ELECTRICAL CIRCUITS

* KIRCHHOFF'S LAW

1. Kirchhoff's First Law

Kirchhoff's first law states that, "The sum of the current entering any point in the circuit is equal to the sum of the current leaving the same point."

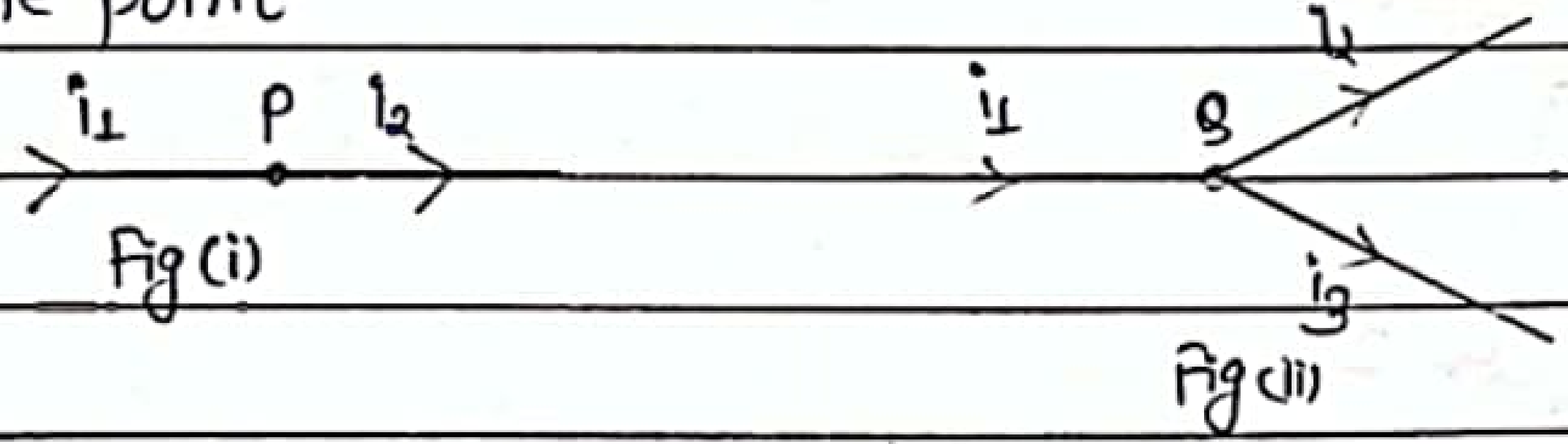


Fig: Kirchhoff's first law

In fig(i), the current into point P must equal the current out. So,

$i_1 = i_2$.

In fig(ii), one current is entering into poin Q and two currents leaving. The current gets divided at Q. So,

$i_1 = i_2 + i_3$

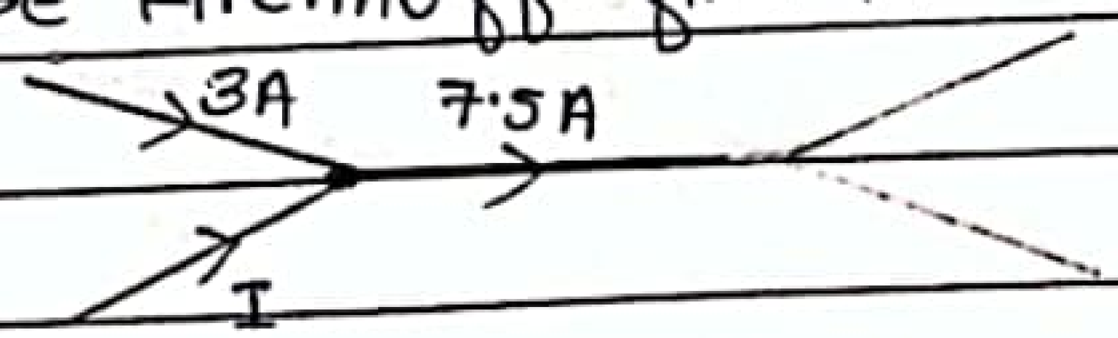
Kirchhoff's first law is an expression of conservation of charge. The idea is that the total amount of charge entering a point must exit the point. Kirchhoff's first law can be written as:-

$\Sigma I_{in} = \Sigma I_{out}$

where, ΣI_{in} = sum of all currents entering into a point.

ΣI_{out} = sum of all currents leaving that point.

Q1) Use Kirchhoff's first law to deduce the value of the current I.

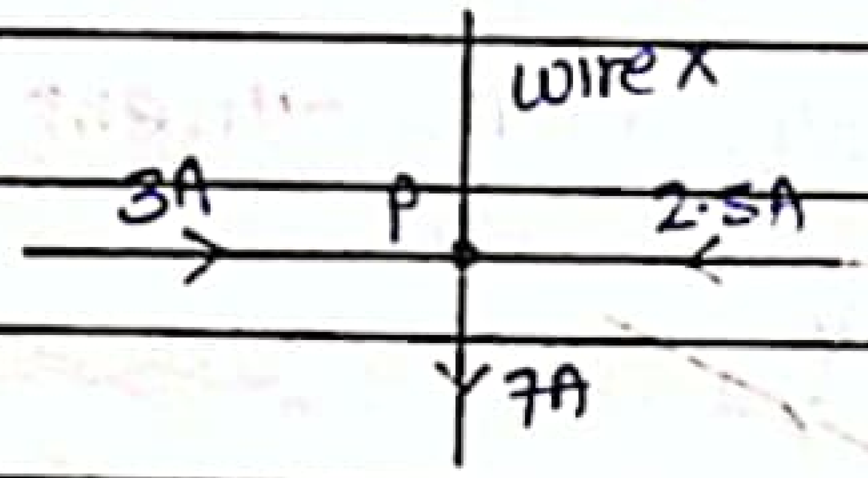


Solution:

$I + 3 = 7.5$

$I = 4.5A$

Q2) Calculate the current in the wire x. State the direction of this current (towards P or away from P).



Solution:

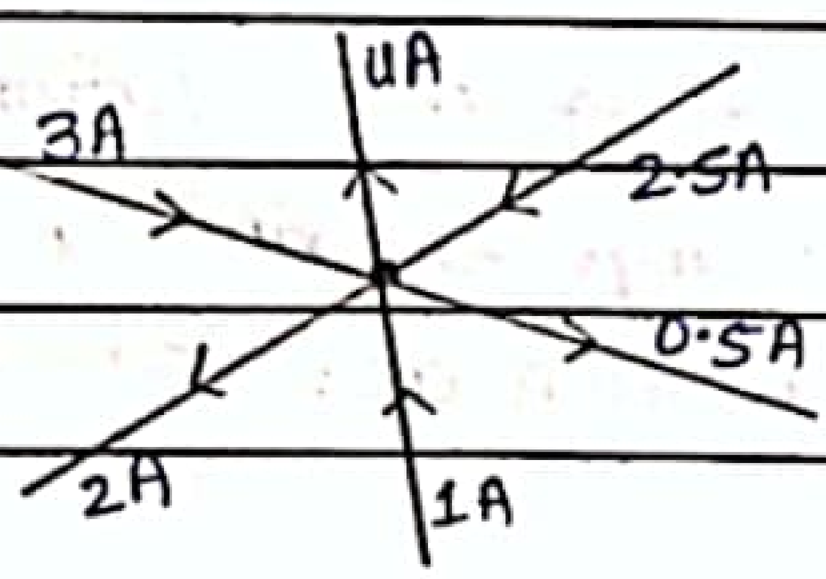
Let, current in wire x be I.

Then, $I + 7 = 3 + 2.5$

or, $I = -1.5A$

∴ The current in wire x is 1.5A towards P.

Q3) Calculate ΣI_{in} and ΣI_{out} in the figure. Is Kirchhoff's first law satisfied.



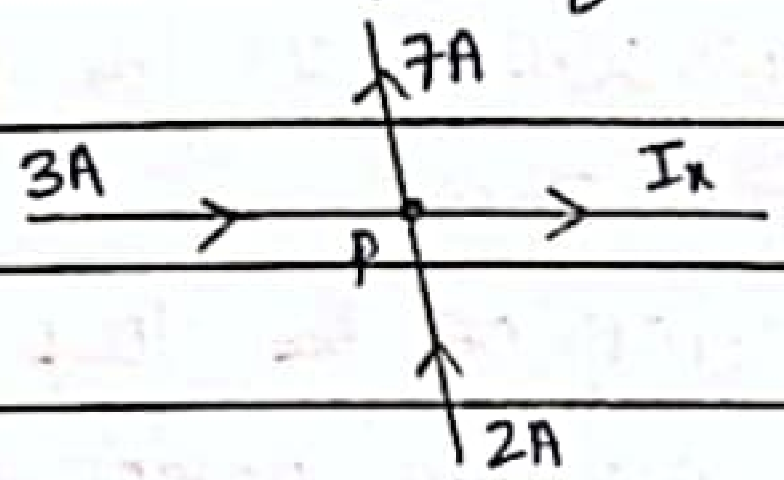
Solution:

$\Sigma I_{in} = 2.5 + 1 + 3 = 6.5A$

$\Sigma I_{out} = 4 + 0.5 + 2 = 6.5A$

As $\Sigma I_{in} = \Sigma I_{out}$, Kirchhoff's first law is satisfied.

34) Use Kirchoff's first law to deduce the value and direction of current I_x.



Solution:

$I_x + 7 = 3 + 2$

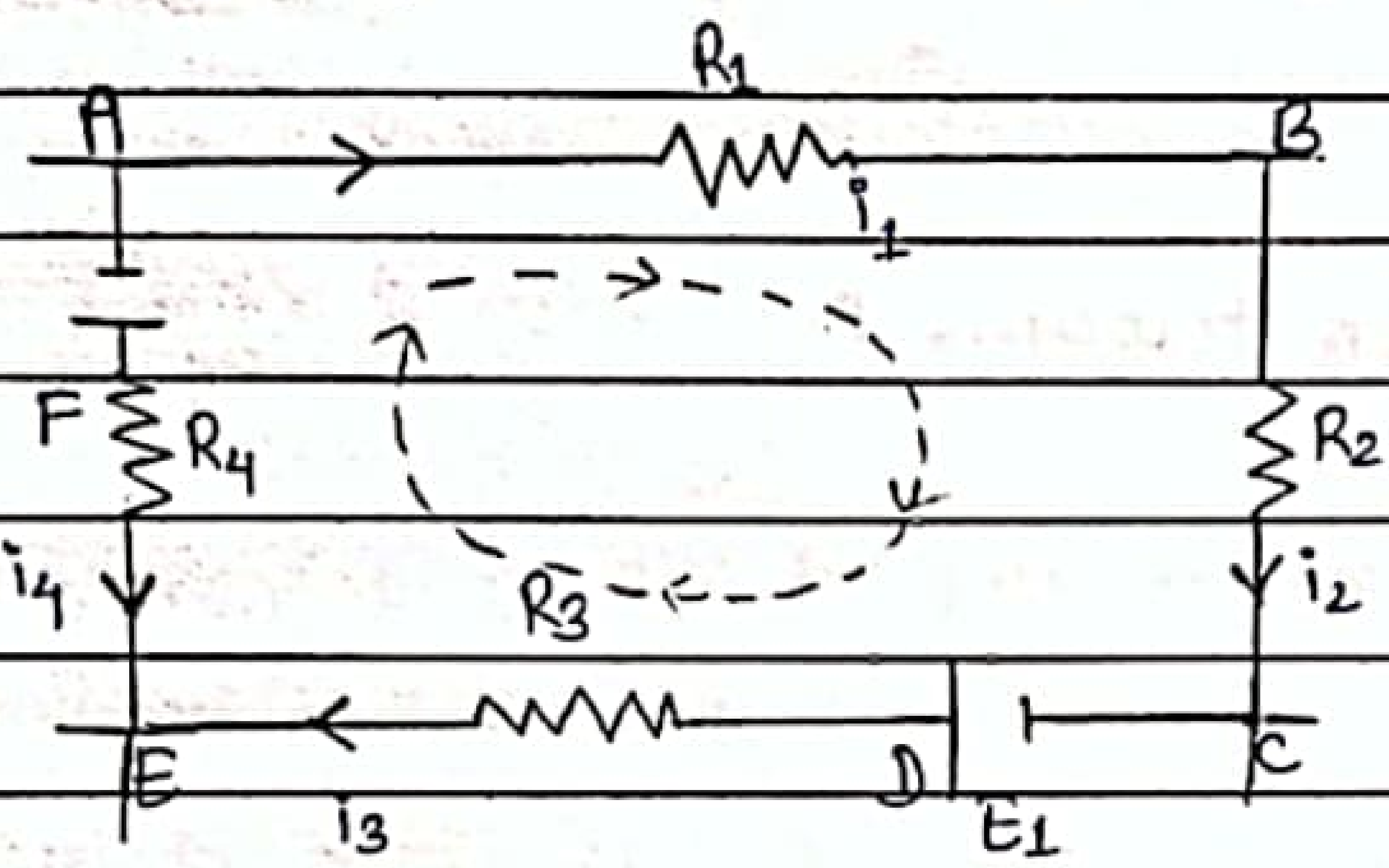
or $I_x = -2A$

$\therefore$ The value of current I_x is 2A towards P.

2. Kirchhoff's Second Law

Kirchhoff's Second Law states, "The algebraic sum of all the potential differences along a closed loop in a circuit is zero."

While using this rule, one starts from a point on the loop and goes along the loop to reach the same point. Any potential drop is taken negative and potential gain is taken positive.



In the figure, considering ABCDEFA a loop, we get the following potential differences.

$V_A - V_B = -i_1 R_1$

$V_B - V_C = -i_2 R_2$

$V_C - V_D = E_1$

$V_D - V_E = -i_3 R_3$

$V_E - V_F = i_4 R_4$

$V_F - V_A = -E_2$

Adding all these,

$0 = -i_1R_1 - i_2R_2 + E_1 - i_3R_3 + i_4R_4 - E_2$

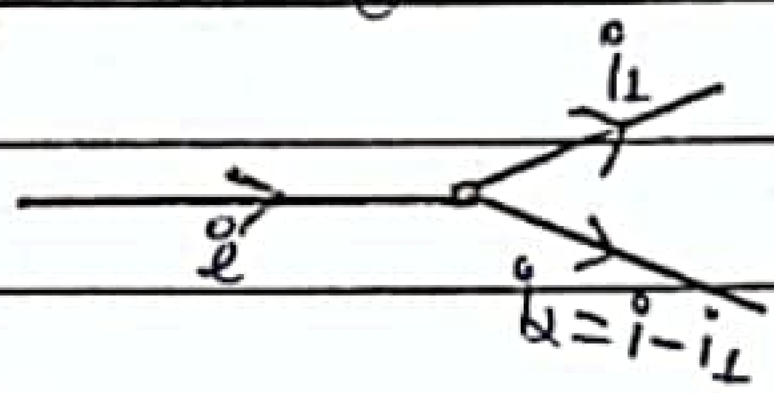
$\therefore \sum \Delta V = 0$

where ΔV = potential differences along a closed loop.

Kirchhoff's second law is an expression of the conservation of energy. It follows directly from the fact that electrostatic force is conservative force and work done by it in any closed path is zero.

APPLYING KIRCHHOFF's LAW

1. Draw current from one or more cell. Follow Kirchhoff's current law (KCL) for distribution of current at junctions.



2. Choosing Loop(s)

i. It/They must be closed loop/loops.

ii. It/They can involve any number of cells, resistors, etc.

3. Direction of Loop/Path

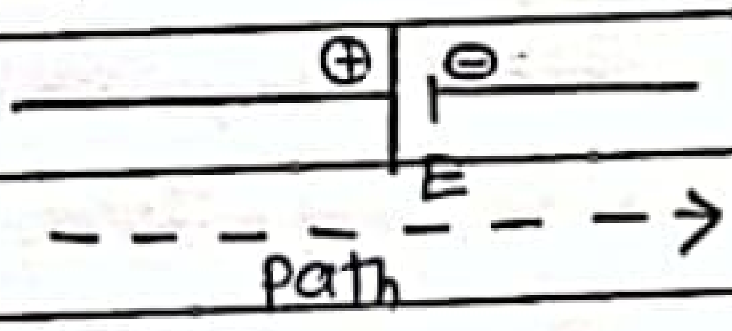
The loop(s) can either be ~~po~~ clockwise or anticlockwise but must be closed loop.

4. Potential drop or Potential gain

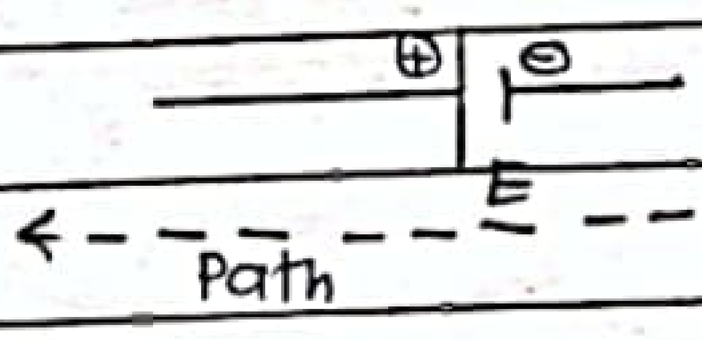
Higher Potential $\xrightarrow[\Delta V = \text{negative}]{\text{Potential drop}}$ Lower Potential

Lower Potential $\xrightarrow[\Delta V = \text{positive}]{\text{Potential gain}}$ Higher Potential

i. For cell

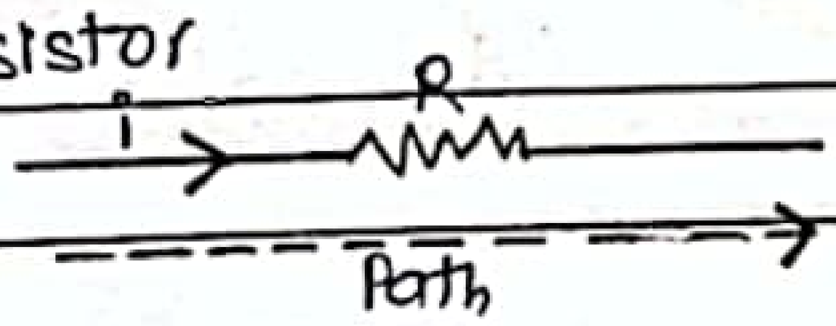


$\Delta V = -E$

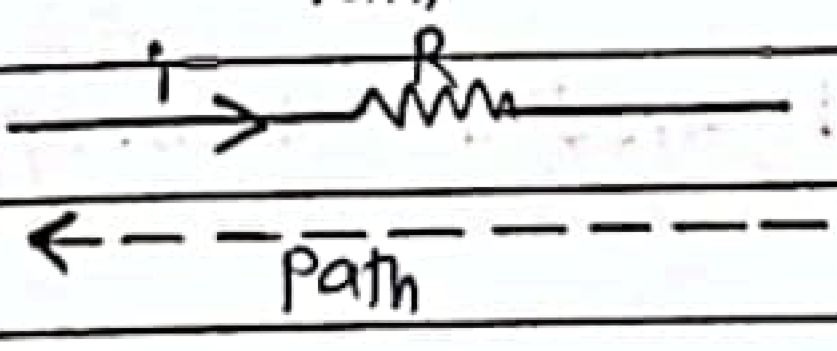


$\Delta V = E$

ii. For Resistor



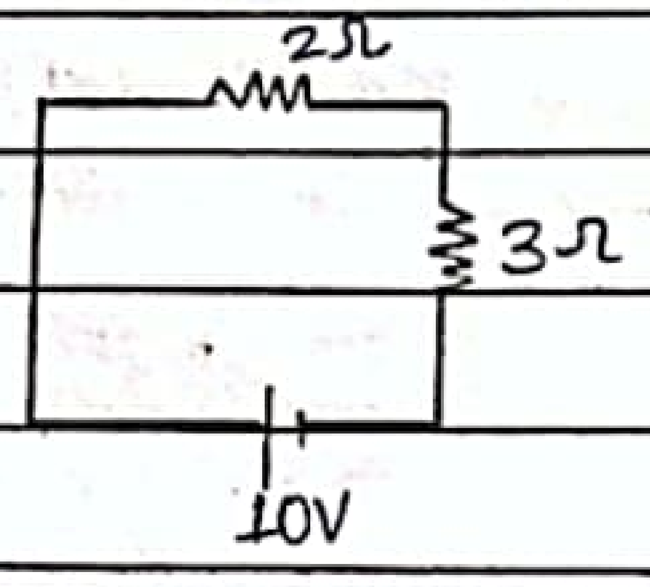
$\Delta V = -iR$



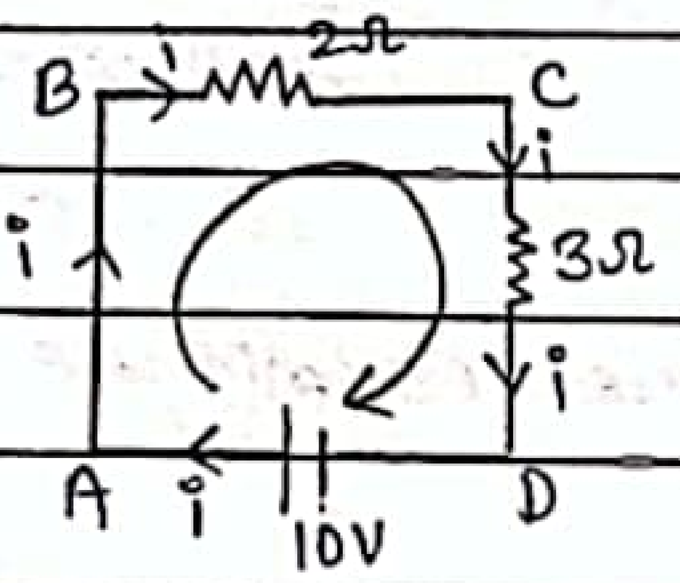
$\Delta V = iR$

Q1. Find current in each resistor.

