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## SENIOR SIX TERM 2

### TOPIC 1/5: CURRENT ELECTRICITY

**Competency:** The learner investigates electric current, its properties, transmission and uses in order to reduce power losses and improve personal and national safety.

#### Current, I

This is the flow of charge

$$I = \frac{\delta Q}{\delta t}$$

The S.I. unit of current is Ampere (A)

An Ampere is the current flowing in a circuit when a charge of one coulomb passes any point through the circuit in one second.

#### Mechanism of conduction in metals (heat effect on metals)

Conduction in metals is due to free electrons. Free electrons have thermal energy, and move randomly through metal from one atom to another. When a battery is connected across the ends of the metal, an electric field is set up. The electrons are accelerated by the field; they gain velocity and kinetic energy. When they collide with an atom vibrating about its fixed mean position (called a lattice site) they give up some of their energy to it. Kinetic energy lost is transferred into heat energy within the metal and causes the temperature of the metal to increase.

Although the movement of electron is erratic, on average the electrons drifts in a direction of a field with mean average speed depending on the strength of the field. It is this electron which constitutes an electric current.

The electrical resistance is caused by the obstruction due to atoms to electron movements.

#### Derivation of $I = nAve$ and $J = nve$

Consider a section of a metallic conductor in which a current is flowing.

Let  $I$  = current through the conductor (A)

$L$  = length of the conductor (m)

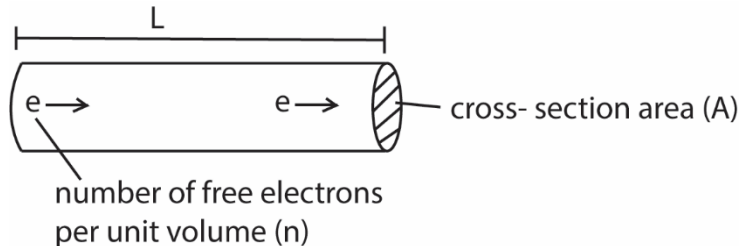
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$A$  = cross-section area ( $\text{m}^2$ )

$n$  = number of free electrons per unit volume ( $n$ )

$e$  = charge on each electron ( $\text{C}$ )

$v$  = average (drift) velocity of the electron ( $\text{ms}^{-1}$ )



It follows that

Volume of the section =  $LA$

Number of free electrons in the section =  $nLA$

Total quantity of charge which is free to move =  $nLAe$

Time taken for an electron to travel through the section =  $\frac{L}{v}$

Rate of flow of charge =  $\frac{nLAe}{L/v} = nLAve$

Hence current,  $I = nLAve$

Current density,  $= \frac{I}{A} = \frac{nLAve}{A} = nve$

### Potential difference (P.d.)

This is work done in transferring a charge of 1 coulomb from one point to another in a circuit. Whenever current flows from one point to another, it does so because the electrical potential at two points are different. If two points are at the same potential, no current can flow between them.

### Resistance (R)

This is the opposition to the flow of current in the material.

Resistance  $R = \frac{V}{I}$ . The S.I. units of resistance is ohms ( $\Omega$ )

An ohm is a resistance of a conductor through which a current of one Ampere is flowing when the potential difference across is one volt. i.e.  $1\Omega = 1\text{VA}^{-1}$ .

### Resistivity ( $\rho$ , rho)

Resistivity is electrical resistance across opposite faces of a cube of 1m long

$R \propto \frac{l}{A}$  or  $R = \rho \frac{l}{A}$  and  $\rho = R \frac{A}{l} \Omega\text{m}$

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### Conductivity ( $\lambda$ )

It is the reciprocal of resistivity

$$\lambda = \frac{1}{\rho} \Omega^{-1}\text{m}^{-1}$$

Some conductors have resistances which depend on current flowing through them; but in most cases the resistance of many conductors (metals) depend only on their physical circumstances e.g. temperature. This was discovered by Ohm and such conductors are called ohmic conductors and obey Ohm's law.

### Coulomb

Is the quantity of charge passing in one second through a given cross-section area of a conductor when current flowing is one Ampere.

### Electromotive force (e.m.f)

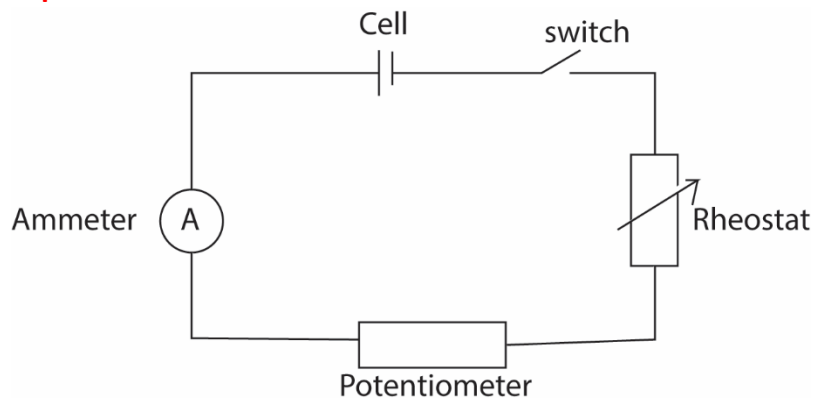
This is the work done in transferring one coulomb of charge around a circuit in which a battery is connected. E.m.f is denoted by E.

### Ohm's law

States that the current flowing through a conductor is directly proportional to the P.d. across it provided that there is no change in physical conditions such as temperature of the conductor.

i.e.  $I = RV$

### Experiment to determine Ohm's law

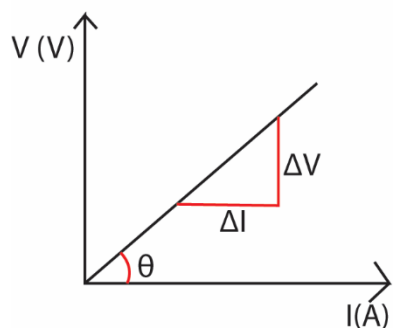


The switch is closed the current ( $I$ ) from ammeter and P.d. ( $V$ ) from the potentiometer are recorded.

The rheostat is adjusted to obtain several values of  $I$  and  $V$

The graph of  $V$  against  $I$  is plotted.

A graph of V against I



A straight line graph through the origin implies that V is directly proportional to I

From the graph  $R = \frac{\Delta V}{\Delta I} = \tan \theta$

### Factors affecting resistance

1. Length: Resistance increases with the length of a conductor; electron make more frequent collision with atoms when the length of the conductor increases. This reduces drift velocity of free electron hence resistance increases.
2. Cross sectional area (A): Resistance reduces with increase in cross sectional area. When the cross-sectional area increases, the number of electrons that drift along the conductor increases. This implies that there is an increase in the number of electrons per second that pass a given point, thus an increase in current and consequently a decrease in resistance.
3. Temperature: Resistance increases with temperature increase. Increase in temperature causes atoms to vibrate with greater amplitude and frequency about their mean positions. The velocity of electrons also increases making more collision between electrons and atoms. This increase in collision between electron and atoms reduces the drift velocity of electrons and increases resistance.

### Ohmic conductors

These are conductors that obey ohm's law, e.g. copper and silver

### Non-ohmic conductors

Are conductors that do not obey ohm's law; examples are semi-diode conductor, sulphuric acid and hot filament

#### Graphs of current (I) against potential difference (V) for ohmic and non-ohmic conductors

Ohmic conductor



E.g. copper;  
silver

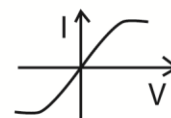
Non-ohmic conductors



Junction diode  
(semi-conductor)



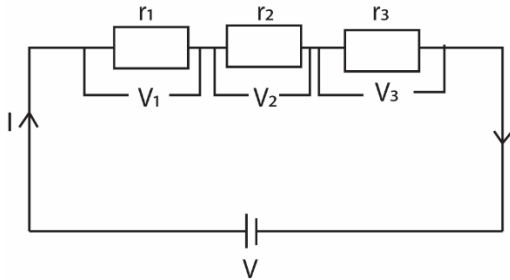
sulphuric acid



hot filament

## Resistance in combination

### (i) Series combination



For series arrangement, the same current  $I$  flows through the resistors but each resistor has its own P.d. across

For  $r_1$ ,  $V_1 = r_1 I$  ..... (i)

For  $r_2$ ,  $V_2 = r_2 I$  ..... (ii)

For  $r_3$ ,  $V_3 = r_3 I$  ..... (iii)

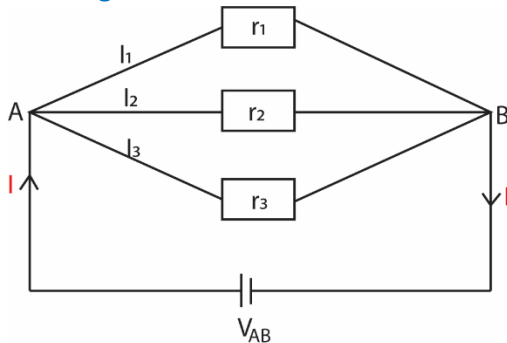
$$V = V_1 + V_2 + V_3$$

$$= r_1 I + r_2 I + r_3 I$$

$$= I(r_1 + r_2 + r_3)$$

Resultant resistance,  $R = \frac{V}{I} = (r_1 + r_2 + r_3)$

### (ii) Parallel arrangement



The p.d. across each resistor is the same  $= V_{AB}$

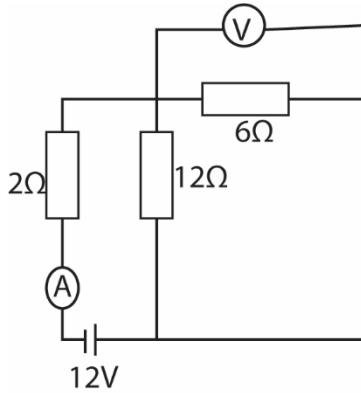
By conservation of current,  $I = I_1 + I_2 + I_3$

From Ohm's law,  $I = \frac{1}{R}$ , where  $R$  is combined resistance of the resistors

$$\begin{aligned} \therefore I &= \frac{V_{AB}}{r_1} + \frac{V_{AB}}{r_2} + \frac{V_{AB}}{r_3} \\ &= V_{AB} \left[ \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \right] \\ \frac{1}{R} &= \frac{I}{V_{AB}} = \left[ \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \right] \end{aligned}$$

### Example 1

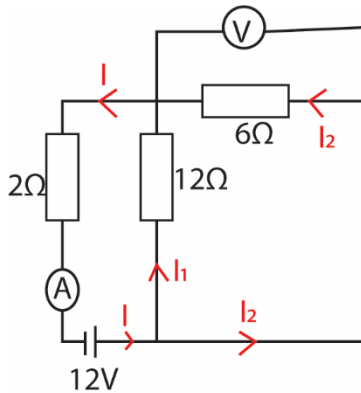
- (i) Define a volt
- (ii) Derive the formula of resultant resistance for 3 combined resistors in parallel.
- (iii) In the circuit, the battery has negligible internal resistance.



Find ammeter and voltmeter reading

Solution

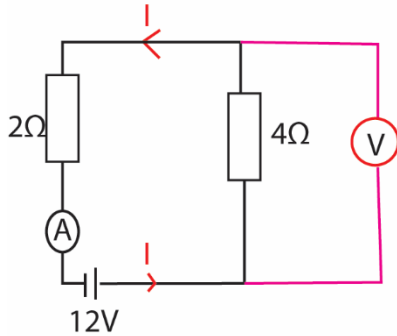
(iii)



$6\Omega$  and  $12\Omega$  are in parallel, let their effective resistance be  $R_1$

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{12} \text{ then } R_1 = 4\Omega$$

Equivalent circuit



2Ω and 4Ω resistors are in series

The effective resistance  $R = 2 + 4 = 6\Omega$

From the circuit formula  $I = \frac{e.m.f}{total\ resistance} = \frac{12}{6} = 2A$

From ohm's law,  $V = IR = 2 \times 4 = 8\Omega$

**Example 2**

The resistance of a nichrome element of an electric wire is 50.9Ω at 20.0°C when operating a 240V supply the current flowing through it is 4.17A. Calculate the steady temperature reached by the electric fire if the temperature coefficient of resistance of nichrome is  $1.7 \times 10^{-4}K^{-1}$ .

Solution

$R_{20} = 50.9\Omega$ ,  $\alpha = 1.7 \times 10^{-4}K^{-1}$ ,  $R_{\theta} = ?$   $V = 240V$ ,  $I = 4.17A$

From Ohm's law

$R_{\theta} = \frac{V}{I} = \frac{240}{4.17} = 57.55\Omega$

Using  $R_{\theta} = R_0(1 + \alpha\theta)$

$R_{20} = R_0(1 + 20\alpha) = 50.9 \dots\dots\dots(i)$

$R_{\theta} = R_0(1 + \alpha\theta) = 57.55 \dots\dots\dots(ii)$

From equation (i) and (ii) and substituting for  $\alpha$

$\theta = 791.1^{\circ}C$

**Example 3**

A nichrome wire of length 1m and uniform diameter 0.722mm at 25°C is made into a coil. The coil is immersed in 200cm<sup>3</sup> at the same temperature and a current 5.0A is passed through the coil for 8 minutes when the water starts to boil at 100°C. Find

- (i) The resistance of the coil
- (ii) The electrical energy expended assuming all of it goes to heating the water
- (iii) The mean temperature coefficient of resistance of nichrome between 0° and 100°C.  
(Resistivity of nichrome at 25°C =  $1.2 \times 10^{-6}$ )

**Solution**

(i)  $L = 1.0\text{m}$ ,  $d = 0.722\text{mm} = 7.2 \times 10^{-4}\text{m}$   
 $A = \pi \frac{d^2}{4} = \pi \frac{[7.2 \times 10^{-4}]^2}{4} = 4.07 \times 10^{-7}\text{m}^2$   
 Using  $R_{25} = \rho_{25} \cdot \frac{L}{A}$

$$R_{25} = 1.2 \times 10^{-6} \times \frac{1}{4.07 \times 10^{-7}} = 2.948\Omega$$

(ii) Assuming no heat losses  
 Electric energy dissipated = heat gained by water =  $mc\theta$   
 $= (200 \times 10^{-3})(4200)(100-75) = 63000\text{J}$

Electric energy dissipated =  $I^2 R_{\text{mean}} x t$   
 $I = 5.0\text{A}$ ,  $t = 8\text{minutes} = 8 \times 60 = 480\text{s}$

$$R_{\text{mean}} = \frac{R_{25} + R_{100}}{2}$$

$$5^2 \times R_{\text{mean}} \times 4800 = 63000$$

$$R_{\text{mean}} = 5.2\Omega$$

$$5.2 = \frac{R_{25} + R_{100}}{2}$$

$$R_{100} = 7.552\Omega$$

Using  $R_\theta = R_0(1 + \alpha\theta)$

$$R_{20} = R_0(1 + 25\alpha) = 2.948 \dots\dots\dots(i)$$

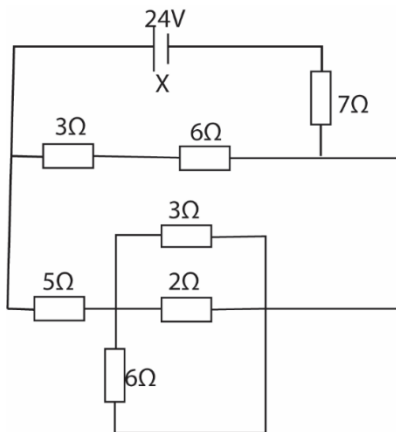
$$R_\theta = R_0(1 + 100\alpha) = 7.552 \dots\dots\dots(ii)$$

Divide eqn (ii) by (i)

$$\frac{1+100\alpha}{1+25\alpha} = \frac{7.552}{2.948}$$

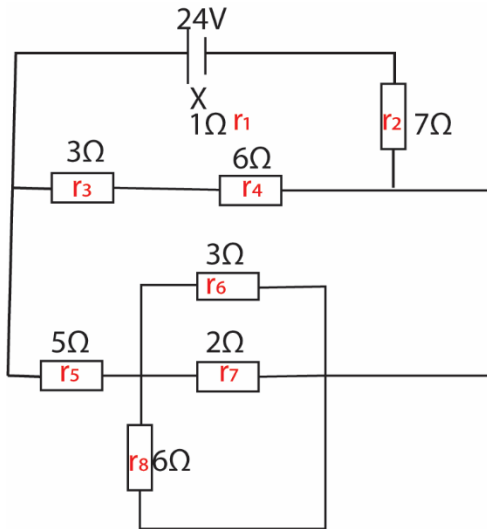
$$\alpha = 0.0434$$

**Example 4**



In the figure X is an accumulator of the e.m.f 24V and having internal resistance of  $1\Omega$ . Find the effective resistance of the circuit.

**Solution**



$r_6, r_7,$  and  $r_8$  are in parallel; let their effective resistance be  $R_1$

$$\frac{1}{R_1} = \frac{1}{3} + \frac{1}{2} + \frac{1}{6}$$

$$R_1 = 1\Omega$$

$R_1$  and  $r_5$  are in series; their effective resistance  $R_2 = 5 + 1 = 6\Omega$

$r_3$  and  $r_4$  are in series, their effective resistance  $R_3 = 3 + 6 = 9\Omega$

$R_2$  and  $R_3$  are in parallel, let their effective resistance be  $R_4$

$$\frac{1}{R_4} = \frac{1}{6} + \frac{1}{9} = \frac{5}{18}$$

$$R_4 = 3.6\Omega$$

$R_4, r_1$  and  $r_2$  are in series their effective resistance,  $R = 3.6 + 1 + 7 = 11.6\Omega$

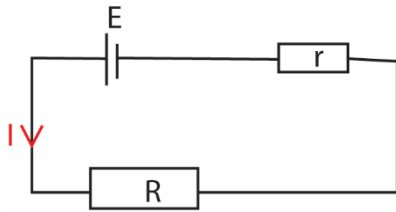
Therefore, effective resistance of the circuit =  $11.6\Omega$

**Example 5**

A battery of unknown e.m.f and internal resistance is connected in series with a load resistance of  $R$  ohms. If a very high resistance voltmeter connected across the load reads 3.2V and the power dissipated in the battery is 0.032W and the efficiency of the circuit is 80%. Find

- (i) The current flowing
- (ii) The internal resistance of the battery
- (iii) The e.m.f of the battery

**Solution**



Total resistance =  $R + r$

From circular formula  $I = \frac{E}{R+r}$  ..... (i)

Power dissipated in the battery =  $I^2r = 0.032w..$ (ii)

From Ohm's law

Terminal p.d. =  $IR = 3.2V$  ..... (iii)

Efficiency =  $\frac{\text{power out put}}{\text{power in put}} \times 100$

Power generated =  $EI = I^2(R+r)$

Power output =  $I^2R$

$$\Rightarrow \frac{I^2R}{I^2(R+r)} = \frac{80}{100}$$

$$\Rightarrow 100R = 80(R + r)$$

$$\Rightarrow R = 4r$$

From equation (3)

$I \times 4r = 3.2$  .....(iv)

Divide eqn. (ii) by (iv)

$$\frac{I^2r}{4Ir} = \frac{0.032}{0.32}$$

$$I = 0.04A$$

From equation (ii)  $r = \frac{0.032}{I^2}$

$$r = 20\Omega$$

$$\text{but } R = 4r = 4 \times 20 = 80\Omega$$

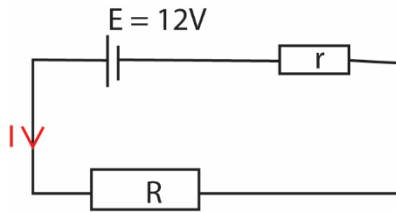
$$E = I(R + r) = 0.04(80 + 20) = 4V$$

### Example 6

A battery of e.m.f 12V and having unknown internal resistance is connected in series with load R. If a very high resistance voltmeter connected across R reads 11.4V and the power dissipated in the battery is 0.653W. Find

- (i) Current flowing
- (ii) Internal resistance of the battery
- (iii) The value R
- (iv) The efficiency of the circuit.

