# OCR A Physics A-level

Topic 4.2: Energy, Power, and Resistance

Notes

Circuit symbols

There are a range of circuit symbols which can be used to **represent the components** used in electrical circuits. They should be drawn carefully, with arrows pointing in the correct directions. Wires in circuits should be shown as **straight lines**, with wires in junctions drawn at 90° angles to each other.
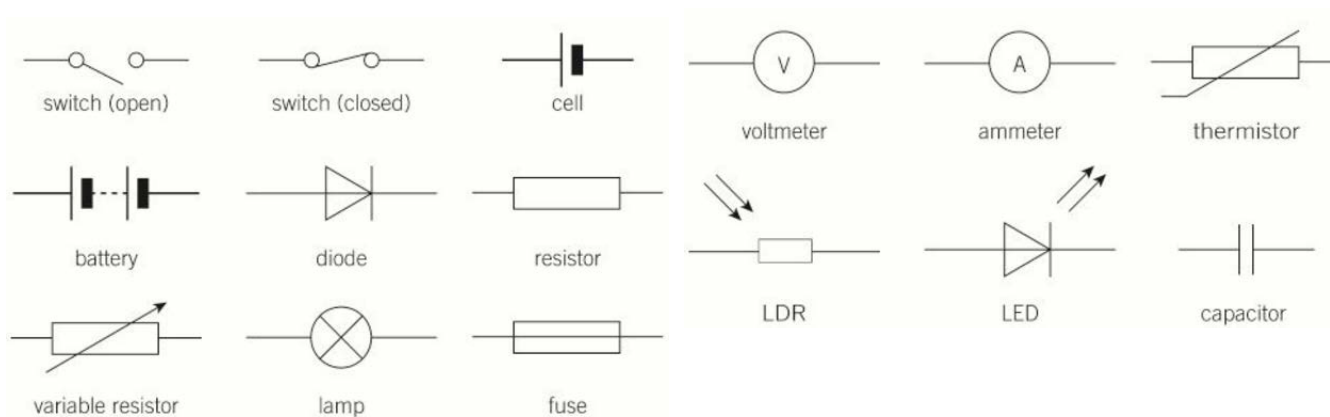
Potential difference and electromotive force

Potential difference (p.d.)

Potential difference, V, is used to measure the **work done by charge carriers**, which **lose energy** as they pass through the components in a circuit. It is defined as the energy transferred from electrical energy to other forms, per unit charge, $V = \frac{W}{Q}$. It is measured in volts (V), where a potential difference of 1 volt is defined as 1 joule of energy transferred per coulomb.

Electromotive force (e.m.f.)

Electromotive force, ε, is used to measure the **work done to charge carriers**, when they **gain energy** as they pass through a cell or power supply. It is defined as the energy transferred from chemical energy to electrical energy per unit charge, $\varepsilon = \frac{W}{Q}$. E.m.f. is also measured in volts.

The electron gun

An electron gun is a device used to produce a thin **beam of electrons**, which are accelerated to high speeds. A small metal filament, which acts as a cathode, is heated by passing a potential difference through it. Some of the electrons in the metal gain enough kinetic energy to escape the metal, in a process known as **thermionic emission**. The circuit is in a vacuum tube, with a high p.d., V, between the filament and the anode, so the freed electrons are **accelerated** towards the anode. If the anode has a small hole in it, a beam of electrons can pass through at a **specific kinetic energy**.

The velocity of these electrons can be determined using the **conservation of energy**. As potential difference is equal to the work done per unit charge, then the work done to accelerate the electron is the charge of the electron, *e*, multiplied by the potential difference between the filament and the anode, V. All of the work done on the electron is transferred to kinetic energy, giving us the equation

$$eV = \frac{1}{2}mv^2$$

This equation can be rearranged to find the final velocity, *v*, of the electron. In this equation, we assume that the electron has **negligible kinetic energy at the cathode**, and that no energy is lost to heat etc. during the acceleration.

Resistance

Resistance and ohms

Each component in a circuit 'resists' the flow of charge to some extent. The resistance, R, of a component is defined as the potential difference across the component, divided by the current in the component, $R = \frac{V}{I}$. Resistance is measured in the unit ohm (Ω), where a resistance of 1 ohm is defined as a 1 volt per unit ampere.

To determine the resistance of a component, a circuit can be set up with a variable power supply, an ammeter in series with the component, and a voltmeter in parallel with the component. By **varying the power supply**, we can vary the potential difference across the component, and record the p.d. and current, to calculate the resistance, which is equal to 1 over the gradient of the I-V graph.
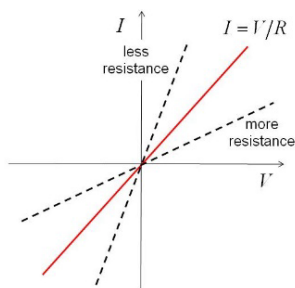
Ohm's law

Ohm's law states *for a metallic conductor kept at a constant temperature, the current in the wire is directly proportional to the potential difference across it*. This is **true for some**, but not all components. Where Ohm's law is true, components are considered ohmic, and their i-v characteristic graph will have a **constant linear gradient**.

For some components, Ohm's law does not hold true, and these components are considered non-ohmic. This is because when the current across the component increases, the metal ions are heated, **gaining kinetic energy** and vibrate more around their fixed points in the metallic lattice. This increases the **frequency of collisions** with electrons, so **more work is done** on the charge carriers, increasing the resistance.

