PROSPERITY ACADEMY

AS PHYSCIS 9702

Crash Course

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ELECTRICITY

COMPLETE NOTES

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Electricity:-

Charge:-

- Measured in coulombs (C)
- $Q = It$
- Charge can be either +ve or -ve
- Charge is quantised.
- Scalar
- like charges repel, unlike charges attract

Definition:- A charge is a property that causes an object to experience a force in an electric field.

Charge is quantised:-

$$Q = N e$$

↳ elementary charge $= 1.6 \times 10^{-19}$ C

N ↓ Number of elementary charges

Charge is a disbalance of +ve and -ve charges:-

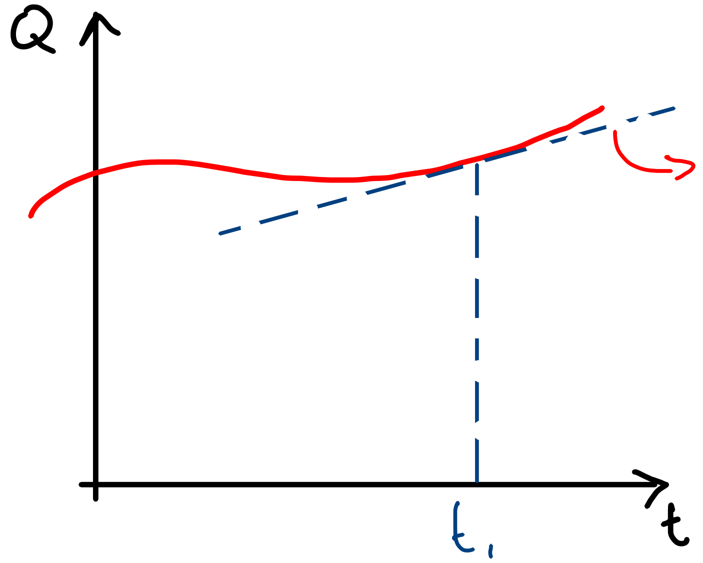
+2C protons -2C electrons	→	+2C protons	or	+4C protons -2C electrons

↳ net charge = 0

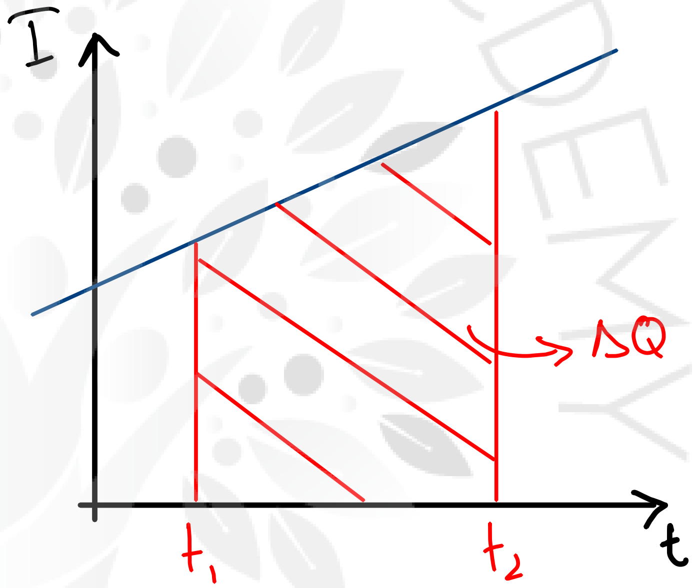
Current :-

Rate of flow of charge. Scalar, measured in Amperes (A).

$I = \frac{dQ}{dt} = \frac{\Delta Q}{\Delta t}$ || $\Delta Q = I \times \Delta t$



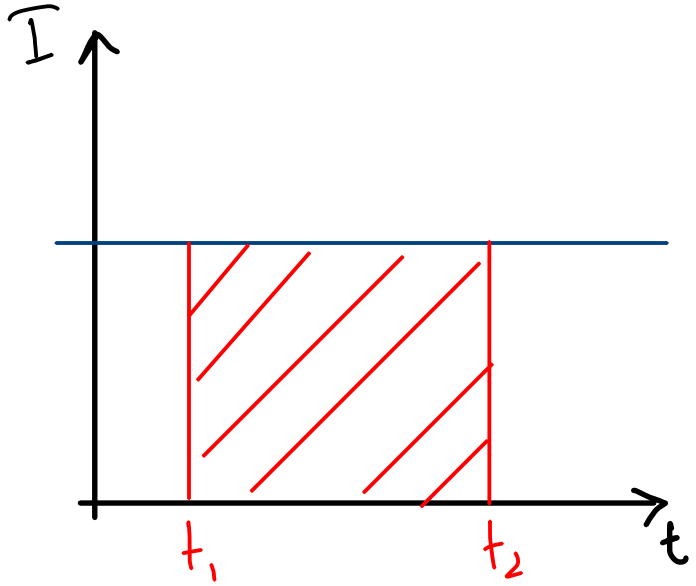
$m = \frac{y_2 - y_1}{x_2 - x_1} = I$



if current is changing then use area under graph

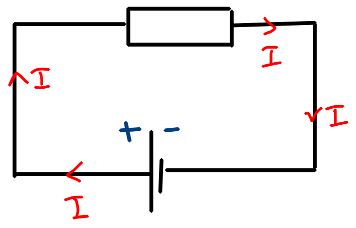
If current is constant :-

$\Delta Q = I \times \Delta t$



We follow conventional current :-

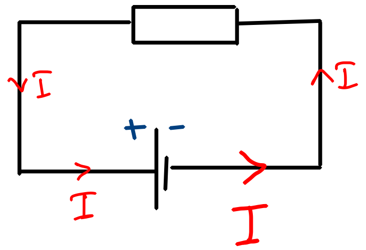
Current → flow of +ve charges



In actuality :-

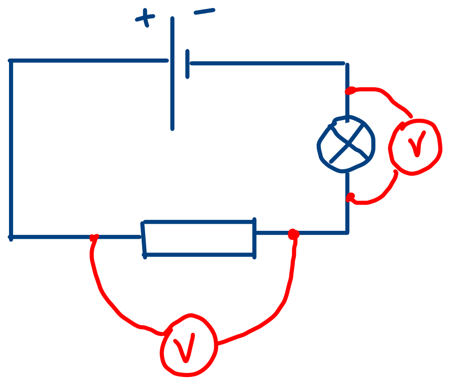
Current is the flow of negative charges / electrons

If examiner asks, follow this



Voltage :- Measured in volts.

1) Potential Difference :-



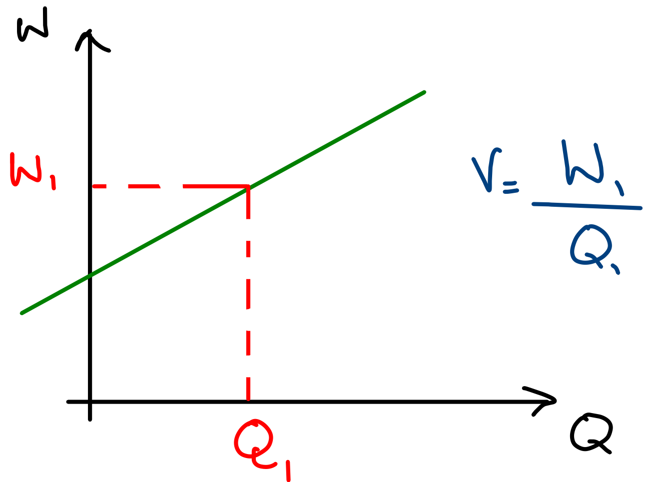
Work done per unit charge in moving that charge from one point to another in a circuit.

or

Work Done per unit charge in converting electrical energy to other forms of energy

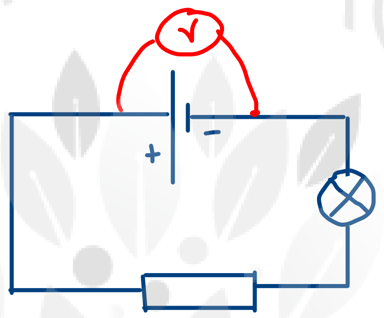
$$\boxed{V = \frac{W}{Q}}$$

ratio



$$V = \frac{W_1}{Q_1}$$

2) Electromotive Force :-



Work done per unit charge in moving that charge around the whole circuit.

or

Work Done per unit charge in converting chemical energy to electrical energy

$$\boxed{V = \frac{W}{Q}}$$

ratio

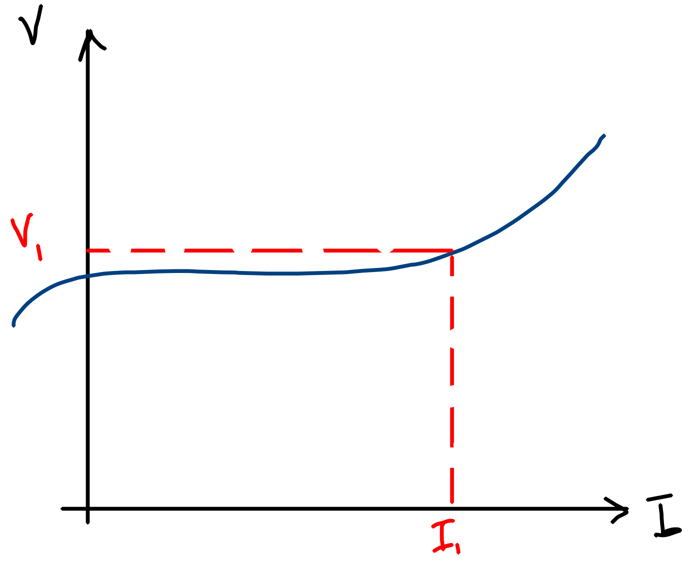
Ohm's law:-

The potential difference across a component is directly proportional to the current given the temperature remains constant.

resistance is constant

$$V \propto I$$

$$\boxed{V = IR} \Rightarrow R = \frac{V}{I} \text{ (ratio)}$$



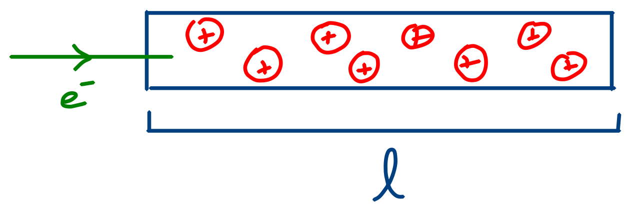
$$R = \frac{V_1}{I_1}$$

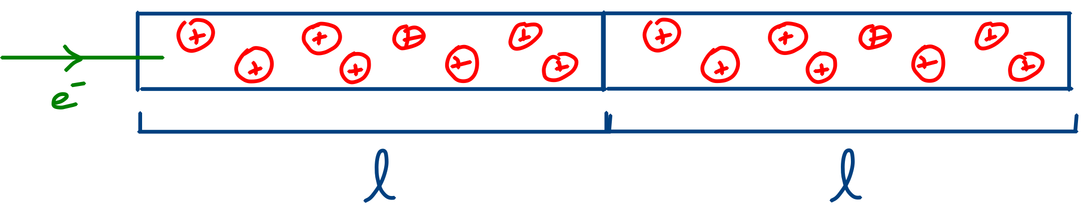
Resistance:- Hindrance to the flow of charge. Scalar, measured in Ohms (Ω).

- $R = \frac{V}{I}$ (ratio)

- Resistance is caused by lattice vibrations.

1) $R \propto l$

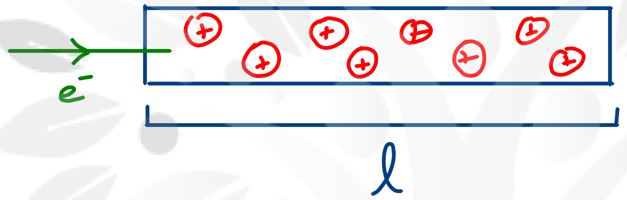




$R = K_1 l$

$\frac{R_1}{l_1} = \frac{R_2}{l_2}$

2) $R \propto T$

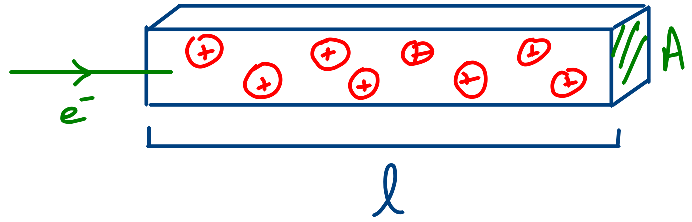


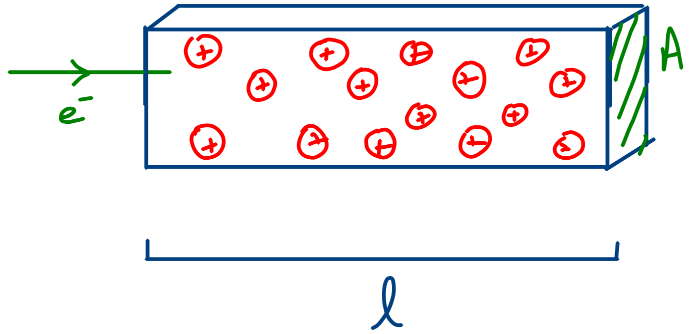
$T\uparrow \rightarrow$ lattice vibrations$\uparrow$

$R = K_2 T$

$\frac{R_1}{T_1} = \frac{R_2}{T_2}$

$R \propto \frac{1}{A}$





$R_1 A_1 = R_2 A_2$

4) $R \propto \frac{l}{A}$

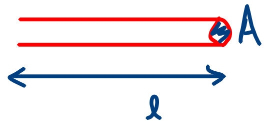
$$\boxed{R = \rho \frac{l}{A}}$$

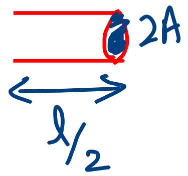
↳ resistivity → constant for a material
constant for a constant temperature

$$\frac{R_1 A_1}{l_1} = \rho = \frac{R_2 A_2}{l_2}$$

Q. A copper wire of length l and cross sectional area A, has resistance R. What is the resistance of another copper wire of length $\frac{l}{2}$ and cross sectional area $2A$

ρ ρ





$$R = \frac{\rho l}{A} \Rightarrow \frac{R_1 A_1}{l_1} = \frac{R_2 A_2}{l_2} \Rightarrow \frac{R \cancel{A}}{\cancel{l}} = \frac{R_2\, 2\cancel{A}}{\cancel{l}/2}$$

$$R = 4R_2 \Rightarrow \boxed{R_2 = \frac{R}{4}}$$

Alt:-

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

$R_2 = \frac{\rho\, l/2}{2A}$

$R_2 = \frac{\rho l}{4A}$ R

$R_2 = \frac{R}{4}$

Is it the voltage that kills or the current?

Resistance of an LED:- $13\ \Omega$

$$V = IR$$

$$9 = I(13)$$

$$\frac{9}{13} = I \simeq 0.7A$$

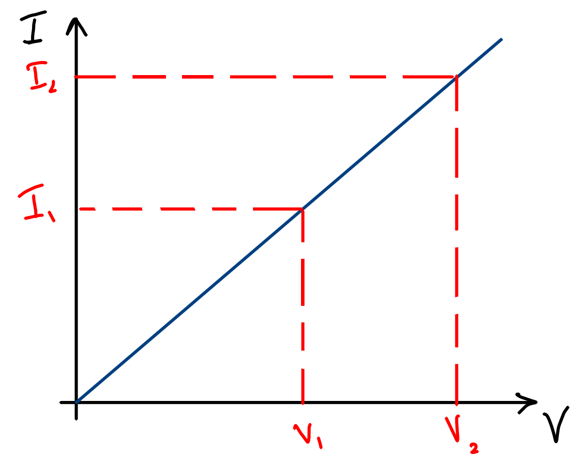
Resistance of a human being:- $10{,}000\ \Omega$

$$9 = I(10000)$$

$$I = 9 \times 10^{-4}\ A$$

It's not the voltage that kills and neither the current kills. Since, everything has a resistance, you need a specific amount of current to kill it, which can only be produced with a high enough voltage.

Ohmic Conductor:- $(V \propto I)$



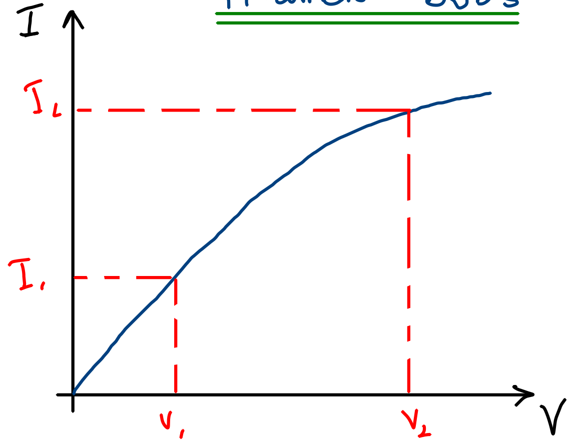
$R = \frac{V_1}{I_1} = \frac{V_2}{I_2}$ const

$V = I R$

(low resistance wire, ideal resistors)

Non ohmic Conductors:-

1) <u>filament bulbs</u>



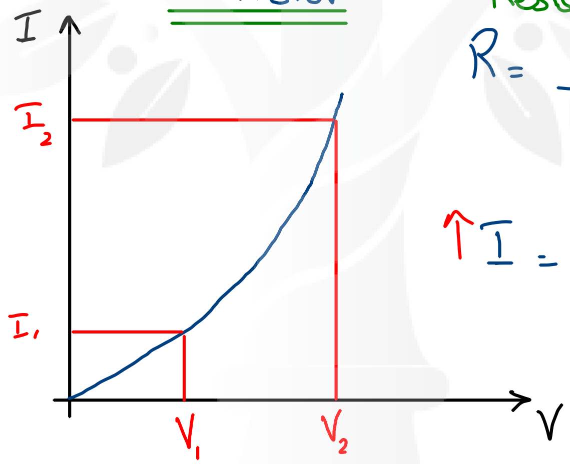
Resistance ↑

$\frac{V_1}{I_1} < \frac{V_2}{I_2}$

$\uparrow V = I\, R\uparrow$ / $\downarrow I = \frac{V}{R\uparrow}$

As current flows, the temperature increase, resistance therefore increases and therefore graph bends towards voltage

2) <u>thermistor</u>



Resistance ↓

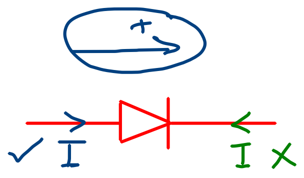
$R = \frac{V_1}{I_1} > \frac{V_2}{I_2}$

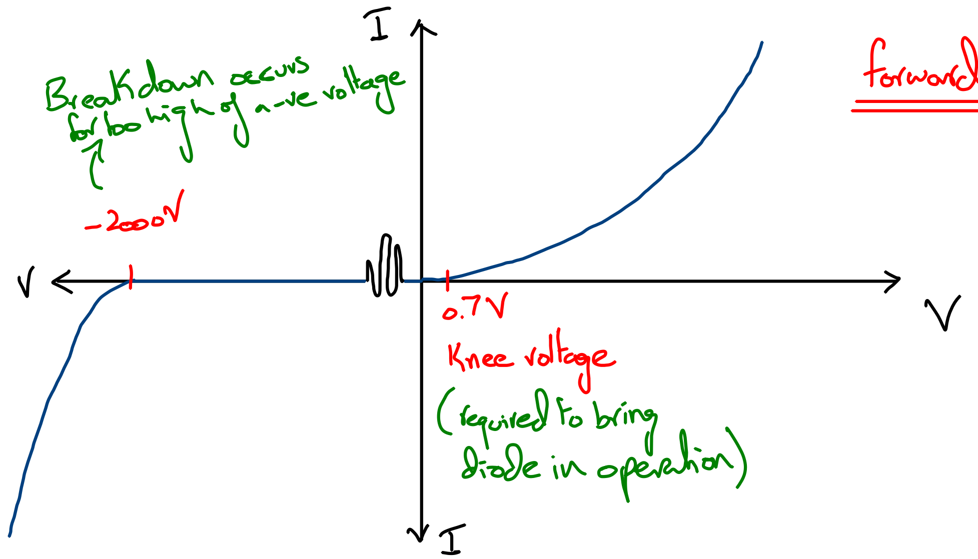
$\uparrow I = \frac{V}{R\downarrow}$

Remember for thermistors:-

As temp ↑, R ↓ } used as a
As temp ↓, R ↑ } thermometer

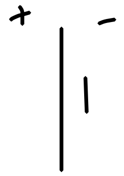
3) <u>Diode</u>

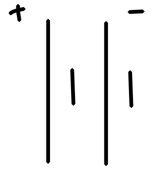


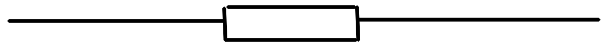


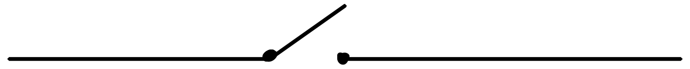
<u>forward bias</u>

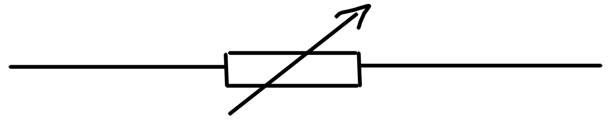
Some important symbols:-

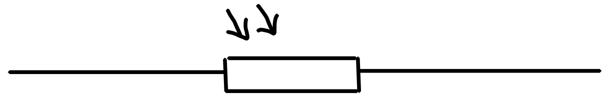
1)  : cell

2)  : battery

3)  : fixed resistor

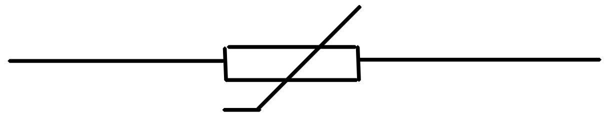
4)  : switch

5)  : variable resistor / rheostat

6)  : Light dependant resistor

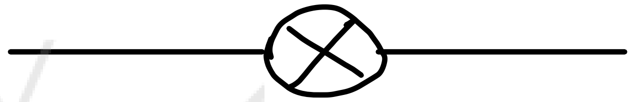
As light intensity on LDR increases, it's resistance decreases

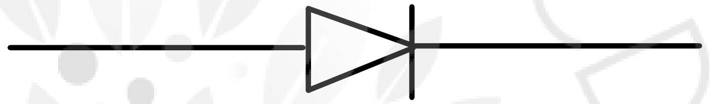
As light intensity on LDR decreases, it's resistance increases

7)  : Thermistor

As temperature increases, it's resistance decreases.