### Solution



NB= p.d. across the internal resistance is the lost volts

$$Ir = E - IR$$

From Ohm's law

$$V = IR = 11.4V \dots\dots\dots(i)$$

Lost volts = e.m.f of battery – terminal p.d

$$Ir = 12 - 11.4 = 0.6V \dots\dots\dots(ii)$$

$$\text{Power dissipated in the battery} = I^2r = 0.653W \dots\dots\dots(iii)$$

(i) Divide eqn. (iii) by (ii)

$$\frac{I^2r}{Ir} = \frac{0.653}{0.6}$$

$$I = 1.088A$$

(ii) From eqn. (ii)

$$r = \frac{0.653}{I^2} = \frac{0.653}{[1.088^2]} = 0.55\Omega$$

(iii) From eqn. (i)

$$V = IR$$

$$R = \frac{11.4}{1.088} = 10.48\Omega$$

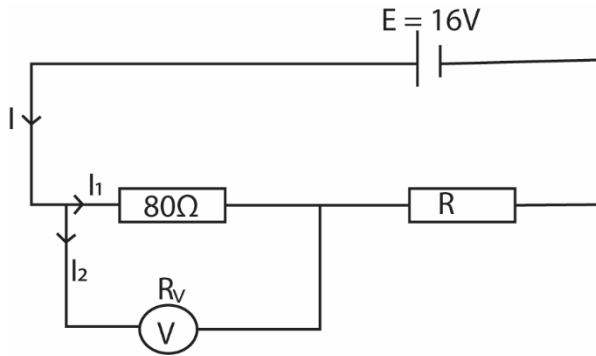
$$\begin{aligned} \text{(iv) Efficiency} &= \frac{\text{power output}}{\text{power in put}} \times 100\% \\ &= \frac{I^2R}{EI} = \frac{1.088^2 \times 10.48}{12 \times 1.088} \times 100 = 95\% \end{aligned}$$

**Example 7**

A battery of e.m.f 16V and having negligible internal resistance is connected in series with  $80\Omega$  and  $R\Omega$ . When a voltmeter is connected across an  $80\Omega$  resistor, it reads 11.28 V while it reads 2.83V when connected across R. find

- (i) The value R.
- (ii) The resistance of the voltmeter

**Solution**



Case 1: let  $R_1$  be effective resistance of  $80\Omega$  and  $R_v$

$$\frac{1}{R_1} = \frac{1}{80} + \frac{1}{R_v}$$

$$R_1 = \frac{80R_v}{80 + R_v} \dots\dots\dots(i)$$

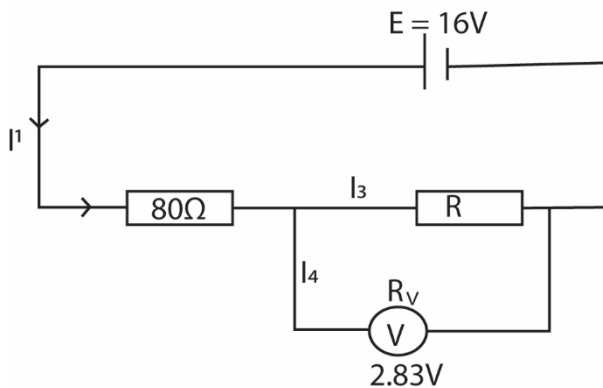
$$IR_1 = 11.28 \dots\dots\dots(ii)$$

$$\left[ \frac{80R_v}{80 + R_v} \right] I = 11.28 \dots\dots\dots(iii)$$

$$IR = 4.72 \dots\dots\dots(iv)$$

Case II

Let effective resistance between  $R_v$  and R be  $R_2$



$$\frac{1}{R_2} = \frac{1}{R} + \frac{1}{R_v}$$

$$R_2 = \frac{R \cdot R_v}{R + R_v}$$

$$\left[ \frac{R \cdot R_v}{R + R_v} \right] I^1 = 2.83 \dots\dots\dots(v)$$

$$80I^1 = 13.17 \dots\dots\dots (vi)$$

$$I^1 = 0.165A$$

$$\frac{R \cdot R_v}{R + R_v} = \frac{2.83}{I^1} = \frac{2.83}{0.165} = 17.152$$

$$RR_v = 17.152R + 17.152R_v \dots\dots\dots(vii)$$

Eqn. (iii) ÷ Eqn. (iv)

$$\frac{80R_v}{R[80+R_v]} = \frac{11.28}{4.72} = 2.39 \dots\dots\dots(viii)$$

$$80R_v = 2.39R(80 + R_v) \dots\dots\dots (ix)$$

$$80R_v = 191.186R + 2.39RR_v \dots\dots\dots (x)$$

Substituting RRv from equation (vii) into equation (x)

$$80R_v = 191.186R + 2.39R(17.152R + 17.152R_v)$$

$$80R_v = 232.179R + 40.993R_v$$

$$R_v = \frac{232.179R}{(80-40.993)} = 5.952R$$

Substituting  $R_v = 5.952R$  in equation (vii)

$$5.952R^2 = 17.152R + 17.152 \times 5.952R$$

$$R = \frac{17.152+102.089}{5.952} = 20.03\Omega$$

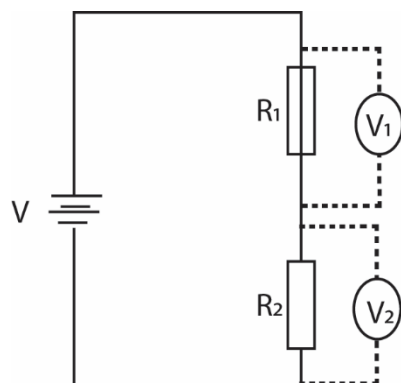
$$R_v = 5.952 \times 20 = 119.04\Omega$$

### Example 8

- (a) What is meant by e.m.f and internal resistance of a battery?
- (b) A d.c source of e.m.f 16V and negligible internal resistance is connected in series with two resistors of  $400\Omega$  and  $R\Omega$  respectively. When voltmeter is connected across  $400\Omega$  resistor it reads 4.0V while it reads 6.0V when connected across the resistor of  $R\Omega$ . Find
  - (i) The resistance of the voltmeter (=  $400\Omega$ )
  - (ii) The value R. ( $600\Omega$ )

## Potential divider

When resistors are arranged in series, they form a potential divider.



Consider two resistors of resistance  $R_1$  and  $R_2$  connected in series with a d.c supply of  $V$  volts as shown and having negligible internal resistance.

$$\text{Total resistance } R = R_1 + R_2 \dots\dots\dots(i)$$

From circuit formula;

$$\text{Current flowing, } I = \frac{\text{e.m.f}}{\text{total resistance}}$$

$$I = \frac{V}{R_1 + R_2} \dots\dots\dots(ii)$$

From Ohm's Law

$$V_1 = IR_1 \dots\dots\dots(iii)$$

Putting (ii) in (iii)

$$V_1 = \left[ \frac{R_1}{R_1 + R_2} \right] V \dots\dots\dots(iv)$$

$$V_2 = IR_2 \dots\dots\dots(v)$$

Put (ii) in (v)

$$V_2 = \left[ \frac{R_2}{R_1 + R_2} \right] V \dots\dots\dots(vi)$$

Dividing (iv) : (vi)

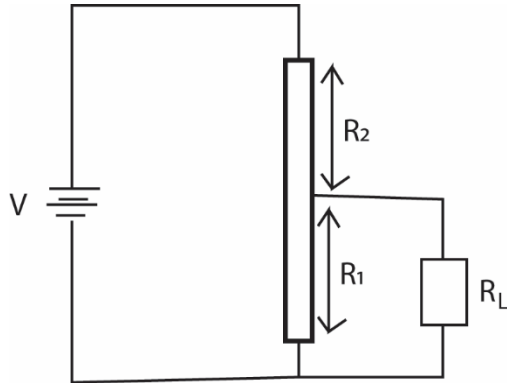
$$V_1 : V_2 = R_1 : R_2$$

For any resistor arranged in series, the p.d. across  $R_1$

$$V_1 = \frac{R_1}{\text{Total resistance}} \times \text{supply voltage}$$

Note: in potential dividers, the load is connected across a section of a divider whose p.d. is equal to the operating voltage of the load. The load may be a cooker, electric bulb, etc. the load resistance, say  $R_1$ ,

will now be considered to be in parallel to the resistance of the lower section of the divider. Let the resistance of the lower section be  $R_1$  and that of the upper section be  $R_2$ .



Now  $R_1$  is in parallel with  $R_L$

P.d. across  $R_1 =$  p.d. across the load

Let  $R$  be effective resistance of  $R_1$  and  $R_L$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_L} = \frac{R_1 + R_L}{R_1 R_L}$$

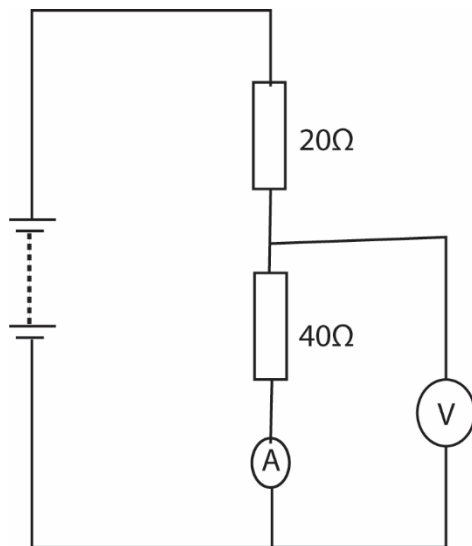
$$R = \frac{R_1 R_L}{R_1 + R_L}$$

Since  $R$  is in series with  $R_2$

Total resistance =  $R + R_2$ .

### Example 9

The figure shows a potential divider,  $V$ , is a very high resistance voltmeter.  $A$  is an accurate ammeter

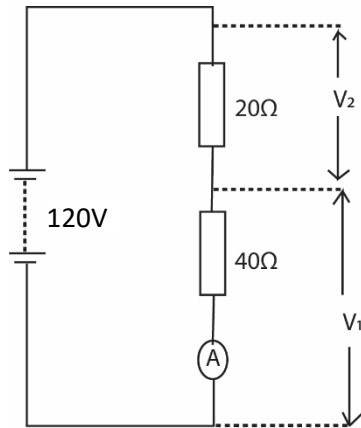


(i) Find the ammeter and voltmeter readings

- (ii) If the voltmeter above was replaced by another voltmeter of resistance 120, what will be the new reading?
- (iii) Find the percentage change in the ammeter reading
- (iv) If the voltmeter is replaced by a C.R.O, what will be its reading

**Solution**

(i)

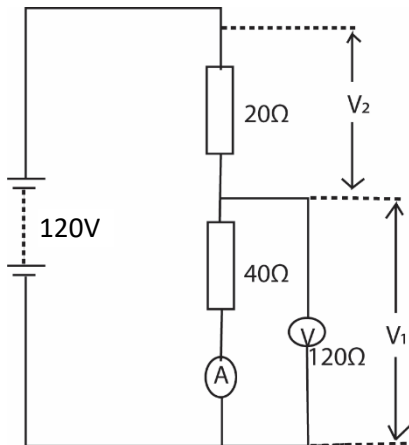


Total resistance  $R = 20 + 40 = 60\Omega$

From the circuit formula  $I = \frac{e.m.f}{total\ resistance} = \frac{120}{60} = 2A$

From Ohm's law  $V = IR = 2 \times 40 = 80V$

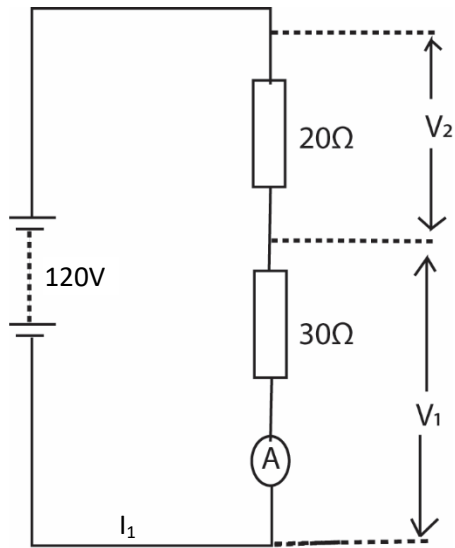
(ii)



Now 40Ω and 120Ω are in parallel, their effective resistance  $R_1$

$$\frac{1}{R_1} = \frac{1}{40} + \frac{1}{120}; R_1 = 30\Omega$$

Equivalent circuit



Total resistance =  $20 + 30 = 50\Omega$

$$\text{Current } I = \frac{120}{50} = 2.4\text{A}$$

From Ohm's law,  $V = IR_1 = 2.4 \times 30 = 72\text{V}$

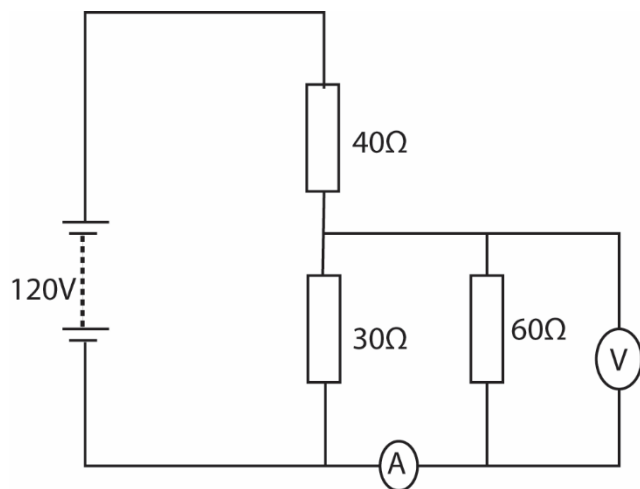
$$\text{From Ohm's law, } I_1 = \frac{V}{R} = \frac{72}{40} = 1.8\text{A}$$

(iii) Percentage change in current =  $\frac{I - I_1}{I} = \frac{2 - 1.8}{2} \times 100\% = 10\%$

(iv) A C.R.O is considered as an ideal voltmeter of infinite resistance which makes it to be very accurate, hence, its reading would be the same as in (i) above i.e. 80V

### Example 10

The figure shows a potential divider. V is a very sensitive voltmeter.



(i) Find the ammeter and voltmeter readings

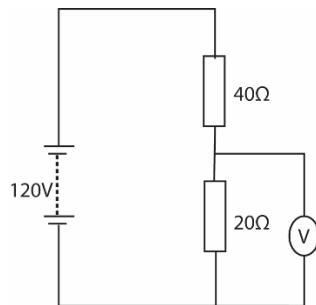
- (ii) If the voltmeter above was replaced by another voltmeter having a resistance of  $120\Omega$ , what is the new reading of voltmeter?
- (iii) Find the percentage change in ammeter reading

**Solution**

(i)  $30\Omega$  and  $60\Omega$  are in parallel. Let their effective resistance be R

$$\frac{1}{R} = \frac{1}{30} + \frac{1}{60} = \frac{3}{60}; R = 20\Omega$$

Equivalent circuit



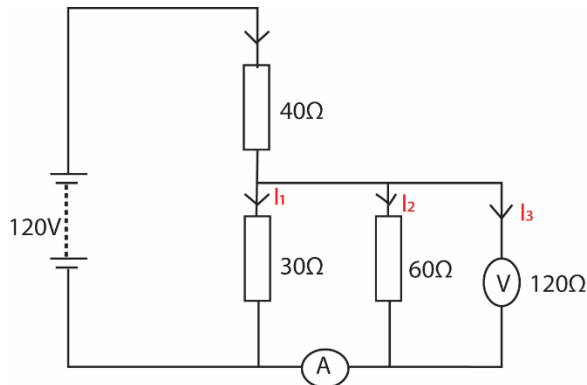
Total resistance =  $40 + 20 = 60\Omega$

$$\text{Current } I = \frac{120}{60} = 2A$$

From Ohm's law  $V = IR = 2 \times 20 = 40V$

$$\text{From Ohm's law ammeter reading} = \frac{V}{R} = \frac{40}{60} = \frac{2}{3}A$$

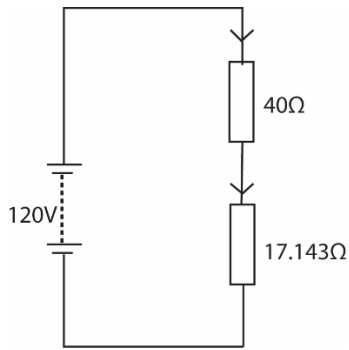
(ii)



$30\Omega$ ,  $60\Omega$  and  $120\Omega$  are in parallel, their effective resistance R is given by

$$\frac{1}{R} = \frac{1}{30} + \frac{1}{60} + \frac{1}{120}; R = 17.143\Omega$$

Effective circuit



40Ω and 17.143Ω are in series

Total resistance = 40 + 17.143 = 57.143Ω

From the circuit formula,  $I = \frac{e.m.f}{total\ resistance} = \frac{120}{57.143} = 2.10A$

From Ohm's law,  $V = IR = 2.1 \times 17.143 = 36V$

Voltmeter reading = 36V

From Ohm's law  $I = \frac{V}{R}$

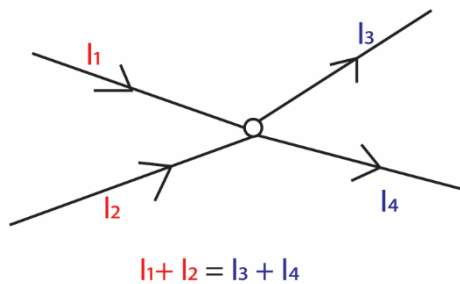
Ammeter reading =  $I_2 + I_3 = \frac{36}{60} + \frac{36}{120} = 0.9A$

Percentage change in ammeter reading =  $\frac{2-0.9}{2} \times 100 = 55\%$

## Kirchhoff's laws (1824-87)

### First law or law of conservation of current a junction

States that the sum of currents entering a junction is equal to the sum of currents leaving the junction



Or the algebraic sum of all currents at a junction is zero. i.e.  $I_1 + I_2 - I_3 - I_4 = 0$

Here a current,  $I$ , is reckoned positive if it flows towards the point and negative if it flows away from it.

### Second law or closed loop equation

In any closed loop, the algebraic sum of all the potential drops is equal to the algebraic sum of all the e.m.fs.

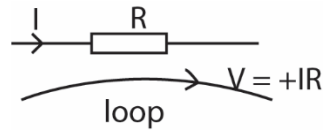
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$\sum V = \sum E$  Where  $V$  is the p.d and  $E$  is the e.m.f.

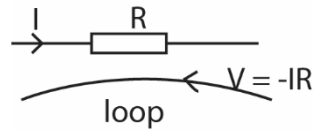
### Sign allocation to p.ds in circuit

When allocating signs to the p.d across a resistor, the direction of current flowing through a resistor is considered in relation to the direction of the loop.

The p.d across a resistor is considered to be positive if the current is in the same direction as that of the loop.

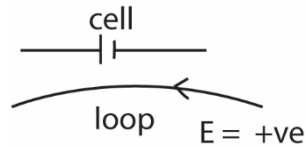


And the p.d is considered to be negative if the current is in an opposite direction to that of the loop.

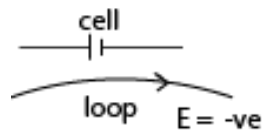


### Sign allocation to e.m.fs

When allocating signs to e.m.fs of cells, the polarity of the cell is considered in relation to the direction of the loop. The e.m.f of a cell is considered to be positive if the loop moves from negative terminal of the cell towards the positive terminal.



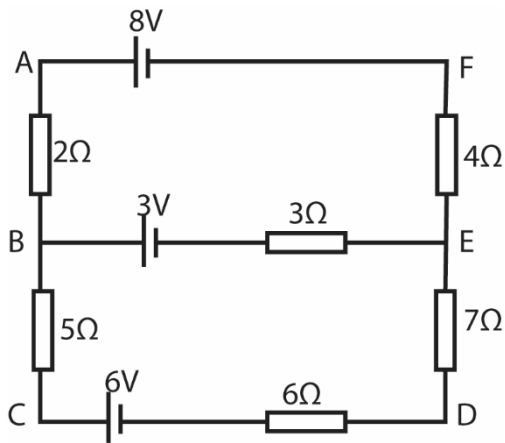
And it is considered to be negative if the loop moves from positive terminal towards the negative terminal



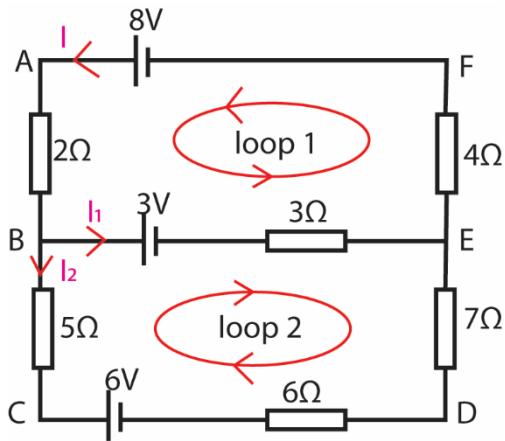
After application of Kirchhoff's law for electric circuit networks independent simultaneous equations involving both the known and unknowns will be obtained and these can now be solved using the available appropriate methods of techniques.

**Example 11**

In the figure, find the current flowing through the  $2\Omega$ ,  $3\Omega$  and  $6\Omega$  resistor.