i)



Solution:



Loop $\underline{ABCDA}$

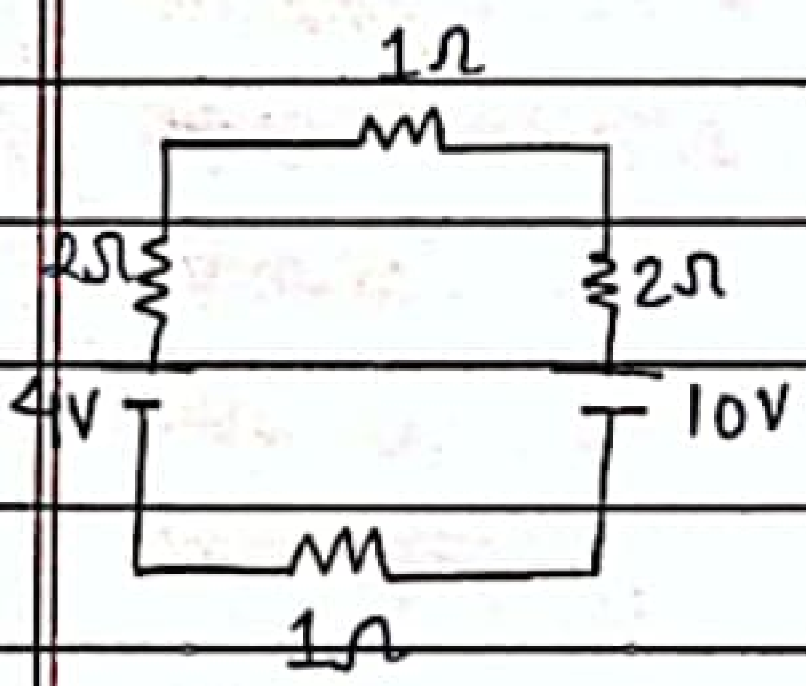
Suppose the current is i in the indicated direction. Applying Kirchhoff's loop law,

$$-2i - 3i + 10 = 0$$

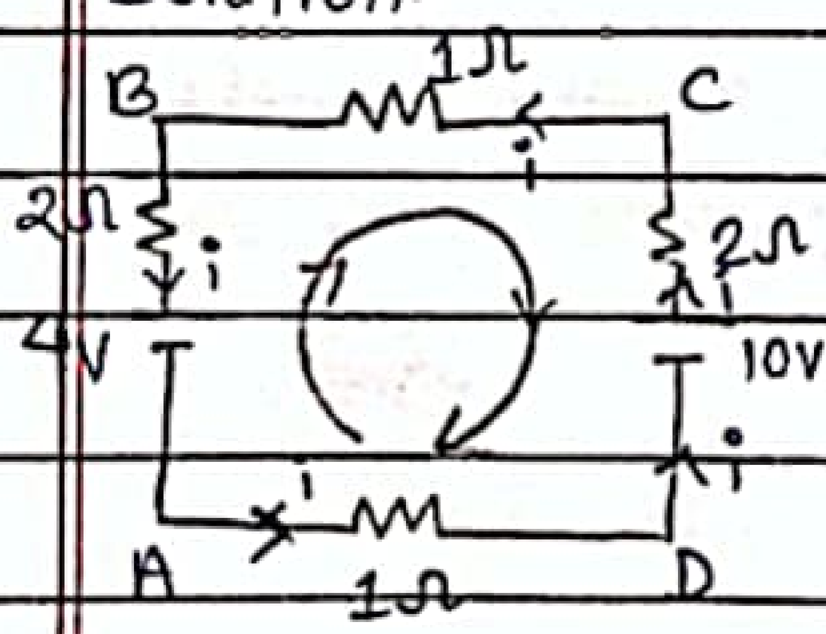
or, $5i = 10$

$\therefore$ $i = 2A$

ii)



Solution:



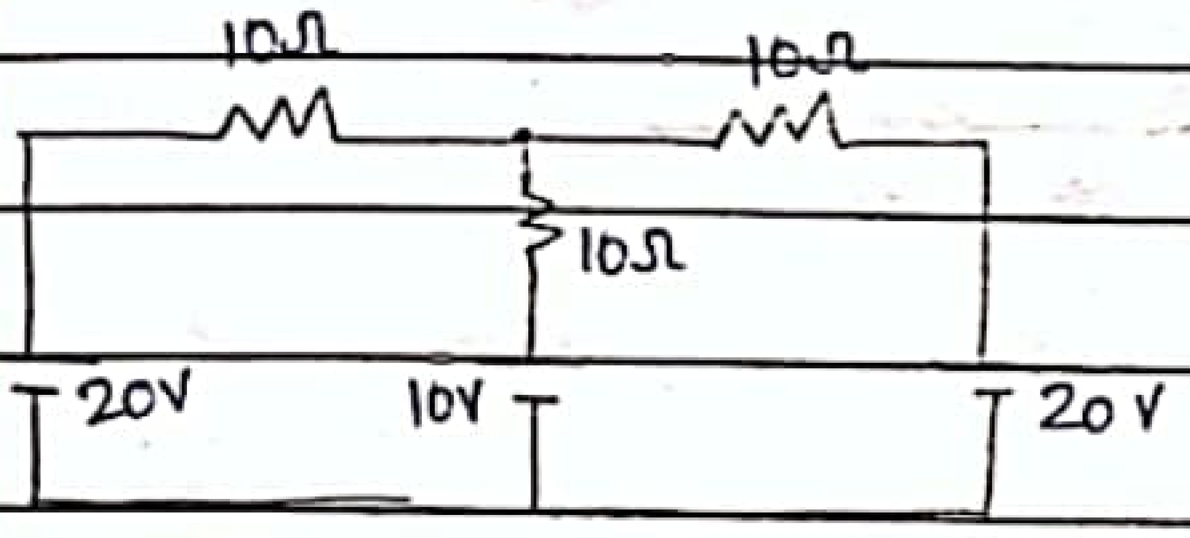
Loop $\underline{ABCDA}$

Suppose the current is i in the indicated direction. Applying Kirchhoff's loop law,

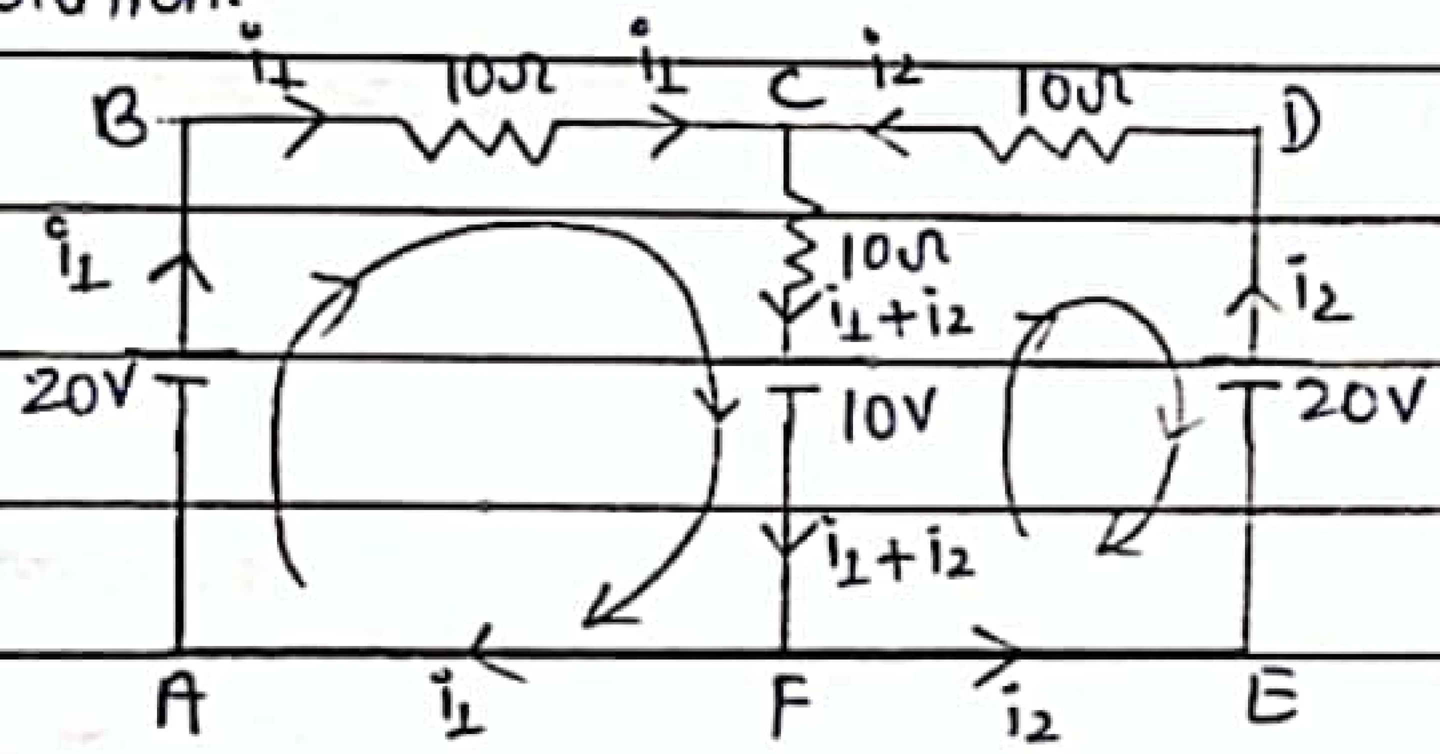
$4 + 2i + i + 2i - 10 + i = 0$

or, $6i = 6$

$\therefore$ $i = 1A$

iii) 

Solution:



Suppose the current is i_1 and i_2 in the indicated direction.

Considering the loop ABCFA,

$20 - 10i_1 - 10(i_1+i_2) - 10 = 0$

$10 - 10i_1 - 10i_1 - 10i_2 = 0$

$2i_1 + i_2 = 1$ --- (i)

Considering the loop CDEFC,

$10 + 10(i_1+i_2) + 10i_2 - 20 = 0$

$-10 + 10i_1 + 20i_2 = 0$

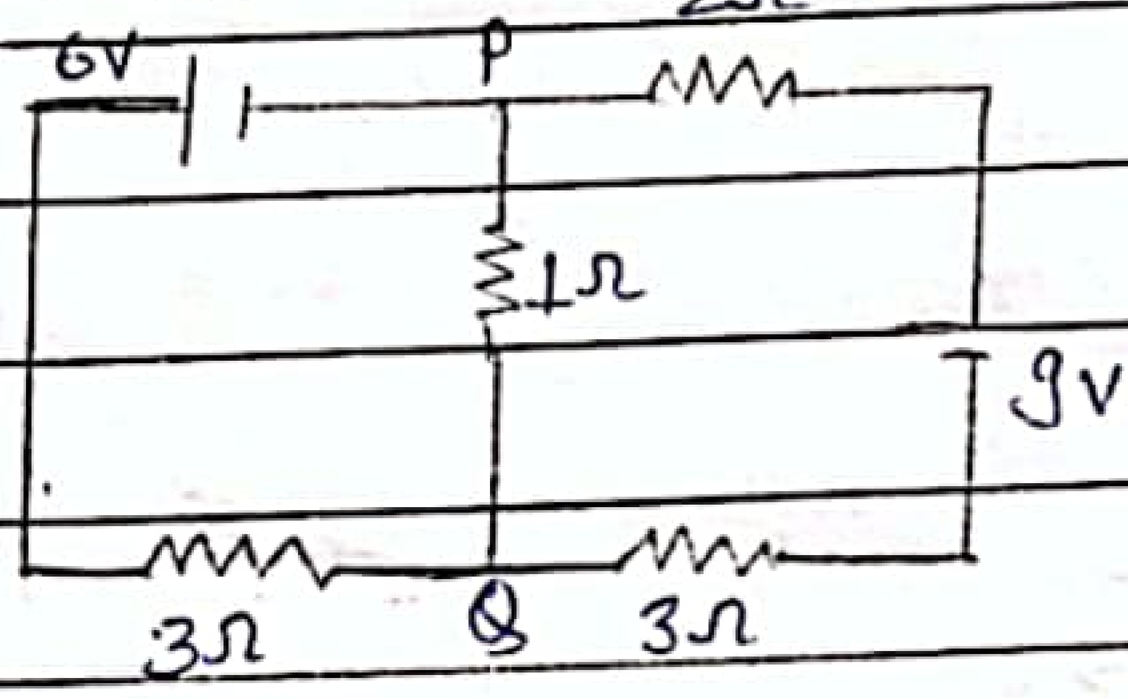
$i_1 + 2i_2 = 1$ --- (ii)

Solving (i) and (ii),

$i_1 = \frac{1}{3}A$, $i_2 = \frac{1}{3}A$

$\therefore$ $i_1 + i_2 = \frac{2}{3}A$

Q2. Find the current in 1Ω resistor.



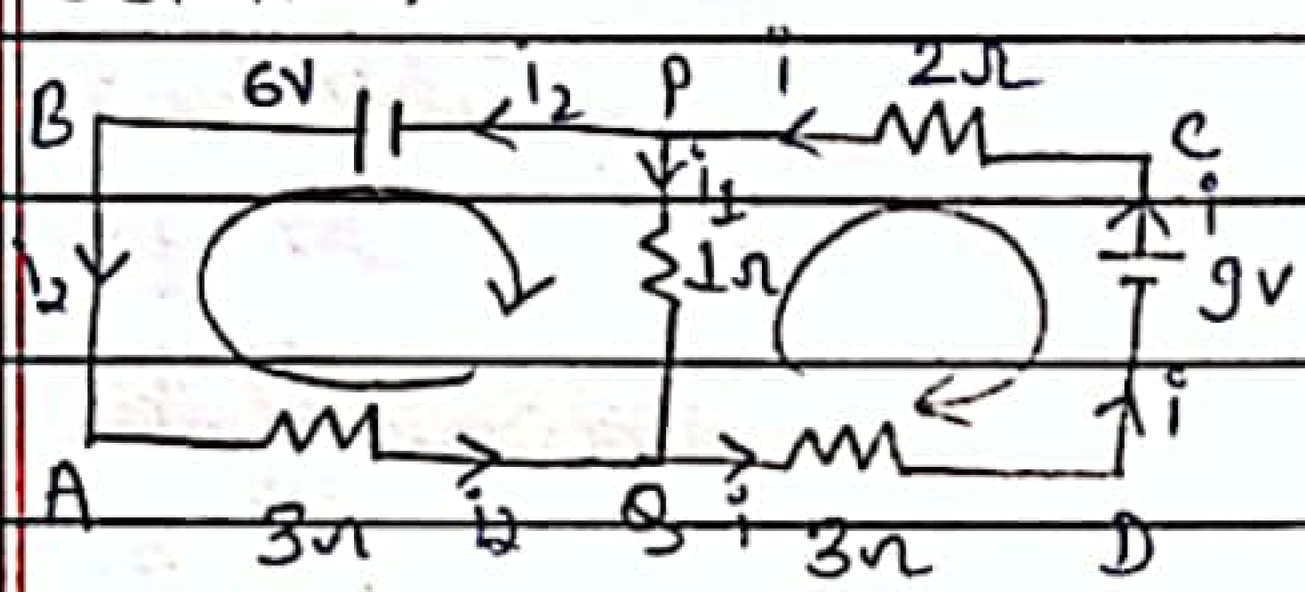
a) 1.13A P→Q

b) 1.13A Q→P

c) 0.13A Q→P

d) 0.13A P→Q

Solution:



Considering loop ABPQA

$3i_2 - 6 - i_1 = 0$

$3i_2 - i_1 = 6$ --- (i)

Considering loop CDQPC,

$-9 + 3i + i_1 + 2i = 0$

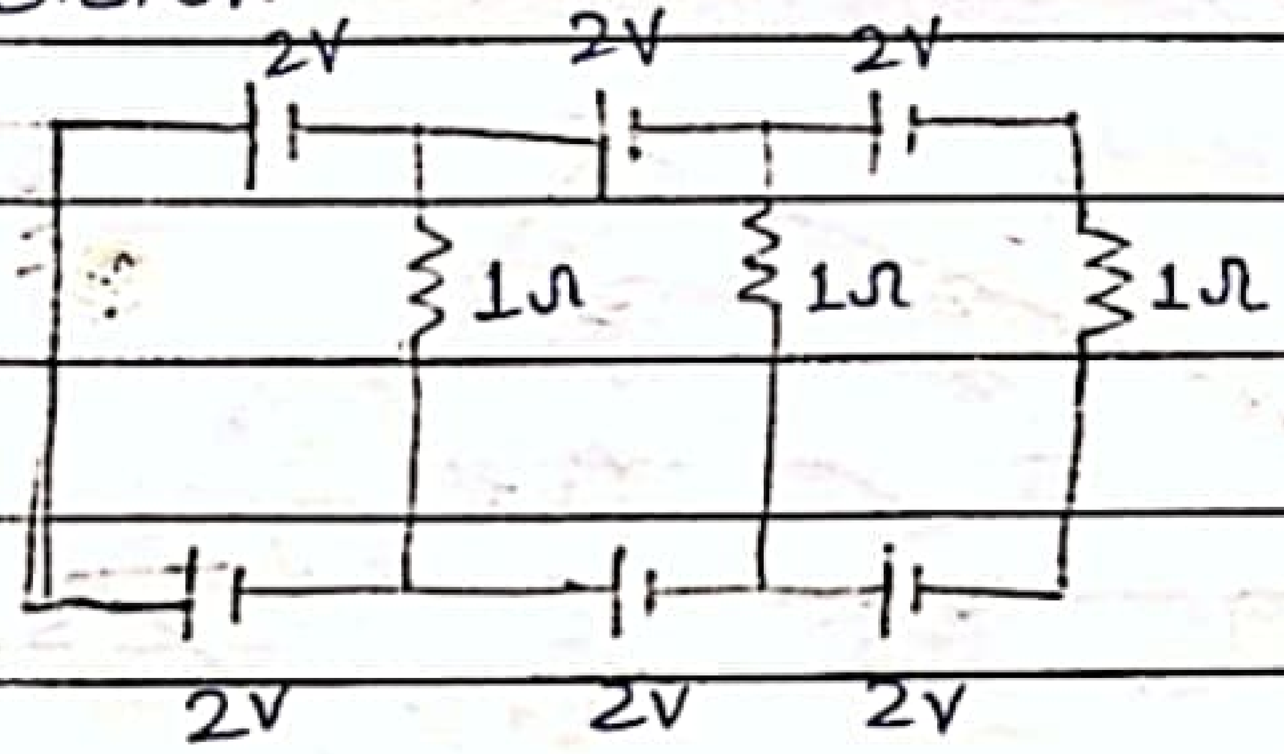
or, $5(i_1 + i_2) + i_1 = 9$

or, $6i_1 + 5i_2 = 9$ --- (ii)

Solving (i) and (ii)

$i_1 \approx -0.13A$

Q3) Find current in each resistor.