I-V characteristics

Fixed resistors are designed so that their resistance is **always constant**, despite environmental changes. The p.d. is proportional to the current, so the component follows Ohm's law. All wires in circuits can be considered as fixed resistors, just with very low values of resistance.
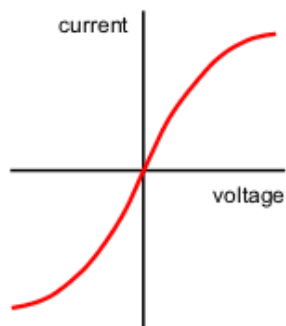

The I-V characteristic for a filament lamp shows that the component is **non-ohmic**. For small values of current, the filament lamp acts like an ohmic component, but as the magnitude of the current increases, the heating effect on the metal ions causes the resistance of the component to **increase**.
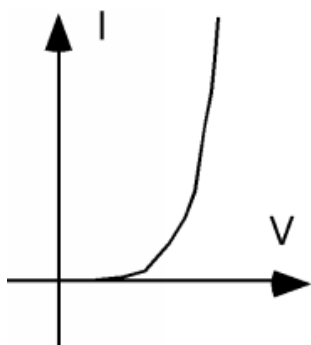

Diodes are components made from semiconductors, which allow current to flow only in **one direction**. The diode is a non-ohmic component. When the diode is reverse biased, it does not conduct at all, and the resistance across it is infinite. The diode does not conduct until a **threshold value** for p.d. is reached. The resistance decreases rapidly as the p.d. is increased above the threshold value, because the number density of charge carriers increases.

NCT thermistor
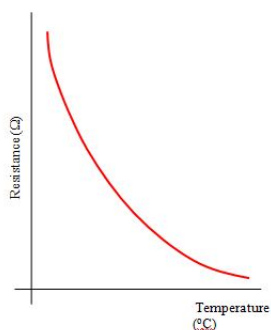
Some semi-conductors have a **negative temperature coefficient** (NCT). This means as the temperature of the material increases, the resistance of the material decreases. The change in resistance is usually dramatic, so they are useful in **temperature sensing circuits** such as thermometers and thermostats.
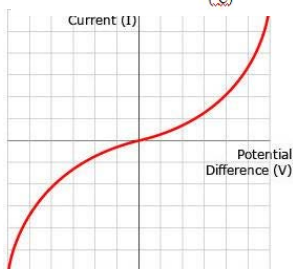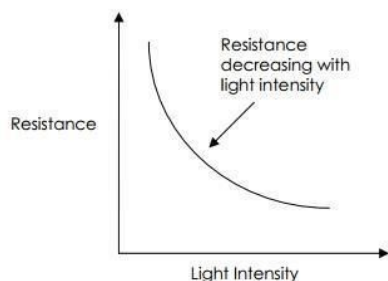
The thermistor is a **non-ohmic component** which is used to electrically measure the temperature. It is made of an NCT semi-conductor material, and as the current, and hence the temperature, through the thermistor increases, the resistance decreases.

Light dependant resistors

Light dependant resistors (LDRs) are small, **non-ohmic** components made from semiconductors. When the light intensity incident on the resistor is increased, the resistance of the LDR decreases.

Resistivity

Resistivity of a material

The resistivity, ρ, of a material is a **physical property** of the material. It is the same for any shape of a given material at a set temperature, and it acts as a **constant** to link the resistance of the material with its area and length. Resistivity is given using the formula $\rho = \frac{RA}{L}$, where R is the resistance of the object, A is the cross-sectional area of the object, and L is the length of the object. Resistivity is measured in Ohm-meters (Ωm), and is small for metals and much larger for insulating materials such as glass.

The resistivity of a material **varies with temperature**. For metals, when the temperature is increased, the fixed metal ions will vibrate at a greater frequency and amplitude. This increases the number of collisions of electrons with the ions, increasing the resistance. For semiconductors, the number density of charge carriers increases with increasing temperature, so the resistance of the material decreases. As the resistivity is a constant linking the shape of the material with its resistance, if the resistance of the material increases or decreases with changing temperature, the value for resistivity of the material will be **affected in the same way**.

Techniques to determine resistivity

The resistivity of a wire at a specified temperature can be determined experimentally. First, the **cross sectional area** of the wire is recorded, by taking multiple readings with Vernier callipers at different points along the wire, and taking an average. Then, a circuit is set up using a **recorded length** of the wire, with a voltmeter connected in parallel and an ammeter in series. The values for p.d. and current can be recorded to determine the resistance of the wire, and used along with the length and cross sectional area to determine the resistivity of the material the wire is made from.

Power

Electrical power

When there is a current through a component, electrical energy is **transferred to other forms**, such as light in a filament bulb. Electrical power is defined as the **rate** of energy transfer, and is measured in watts (W) or Js^{-1}. Using the definition of power as work done per unit time, we can derive an equation for power that is easier to use in circuit analyses.

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

As potential difference across a component is equal to work done per unit charge, we can rewrite work done as p.d. multiplied by charge

$$P = \frac{VQ}{t}$$

And as current through a component is equal to the rate of flow of charge, we can used this to get the final equation

$$P = VI$$

As V = IR, we can substitute this formula in place of either current or p.d., to obtain two more equations for power, which are useful in circuits where either current or p.d. are unknown

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

Energy transfer and the kilowatt

As power is the energy transferred per unit time, we can calculate the energy transferred, W, by a component by multiplying the power to the component by the time the component is used for.

$$W = Pt \rightarrow W = (VI)t$$

The SI unit for energy is joules, but this is a very small measure of energy, so when measuring the energy used for **industrial or domestic purposes** (such as for household energy bills), the unit kilowatt-hours (kWh) is used instead. 1 kilowatt-hour is defined as the energy transferred by a device with a power of 1 kilowatt when it is operated for a time of 1 hour.

The cost of energy is usually given per kWh, and this value can be multiplied by the number of kWh used to calculate the **total cost of running** a device.