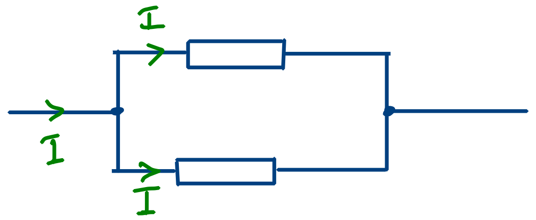
As temperature decreases, it's resistance increases

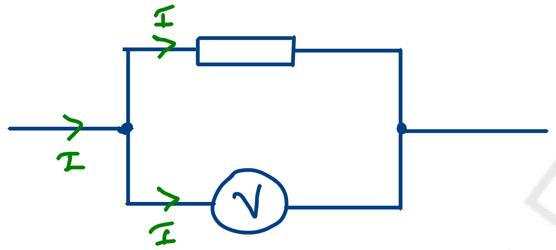
 : Filament bulb

 : Diode

Q. What is a parallel connection?

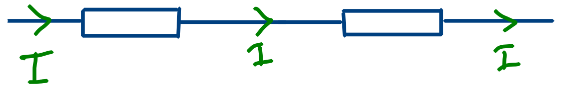
Ans. 2 or more things are connected across each other.



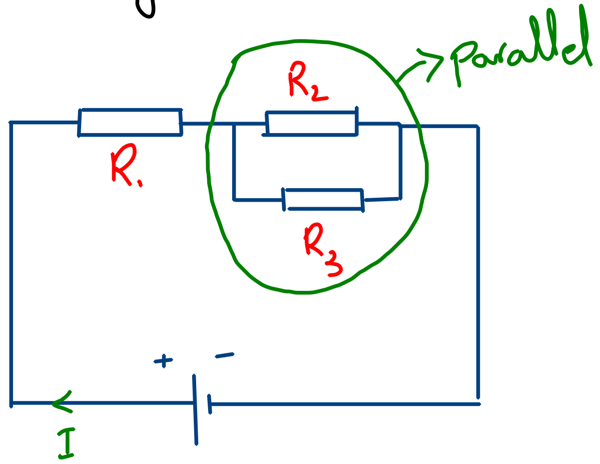


Q. What is a series connection?

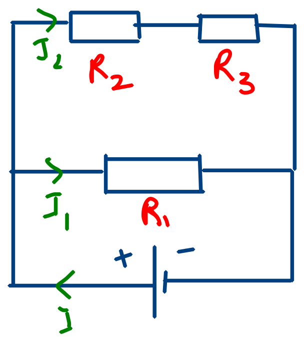
Ans. When 2 or more things are connected one after another (current has only one direction to flow)



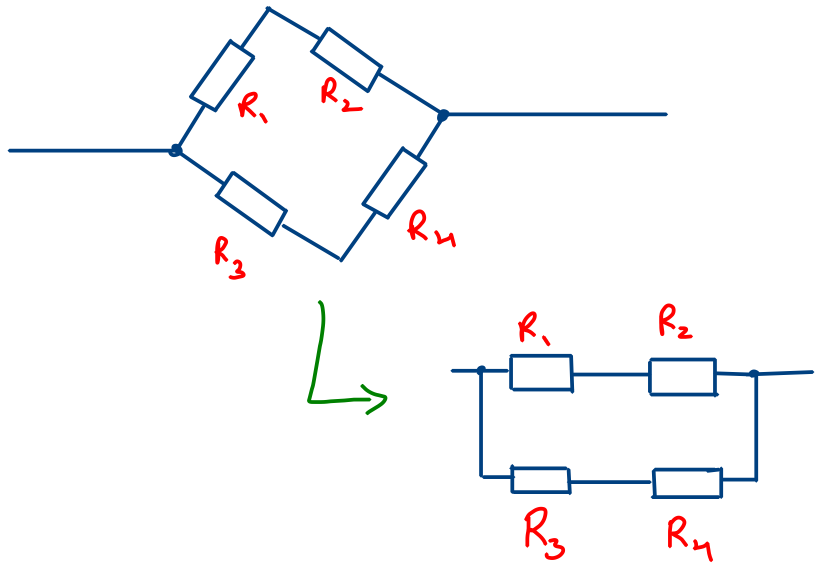
Identify Series or parallel:-



R_1 is in series with the combined resistance of R_2 & R_3 in parallel



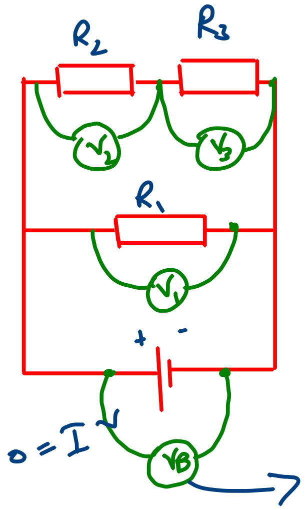
R_2 and R_3 are in series.
R_1 is in parallel to the combined resistance of R_2 & R_3 in series



R_1 and R_2 are in series and R_3 and R_4 are in series. The branches are in parallel.

Voltmeters:-

- measures voltage
- Always connected in parallel
- ideal voltmeters must have ∞ resistance



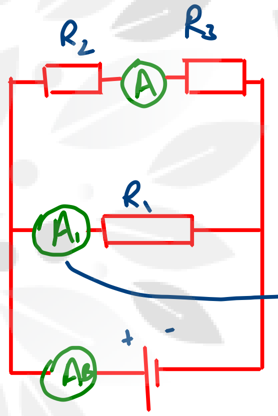
$\rightarrow R = \infty \Rightarrow V = IR \Rightarrow I = \frac{V}{R} = \frac{V}{\infty} = 0$

Why have ∞ resistance:-

- so that no current flows into the voltmeter

Ammeters:-

- measures current
- Always connected in series
- Ideal ammeters have zero resistance



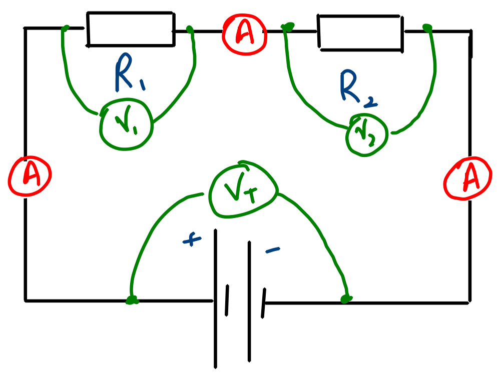
$\rightarrow R = 0 \Rightarrow V = IR$

$V = 0$

Why have 0 resistance:-

- so that there is no hindrance to current due to ammeter resistance
- so that there is no voltage drop across ammeter

Series Circuits:-



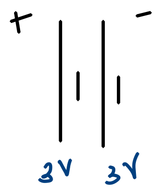
R_1 & R_2 are in series

- Current remains same
- Total voltage is the sum of the individual voltages

$$V_T = V_1 + V_2 + \dots\dots$$

- Total resistance :- $R_T = R_1 + R_2 + \dots\dots$

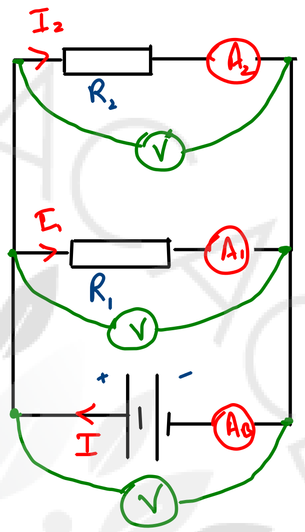
Voltage sources:-



$\Rightarrow V_T = 3 + 3 = 6$

(Application:- increases voltage)

Parallel Circuits:-



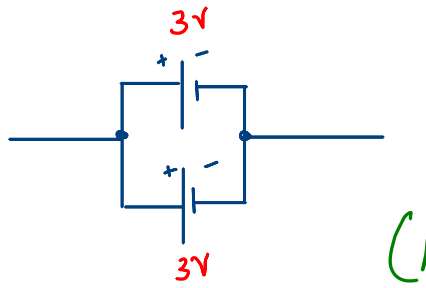
- Voltages are same in parallel
- The total current is the sum of the individual currents

$$I = I_1 + I_2 + \dots\dots$$

- Total resistance:- $\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dots$

$$R_T = \left(\frac{1}{R_1} + \frac{1}{R_2} + \dots\right)^{-1}$$

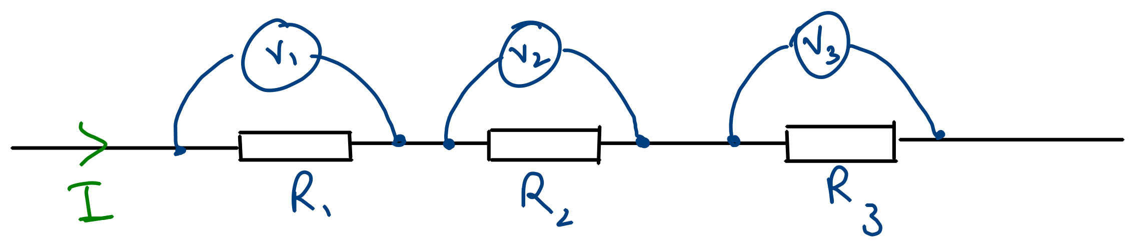
Voltage sources:-



$V_T = 3V$

(Application:- provides more current)

Derivation of resistance in series:-

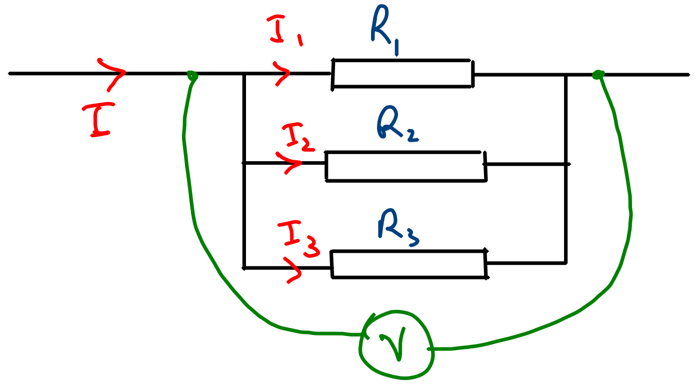


$$V_T = V_1 + V_2 + V_3$$

$$\cancel{I} \times R_T = (\cancel{I} \times R_1) + (\cancel{I} \times R_2) + (\cancel{I} \times R_3)$$

$$R_T = R_1 + R_2 + R_3 + \dots$$

Derivation of resistance in parallel:-

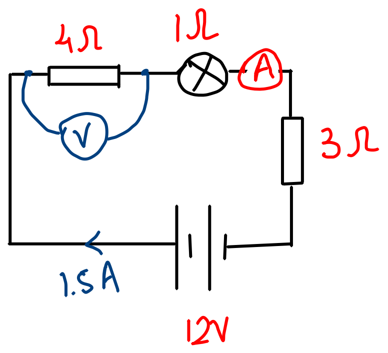


$$I = \frac{V}{R} \Rightarrow I_T = I_1 + I_2 + I_3$$

$$\frac{\cancel{V}}{R_T} = \frac{\cancel{V}}{R_1} + \frac{\cancel{V}}{R_2} + \frac{\cancel{V}}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Exercise #1 :-



Q1. Connect a voltmeter to give P.D of 4Ω resistor?

Q2. Connect an ammeter to give current of the filament lamp?

Q3. The lamp requires 3V to turn on. Will it turn on in this circuit?

$V_T = I_T \times R_T$

$12 = I_T \times (4+1+3)$

$I_T = \frac{12}{8} = 1.5A$

$V = IR$

$V = (1.5) \times 1$

$V = 1.5V$

The lamp will not turn on

Q4. The circuit stays on for one hour. Calculate the total charge that flowed and the work done in moving that charge?

$I_T = \frac{\Delta Q_T}{\Delta t_T} \Rightarrow Q_T = 1.5 \times (60 \times 60)$

$= 5400\,C$

$V = \frac{W}{Q} \Rightarrow W_T = V_T \times Q_T$

$W_T = 12 \times 5400 = 64800\,J$

Q5. What was the work done in moving charge across the 3Ω resistor for 1 hour?

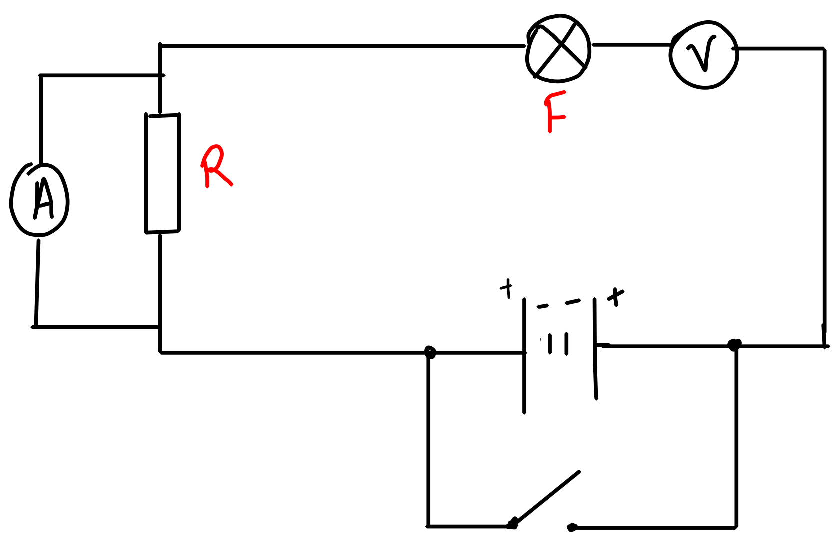
$Q = 5400\,C$

$W = V \times Q$

$W = (1.5)(3) \times 5400 = 24300\,J$

Exercise # 2 :-

John builds the following circuit :-



Q. John closes the switch. Predict what happens?

Ans. The lamp does not turn on

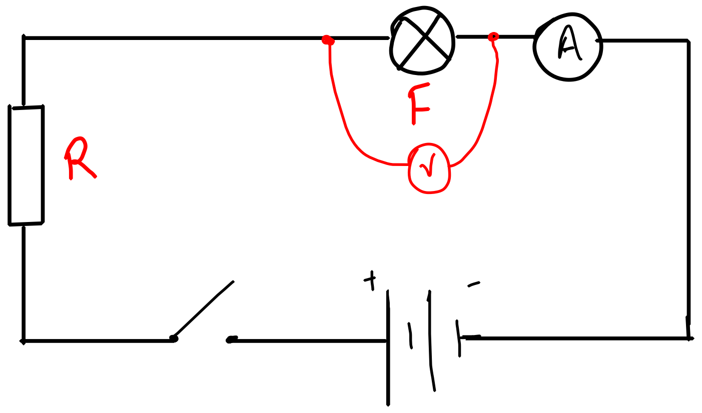
Q. What is a short?