Solution



At junction B;

$$I = I_1 + I_2 \dots\dots\dots (1)$$

Considering loop 1 (ABEFA)

$$2I + 3I_1 + 4I = 8 + -3$$

$$6I + 3I_1 = 5 \dots\dots\dots (2)$$

Considering loop 2 (BEDCB)

$$3I_1 + -7I_2 - 6I_2 - 5I_2 = -3 + 6 =$$

$$3I_1 - 18I_2 = 3 \dots\dots\dots(3)$$

Divide equation 3 by 3

$$I_1 - 6I_2 = 1 \dots\dots\dots(4)$$

Substituting eqn. 1 in eqn.2

$$6(I_1 + I_2) + 3I_1 = 5$$

$$9I_1 + 6I_2 = 5 \dots\dots\dots (5)$$

Eqn. (4) and eqn. (5)

$$10I_1 = 6$$

$$I_1 = \frac{6}{10} = 0.6A$$

From eqn. (4)

$$I_2 = \frac{I_1 - 1}{6} = \frac{0.6 - 1}{6} = -0.067A$$

$$I = I_1 + I_2 = 0.6 + -0.067 = 0.533A$$

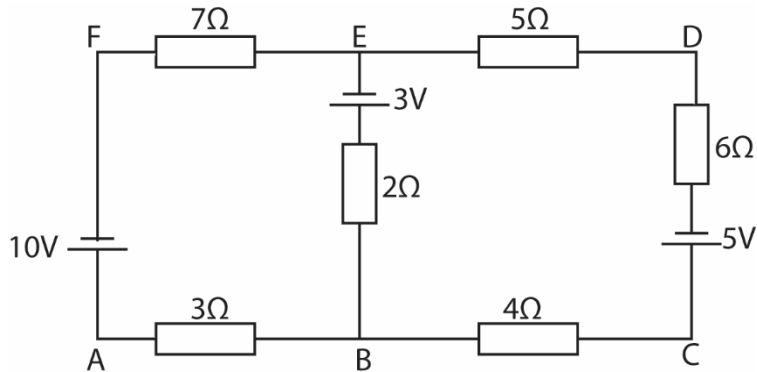
∴ Currents are

$$I_1 = 0.6A$$

$$I_2 = 0.067A \text{ (in a direction opposite to that assumed in the diagram)}$$

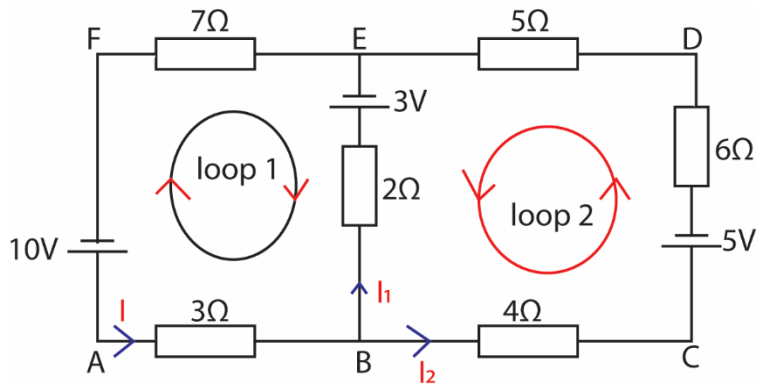
$$I_3 = 0.533A$$

### Example 12



- (a) In the figure, find the current flowing through the 3Ω, 2Ω and 4Ω resistors.
- (b) If a very high resistance voltmeter is connected across BD, what will be its readings?

### Solution



At junction B;

$$I = I_1 + I_2 \dots\dots\dots(i)$$

Considering loop 1 (ABEFA)

$$3I + 2I_1 + 7I = 10 + -3 \dots\dots\dots (ii)$$

$$10I + 2I_1 = 7 \dots\dots\dots (iii)$$

Considering loop 2 (BEDCB)

$$2I_1 - 5I_2 - 6I_2 - 4I_2 = -3 + 5$$

$$2I_1 - 15I_2 = 2 \dots\dots\dots (iv)$$

Substitute eqn. (i) into eqn. (iii)

$$10(I_1 + I_2) + 2I_1 = 7$$

$$12I_1 + 10I_2 = 7 \dots\dots\dots(v)$$

Multiply 6 into eqn. (iv)

$$6 \times [2I_1 - 15I_2 = 2]$$

$$12I_1 - 90I_2 = 12 \dots\dots\dots(6)$$

Eqn. (v) – eqn. (6)

$$100I_2 = -5$$

$$I_2 = -0.05A$$

From eqn. (iv)

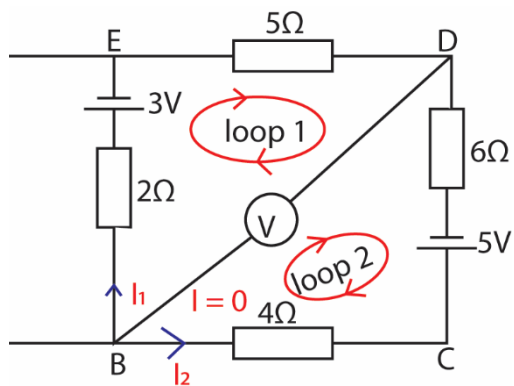
$$I_1 = \frac{2 + 15(-0.05)}{2} = 0.625A$$

From eqn. (i)

$$I = I_1 + I_2 = 0.625 + -0.05 = 0.575A$$

∴ currents are 0.575A, 0.625A, and 0.05A (in direction opposite to that assumed in the diagram)

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Considering loop 1(BEDB)

Let V be p.d across BD

$$2I_1 - 5I_2 - V = -3$$

$$V = 3 + 2I_1 - 5I_2 = 3 + (2 \times 0.625) - (10 \times -0.05) = 4.5V$$

Alternatively

Considering loop 2 (BDCB)

$$V - 6I_2 - 4I_2 = 5$$

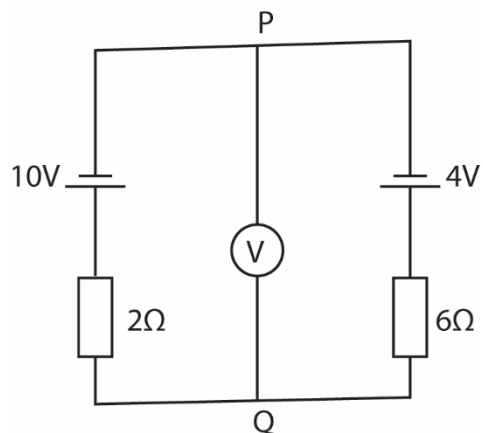
$$V = 5 + 10I_2$$

$$= 5 + 10 \times -0.05$$

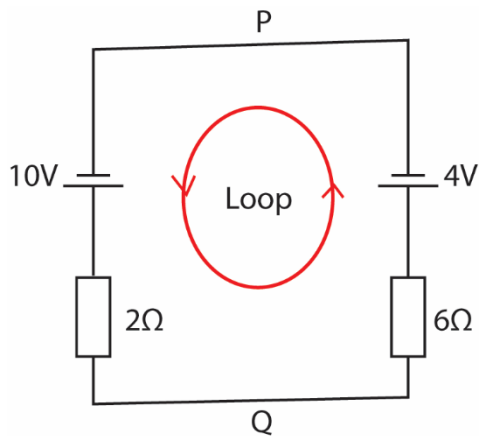
$$= 4.5V$$

### Example 13

In the diagram, V is a very high resistance voltmeter. Find its reading



### Solution



Considering the loop  $\sum V = \sum E$

$$2I + 4I = 10 - 4 = 6$$

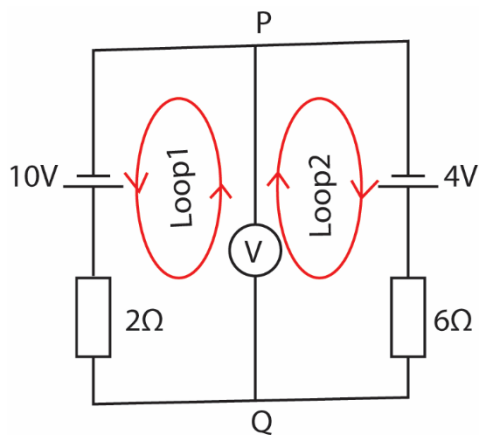
$$I = 1A$$

Alternatively, net p.d =  $10 - 4 = 6$

Total resistance =  $4 + 2 = 6\Omega$

From circuit formula

$$\text{Current, } I = \frac{\text{net p.d}}{\text{total resistance}} = \frac{6}{6} = 1A$$



Considering loop 1

$$V + 2I = 10$$

$$V = 10 - 2I = 10 - (2 \times 1) = 8V$$

Alternatively

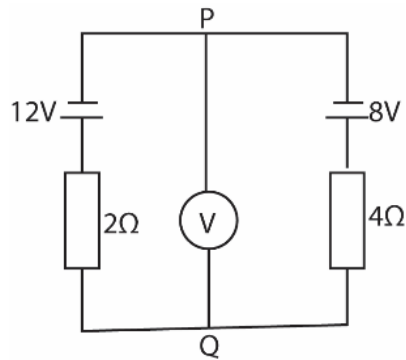
Considering loop 2

$$V - 4I = 4$$

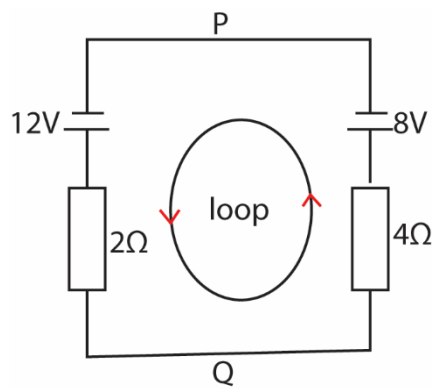
$$V = 4 + 4I = 4 + 4 \times 1 = 8V$$

### Example 14

In the diagram, V is a high resistance voltmeter. Find its reading.



### Solution



Considering the loop  $\sum V = \sum E$

$$2I + 4I = 12 - 8 = 4$$

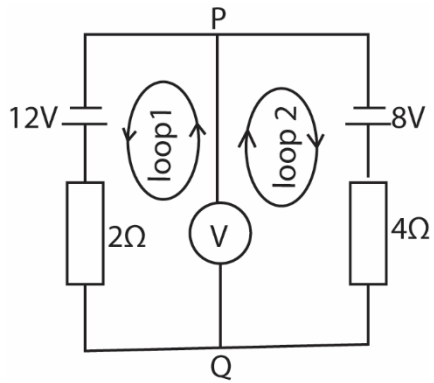
$$I = 0.667A$$

Alternatively, net p.d =  $12 - 8 = 4$

Total resistance =  $4 + 2 = 6\Omega$

From circuit formula

$$\text{Current, } I = \frac{\text{net p.d}}{\text{total resistance}} = \frac{4}{6} = 0.66A$$



Considering loop 1

$$V + 2I = 12$$

$$V = 12 - 2I = 12 - (2 \times 0.667) = 10.67V$$

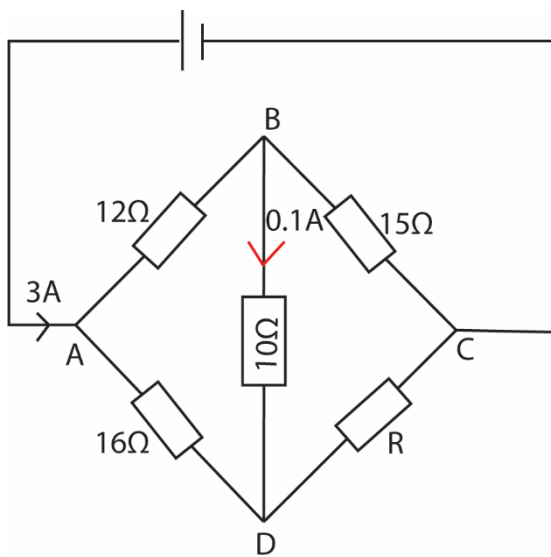
Alternatively

Considering loop 2

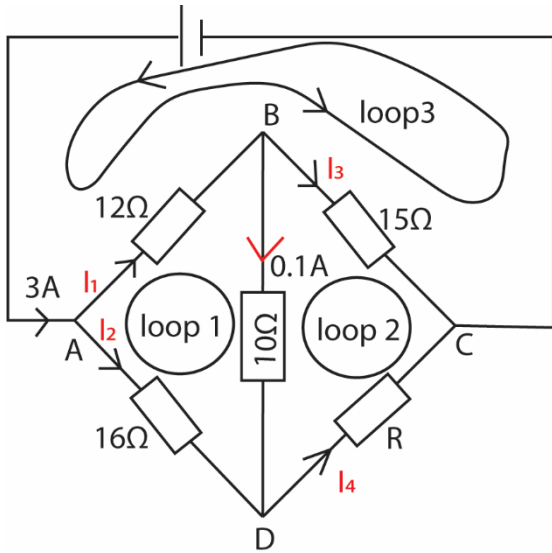
$$V - 4I = 8$$

$$V = 8 + 4 \times 0.667 = 10.67V$$

### Example 15



**Solution**



At junction A;

$$I_1 + I_2 = 3 \dots\dots\dots (i)$$

At junction B

$$I_1 = I_2 + 0.1 \dots\dots\dots (ii)$$

At junction D

$$I_2 + 0.1 = I_4 \dots\dots\dots (iii)$$

Considering loop 1 (ABDA)

$$12I_1 + 10 \times 0.1 - 16I_2 = 0$$

$$12I_1 - 16I_2 = -1 \dots\dots\dots (4)$$

Considering loop 2 (BCDB)

$$15I_3 - RI_4 = 1 \dots\dots\dots (5)$$

Considering loop 3

$$12I_1 + 15I_3 = x \dots\dots\dots (6)$$

From eqn. (1)

$$I_2 = 3 - I_1 \dots\dots\dots (7)$$

Put (7) into (4)

$$12I_1 - 16(3 - I_1) = -1$$

$$28I_1 = 47$$

$$I_1 = 1.679A$$

$$I_2 = 3 - I_1$$

$$I_2 = 3 - 1.679 = 1.321\text{A}$$

From equation (2)

$$I_3 = I_1 - 0.1 = 1.679 - 0.1 = 1.579\text{A}$$

From eqn. (3)

$$I_4 = I_2 + 0.1 = 1.321 + 0.1 = 1.421\text{A}$$

(ii) From eqn. (5)

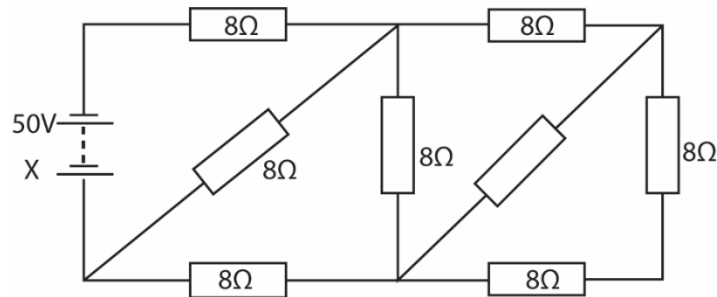
$$RI_4 = 15I_3 - (10 \times 0.1)$$

$$R = \frac{(15 \times 1.579) - 1}{1.421} = 15.964\Omega$$

For cell X,

$$X = 12I_1 + 15I_3 = (12 \times 1.679) + (15 \times 1.579) = 43.833\text{V}$$

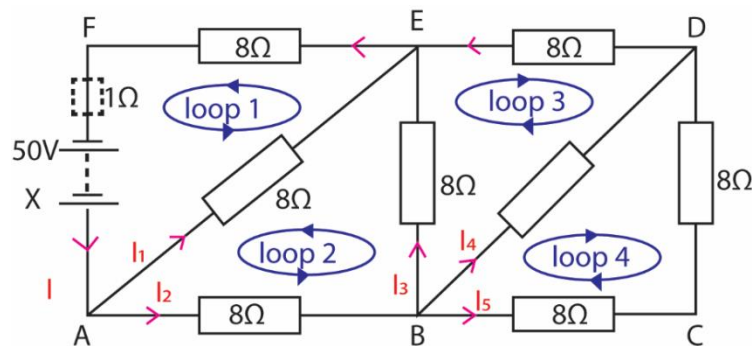
### Example 16



In the figure A is a battery of e.m.f 50V and having internal resistance of 1Ω. Find

- (i) The effective resistance of the circuit
- (ii) The power in the battery.

### Solution



At junction A

$$I = I_1 + I_2 \dots\dots\dots(i)$$

At junction B

$$I_2 = I_3 + I_4 + I_5 \dots\dots\dots(ii)$$

Considering loop 1 (AEFA)

$$8I_1 + 8I + I = 50 \dots\dots\dots (iii)$$

$$8I_1 + 9I = 50 \dots\dots\dots (iv)$$

Considering loop 2 (ABEA)

$$8I_2 + 8I_3 - 8I_1 = 0 \dots\dots\dots (v)$$

Considering loop 3 (BEDB)

$$8I_3 - 8(I_4 + I_5) - 8I_4 = 0$$

$$8I_3 - 16I_4 - 8I_5 = 0 \dots\dots\dots (vi)$$

Considering loop 4 (BDCB)

$$8I_4 - 8I_5 - 8I_5 = 0$$

$$8I_4 - 16I_5 = 0 \dots\dots\dots(vii)$$

From eqn. (vii)

$$8I_4 = 16I_5$$

$$I_4 = 2I_5 \dots\dots\dots (viii)$$

From eqn.(vi) and (viii)

$$8I_3 - 16(2I_5) - 8I_5 = 0$$

$$I_3 = 5I_5 \dots\dots\dots (ix)$$

From eqn. (2)

$$I_2 = 5I_5 + 2I_5 + I_5 = 8I_5 \dots\dots\dots (x)$$

From eqn. (v)

$$8(8I_5) + 8(5I_5) - 8I_1 = 0$$

$$I_1 = 13I_5 \dots\dots\dots (xi)$$

From eqn. (i)

$$I = 13I_5 + 8I_5 = 21I_5$$

From eqn. (iv)

$$8(13I_5) + 9(21I_5) = 50$$

$$I_5 = \frac{50}{293}$$

$$I = 21 \times \frac{50}{293} = \frac{E}{R} = \frac{50}{R}$$

$$R = 13.952\Omega$$

Alternatively

Taking path BCD

$$\text{Effective resistance} = 8 + 8 = 16\Omega$$

$16\Omega$  and  $8\Omega$  are in parallel

$$\frac{1}{R} = \frac{1}{16} + \frac{1}{8}; R = \frac{16}{3}\Omega$$

Now  $\frac{16}{3}\Omega$  is in series with  $8\Omega$

$$\text{Effective resistance} = \frac{16}{3}\Omega + 8 = \frac{40}{3}\Omega$$

$\frac{40}{3}\Omega$  is in parallel with  $8\Omega$  along BE

$$\frac{1}{R} = \frac{1}{8} + \frac{3}{40}; R = 5\Omega$$

$5\Omega$  and  $8\Omega$  (AB) are in series and their effective resistance =  $5 + 8 = 13\Omega$

$13\Omega$  and  $8\Omega$  (AE) are in parallel

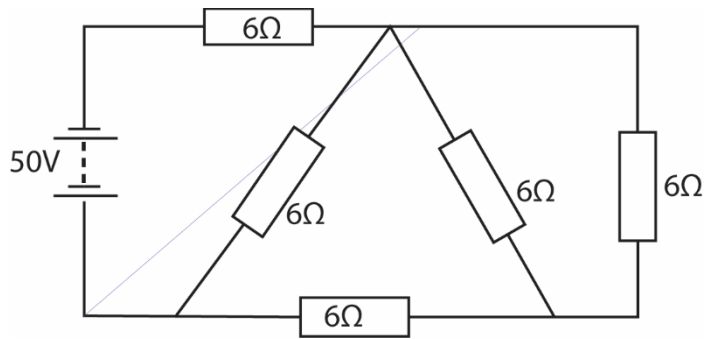
$$\frac{1}{R} = \frac{1}{13} + \frac{1}{8}; R = \frac{104}{21}\Omega$$

Now  $\frac{104}{21}\Omega$ ,  $8\Omega$  (EF),  $1\Omega$  are in series

$$\text{Total resistance} = \frac{104}{21}\Omega + 8\Omega + 1\Omega = 13.952\Omega$$

$$\text{(ii) power dissipated} = I^2 r = \left(21 \times \frac{50}{293}\right)^2 \times 1 = 12.84\text{W}$$

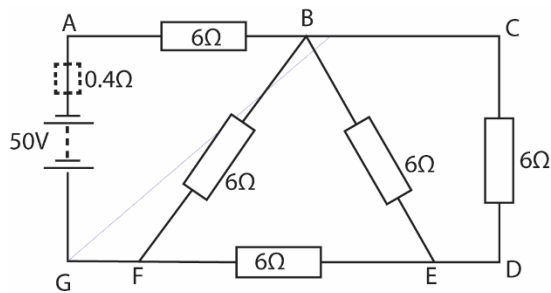
**Example 17**



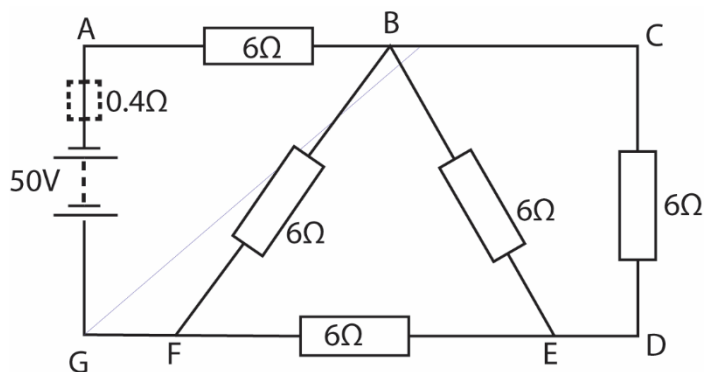
The figure shows a network of resistors connected to a battery of e.m.f 50V and internal resistance 0.4Ω. find

- (i) Effective resistance in the circuit
- (ii) Power dissipated in the battery

**Solution**



**Solution**



$R_1$  is the effective resistor for Resistors EB is in parallel with resistor DC

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{6}; R_1 = 3\Omega$$

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$R_1$  is in series with resistor FE

$$R_2 = 3 + 6 = 9\Omega$$

$R_2$  is parallel with resistor FB

$$\frac{1}{R_3} = \frac{1}{9} + \frac{1}{6}; R_3 = 3.6\Omega$$

$R_3$  is in series with resistors BA and AG

$$\text{Effective resistor } R = 3.6 + 6 + 0.4 = 10\Omega$$

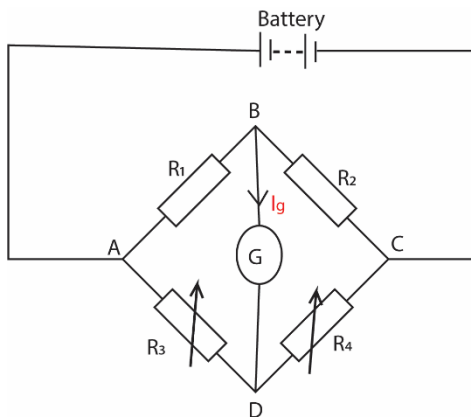
From  $V = IR$

$$I = \frac{V}{R} = \frac{50}{10} = 5A$$

$$\text{(ii) power} = I^2 r = 5^2 \times 0.4 = 10W$$

### The Wheatstone bridge (1843) circuit network

It an arrangement of four resistors; the unknown resistor, the standard resistor, and the variable resistors. It is used in comparison of resistances. The circuit is arranged as shown below:



$R_1$  – unknown

$R_2$  – standard resistor

$R_3$  and  $R_4$  are variable resistor

G –center zero galvanometer

$I_g$ - current flowing through the galvanometer.

