CURRENT ELECTRICITY : ELECTRICITY

Ohm's Law : The voltage (potential difference) is directly proportional to current, provided that the length, area and temperature remains constant

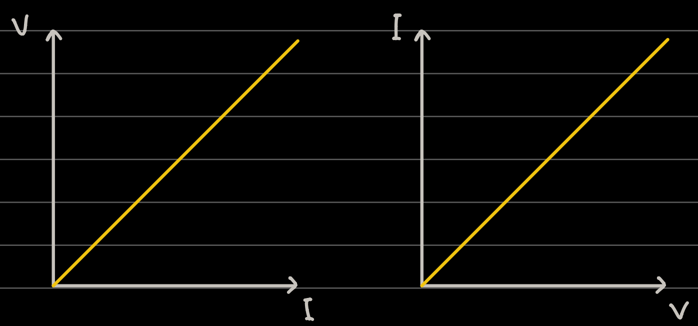
Resistance : The ratio of voltage to current → preferred

OR

The opposition faced by the current flowing in the circuit

CONDUCTORS :

1. Ohmic Conductors



Q. What feature of a Voltage - Current graph indicates that a conductor is ohmic?

A : A straight line passing through the origin / constant gradient

OR

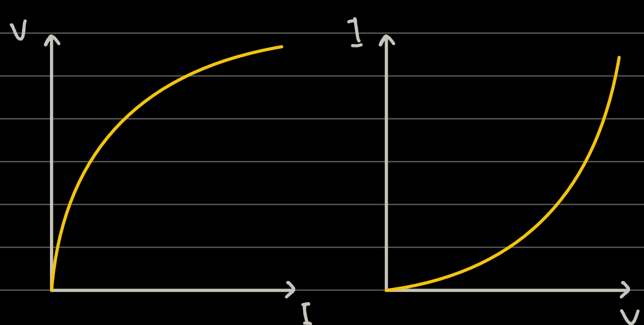
Ratio of V / I is constant, therefore resistance is also constant

→ Preferred

Examples :
- Fixed Resistors
- All metals (at constant temperatures)

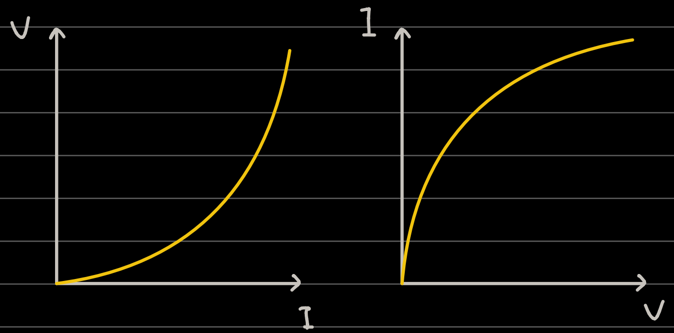
2. Non-Ohmic Conductors

Examples:
1. Thermistors () → As temperature increases, resistance decreases



Ratio of V / I is decreasing, hence resistance is decreasing

2. Filament Lamp ( ) → As temperature increases, resistance increases

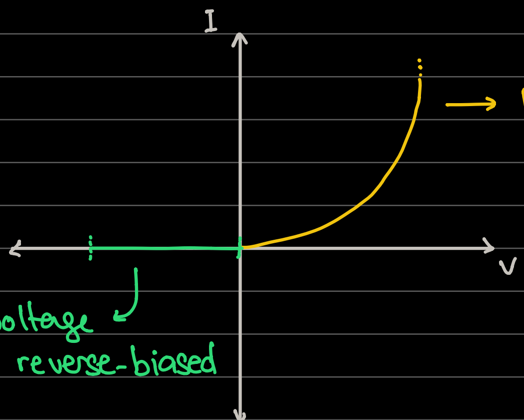


Ratio of V/I increases, hence resistance increases

2. Diodes ( )
→ cathode
anode ↲

\+ − : Forward biased condition
↳ Low resistance, allows current to flow

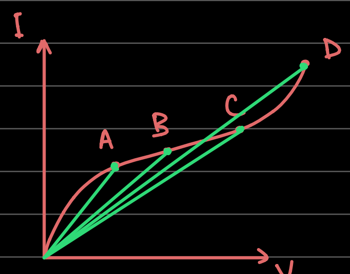
− + : Reverse biased conditions
↳ Very high resistance, no current flows



→ Positive voltage and non-zero current indicates forwards biased condition

Negative voltage indicates reverse-biased condition
↳ current here is 0 and since $R = \frac{V}{I}$, R is infinite → high resistance

Example:



Q. At which point is resistance the least?
A: Line to A is steepest, hence resistance is lowest at A

Note: Resistance is not the gradient, which is why D is not the correct option here

Because we define resistance as ratio of V to I and not ΔV to ΔI

FACTORS AFFECTING RESISTANCE :

1. $R \propto L$

   Resistance is directly proportional to length

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

   Resistance is inversely proportional with cross sectional area

Hence...