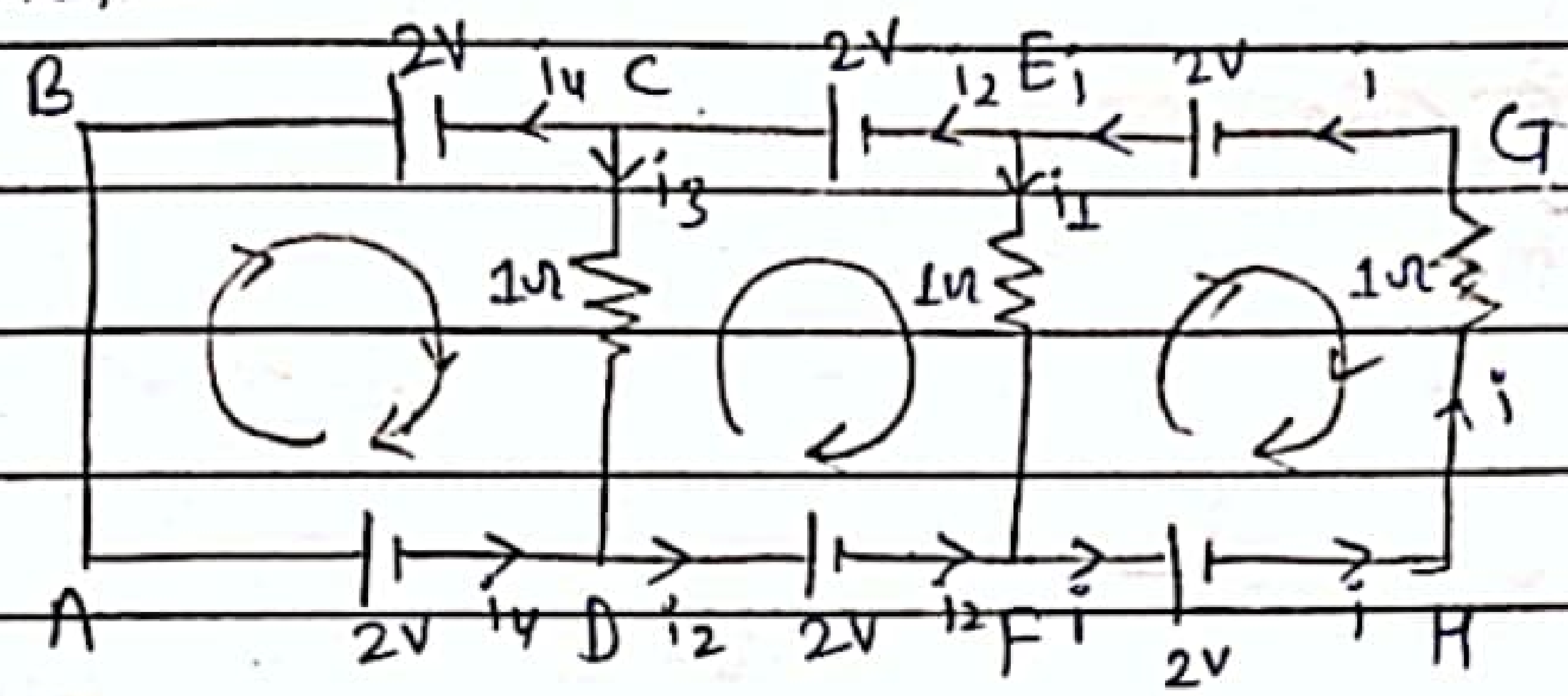
a) 0.25A

b) 0.5A

c) 0A ✓

d) 0.75A

Solution:



Considering loop ABCDA

$2 - 2 - i_3 = 0$

$i_3 = 0A$

Considering loop CEFDC

$2 + i_3 - 2 - i_1 = 0$

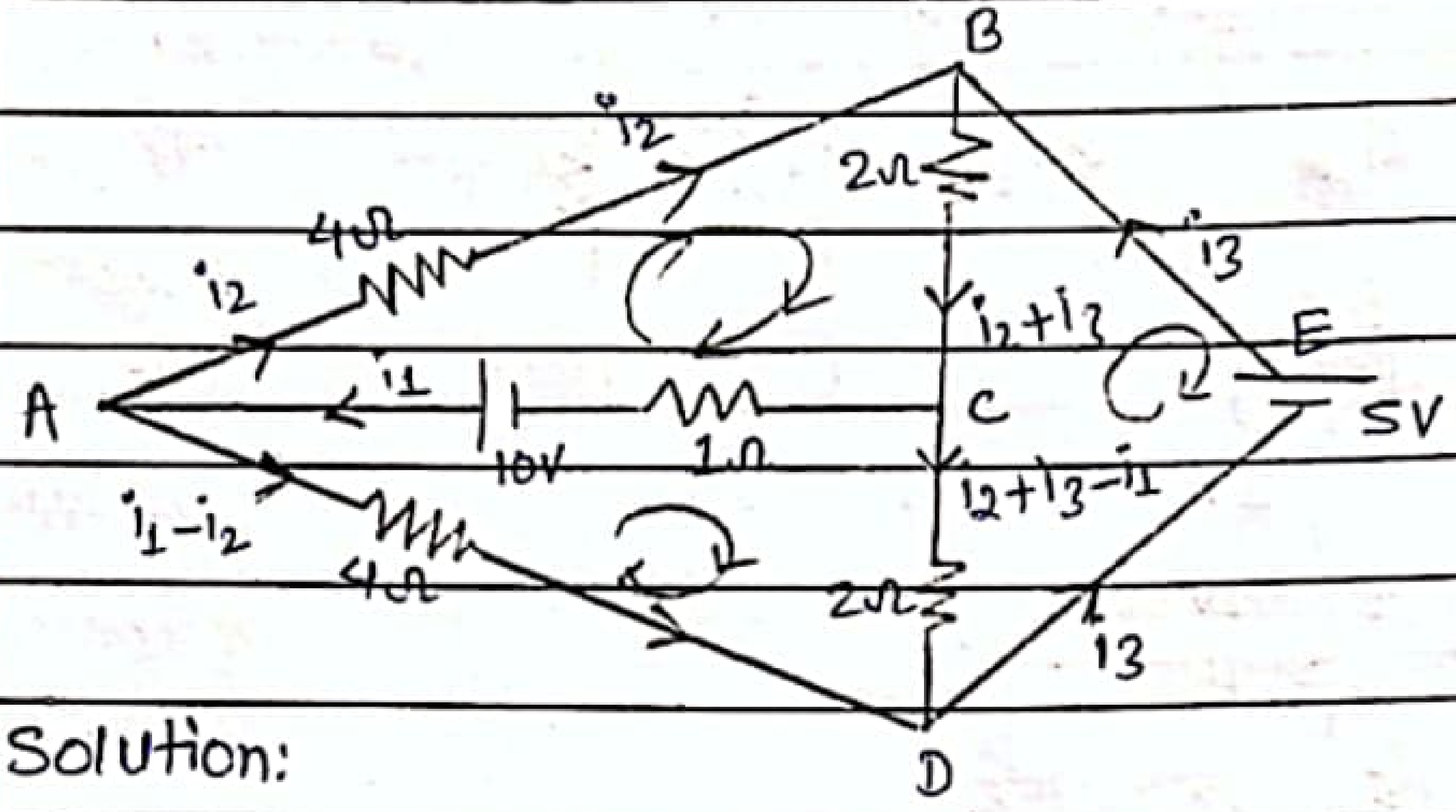
$i_3 = i_1 = 0A$

Considering loop EGHFE

$2 + i_1 - 2 + i = 0$

$i = 0A$

Q4) Find current in each resistor.



Solution:

For loop ABCA

$10 - 4i_2 - 2i_2 - 2i_3 - i_1 = 0$

$10 - 6i_2 - 2i_3 - i_1 = 0$

$i_1 + 6i_2 + 2i_3 = 10$ --- (i)

For loop ACDA

$-10 + i_1 - 2i_2 - 2i_3 + 2i_1 + 4i_1 - 4i_2 = 0$

$7i_1 - 6i_2 - 2i_3 = 10$ --- (ii)

For loop BEDB,

$-5 + 2i_2 + 2i_3 - 2i_1 + 2i_2 + 2i_3 = 0$

$4i_2 + 4i_3 - 2i_1 = 5$ --- (iii)

Adding (i) and (ii)

$8i_1 = 20$

$i_1 = \frac{20}{8} = \frac{5}{2} A = 2.5A$ --- (iv)

From (iv) and (i) & (i) and (iii) and (iv)

$6i_2 + 2i_3 = 7.5$ --- (v)

$4i_2 + 4i_3 = 10$ --- (vi)

Solving (v) and (vi),

$i_2 = \frac{5}{8} = 0.625A$ and $i_3 = \frac{15}{8} = 1.875A$

∴ Current in each resistor situated at

$AB = i_2 = 0.625A$

$BC = i_2 + i_3 = 0.625 + 1.875 = 2.5A$

$CD = i_2 + i_3 - i_1 = 0.625 + 1.875 - 2.5 = 0A$

$CA = i_1 = 2.5A$

$AD = i_1 - i_2 = 2.5 - 0.625 = 1.875A$

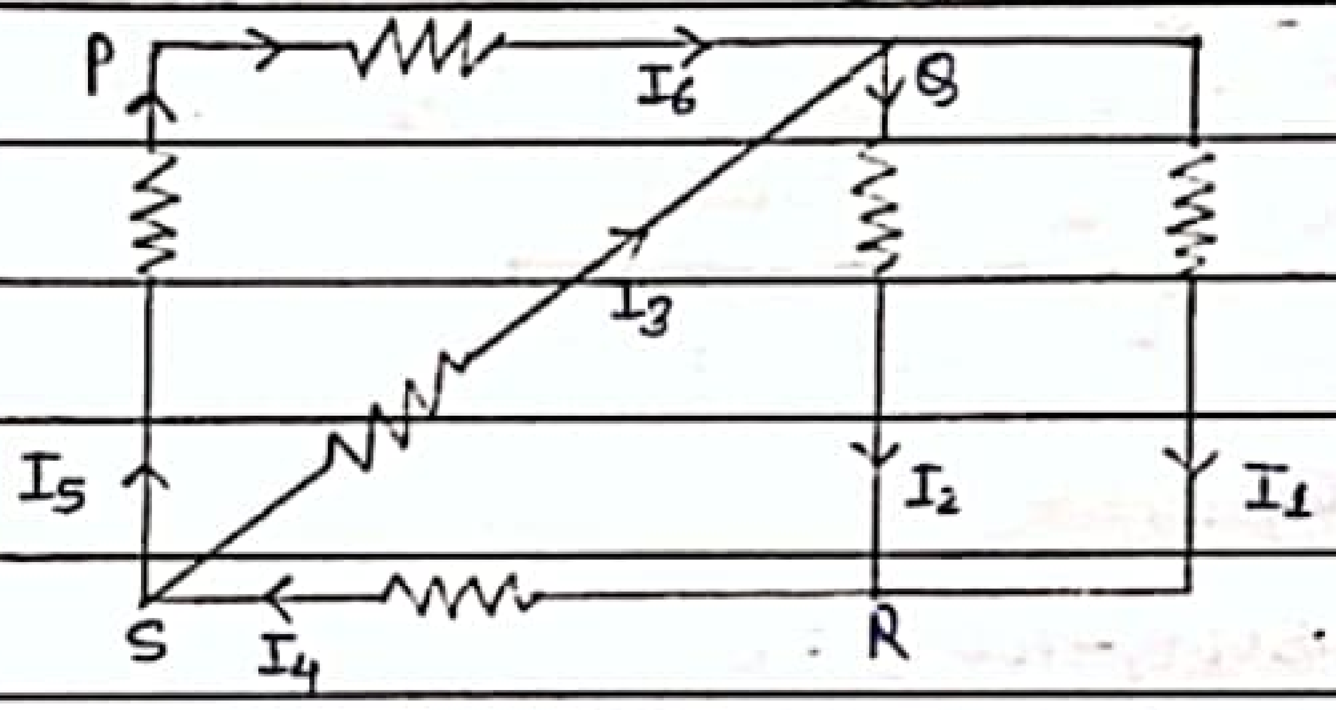
Q5) In the given circuit diagram, the currents $I_1 = -0.3A$, $I_4 = 0.8A$ and $I_5 = 0.4A$, are flowing as shown, the current I_2, I_3 and I_6 respectively are.

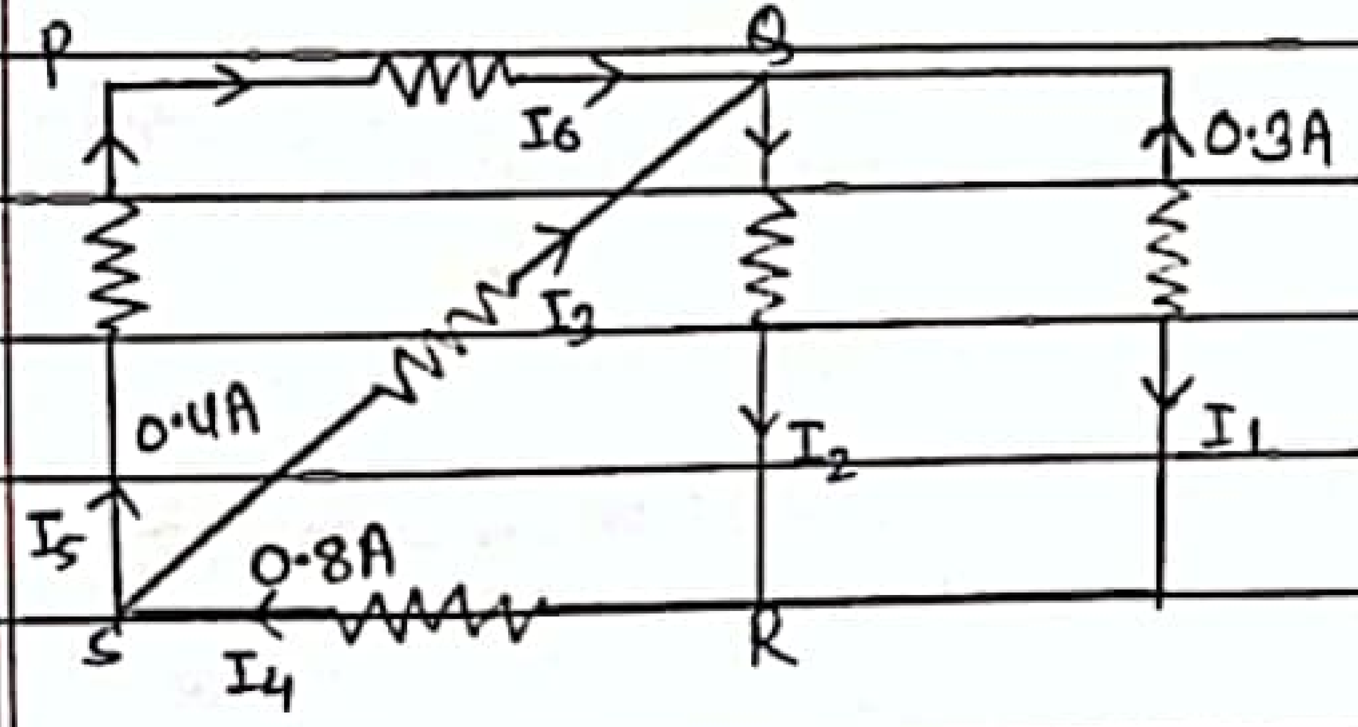
a) 1.1A, 0.4A, 0.4A ✓

b) 1.1A, −0.4A, 0.4A

c) 0.4A, 1.1A, 0.4A

d) −0.4A, 0.4A, 1.1A





$I_6 = I_5 = 0.4A$

$I_3 = 0.8 - 0.4 = 0.4A$

$I_2 = 0.3 + 0.4 + 0.4 = 1.1A$

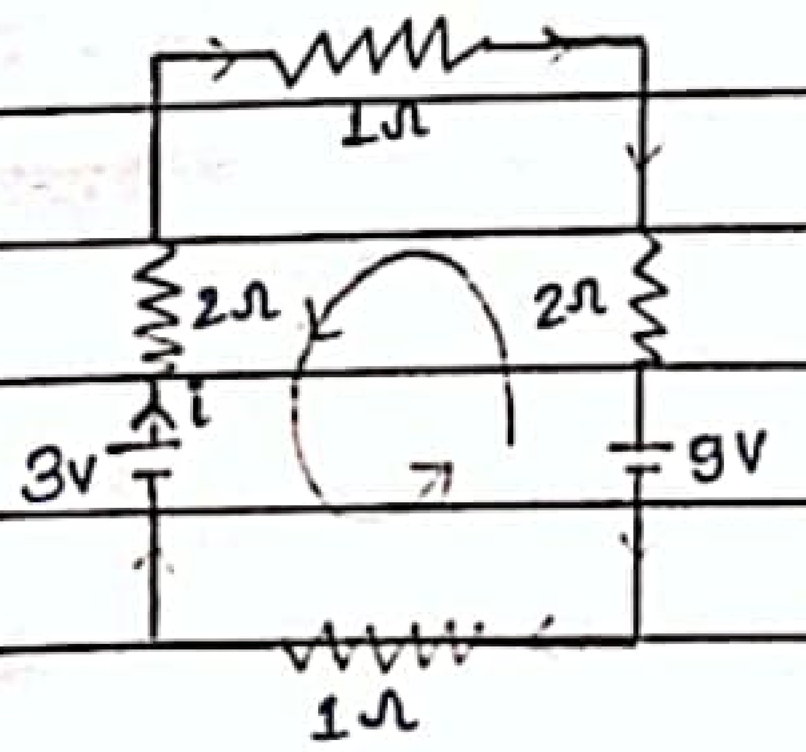
Q6) What is the current i.