Ans. You give zero resistance path way

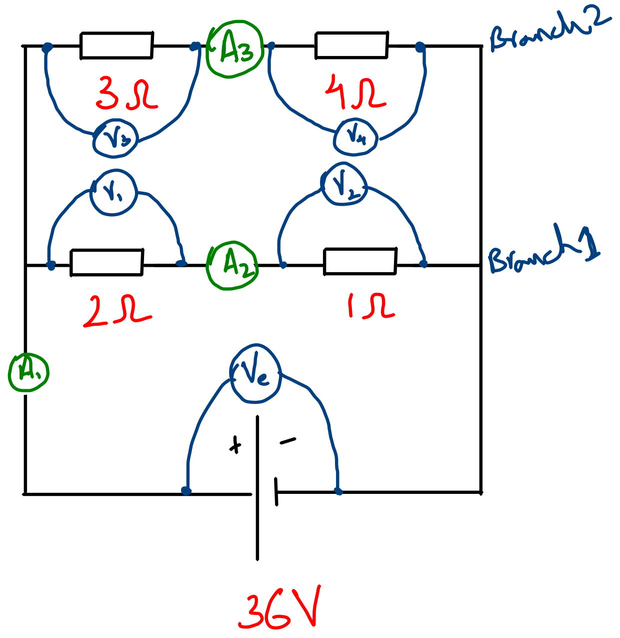
$$I = \frac{V}{R \to 0}$$

$$I = \infty$$

Q. Correct John's circuit. The voltmeter and ammeter must give the voltage and current of the filament lamp.



Exercise #3 :-



Q. Find V_1, V_2, V_3, V_4, V_e, A_1, A_2, A_3.

$V_e = 36V$

A_1 :-

$V_T = I_T \times R_T$

$36 = I_T \times 2.1$

$I_T = \frac{36}{2.1} = 17.14A$

$A_1 = 17.14A$

Branch 1 $R = 1+2 = 3\ \Omega$

Branch 2 $R = 3+4 = 7\ \Omega$

$R_T = \left(\frac{1}{3} + \frac{1}{7}\right)^{-1}$

$R_T = 2.1\ \Omega$

A_2 / Branch 1 current:-

$V = IR$

$36 = I \times 3$

$I = 12A$

$A_2 = 12A$

A_3 / Current in Branch 2:-

$V = IR$

$36 = I\ (7)$

$I = 5.14A = A_3$

V_1 :-

$V = IR$

$V = 12 \times 2$

$V = 24V$

V_2 :-

$V = IR$

$V = 12 \times 1$

$V = 12V$

V_3 :-

$V = IR$

$V = 5.14 \times 3$

$V = 15.42V$

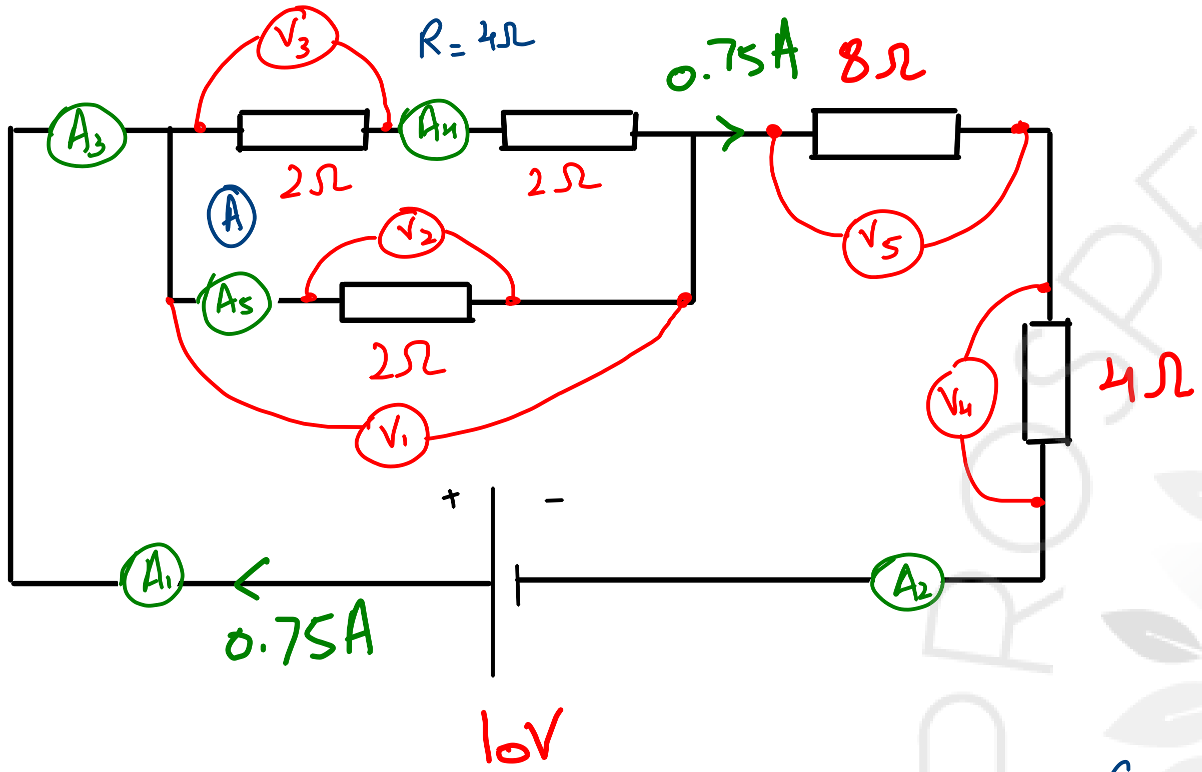
V_4 :-

$V = IR$

$V = 5.14 \times 4$

$V = 20.56V$

Exercise #4 :-



Q. Find $A_1, A_2, A_3, A_4, A_5, V_1, V_2, V_3, V_4, V_5$.

$$R_A = \left(\frac{1}{4} + \frac{1}{2}\right)^{-1}$$
$$= \frac{4}{3}\,\Omega$$

$$V_T = I_T \times R_T$$
$$10 = I_T\left(\frac{4}{3} + 8 + 4\right)$$
$$I_T = 0.75\,A = A_1 \;\&\; A_2 \;\&\; A_3$$

$$V = IR$$
$$V = (0.75)\left(\frac{4}{3}\right)$$
$$V = 1V = V_1 \;\&\; V_2$$

$$V = IR$$
$$1 = I(4)$$
$$I = 0.25A = A_4$$

V_5 :-

$$V = IR$$
$$V = (0.75)(8)$$
$$= 6V$$

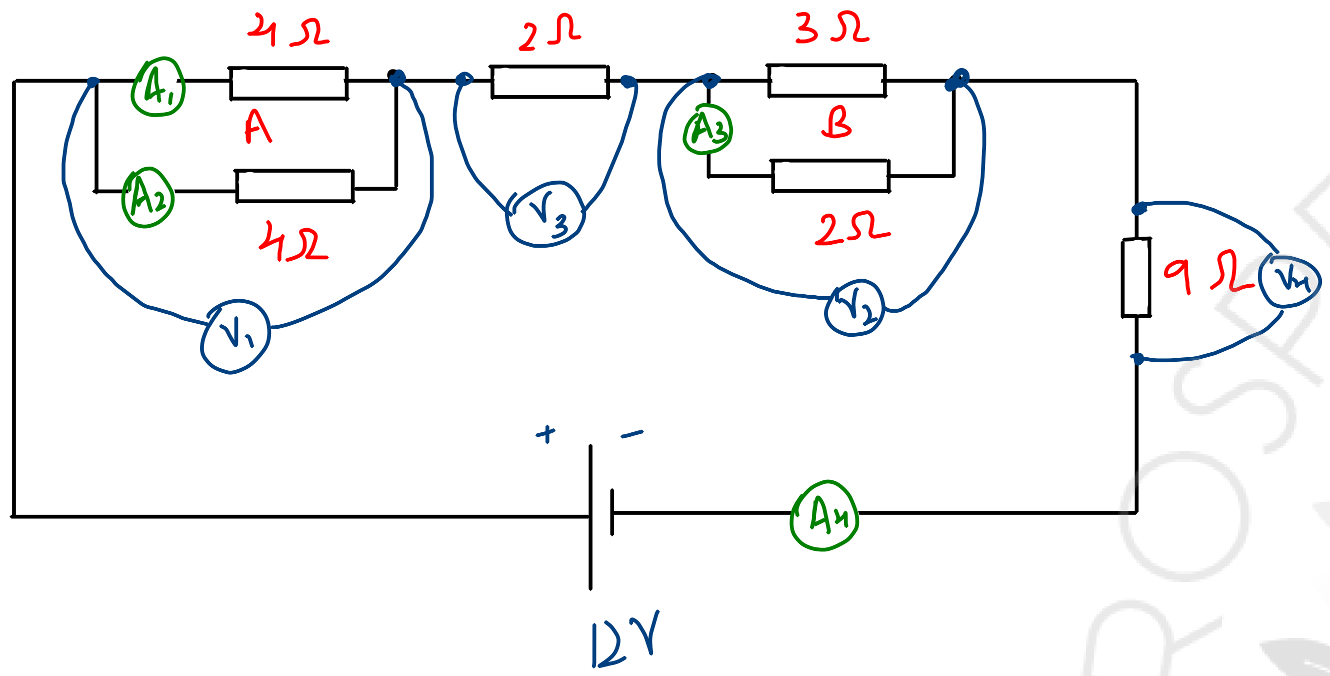
V_4

$$V = IR$$
$$V = (0.75)(4)$$
$$V = 3V$$

$$V = IR$$
$$1 = I(2)$$
$$I = 0.5A = A_5$$

$$V = IR$$
$$V = (0.25)(2)$$
$$V = 0.5\,V = V_3$$

H.W. Exercise:-



$V_T = I_T \times R_T$

$12 = I_T \times (2+2+1.2+9)$

$I_T = 0.845\ A$

$R_A = \left(\frac{1}{4} + \frac{1}{4}\right)^{-1} = 2\ \Omega$

$R_B = \left(\frac{1}{3} + \frac{1}{2}\right)^{-1} = 1.2\ \Omega$

$V_4 = 0.845 \times 9$

$V_4 = 7.605\ V$

$V_1 = I_T \times R_A$
$= 0.845 \times 2$
$= 1.69V$

$V = IR$
$1.69 = I(4)$
$\frac{1.69}{4} = I$
$I = 0.423\ A = A_1 = A_2$

$V_3 = IR$
$V_3 = 0.845 \times 2$
$V_3 = 1.69V$

$V_2 = I_T \times R_B$
$V_2 = 0.845 \times (1.2)$
$V_2 = 1.014V$

$V_2 = I \times R$
$1.014 = I \times 2$
$I = 0.507\ A = A_3$

Electrical power and Energy:-

$$P = \frac{dW}{dt} \qquad V = \frac{W}{Q} \Rightarrow W = V \times Q$$

$$P = \frac{d(V \times Q)}{dt}$$

$$P = V\left(\frac{dQ}{dt}\right) \Rightarrow \boxed{P = IV} \quad ①$$

$$P = I(IR) \qquad V = IR$$

$$\boxed{P = I^2R \quad ②}$$

$$P = IV \qquad I = \frac{V}{R}$$

$$P = \frac{V}{R} \times V$$

$$\boxed{P = \frac{V^2}{R}} \quad ③$$

$$P = \frac{\Delta W}{\Delta t}$$

$$\Delta W = P \times \Delta t$$

$$\boxed{E = IVt \quad \text{or} \quad E = I^2Rt \quad \text{or} \quad E = \frac{V^2}{R}t}$$

Q. Is it the voltage or current Kills?

$\downarrow E = IVt\downarrow$ Time is also required to kill

w18 qp22 q6

6 (a) Define the *volt*.

It is joule / coulomb

....[1]

(b) A battery of electromotive force (e.m.f.) 7.0 V and negligible internal resistance is connected in series with three components, as shown in Fig. 6.1.

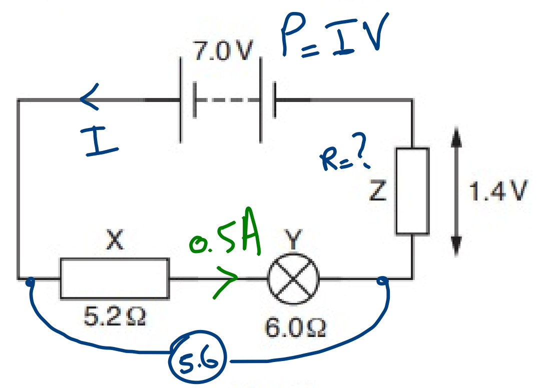


Fig. 6.1

Resistor X has a resistance of 5.2 Ω. The resistance of the filament wire of lamp Y is 6.0 Ω. The potential difference across resistor Z is 1.4 V.

(i) Calculate the current in the circuit.

① $7 - 1.4 = I(5.2 + 6)$

$I = 0.5\,A$

② $V_T = V_1 + V_2 + V_3$

$7 = I(5.2) + I(6) + 1.4$

$I = 0.5\,A$

current = ...0.50........ A [2]

(ii) Determine the resistance of resistor Z.

$V = IR \Rightarrow \dfrac{1.4}{0.5} = R$

resistance = ...2.8........ Ω [1]

(iii) Calculate the percentage efficiency with which the battery supplies power to the lamp.

$\eta = \dfrac{P \text{ in lamp}}{P \text{ by battery}} \times 100 = \dfrac{I^2R}{IV} \times 100 = \dfrac{(0.5)^2 \times 6}{(0.5) \times 7} \times 100$

$= 43\,\%$

efficiency = ...43........ % [3]

(iv) The filament wire of the lamp is made of metal of resistivity $3.7 \times 10^{-7}\,\Omega\,m$ at its operating temperature in the circuit.

ρ $\left(R = \dfrac{\rho l}{A}\right)$

Determine, for the filament wire, the value of α where

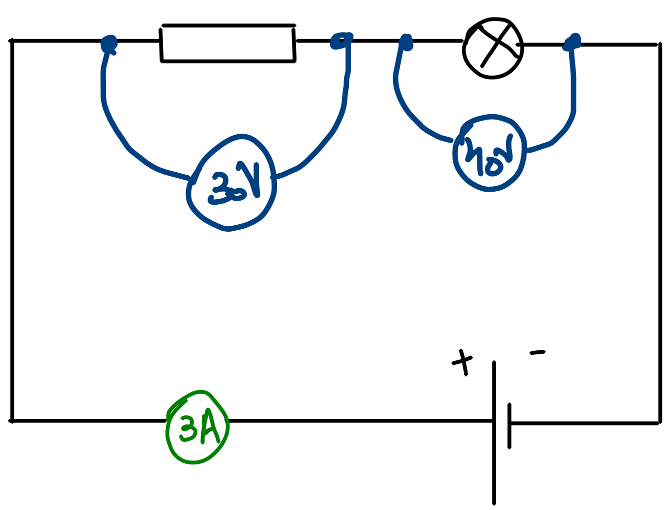
$$\alpha = \frac{\text{cross-sectional area}}{\text{length}}.$$

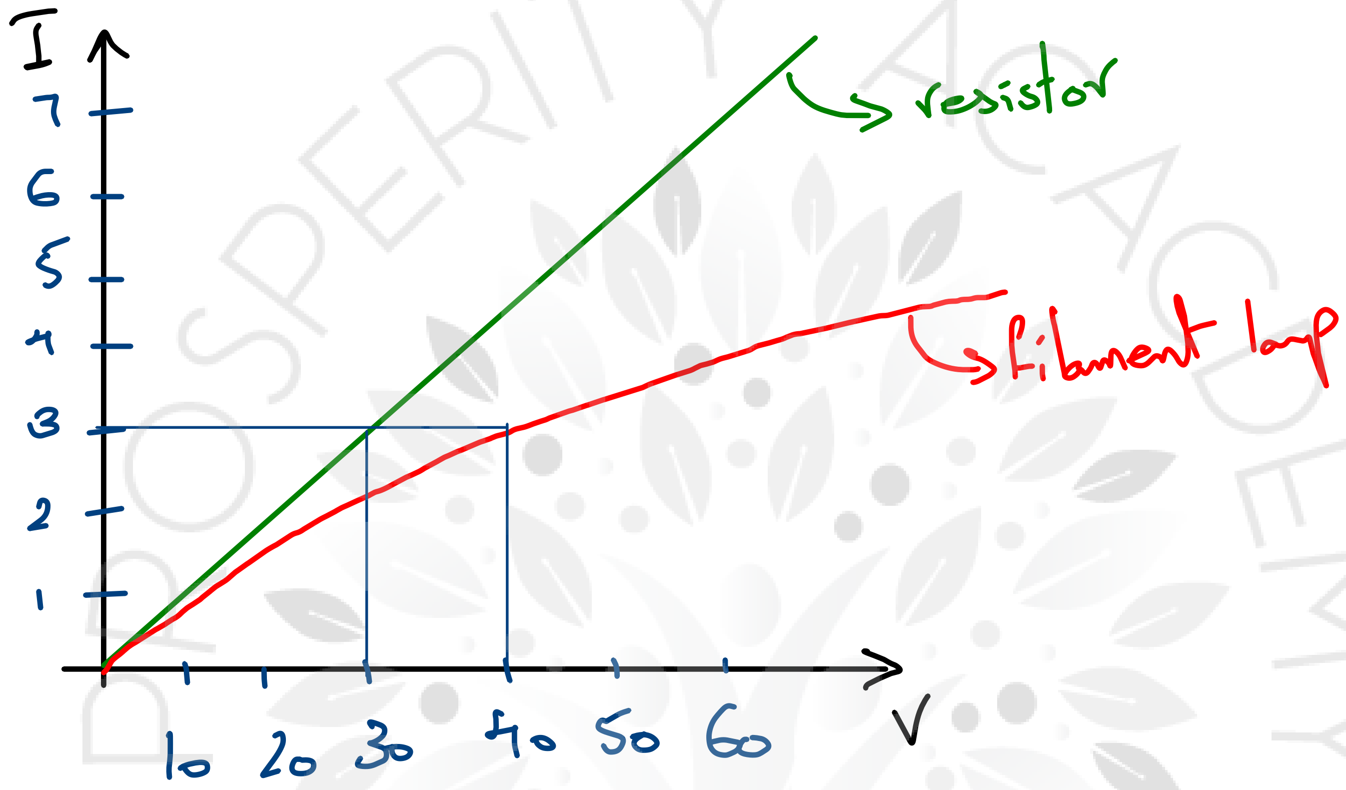
$R = \dfrac{\rho l}{A} \Rightarrow \dfrac{A}{l} \rightarrow \alpha = \dfrac{\rho}{R} \Rightarrow \alpha = \dfrac{\rho}{R} = \dfrac{3.7 \times 10^{-7}}{6} = 6.2 \times 10^{-8}$

α = ...6.2×10^{-8}........ m [2]

[Total: 9]

Exercise # 5 :-

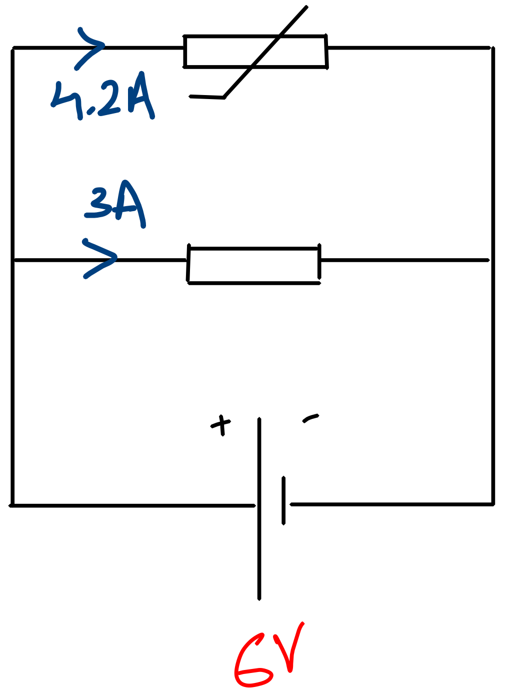


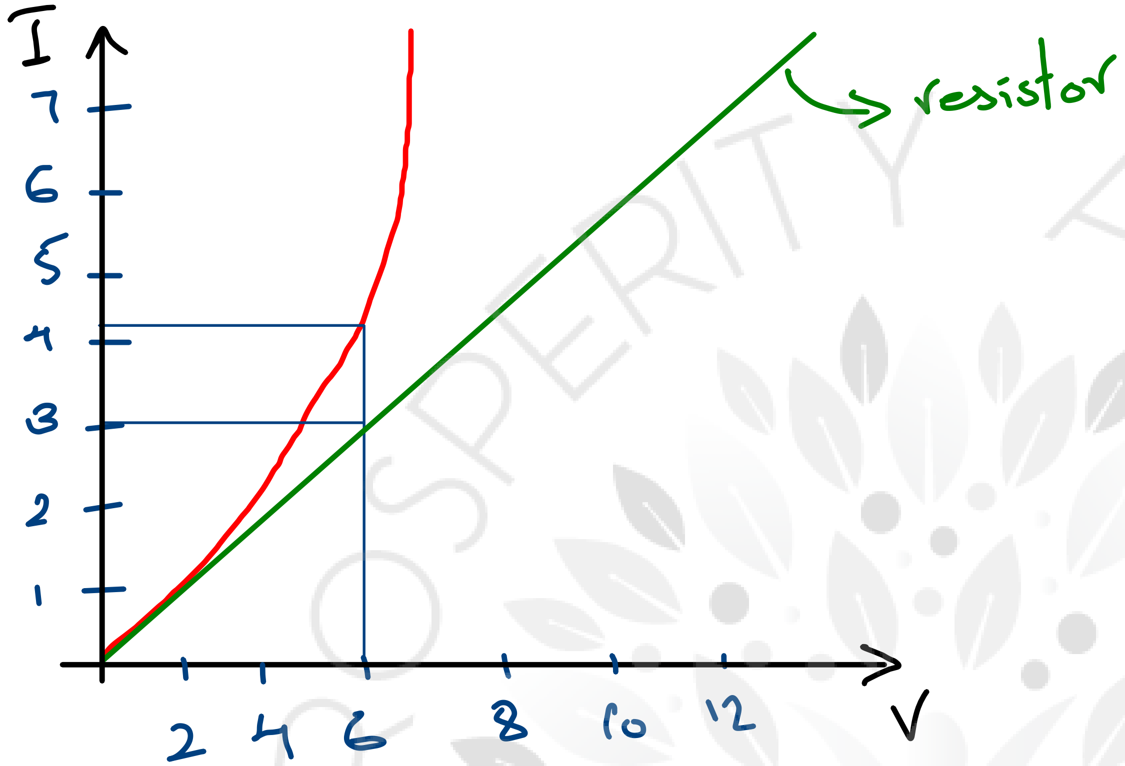


Q. What is the e.m.f of the battery?

$V_T = 30 + 40 = 70V$

Exercise # 6 :-





Q. What is the current in both branches and the total current?

$$I_T = 3 + 4.2 = 7.2\,A$$

s18 qp21 q6

6 **(a)** Define the *volt*.

joule / coulomb ....[1]

(b) A battery of electromotive force (e.m.f.) 4.5 V and negligible internal resistance is connected to two filament lamps P and Q and a resistor R, as shown in Fig. 6.1.

