X can be calculated by knowing the value of R are ℓ_1.

The experiment can repeated by varying the values of R and the mean values of X is determined.

Precautions :

1. Jockey should not be dragged along the wire
2. The current value should be as small as possible
3. Current should be passed only while taking the readings.

3. **Describe the construction of a metre bridge. Explain the method of find the resistivity of the material of a wire?**

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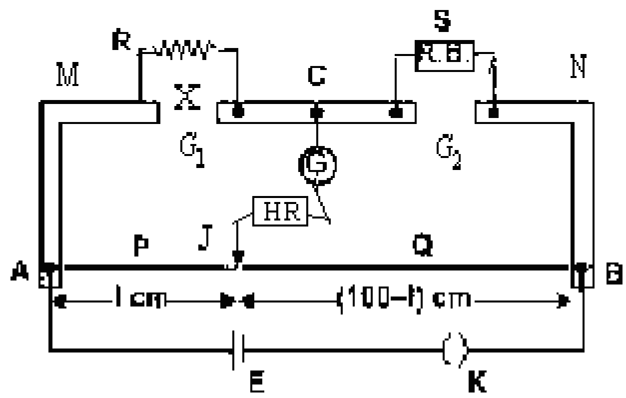
Meter Bridge works on the principle of Wheatstone Bridge.

Description : A meter Bridge consists of a manganine wire of uniform cross-section one meter in length, which is fixed on a wooden board between A and B. Two L shaped copper strips M and N are arranged on the wooden bard so that two gaps G_1 and G_2 are formed between the two strips by means of another strip C. A meter scale is fixed on the wooden board parallel to the length of the wire.



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Measurement of Sp. Resistance : The resistance of the wire x is determined by using meter bridge. Length of the wire is measured using a scale. The radius of the wire is determined accurately using a screw guage. The sp resistance of the meter of the wire (S) can be determine when

$$R = \frac{s\ell}{A} (or)\, s = \frac{RA}{\ell} = \frac{x \times \pi r^2}{\ell}$$

Precautions :

1. Jockey should not be dragged along the wire
2. The current value should be as small as possible
3. Current should be passed only while taking the readings.

SHORT ANSWER QUESTIONS

1. State and explain kirchhoffs laws. (May2009)

A. **Ist Law** : **Node (or) Junction theorem.**

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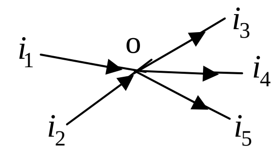

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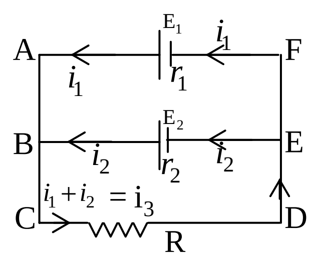

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In the closed loop ABEFA

$E_1 - E_2 = i_1 r_1 - i_2 r_2$

2. **Apply Krichhoff's law to wheatstone's bridge? (March2010, March2009))**

A. Wheat stones bridge is used to compare the resistances, to determine unknown resistance and to measure small strain in hard materials. This works on the principle of Kirchoff's laws.

Description :

Wheatstone bridge consists of four resistances PQR and S connected in the four arms of a square to form four Junctions. ABC and D. A Galvanometer G is connected between the Junction B and D. A battery of emf E is connected across the Junction A and C through a plug key K.

Principle : (Theory)

When the key K is pressed, Let i_1, i_2, i_3 and i_4 be the currents passing through P,Q,R and S respectively. Let i_g be the current passing through the galvanometer and G be its resistance.

By applying Kirchoff's first law to the Junction B and D.

$i_1 = i_3 + i_g$ – (1) and $i_2 + i_g = i_4 - (2)$

By applying Kirchoff's 2nd law to the closed loop ABDA,

$i_1 P + i_g G - i_2 R = 0$ - (3)

By applying Kirchoff's 2nd law to the closed loop BCDB,

$i_3 Q - i_4 s - i_g G = 0$ - (4)

From equation (3) and (4)

$i_1P = i_2R$ and $i_3Q = i_4S$

Dividing the above $\boxed{\frac{P}{Q} = \frac{R}{S}}$

This is the wheatstone's bridge balancing condition.