a) 1A

b) −1A ✓

c) 2A

d) 3A



$\Rightarrow 9 + 2i + i + 2i - 3 + i = 0$

$6i = -6$

$i = -1A$

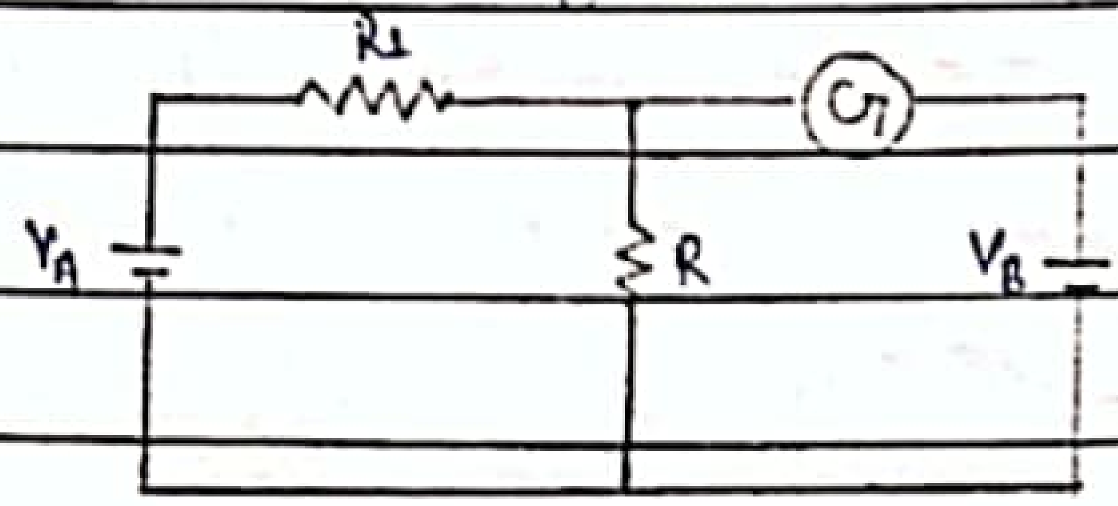
Q7) In the circuit shown the cells A and B have negligible resistances. For $V_A = 12V$, $R_1 = 500\Omega$ and $R = 100\Omega$, the galvanometer (G) shows no deflection. The value of V_B is:

a. 4V

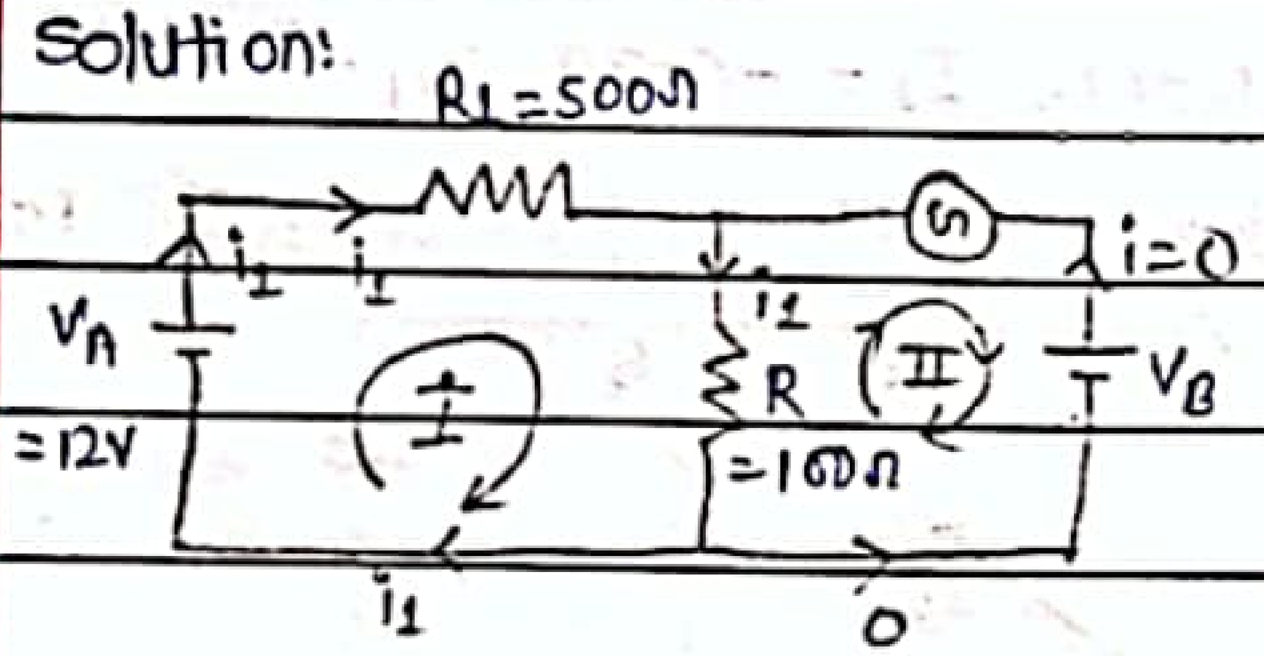
b. 2V ✓

c. 12V

D. 6V



Solution:



For loop I,

$12 - 500 i_1 - 100 i_1 = 0$

$600 i_1 = 12$

$i_1 = \frac{12}{600} = \frac{1}{50}$ A

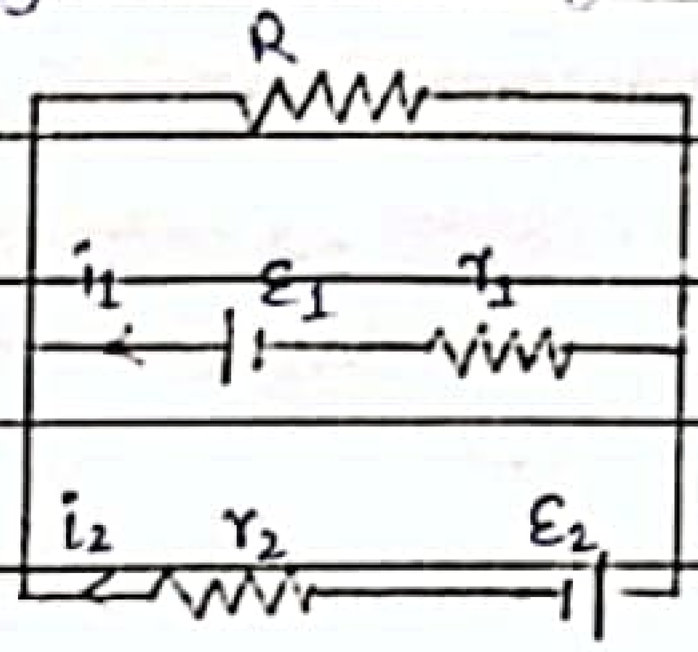
For loop II,

$100 i_1 - V_B = 0$

$V_B = 100 i_1$

$V_B = 100 \times \frac{1}{50} = 2V$

88) See the electrical circuit shown in the figure. Which of the following equations is a correct equation for it?



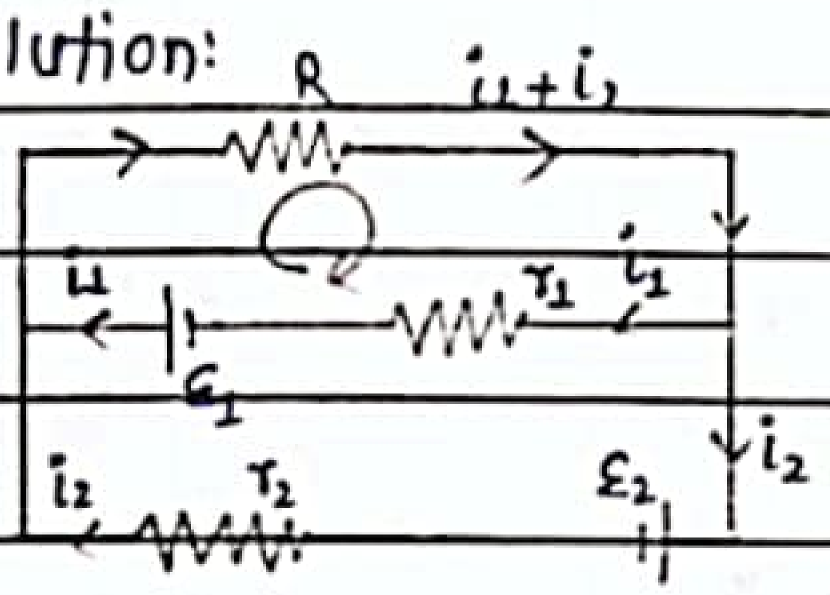
a. $\varepsilon_1 - (i_1 + i_2)R - i_1 r_1 = 0$

b. $\varepsilon_2 - i_2 r_2 - \varepsilon_1 - i_1 r_1 = 0$

c. $-\varepsilon_2 - (i_1 + i_2)R + i_2 r_2 = 0$

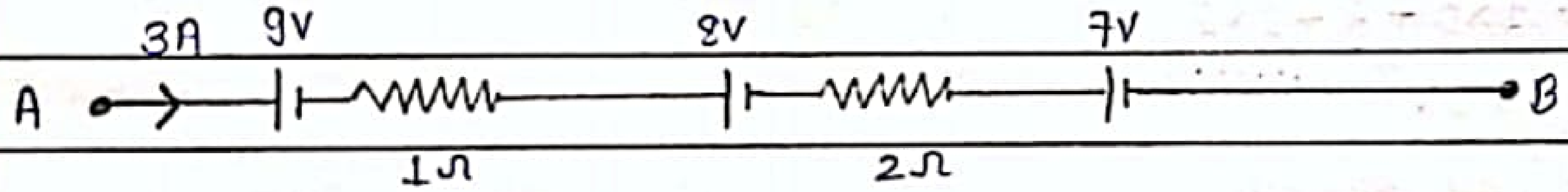
d. $\varepsilon_1 - (i_1 + i_2)R + i_1 r_1 = 0$

Solution:



$\Rightarrow \varepsilon_1 - (i_1 + i_2)R - i_1 r_1 = 0$

89) Find the potential difference between A and B $(V_A - V_B)$.



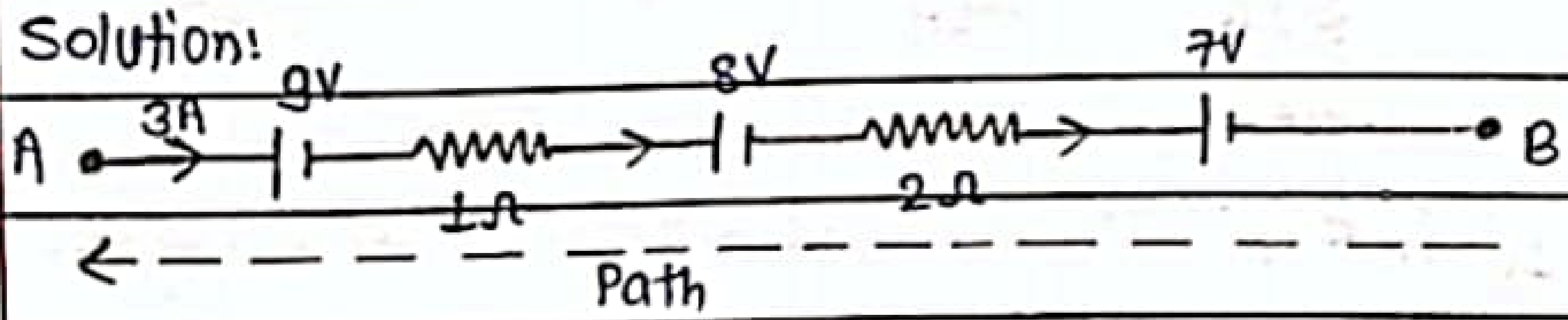
a) 30V

b) -30V

c) 33V

d) -33V

Solution:



$V_A - V_B = 7 + 2\times3 + 8 + 1\times3 + 9$

$= 33V$

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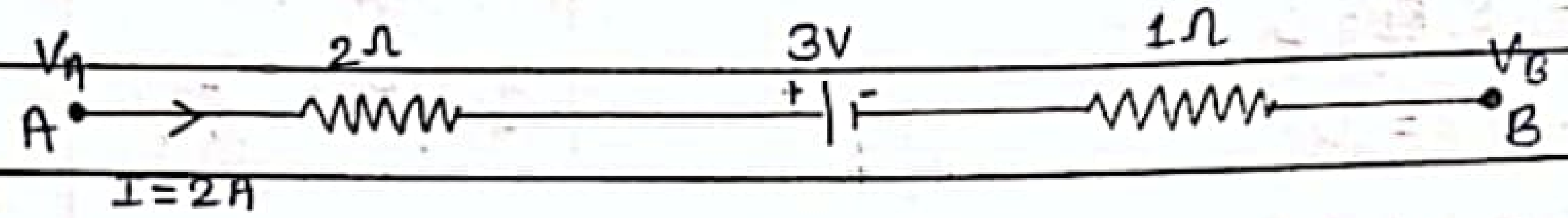
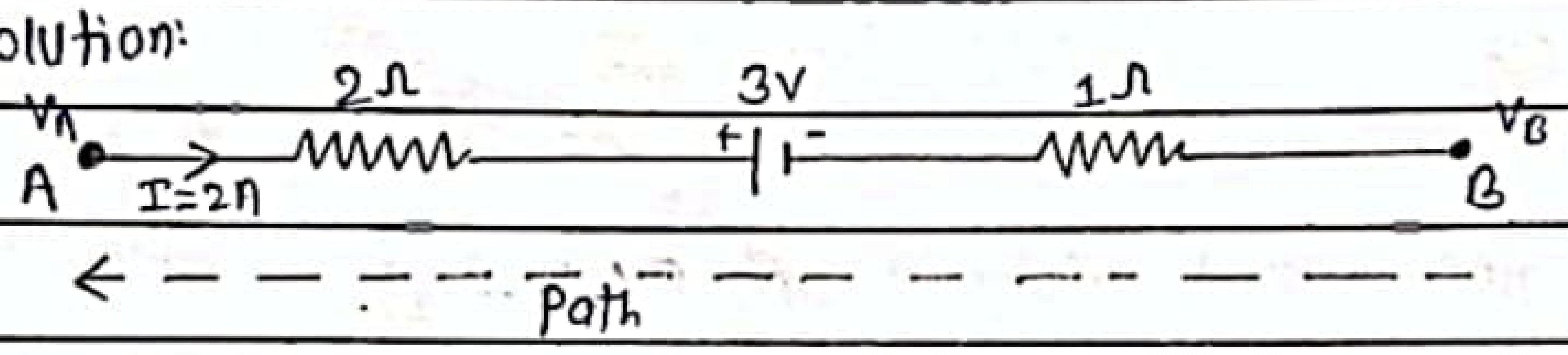
Q10) The potential difference $(V_A - V_B)$ between the points A and B in the given figure is:



a) +9V ✓
b) −3V
c) +3V
d) +6V

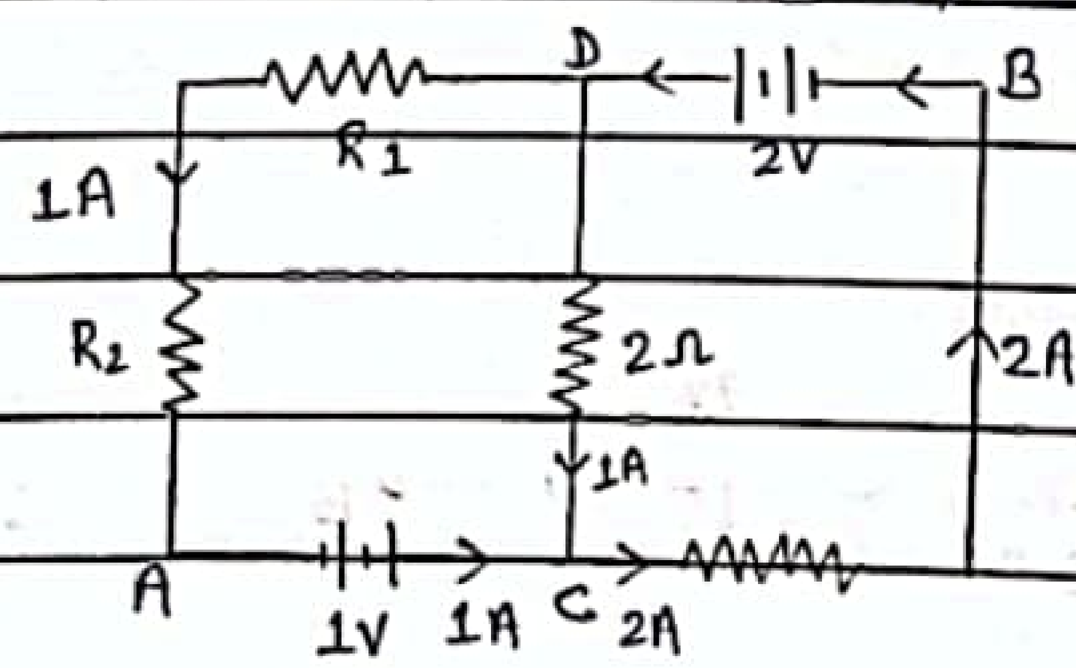
Solution:



$V_A - V_B = 1\times2 + 3 + 2\times2$

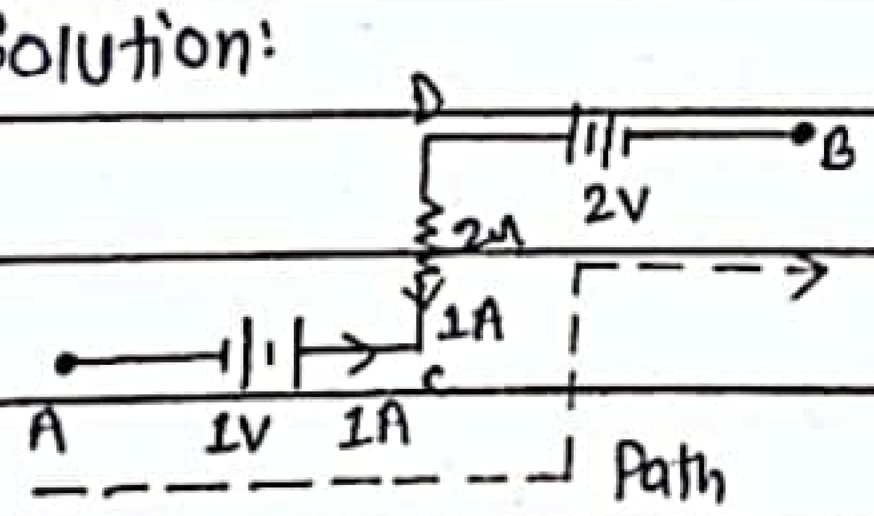
$= +9V$

Q11) In the circuit shown in the figure, if the potential at point A is taken to be zero, the potential at point B is



a. −2V
b. +1V ✓
c. −1V
d. +2V

Solution:



$1 + 2 - 2 = V_B - V_A$

$V_B = +1V$

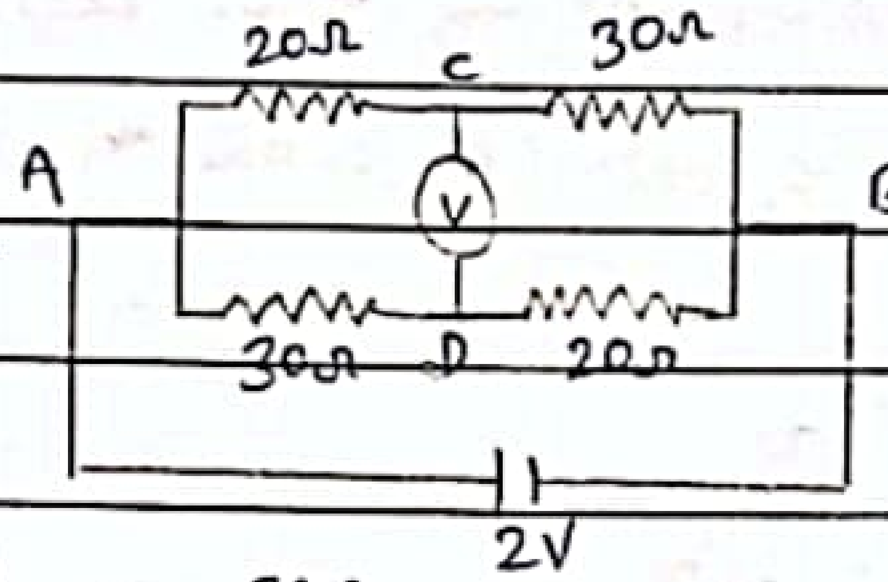
Q12) The reading of an ideal voltmeter in the circuit shown is,

a. 0.4V ✓

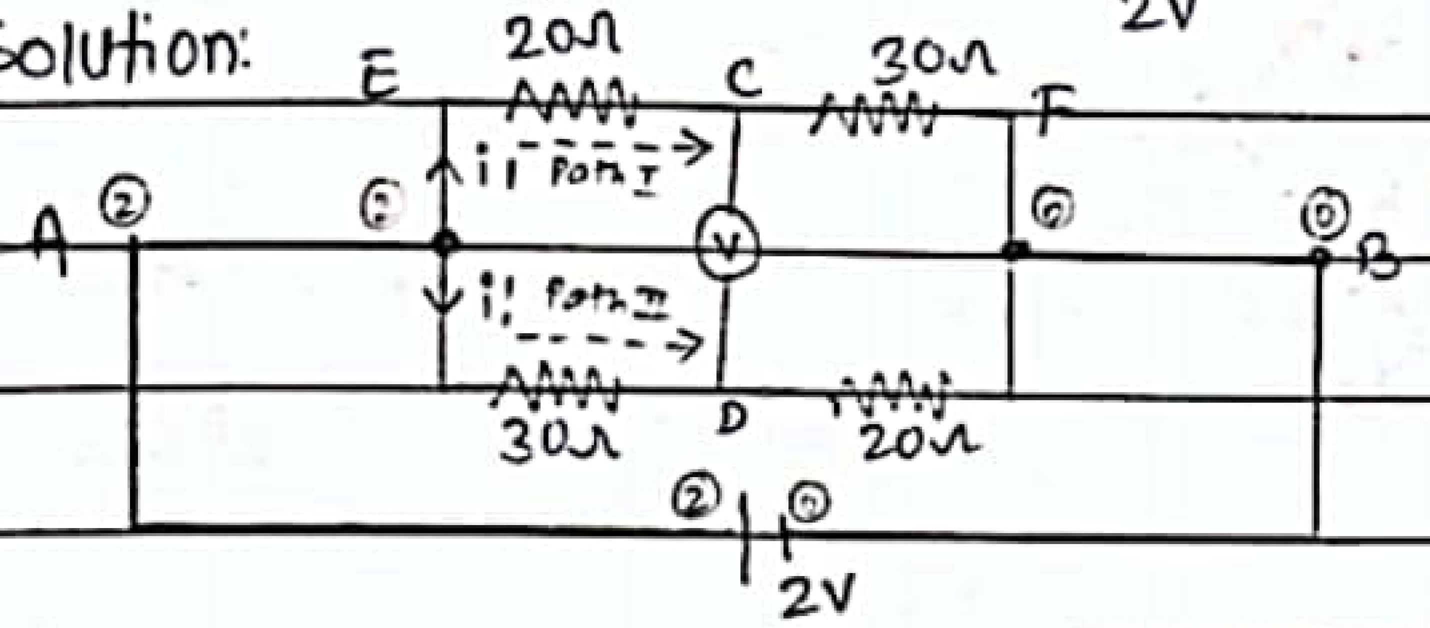
b. 0.6V

c. 0V

d. 0.5V



Solution:



Equivalent Resistance of branch EF (R_e) = 50Ω

$i = \frac{V}{R_{eq}} = \frac{2}{50} A$

In Path I,

$V_C - V_A = -20i$ --- (i)

In Path II,

$V_D - V_A = -30i$ --- (ii)

solving (i) and (ii)

$V_C - V_D = 10i = 10 \times \frac{2}{50}$

$V_C - V_D = 0.4V$

Ideal Voltmeter

$R \to \infty$

$i = \frac{V}{R} = 0$

No current in voltmeter branch.