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

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

ρ, which is the inequality constant here, represents "resistivity of a material"

Resistivity : The resistivity of a material is said to be equal to its resistance, provided that the material has a unit length and a unit area.

Units : Ωm

Opposite/ Reciprocate

Conductivity : Represented by σ , Units : $\frac{1}{\Omega m}$

$$\rho = \frac{RA}{L} \qquad \sigma = \frac{L}{RA} \qquad \rho = \frac{1}{\sigma}$$

Example: Resistance = $10\,\Omega$
Length = Doubles
Volume = Constant
Calculate the new resistance.

$$R = \frac{\rho L\uparrow}{A\downarrow} \qquad V = \downarrow A \times L\uparrow$$

constant

$$R = \frac{\rho 2L}{\frac{1}{2}A}$$

$$R = 4\left(\frac{\rho L}{A}\right)$$

Hence, resistance increases by a factor of 4.

CURRENT

- Rate of flow of charge

$\left[I = \frac{Q}{t} \quad \text{or} \quad Q = It \right] \rightarrow$ Only applicable when current is constant

As such, if the current in the circuit varies, the avg current is used

Example:

Q. Current is known to vary from 40mA to 120mA in a time of 12 seconds. Calculate charge Q.

$$Q = I_{avg} \times t$$
$$Q = \left(\frac{40 + 120}{2} \right) \times 12$$

$$Q = 960 \text{ mC} \longrightarrow \text{Ans}$$

VOLTAGE:

Amount of work done in moving a unit charge around a circuit

$$V = \frac{W}{Q} \quad \text{or} \quad W = QV$$

Units : V or JC^{-1}

POWER:

$P = IV \qquad P = I^2R \qquad P = \frac{V^2}{R}$

Power Loss

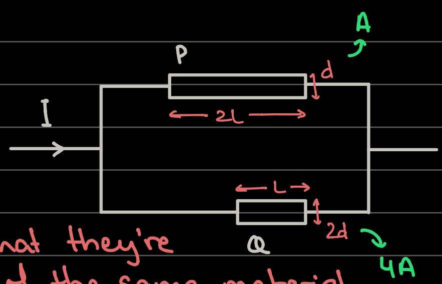
ENERGY:

$E = IVt \qquad E = I^2Rt \qquad E = \frac{V^2t}{R}$

Energy Dissipated

Example

Q. Calculate ratio of $\frac{I_P}{I_Q}$, given that they're made of the same material



$$R_P = \frac{\rho 2L}{A}$$
$$R_P = 2\left(\frac{\rho L}{A}\right)$$

$$R_Q = \frac{\rho L}{4A} = \frac{1}{4}\left(\frac{\rho L}{A}\right)$$

Resistance is inversely proportional to current.

$R = \frac{V}{I}$ $\qquad$ $\frac{1}{R} = I$

$\frac{R_P}{R_Q} = \frac{2}{\frac{1}{4}} = \frac{8}{1}$

↳ Reciprocating this gives ratio of I_P and I_Q

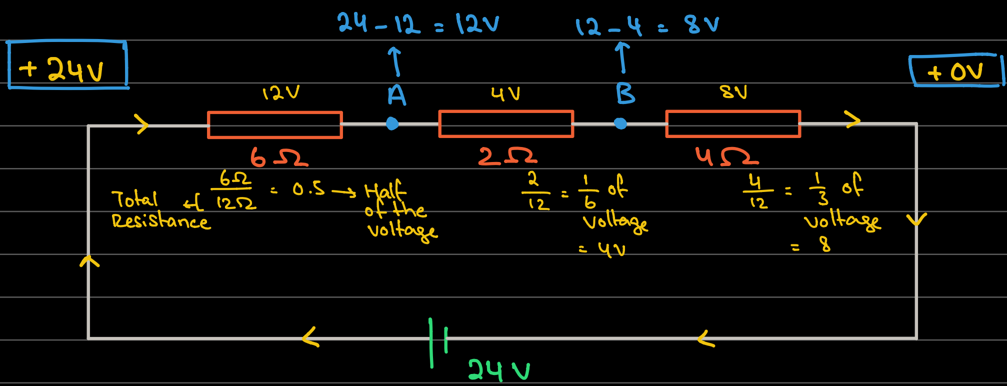
$\therefore, \frac{I_P}{I_Q} = \frac{1}{8} \rightarrow \underline{\underline{Ans}}$

