Edexcel Physics A-level

Topic 3: Electric Circuits

Key Points

Current

Current is defined as the **rate of flow of charge** in a circuit. It is measured in Amperes. You should be aware of two different ways of describing current flow:

1. **Electron flow** is from negative to positive and is the direction that electrons actually flow in a circuit
2. **Conventional current flow** is from positive to negative and is more commonly used to describe the direction of current

As an equation, current is defined as:

$$I = \frac{\Delta Q}{\Delta t}$$

1 Ampere is the current flow when 1 Coulomb of charge passes a point each second.

Potential Difference

Potential difference is equal to the **work done** per **coulomb** of charge travelling in a circuit. As an equation this is defined as:

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

It is measured in **Volts,** where 1 Volt is equal to 1 Joule of work being done by each Coulomb of charge.

To measure the potential difference over a specific component, a voltmeter can be used. It should be connected in **parallel** over the component.

An **ideal voltmeter** has **infinite resistance**, so that no current is drawn from the circuit.

Resistance

Resistance is a measure of how difficult it is for current to flow in a circuit. It is **directly** proportional to the **potential difference** in a circuit, and **inversely** proportional to the **current** flow. As an equation it is defined as:

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

It is measured in **Ohms**.

An **ohmic conductor** is a conductor which follows **Ohm's law**, meaning that the current flowing through it is directly proportional to potential difference, when it is held at a **constant temperature**.
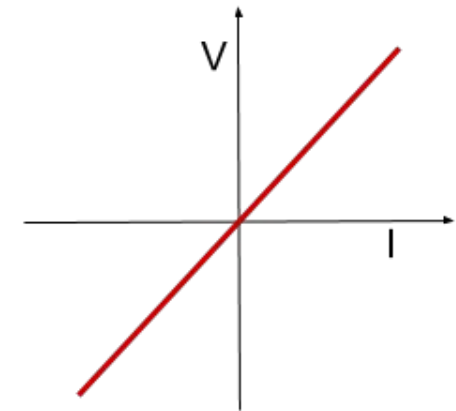
Resistivity

The resistivity of a material is a measure of how easily it allows charge to flow through it and depends on several different factors. They are:

1. **Cross sectional area** - the greater the area, the easier the passage of electrons
2. **Length** - the longer the length, the harder it is to send a current through it
3. **Resistance** - the larger the resistance through a material, the larger its resistivity

Combining these factors allows an equation for resistivity to be formed:

$$\rho = \frac{RA}{L}$$

The unit for resistivity is **Ωm**.

Current and Potential

The **current (I)** through a wire can be measured using the following equation:

$$I = nqvA$$

Where...

$\boldsymbol{n}$ = the density of charge carriers (m^{-3})

$\mathbf{q}$ = is the charge of charge carriers (usually 1.6×10^{-16} C)

$\mathbf{v}$ = the velocity of the charge carriers (ms^{-1})

$\mathbf{A}$ = the area of the wire (m^2)

Therefore, materials have a **large range of resistivities** since the density of charge carriers (free electrons) in them varies greatly.

When you increase the length of a wire, the resistance across it also increases following the equation:

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

As potential difference (V) is equal to the product of current and resistance (V = IR), the **potential across the wire also increases with length**.

Superconductors and Semiconductors

Superconductors are materials which have **zero resistivity** at and below a **critical temperature**. This temperature differs for each material, but currently are too low to be used effectively. If materials with high enough critical temperatures can be developed, they could be used in electricity transmission to **reduce energy loss** as well as in the production of **extremely strong magnetic fields**.

Semiconductors are components for which the resistance changes depending on **external conditions**. The two main types you need to know about are:

1. **Light Dependant Resistors (LDRs)** are light sensitive components - when light intensity increases, electrons in the LDR are released and so its resistance decreases. This is because the number of conduction electrons increases.
2. **Thermistors** are temperature sensitive components - when their temperature increases, electrons in the thermistor are released and so its resistance decreases. This is because the number of conduction electrons increases.