Ideal Ammeter

$R \to 0$

* WHEATSTONE BRIDGE

Wheatstone Bridge is an arrangement of four resistances which can be used to measure one of them in terms of the rest.

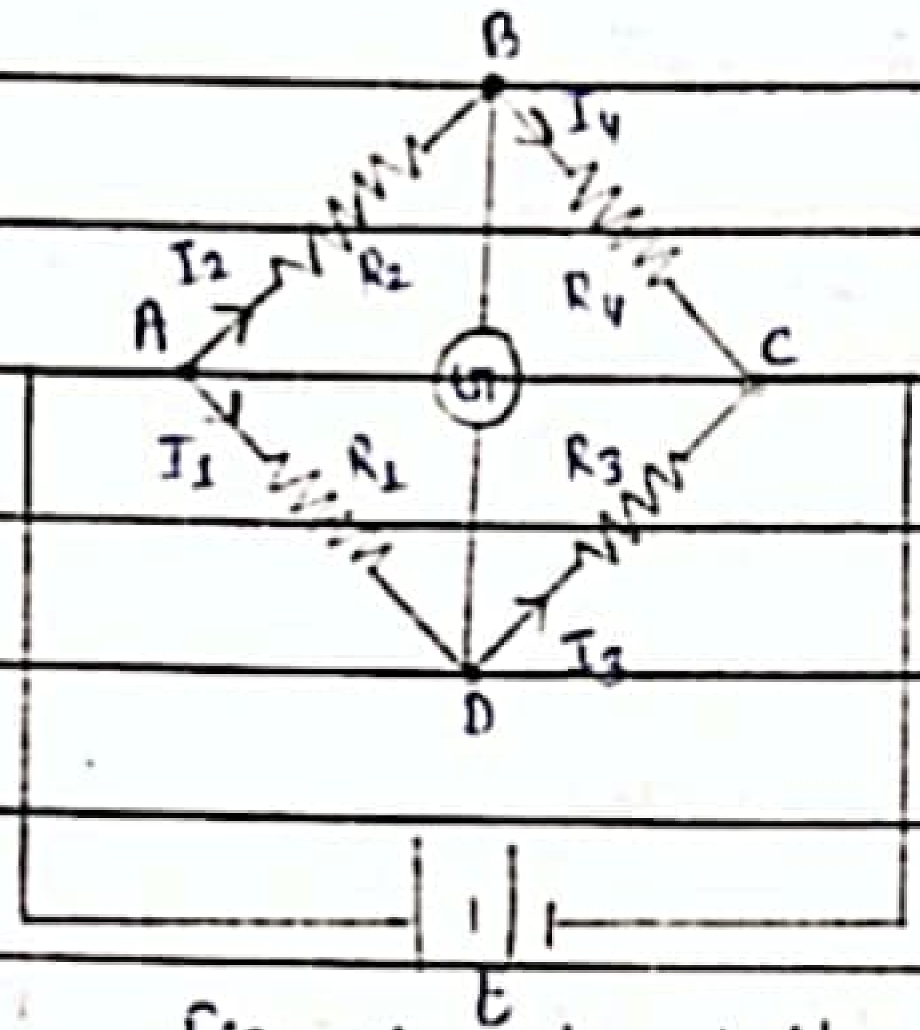


Fig: wheatstone bridge

Assume that the cell has no internal resistance. In general, there will be currents flowing across all branches as well as I_g through G. Of special interest, is the case of a balanced bridge where the resistors are such that $I_g = 0$. In this case, $I_1 = I_3$ and $I_2 = I_4$.

Applying loop law in loop ABDA

$-I_2R_2 + 0 + I_1R_1 = 0$

$I_1R_1 = I_2R_2$

$\frac{I_1}{I_2} = \frac{R_2}{R_1}$ --- (i)

In loop BCDB.

$-I_4R_4 + I_3R_3 + 0 = 0$

$I_3R_3 = I_4R_4$

$\frac{I_3}{I_4} = \frac{I_1}{I_2} = \frac{R_4}{R_3}$ --- (ii)

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

This equation is called the balance condition for the galvanometer to give zero or null deflection.

Page : Date :

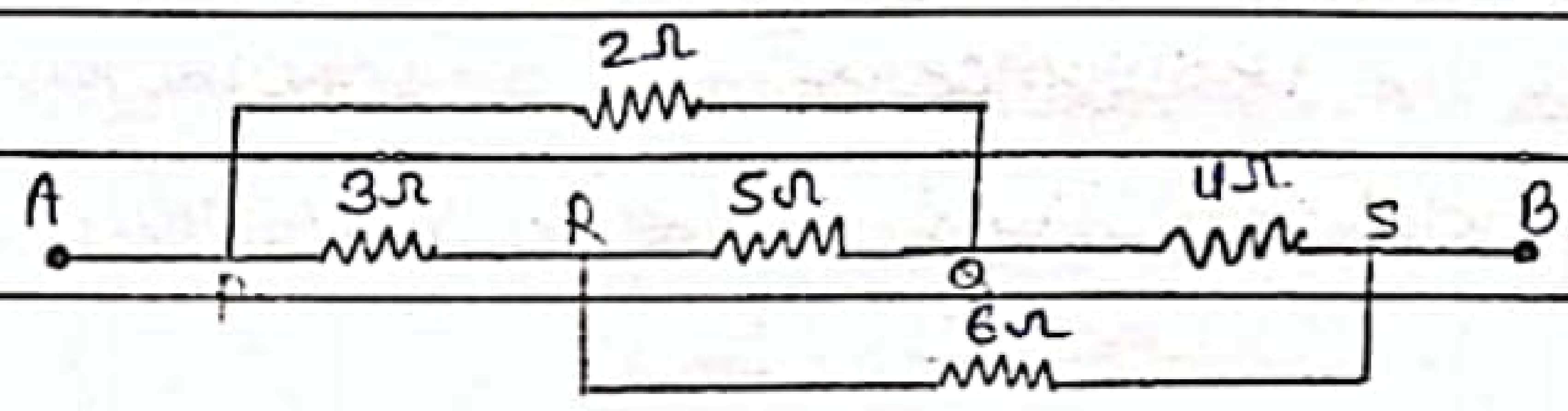
Q1) Calculate equivalent resistance between points A and B.

a. $3/5\,\Omega$

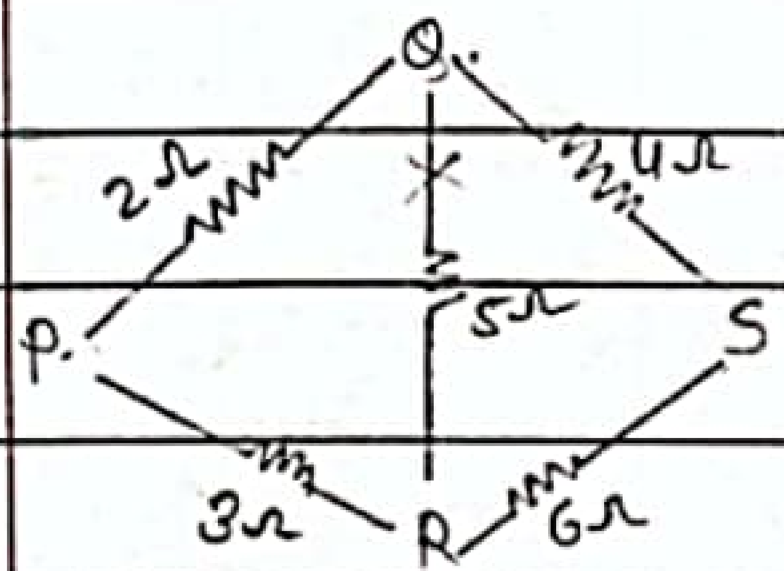
b. $6/5\,\Omega$

c. $9/5\,\Omega$

d. $18/5\,\Omega$ ✓



Solution:



$$\Rightarrow R_{eq} = \frac{6\times 9}{6+9} = \frac{54}{15} = \frac{18}{5}\,\Omega$$

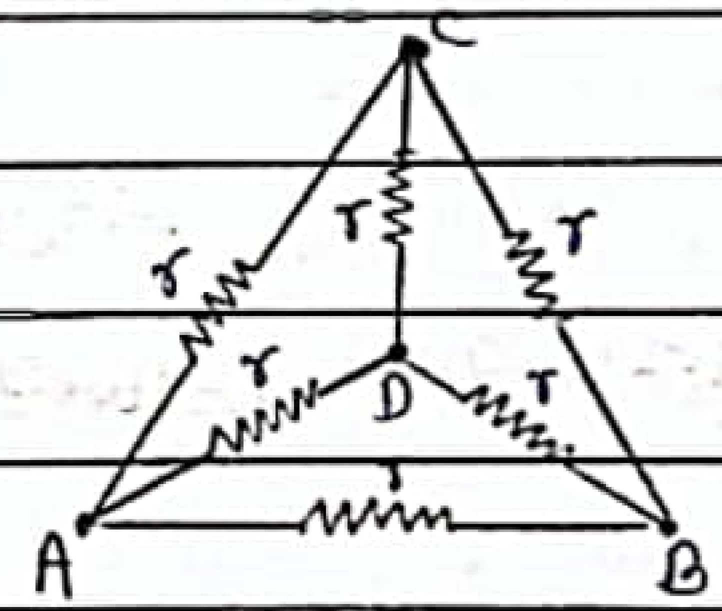
Q2) Calculate equivalent resistance between points A and B.

a. $r/2$ ✓

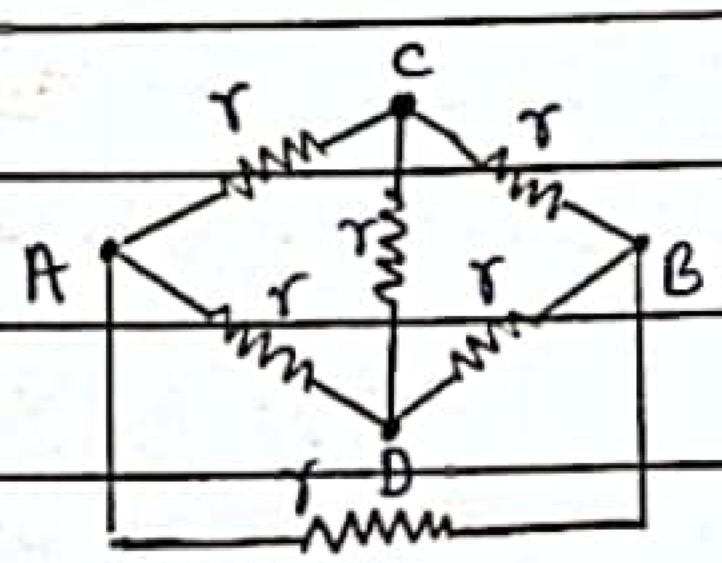
b. r

c. $2r$

d. $4r$



Solution:



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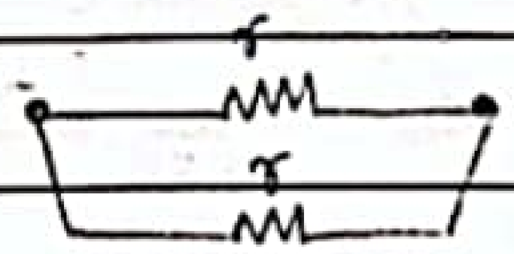


$R_{eq} = r/2$

Q3) In a wheatstone bridge, all four arms have equal resistance R. If the resistance of the galvanometer arm is also R, the equivalent resistance of the combination as seen by the battery is

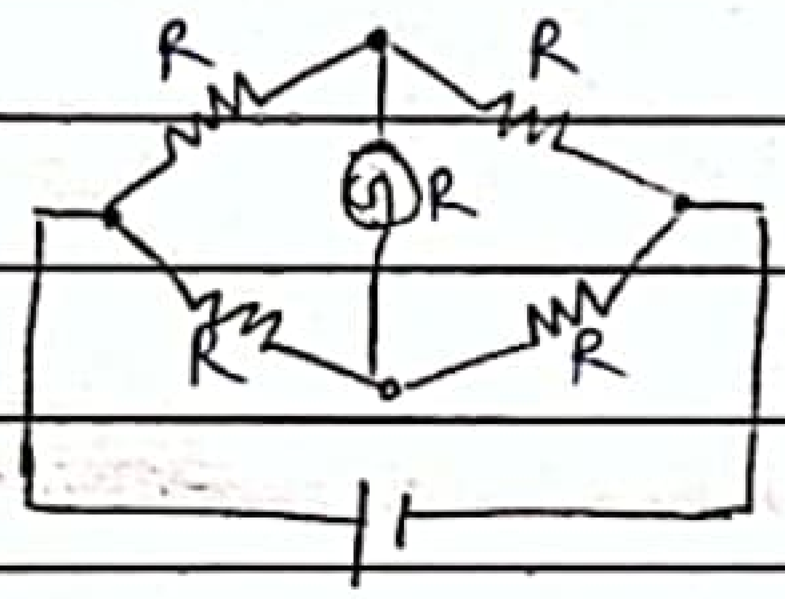
a. R/4

b. R/2

c. R

d. 2R.

Solution:



$Re = \frac{2R}{2} = R$

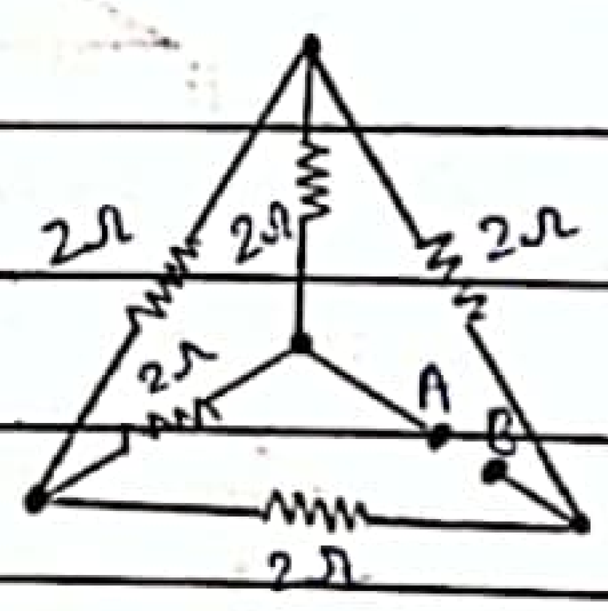
Q4) In the network shown in the figure each of the resistance is equal to 2Ω. The resistance between points A and B is

a. 1Ω

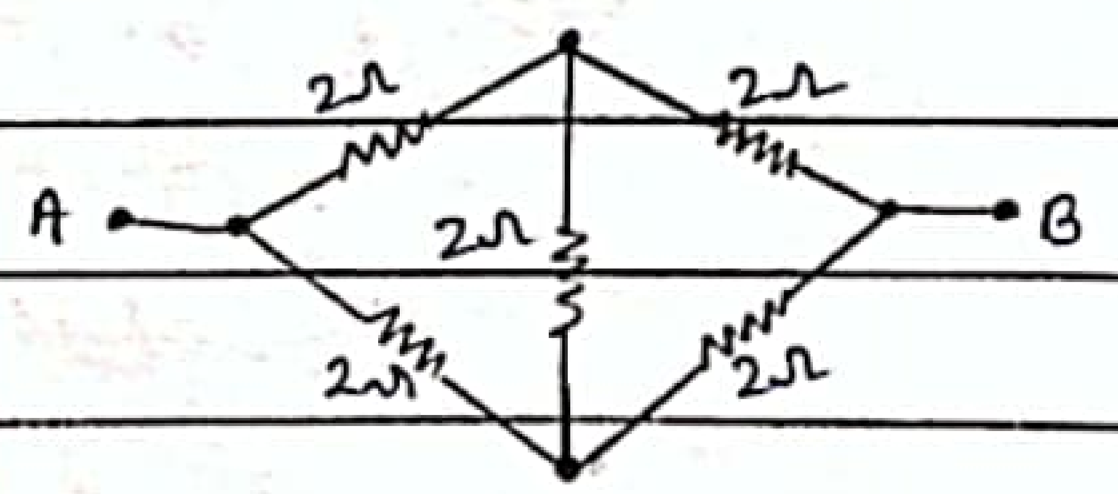
b. 4Ω

c. 3Ω

d. 2Ω



Solution:



$Re = \frac{4}{2} = 2\Omega$

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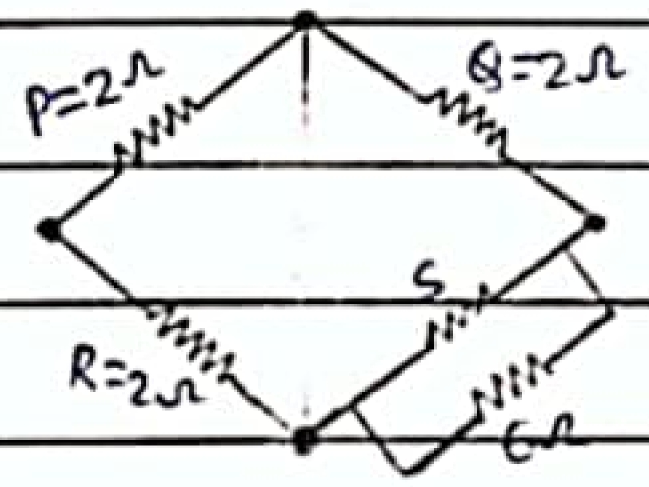
Q5) Three resistance P, Q, R each of 2Ω and an unknown resistance S form the four arms of Wheatstone bridge circuit. When a resistance of 6Ω is connected parallel to S, the bridge gets balanced. What is the value of S?

a. 3Ω ✓
b. 6Ω
c. 1Ω
d. 2Ω

Solution:



Equivalent of 6Ω and $S = \frac{6S}{6+S}$

$$\frac{2}{2} = \frac{2}{\frac{6S}{6+S}}$$

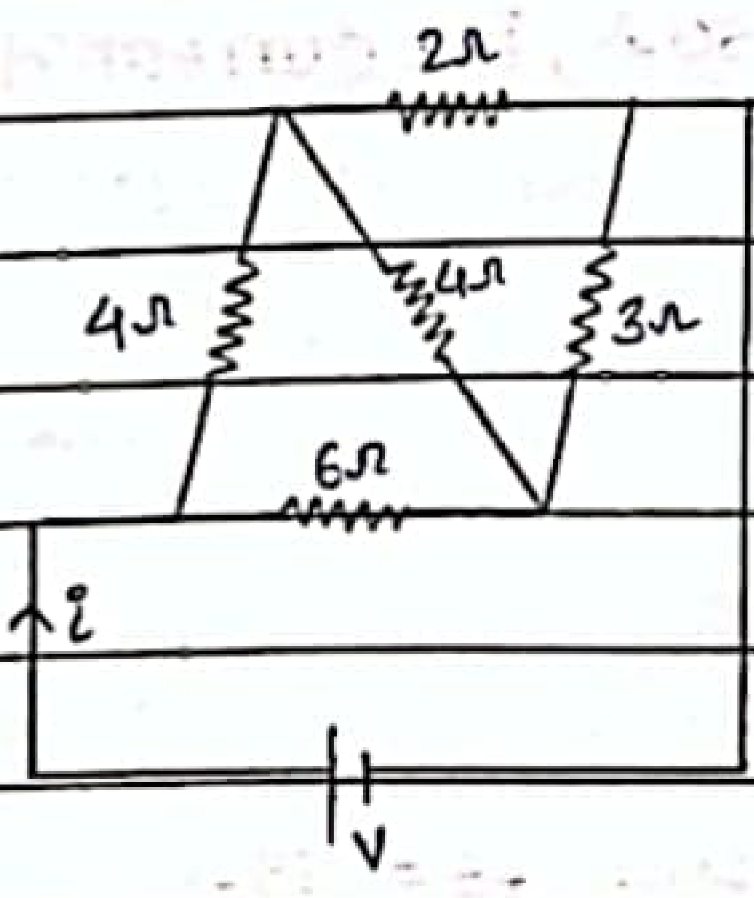
or $\frac{6S}{6+S} = 2$

or $3S = 6+S$

or $S = 3\Omega$

Q6) For the network shown in the figure, the value of current is

a. $\frac{9V}{35}$
b. $\frac{5V}{18}$ ✓
c. $\frac{5V}{9}$
d. $\frac{18V}{5}$



Solution:

$R_e = \frac{6\times 9}{6+9} = \frac{18}{5}$, $i = \frac{V}{R_e} = \frac{5V}{18}$

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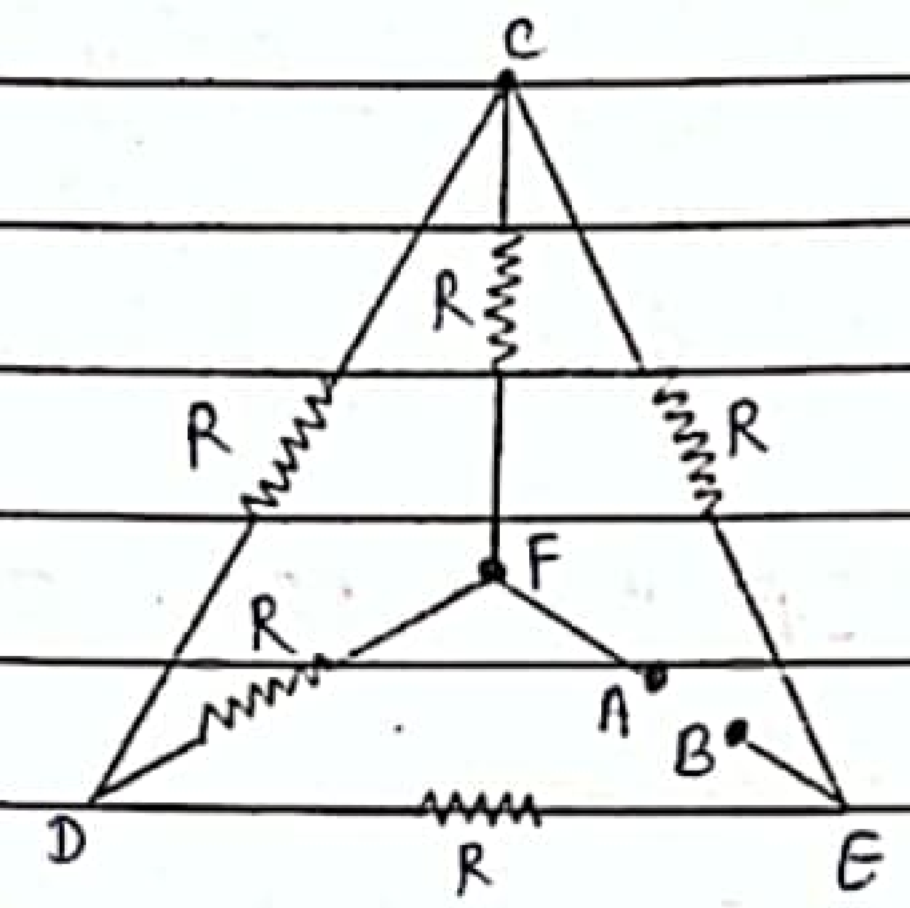
Q7.) Five equal resistances each of resistance R are connected as shown in the figure. A battery of V volts is connected between A and B. The current flowing in AFCEB will be.

a. $\frac{3V}{R}$

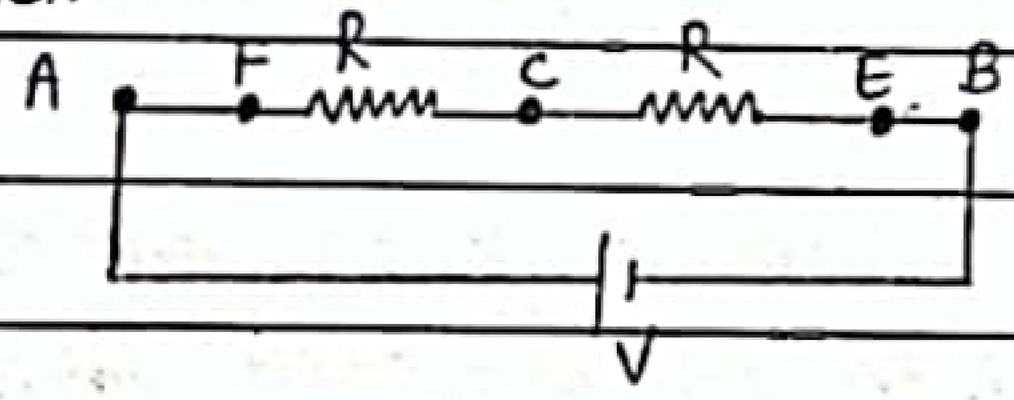


b. $\frac{V}{R}$

c. $\frac{V}{2R}$

d. $\frac{2V}{R}$

Solution:



$i = \frac{V}{2R}$

Q8) The resistance of the four arms P, Q, R and S in a Wheatstone's bridge are 10Ω, 30Ω, 30Ω and 90Ω respectively. The emf and internal resistance of the cell are 7V and 5Ω respectively. If the galvanometer resistance is 50Ω, the current drawn from the cell will be

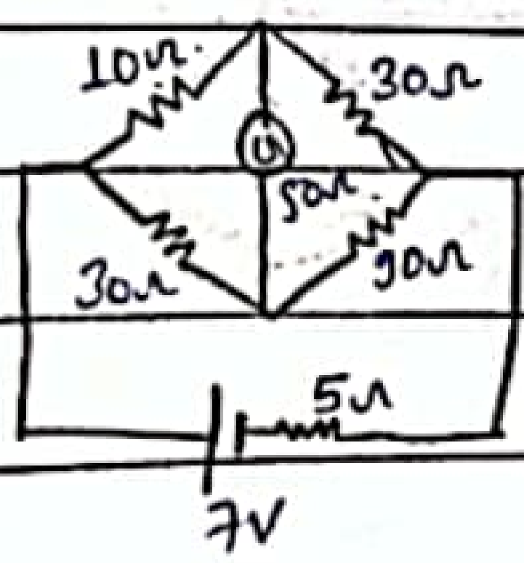
a. 1.0A

b. 0.2A

c. 0.1A

d. 2.0A

Solution:



$R_e = \frac{40 \times 120}{40 + 120} + 5 = 35Ω$

$i = \frac{V}{R_e} = \frac{7}{35} = 0.2A$

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* METER BRIDGE

A meter bridge is an electrical instrument based on the principle of balanced wheatstone bridge that helps in determining the value of unknown resistance.

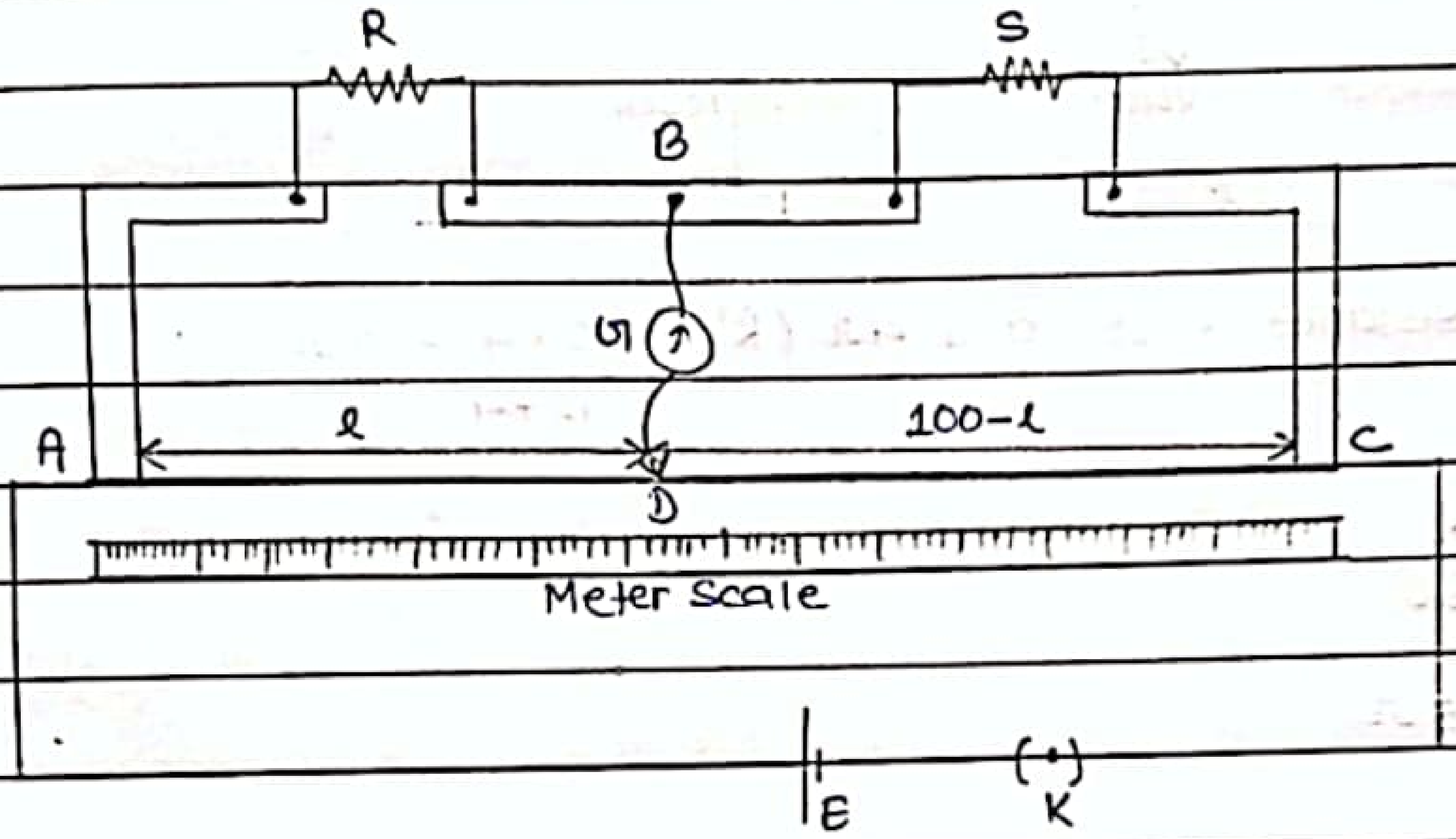


Fig: Meter bridge

In the above diagram, R is the unknown resistance, S is the known resistance, G is galvanometer and D is the position of Jockey as it is made to move along the wire AC of length 1 meter or 100cm. The Jockey is moved till the galvanometer shows zero deflection. This confirms that the wheatstone bridge is balanced.

Let $r\,\Omega/cm$ be the resistance per unit length of wire AC. Then resistance of branch AD (R_{AD}) = rl and DC (R_{DC}) = $r(100-l)$.

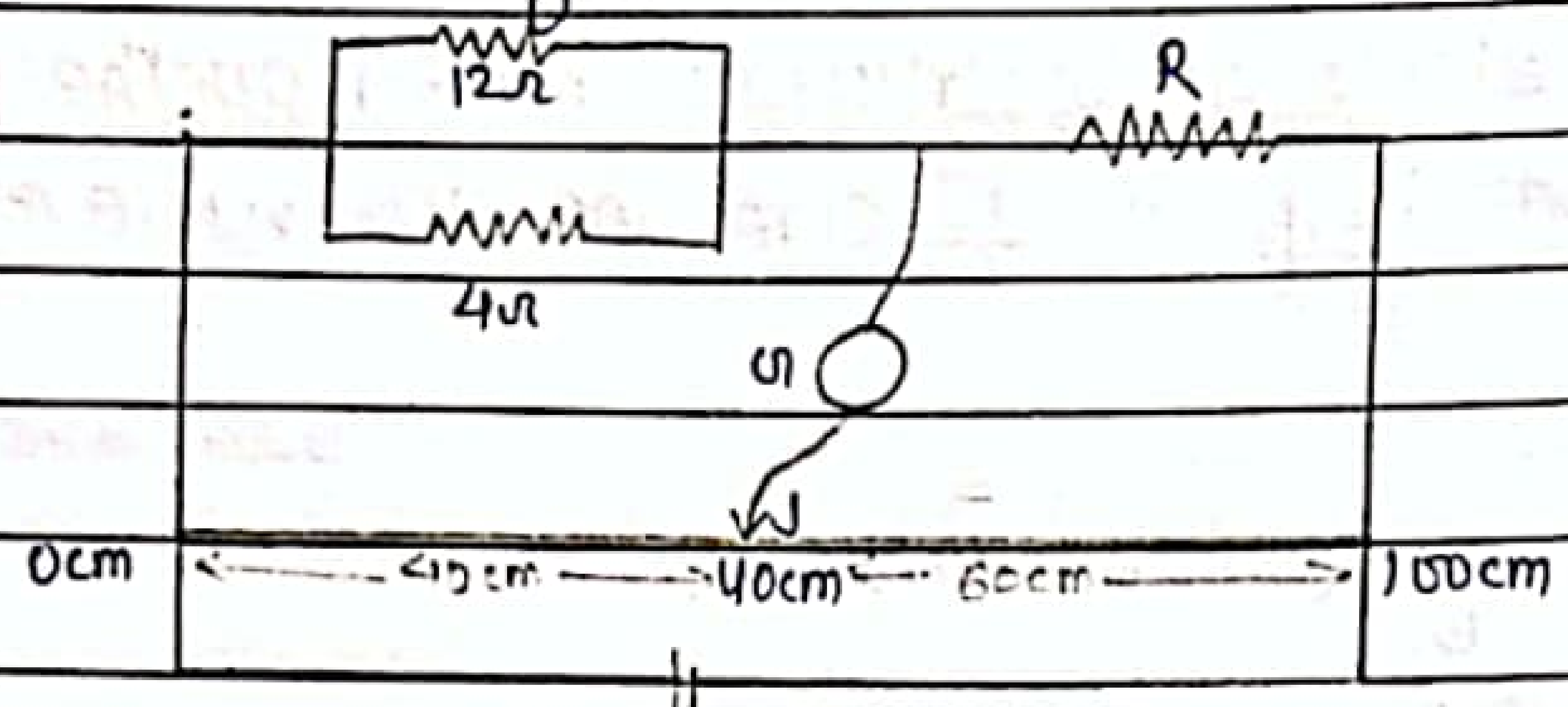
The balanced condition thus gives,

$$\frac{R}{R_{AD}} = \frac{S}{R_{DC}}$$

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

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

Q) Find the value of R such that null point is at 40cm.



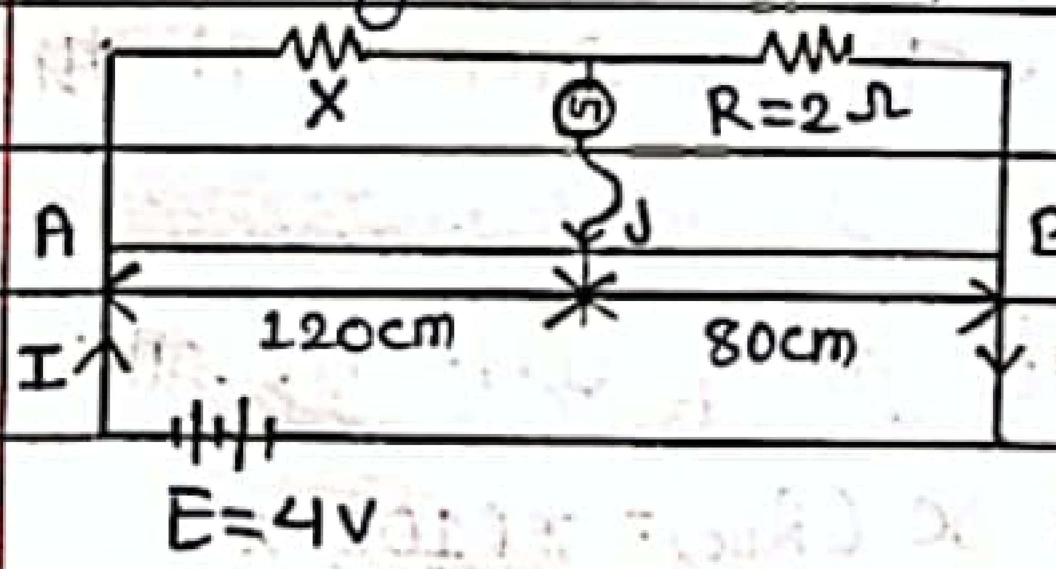
Solution:

Equivalent resistance of 12Ω and 4Ω $(R') = \frac{12 \times 4}{12+4} = 3\Omega$

Then, $\frac{3}{40} = \frac{R}{60}$

or $R = \frac{180}{40} = 4.5\Omega$

Q) Calculate the current and unknown resistance (X) if no current flows in the galvanometer as in figure alongside. Assuming resistance per unit length of the wire AB is $0.01\ \Omega cm^{-1}$.



Solution:

Unknown resistance (X) = ?

Current (I) = ?

$R = 2\Omega$

$l_1 = 120cm$

$l_2 = 80\ cm$

For no galvanometer deflection,

$\frac{X}{120} = \frac{2}{80}$

or, $X = 3\Omega$

Equivalent resistance of X and R $(R_1) = 5\Omega$

Total resistance of wire AB $(R_2) = 200 \times 0.01$

$= 2\Omega$

Effective resistance of the circuit $(R) = \frac{5 \times 2}{5+2} = \frac{10}{7}\Omega$

Current $(I) = \frac{4}{10/7} = 2.8A$

* POTENTIOMETER

A potentiometer is an arrangement or a device which does not draw any current from the given circuit and still measures the potential difference or emf of a cell.

A potentiometer measures emf accurately without drawing any current from the cell as this method of measurement follows null deflection.

Principle:

The voltage drop across the length of the conductor having uniform cross section and composition is directly proportional to its length.

$V \propto l$

$V = kl$

$k = \frac{V}{l}$ where k is a constant called potential gradient and is the voltage drop per unit length of the conductor.

Construction

Potentiometer is basically a uniform wire, sometimes a few meters in length across which a standard cell is connected. In the figure, the wire runs from A to C. The small vertical portions are the thick metal strips connecting the various sections of the wire. A current I flows through the wire which can be verified by rheostat.