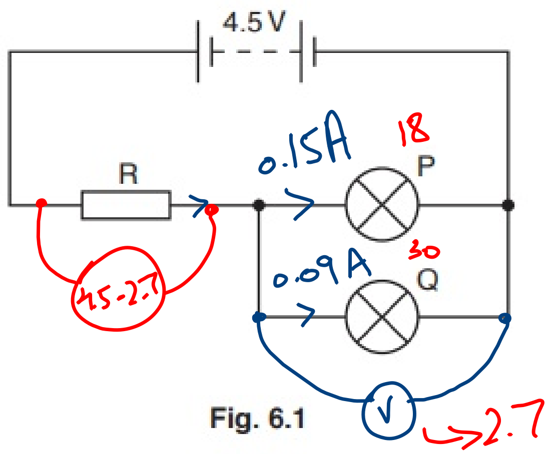


Fig. 6.1

$$R_T = \left(\frac{1}{18} + \frac{1}{30}\right)^{-1} = 11.25\,\Omega$$

$$\uparrow V = IR \uparrow$$

The current in lamp P is 0.15 A.
The I–V characteristics of the filament lamps are shown in Fig. 6.2.

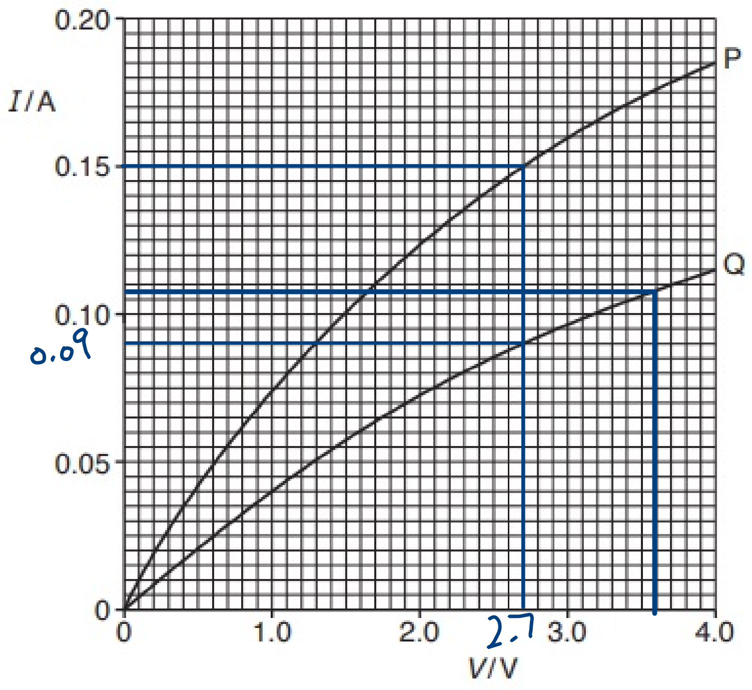


Fig. 6.2

$$R_P = \frac{2.7}{0.15} = 18\,\Omega$$

$$R_Q = \frac{2.7}{0.09} = 30\,\Omega$$

(i) Use Fig. 6.2 to determine the current in the battery. Explain your working.

Both lamps will have same p.d. as they are in parallel

$$I_T = 0.15 + 0.09 = 0.24\text{A}$$

current = ...0.24.... A [2]

(ii) Calculate the resistance of resistor R.

$$R = \frac{V}{I} = \frac{4.5 - 2.7}{0.24}$$

$$= 7.5\,\Omega$$

resistance = ...7.5 Ω.... Ω [2]

(iii) The filament wires of the two lamps are made from material with the same resistivity at their operating temperature in the circuit. The diameter of the wire of lamp P is twice the diameter of the wire of lamp Q.

Determine the ratio

$$\frac{\text{length of filament wire of lamp P}}{\text{length of filament wire of lamp Q}}.$$

Wire Q	Wire P
ρ	ρ
l_Q	l_P
d	$2d$
$30\,\Omega$	$18\,\Omega$

$$R = \frac{\rho l}{A} \Rightarrow l = \frac{AR}{\rho} \Rightarrow l = \frac{\pi d^2 \times R}{4\rho}$$

$$\frac{l_P}{l_Q} = \frac{\pi (2d)^2 \times 18}{4\rho} \div \left(\frac{\pi d^2 \times 30}{4\rho}\right) \Rightarrow \frac{\cancel{\pi} \times 4\cancel{d^2} \times 18}{\cancel{4\rho}} \times \frac{\cancel{4\rho}}{\cancel{\pi d^2} \times 30} = \frac{4 \times 18}{30} = 2.4$$

ratio = ...2.4.... [3]

(iv) The filament wire of lamp Q breaks and stops conducting.

State and explain, qualitatively, the effect on the resistance of lamp P.

The voltage across lamp P increases. As the voltage increases, there is a greater current through P and therefore its resistance also increases.

....................[2]

w19 qp22 q6

6 (a) ~~State Kirchhoff's first law.~~

~~...~~

~~... [1]~~

(b) The variations with potential difference V of the current I for a resistor X and for a semiconductor diode are shown in Fig. 6.1.

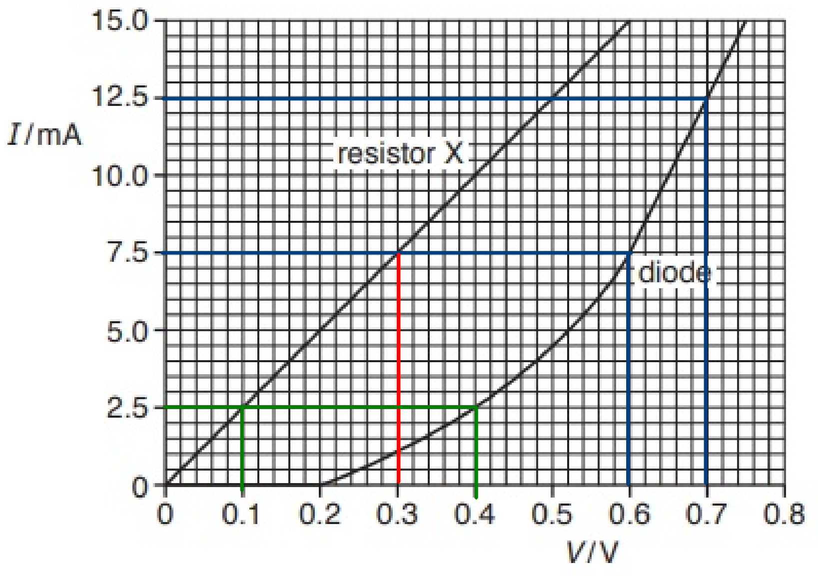


Fig. 6.1

(i) Determine the resistance of the diode for a potential difference V of 0.60 V.

$R = \frac{V}{I} = \frac{0.6}{7.5\times10^{-3}} = 80$

resistance = ...80........ Ω [3]

(ii) Describe, qualitatively, the variation of the resistance of the diode as V increases from 0.60 V to 0.75 V.

........decreases........ [1]

$R = \frac{0.7}{12.5\times10^{-3}} = 56\Omega$

(c) The diode and the resistor X in **(b)** are connected into the circuit shown in Fig. 6.2.

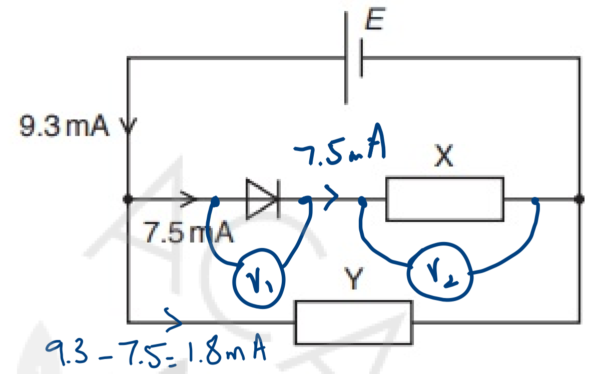


Fig. 6.2

The cell has electromotive force (e.m.f.) E and negligible internal resistance. Resistor Y is connected in parallel with resistor X and the diode. The current in the cell is 9.3 mA and the current in the diode is 7.5 mA.

(i) Use Fig. 6.1 to determine E.

$0.6 + 0.3$

E = ...0.90........ V [1]

(ii) Determine the resistance of resistor Y.

$V = IR$

$0.90 = (1.8\times10^{-3})R_y$

$R_y = 500$

resistance = ...500........ Ω [2]

(iii) Calculate the power dissipated in the diode.

$P = IV$

$= (7.5\times10^{-3})(0.6)$

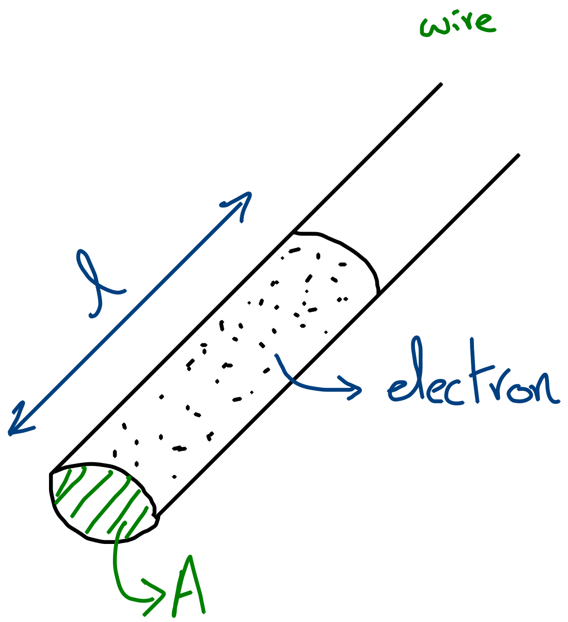
$= 4.5\times10^{-3}$

power = ...4.5×10^{-3}........ W [2]

(iv) The cell is now replaced by a new cell of e.m.f. 0.50 V and negligible internal resistance. Use Fig. 6.1 to determine the new current in the diode.

current = ...2.5........ mA [1]

$I = nAve$:-



→ electron density (n) :- No of electrons per unit volume (constant for a material) [unit : m^{-3}]

N (number of electrons) $\Rightarrow N = n \times V$

$\Rightarrow N = n \times A \times l$

$Q = Ne$

$Q = n \times A \times l \times e$

$$I = \frac{dQ}{dt} = \frac{d(\overbrace{n \times A \times l \times e}^{\text{const}})}{dt} = n \times A \times e \times \frac{dl}{dt}$$

$$\boxed{I = n \times A \times v \times e}$$

↳ drift velocity of electrons

6 ~~(a) State Kirchhoff's second law.~~

....

....

.... [2]

(b) An electric heater containing two heating wires X and Y is connected to a power supply of electromotive force (e.m.f.) 9.0 V and negligible internal resistance, as shown in Fig. 6.1.

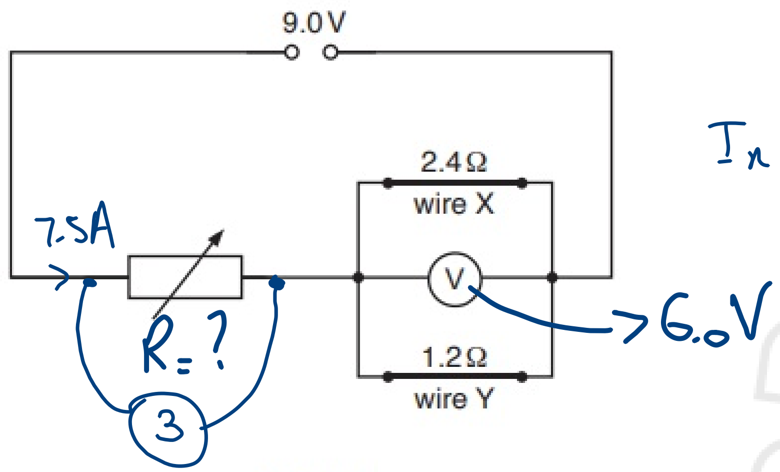


Fig. 6.1

$I_x = \frac{6}{2.4} = 2.5$

$I_y = \frac{6}{1.2} = 5$

Wire X has a resistance of 2.4 Ω and wire Y has a resistance of 1.2 Ω. A voltmeter is connected in parallel with the wires. A variable resistor is used to adjust the power dissipated in wires X and Y.

The variable resistor is adjusted so that the voltmeter reads 6.0 V.

(i) Calculate the resistance of the variable resistor.

$R_{xy} = \left(\frac{1}{2.4} + \frac{1}{1.2}\right)^{-1} = 0.80\ \Omega$

$I = \frac{V}{R} = \frac{6}{0.8} = 7.5\text{A}$ $\qquad R = \frac{V}{I} = \frac{3}{7.5}$

resistance = ...0.40...... Ω [3]

(ii) Calculate the power dissipated in wire X.

$P = \frac{V^2}{R} = \frac{6^2}{2.4} = 15$

power = ...15...... W [2]

(iii) The cross-sectional area of wire X is three times the cross-sectional area of wire Y. Assume that the resistivity and the number density of free electrons for the metal of both wires are the same.

Wire X: $3A$, ρ, n, $2.4\ \Omega$

Wire Y: A, ρ, n, $1.2\ \Omega$

Determine the ratio

1. $\frac{\text{length of wire X}}{\text{length of wire Y}}$,

$R = \frac{\rho l}{A} \Rightarrow \frac{R_1 A_1}{l_1} = \frac{R_2 A_2}{l_2}$

$\frac{(\cancel{2.4}^{2})(3\cancel{A})}{l_x} = \frac{(\cancel{1.2})(\cancel{A})}{l_y} \Rightarrow 6 = \frac{l_x}{l_y}$

ratio = ...6.0...... [2]

2. $\frac{\text{average drift velocity of free electrons in wire X}}{\text{average drift velocity of free electrons in wire Y}}$.

$I = nAve$

$v = \frac{I}{nAe}$

$\frac{v_x}{v_y} = \frac{I_x}{n \times 3A \times e} \div \frac{I_y}{n \times A \times e}$

$= \frac{I_x}{\cancel{n} \times 3\cancel{A} \times \cancel{e}} \times \frac{\cancel{n} \times \cancel{A} \times \cancel{e}}{I_y} = \frac{2.5}{3(5)} = 0.16667$

ratio = ...0.17...... [2]

w17 qp22 q6

6 (a) State what is meant by an *electric current*.

It is the rate of flow of charge ....[1]

(b) A metal wire has length L and cross-sectional area A, as shown in Fig. 6.1.

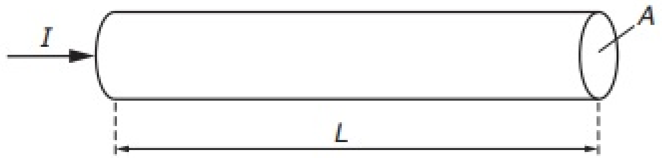


Fig. 6.1

$N = n \times V$
$= n \times A \times l$
$Q = Ne$
$Q = n \times A \times l \times e$

I is the current in the wire,
n is the number of free electrons per unit volume in the wire,
v is the average drift speed of a free electron and
e is the charge on an electron.

(i) State, in terms of A, e, L and n, an expression for the total charge of the free electrons in the wire.

$Q = n \times A \times l \times e$ ....[1]

(ii) Use your answer in (i) to show that the current I is given by the equation

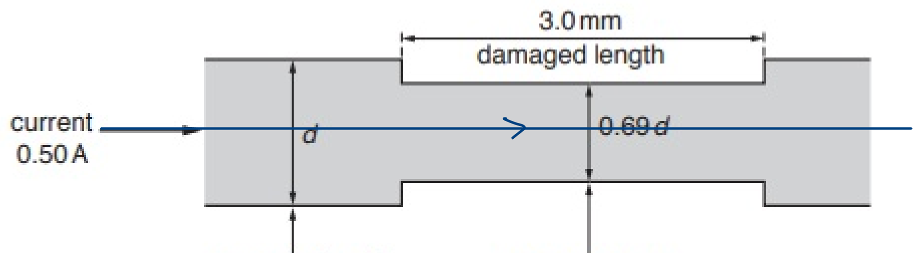
$I = nAve$.

$$I = \frac{dQ}{dt} \Rightarrow \frac{d(n \times A \times l \times e)}{dt} = n \times A \times e \times \frac{dl}{dt}$$
$$= \boxed{n \times A \times v \times e}$$

shown [2]

n same   ρ same

(c) A metal wire in a circuit is damaged. The resistivity of the metal is unchanged but the cross-sectional area of the wire is reduced over a length of 3.0 mm, as shown in Fig. 6.2.



$A_x = \frac{\pi d^2}{4}$ $A_y = \frac{\pi (0.69d)^2}{4} = \pi \times 0.69^2 \times$

Fig. 6.2

The wire has diameter d at cross-section X and diameter $0.69d$ at cross-section Y.
The current in the wire is 0.50 A.

(i) Determine the ratio

$$\frac{\text{average drift speed of free electrons at cross-section Y}}{\text{average drift speed of free electrons at cross-section X}}.$$

$$v = \frac{I}{nAe} \qquad \frac{v_y}{v_x} = \frac{I}{nA_ye} \div \frac{I}{nA_xe}$$
$$= \frac{\cancel{I}}{\cancel{n}A_y\cancel{e}} \times \frac{\cancel{n}A_x\cancel{e}}{\cancel{I}} \Rightarrow \frac{A_x}{A_y} = \frac{\cancel{\pi}\cancel{d^2}}{\cancel{4}} \times \frac{\cancel{4}}{\cancel{\pi} \times 0.69^2 \times \cancel{d^2}} = \frac{1}{0.69^2}$$

ratio = 2.1 ....[2]

(ii) The main part of the wire with cross-section X has a resistance per unit length of $1.7 \times 10^{-2}\,\Omega\,m^{-1}$.

$\frac{R_x}{l_x} = 1.7 \times 10^{-2}$

For the damaged length of the wire, calculate

1. the resistance per unit length,

$$R = \frac{\rho l}{A} \Rightarrow \frac{R_x}{l_x} = \frac{\rho}{A_x} \Rightarrow 1.7 \times 10^{-2} = \frac{4\rho}{\pi d^2} \Rightarrow \rho = \frac{(1.7 \times 10^{-2})\pi d^2}{4}$$
$$\frac{R_y}{l_y} = \frac{\rho}{A_y} = \frac{(1.7 \times 10^{-2})\cancel{\pi}\cancel{d^2}}{\cancel{4}} \times \frac{\cancel{4}}{\cancel{\pi} \times 0.69^2 \times \cancel{d^2}} \Rightarrow \frac{R_y}{l_y} = \frac{(1.7 \times 10^{-2})}{0.69^2} = 0.036$$

resistance per unit length = 3.6×10^{-2} ....$\Omega\,m^{-1}$ [2]

2. the power dissipated.

$$P = I^2R = I^2 \times \left(\frac{R_y}{l_y} \times l_y\right) = (0.5)^2 \times (3.6 \times 10^{-2} \times 3 \times 10^{-3})$$
$$P = 2.7 \times 10^{-5}$$

power = 2.7×10^{-5} .... W [2]

(iii) The diameter of the damaged length of the wire is further decreased. Assume that the current in the wire remains constant.