### Comparison of resistance

In comparison of resistance, the unknown resistor is connected on one side of the bridge with a standard resistor on the opposite side as shown in the circuit.

#### Procedure

The variable resistor R3 and R4 are varied until the galvanometer indicates zero deflection.

As the resistors R3 and R4 are varied, the potentials at B and D change.

The galvanometer reads zero when  $V_D = V_B$

When the potential at B ( $V_B$ ) is greater than the potential at D ( $V_D$ ), then  $I_g$  flows from B to D, giving a deflection to one side of the galvanometer. When ( $V_D$ ) > ( $V_B$ ) current flows from D to B and the galvanometer deflects to another side.

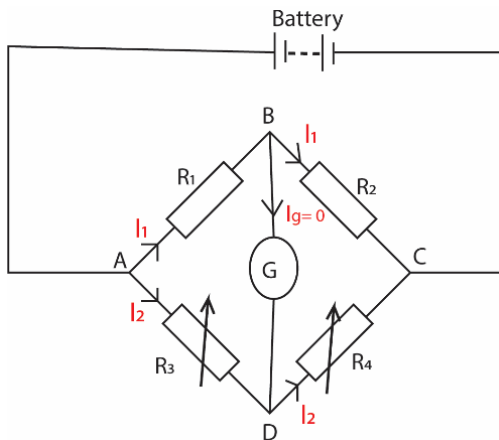
### Conditions for balance

These can be derived in two ways

- (i) By considering the physical principles involved
- (ii) By application of Kirchhoff's laws

Considering the physical principle

Consider a Wheatstone bridge below



At balance,  $V_B = V_D$

$$\Rightarrow V_{AB} = V_{AD}$$
$$I_1 R_1 = I_2 R_3 \dots\dots\dots(i)$$

Similarly

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$$V_{BC} = V_{CD}$$

$$I_1 R_2 = I_2 R_4 \dots\dots\dots(ii)$$

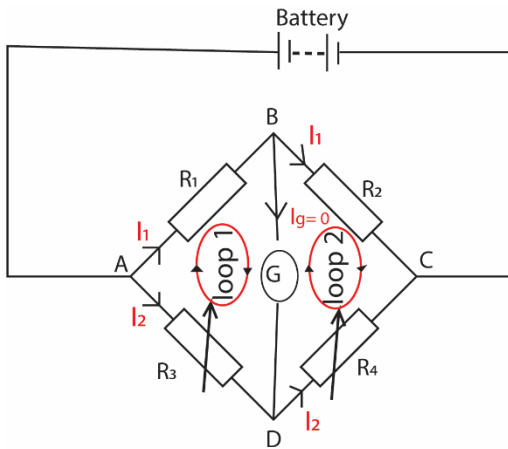
Divide eqn. (i) by eqn. (ii)

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_4}$$

Or at balancing point

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

**(ii) Applying Kirchoff's laws**



Considering loop 1 (ABDA)

$$I_1 R_1 + 0 \times R_g - I_2 R_3 = 0$$

$$I_1 R_1 = I_2 R_3 \dots\dots\dots (i)$$

Considering loop 2 (BCDB)

$$I_1 R_3 + 0 \times R_g - I_2 R_4 = 0$$

$$I_1 R_3 = I_2 R_4 \dots\dots\dots (ii)$$

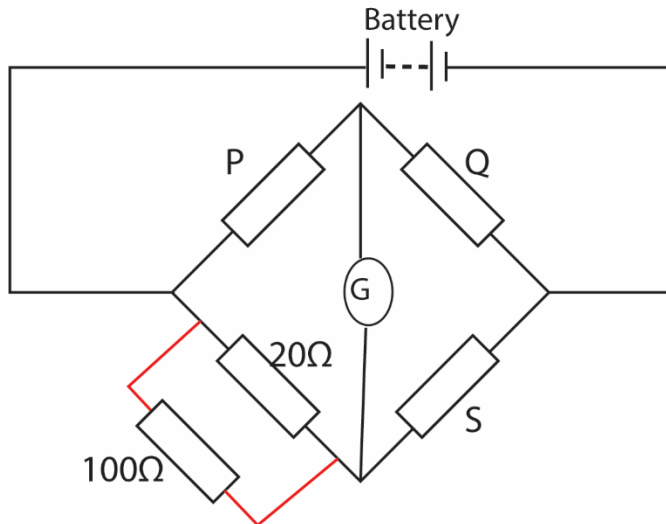
Divide (i) by (ii)

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

The resistance of unknown resistor,  $R_1 = \frac{R_3}{R_4} \times R_2$

**Example 18**

- (a) Draw a Wheatstone bridge circuit network and use to derive the balancing condition.
- (b) Explain how the network in (a) can be used to determine resistance of unknown resistor.
- (c)



In the figure, the 20Ω resistor is shunted with a 100Ω resistor for the bridge to balance. When P and Q are interchanged, the shunt resistance changes to 50Ω for the bridge to balance again. Find the value of S and true ratio P:Q.

Solution

Effective resistance of 20 and 100

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{100}; R = \frac{50}{3}$$

At balance

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

$$\Rightarrow \frac{P}{Q} = \frac{50}{3S} \dots\dots\dots(i)$$

Effective resistance, R<sub>1</sub>, for 20Ω and 50Ω

$$\frac{1}{R_1} = \frac{1}{20} + \frac{1}{50}; R_1 = \frac{100}{7} \Omega$$

At balance

$$\frac{P}{Q} = \frac{S}{R_1}$$

$$\frac{P}{Q} = \frac{7S}{100} \dots\dots\dots(ii)$$

Eqn. (i) and eqn. (ii)

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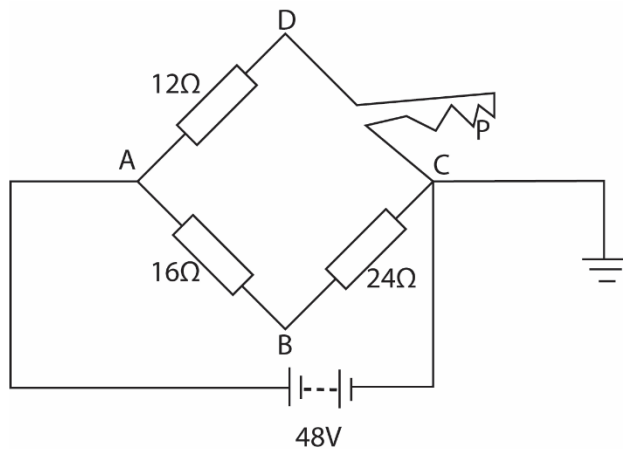
$$\frac{7S}{100} = \frac{50}{3S'}; S = 15.43\Omega$$

From eqn. (ii)

$$\frac{P}{Q} = \frac{7S}{100} = \frac{7 \times 15.43}{100} = 1.08$$

### Example 19

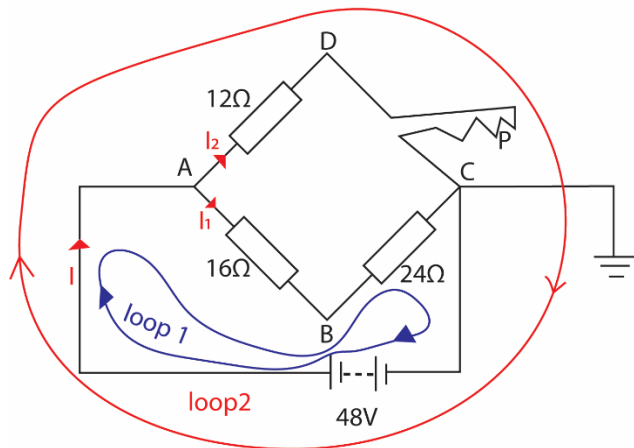
The figure below shows unbalanced Wheatstone bridge circuit network. P is a coil of resistance  $16.5\Omega$  at  $00C$ .



Find

- (i) The potential at B and D
- (ii) If the galvanometer is connected across BD, in which direction would the current flow
- (iii) If the temperature coefficient of resistance of the coil is  $2.0 \times 10^{-3}K^{-1}$ , to what temperature must the coil be raised in order to balance?

### Solution



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Considering loop  $16I_1 + 24I_1 = 48$

$$40I_1 = 48$$

$$I_1 = 1.2A$$

Considering loop 2

$$12I_2 + 16.5I_2 = 48$$

$$I_2 = 1.684A$$

$V_{CB} = V_B - V_C = IR$  (since current flows from region of high potential to that of low potential)

But  $V_C = 0$  (since potential due to the earth is zero)

$$V_B = IR = 1.684 \times 16.5 = 27.79V$$

Potential at B,  $V_B = 27.79V$

$$V_{CD} = V_D - V_C = IR$$

But  $V_C = 0$

$$V_D = IR = 1.2 \times 24 = 28.8V$$

Potential at D = 28.8V

(ii) The current would flow from D to B since D is at a higher potential than at B.

(iii) Let the temperature be  $\theta$

At balance;

$$\frac{R_0}{12} = \frac{24}{16}; R\theta = 18\Omega$$

Using  $R_\theta = R_0(1 + \alpha\theta)$

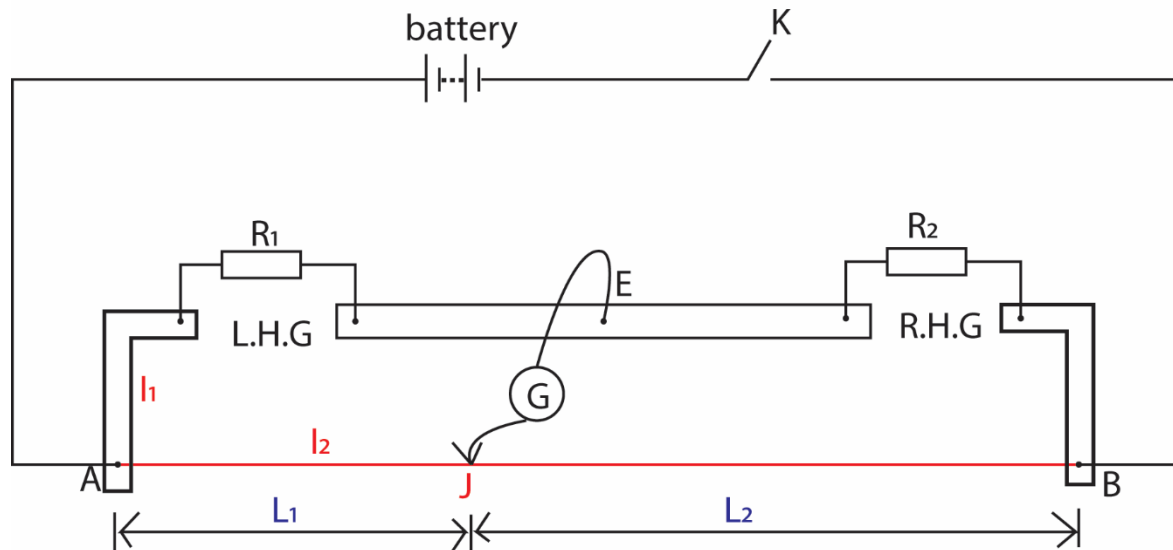
$$18 = 16.5(1 + 2.0 \times 10^{-3}\theta)$$

$$\theta = 45.5^\circ$$

The coil must be raised to  $45.5^\circ$  to balance

### The meter bridge

A meter bridge consists of a uniform slide wire 1m long (or mounted on a meter rule). The wire is connected in series with an accumulator (driver cell) which maintains a steady current through the wire. A meter bridge is used in measurement of resistances, resistivity and temperature coefficient of resistance. The circuit is arranged as shown below.



### Procedure

The unknown resistor is connected to L.H.G of the meter bridge. Switch K is closed and Jockey is placed at different places on the slide wire until the galvanometer indicates zero deflection. The meter bridge is said to be balanced. The balancing lengths  $L_1$  and  $L_2$  are noted and recorded.

At balancing point

$$\frac{R_1}{R_{AJ}} = \frac{R_2}{R_{JB}}$$

But  $R_{AJ} = KI_1$  and  $R_{JB} = KI_2$ , where K is resistance per cm of the wire

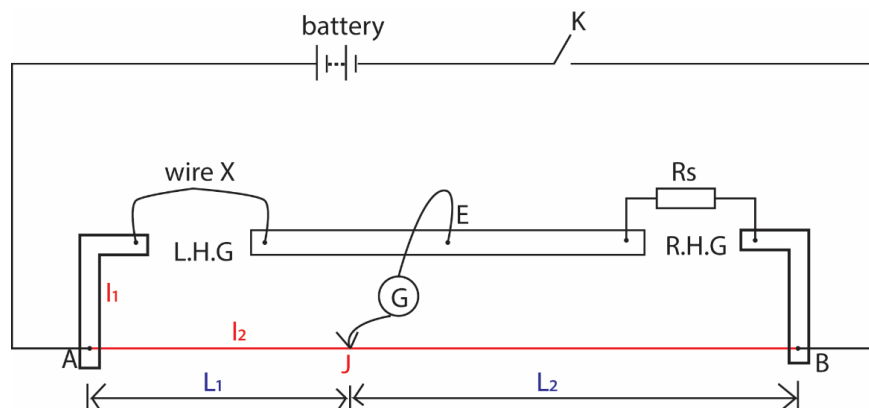
$$\frac{R_1}{KI_1} = \frac{R_2}{KI_2}$$

Thus,  $\frac{R_1}{R_2} = \frac{L_1}{L_2}$

### Example 20

Draw a circuit diagram of a meter bridge and use it to derive the balancing conditions.

### Experiment to determine the resistivity of a material of a wire



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## Procedure

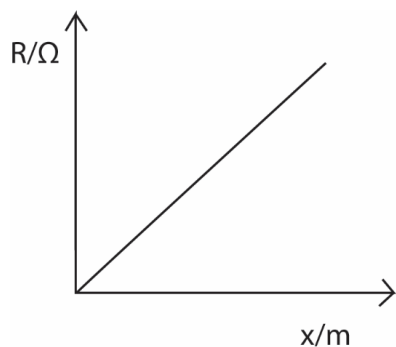
- (i) The mean diameter ( $d$ ) of wire X is measured using a micrometer screw gauge, and cross section area,  $A = \frac{\pi d^2}{4}$  of the wire is calculated
- (ii) Starting with a suitable measured length of X in meters, the balancing point is determined using a Jockey.
- (iii) The balancing length  $L_1$  and  $L_2$  are noted.
- (iv) The resistance of specimen wire X is calculated from  

$$R = R_s \times \frac{L_1}{L_2}$$
- (v) The experiment is repeated for different lengths of X and corresponding balance lengths  $L_1$  and  $L_2$  are obtained.

Table of results

| Length of wire X | $L_1$ (m) | $L_2$ (m) | $R = R_s \times \frac{L_1}{L_2}$ |
|------------------|-----------|-----------|----------------------------------|
|                  |           |           |                                  |

A graph of R of R against X is plotted. This is a straight line within limits of experimental errors passing through the origin



The slope of the graph is determined.

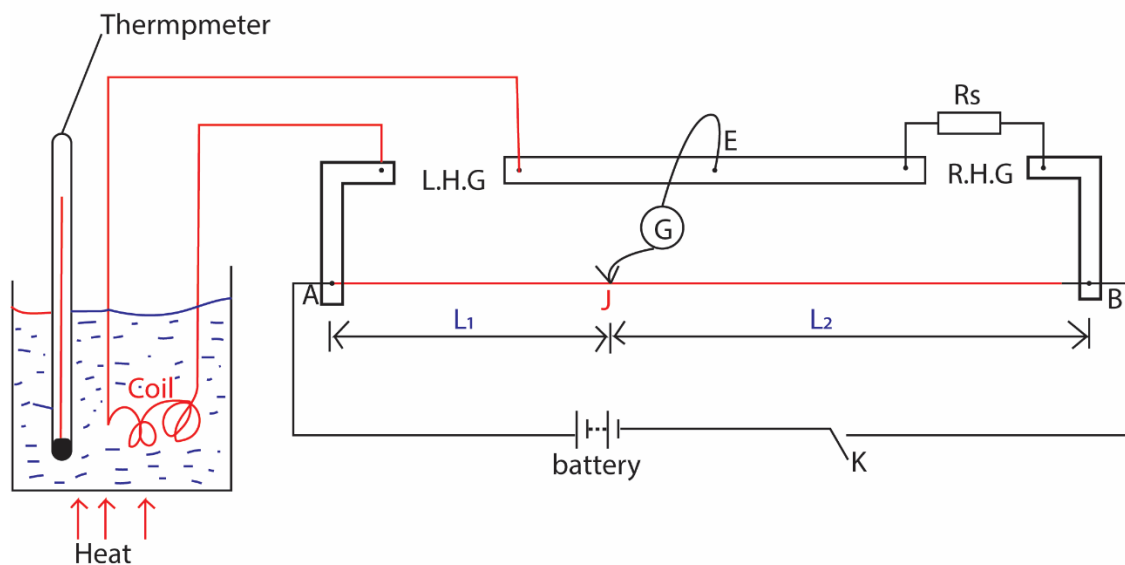
The resistivity of the wire can be obtained from  $\rho = \text{slope} \times A$

Theory of the experiment

From  $\frac{\rho X}{A}$ . This is in the form  $y = mx$ ; gradient =  $\rho$

### Experimental determination of temperature coefficient of resistance.

A specimen wire in form of a coil immersed in a water bath where temperature  $\theta$  is varied and measured by a thermometer. The end of the coil are connected to L.H.G of the meter bridge with a standard resistor in R.H.G. the circuit is as below:

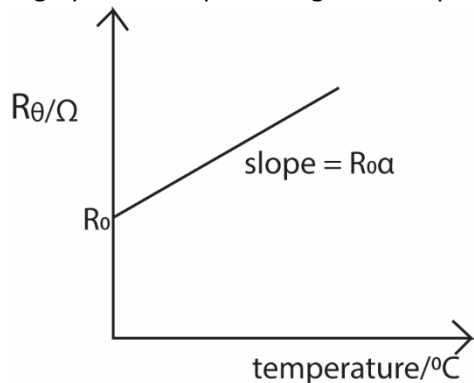


#### Procedure

- (i) Starting with suitable temperature, stop heating and switch  $K$  is closed.
- (ii) Balancing point is determined
- (iii) The balance lengths  $L_1$  and  $L_2$  are obtained
- (iv) The resistance  $R_\theta$  of the coil at temperature  $\theta$  is calculate.  $R_\theta = R_0 \frac{L_1}{L_2}$
- (v) The experiment is repeated for different values of  $\theta$  and corresponding values of  $L_1$  and  $L_2$  are tabulated.

| Length of wire X | $L_1$ (m) | $L_2$ (m) | $R_\theta = R_0 \times \frac{L_1}{L_2}$ |
|------------------|-----------|-----------|---|
|                  |           |           |   |

A graph of  $R_\theta$  is plotted against temperature. A straight line is obtained.



