TOPIC 17 Current of Electricity

Objectives

Candidates should be able to:

(a) state that current is a rate of flow of charge and that it is measured in amperes
(b) distinguish between conventional current and electron flow
(c) recall and apply the relationship charge = *current* × *time* to new situations or to solve related problems
(d) define electromotive force (e.m.f.) as the work done by a source in driving unit charge around a complete circuit
(e) calculate the total e.m.f. where several sources are arranged in series
(f) state that the e.m.f. of a source and the potential difference (p.d.) across a circuit component is measured in volts
(g) define the p.d. across a component in a circuit as the work done to drive unit charge through the component
(h) state the definition that resistance = *p.d. / current*
(i) apply the relationship $R = V/I$ to new situations or to solve related problems
(j) describe an experiment to determine the resistance of a metallic conductor using a voltmeter and an ammeter, and make the necessary calculations
(k) recall and apply the formulae for the effective resistance of a number of resistors in series and in parallel to new situations or to solve related problems
(l) recall and apply the relationship of the proportionality between resistance and the length and cross-sectional area of a wire to new situations or to solve related problems
(m) state Ohm's Law
(n) describe the effect of temperature increase on the resistance of a metallic conductor
(o) sketch and interpret the I/V characteristic graphs for a metallic conductor at constant temperature, for a filament lamp and for a semiconductor diode

NOTES

17.1 Conventional Current and Electron Flow

1. Definition of current: the rate of flow of electric charges.

2. Equation: $\boxed{I = \dfrac{Q}{t}}$

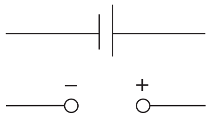
   I is the current (unit: A)
   Q is the charge (unit: C, or equivalent unit: A s)
   t is the time (unit: s)

3. Definition of ampere: 1 ampere is the current carried by 1 coulomb of charge flowing in a circuit in 1 second.

4. The flow of conventional current in a circuit arises from the flow of electrons (negative charges) in the opposite direction.

5. Direct Current (d.c.): A direct current only flows in one direction.

6. Alternating Current (a.c.): An alternating current periodically reverses its direction back and forth.

 d.c. source	 a.c. source

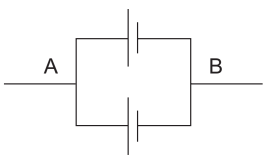
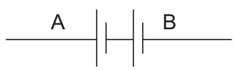
17.2 Electromotive Force (e.m.f.)

1. Definition of electromotive force: The electromotive force of a d.c. source is the work done by the source to drive a unit charge round a closed circuit.

2. Equation: $\boxed{W = QV}$

   W is the work done by source (unit: J)
   Q is the charge (unit: C)
   V is the e.m.f. (unit: V)

3. The following table shows some of the different types of arrangement of 1.5 V cells and the resultant e.m.f.:

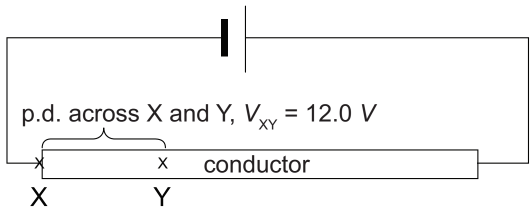
Two cells in parallel Overall e.m.f. across AB = 1.5 V	**Two cells in series** Overall e.m.f. across AB = 3.0 V
	

17.3 Potential Difference (p.d.)

1. Definition of potential difference: The potential difference across a circuit component is the work done to drive a unit charge through the circuit component.

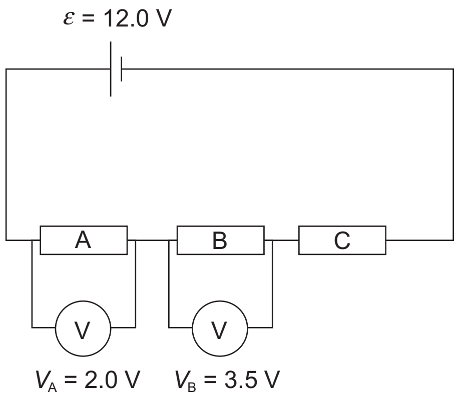
Example 17.1

For a conductor (resistor wire) connected in a closed circuit, the potential difference across two points, X and Y, in part of the conductor is the work done to drive a unit charge across the two points through that part of the conductor.