State and explain qualitatively the change, if any, to the power dissipated in the damaged length of the wire.

As the diameter decreases, the cross sectional area of the wire decreases and so the resistance increases. The power will also increase as $P = I^2R$ ....[2]

[Total: 12]

$$\uparrow R = \frac{\overbrace{\rho l}^{\text{const}}}{A\downarrow} \qquad d\downarrow$$
$$\hookrightarrow \uparrow P = \underbrace{I^2}_{\text{const}} R\uparrow$$
$$\uparrow P \propto \frac{1}{d^2\downarrow}$$

$$R = \frac{\overbrace{\rho l}^{\text{const}}}{A}$$
$$R \propto \frac{1}{d^2}$$

w18 qp22 q7

7 **(a)** The current I in a metal wire is given by the expression

$$I = Anve.$$

State what is meant by the symbols A and n.

A: Cross sectional area

n: number density of electrons / electrons per unit volume

[2]

(b) The diameter of a wire XY varies linearly with distance along the wire as shown in Fig. 7.1.

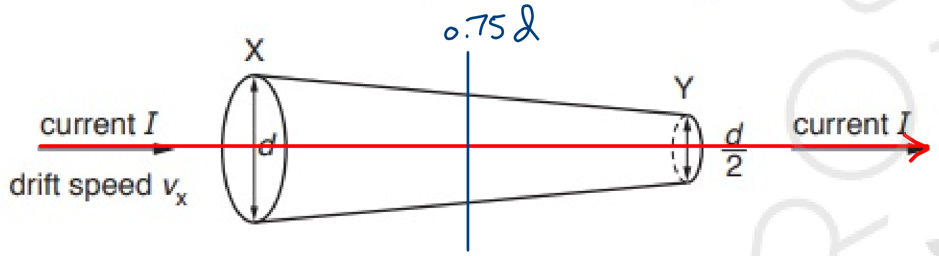
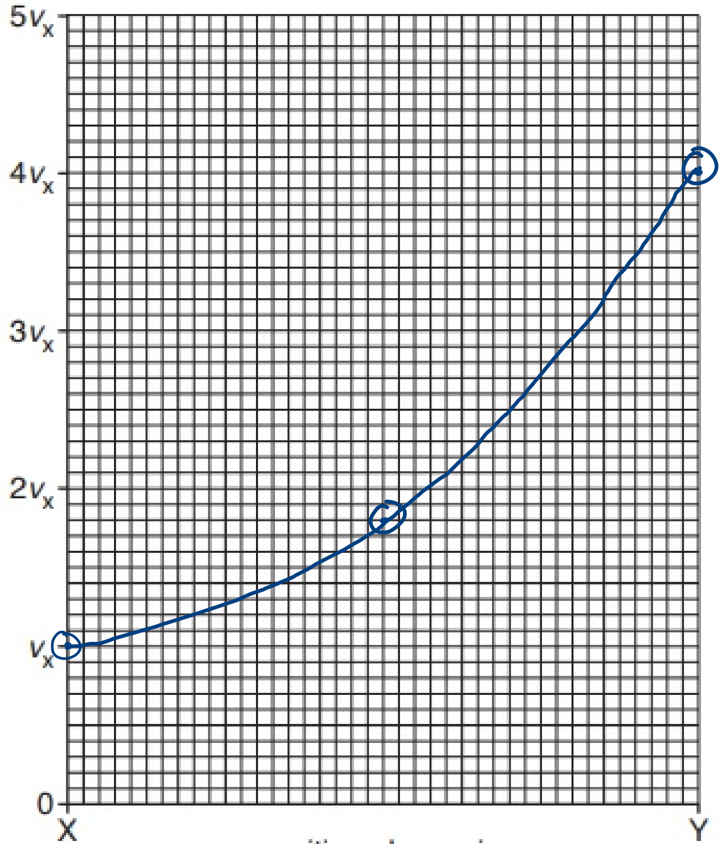


Fig. 7.1

There is a current I in the wire. At end X of the wire, the diameter is d and the average drift speed of the free electrons is v_x. At end Y of the wire, the diameter is $\frac{d}{2}$.

On Fig. 7.2, sketch a graph to show the variation of the average drift speed with position along the wire between X and Y.

average drift speed



position along wire

$I = nAve$

$v = \frac{I}{neA}$ const

$v \propto \frac{1}{A}$

$y \propto \frac{1}{x^2}$

$v \propto \frac{1}{\frac{\pi d^2}{4}}$ const $\Rightarrow v \propto \frac{1}{d^2}$

$v \propto \frac{1}{d^2}$

$v_1 d_1^2 = K = v_2 d_2^2$

$v_x d^2 = v_y \times \left(\frac{d}{2}\right)^2$

$v_x \cancel{d^2} = v_y \times \frac{\cancel{d^2}}{4}$

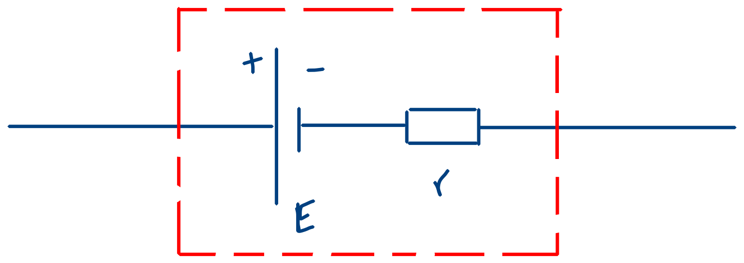
$v_y = 4v_x$

$v_x d^2 = v(0.75d)^2$

$v_x \cancel{d^2} = v \times 0.75^2 \times \cancel{d^2}$

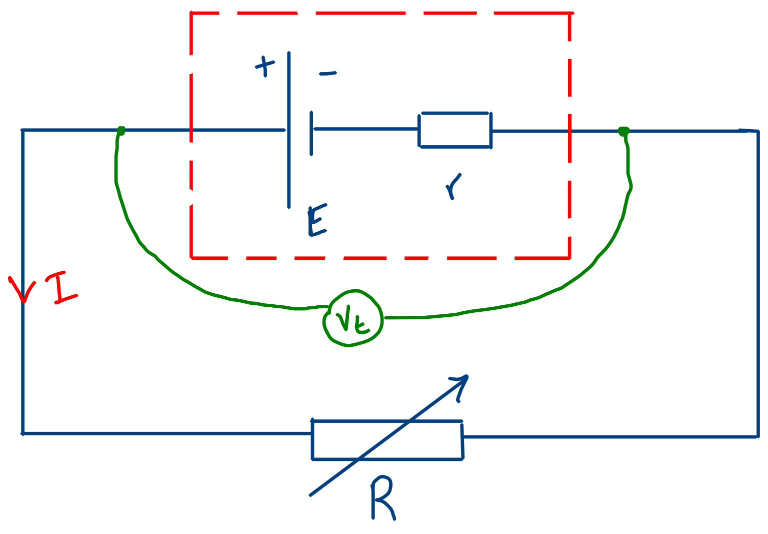
$1.8 v_x \approx v$

Internal resistance:-



Note:- The power delivered to the external resistor (R) is max when $r = R$

It is the small resistance marked / drawn with each battery to account for the power losses through it.



V_t : Terminal voltage

$V_T = I_T \times R_T$

$E = I \times (R + r)$

$E = IR + Ir$

$E = V_t + Ir$

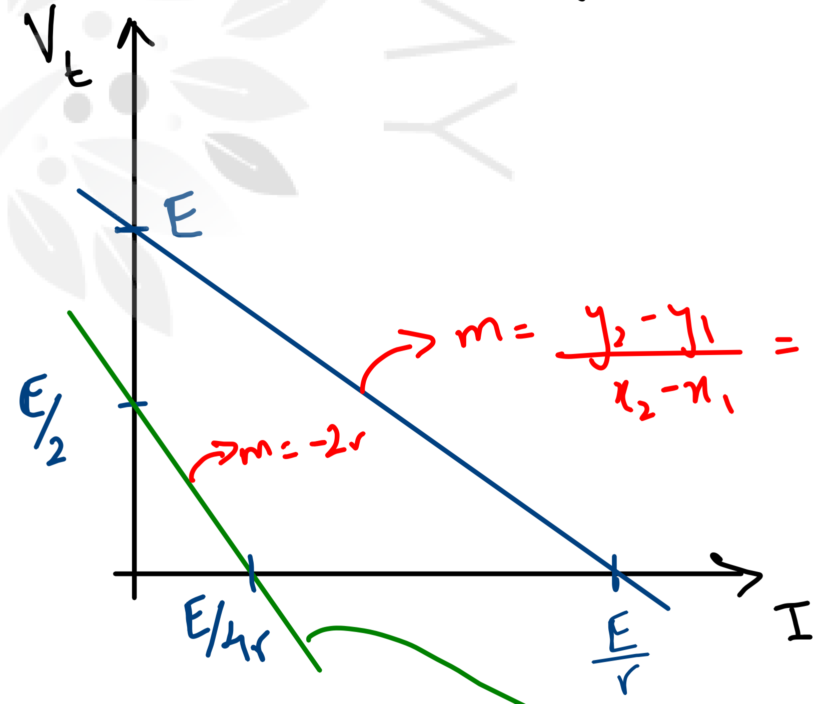
$\boxed{V_t = E - Ir}$ $\Rightarrow$ $V_t = -r(I) + E$

$y = m x + c$

$0 = -r(I) + E$

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

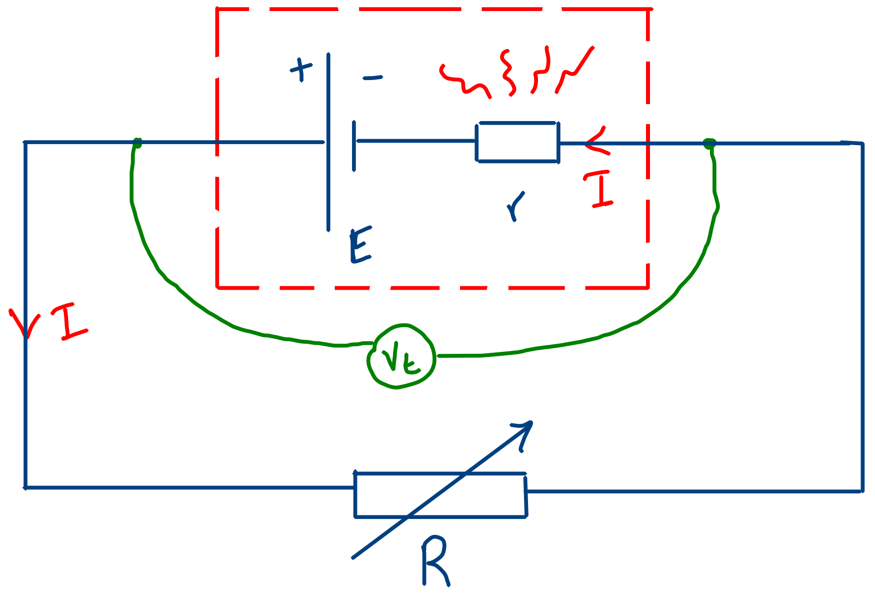
Q. Predict the shape of V_t against I :-

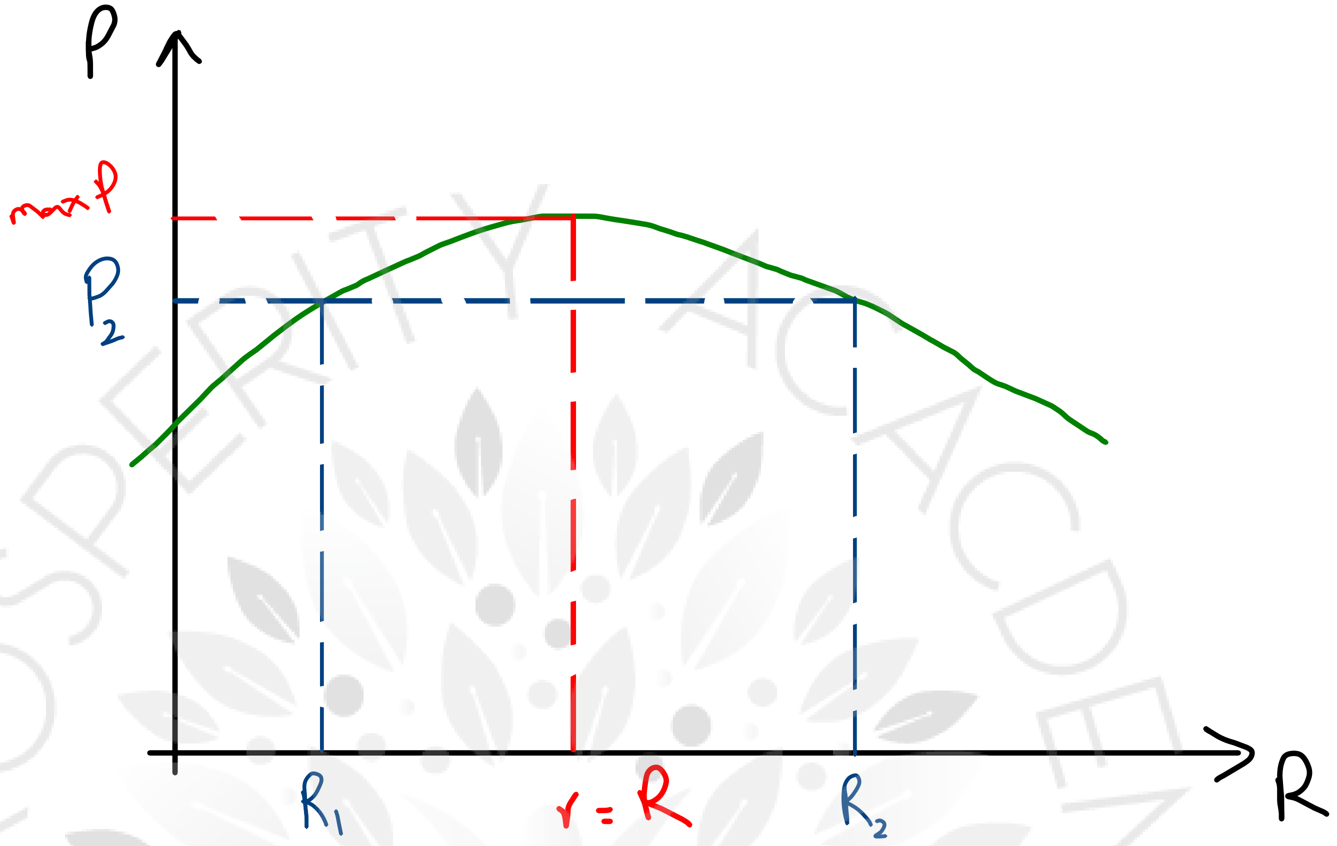


new e.m.f $= \frac{E}{2}$

internal resistance $= 2r$

Draw the new graph





Power P_2 is achieved at both R_1 and R_2.

Q. Should we use R_1 or R_2 to get power P_2?

$\uparrow I = \dfrac{V}{R_1 \downarrow}$ or $\downarrow I = \dfrac{V}{R_2 \uparrow}$ choose this.

The power loss through the internal resistance $\downarrow P = \downarrow I^2 r$ const

s19 qp21 q6

6 A battery of electromotive force (e.m.f.) E and internal resistance r is connected to a variable resistor of resistance R, as shown in Fig. 6.1.

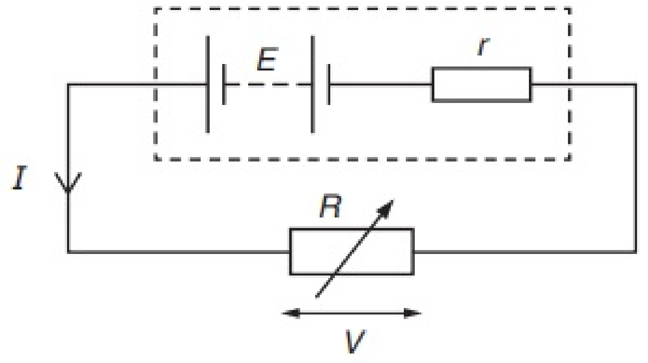


Fig. 6.1

The current in the circuit is I and the potential difference across the variable resistor is V.

(a) Explain, in terms of energy, why V is less than E.

V is less than E as energy is wasted in the internal resistance ....[1]

(b) State an equation relating E, I, r and V.

$V = E - Ir$ ....[1]

(c) The resistance R of the variable resistor is varied. The variation with I of V is shown in Fig. 6.2.

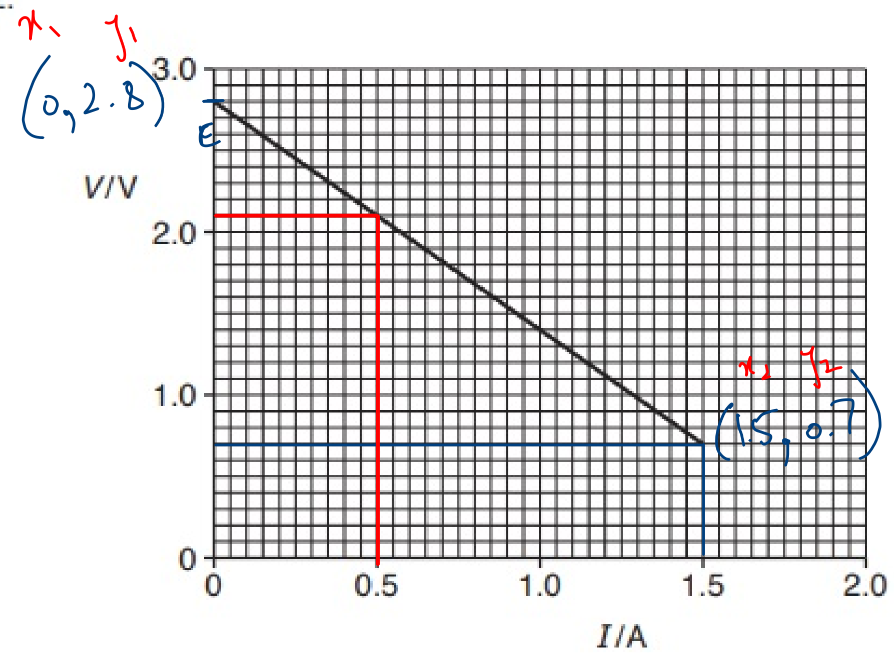


Fig. 6.2

$V = (-r)I + E$

$y = m x + c$

Use Fig. 6.2 to:

(i) explain how it may be deduced that the e.m.f. of the battery is 2.8 V

Upon linearising $V = E - Ir$, we can see that the e.m.f can be given by the y-intercept ....[1]

(ii) calculate the internal resistance r.

$-r = \frac{0.7 - 2.8}{1.5 - 0} \Rightarrow r = 1.4$

$r =$ 1.4 .... Ω [2]

(d) The battery stores 9.2 kJ of energy. The variable resistor is adjusted so that $V = 2.1$ V. Use Fig. 6.2 to:

(i) calculate resistance R

$R = \frac{V}{I} = \frac{2.1}{0.5} = 4.2$

$R =$ 4.2 .... Ω [1]

(ii) calculate the number of conduction electrons moving through the battery in a time of 1.0 s

$Q = I \times \Delta t$

$Q = 0.5 \times (1)$

$Q = 0.5C$

$Q = Ne$

$0.5 = N(1.6 \times 10^{-19}) \Rightarrow 3.1 \times 10^{18}$

number = 3.1×10^{18} .... [1]

(iii) determine the time taken for the energy in the battery to become equal to 1.6 kJ. (Assume that the e.m.f. of the battery and the current in the battery remain constant.)