Q. Calculate ratio of $\frac{V_P}{V_Q}$

Voltage stays same in parallel, hence ratio would be $\frac{1}{1}$

HOW TO CALCULATE VOLTAGE / POTENTIAL at different points in a circuit

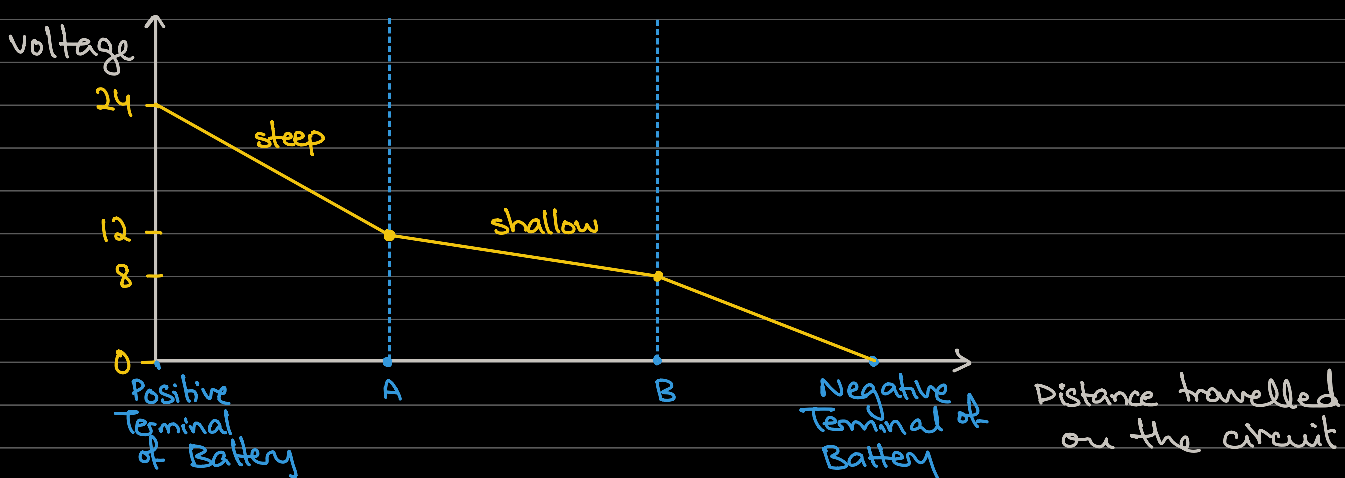
Example 1 (Series)



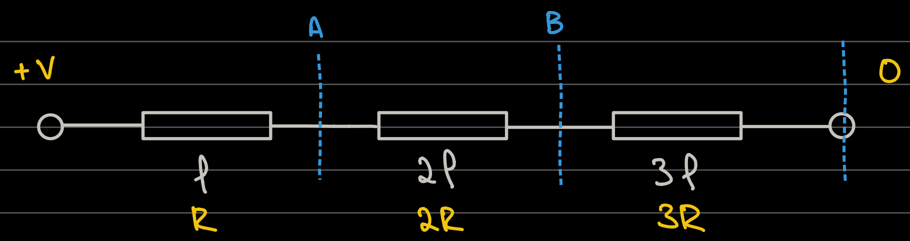
Observations (in a series circuit)

- The resistor with the highest resistance gets the highest voltage / more of a "voltage drop" across that particular resistor