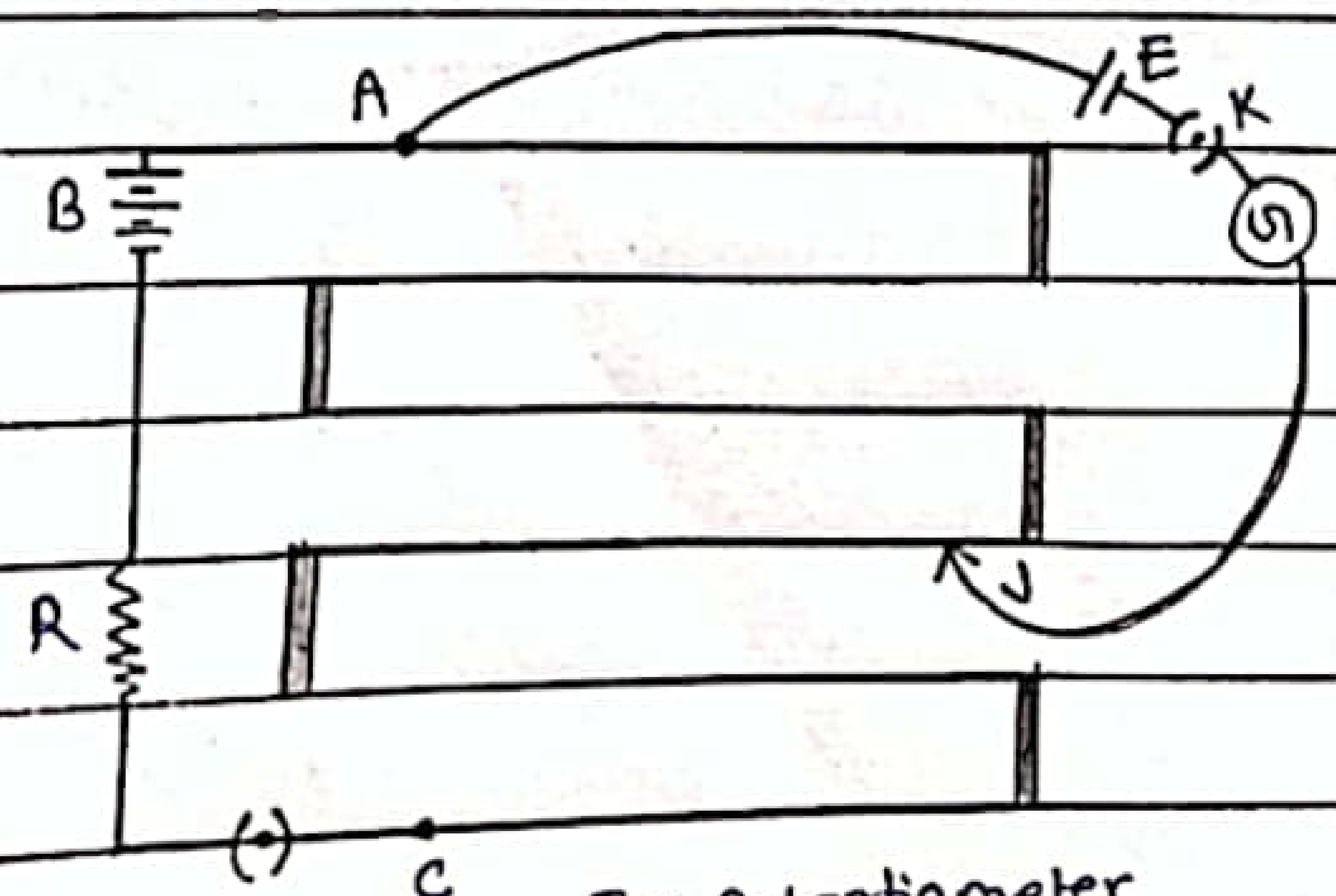
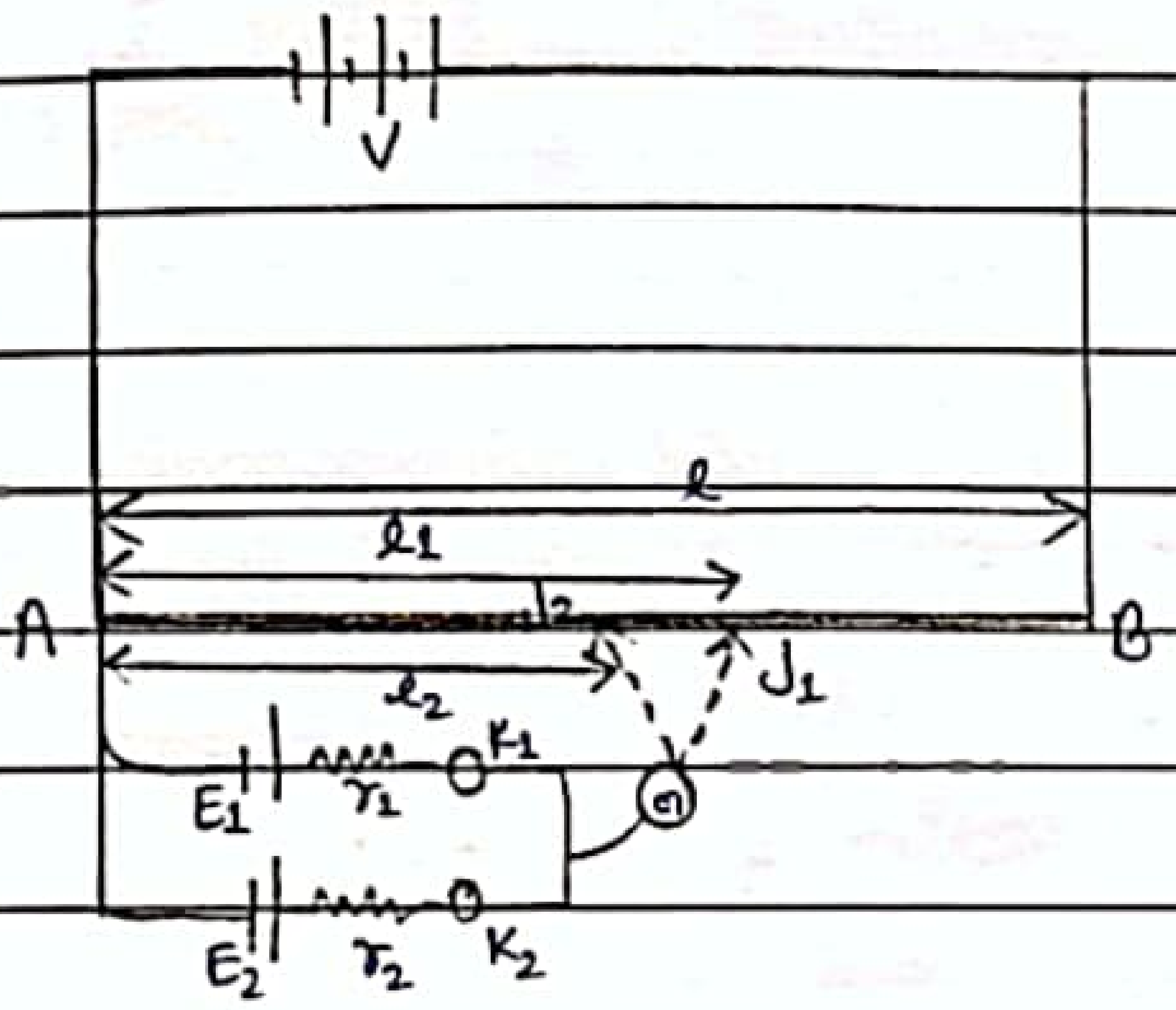


Fig: Potentiometer

Uses of potentiometer

- Comparison of EMFs of two cells



Note
* Polarity must be same
* p.d. across potentiometer wire > cell's emf.

If K_1 is closed and K_2 is open, let null deflection is obtained at l_1.

Then, $\frac{V}{l} \times l_1 = E_1$

or, $E_1 = k \times l_1$ --- (i)

Similarly, if K_1 is open and K_2 is closed, let null deflection is obtained at l_2. Then,

$\frac{V}{l} \times l_2 = E_2$

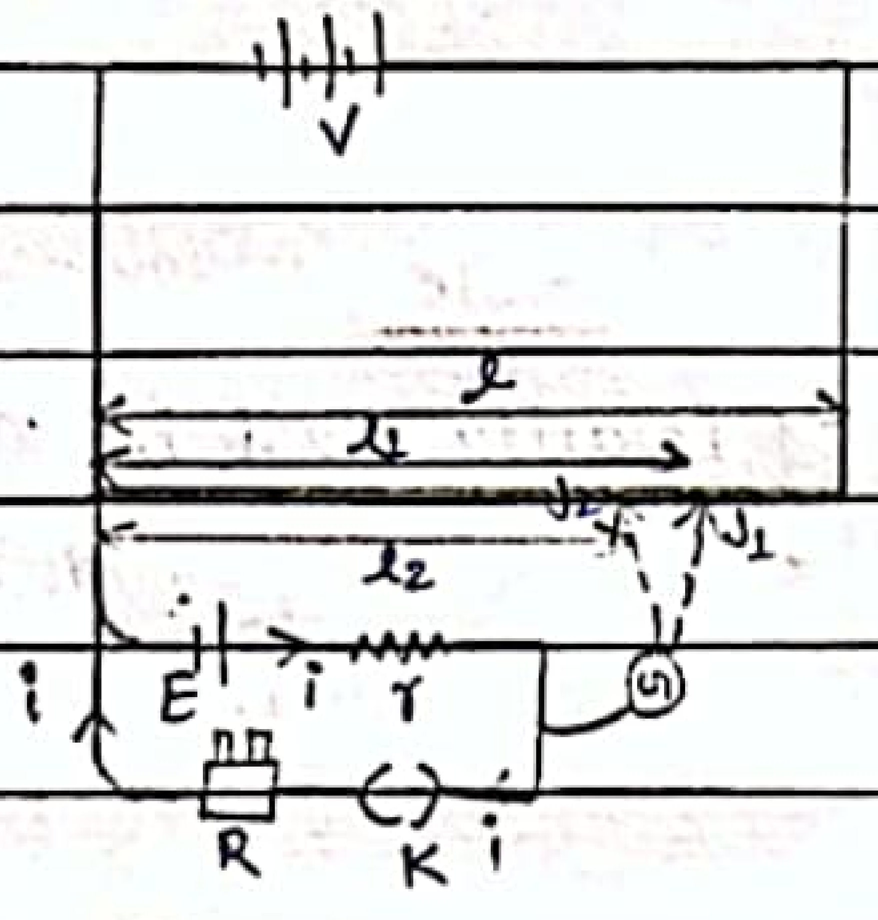
or, $E_2 = k \times l_2$ --- (ii)

From equations (i) and (ii),

$\frac{E_1}{E_2} = \frac{l_1}{l_2}$ --- (iii)

Equation (iii) can be used to compare the EMFs of two cells by measuring l_1 and l_2.

- Measurement of Internal resistance of the cell.



From Ohm's law in lower circuit,

$$i = \frac{E}{R+r}$$

If k is open and null deflection point is obtained at length l_1. Then,

$$\frac{V}{l} \times l_1 = E$$

$$E = kl_1 \quad ---(i)$$

If k is closed and null deflection point is obtained at length l_2. Then,

$$\frac{V}{l} \times l_2 = E - ir$$

or, $$E - \left(\frac{E}{R+r}\right) r = kl_2$$

or $$\frac{ER + Er - Er}{R+r} = kl_2$$

or. $$\frac{ER}{R+r} = kl_2 \quad ---(ii)$$

From (i) and (ii)

$$\frac{l_1}{l_2} = \frac{E(R+r)}{ER}$$

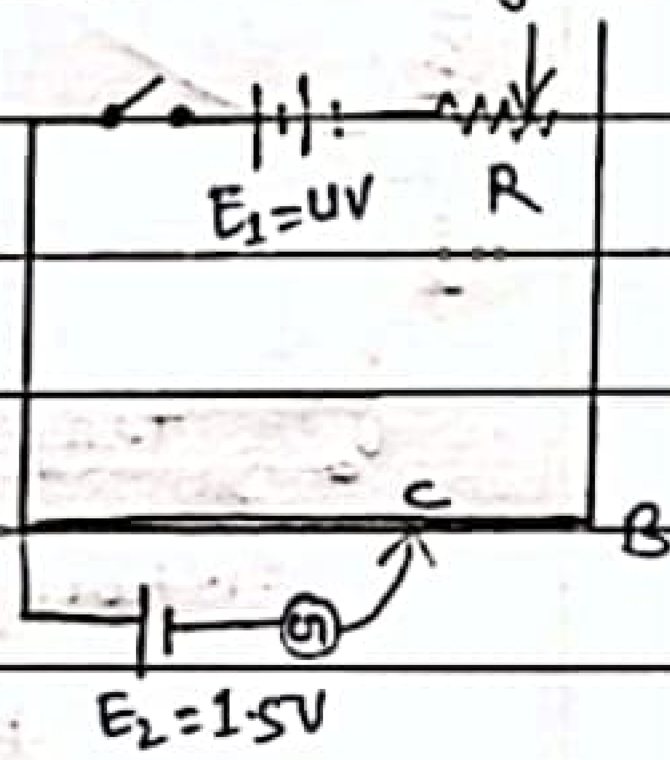
or, $$\frac{R+r}{R} = \frac{l_1}{l_2}$$

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

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

$\therefore$ The value of internal resistance (r) can be calculated by knowing R, l_1 and l_2.

Q) A simple potentiometer circuit is set up as in figure using a uniform wire AB, 1m long, which has a resistance of 2Ω. The resistance of the 4V battery is negligible. If the variable resistor R were given a value of 2.4Ω, what would be the length AC for zero galvanometer deflection?



Solution

$E_1 = 4V$

$E_2 = 1.5V$

$R = 2.4\Omega$

$R_{AB} = 2\Omega$

$l_{AB} = 1m$

$l_{AC} = ?$

Current (I) $= \frac{4}{2.4+2} = 0.9A$

Potential drop across AB $= 2 \times 0.9 = 1.81V$

We know

$E_2 = \frac{1.81 \times l_{AC}}{1}$

or $\frac{1.5}{1.81} = l_{AC}$

$\therefore l_{AC} = 0.825\,m.$

* Superconductivity

Certain metals and alloys that acquire infinite conductivity (zero resistivity) at low temperature are superconductors and the property of superconductors is called superconductivity.

The temperature below which the special metal exhibit the superconductivity is called critical temperature (T_c).

The variation of resistivity on changing temperature for normal metals and superconductors are shown below:

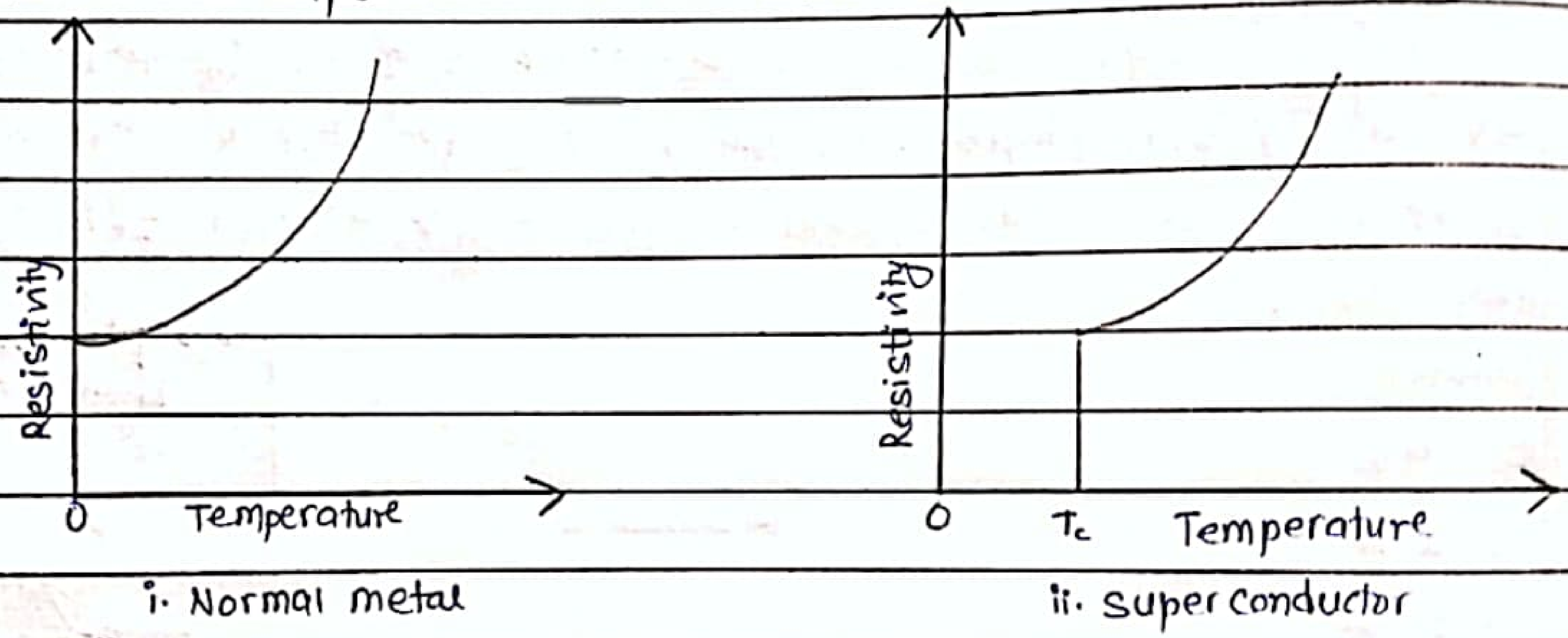


Fig: Resistivity vs temperature graph

The magnetic lines of force are pushed out from superconductors when placed in the magnetic field. This effect is called Meissner effect.

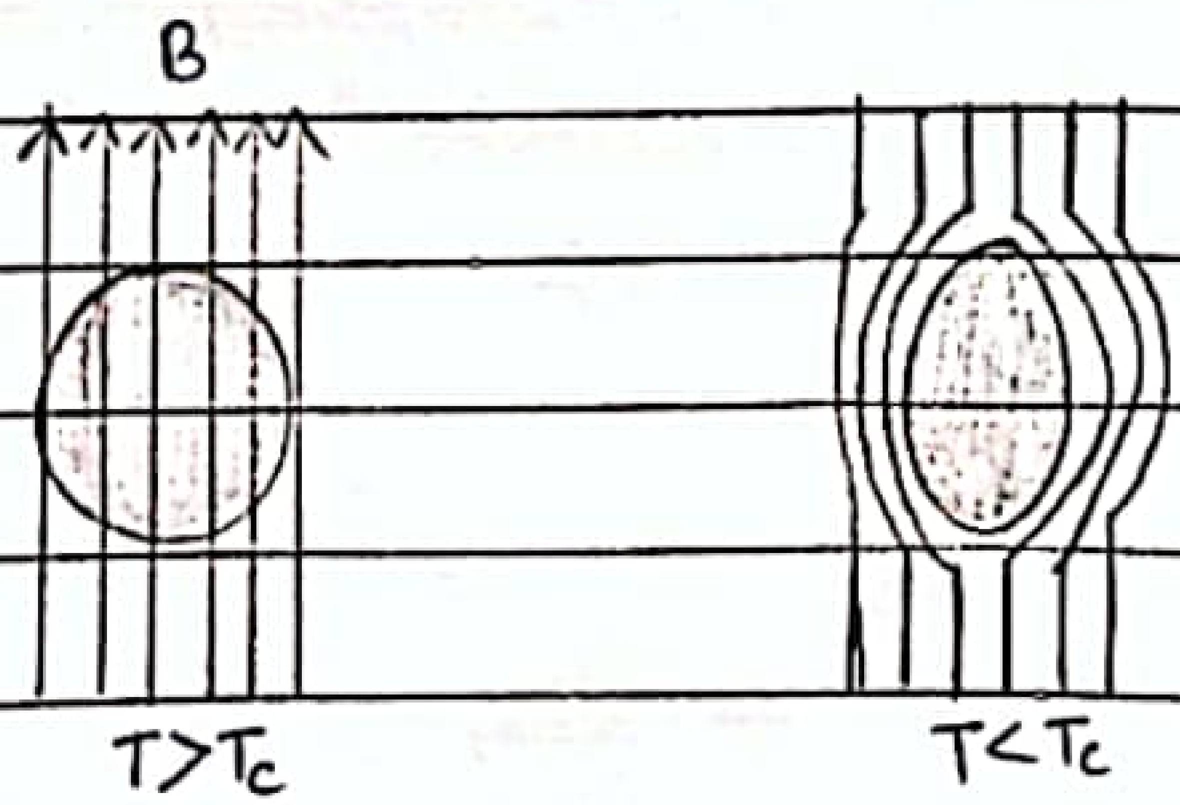


Fig: Meissner effect

Perfect Conductors

Perfect conductors are ideal conductors having zero resistivity.