$P = \frac{\Delta W}{\Delta t}$

$\Delta t = \frac{\Delta W}{P} \Rightarrow \frac{(9.2 - 1.6) \times 10^3}{0.5 \times 2.8}$

P → $\boxed{IV}$

$= 5.4 \times 10^3$

Alt:-

$\Delta E = IV\Delta t$

$\Delta t = \frac{\Delta E}{IV}$

time taken = 5.4×10^3 .... s [3]

[Total: 10]

w20 qp23 q6

6 (a) Define *electric potential difference* (p.d.).

The work done per unit charge in converting electrical energy to other forms of energy [1]

(b) A wire of cross-sectional area A is made from metal of resistivity ρ. The wire is extended. Assume that the volume V of the wire remains constant as it extends.

Show that the resistance R of the extending wire is inversely proportional to A^2.

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

$V = l \times A$

$l = \frac{V}{A}$

$R = \frac{\rho V}{A^2}$ as ρ and V are constant $R \propto \frac{1}{A^2}$

[2]

(c) A battery of electromotive force (e.m.f.) E and internal resistance r is connected to a variable resistor of resistance R, as shown in Fig. 6.1.

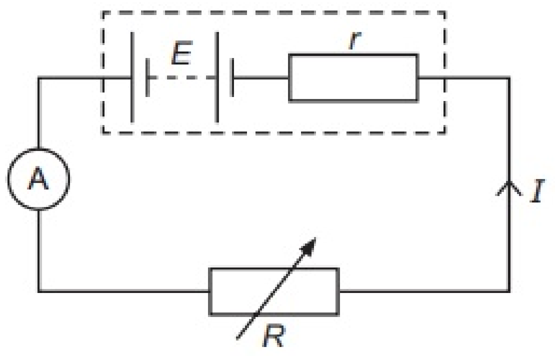


Fig. 6.1

The current in the circuit is I.

Use Kirchhoff's second law to show that

$$R = \left(\frac{E}{I}\right) - r.$$

[1]

(d) An ammeter is used in the circuit in (c) to measure the current I as resistance R is varied. Fig. 6.2 is a graph of R against $\frac{1}{I}$.

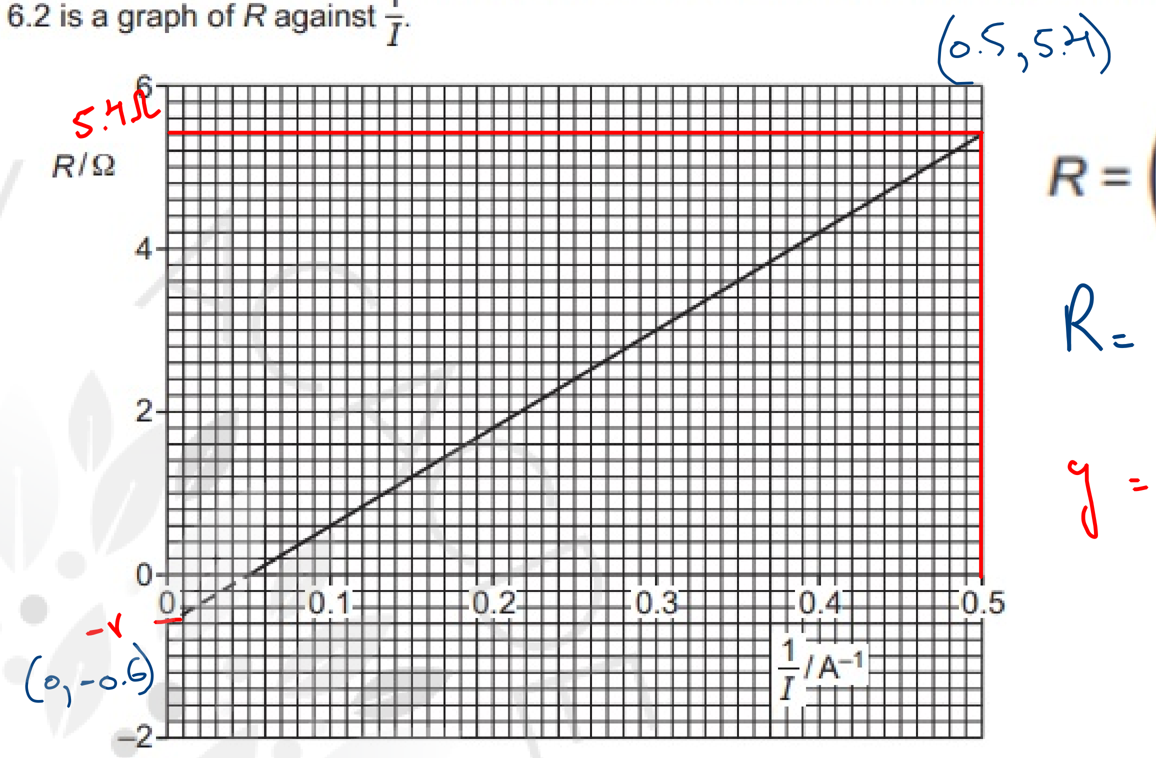


Fig. 6.2

$R = \left(\frac{E}{I}\right) - r.$

$R = E\left(\frac{1}{I}\right) - r$

$y = m \; x + c$

(i) Use Fig. 6.2 to determine the power dissipated in the variable resistor when there is a current of 2.0 A in the circuit.

$\frac{1}{2.0} = 0.5\ A^{-1}$

$P = I^2 R$

$P = (2)^2 \times 5.4$

power = 22 W [3]

(ii) Use Fig. 6.2 and the equation in (c) to:

1. state the internal resistance r of the battery

$+r = +0.6$

r = 0.6 Ω

2. determine the e.m.f. E of the battery.

$\frac{5.4 - (-0.6)}{0.5 - 0} = 12\ V$

E = 12 V

[3]

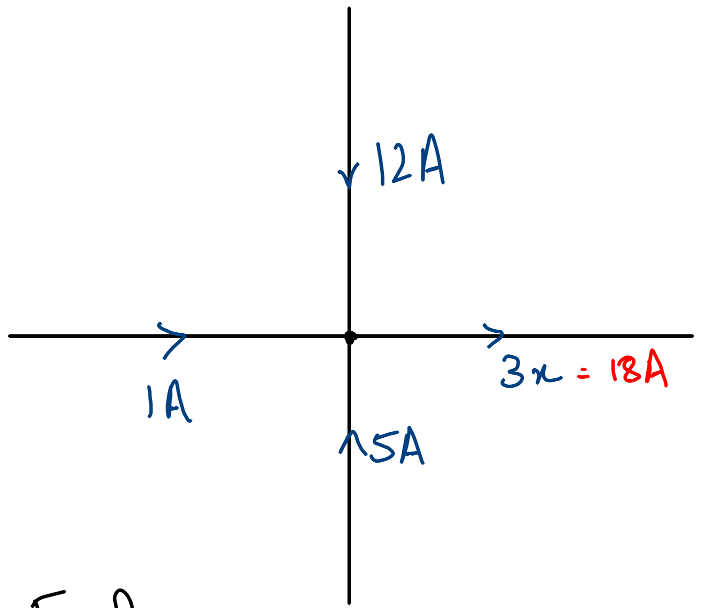
Kirchoff's laws:-

1) Kirchoff's first law:-

- Kirchoff's current law (KCL)
- sum of incoming currents in a junction = sum of the outgoing currents from the junction
- based on the principle of conservation of charge

$$\boxed{\Sigma I_{incoming} = \Sigma I_{outgoing}}$$

1)

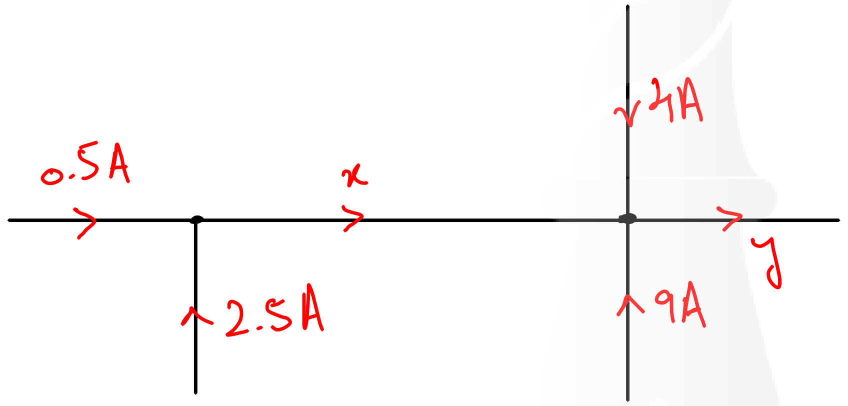


Q. Find x

$1 + 5 + 12 = 3x$

$x = 6A$

2)



Find x and y

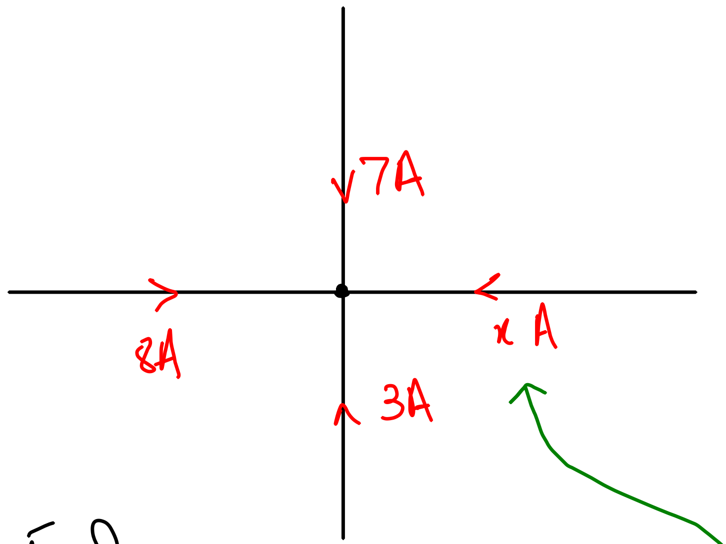
$0.5 + 2.5 = x$

$3A = x$

$4 + 9 + 3 = y$

$y = 16A$

3)



Find x

$7 + 8 + 3 + x = 0$

$x = -18\ A$

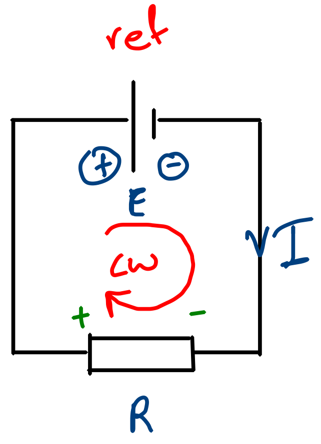
tells us that our marked direction is wrong

2) Kirchoff's second law :-

- Kirchoff's voltage law (KVL)
- CAIE :- sum of e.m.f.s = sum of p.d.s in a closed loop

  The sum of voltages in a closed loop is always zero.

- Based upon conservation of energy



$+E - IR = 0$

$E = IR$

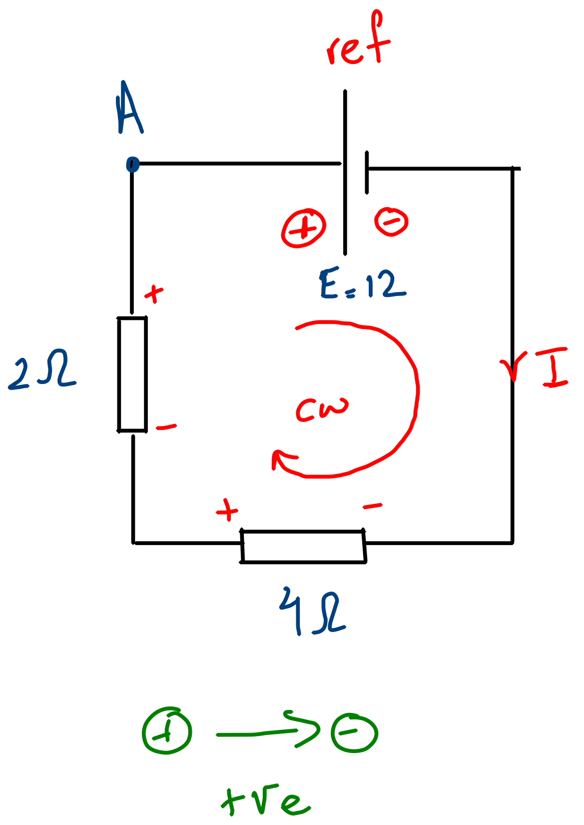
1) Make any one battery your reference battery and mark its ⊕ and ⊖ terminals
2) For any resistors/energy consuming devices, make the leg closer to the battery's ⊕ as ⊕
3) Choose a direction of looping :- acw or cw
4) As you move across the circuit through a component :-

   if you move ⊕ → ⊖ then treat the voltage as +ve

   if you move ⊖ → ⊕ then treat the voltage as -ve

5) Finally write the equation down and equate it to zero

Q. Find the current

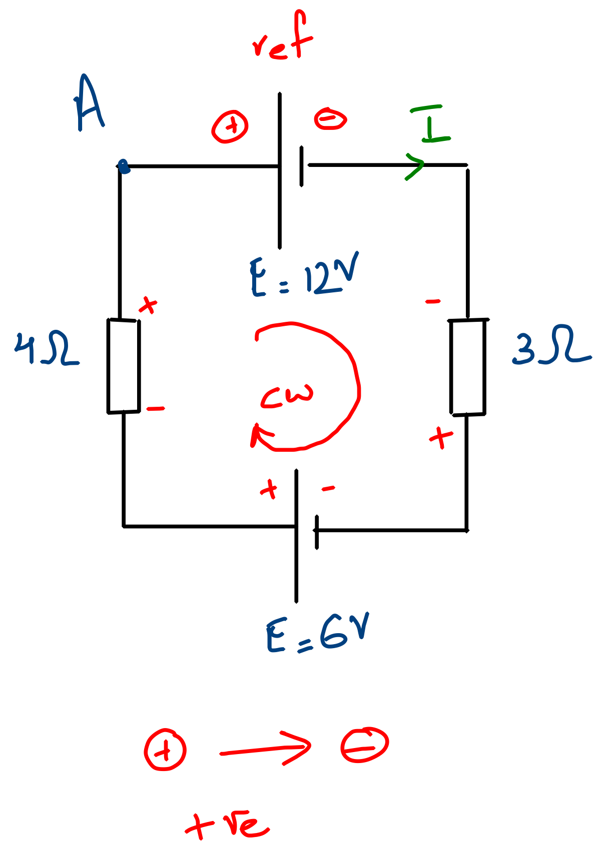


$$+12 - I(4) - I(2) = 0$$

$$12 - 4I - 2I = 0$$

$$12 = 6I$$

$$I = 2A$$



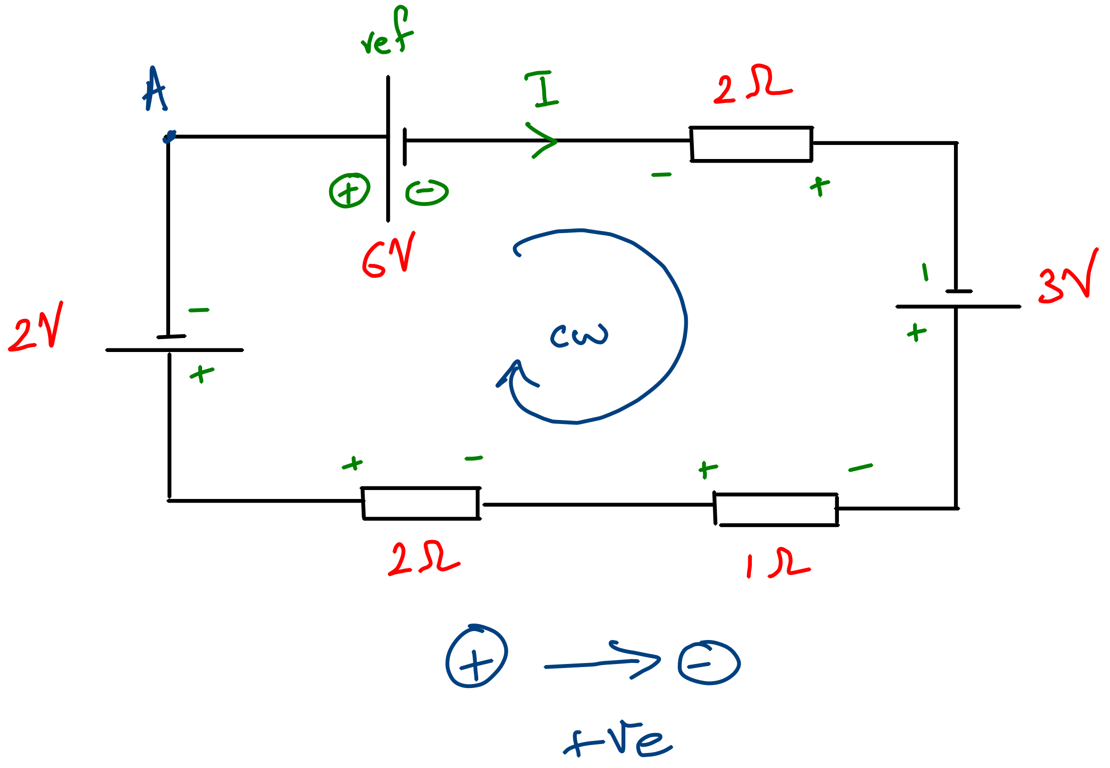
- For multiple choose only 1 reference battery and use it to mark polarity of resistors

$$+12 - 3I - 6 - 4I = 0$$

$$6 = 7I$$

$$I = \frac{6}{7}\,A$$

* If you have more than one battery use KVL.