  ↳ and vice versa

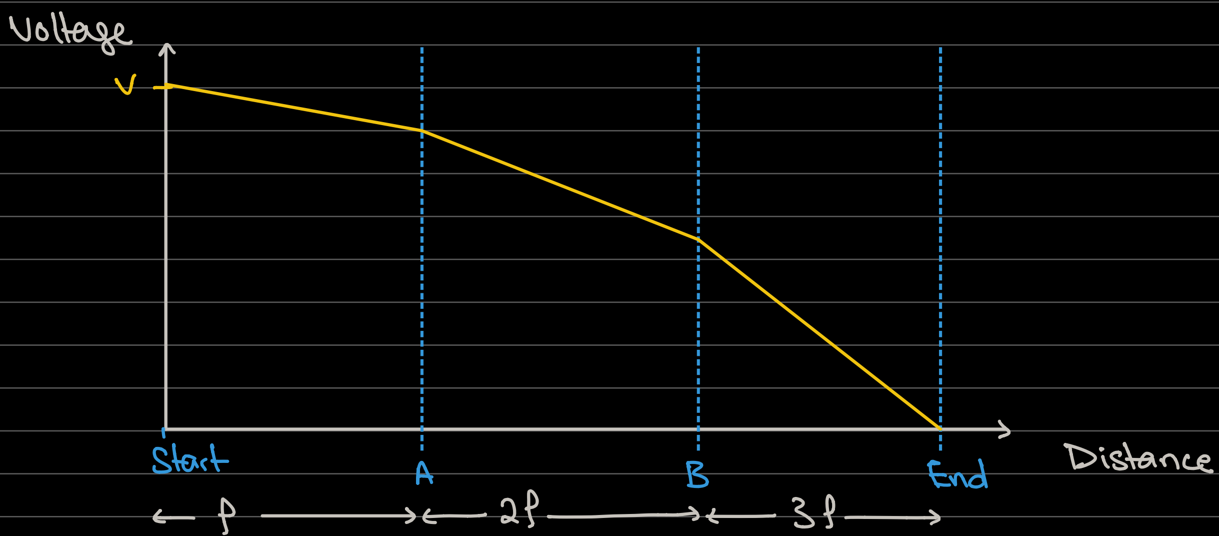


Example 2 :



Remember : ρ represents resistivity and also Resistance ∝ ρ

Q. Sketch a graph for voltage against distance travelled on the circuit

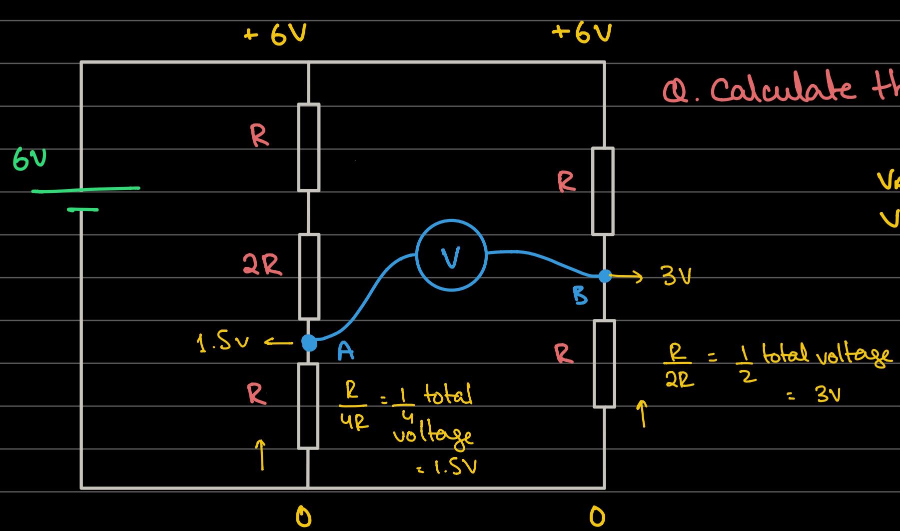


HOW TO CALCULATE POTENTIAL DIFFERENCE

Note : The difference between potential and potential difference is :

Potential : The voltage at one particular point on the circuit

Potential Difference : The voltage difference between any two points on the circuit



Q. Calculate the voltmeter (–Ⓥ–) reading

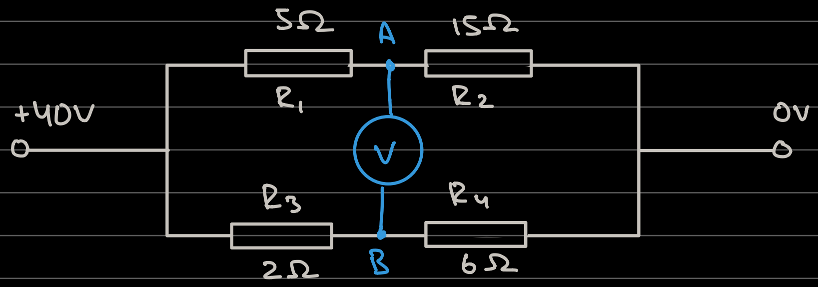
$V_A = 1.5V$

$V_B = 3V$

↳ Hence, potential difference / voltmeter reading is 1.5V.