3. Explain the principle and working of a wheatstone bridge. On interchanging the battery and the galvanometer in the bridge, how is the balancing condition altered?

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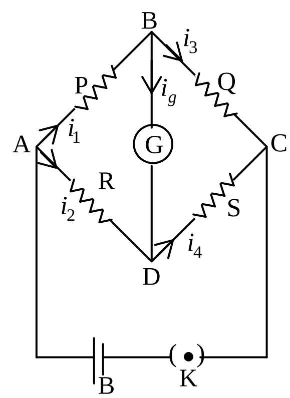

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$i_1 = i_3 + i_g$ − (1) and $i_2 + i_g = i_4 - (2)$

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From equation (3) and (4)

$i_1P = i_2R$ and $i_3Q = i_4S$

Dividing the above $\boxed{\frac{P}{Q} = \frac{R}{S}}$

This is the wheat stone's bridge balancing condition.

Now suppose the positions of the battery (E) and the galvanometer (G) are interchange, the balancing condition $\frac{P}{Q} = \frac{R}{S}$ is not altered.

<u>VERY SHORT ANSWER QUESTIONS</u>

1. On what conservation principles the first and the second laws of Kirchhoff are based?

A. Kirchhoff's first law is a consequence of the law of conservation of charge. Kirchhoff's second law is a consequence of the law of conservation of energy.

2. What is the advantage of a metre bridge over a wheat stone bridge?

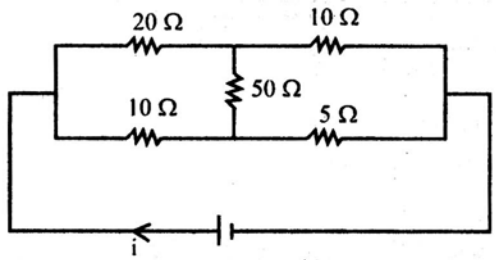
A. Meter bridge is a simplified from of Wheatstone bridge.

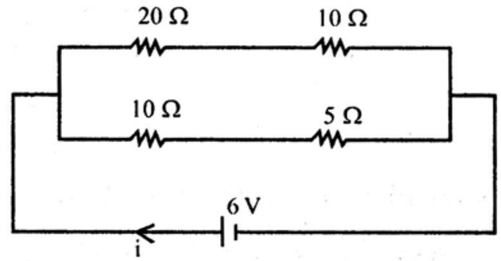
Wheatstone bridge is not suitable for measuring very low resistances and very high resistances. One can measure very low and very high resistances using meter bridge

SOLVED PROBLEMS

1. Calculate the current in the given circuit.

Sol. The circuit is a balanced Wheatstone bridge.





$$R_{eff} = \frac{30\times15}{(30+15)} = 10\Omega$$

$$\therefore \text{ Current in the circuit } i = \frac{E}{R_{eff}} = \frac{6}{10} = 0.6A$$

2. Two unknown resistance x and y are connected in the left and right gaps of a metre bridge and the balancing point is obtained at 60 cm from the left. When a 20Ω resistance is connected in parallel to x, the balance point is 50 cm. Calculate x and y. (May2009)

Sol. $l_1 = 60\text{cm}; l_2 = (100-60) = 40\text{cm}$ and $\frac{x}{y} = \frac{l_1}{l_2} = \frac{60}{40} = \frac{3}{2}$ ……………(1)

When 20Ω is in parallel to in the left gap, effective resistance in left gap $= \frac{20x}{(20+x)}$

$l_1 = 50\text{cm}$ and $l_2 = (100-50) = 50\text{cm}$

$$\therefore \frac{\frac{20x}{(20-x)}}{y} = \frac{50}{50} = 1 \qquad \text{……………(2)}$$

From (1) by (2) , $x = 10\Omega$ and $y = \frac{20}{3}\Omega$

3. Two unknown resistance x and y are connected in the left and right gaps of a metre bridge respectively. Its balance point is at 50 cm. When a resistance of 20Ω is connected in series with x the balance point is at 60 cm. Calculate x and y.