The slope and intercept of the graph are determined. The temperature coefficient of resistance (T.C.R) can be obtained by the intercept

$$\alpha = \frac{\text{slope}}{\text{intercept}}$$

Theory of the experiment

$$\text{From } R_\theta = R_0(1 + \alpha\theta) = R_0 + R_0\alpha\theta$$

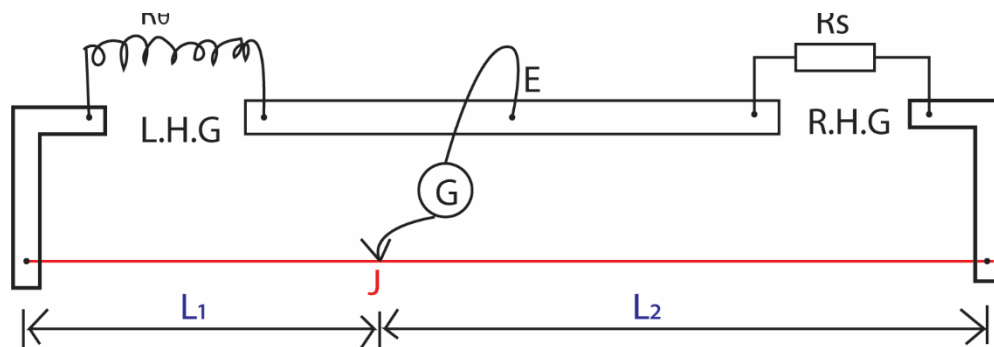
The intercept is =  $R_0$

$$\text{Slope} = R_0\alpha$$

### Example 21

A specimen wire in the form of a coil was connected in the L.H.G of a meter bridge with a standard resistor in the R.H.G. when the temperature of the coil reached  $45^\circ\text{C}$ , a balance length of 45.2 was obtained and when the temperature was raised to  $80^\circ\text{C}$  a balance length of 51.2cm was obtained. Find the temperature coefficient of resistance of the coil.

### Solution



Let  $R_\theta$  be the resistance at  $\theta^\circ\text{C}$

At balance

$$\frac{R_\theta}{l} = \frac{R_s}{(100-l)}$$

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$$\frac{R_{45}}{45.2} = \frac{R_s}{(54.8)}$$

$$R_{45} = 45.2 \times \frac{R_s}{54.8} \dots\dots\dots(i)$$

$$\frac{R_{80}}{51.8} = \frac{R_s}{(48.2)}$$

$$R_{80} = 51.8 \times \frac{R_s}{48.2} \dots\dots\dots(ii)$$

Using  $R_\theta = R_0(1 + \alpha\theta)$

$$R_{45} = R_0(1 + 45\alpha) \dots\dots\dots(iii)$$

$$R_{80} = R_0(1 + 80\alpha) \dots\dots\dots(iv)$$

Eqn. (iv) ÷ eqn.(iii)

$$\frac{R_{80}}{R_{45}} = \frac{(1 + 80\alpha)}{(1 + 45\alpha)} \dots\dots\dots(v)$$

Eqn. (ii) ÷ eqn.(i)

$$\frac{R_{80}}{R_{45}} = \frac{51.8R_s}{48.2} \times \frac{54.8}{45.2R_s} \dots\dots\dots(vi)$$

Equating (v) and (vi)

$$\frac{(1 + 80\alpha)}{(1 + 45\alpha)} = \frac{51.8R_s}{48.2} \times \frac{54.8}{45.2R_s}$$

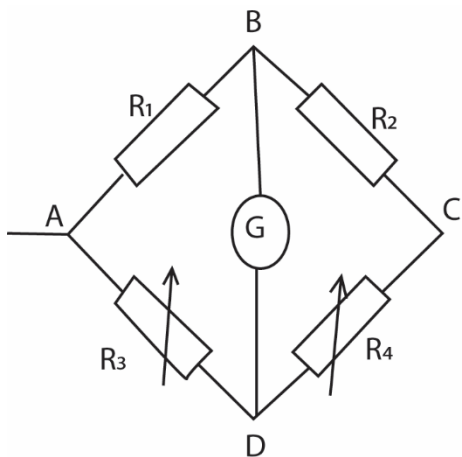
$$\alpha = 1.4182 \times 10^{-3} \text{K}^{-1}$$

**Example 22**

Explain why a Wheatstone bridge/meter bridge is unsuitable for comparison of very high or low resistance.

Solutions

Consider a Wheatstone bridge circuit network below



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If  $R_1$  is much larger than  $R_2$ , the current would pass through  $R_2$  and the galvanometer will deflect on one side for all adjustment on  $R_3$  and  $R_4$ .

In case of Meter Bridge the current would pass through the slide wire only and the galvanometer would deflect on one side for all positions of the jockey along the slide wire and hence a balance point cannot be obtained.

Hence a Wheatstone bridge becomes unsuitable for comparison of resistances which differ very much in magnitude.

### Very low resistances

Where the resistances to be compared are very low, the resistance of the connecting wires become substantial and the balancing point  $\frac{R_1}{R_2} = \frac{R_3}{R_4}$  becomes inaccurate.

For accuracy, the balancing condition becomes  $\frac{R_1+r_1}{R_2+r_2} = \frac{R_3+r_3}{R_4+r_4}$ , where  $r_1, r_2, r_3$  and  $r_4$  are the resistances of the connecting wires

In the case of a meter bridge, the balancing length will be very low that the resistances of end connection become substantial. Thus end correction needs to be added to improve the accuracy.

$$\frac{R_1}{R_2} = \frac{L_1 + e}{L_2 + e}$$

An end correction is the length of the slide wire which has the same resistance at the contact at zero end of the wire.

### Measurements of current and voltage

**Current** is measured by milliammeter (in milliamperes) or by ammeters in amperes. The milliammeter and ammeters are low resistance instruments to allow much current through them.

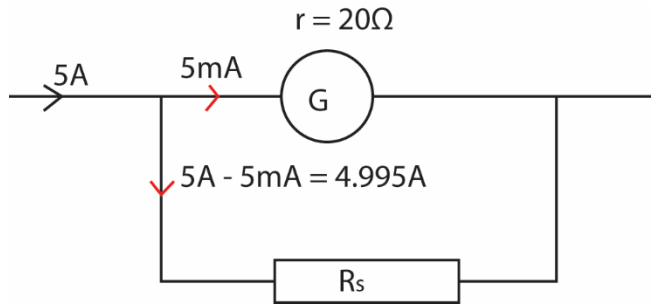
**Potential differences** are measured by voltmeters in volts. Voltmeters are high resistance instruments not to allow current through them

### Conversion of a milliammeter into an ammeter.

Moving coil instruments give full scale deflections (f.s.d) for currents smaller than those generally encountered in the laboratory.

A moving coil ammeter can be converted into an ammeter in order to read big currents by connecting low resistance ( $S$ ) called a **shunt** across its terminals. The shunt diverts most of the current to be measured away from the coils (not to damage it)

Suppose the coil of the meter has a resistance  $r = 20\Omega$  and full scale deflection  $I_s$  of 5 millamperes. And we wish to shunt it so as to give f.s.d of 5 amperes.



Then the current through the shunt =  $(I - I_g) = (5 - 0.005) = 4.995A$

The potential difference across the shunt is the same as that across the coil =  $IR$

$$= 20 \times 0.005 = 4.995 \times R_s$$

$$R_s = 0.02002\Omega$$

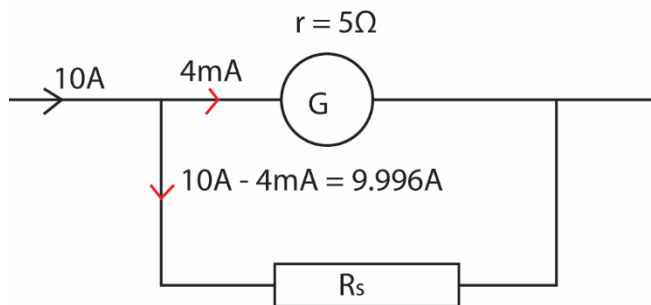
Therefore the resistance of the shunt =  $0.02002\Omega$

### Example 22

A moving coil galvanometer gives a full scale deflection of  $4mA$  and has a resistance of  $5\Omega$ . How can such an instrument be converted into an ammeter that give f.s.d of  $10A$

Solution

Let the required resistance be  $R_s$ .



Current through the shunt resistor =  $10A - 4mA = 10 - 0.004 = 9.996A$

The potential difference across the shunt is the same as that across the coil =  $IR$

$$= 5 \times 0.004 = 9.996 \times R_s$$

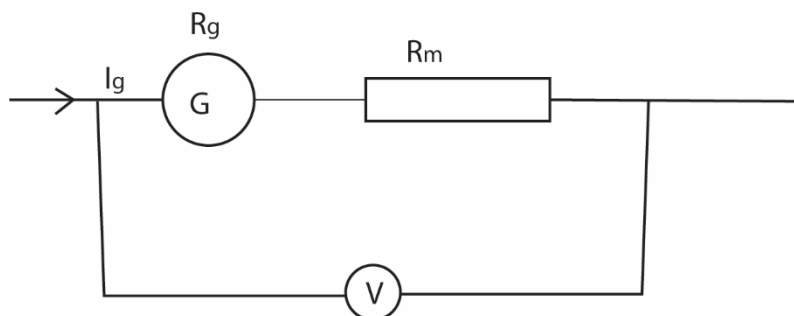
$$R_s = 0.002\Omega$$

### Conversion of a milliammeter into a voltmeter.

Moving coil instrument are more sensitive and accurate than other form of voltmeters.

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To convert a milliammeter, a large resistance called a multiplier is connected in series to draw extra p.d. to it.



From the diagram

$$V = (\text{p.d. across the galvanometer}) + (\text{p.d across the resistor})$$

$$= I_g R_g + I_g R_m$$

### Example 23

A moving coil galvanometer gives a f.s.d of 6mA and has a resistance of 4Ω. How can the instrument be converted into

- (i) Ammeter giving a f.s.d of 15A
- (ii) Voltmeter reading up to 20V

Solution

- (i) A shunt of resistance  $R_s$  is used  
 Current through the shunt =  $15 - 0.006 = 14.994\text{A}$   
 p.d across the galvanometer = p.d across the shunt = IR  
 $0.006 \times 4 = 14.994 \times R_s$   
 $R_s = 0.0016\Omega$
- (ii) A multiplier resistor of resistance  $R_m$  used  
 voltage across the galvanometer = IR =  $0.006 \times 4 = 0.024$   
 voltage across the multiplier resistor =  $20 - 0.024 = 19.976\text{V}$   
 $R_m = \frac{19.976}{0.006} = 3329\Omega$

### Example 24

A moving coil galvanometer of resistance 5Ω and current sensitivity of 2div/mA gives a full scale deflection of 16div. how can such an instrument be converted into

- (i) Ammeter reading up to 20A
- (ii) A voltmeter in which each division represents 2V.

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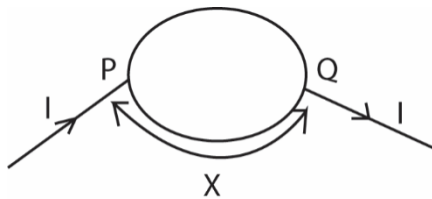
**Solution**

Full scale deflection galvanometer reading =  $\frac{16 \text{div} \times 1}{2} \text{ mA}$

- (i) A shunt of resistance  $R_s$  is used  
 Current through the shunt =  $20 - 0.008 = 19.992 \text{ A}$   
 p.d across the galvanometer = p.d across the shunt =  $IR$   
 $0.008 \times 5 = 19.992 \times R_s$   
 $R_s = 0.002 \Omega$
- (iii) A multiplier resistor of resistance  $R_m$  used  
 voltage across the galvanometer =  $IR = 0.008 \times 5 = 0.04 \text{ V}$   
 Total voltage to be read =  $2 \text{ V} \times 16 = 32 \text{ V}$   
 voltage across the multiplier resistor =  $32 - 0.04 = 31.96 \text{ V}$   
 $R_m = \frac{31.96}{0.008} = 3995 \Omega$

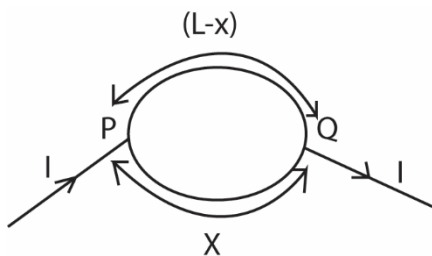
**Example 25**

A wire of diameter,  $d$ , length,  $L$  and resistivity,  $\rho$ , is made in form of a circular loop. A current enters and leaves the loop at points P and Q respectively.



Show that the resistance  $R$  of the wire is given by  $R = \frac{4\rho x(L-x)}{\pi d^2 l}$

Solution



Let  $R_1$  and  $R_2$  be the resistance of wire of length  $x$  and  $(L-x)$

$R_1 = \frac{\rho x}{A}$  .....(i)

$R_2 = \frac{\rho(L-x)}{A}$  .....(ii)

Where  $A$  is the cross section area =  $\frac{\pi d^2}{4}$  ..... (ii)

Effective resistance,  $R$ , for the loop

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$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{A}{\rho x} + \frac{A}{\rho(L-x)}$$

Substituting for A

$$R = \frac{4\rho x(L-x)}{\pi d^2 l}$$

### Example 26

- (i) Define the term resistivity and temperature coefficient
- (ii) Explain why metals have positive temperature coefficient of resistance.
- (iii) Explain why semi-conductors have negative temperature coefficient of resistance.
- (iv) Give two substance with negative coefficient of temperature.

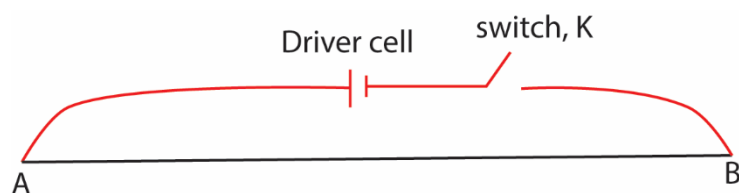
Solution

- (i) Resistivity is the resistance across opposite faces of a cube of material of side 1m
- (ii) Metals have positive temperature coefficient of resistance because their resistance increases with temperature. Increasing temperature increases the speed and kinetic energy of electrons and the amplitude of vibration of atoms. The vibration of atoms hinder the movement of electrons increasing resistance with temperature.
- (iii) Semi-conductors have negative temperature coefficient of resistance because increase in temperature breaks the strong forces of attraction between outer electrons and the nuclear attraction. This sets electrons free to conduct heat and electricity.

### Potentiometer

It consist of a uniform slide wire which can be of any length (but usually 1m) connected in series with an accumulator or driver cell which maintains a steady current through the wire.

The driver cell supplies a uniform p.d across the wire and hence the p.d across any length of the wire is directly proportional to the length of the section.



Principle of a slide wire potentiometer

Potentiometers are used to measure resistance, current and voltages. In all cases the unknown p.d is balanced against the p.d across a given section of the slide wire when the galvanometer shows no deflections.

The unknown p.d could be the p.d across a resistor, terminal p.d of a cell on either an open circuit or closed circuit or e.m.f of thermocouples.

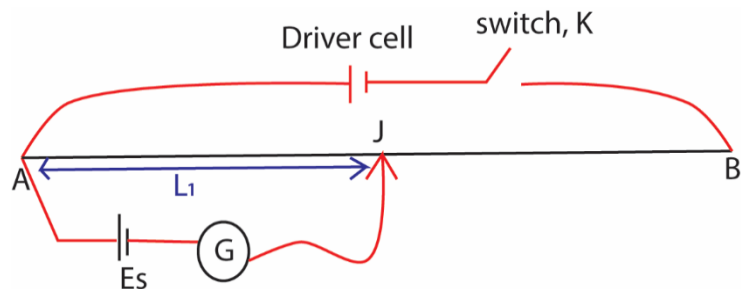
N.B. In order to balance, the positive terminal of the unknown p.d is connected to the positive terminal of the driver cell.

Standardization or calibration of the slide wire

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Standardization is a process of calibrating a slide wire so that its p.d per cm is known.

A standard cell is balanced against the slide wire; this is done using the circuit below.



**Procedure**

K is closed and the jockey is placed at different places along the slide wire until the galvanometer shows zero deflection. The balance point  $L_1$  is obtained

At balance  $E_s = kL_1$  .....(i)

Where k is the p.d per centimeter of the slide wire

From equation (i)

$$k = \frac{E_s}{L_1}$$

note that: if the resistance of the wire is known, then the steady current flowing in the slide wire can be calculated given the e.m.f of the standard cell.

At balance

Let I be the steady current flowing

$$E_s = V_{AJ} = IR_{AJ}$$

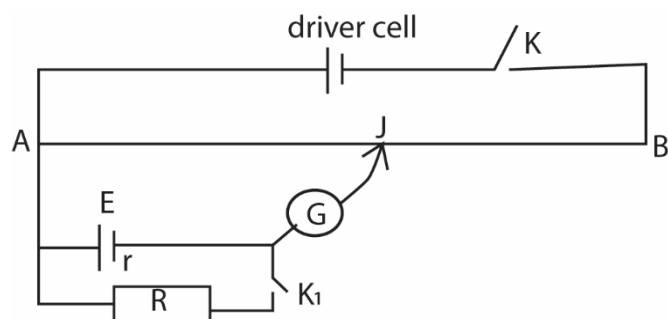
Let r be the resistance per cm, then

$$R_{AJ} = rL_1$$

$$E_s = IrL_1$$

Hence I can be obtained from  $I = \frac{E_s}{rL_1}$

Consider the following cases



When K is closed and  $K_1$  open, the balance length is  $L_0$  and when K and  $K_1$  are closed, the balance length changes to  $L_1$ .

### Procedure

Case 1 K closed,  $K_1$  open

$$E = V_{AJ} = kL_0 \dots\dots\dots(i)$$

When K and  $K_1$  are closed

$$IR = kL_1 \dots\dots\dots (ii)$$

$$\text{From circuit formula, } I = \frac{E}{R+r} \dots\dots\dots(iii)$$

Substitute eqn, (iii) in eqn.(ii)

$$\frac{ER}{R+r} = kL_1$$

Divide (i) by (iv)

$$\frac{E(R+r)}{ER} = \frac{L_0}{L_1}$$

$$1 + \frac{r}{R} = \frac{L_0}{L_1}$$

$$\frac{r}{R} = \left( \frac{L_0}{L_1} - 1 \right)$$

$$r = R \left( \frac{L_0}{L_1} - 1 \right)$$

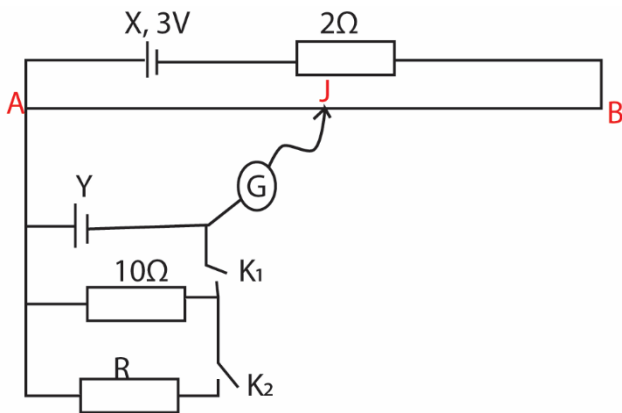
or

$$\frac{1}{R} = \left( \frac{L_0}{r} \right) \frac{1}{L_1} - \frac{1}{r}$$

A graph of  $\frac{1}{R}$  against  $\frac{1}{L_1}$  gives a straight line with the slope  $\frac{L_0}{r}$  and intercept =  $-\frac{1}{r}$

### Example 27

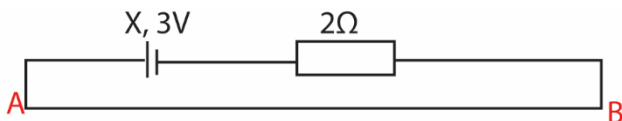
In the figure, X is a cell of e.m.f 3V and having negligible internal resistance. AB is a uniform slide wire 1.2m long and having a resistance of  $4\Omega$ . Y is a cell of unknown e.m.f and internal resistance.