Example 3:

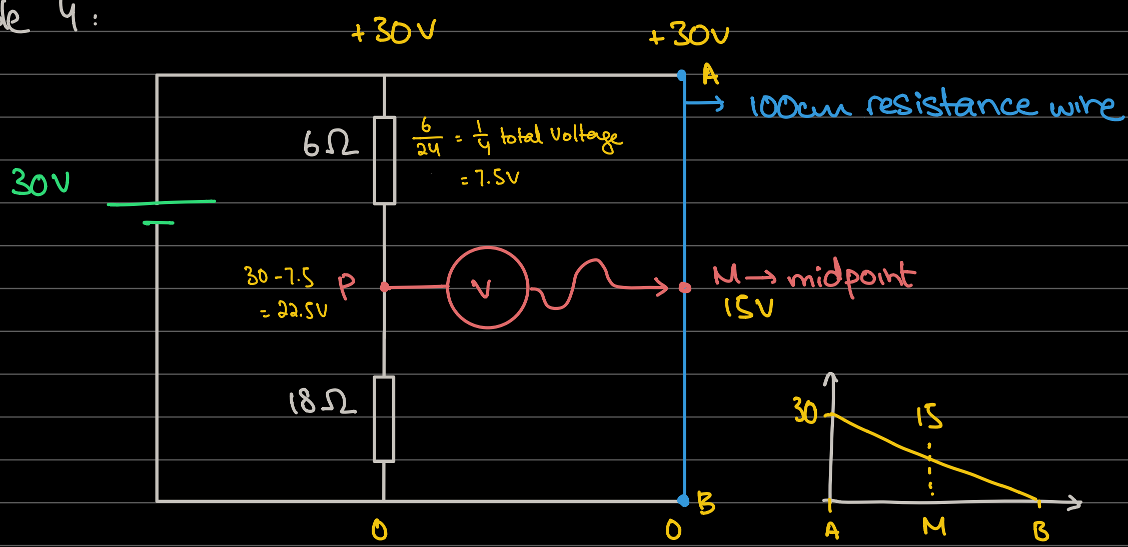
Q. Calculate the voltmeter reading.



Since ratio of R_1 to R_2 and R_3 to R_4 is the same, then the potential / voltage at both A and B will be the same, resulting in a potential difference of 0.

Therefore, a reading of zero / zero deflection is observed on the voltmeter

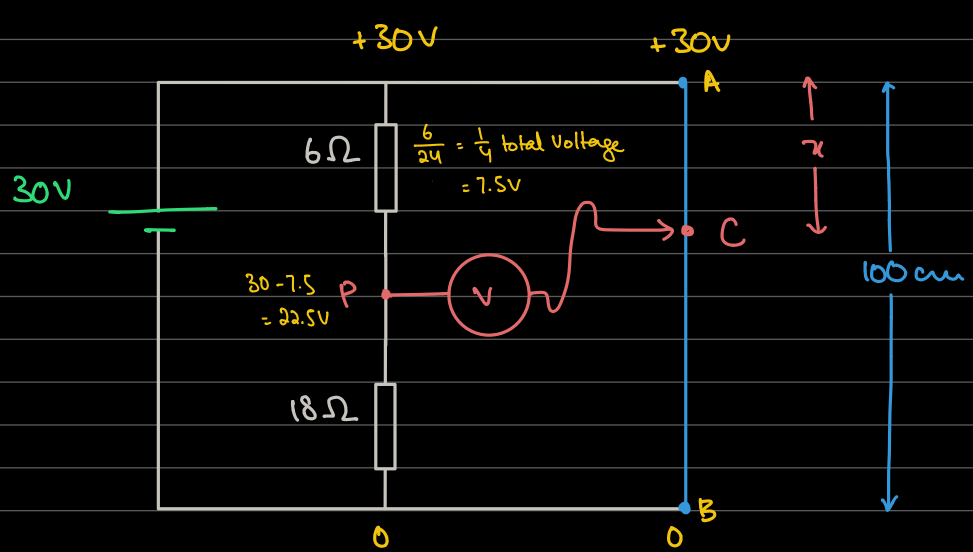
Example 4:



Q. i) Calculate the voltmeter reading if the sliding contact is placed at M

$22.5 - 15 = \boxed{7.5V}$ → Ans, reading on voltmeter

ii)