Q. Find the current

$$+6 - 2I - 3 - 1I - 2I + 2 = 0$$

$$5 = 5I$$

$$I = 1A$$

w17 qp21 q5

5 Three cells of electromotive forces (e.m.f.) E_1, E_2 and E_3 are connected into a circuit, as shown in Fig. 5.1.

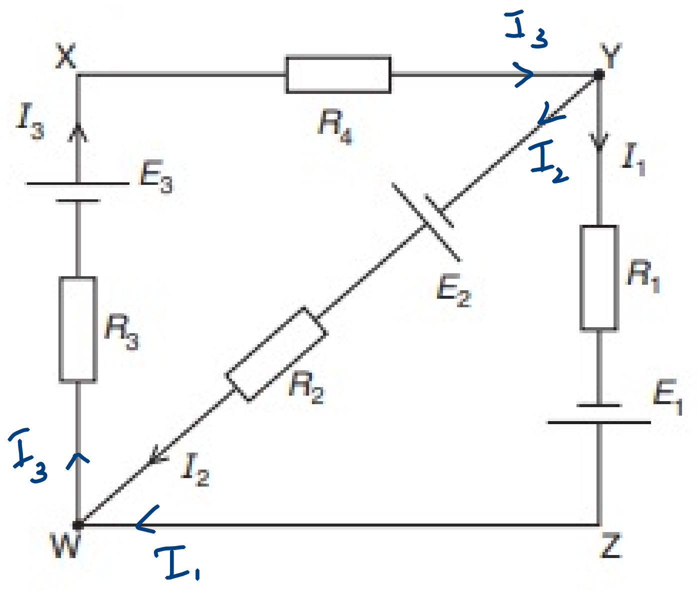
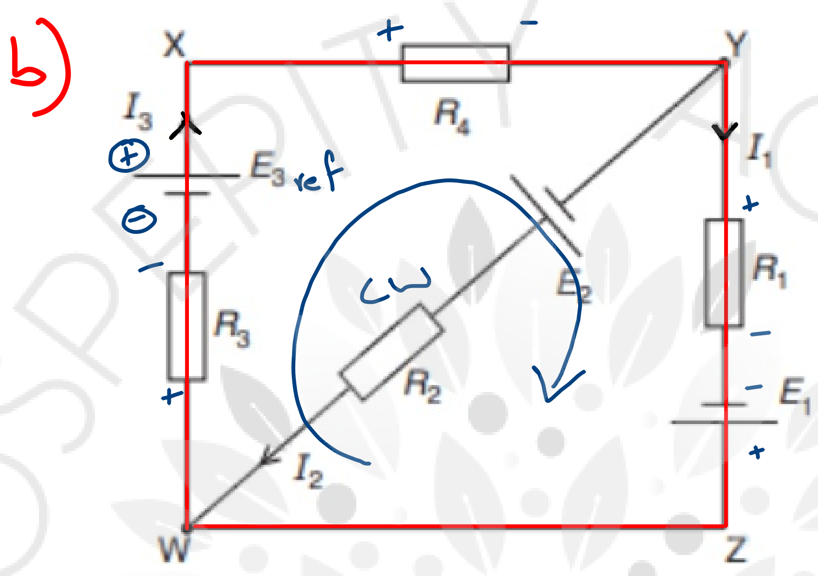


Fig. 5.1

b)



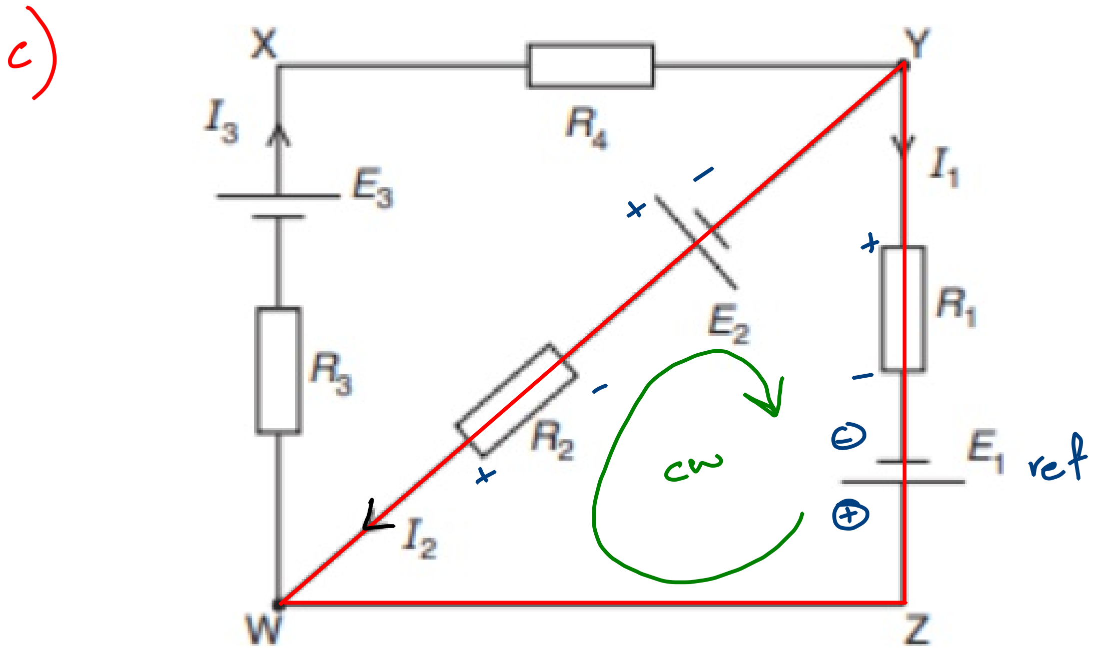
$\oplus \rightarrow \ominus$

+ve

$$+I_3R_3 - E_3 + I_3R_4 + I_1R_1 - E_1 = 0$$

$$I_3R_3 + I_3R_4 + I_1R_1 = E_1 + E_3$$

c)



$\oplus \rightarrow \ominus$

+ve

$$-I_2R_2 + E_2 + I_1R_1 - E_1 = 0$$

$$E_2 - E_1 = I_2R_2 - I_1R_1$$

The circuit contains resistors of resistances R_1, R_2, R_3 and R_4.
The currents in the different parts of the circuit are I_1, I_2 and I_3.
The cells have negligible internal resistance.

Use Kirchhoff's laws to state an equation relating

(a) I_1, I_2 and I_3,

$I_3 = I_1 + I_2$ .... [1]

(b) E_1, E_3, R_1, R_3, R_4, I_1 and I_3 in loop WXYZW,

$I_3R_3 + I_3R_4 + I_1R_1 = E_1 + E_3$ .... [1]

(c) E_1, E_2, R_1, R_2, I_1 and I_2 in loop YZWY.

$E_2 - E_1 = I_2R_2 - I_1R_1$ .... [1]

[Total: 3]

s19 qp22 q5

5 (a) State Kirchhoff's second law.

sum of e.m.fs = sum of p.ds in a closed loop [2]

(b) A battery of electromotive force (e.m.f.) 5.6 V and internal resistance r is connected to two external resistors, as shown in Fig. 5.1.

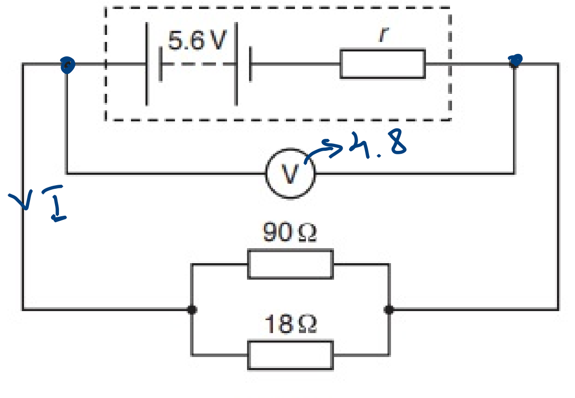


Fig. 5.1

The reading on the voltmeter is 4.8 V.

(i) Calculate:

1. the combined resistance of the two resistors connected in parallel

$$R_{eff} = \left(\frac{1}{90} + \frac{1}{18}\right)^{-1} = 15$$

combined resistance = 15 Ω [2]

2. the current in the battery.

$$V = IR$$

$$4.8 = I(15) \Rightarrow I = 0.32$$

current = 0.32 A [2]

(ii) Show that the internal resistance r is 2.5 Ω.

$$V_t = E - Ir$$

$$4.8 = 5.6 - 0.32(r)$$

$$r = \frac{4.8 - 5.6}{-0.32} = 2.5\,\Omega$$

[2]

(iii) Determine the ratio

$$\frac{\text{power dissipated by internal resistance } r}{\text{total power produced by battery}} = \frac{I^2 r}{IV}$$

$$\frac{(0.32)^2 \times 2.8}{(0.32) \times 5.6} = 0.16$$

ratio = 0.16 [3]

(c) The battery in (b) is now connected to a battery of e.m.f. 7.2 V and internal resistance 3.5 Ω. The new circuit is shown in Fig. 5.2.

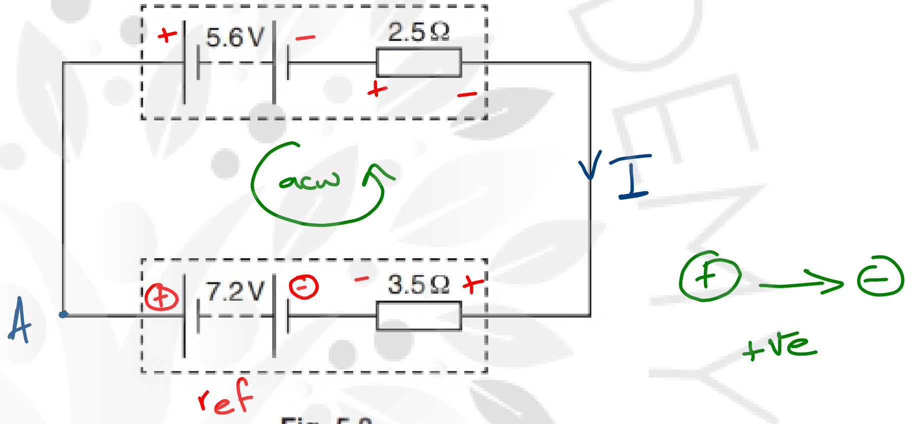


Fig. 5.2

Determine the current in the circuit.

$$+7.2 - I(3.5) - I(2.5) - 5.6 = 0$$

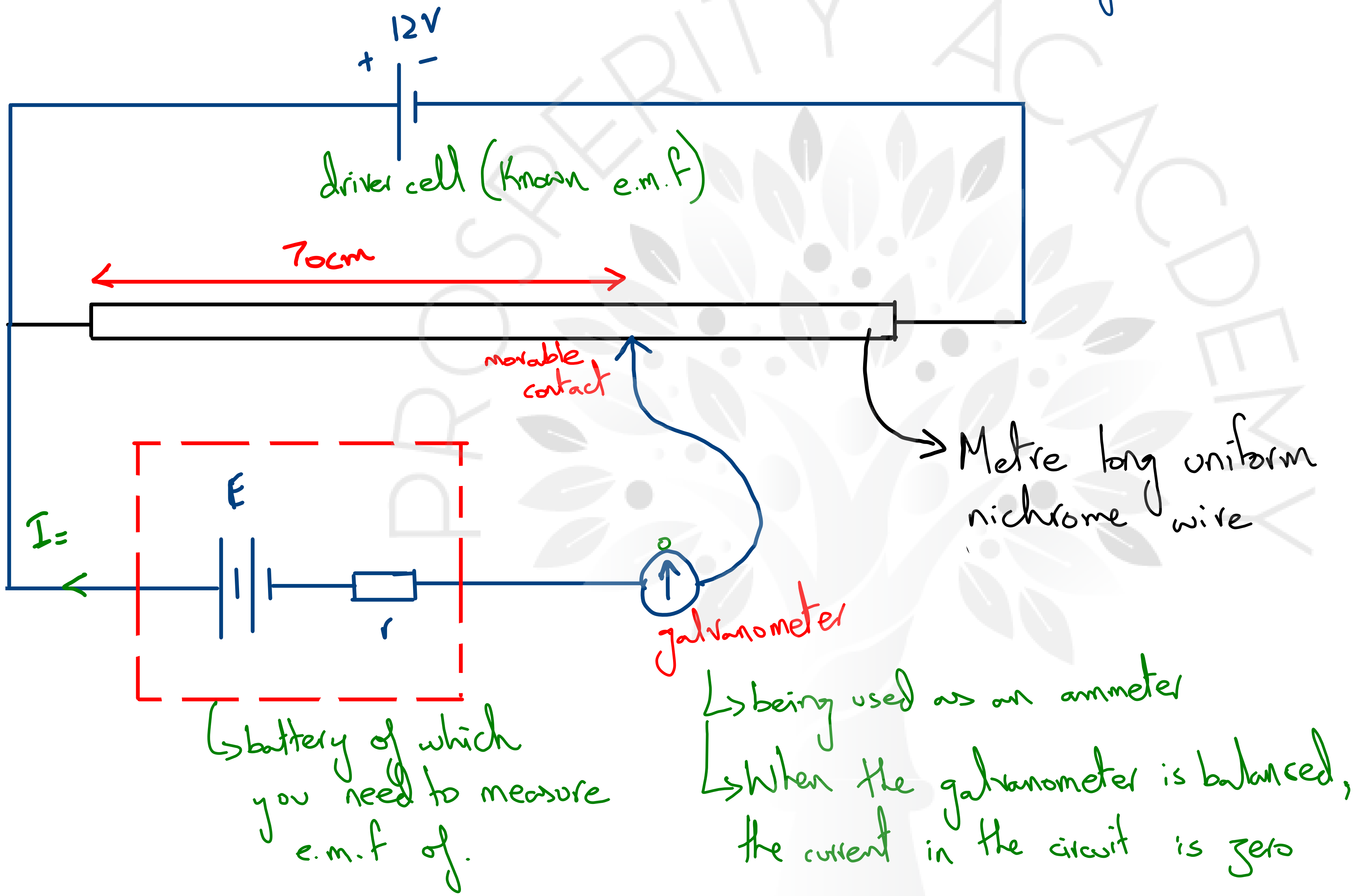
$$1.6 = 6I$$

$$I = \frac{1.6}{6} = 0.27$$

current = 0.27 A [2]

[Total: 13]

Potentiometer:- It is an electrical device used to measure the e.m.f of a battery.



$$(R \propto l, \quad V \propto R)$$

$$(V \propto l)$$

$$12V : 1\,m$$

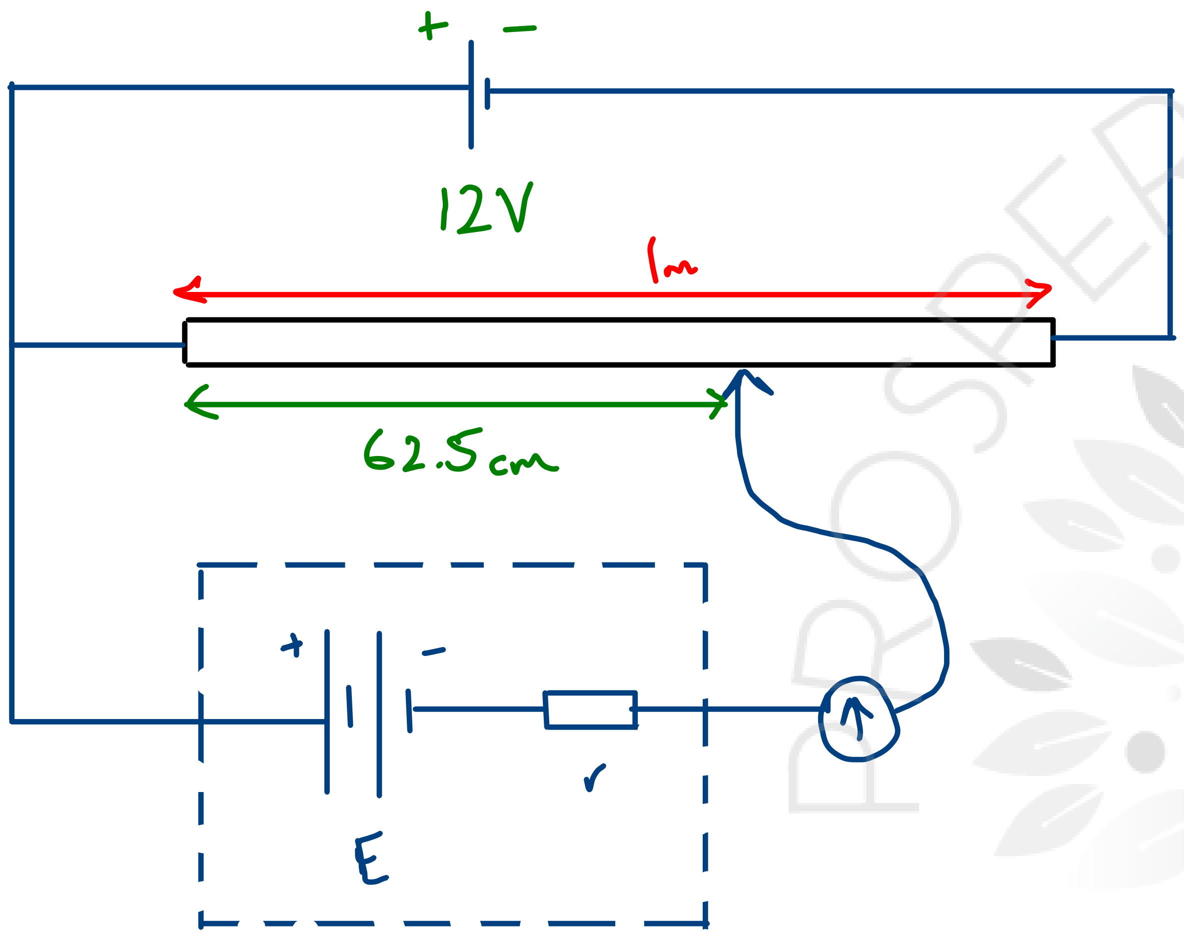
$$x\,V : (70 \times 10^{-2})\,m$$

$$x = 8.4V$$

Current flows when there is potential difference

$$V_t = E - Ir \implies V_t = E$$

Q. In the diagram shown below, the galvanometer is balanced:-



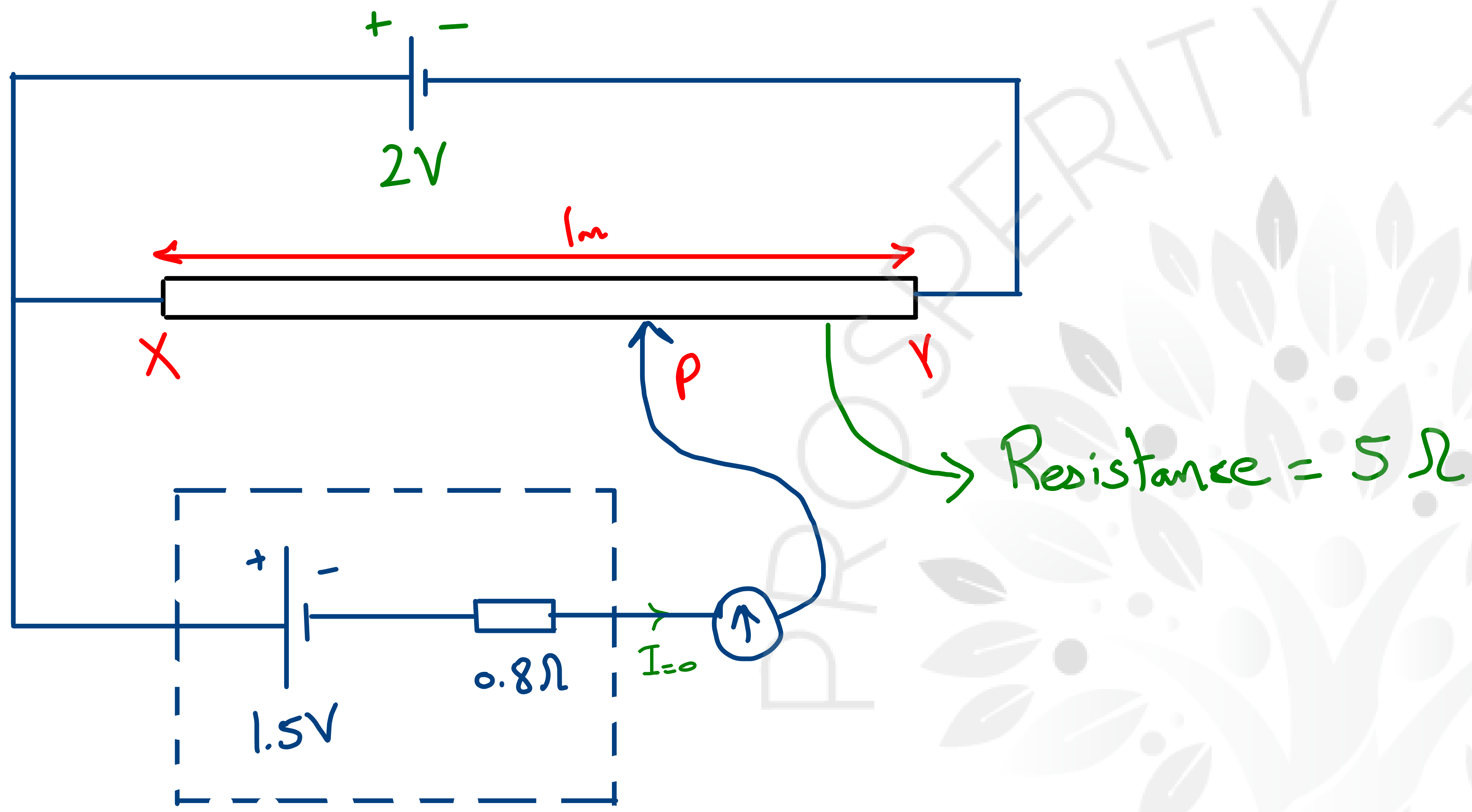
What is the e.m.f of the battery?