Sol. $l_1 = 50\text{cm}; l_2 = (100-50) = 50\text{cm}$

$$\frac{x}{y} = \frac{l_1}{l_2} = \frac{50}{50} = 1 \qquad \text{…………..(1)}$$

When 20Ω is in series with x, the effective resistance is x + 20 and now $l_1 = 60\text{cm}$ and $l_2 = (100-60) = 40\text{cm}$

$$\therefore \frac{x+20}{y} = \frac{60}{40} = \frac{3}{2} \qquad \text{……………(2)}$$

(1) Divided by (2) gives,

$$\frac{\frac{x}{y}}{\left(\frac{x+20}{y}\right)} = \frac{1}{\left(\frac{3}{2}\right)}$$

$$\frac{x}{x+20} = \frac{2}{3}$$

3x = 2x + 40

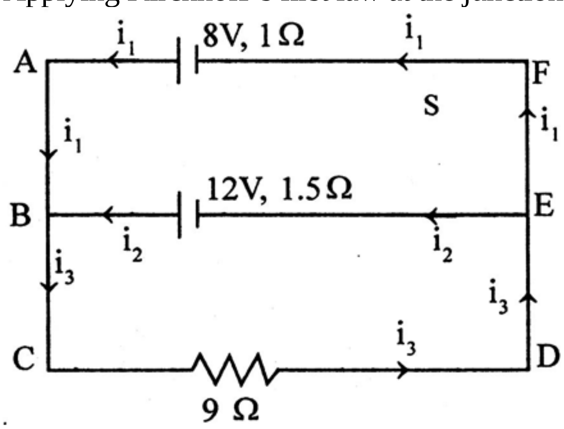
Or $x = 40\Omega$ and $y = x = 40\Omega$ ……………(3)

4. Solve for current values in Figure.

Sol. $E_1 = 8V, r_1 = 1\Omega$

$E_2 = 12V, r_2 = 1.5\Omega$ and $R = 9\Omega$

Applying KirchhofF's first law at the junction B we have



$i_1 + i_2 = i_3$ …………… (1)

Applying KirchhofF second law to loop ABEFA

$-12 + i_2 \times 1.5 - i_1 \times 1 + 8 = 0$

$i_1 - 1.5 i_2 = 4$ .... (2)

From loop BCDEB

$-(i_2 \times 1.5) - (i_3 \times 9) + 12 = 0$

$1.5i_2 + 9i_3 = 12$ .... (3)

But, $i_3 = i_1 + i_2$ form (1)

$1.5i_2 + 9i_1 + 9i_2 = 12$

$9i_1 + 10.5i_2 = 12$ .... (4)

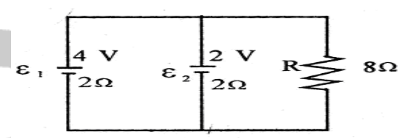
(2) × - 9 gives $-9i_1 + 13.5\,i_2 = +36$......... (5)

Adding (4) and (5), $24i_2 = 48$; $i_2 = 2$ A.

From equation (4), $i_1 = -1$ A; $i_3 = 1$A.

Here $i_1 = -1$A means that the current i, flows in the direction of BAFE and not in EFAB direction as we assumed in the beginning.