Calculate the length x required for the voltmeter to give a reading of 0 / no deflection

$$\frac{AC}{CB} = \frac{6}{18}$$

$$\frac{AC}{AB} = \frac{6}{24}$$

$$\frac{AC}{100} = \frac{1}{4}$$

$$\left[\therefore, AC = 25\text{cm} \right] \to \text{Ans}$$

iii) The $18\,\Omega$ resistor is replaced with a $30\,\Omega$ resistor. Suggest what happen to the length x for null deflection to occur.

$$\frac{6}{36} = \frac{AC}{AB}$$

$$\frac{1}{6} = \frac{AC}{100}$$

$$\frac{100}{6} = 16.67\text{cm}$$ → ∴, the length of x decreases

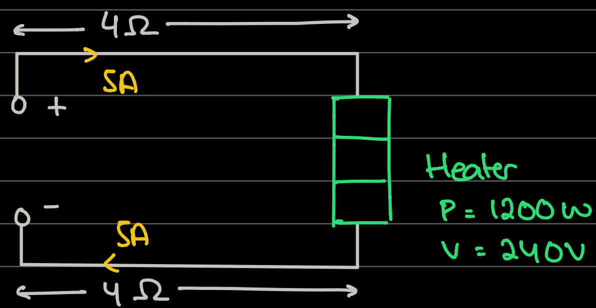
Reasoning:

If $18\,\Omega$ is replaced by $30\,\Omega$, the voltage drop across the $30\,\Omega$ would be equal to a higher percentage of the total voltage. Hence the voltage drop across the $6\,\Omega$ resistor.

↳ Therefore, V_{AC} will also decrease, therefore AC will decrease

EFFICIENCY : ELECTRICITY

CALCULATING THE EFFICIENCY IN AN ELECTRICAL CIRCUIT



i) Calculate the current in the circuit.

$P = IV$

$1200 = I(240)$

$\frac{1200}{240} = I$

$5A = I \longrightarrow$ Ans (i)

ii) Calculate voltage dropped across connecting wires

$V = IR$

$V = (5)(4)$

$V = 20V \longrightarrow$ Ans (ii)

iii) Calculate voltage supplied by the battery

Total Voltage $= 240 + 2(20)$

$= 240 + 40$

$= 280\ V$

This is because while the heater itself may only demand 240V, the connecting wires cause the voltage demand of the entire circuit to be greater than just 240V.

iv) Calculate the efficiency of the circuit

Efficiency $= \frac{240}{280} \times 100 = 85.7\%$

v) How can this efficiency be improved?

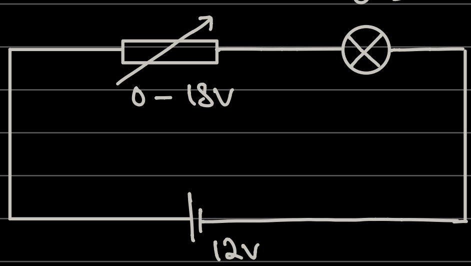
- We can double the diameter of the connecting wires (quadruple the area, hence a 4x drop in resistance)
  - ↳ Lower resistance means a lower voltage drop across the wires, hence a more efficient circuit

  Another advantage of using thick wires is that there are less chances of melting due to overheating

  A disadvantage would be that a thicker wire would be costlier

COMPARISON BW. VARIABLE RESISTOR CIRCUIT AND A POTENTIAL DIVIDER CIRCUIT

VARIABLE RESISTOR CIRCUIT



i) Calculate minimum current in bulb

$$I = \frac{12}{18+6} = 0.5A$$

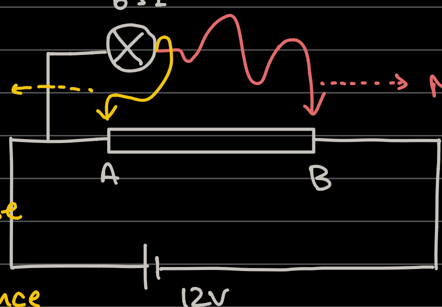
(ii) Calculate maximum current in the bulb

