OCR A Physics A-level

Topic 4.1: Charge and Current

Notes

Charge

Electric current

Electric current, I, is defined as the **rate of flow of charge** $I = \frac{dQ}{dt}$. The SI base unit for current is **Amperes** (A). The current in an electrical circuit can be measured using an ammeter, which is placed in series.

Charge and coulombs

Charge, Q, is a physical quantity, which can be either positive or negative. It is measured in **coulombs** (C), where 1 coulomb is defined as the flow of charge in a time of 1 second when the current is 1 ampere. It has the SI base units of Is. Like charges repel each other, whereas opposite charges attract each other.

When we refer to the charge of ions and the components of atoms, we look at it as a **quantised number** – a proton has a charge of +1, and an electron has a charge of -1. However, these numbers represent **multiples** of the **elementary charge**, *e*, 1.6×10^{-19} C.

The net charge of a particle is due to the gain or loss of electrons. In an atom, the number of protons equals the number of electrons, so the charges cancel each other out and the overall charge is neutral. Increasing the number of electrons will produce a **negative ion**. Removing electrons will produce a **positive ion**, as there are now more protons than electrons. The net charge on a particle Q is given by $Q = \pm ne$, where n is the number of electrons added or remove, and also the **quantised charge value** for the particle.

Charge carriers

Electric current is the rate of flow of charge, but charge can be **carried in several ways**, depending on the **material** the current is passing through. The current in metals is carried by electrons. In a metal, there is a lattice of **positive ions**, surrounded by **free electrons**. The positive metal ions are fixed in place, but the electrons can move around, and so when one side of the metal is made positive, and the other side is made negative, the electrons will be attracted to the positive side, and move through the metal as electric current.

Some liquids can conduct a charge. These conducting liquids are called **electrolytes**, and are commonly **ionic solutions**. This means they contain positive and negative ions. An example of this is water with salt, NaCl, dissolved in it. The salt splits in to Na^+ cations and Cl^- anions. When a pair of **electrodes** (the anode is the positive electrode and the cathode is the negative electrode) are placed in the solution, the cations will be attracted to the cathode, and the anions will be attracted to the anode. This produces an electrical current.

Conventional current

Conventional current was discovered and defined well before the discovery of the electron. It is the rate of flow of charge **from the positive to the negative** terminal, and this is how all electric currents are treated, regardless of the direction the charge carriers are moving in. In metals, the electrons flow from negative to positive, so the **electron flow** is in the **opposite direction** to the conventional current.

Kirchhoff's first law

Kirchhoff's first law states *for any point in an electrical circuit, the sum of the currents in to that point is equal to the sum of the currents coming out of that point*. This law is a consequence of the **conservation of charge**. Charge is a fundamental physical property, which cannot be created or destroyed, so it must be conserved.

Mean drift velocity

When electrons move through a metal, they frequently **collide** with the positive metal ions, resulting in **random movement**. When a power supply is connected, the free electrons are attracted towards the positive terminal, but they still collide with the positive metal ions. The **mean drift velocity**, *v*, is defined as the average velocity of the electrons as they travel down the wire, colliding with positive metal ions.

The number density, n, of a material represents the number of **free electrons per unit volume**. Conductors, such as metals, have very high number densities, around 10^{28} per m^3. Insulators, such as plastics, have much smaller number densities, and semi-conductors like silicon have in-between values. When the value of n is lower, the electrons must travel **faster** to carry the same current.

An additional formula for current can be determined.

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

The total charge, Q in the wire is the product of the number of free electrons per unit volume, n, the elementary charge, *e*, and the volume, V:

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

The volume of the wire is equal to its cross sectional area, A, multiplied by its length. The length of the wire divided by the time taken for the electrons to cross this distance is equal to the mean drift velocity, *v*, so we can rewrite $\frac{V}{dt}$ as A*v*.

This gives us our final equation,

$$I = Anev$$

We can rearrange this equation to find the mean drift velocity for electrons in a wire when the current, the cross sectional area of the wire, and the number density of the metal are known.