Topic 14 - Current of electricity

1 Electric Current and charge

1.1 Electric Current

Electric current is defined as the rate of flow of charge

$$I = \frac{dQ}{dt}$$

The S.I. unit for current is Ampere

1.2 Charge

Electical charge is a fundamental property of matter which causes a charged particle to experience a force when placed in an electric field.

When a current I flows through a cross-section of a conductor for duration t, the amount of **electrical charge** passing through is given by

$$Q = It$$

One **coulomb** is defined as the amount of charge that passes through a point in one second due to a current of one ampere

1.3 Drift velocity

For a conductor with cross sectional area A and n charge carriers per unit volume, and a current I

In the time interval Δt , each charge moves a distance of

$$v_D(\Delta T), \text{ where } v_D \text{ is the drift velocity}$$

The number of charge carriers passing through a point in duration Δt is thus

$$nAv_D\Delta t$$

total charge passing through is

$$nAv_d\Delta tq$$

current is thus

$$I = \frac{nAv_d\Delta t}{\Delta t} = nAv_Dq$$

2 Potential difference

The **potential difference** between two points in a circuit is defined as the amount of electrical energy per unit charge that is converted to other forms of energy when charge passes from one point to another

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

The SI units for p.d. is volt
one volt is the potential difference between two points when one joule of electrical energy is converted to other forms of energy as one coulomb of charge passes from one point to another

3 Electromotive Force

the **electromotive force** of a source is defined as the amount of electrical energy per unit charge that is converted from other forms of energy when charge passes through the source

$$E = \frac{W}{Q}$$

4 Resistance and resistivity

The **resistance** of a circuit component is defined as the ratio of the potential difference across it to the current flowing through it

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

one Ω is the resitance of a conductor when a potential difference of one volt across it causes a current of one ampere to flow through

4.1 Ohm's law

Ohm's law states that the potential difference across a conductor is proportial to the electric current passing through it, provided that its temperature remains constant

4.2 Resistivity ρ

The resistance of a unifom conductor is

- directly proportional to its length, l
- inversely proportional to its cross sectional area, A

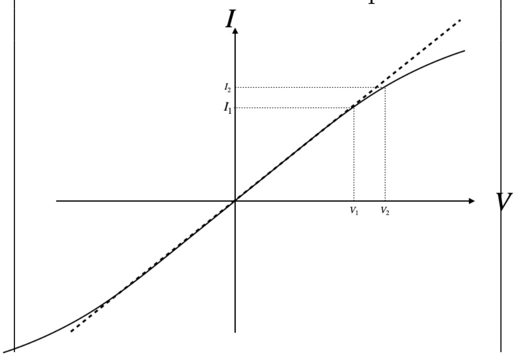
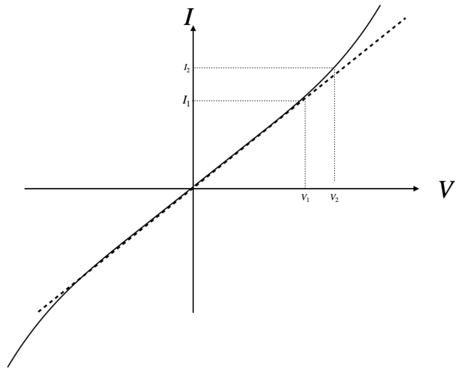
hence

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

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

4.3 Effect of temperature changes

- Effect 1: increase in density of free electrons. More electrons able to break free from atoms, more mobile electrons
- Effect 2: lattice ions vibrate faster with greater amplitudes. Electrons lose KE to fixed ions during collision, hence emperature increases. Ions then vibrate faster with greater amplitudes, making it more difficult for electrons to pass through the lattice

materials	metallic conductors	semiconductors - NTC thermistors
Effect 1	Electrons are already mobile at room temperature. No appreciable increase in number of conducting electrons	Semiconductors are poor conductors at low temperatures. Conductivity increases significantly with temperature
Effect 2	Significantly greater vibration of lattice ions, resistance increases	Significantly greater vibration of lattice ions.
Change in resistance	Effect 1 insignificant, effect 2 is present, resistance increases with temperature 	Effect 1 more significant than effect 2. Resistance decreases with temperature 

5 Electrical power

When a charge Q moves through a p.d. V, the amount of electrical energy converted to other forms is

$$W = QV$$

the rate of energy convertion is

$$P = \frac{dW}{dt} = \frac{d(QV)}{dt} = \frac{dQ}{dt}V = IV$$

5.1 Power of an ideal source

For an ideal source, work done is

$$W = QE$$

The power supplied is

$$P = \frac{dW}{dt} = \frac{dQ}{dt}E$$
$$P = IE$$

5.2 Power dissipated by a resistor

The p.d. across a resistor is

$$V = IR$$

The rate of energy dissipation is

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

6 Internal resistance of a source

For a real battery with internal resistance r connected to a circuit with resistor R

The power supplied by source is

$$P_s = IE$$

Power dissipated in internal resistance is

$$P_r = I^2r$$

Power dissipated in external load is

$$P_R = I^2R$$

By principle of conservation of energy

$$P_S = P_r + P_R$$
$$IE = I^2 r + I^2 R$$

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

$$E = Ir + V_R$$

$$V_R = E - Ir$$

Hence terminal p.d. V decreases with increasing I

6.1 Power output and max power theorem

since

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

heat transferred to external load R is

$$P_R = I^2 R = \left(\frac{E}{r + R}\right)^2 R$$

$$P_R = \frac{E^2 R}{(r + R)^2}$$

Max power delivered to external load R can be found by taking the derivative

$$\begin{aligned} \frac{dP_R}{dR} &= 0 \\ 0 &= \frac{E^2(r + R) - 2E^2 R}{(r + R)^3} \\ E^2(r + R) - 2E^2 R &= 0 \\ r + R - 2R &= 0 \\ r &= R \end{aligned}$$

Hence a source of emf delivers the maximum amount of power to an external load when the resistance of the load is equal to the internal resistance of the source