$$I = \frac{12}{0+6} = 2A$$

$0.5A \le I \le 2A$

↳ Range

POTENTIAL DIVIDER CIRCUIT



Minimum current

Maximum current

$I = \frac{V}{R} = 0$ because path of least resistance

$I = \frac{V}{R} = \frac{12}{6} = 2A$

Since voltage stays same in

doesn't go through bulb

parallel

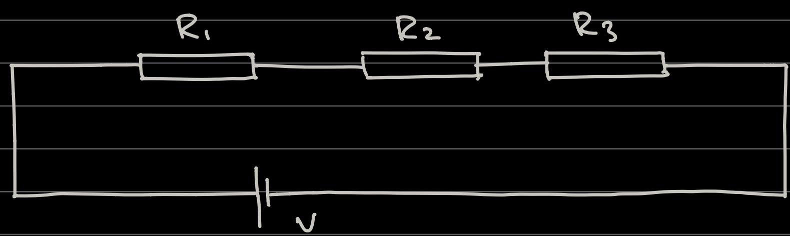
$0 \leq I \leq 2A$

↳ Range

- The potential divider circuit provides a larger range of currents, and is therefore preferred over a variable resistor circuit

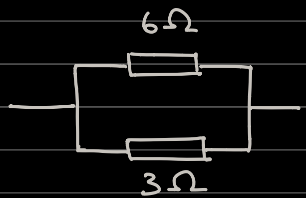
PROPERTIES OF RESISTORS CONNECTED IN SERIES AND PARALLEL

SERIES :



i) $R_{TOTAL} = R_1 + R_2 + R_3$
ii) I remains same throughout
iii) $V \propto R$
iv)

PARALLEL :



Shortcut (only valid for 2 parallel resistors)

$$R_T = \frac{\text{Product}}{\text{Sum}}$$

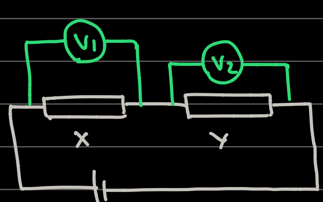
$$= \frac{6 \times 3}{6 + 3}$$

$$= \frac{18}{9}$$

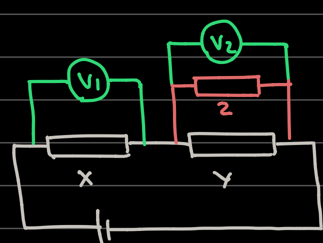
$$= 2\,\Omega$$

- As you keep adding resistors in parallel, the total resistance decreases rather than increasing

↳ Example :



vs.

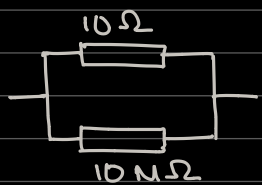


- When adding identical resistors in parallel, the following method can be used to calculate the total resistance

$$R_T = \frac{R}{N}$$

$R \rightarrow$ Resistor of one resistor
$N \rightarrow$ Number of resistors

- When there are two resistors in parallel, and the resistance of one is significantly smaller than the other, then the combined resistance is the resistance of the lesser resistor



$$R = \frac{1}{10} + \boxed{\frac{1}{10^6}}$$ $\rightarrow$ For really large denominators, this approaches 0

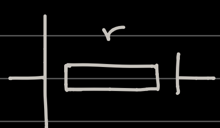
Hence $R = 10\ \Omega$

EXTERNAL RESISTANCE (R)

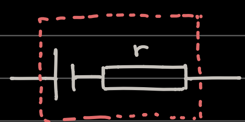
- Refers to any component (load, appliance, etc.) connected in the external circuit (anything outside the battery
- Represented how normal resistors and components are drawn in circuits

INTERNAL RESISTANCE (r)

- The resistance offered by the chemicals inside the battery.



Old Representation

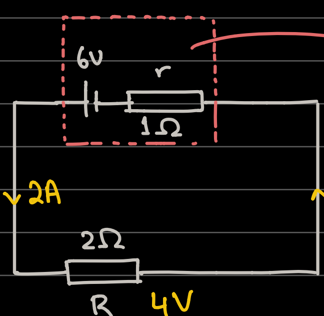


New Representation

Example:

Q.i) Calculate current

$V = IR$
$6 = I(3)$
$2A = I$



2v $\rightarrow$ aka. Lost Volts
Lost Potential
Potential Drop
Voltage Drop

Symbol : v
Formula : $v = Ir$
Definition : The energy supplied by the battery per unit charge

which is wasted / lost in overcoming the internal resistance of the cell.

ii) How much of the voltage does 'R' receive?