When both  $K_1$  and  $K_2$  are open,  $G$  shows no deflection when  $AJ = 86.5\text{cm}$ . When both  $K_1$  and  $K_2$  are closed,  $G$  shows no deflection when  $AJ = 83.3\text{cm}$ . Find

- (i) The e.m.f of cell  $Y$
- (ii) The internal resistance of cell  $Y$
- (iii) The value of  $R$

**Solution**



Resistance  $AB$ ,  $R_{AB} = 4$

Total resistance =  $4 + 2 = 6\Omega$

From circuit formula  $I = \frac{e.m.f}{total\ resistance} = \frac{3}{6} = 0.5A$

$V_{AB} = IR_{AB} = 0.5 \times 4 = 2V$

p.d. per cm =  $\frac{V_{AB}}{L} = \frac{2}{120} = \frac{1}{60} Vcm^{-1}$

(i) With  $K_1$  and  $K_2$  open,

At balance;  $E = V_{AJ} = R_{AJ} = kL = \frac{1}{60} \times 90 = 1.5V$

e.m.f of cell,  $E = 1.5V$

Alternatively

$E = V_{AJ} = IR_{AJ}$

$R_{AJ} = \text{resistance per cm} \times L = \frac{4}{120} \times 90 = 1.5V$

(ii) At balance  $IR = kL$  .....(i)

From the circuit formula  $I = \frac{E}{R+r}$

$$\Rightarrow \frac{ER}{R+r} = kL$$

$$\frac{1.5 \times 10}{10+r} = \frac{1}{60} \times 86.5$$

$$r = 0.4\Omega$$

(iii) Let  $R_1$  be the effective resistance between R and  $10\Omega$

$$R_1 = \frac{10R}{10+R}$$

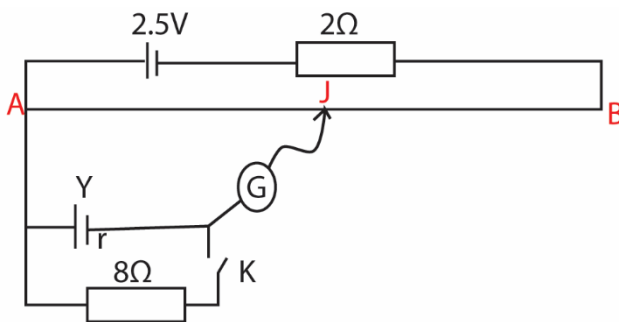
$$IR_1 = \frac{E}{R_1+0.4} = \frac{1}{60} \times 84.3$$

$$R_1 = 6\Omega = \frac{10R}{10+R}$$

$$R = 15\Omega$$

### Example 28

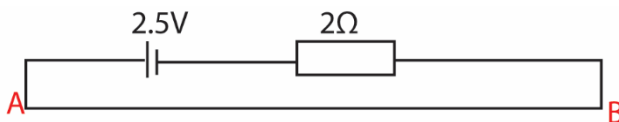
In the figure AB is a uniform wire 1m long and having a resistance of  $4\Omega$ . Y is a cell of unknown e.m.f and internal resistance.



When K is open, G shows no deflection when  $AJ = 90.0\text{cm}$ . When K is closed, G shows no deflection when  $AJ = 87.8\text{cm}$ . Find

- E.m.f of the cell Y
- Internal resistance of Y.

Solution



$$R_{AB} = 4\Omega$$

$$\text{Total resistance} = (4 + 2) = 6\Omega$$

$$\text{Total current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{2.5}{6} \text{ A}$$

$$V_{AB} = IR_{AB} = \frac{2.5}{6} \times 4 = \frac{5}{2} \text{ V}$$

$$\text{p.d. per cm } k = \frac{5}{2} \div 100 = \frac{1}{60} \text{ Vcm}^{-1}$$

when K is open,  $L = 90.0\text{cm}$

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At balance ,  $E = V_{AJ} = KI = \frac{1}{60} \times 90 = 1.5V$

Alternatively

$E = V_{AJ} = IR_{AJ}$

Resistance per cm =  $\frac{R_{AB}}{L} = \frac{4}{100} = 0.04\Omega cm^{-1}$

$R_{AJ} = 0.04 \times 90 = 3.6\Omega$

$E = \frac{2.5}{6} \times 3.6 = 1.5V$  (which is e.m.f of cell Y)

(ii) when K is closed  $L = 87.8cm$

From the formula,  $I = I = \frac{E}{R+r}$

$I = \frac{ER}{R+r} = kL$

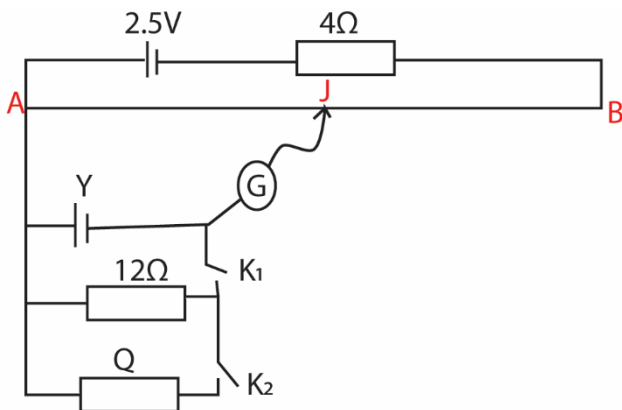
$R = 8\Omega, E = 1.5V$

$\Rightarrow \frac{1.5 \times 8}{8+r} = \frac{1}{60} \times 87.8$

$\Rightarrow r = 0.2\Omega$

**Example 29**

In the figure Ab is a uniform slide wire of 1.0m long and having a resistance of 4Ω. Y is a cell of unknown e.m.f and internal resistance.



When  $K_1$  and  $K_2$  are open G shows no deflection when  $AJ = 96cm$ . when  $K_2$  is closed and  $K_1$  is left open, G shows no deflection when  $AJ = 92.9cm$ . When  $K_1$  and  $K_2$  are closed, G shows no deflection when  $AJ = 91.4cm$ . Find

- (i) The e.m.f of cell Y
- (ii) Internal resistance of Y
- (iii) The value of Q

Solution

Resistance AB,  $R_{AB} = 4$

Total resistance =  $4 + 4 = 8\Omega$

From circuit formula  $I = \frac{e.m.f}{total\ resistance} = \frac{2.53}{8} = 0.3125A$

$V_{AB} = IR_{AB} = 0.3125 \times 4 = 1.25V$

p.d. per cm =  $\frac{V_{AB}}{L} = \frac{1.25}{100} = \frac{1}{80} Vcm^{-1}$

(i) With  $K_1$  and  $K_2$  open,

At balance;  $E = V_{AJ} = R_{AJ} = kL = \frac{1}{80} \times 96 = 1.2V$

e.m.f of cell,  $E = 1.2V$

Alternatively

$E = V_{AJ} = IR_{AJ}$

$R_{AJ} = \text{resistance per cm} \times L = \frac{1.25}{100} \times 96 = 1.2V$

(ii) At balance  $IR = kL$  .....(i)

From the circuit formula  $I = \frac{E}{R+r}$

$$\Rightarrow \frac{ER}{R+r} = kL$$

$$\frac{1.2 \times 12}{12+r} = \frac{1}{80} \times 92.9$$

$$r = 0.4\Omega$$

(iii) Let  $R_1$  be the effective resistance between Q and  $12\Omega$

$$\frac{1}{R_1} = \frac{1}{Q} + \frac{1}{12} \dots\dots\dots (i)$$

At balance  $IR_1 = kL$

$$\frac{ER_1}{R_1+r} = kL$$

$$\frac{1.2R_1}{R_1+0.4} = \frac{1}{80} \times 92.9 = 1.1425$$

$$R_1 = 7.9$$

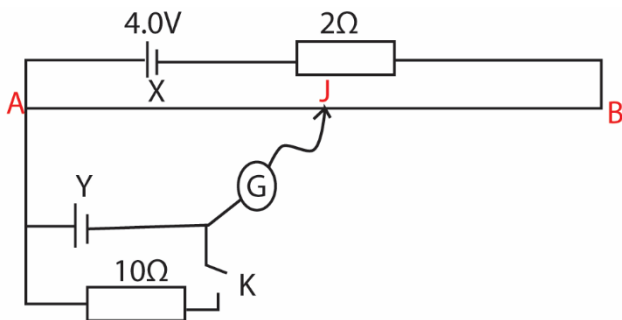
Substituting  $R_1$  in equation (i)

$$\frac{1}{7.9} = \frac{1}{Q} + \frac{1}{12}$$

$$Q = 24\Omega$$

### Example 30

In the figure AB is a uniform slide wire of 1m long and having a resistance of  $4\Omega$ .



X is an accumulator of e.m.f  $4.0\text{V}$  and having negligible internal resistance.

When K is open, G shows no deflection when  $AJ = 56.25\text{cm}$ . When K is closed, G shows no deflection when  $AJ = 51.5\text{cm}$ . Find

- (i) E.m.f of the cell Y
- (ii) Internal resistance of Y

Solution

$$R_{AB} = 4\Omega$$

$$\text{Total resistance} = (4 + 2) = 6\Omega$$

$$\text{Total current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{4.0}{6} \text{ A}$$

$$V_{AB} = IR_{AB} = \frac{4.0}{6} \times 4 = \frac{8}{3} \text{ V}$$

$$\text{p.d. per cm } k = \frac{V_{AB}}{L} = \frac{\frac{8}{3}}{100} = \frac{2}{75} \text{ Vcm}^{-1}$$

(i) When K is open,  $L = 56.25\text{cm}$

$$\text{At balance, } E = V_{AJ} = kL = \frac{2}{75} \times 56.25 = 1.5\text{V (e.m.f of Y)}$$

Alternatively

$$E = V_{AJ} = IR_{AJ}$$

$$\text{Resistance per cm} = \frac{R_{AB}}{L} = \frac{4}{100} = 0.04\Omega\text{cm}^{-1}$$

$$R_{AJ} = 0.04 \times 56.25 = 2.25\Omega$$

$$E = IR_{AJ} = \frac{4}{6} \times 2.25 = 1.5\text{V (which is e.m.f of cell Y)}$$

(ii) When K is closed  $L = 51.5\text{cm}$

$$\text{From the formula, } I = \frac{E}{R+r}$$

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$$I = \frac{ER}{R+r} = kL$$

$$R = 10\Omega, E = 1.5V$$

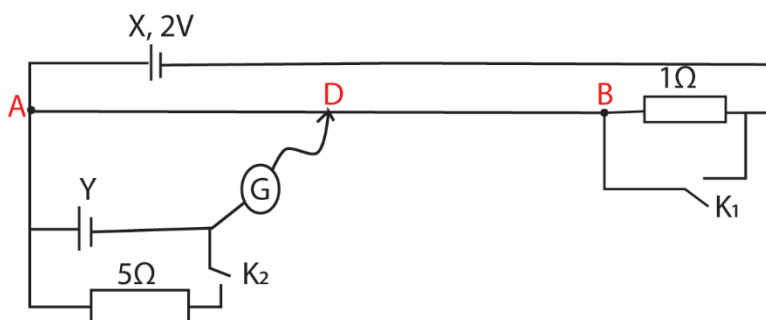
$$\Rightarrow \frac{1.5 \times 10}{10+r} = \frac{2}{75} \times 51.1$$

$$\Rightarrow r = 1\Omega$$

$\therefore$  internal resistance of a cell =  $1\Omega$

### Example 30

In the figure, cell X is of e.m.f 2.0V and negligible internal resistance, AB is a uniform slide wire of length 100cm and resistance  $5\Omega$



When both  $K_1$  and  $K_2$  is open, the balance length  $AD = 90\text{cm}$ . When  $K_2$  is closed, the balance length change to  $75\text{cm}$ . Find

- (i) E.m.f of the cell Y
- (ii) Internal resistance of Y
- (iii) The balance length if both  $K_1$  and  $K_2$  are closed

### Solution

**$K_1$  is open**

$$R_{AB} = 5\Omega$$

$$\text{Total resistance} = (5 + 1) = 6\Omega$$

$$\text{Total current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{2.0}{6} = \frac{1}{3} \text{ A}$$

$$V_{AB} = IR_{AB} = \frac{1}{3} \times 5 = \frac{5}{3} \text{ V}$$

$$\text{p.d. per cm } k = \frac{V_{AB}}{L} = \frac{\frac{5}{3}}{100} = \frac{5}{300} \text{ Vcm}^{-1}$$

(i) When  $K_1$  is closed

$$\text{Total resistance} = 5\Omega$$

$$\text{Total current} = \frac{2}{5} \text{ A}$$

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$$V_{AB} = IR_{AB} = \frac{2}{5} \times 5 = 2V$$

$$\text{p.d. per cm } k = \frac{V_{AB}}{L} = \frac{2}{100} = \frac{1}{50} \text{ Vcm}^{-1}$$

$$kl = Ey = \frac{5}{300} \times 90 = 1.5V$$

∴ e.m.f of a cell = 1.5V

(ii) When K is open  $L = 75\text{cm}$

From the formula,  $I = I = \frac{E}{R+r}$

$$I = \frac{ER}{R+r} = kL$$

$R = 5\Omega$ ,  $E = 1.5V$

$$\Rightarrow \frac{1.5 \times 5}{5+r} = \frac{5}{300} \times 75$$

$$\Rightarrow r = 1\Omega$$

∴ internal resistance of a cell =  $1\Omega$

(iii) Balance length if both  $K_1$  and  $K_2$  are closed

$$kl = IR = \frac{ER}{R+r}$$

$$\frac{1}{50} L = \frac{1.5 \times 5}{5+1}$$

$$L = 62.6\text{cm}$$

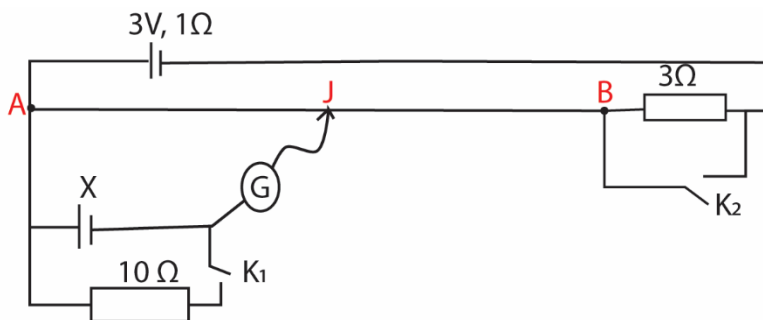
NB when  $K_1$  is closed, current passes through the switch alone where there is less resistance.

When  $K_1$  is closed, current passes through  $1\Omega$  resistor

Hence the different values of resistance.

### Example 31

In the figure below when  $K_1$  is open and  $K_2$  closed, G shows no deflection for  $AJ = 83.3\text{cm}$ .



When  $K_1$  is closed and  $K_2$  open, G shows no deflection when  $AJ = 67.5\text{cm}$

- (a) Find the resistivity of the potentiometer wire 1m long with a diameter 0.5mm and having a resistance of  $5\Omega$
- (b) Calculate
- e.m.f of cell X
  - internal resistance of X
  - the balance length when both switches  $K_1$  and  $K_2$  are closed
  - the balance length when both  $K_1$  and  $K_2$  are open.

**Solution**

$$(a) \rho = \frac{RA}{L} = \frac{R\pi d^2}{4L} = \frac{5 \times \pi \times (0.5 \times 10^{-3})^2}{4 \times 1} = 9.81 \times 10^{-7} \Omega m$$

(b) when  $K_2$  is open

$$R_{AB} = 5\Omega$$

$$\text{Total resistance} = (5 + 3 + 1) = 9\Omega$$

$$\text{Total current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{3}{9} = \frac{1}{3} A$$

$$V_{AB} = IR_{AB} = \frac{1}{3} \times 5 = \frac{5}{3} V$$

$$\text{p.d. per cm } k = \frac{V_{AB}}{L} = \frac{\frac{5}{3}}{100} = \frac{1}{60} V cm^{-1}$$

(i) When  $K_2$  is closed

$$\text{Total resistance} = 5 + 1 = 6\Omega$$

$$\text{Total current} = \frac{3}{6} = \frac{1}{2} A$$

$$\text{Resistance per centimeter} = \frac{5}{100}$$

$$\text{p.d. per cm } IR_{/cm} k = \frac{5}{100} \times \frac{1}{2} = \frac{1}{40} V cm^{-1}$$

$$(i) E_x = k l = \frac{1}{40} \times 83.3 = 2.1V$$

$$\therefore \text{e.m.f of a cell} = 2.1V$$

(ii) When  $K_1$  is closed and  $K_2$  is open  $L = 67.5cm$

$$\text{From the formula, } I = I = \frac{E}{R+r}$$

$$I = \frac{ER}{R+r} = kL$$

$$R = 10\Omega, E = 2.1V$$

$$\Rightarrow \frac{2.1 \times 10}{10+r} = \frac{1}{60} \times 67.5$$

$$\Rightarrow r = 8.67\Omega$$

(iii) Balance length if both  $K_1$  and  $K_2$  are closed

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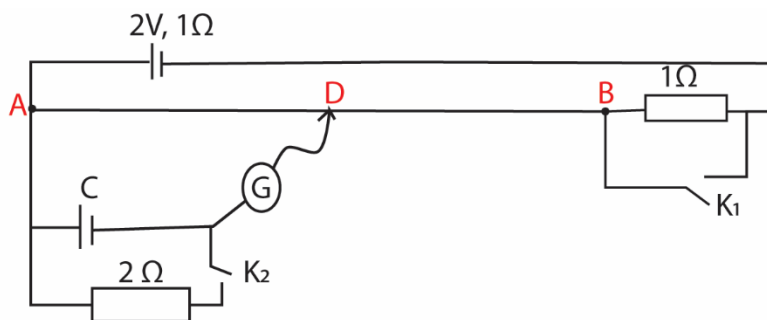
$$kl = IR = \frac{ER}{R+r}$$

$$\frac{1}{60} L = \frac{2.1 \times 9}{9 + 8.67}$$

$$L = 64.18 \text{ cm}$$

### Example 32

The figure below shows a slide wire AB of length 1m and resistance  $0.04 \Omega \text{ cm}^{-1}$



When  $K_1$  and  $K_2$  are open, galvanometer shows no deflection when  $AD = 90.0 \text{ cm}$ . When  $K_1$  is open and  $K_2$  is closed,  $AD$  changes to  $60.0 \text{ cm}$ . Find

- (i) E.m.f cell C
- (ii) Internal resistance of cell C
- (iii) The value of  $AD$  when  $K_1$  and  $K_2$  are closed

### Solution

#### $K_1$ is open

$$R_{AB} = 0.04 \times 100 = 4 \Omega$$

$$\text{Total resistance} = (4 + 1 + 1) = 6 \Omega$$

$$\text{Total current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{2.0}{6} = \frac{1}{3} \text{ A}$$

$$V_{AB} = IR_{AB} = \frac{1}{3} \times 4 = \frac{4}{3} \text{ V}$$

$$\text{p.d. per cm } k = \frac{V_{AB}}{L} = \frac{\frac{4}{3}}{100} = \frac{5}{300} = \frac{1}{75} \text{ V cm}^{-1}$$

(i) When  $K_1$  is closed,  $K_2$  is open

$$\text{Total resistance} = 4 + 1 = 5 \Omega$$

$$\text{Total current} = \frac{2}{5} \text{ A}$$

$$V_{AB} = IR_{AB} = \frac{2}{5} \times 4 = 1.6V$$

$$\text{p.d. per cm } k = \frac{V_{AB}}{L} = \frac{1.6}{100} = \frac{2}{125} Vcm^{-1}$$

$$kL = Ey = \frac{1}{75} \times 90 = 1.5V$$

∴ e.m.f of a cell = 1.5V

(iv) When  $K_1$  is open and  $K_2$  closed  $L = 60\text{cm}$

From the formula,  $I = I = \frac{E}{R+r}$

$$I = \frac{ER}{R+r} = kL$$

$$R = 2\Omega, E = 1.5V$$

$$\Rightarrow \frac{1.5 \times 2}{2+r} = \frac{1}{75} \times 60$$

$$\Rightarrow r = 1\Omega$$

∴ internal resistance of a cell =  $1.75\Omega$

(v) Balance length if both  $K_1$  and  $K_2$  are closed

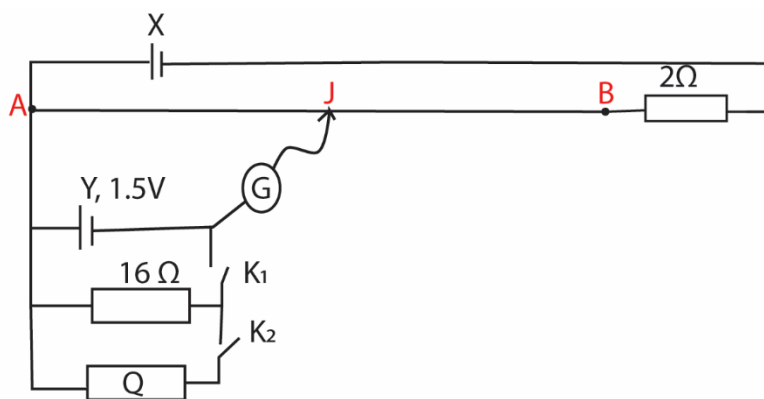
$$kL = IR = \frac{ER}{R+r}$$

$$\frac{2}{125} L = \frac{1.5 \times 2}{2+1.75}$$

$$L = 50.0\text{cm}$$

### Example 33

In the figure, AB is a uniform slide wire  $1.2\text{m}$  long and having resistance  $4\Omega$ . Y is a cell of e.m.f  $1.5\text{V}$  and having unknown internal resistance.