5. **Two cells ε_1 (with emf 4V and internal resistance 2Ω) and ε_2 (with emf 2 V and 'internal resistance 2Ω) are connected in parallel. The combination is connected in parallel with a 8Ω resistance R as shown in figure 6.23. Calculate the currents passing through 2 ∀ cell and through the resistance R.**



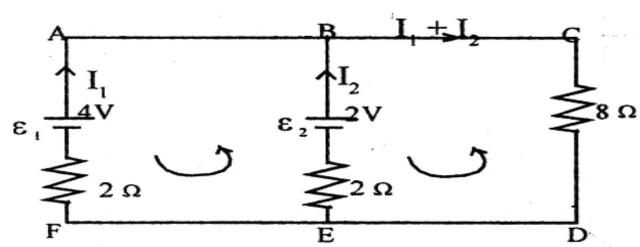
Sol. Consider the anticlockwise direction to traverse the loop BEDCB. From Kirchhoff 's second law ,

$$-2 + (2I_2) + 8(I_1 + I_2) = 0$$

$$8I_1 + 10I_2 = 2$$

$$4I_1 + 5I_2 = 1$$

...........(1)



Consider the anti-clockwise direction to traverse the loop AFEBA. From Kirchhoff 's second law we get,

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

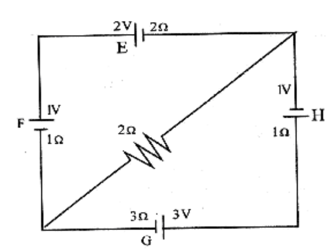
$$2I_1 - 2I_2 = 2$$

$$I_1 - I_2 = 1 \quad ....(2)$$

Solving Eqns. (1) and (2), we get

Thus, the current passing through 2 V cell is $I_2 = -\frac{1}{3}$A . That is $\frac{1}{3}$A current flows though 2V cell from B to E direction. And $\frac{1}{3}$A current flows through 8Ω resistance from C to D.

6. **Find the current through the 2Ω, resistor across DB in the given circuit, Fig. 6.25. Cell E is of emf 2V and internal resistance 2Ω. Cell F is of emf 1 V resistance**



2Ω. **Cell Ω is of emf 3 V and internal resistance 3Ω and cell H is of emf 1V and internal resistance 1Ω.**

Sol. From Kirchhoff's first law. at junction D, $i = i_1 + i_2$ ..... (1)

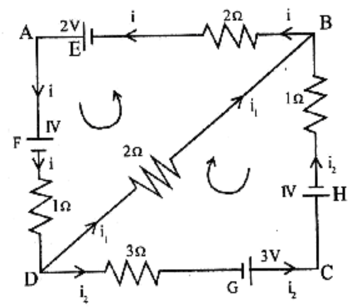
Consider anti- clockwise direction to go from B to A to D to B in the closed loop BADB. From Kirchhoff's second law,

$+2-(2i)-(1i)-1-2i_1=0$

$3i+2i_1=1$

$3(i_1+i_2)+2i_1=1$

$5i_1+3i_2=1$ …………… (2)



Consider clockwise direction to traverse the closed loop BCDB from B to C to D to B. Applying Kirchhoff's second law we have,

$(1\times i_2)+1-3+(3i_2)-2i_1=0$

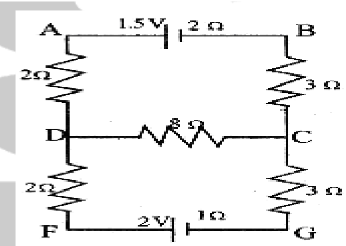
Or $4i_2-2i_1=2$

Solving Eqns (2) and (3)

$i_1=-\frac{1}{13}$ and $i_2=\frac{6}{13}$

This means that, the current through 2Ω resistance across DB will be of magnitude $\frac{1}{13}$A and flows from B to D. (This is because of the result $i_1=-\frac{1}{13}$)

7. Find the potential difference across the 8Ω resistor in the given circuit.



Sol. From Kirchhoff's first law, we have current through 8Ω resistor as $I=I_1+I_2$.

Consider the anti-clock wise direction to traverse the closed loop ADCBA.

Applying Kirchhoff's second law, we have

$-(2I_1)-8(I_1+I_2)-(3I_1)-2I_1+1.5=0$

Or $15i_1+8I_2=1.5$ ……….. (2)

Let us follow the anticlockwise direction to traverse the closed loop DFGCD.