$12 : 1m$

$x : (62.5 \times 10^{-2})$

$x = 7.5V = E$

Q. In the diagram shown below, the galvanometer is balanced:-



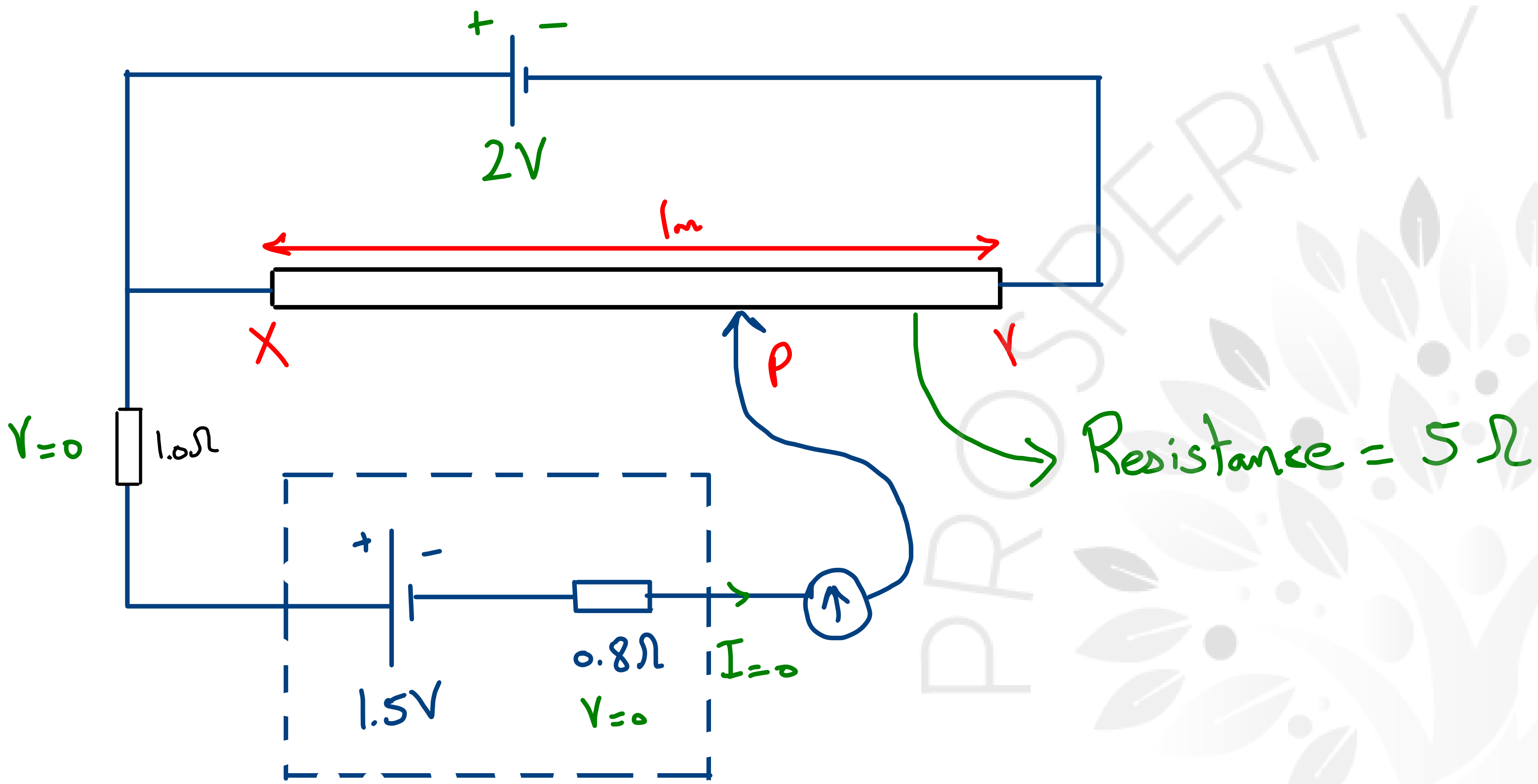
What is the length XP?

2V : 1m

1.5V : XP

$$XP = \frac{1.5}{2} = 0.75\,m$$

Q. In the diagram shown below, the galvanometer is balanced:-

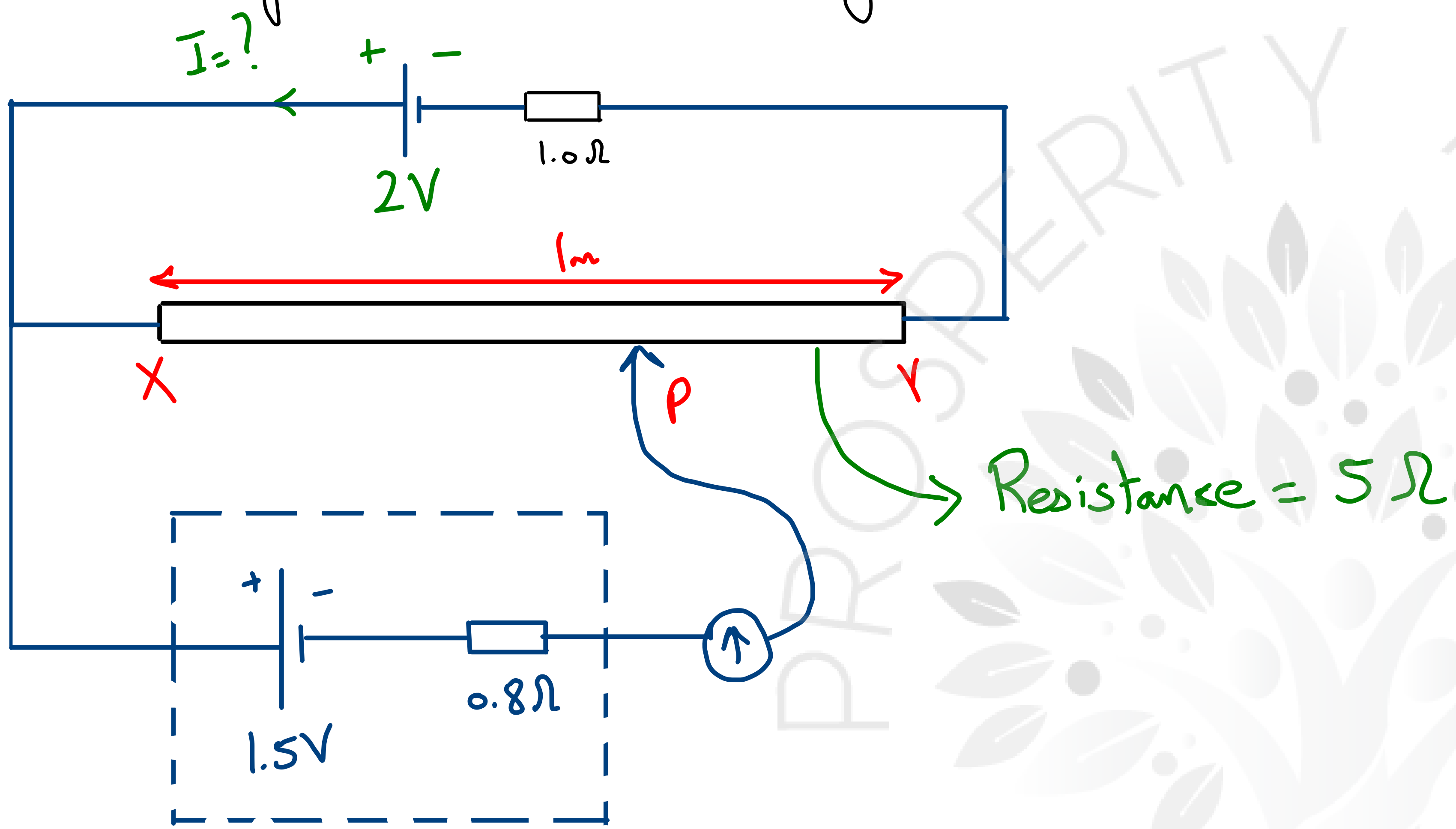


What is the length XP?

2V : 1m

1.5V : XP $\Rightarrow$ $\boxed{XP = 0.75\ m}$

Q. In the diagram shown below, the galvanometer is balanced:-



What is the length XP?

$V_T = I_T R_T$

$2 = I_T (1+5)$

$I_T = \frac{2}{6} = \frac{1}{3} A$

$V_{XY} = IR$

$V_{XY} = \left(\frac{1}{3}\right)(5)$

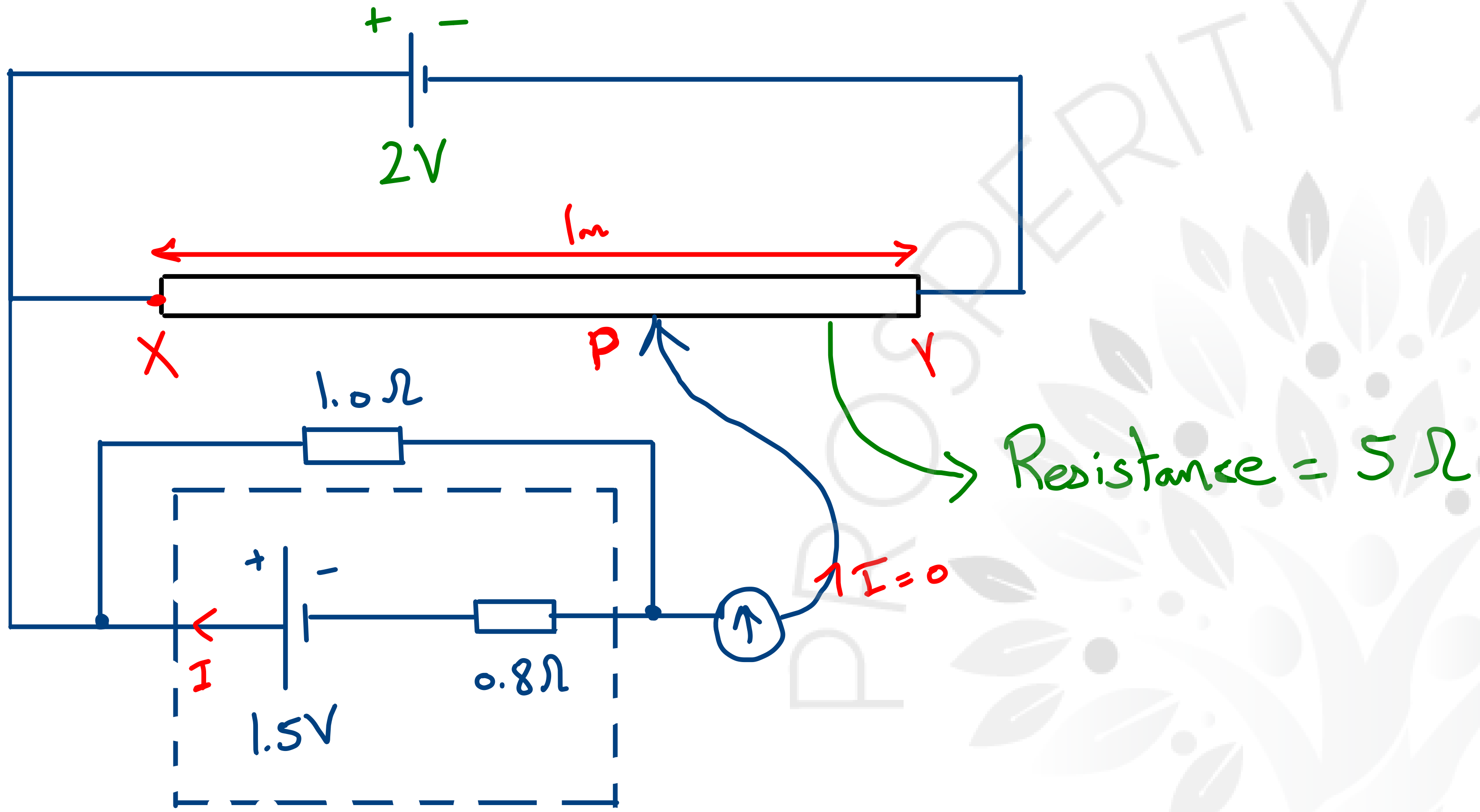
$V_{XY} = \frac{5}{3} V$

$\frac{5}{3} V : 1m$

$1.5V : XP$

$XP = \frac{1.5 \times 3}{5} = \boxed{0.9 m}$

Q. In the diagram shown below, the galvanometer is balanced:-



What is the length XP?

$V_T = I_T R_T$

$1.5 = I_T (0.8 + 1)$

$I_T = \frac{5}{6} A$

$V_t = IR$

$= \frac{5}{6}(1)$

$V_t = \frac{5}{6} V$

$V_t = E - Ir$

$V_t = 1.5 - \frac{5}{6}(0.8)$

$V_t = \frac{5}{6} V$

2V : 1m

$\frac{5}{6}$V : XP

$\boxed{XP = 0.417\,m}$

5 (a) State Kirchhoff's second law.

sum of e.m.fs = sum of p.ds in a closed loop

[2]

(b) A battery has electromotive force (e.m.f.) 4.0 V and internal resistance 0.35 Ω. The battery is connected to a uniform resistance wire XY and a fixed resistor of resistance R, as shown in Fig. 5.1.

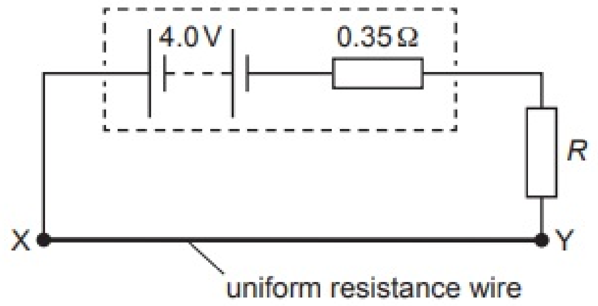


Fig. 5.1

Wire XY has resistance 0.90 Ω. The potential difference across wire XY is 1.8 V.

Calculate:

(i) the current in wire XY

$V = IR \Rightarrow 1.8 = I(0.90)$

$I = 2$

current = 2.0 A [1]

(ii) the number of free electrons that pass a point in the battery in a time of 45 s

$Q = It$

$Q = 2(45)$

$Q = 90\ C$

$Q = Ne$

$90 = N \times (1.6 \times 10^{-19})$

$N = 5.6 \times 10^{20}$

number = 5.6×10^{20} [2]

(iii) resistance R.

$V_T = I_T R_T$

$4 = 2(0.35 + 0.90 + R)$

$4 = 2.5 + 2R \Rightarrow \frac{4 - 2.5}{2} = R$

R = 0.75 Ω [2]

(c) A cell of e.m.f. 1.2 V is connected to the circuit in **(b)**, as shown in Fig. 5.2.

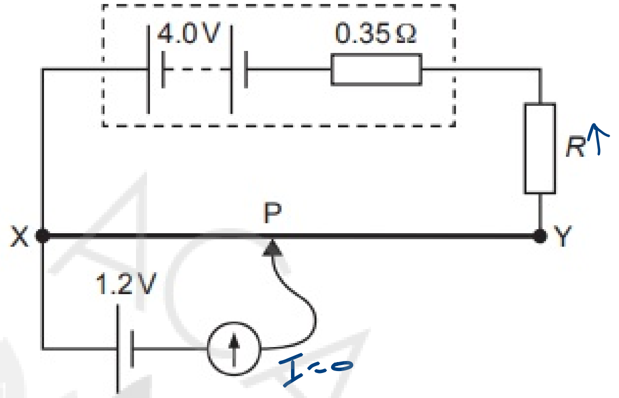


Fig. 5.2

The connection P is moved along the wire XY. The galvanometer reading is zero when distance XP is 0.30 m.

(i) Calculate the total length L of wire XY.

$1.8 : L$

$1.2 : 0.30$

$\frac{1.8 \times 0.3}{1.2} = L = 0.45$

L = 0.45 m [2]

(ii) The fixed resistor is replaced by a different fixed resistor of resistance greater than R.

State and explain the change, if any, that must be made to the position of P on wire XY so that the galvanometer reading is zero.

As R increases, the voltage XY decreases and therefore the pointer will have to be moved to the right to once again give a voltage of 1.2 V

[2]

[Total: 11]

w21 qp23 q6

6 (a) A resistance wire of uniform cross-sectional area $3.3 \times 10^{-7}\,m^2$ and length 2.0 m is made of metal of resistivity $5.0 \times 10^{-7}\,\Omega\,m$.

Show that the resistance of the wire is 3.0 Ω.

$$R = \frac{\rho l}{A} \Rightarrow \frac{(5\times10^{-7})(2)}{(3.3\times10^{-7})} = 3.03$$

$$R \approx 3.0\,\Omega$$

[2]

(b) The ends of the resistance wire in **(a)** are connected to the terminals X and Y in the circuit shown in Fig. 6.1.

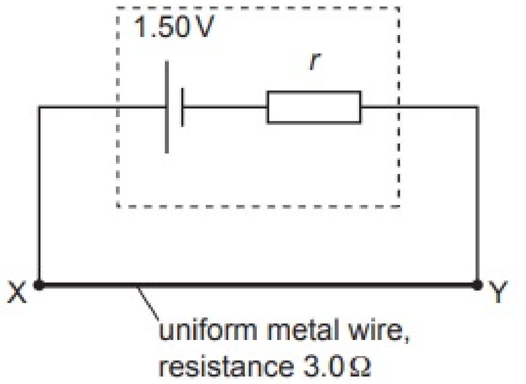


Fig. 6.1

The cell has an electromotive force (e.m.f.) of 1.50 V and internal resistance *r*. The potential difference between X and Y is 1.20 V.

Calculate:

(i) the current in the circuit

$$V = IR$$

$$1.2 = I(3) \Rightarrow I = 0.4\,A$$

current = ...0.40...... A [1]

(ii) the internal resistance *r*.

$$V_t = E - Ir$$

$$1.2 = 1.5 - 0.4r$$

$$r = \frac{1.2 - 1.5}{-0.4} \Rightarrow r = 0.75$$

r = ...0.75...... Ω [2]

(c) A galvanometer and a cell of e.m.f. *E* with negligible internal resistance are connected to the circuit in **(b)**, as shown in Fig. 6.2.

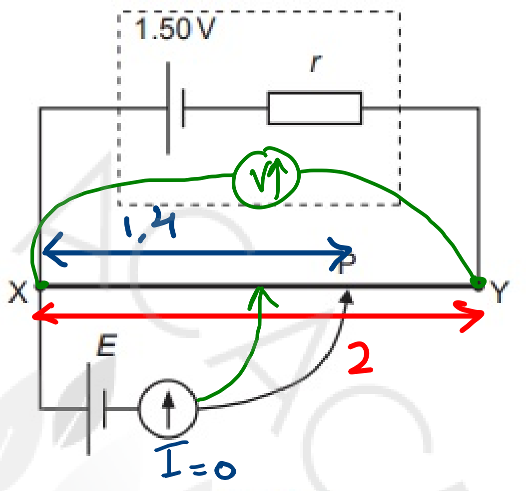


Fig. 6.2

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

$$\uparrow V = IR\uparrow$$

The resistance wire between X and Y has a length of 2.0 m. The galvanometer has a reading of zero when the connection P is adjusted so that the length XP is 1.4 m.

Determine the e.m.f. *E* of the cell.

$$1.2 : 2$$

$$E : 1.4$$

$$E = \frac{1.2 \times 1.4}{2} = 0.84$$

E = ...0.84...... V [2]

(d) The circuit in Fig. 6.2 is modified by replacing the original resistance wire with a second resistance wire. The second wire has the same length as the original wire (l) and is made of the same metal. (ρ)

The second wire has a smaller cross-sectional area than the original wire. $A\downarrow$

Connection P is adjusted on the second wire so that the galvanometer has a reading of zero.

State and explain whether length XP for the second wire is shorter than, longer than or the same as length XP for the original wire when the galvanometer reading is zero.

As the area decreases, the resistance of the wire will increase and so the potential difference across it will also increase. Length XP will have to be made shorter to get the same 0.84V.

[3]

[Total:10]