When both  $K_1$  and  $K_2$  are open  $G$  shows no deflection when  $AJ = 90.0\text{cm}$ ; when  $K_1$  is closed and  $K_2$  open,  $G$  shows no deflection when  $AJ = 88.3\text{cm}$ . When Both  $K_1$  and  $K_2$  are closed,  $G$  shows no deflection when  $AJ = 87.3$ . Find

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- (i) The current flowing through the slide wire
- (ii) The e.m.f of cell X
- (iii) Internal resistance of Y
- (iv) The value Q

**K1 is open**

$$R_{AB} = 4\Omega$$

$$\text{Total resistance} = (4 + 2) = 6\Omega$$

$$\text{Total current } I = \frac{\text{e.m.f}}{\text{total resistance}} = \frac{E_x}{6} \dots\dots\dots(i)$$

- (i) When  $K_1$  and  $K_2$  are open,  $L = 90$

At balance

$$E_Y = V_{AJ} = IR_{AJ} = 1.5V \dots\dots\dots(ii)$$

$$\text{Resistance per cm} = \frac{4}{1.2 \times 100} = \frac{1}{30} \Omega \text{cm}^{-1}$$

$$R_{AJ} = \frac{1}{30} \times 90 = 3\Omega$$

From eqn. (ii)

$$I \times 3 = 1.5$$

$$I = 0.5A$$

- (ii) From eqn.

$$E_x = IR = 6 \times 0.5 = 3V$$

$$\therefore \text{e.m.f of cell X} = 3V$$

- (iii) When  $K_1$  is closed,  $K_2$  is open,  $L = 88.3\text{cm}$

$$\text{At balance, } IR = V_{AJ} = IR_{AJ}$$

From circuit formula

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

Then

$$\frac{ER}{R+r} = IR_{AJ}; \text{ but } R_{AJ} = \frac{1}{30} \times 88.3$$

$$\frac{1.5 \times 16}{16+r} = 0.5 \times \frac{1}{30} \times 88.3$$

$$r = 0.3\Omega$$

- (iv) When  $K_1$  and  $K_2$  are closed,  $L = 87.3\text{cm}$ , let the effective resistance  $R_1$

From circuit formula

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

Then

$$\frac{ER}{R+r} = IR_{AJ}; \text{ but } R_{AJ} = \frac{1}{30} \times 87.3$$

$$\frac{1.5 \times R_1}{R_1+0.3} = 0.5 \times \frac{1}{30} \times 87.3$$

$$R_1 = 9.7\Omega$$

But

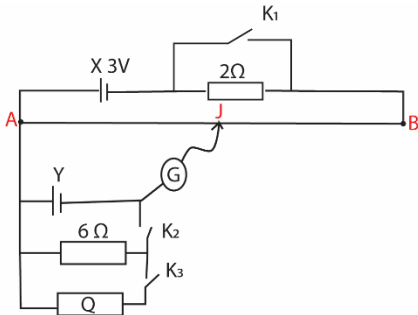
$$\frac{1}{R_1} = \frac{1}{16} + \frac{1}{Q}$$

$$\frac{1}{9.7} = \frac{1}{16} + \frac{1}{Q}$$

$$Q = 24.63\Omega$$

### Example 34

In the figure X is accumulator of e.m.f 3V and having negligible internal resistance. AB is a uniform slide wire 1.2m long and having a resistance 4Ω. Y is a cell of unknown e.m.f and internal resistance



When  $K_1$ ,  $K_2$  and  $K_3$  are open the balance length,  $AJ = 90\text{cm}$

When  $K_1$ ,  $K_2$  are closed and  $K_3$  is open the balance length,  $AJ = 43.9\text{cm}$

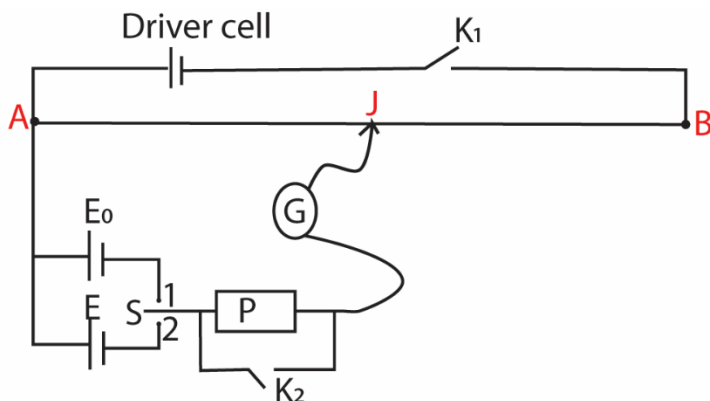
When  $K_2$ ,  $K_3$  are closed and  $K_1$  are open the balance length,  $AJ = 58.1\text{cm}$

Find

- (i) The e.m.f of cell Y (ans. 1.5V)
- (ii) Internal resistance of a cell Y (ans.  $0.2\Omega$ )
- (iii) Value Q (ans.  $12\Omega$ )
- (iv) Balancing length when  $K_1$ ,  $K_2$  and  $K_3$  are all closed (ans.  $38.71\text{cm}$ )

Comparison of e.m.f

The e.m.f of two cells can be compared using circuit below:



P= protective resistor

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$E_0$  = standard cell

$E$  = cell of unknown e.m.f

$G$  center zero galvanometer

### Procedure

(a) The standard cell is first balanced against the slide wire. This is done as follows:

- $K_1$  if closed and  $S$  is put in position 1 with  $K_2$  open, the jockey is placed at different places along the slide wire until the galvanometer indicates zero deflection.
- An approximate balance point is obtained,  $K_2$  is closed to obtain the actual balance length  $L_0$ .  
 $E_0 = kL_0$  .....(i) (where  $k$  is the p.d per cm of the slide wire.

(b)  $S$  is placed in position 2 and the new balance length  $L$  is obtained

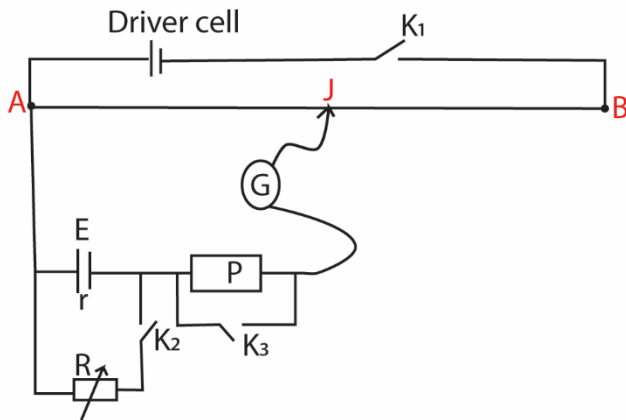
$$E = kL \text{ ..... (ii)}$$

Dividing (ii) by (i)

$$\frac{E}{E_0} = \frac{L}{L_0}$$

$$\text{Or } E = \frac{L}{L_0} \times E_0$$

### Experiment to determine internal resistance of a cell



$P$  = protective resistor

$R$  = variable resistor

$G$  = center zero galvanometer

$E$  = dry cell whose internal resistance is required

$J$  = jockey

### Procedure

(a) The dry cell is first balanced against the slide wire as follows:

$K_1$  is closed while  $K_2$  and  $K_3$  are left open, the jockey is placed in different places on the slide wire until the galvanometer shows no deflection.  $K_3$  is then closed and the actual balance length  $L_0$  is noted.

At balance

$$E = kL_0 \dots\dots\dots(i) \text{ where } k \text{ is the p.d per cm}$$

(b) The variable resistor is adjusted to a suitable value and the p.d across it is balanced against the slide wire as follows

With  $K_1$  and  $K_2$  closed,  $K_3$  open, an approximate balance length is obtained.  $K_3$  is then closed and actual balance length,  $L$  is obtained.

At balance

$$IR = kL \dots\dots\dots(ii) \text{ where } I \text{ is current flowing through the resistor}$$

The experiment is repeated for different values of  $R$  and corresponding lengths,  $L$  are recorded.

The results tabulated including values of  $\frac{1}{R}$  and  $\frac{1}{L}$

A plot of  $\frac{1}{R}$  against  $\frac{1}{L}$  give a straight line with intercept =  $-\frac{1}{r}$

### Theory of the experiment

$$E = kL_0 \dots\dots\dots(i)$$

$$IR = kL \dots\dots\dots (ii)$$

From the formula

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

$$\Rightarrow \frac{ER}{R+r} = kL \dots\dots\dots(iii)$$

Divide (i) by (iii)

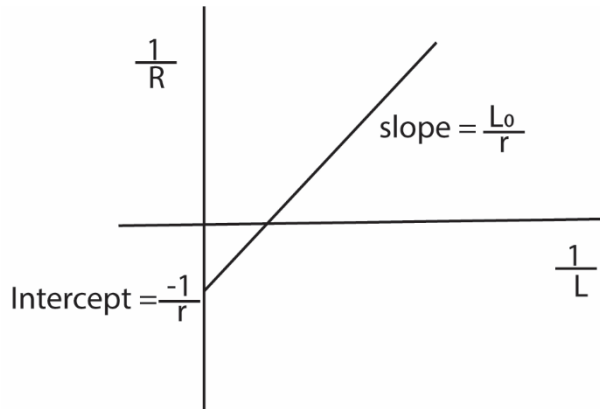
$$\frac{(R+r)E}{ER} = \frac{L_0}{L}$$

$$\frac{R+r}{R} = \frac{L_0}{L}$$

$$1 + \frac{r}{R} = \frac{L_0}{L}$$

$$\frac{1}{R} = \left(\frac{L_0}{r}\right)\frac{1}{L} - \frac{1}{r}$$

A graph of  $\frac{1}{R}$  against  $\frac{1}{L}$



### Example 35

Outline the principles of a slide potentiometer

Solution

A potentiometer consists of a uniform slide wire which can be any length (about 1m long) connected with a driver cell which maintains a steady current through the wire. Since the wire is uniform, has a constant resistance per cm, driver cell supplies a constant p.d per cm of the wire or uniform p.d so that p.d across any length,  $L$ , of the wire is directly proportional to the length.

i.e.  $V \propto L$  or  $V = kL$

the unknown p.d is balanced against the slide wire by placing the jockey along the slide wire until the galvanometer shows no deflection.

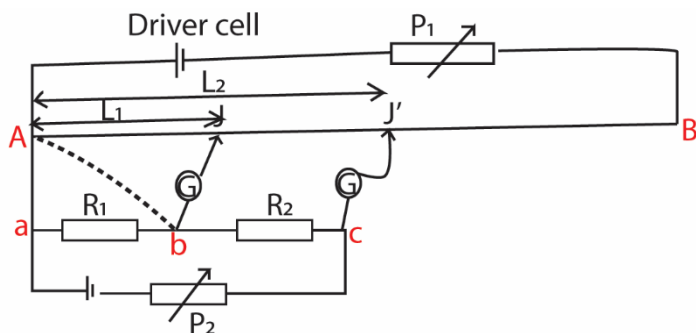
In order to balance, the unknown p.d must be connected in the opposition with the driver cell.

### Example 36

With the aid of a circuit diagram, describe how you would determine the internal resistance of a dry cell using a potentiometer.

### Comparison of resistance using a potentiometer

The resistance can be compared using the circuit below



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G = center zero galvanometer

P<sub>1</sub> and P<sub>2</sub> = rheostat

R<sub>1</sub> = standard resistor

R<sub>2</sub> = unknown resistor

### Procedure

With connections at a and b (shown by full lines,) the p.d across R<sub>1</sub> is balanced against the slide wire. The jockey is placed at different points along the slide wire until the galvanometer shows no deflection. The balance length L<sub>1</sub> is noted.

At balance

$$IR_1 = kL_1 \dots\dots\dots (i)$$

Where k is the p.d per cm of the slide wire and I is the current flowing through the resistance.

The connection at a and b are now replaced by those at b and c ( shown by dotted line). The p.d across R<sub>2</sub> is now balanced against the slide wire. The balance length L<sub>2</sub> is noted

At balance

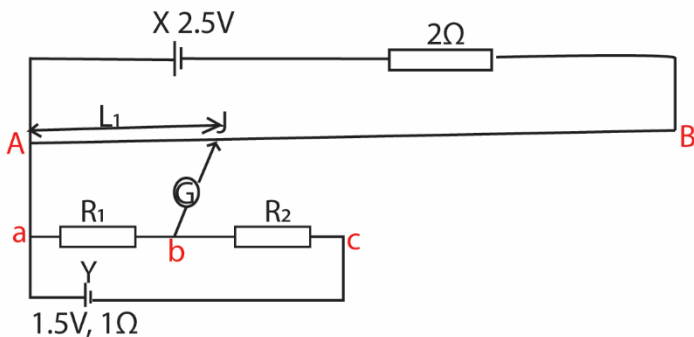
$$IR_2 = kL_2 \dots\dots\dots (ii)$$

Divide eqn. (i) by eqn. (ii)

$$\frac{R_1}{R_2} = \frac{L_1}{L_2}$$

### Example 36

In the figure X is an accumulator of e.m.f 2.5V and having negligible internal resistance. Y is a cell of e.m.f 1.5V having internal resistance 1Ω.

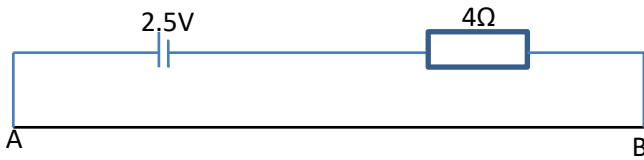


AB is a uniform wire 1m long and having a resistance of 40Ω. With the connection at a and b a balance length of 39.8cm was obtained. When the connection at a and b were replaced by those at a and c, a balance length of 82.4cm was obtained. Find

- (i) Current flowing through slide wire
- (ii) The resistance R<sub>1</sub> and R<sub>2</sub>.

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**Solution**



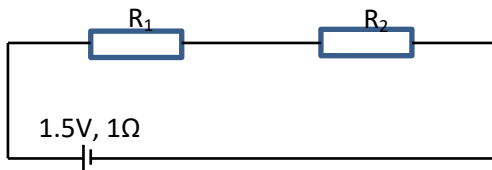
Total resistance =  $4 + 2 = 6\Omega$

Steady current flowing

$$I = \frac{e.m.f}{total\ resistance} = \frac{2.5}{6} = \frac{5}{12} A$$

Resistance per cm =  $\frac{4}{100} = 0.04\Omega cm^{-1}$

p.d per cm,  $k = IR/cm = \frac{5}{12} \times \frac{4}{100} = \frac{1}{60} Vcm^{-1}$



Total resistance =  $R_1 + R_2 + 1$

Current flowing,  $I = \frac{1.5}{R_1 + R_2 + 1}$  .....(i)

with connections at a and b

At balance

$IR_1 = kL_1$ ;  $L_1 = 39.8cm$

$IR_1 = \frac{1}{60} \times 39.8 = 0.6633$  .....(ii)

With connections at a and c

$I(R_1 + R_2) = kL_2 = \frac{1}{60} \times 82.4 = 1.3733$  ..... (iii)

From eqn. (i)

$I(R_1 + R_2 + 1) = 1.5$  ..... (iv)

Substituting eqn. (iii) into eqn. (iv)

$I(R_1 + R_2) + I = 1.5$

$1.3733 + I + 1.5$

$I = 0.1267A$

From eqn. (ii)

$$R_1 = \frac{1.6633}{0.1267} = 5.24\Omega$$

From eqn. (iii)

$$R_1 + R_2 = \frac{1.3733}{0.1267} = 10.84\Omega$$

$$R_2 = 10.84 - 5.24 = 5.60\Omega$$

### Possible problems of the experiment

If balance point cannot be obtained, then either the p.d. per cm is too small or too big. The variable resistor P1 is adjusted until measurable balance length is obtained

Or

The p.d across the resistances may be too small or too big. The variable resistor P2 is adjusted until balance point is restored. (The variable resistors P<sub>1</sub> and P<sub>2</sub> are adjusted until balance point is obtained.)

Note

P<sub>1</sub> adjust the current through the slide wire or current delivered by the driver cell and consequently this changes p.d per cm of the slide wire and directly affects the balance point.

P<sub>2</sub> adjusts the current through the resistors and hence the p.d across them.

If the resistances to be compared are very small, then the balance length L<sub>1</sub> and L<sub>2</sub> will be very small. An end error correction needs to be added for accurate results.

$$\frac{R_1}{R_2} = \frac{L_1}{L_2} \text{ becomes inaccurate}$$

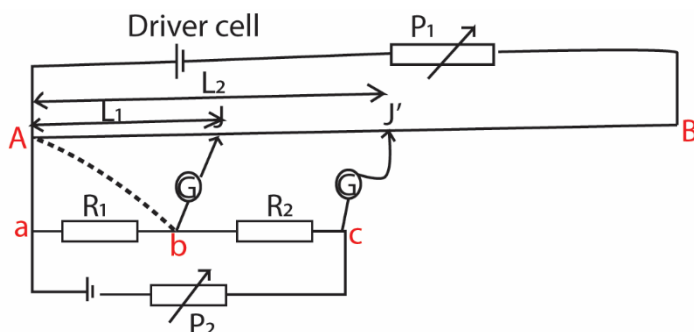
$$\text{For accuracy, } \frac{R_1}{R_2} = \frac{L_1 + e}{L_2 + e}$$

Note that

An end correction is the length of the slide wire which has the same resistance as the contact at the zero end or extreme end of the wire.

How to obtain end correction

- The p.d across R<sub>1</sub> is balanced against the slide wire using the circuit below



- The balance length  $L_1$  is measured and recorded. Let  $e$  be end correction  
At balance  
 $IR_1 = k(L_1 + e)$  .....(i)
- The p.d across  $R_2$  is now balanced against the slide wire and its balance say  $L_2$  is noted  
At balance  
 $IR_2 = k(L_2 + e)$  ..... (ii)
- The p.d across both  $R_1$  and  $R_2$  is now balanced against the slide (with connection at a and c) and the balance length  $L_3$  is noted.  
 $I(R_1 + R_2) = k(L_3 + e)$  ..... (iii)  
The end correction of the wire is obtained from  
( $e = L_3 - (L_1 + L_2)$ )

**Theory**

Add (i) and (ii)

$$I(R_1 + R_2) = k(L_1 + L_2 + 2e)$$
 ..... (iv)

Eqn. (iii) and (iv)

$$L_1 + L_2 + 2e = L_3 + e$$

$$L_1 + L_2 + e = L_3$$

$$e = L_3 - (L_1 + L_2)$$

**Note that:**

- If the e.m.f out of the dry cell is greater than that of the driver cell, the balance point will not be obtained.
- Similarly, if the positive terminal of the driver cell is connected to the negative terminal of the dry cell the balance point cannot be obtained since current flows in one direction.

**Example 37**

When resistors  $4\Omega$  and  $8\Omega$  are connected respectively in the LHG and RHG of meter bridge, balance point is obtained at a point a distance  $32.0\text{cm}$  from left hand of the bridge wire. When the resistors are interchanged a balance point of  $68.0\text{cm}$  from the left is obtained.

The resistance of the slide wire is uniform equal to  $5\Omega$ . Calculate the end error.

**Solution**

If  $e_1$  is the end error on the LHS and  $e_2$  is the end error of RHS

From,

$$\frac{R_1}{L_1 + e} = \frac{R_2}{L_2 + e}$$

$$\frac{4}{32 + e_1} = \frac{8}{68 + e_2}$$

$$2e_1 - e_2 = 4$$
 .....(i)

*on interchanging the resistors,*

$$\frac{4}{68+e_1} = \frac{8}{32+e_2}$$

$$2e_2 - e_1 = 4 \dots\dots\dots(ii)$$

solving simultaneous equation for eqn. (i) and (ii)

$$e_1 = e_2 = 4\text{cm}$$

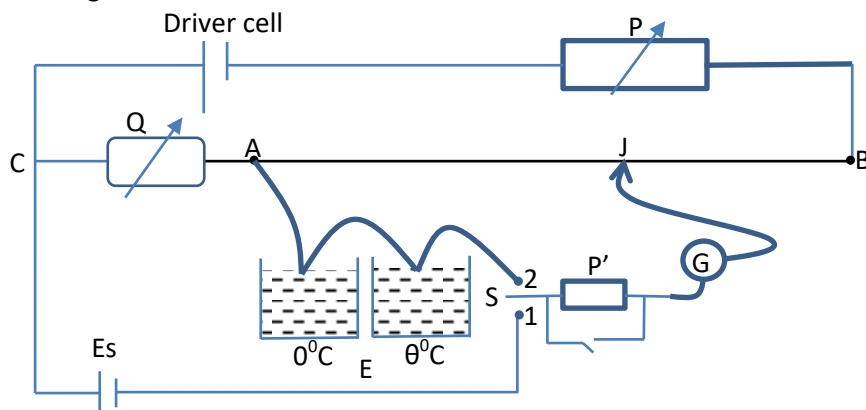
$$\text{resistance per cm} = \frac{5}{100} = 0.05\Omega\text{cm}^{-1}$$

$$\text{resistance } e_1 = e_2 = 4 \times 0.05 = 0.2\Omega$$

### Measurement of thermoelectric e.m.f

Thermoelectric e.m.fs are of order  $10^{-3}$  volts or  $10^{-4}$  volts. In the measurements of thermoelectric e.m.f, the uniform slide wire is connected in series with very high variable resistance and the driver cell so that the current flowing through the wire is very small and consequently the p.d across the wire will be of the same order as the thermoelectric e.m.f to be measured.