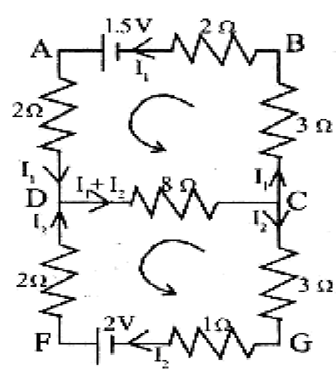
From Kirchhoff's second law we have,

$+(2I_2)-2(1I_2)+(3I_2)+8(I_1+I_2)=0$

or $8I_1+14I_2=2$ …………. (3)

Solving (2) and (3) we get $I_1=\frac{5}{146}$ and

$I_2=\frac{18}{146}$

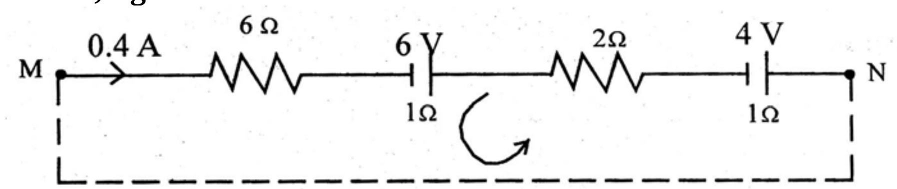


Hence, current though 8Ω resistor is

$I=I_1+I_2=\frac{23}{146}A$.

Potential difference across the 8Ω resistor is $V = IR = \left(\frac{23}{146}\right)8 = 1.26V$

8. Find the potential difference between M and N in the given branch of a circuit, figure 6.29.



Sol.

Let us have a closed circuit by joining to N with dotted lines. Let the potentials at M and N be V_M and V_N respectively.

Consider anti-clockwise direction and applying Kirchhoff's second law, we get

$(V_N - V_M) - 4 + (0.4\times1) + (0.4\times2) - 6 + (0.4\times1) + (0.4\times6) = 0$

$(V_N - V_M) - 10 + 0.4 + 0.8 + 0.4 + 2.4 = 0, V_N - V_M = 6V$

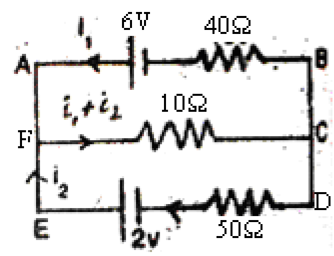
UNSOLVED PROBLEMS

1. Find the current in each cell considering circuit given in the figure.

A. Applying Kirchhoff's voltage law across ABCFA and FCDEF

$40i_1 + 10(i_1 + i_2) = 6$ and

$10(i_1 + i_2) + 50i_2 = 2$



Solving we get , $i_1 = 0.1172A; i_2 = 0.0138A$

2. Find the balance length in a meter bridge, if the resistance in the left and right gaps is in the ratio of 2 : 3.

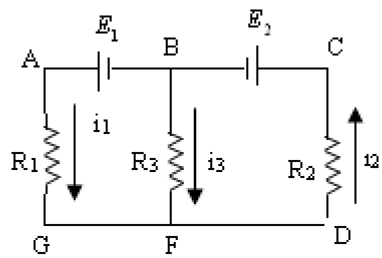
A. $\frac{x}{R} = \frac{l}{100-l} \Rightarrow \frac{1}{100-l} = \frac{2}{3} \Rightarrow 3l = 200 - 2l \Rightarrow l = 40cm$ from left

3. A balance point in meter bridge experiment is obtained at 30 cm from the left. If the right gap contains 3.5Ω, what is the resistance in the left gap?