Example 17.2

The following circuit shows three resistors, A, B and C, connected in series. The potential difference across A and B are given as V_A = 2.0 V and V_B = 3.5 V. Given that the e.m.f. of the battery is 12.0 V, find the potential difference across resistor C.

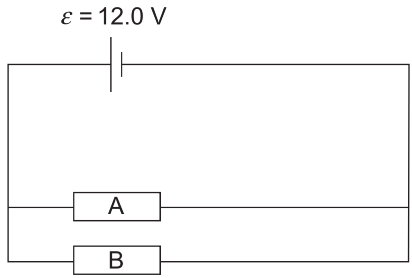


Solution

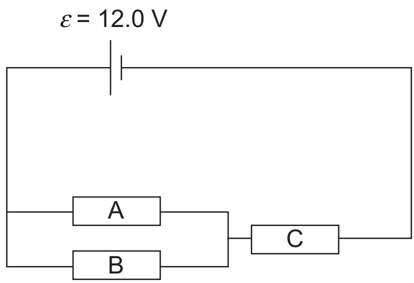
$V_C = 12.0 - 2.0 - 3.5 = 6.5$ V

2. In a circuit with two resistors A and B, the potential difference across resistor A is the same as the potential difference across resistor B if the two resistors are arranged in parallel.

$V_A = V_B = 12.0$ V



Example 17.3
Given that $V_C = 5.0$ V, find the potential difference across A and B.



Solution
Since resistors A and B are arranged in parallel, $V_A = V_B = 12.0 - 5.0 = 7.0$ V.

17.4 Resistance

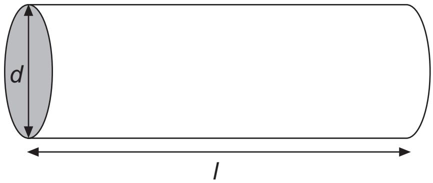
1. Definition of resistance: The ratio of potential difference (V) across the conductor to the current (I) flowing through it.

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

R is resistance of conductor (unit: Ω, equivalent unit: $1\ \Omega = 1\ \text{V A}^{-1}$)
V is potential difference across the conductor (unit: V)
I is current through the conductor (unit: A)

2. The resistance of a piece of cylindrical wire R is related to its length l, cross sectional area A and its resistivity, ρ (each type of material has its own resistivity):

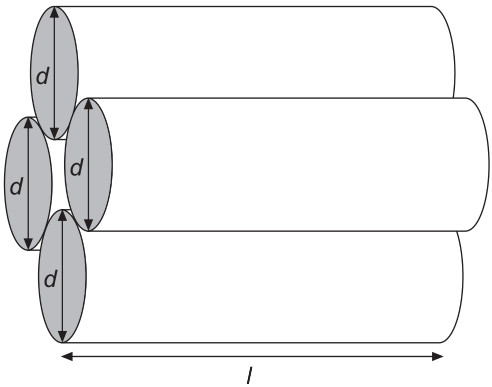
$$\boxed{R = \frac{\rho l}{A}}$$



d – diameter of wire
l – length of wire
Cross-sectional area of wire,

$$A = \pi\left(\frac{d}{2}\right)^2$$

3. Parallel resistors
4 identical resistors are connected in parallel as shown in the diagram.



Effective cross-sectional area = $4 \times A = 4A$

Effective length of bundle of 4 resistors = l

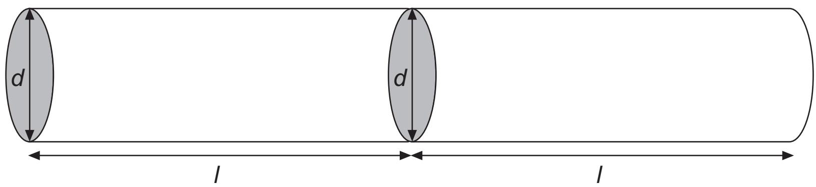
Effective resistance, R_{eff}
$= \dfrac{\rho l}{4A} = \dfrac{1}{4}R$

Formula:

$$\boxed{\frac{1}{R_{\text{elf}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$

4. Series resistors

   2 identical resistors are connected in series as shown in the diagram.