The circuit is arranged as shown below:



G – Center zero galvanometer

P' - protective resistor

Es- standard cell

P and Q variable resistors

S – Switch

E - Thermocouple

#### Procedure

- The variable resistor P and Q are first adjusted so that the current flowing through the slide wire is very small and consequently the p.d. across AB is of the same order as thermoelectric e.m.f

- S is put in position 1. With K open, the jockey is placed at different places of the slide wire until the galvanometer shows no deflection. P and Q are adjusted until a measurable/reasonable approximate balance length is obtained. K is then closed and actual balance length  $L_s$  obtained

At balance

$$E_s = V_{CJ} = I(Q + rL_s) \dots \dots \dots (i)$$

Where r is the resistance per cm of the slide wire

- The e.m.f of the thermocouple is now balanced against the slide when S is in position 2; the balance length L is obtained.

At balance

$$E = V_{AJ} = Irl \dots \dots \dots (ii)$$

$$\text{From (i) } I = \frac{E_s}{Q + rL_s} \dots \dots \dots (iii)$$

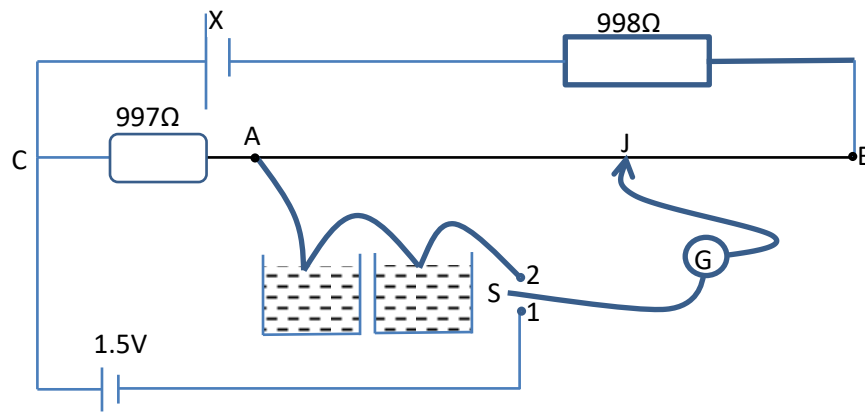
Put (iii) in (ii)

$$E = \frac{E_s r L}{Q + rL_s}$$

Thus, the e.m.f of the thermocouple can be obtained from  $E_s$ , r, L, Q and  $L_s$  which are known.

**Example 38**

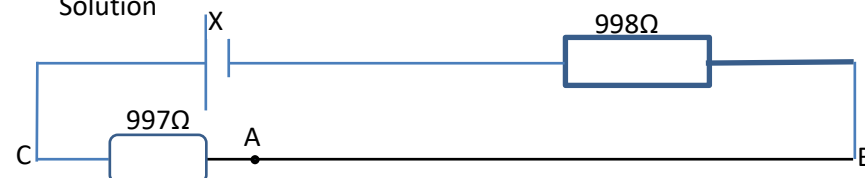
In the figure AB is a uniform slide wire 1m long and having a resistance of 5Ω. X is a cell of unknown e.m.f and having negligible internal resistance.



When S is put in position 1, G shows no deflection when  $AJ = 60.0\text{cm}$ . When S is put in position 2 a balance length of  $40.0\text{cm}$  is obtained. Find

- The current flowing in the slide wire
- The e.m.f of cell X
- The e.m.f of the thermocouple

Solution



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Resistance AB = 5Ω

Total resistance = 997 + 998 + 5 = 2000Ω

Steady current flowing

$$I = \frac{e.m.f}{total\ resistance} = \frac{E_x}{2000} \dots\dots\dots (i)$$

At balance

$$E_s = V_{CJ} = I(997 + R_{AJ}) = 1.5$$

$$\frac{resistance}{cm} = \frac{5}{100} = 0.05\Omega cm^{-1}$$

L = 60cm

$$R_{AJ} = rL = 0.05 \times 60 = 3\Omega$$

$$I(997 + 3) = 1.5$$

$$I = \frac{1.5}{1000} = 1.5 \times 10^{-3} A$$

Current flowing I = 1.5 x 10<sup>-3</sup>A

$$\text{From (i) } E_x = 2000I = 2000 \times 1.5 \times 10^{-3} = 3V$$

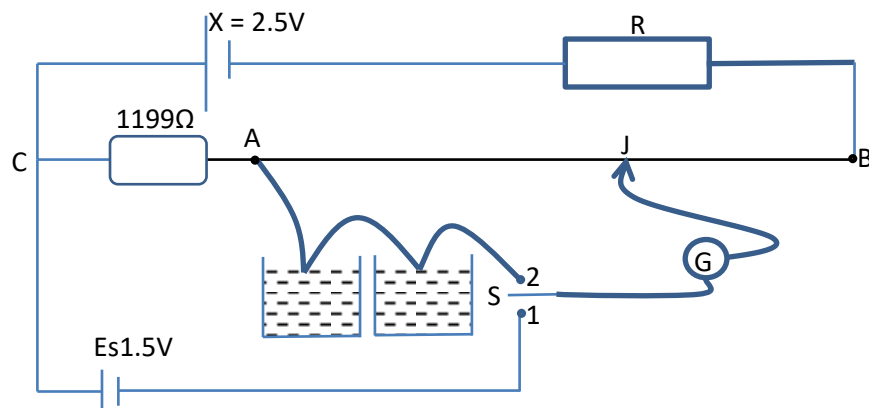
At balance e.m.f of thermocouple E = V<sub>AJ</sub> = IR<sub>AJ</sub>

$$R_{AJ} = rL = 0.05 \times 40 = 2\Omega$$

$$E = 1.5 \times 10^{-3} \times 2 = 3.0mV$$

**Example 39**

In the figure AB is a uniform slide wire 1m long and having a resistance of 4Ω. X is a cell of e.m.f 2.5V and having negligible internal resistance.

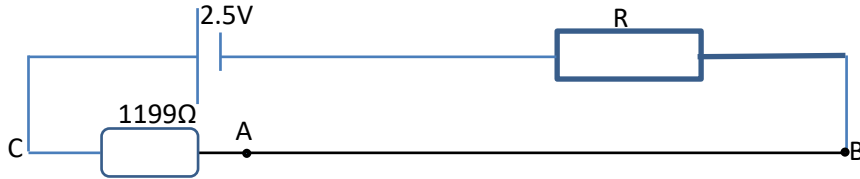


When S is put in position 1, G shows no deflection when AJ = 25.0cm. When S is put in position 2, the balance length changes to 40cm. Find

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- (i) The current flowing
- (ii) The resistance R
- (iii) The e.m.f of thermocouple

**Solution**



Resistance of AB =  $4\Omega$

Total resistance =  $(1199 + 4 + R)\Omega$

Steady current flowing

$$I = \frac{e.m.f}{total\ resistance} = \frac{2.5}{(1199+4+R)} \dots\dots\dots (i)$$

At balance,  $E_s = I(1199 + R_{AJ}) = 1.5$

$$Resistance /cm = \frac{4}{100} = 0.04cm^{-1}$$

$L = 25cm$

$$R_{AJ} = rL = 0.04 \times 25\Omega = 1\Omega$$

$$I = \frac{1.5}{1200} = 1.25 \times 10^{-3}A$$

Current flowing =  $1.25 \times 10^{-3}A$

(ii) From eqn. (i)

$$I = \frac{2.5}{(1199+4+R)} = 1.25 \times 10^{-3}A$$

$$R = 797\Omega$$

(iii) At balance

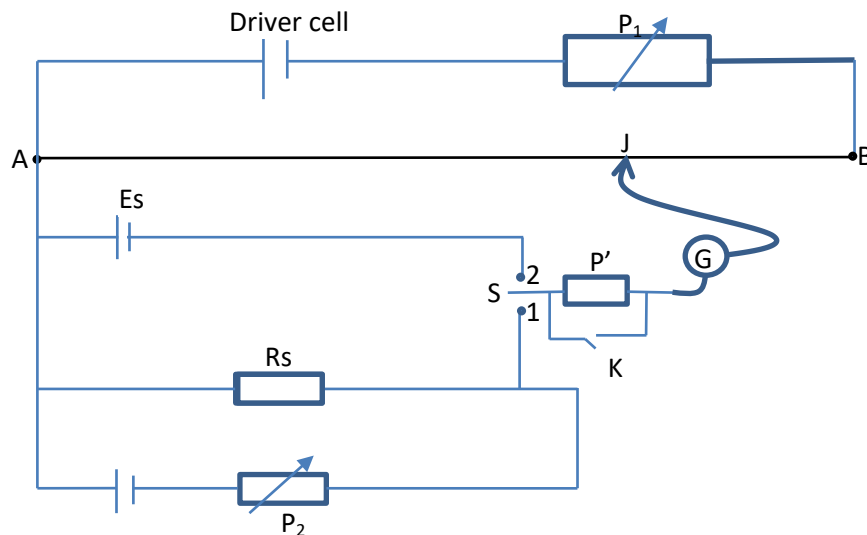
$$E = VAJ = IRAJ$$

$$R_{AJ} = rL = 0.04 \times 40 = 1.6\Omega$$

$$E = 1.24 \times 10^{-3} \times 1.6 = 2mV$$

## Measurement of current

The current flowing through a resistor can be determined by measuring the potential difference which it sets across a standard resistor. The circuit is arranged as shown below:



### Procedure

- (i) The slide wire is first calibrated so that p.d per cm is known. This is done as follows:
- With S in position 1, and K open, the standard cell is balanced against the slide wire.
  - The jockey is placed at different points along the slide wire until the galvanometer shows no deflection. K is then closed and actual balance length,  $L_s$  is measured and recorded.

At balance

$E_s = kL_s$  where  $k$  is the p.d per cm

$$k = \frac{E_s}{L_s} \dots\dots\dots (i)$$

- (ii) The p.d across a standard resistor is now balanced against the slide wire as follows
- With S in position 2 and K open, the rheostats are adjusted the experiment repeated until a measurable approximate balance length obtained, K is then closed, the actual balance length say  $L$  is measured and recorded

At balance

$$I_a R_s = kL \dots\dots\dots (ii)$$

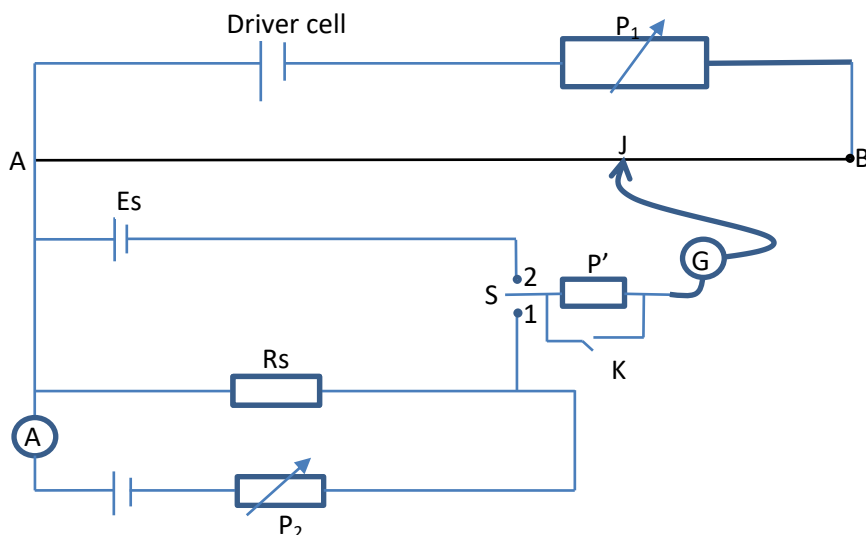
Where  $I_a$  is the actual current flowing in the resistors

$$I_a = \frac{E_s L}{R_s L_s}$$

Thus, the current flowing in the resistors can be obtained from values of  $E_s$ ,  $L_s$ ,  $R_s$  and  $L$ .

## Calibration of an ammeter

The circuit is arranged as shown below



$P_1$  and  $P_2$  = rheostat

$R_s$  = Standard resistor

G = Center zero galvanometer

$E_s$  – Standard cell

AB – Uniform slide wire

A – Ammeter to be calibrated

### Procedure

- The slide wire is first calibrated so that its p.d per cm is known. This is done as follows: with S put in position 1, and K open, the standard cell is balanced against the slide wire until the galvanometer shows no deflection. K is then closed and the actual balance  $L_s$  is measured and recorded.  
At balance  
 $E_s = kL_s$  ..... (i) where k is the p.d. per cm
- The p.d across a standard resistor is now balanced against the slide wire. This is done as follows: with S put in position 2 and K open, the rheostats are adjusted until the ammeter indicates a suitable reading  $I$  and an approximate balance length is obtained. K is then closed and the actual balance length  $L$  is measured.  
At balance  
 $I_a R_s = kL$  .....(ii) where  $I_a$  is the current flowing through the resistors.  
$$I_a = \frac{E_s L}{R_s L_s}$$
- The experiment is repeated for different ammeter readings  $I$  and corresponding balance length,  $L$  are measured and recorded. The results are tabulated including values of  $I_a$ .

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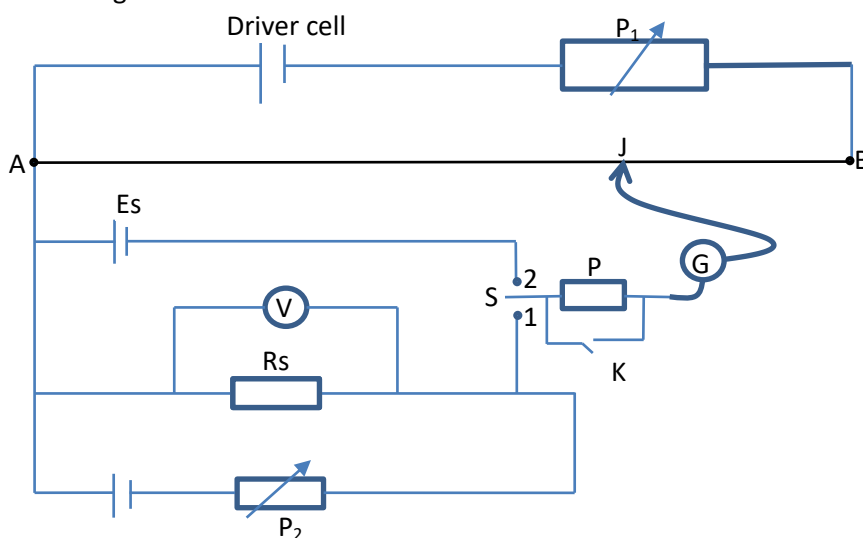
Table of results

| I(A) | L | $I_a$ |
|------|---|-------|
|      |   |       |

A graph of  $I_a$  against I is plotted. This gives a calibration curve for the ammeter.

### Calibration of a voltmeter

The circuit is arranged as shown below



$P_1$  and  $P_2$  = rheostat

$R_s$  = Standard resistor

G = Center zero galvanometer

$E_s$  – Standard cell

AB – Uniform slide wire

V – Voltmeter to be calibrated

J – sliding contact (jockey)

#### Procedure

The standard cell is first balanced against the slide wire. This is done as follows:-

With S placed in position 1 and K open, the jockey is tapped at different places of the slide wire until the galvanometer shows no deflection. This is an approximate point.

K is closed and actual balance length  $L_s$  is measured.

At balance

$$E_s = kL_s \dots\dots\dots(i) \text{ where } k \text{ is the p.d per cm.}$$

The p.d across the standard resistor is now balanced against the slide wire as follows  
With S placed in position 2 and K open, the rheostat  $P_2$  is first adjusted until the voltmeter indicates suitable reading.

The experiment is repeated and an approximate balance length is obtained. K is closed and actual balance length L is measured.

If  $V_a$  is the actual p.d. across, then

At balance

$$V_a = kL \dots\dots\dots (ii) \text{ but } k = \frac{E_s}{L_s}$$

$$V_a = \frac{E_s L}{L_s} \dots\dots\dots(iii)$$

- The experiment is repeated for different voltmeter readings and the corresponding balance lengths, L are obtained.
- The results are tabulated including values of  $V_a$ .

Table of results

| V(V) | L(cm) | $V_a = \frac{E_s L}{L_s}$ |
|------|-------|---------------------------|
|      |       |                           |

A graph of V against V is plotted. This gives a calibration curve for the voltmeter.

### Advantage of potentiometer

- At balance it does not draw current from the circuit and hence the resistance of the connecting wires are irrelevant in the calculations.
- It is more accurate compared to a voltmeter since at balances and does not draw current.
- It can measure a wide range of voltages only limited by the e.m.f of driver cell

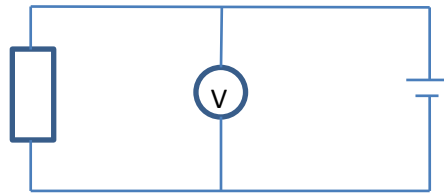
### Disadvantages of a potentiometer

- It does not give direct readings
- It requires a skilled person to operate
- It is bulky

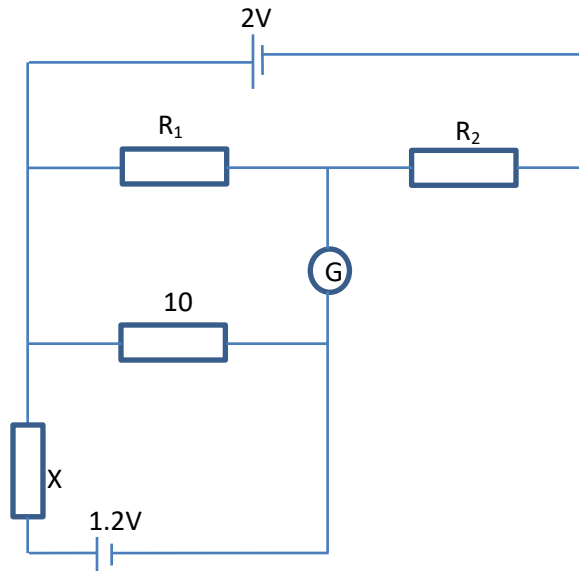
### Example 39

- (a) Define current density and the ohm and state their units.
- (b) (i) Sketch the current versus voltage characteristic for a gas discharge tube.  
(ii) Explain the main features of the graph in (b)(i).

- (c) The figure shows a cell of e.m.f,  $E$  and internal resistance,  $r$ , connected to a voltmeter,  $V$  and variable resistance,  $R$ . explain how the value of  $V$  varies with  $R$ .



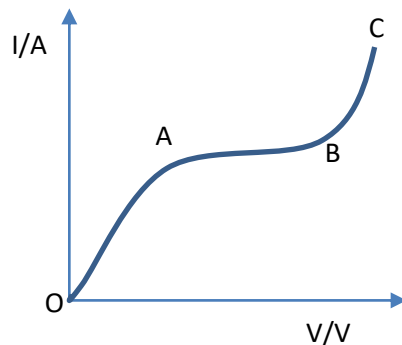
- (d) In figure  $R_1$  and  $R_2$  are resistor of  $10\Omega$  and  $90\Omega$  respectively. If the cells have negligible internal resistances, find the value of  $X$  at which  $G$  shows no deflection



- (e) Describe how the internal resistance of a cell can be measured using a slide wire potentiometer

**Solution**

- (a) Current density is the amount of current flowing through a conductor having a cross sectional area of  $1\text{m}^2$ .  
Ohm is the resistance of a conductor that has a p.d of  $1\text{V}$  across it when carrying a current of  $1\text{A}$ .
- (b) (i)



(ii) Along OA the p.d is low so the electrons and the positive ions have low velocities. Consequently the current flowing is low. The current flowing is also proportional to the applied p.d so ohms law is obeyed

Along AB, all ions produced by the ionizing agent are collected by the electrode. So a constant current called saturated current flows

Also in this region the different velocity is sufficient to prevent appreciable recombination of positive ions and electrons.

Along BC the p.d is high enough to enable the electrons to have sufficient K.e for knocking electrons out of the electrons they collide with. At higher p.d even the electrons produced by collision acquire enough K.e to enable them to cause ionization when they collide with neutral atoms. So there is uncontrollable growth of current and the gas is said to be broken down

- (c) As R increases, I decreases, since r is constant it implies that the quantity Ir decrease. But because E is constant it follows that  $V = E - Ir$  will increase.

When R decreases, I increases, V decreases

- (d) Suppose current flowing in driver circuit is I

$$I = \frac{2}{(10+90)} = 0.02A$$

$$\text{p.d across } R_1 = IR_1 = 0.02 \times 10 = 0.2V$$

$$\text{p.d across } 10\Omega = 0.2V$$

$$\text{but also p.d across } 10\Omega \text{ resistor} = 0.2 = \frac{10}{(x+10)} \times 1.2; x = 50\Omega$$

**Thank you**  
**Dr. Bbosa Science**