A. Let X be the resistance in the left gap $\frac{X}{3.5} = \frac{30}{70} \Rightarrow X = 3.5\times\frac{30}{70} = 1.5\Omega$

5. In the given circuit, the values are as following $E_1 = 2V, E_2 = 4V$

$R_3 = 1\Omega$ *and* $R_2 = R_3 = 1\Omega$. Calculate the value of i_1, i_2 *and* i_3.



A. According to Kirchhoff's 1st law at B, we have

$i_2 = i_1 + i_3 \Rightarrow i_3 = i_2 - i_1$ ……. (1)

Applying the KVL to the loop ABFGA, we get $i_1R_1 - i_3R_3 = E_1 \Rightarrow i_1 - i_3 = 2$

$\Rightarrow i_3 \times 1 - i_1 \times 1 = -2$

$\Rightarrow i_3 - i_1 = -2 \Rightarrow (i_2 - i_1) - i_1 = -2$

$\Rightarrow 2i_1 - i_2 = 2$ ….. (2)

Applying the KVL to the loop BCDFB weget

$-R_2i_2 - i_3R_3 = E_2$

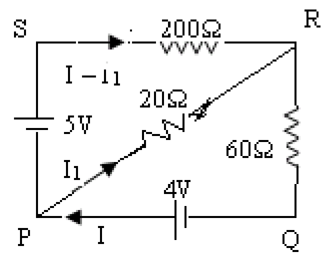
$\Rightarrow -1 \times i_2 - i_3 \times 1 = 4 \Rightarrow -i_2 - (i_2 - i_1) = 4$

$i_1 - 2i_2 = 4$ …… (3)

By solving the equations 2 & 3, we get $i_1 = 0$ *and* $i_2 = -2$ amp

$\therefore i_3 = i_2 - i_1 = -2 - 0 = -2 amp$

6. In the given circuit, the two cells have no internal resistance. Calculate the potential difference across the 20Ω resistor.



A. Applying Kirchhoff's II law for PSRPS,

$5 - (I - I_1)(200) + 20I_1 = 0$

$\Rightarrow 5 - 200I + 200I_1 + 20I_1 = 0$

$\Rightarrow -200I + 220I_1 = -5$

$= -40I + 44I_1 = -1$ …. (1)

Applying Kirchhoff's II law for PRQP,

$-20I1 - 60I + 40 = 0$

$-20I_1 - 60I = -4$

$5I_1 - 15I = 1$ …. (2)

Solving we get , $I_1 = \frac{5}{172}A$

P.D across $20\Omega = I_1\ (20) = \frac{5}{172}(20) = 0.58V$

<u>ASSESSS YOURSELF</u>

1. **Out of the two Kirchhoff's laws which one explicitly shows that electrostatic force is a conservative force?**

A. Kirchhoff s second law.

2. **with a metre bridge, you are advised to preferably obtain a balancing length *l* in the middle one third of the wire. Why ?**

A. The bridge is most sensitive when $\frac{P}{Q} = \frac{R}{S} = 1$. That is when $\frac{l}{100 - l} = 1$ or $l = 50$ cm. More than 15 cm deviation is not good. So, it is preferable to obtain a balancing length in the middle one third of the wire.

3. **You are to compare two resistances that are in the ration 1 : 2. The wire of metre bridge given is of length 99 cm only. With full calculations explain how the error is minimized by taking additional readings with resistance interchanged.**

A. $\frac{R}{S} = \frac{1}{2} = \frac{l}{99 - l}$ given $l = 33$ cm

But we read the lengths as $l = 33$cm and 100 - 33 = 67 cm and write

$$\frac{R}{S} = \frac{33}{67} = 0.4925$$

Now, when we interchange the resistances, we should have $\frac{S}{R} = \frac{2}{1} = \frac{l}{99 - l}$

Which gives $l = 66$ cm - But we read lengths as $l = 66$ cm and 100 - 66 = 32 cm and write $\frac{S}{R} = \frac{66}{34}$ or $\frac{R}{S} = \frac{34}{66} = 0.5152$

The average of 0.4925 and 0.5152 is 0.5038 and is very close to $\frac{1}{2}$