   Effective cross-sectional area = A

   Effective length of 2 resistors = $2l$

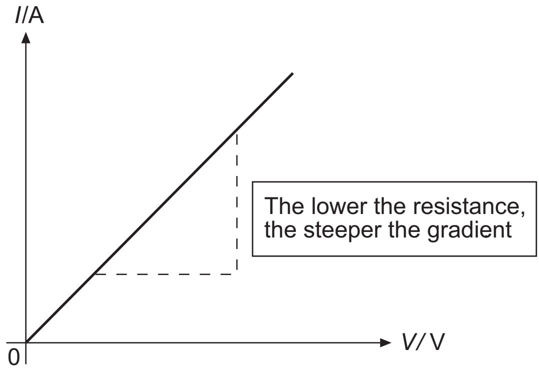
   Effective resistance, $R_{eff} = \frac{\rho(2l)}{A} = 2\frac{\rho l}{A} = 2R$

   Formula:

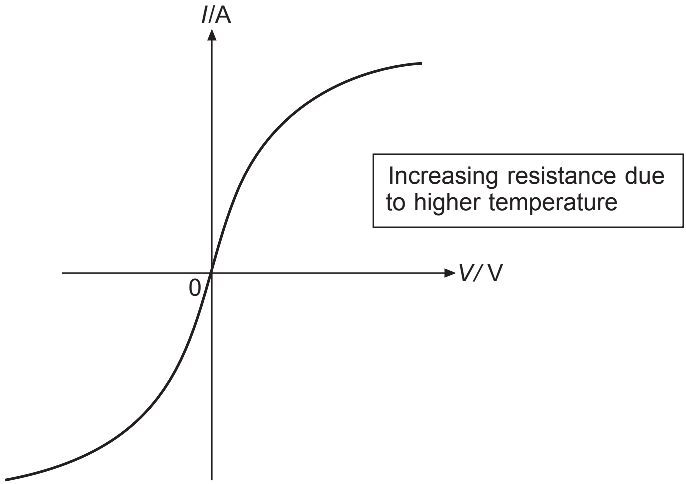
$$\boxed{R_{eff} = R_1 + R_2}$$

5. Ohm's Law: Ohm's law states that the current flowing in a conductor is directly proportional to the potential difference applied across it when all other physical conditions such as temperature are constant.

   The I-V graph of an ohmic conductor is as follows:



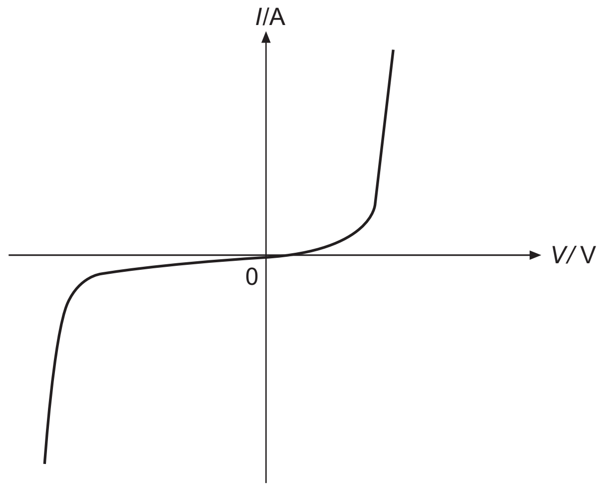
6. For a filament lamp (non-ohmic conductor), its *I-V* graph is not a straight line. As such, it does not obey Ohm's Law. As more current flows in a lamp, its metal filament becomes hotter and atoms in the filament vibrate faster, moving further away from their positions. This leads to an increase in the frequency of collisions with the travelling electrons that hinder their flow, causing more resistance. Hence, the gradient of its graph is fairly constant at low current *I* and potential difference *V*, but with increasing current, the resistance increases (gradient decreases).



17.5 Diode and Light-dependent Resistor

1. A diode can be used to convert a.c. to d.c. in a process called rectification. A diode is a semiconductor device that allows current to only flow in one direction.

2. The *I-V* characteristic graph for the semiconductor diode is shown:



3. A light dependent resistor (LDR) is a semiconductor. When light shines onto the LDR, electrons are released. This increases the number of current-carrying electrons. As the light intensity increases, the current also increases, resulting in a fall in resistance. In the dark, there are no electrons and the current experiences a greater resistance.