Differences between perfect conductors and superconductors

Perfect conductors	Superconductors
Magnetic field inside the perfect conductor has non zero value.	Magnetic field inside the superconductor is zero.
They don't show Meissner effect.	They show Meissner effect.
Temperature should be decreased to 0K to get a perfect conductor.	Superconductors can be made above 0K, below critical temperature.

* Electrical Devices

1. Voltmeter

A voltmeter is an electrical device which is used to measure the electric potential difference between two points in an electric circuit. A voltmeter is connected in parallel with a device to measure the voltage drop across it.

2. Ammeter

An ammeter is an electrical device which is used to measure the electric current in a circuit. It is connected in series with the circuit.

3. Galvanometer

Galvanometer is an electrical device which detects the presence of current in a circuit. It is denoted in circuit by: —(G)—.

Shunt: A very small resistance connected in parallel to the galvanometer is called a shunt. It is denoted by S. It serves to reduce the internal resistance of an ammeter.

Multiplier: A very high resistance connected in series to the galvanometer is called a multiplier. It is denoted by R. It serves to increase the internal resistance of a voltmeter.

i. Conversion of a galvanometer into an ammeter

To convert a galvonometer into an ammeter, a very low resistance i.e. shunt is connected in parallel with galvanometer coil so that maximum current can flow through it. Shunt provides an alternative path for excess current.

Let, S be the value of shunt resistance, G be the galvanometer resistance, i be the total current through the circuit and i_g be the maximum current through the galvanometer which gives full scale deflection in it and $(i-i_g)$ be the remaining current passing through the shunt

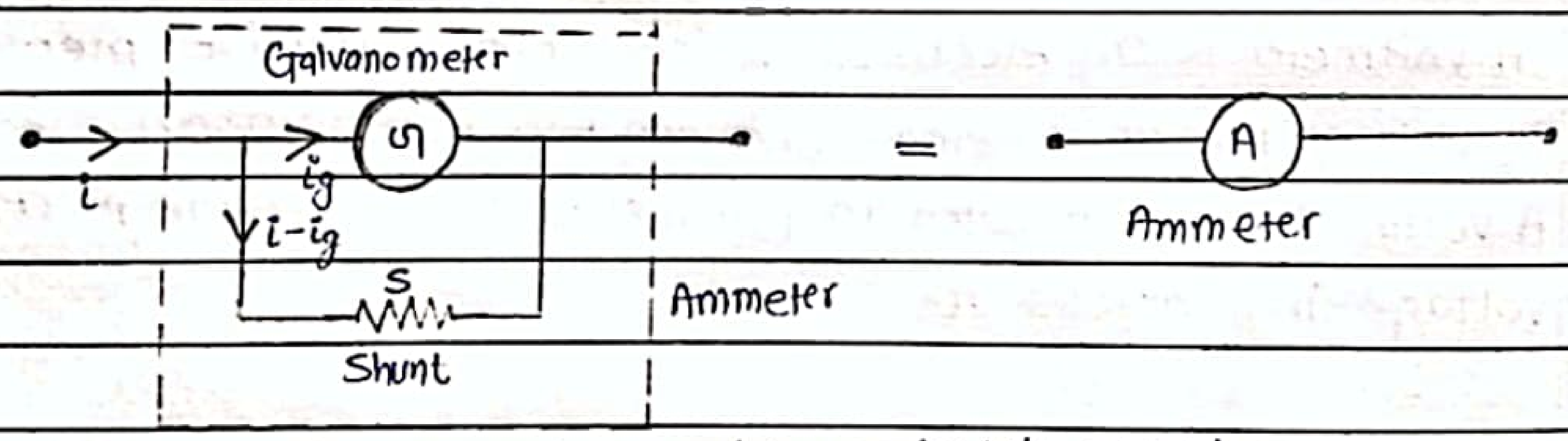


Fig: conversion of galvanometer into ammeter

As the galvanometer and shunt are connected parallel to each-other,
Potential difference across galvanometer = Potential difference across shunt

i.e. $i_g G = (i-i_g)S$

$\therefore S = \left(\frac{i_g}{i-i_g}\right)G$

This gives the required value of shut which when connected in parallel with galvanometer coil to convert galvanometer into ammeter.

- **Internal Resistance of Ammeter**

The equivalent resistance of ammeter is,

$R = \frac{SG}{S+G}$ which is even smaller than the resistance of the shunt (S).

8) A galvanometer ~~coi~~ whose coil resistance is 10Ω gives full scale deflection for 5mA. How can you convert it into an ammeter of range 0 – 5A?

Solution:

$G = 10\Omega$

$i_g = 5mA = 5\times10^{-3}A$

$i = 5A$

$S = ?$

Now,

$$S = \left(\frac{i_g}{i - i_g}\right)G$$

$$= \left(\frac{5\times10^{-3}}{5-5\times10^{-3}}\right)\times 10$$

$$= 0.01\Omega$$

∴ It can be converted into an ammeter of range 0 – 5A by connecting a shunt of 0.01Ω in parallel with galvanometer coil.

8) A galvanometer whose coil resistance is 1Ω has 50 divisions which measures 1 µA per division. How can you convert it into an ammeter of range 0–10A?

Solution:

$G = 1\Omega$

No. of divisions $(n) = 50$

$i_g = 1\mu A \times 50 = 50\mu A = 50 \times 10^{-6} A$

$i = 10 A$

$S = ?$

Now,

$$S = \left(\frac{i_g}{i - i_g}\right) G$$

$$= \left(\frac{50 \times 10^{-6}}{10 - 50 \times 10^{-6}}\right) \times 1$$

$$= 5 \times 10^{-6} \Omega$$

∴ It can be converted into an ammeter of range 0–10A by connecting a shunt of $5 \times 10^{-6} \Omega$ in parallel with galvanometer coil.

ii. Conversion of a galvanometer into voltmeter

To convert a galvanometer into voltmeter, a very high resistance i.e. multiplier is connected in series with galvanometer coil so that minimum current can flow through it.

Let, R be the value of multiplier resistance, G be the galvanometer resistance, I be the total current through the circuit and i_g be the maximum current through the galvanometer which gives full scale deflection in it. ~~and~~

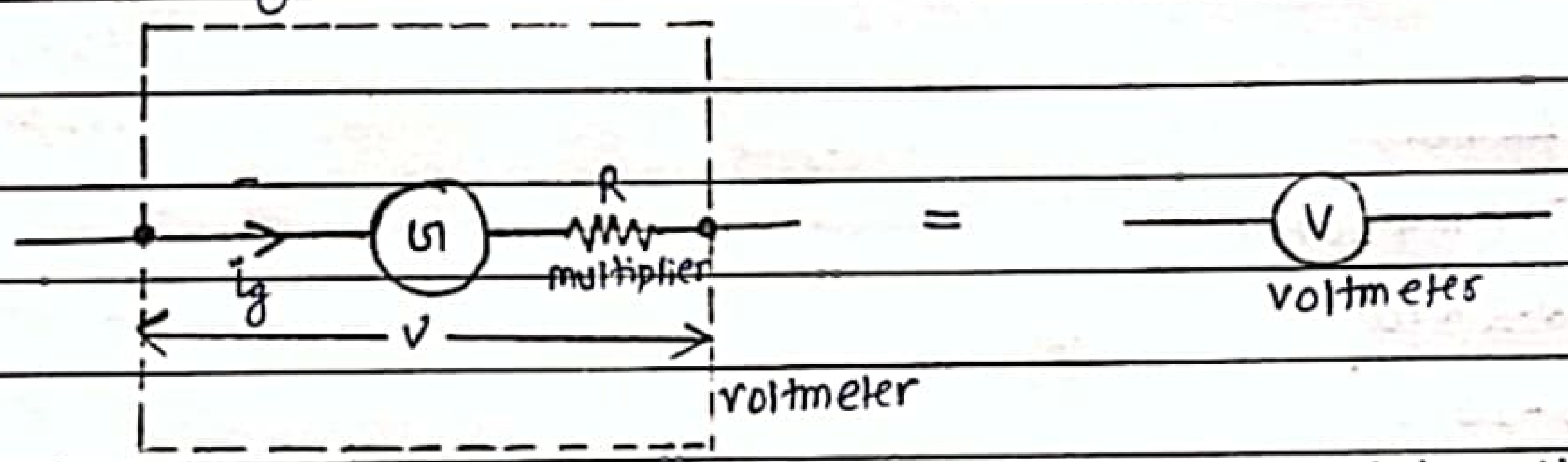


Fig: conversion of galvanometer into voltmeter.

The potential difference (V) of the combination of G and R is

$$V = i_g(G+R)$$

or, $$G+R = \frac{V}{i_g}$$

or, $$R = \frac{V}{i_g} - G$$

This gives the required value of multiplier which when connected in series with galvanometer coil to convert galvanometer into voltmeter.

• Internal Resistance of voltmeter.

The equivalent resistance of voltmeter is

$R_v = R + G$ which is greater than the resistance of multiplier. The internal resistance is considered infinity in an ideal voltmeter.

3) A galvanometer whose coil has resistance 10Ω gives full deflection for 1mA. How can you convert it into a voltmeter of range 0–2.5V?

Solution:

$G = 10\Omega$

$I_g = 1 mA = 1\times10^{-3} A$

$V = 2.5V$

$R = ?$

Now,

$V = I_g (R+G)$

or $2.5 = 10^{-3} (R+10)$

or $R+10 = 2.5\times10^{3}$

or $R = 2500-10$

$\therefore R = 2490\Omega$

$\therefore$ It can be converted into a voltmeter of range 0–2.5V by connecting a multiplier of 2490Ω in series with galvanometer coil.

4. Ohmmeter

An ohmmeter is an electrical instrument that measures electrical resistance.

* Joules law of Heating

According to Joules Law of heating, the amount of heat (H) developed in an ohmic conductor by passage of current is

i. directly proportional to the square of current flowing through the conductor.

$H \propto I^2$ --- (i)

ii. directly proportional to the resistance of the conductor

$H \propto R$ --- (ii)

iii. directly proportional to the time of current flow

$H \propto t$ --- (iii)

From (i), (ii) and (iii),

$H \propto I^2 RT$

$H = KI^2RT$ - (iv) where K is the proportionality constant. Its value depends on the system of unit of heat.

- In calorie, $K = \frac{1}{J}$

Here, J is the unit conversion factor whose value is 4.2 J/calorie. It is also called mechanical equivalent of heat. It is not a physical quantity.

From (iv),

$H = \frac{I^2RT}{J}$ (calorie)

- In SI unit, K=1. So,

$H = I^2Rt$ (Joule)

Experimental Verification of Joule's law

The experimental arrangement for the verification of Joules law is as shown in the figure where a battery, a Rheostat, an ammeter, a key and a resistance wire are connected in series. The wire is immerged in insulated water through which current is passed and the thermometer is used to record the temperature of water.

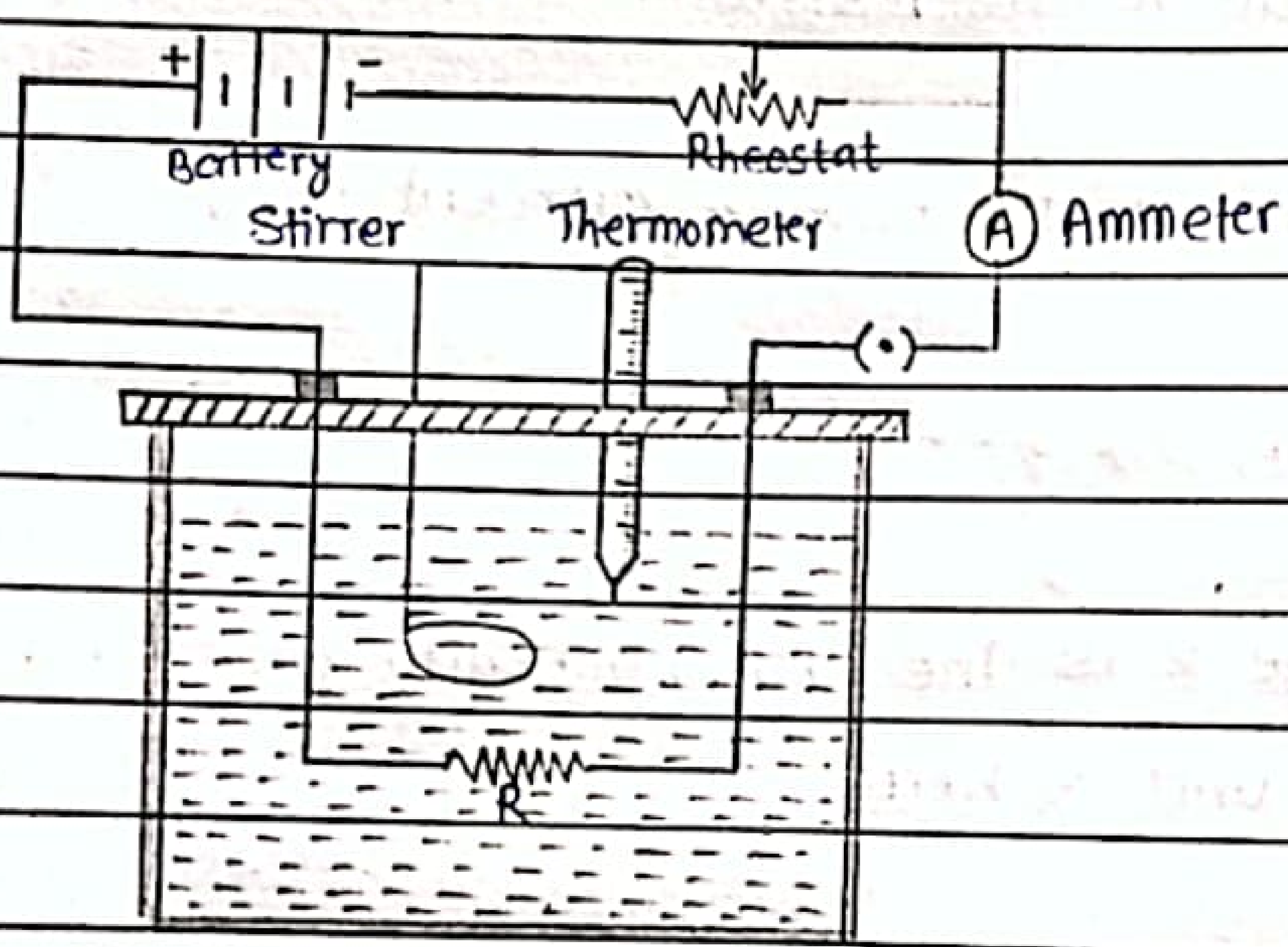


Fig: Experimental arrangement for verification of Joules Law

At first when the key is closed, current flows in the circuit and the heat is produced in the wire and the temperature of the wire rises. The raise in temperature is directly proportional to amount of heat produced.

i. To verify $H \propto I^2$ (at constant R and t)

Different magnitude of current ($I_1, I_2, I_3, \ldots$) is passed for same time with the help of rheostat. The raise in temperature and their corresponding amount of heat produced ($H_1, H_2, H_3, \ldots$) are noted. Then, experimentally it is found that

$$\frac{H_1}{I_1^2} = \frac{H_2}{I_2^2} = \frac{H_3}{I_3^2} = \text{constant}$$

$\therefore \frac{H}{I^2} = \text{constant}$

$\therefore H \propto I^2$ --- (i)

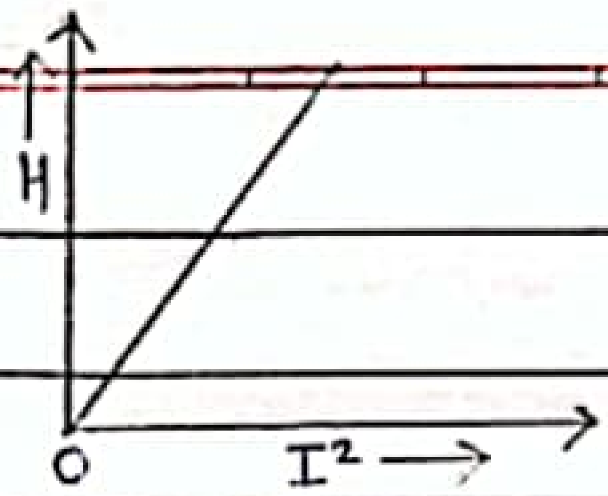


Fig: Graph of H versus I^2

ii. To verify $H \propto R$ (at constant I and t)

The experiment is repeated for the wire of same material and diameter but of different length. When the current is passed through the wire, the heat is produced and temperature of water raises. It is found that the amount of heat produced is directly proportional to length. As resistance of wire is directly proportional to length, the amount of heat produced (H_1, H_2, H_3 ---) is proportional to resistance (R_1, R_2, R_3, ---).

$\frac{H_1}{R_1} = \frac{H_2}{R_2} = \frac{H_3}{R_3} = \text{constant}$

$\frac{H}{R} = \text{constant}$

$\therefore H \propto R$ --- (ii)

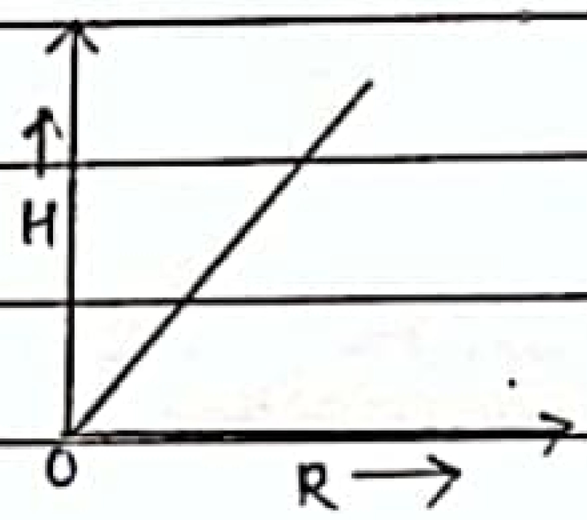


Fig: Graph of H versus R

iii. To verify $H \propto t$ (at constant I and R)

The experiment is repeated for the wire of same length and same amount of current is passed for different time. In this case, we observe that the amount of heat produced (H_1, H_2, H_3, ---) is directly proportional to the time (t_1, t_2, t_3, ---) for which the current is passed.

$\frac{H_1}{t_1} = \frac{H_2}{t_2} = \frac{H_3}{t_3} = \text{constant}$

$\frac{H}{t} = \text{constant}$

$H \propto t$ --- (iii)

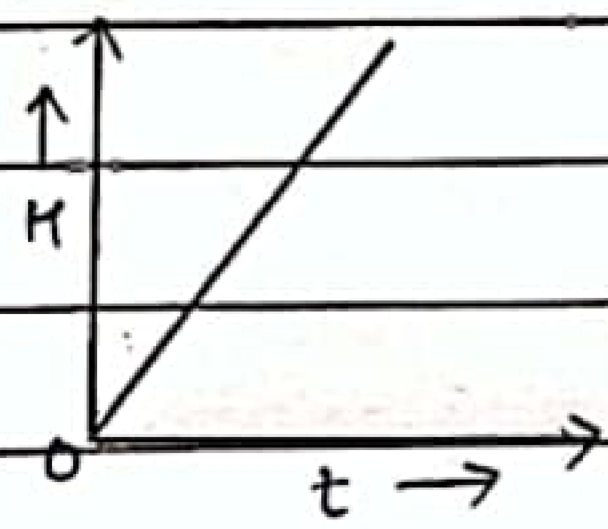


Fig: Graph of H versus t

Combining equations (i), (ii) and (iii), we get

$H \propto I^2Rt$

$H = I^2RT$

Thus, Joules law is verified.