4V ⟶ aka. Voltage
Potential Difference
Terminal Potential Difference (preferred)

Symbol : V
Formula : $V = IR$
Definition : The amount of electrical energy converted into other forms ie light, heat when a unit charge flows through the external circuit

ELECTROMOTIVE FORCE (EMV)

$V + v = 4V + 2V = 6V$ ⟶ EMF of the cell

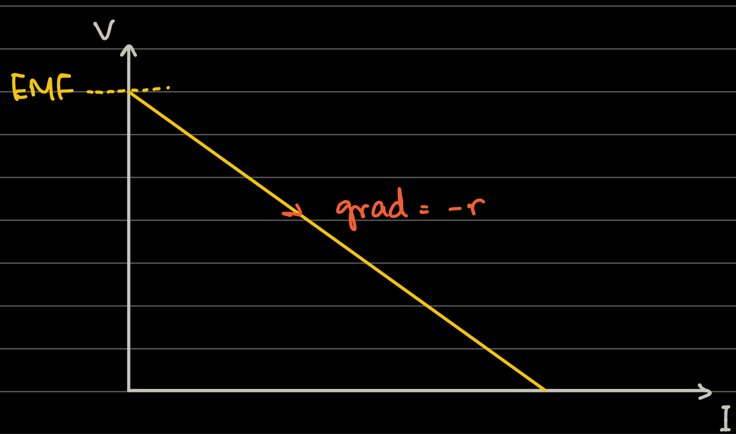
The sum of V and v defines the EMF (E) of the cell

Formula :
$$E = V + v$$
$$E = V + Ir$$
$$E = IR + Ir$$
$$E = I(R + r)$$

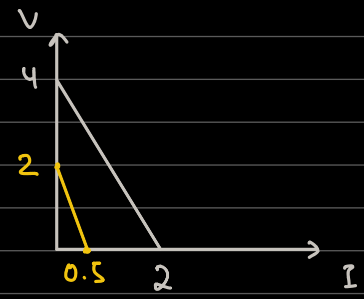
Definition : Amount of chemical energy converted by the battery into electrical form when a unit charge flows through the entire circuit (ie. both the internal and external circuits).

Representing $E = V + Ir$ on a graph

$V = -rI + E$ ⟶ Straight line with a negative gradient and a positive y-intercept.
$y = mx + c$



Example:



i) State EMF

4V

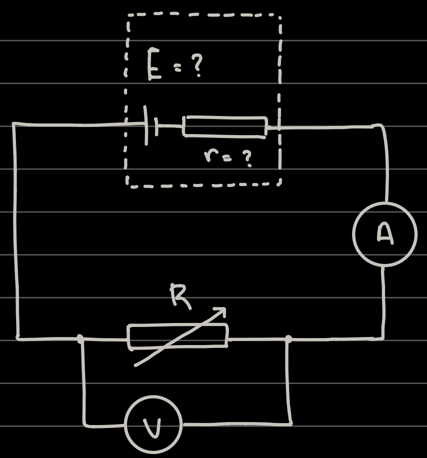
ii) State r

2V

iii) Sketch a new graph where E is half and r is doubled

Done

Example 2:



When variable resistor is set at R_1

-(V)- = 1V

-(A)- = 0.25A

When variable resistor is set at R_2

-(V)- = 0.9V

-(A)- = 0.3A

i) Calculate the values of R_1 and R_2

$$R_1 = \frac{V}{I} = \frac{1}{0.25}$$

$R_1 = 4\Omega \rightarrow$ Ans

Value of R_1

$$R_2 = \frac{V}{I} = \frac{0.9}{0.3}$$

$= 3\Omega \longrightarrow$ Ans

Value of R_2

ii) Calculate the value of r and of E

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

① $E = 0.25(4 + r)$ ② $E = 0.3(3 + r)$

and then solving simultaneously...

$E = 1 + 0.25r$ ①

② $1 + 0.25r = 0.3(3 + r)$

$1 + 0.25r = 0.9 + 0.3r$

$0.1 = 0.05r$

$\frac{0.1}{0.05} = r$

$2\Omega = r$ ②

$E = 1 + 0.25(2)$

$= 1 + 0.5$

$E = 1.5V$

$E = 1.5V$

$r = 2\Omega$

How do we practically determine the internal resistance (r) of a cell?

- Connect a voltmeter across the battery to find the EMF
- Connect a resistor (of any resistance) to the battery, and connect the voltmeter across the resistor to measure the terminal potential difference
- Also use an ammeter to measure the current in the circuit
- Calculate 'r' using $E = V + Ir$