Power

Power is defined as the **rate of energy transfer**. It can be calculated using:

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

It can also be defined by combining the above equation with the equations defining potential difference, resistance and current to give:

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

The unit of power is the **Watt**, where 1 Watt is the power dissipated when 1 joule of energy is transferred each second.

I-V Characteristics

You should be familiar with the two I-V characteristics below, as well as with the straight-line ohmic conductor graph.

Filament Lamp

When a filament bulb is used, as current is increased, the **temperature** of the filament increases. This causes the **metal ions** to vibrate with more kinetic energy and consequently, makes it harder for the **charge carriers** to pass through. This means the resistance **increases**.
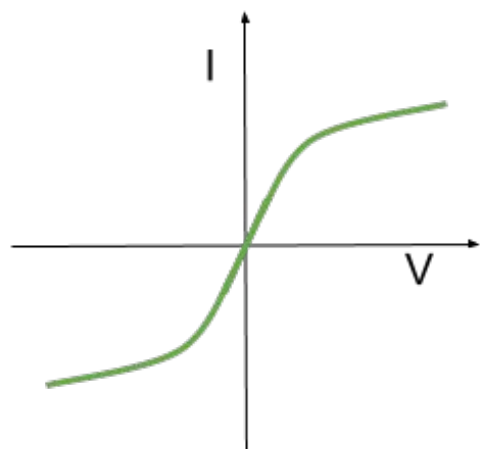
Diode

Diodes are components that only let current flow through in **one direction**. In the opposite direction the resistance is very high and means current can't flow through. In the correct direction, diodes have a **threshold voltage** of around **0.6 V**, after which current can flow through normally.
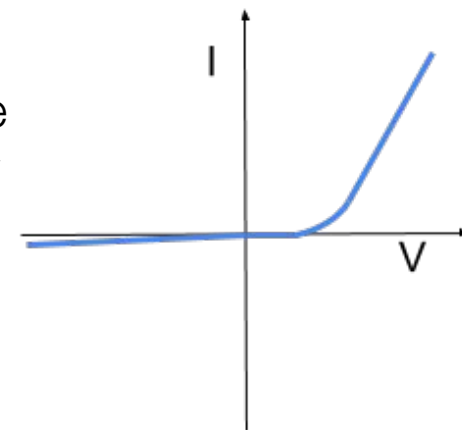
Series and Parallel Circuits

Series circuits are ones where all the components are part of the **same loop**. You need to know that:

- The **current** is the same in all positions in a series circuit
- The **potential difference** over the loop is split between all the components, in the ratio of their resistances

Parallel circuits are ones where the components are in **adjacent loops**. You need to know that:

- The **potential difference** over each loop is the same
- The **current** is split between each branch and so is different in different parts of the circuit

Kirchoff's Laws

Energy and **charge** are **conserved** in circuits which means that e.m.f and current are too (as they're related to energy and charge respectively).

Kirchhoff's 1st Law:

The total current entering a junction is equal to the total current leaving it.

$$I_t = I_1 + I_2 + I_3 ...$$

$$\frac{V}{R_t} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

From this we can derive total resistance in a parallel circuit as shown above.

Kirchhoff's 2nd Law:

The sum of e.m.f in any loop of the circuit is equal to the sum of the p.d's of each component.

$$\varepsilon = \Sigma IR$$

$$IR_t = IR_1 + IR_2 + IR_3 ...$$

$$R_t = R_1 + R_2 + R_3 ...$$

From this we can derive total resistance in a series circuit as shown above.

E.M.F and Internal Resistance

All power sources have a value for their EMF. **Electromotive force** can be defined as the amount of **energy** supplied by the **source** per unit charge. It is measured in Volts.

In reality, the **terminal potential difference** of the power source is **never equal** to this **EMF** value. This is because energy is **dissipated** within the source due to the cell's internal resistance.

Internal resistance can be described as the opposition to the flow of charge within a cell.

$\varepsilon = I\,R + I\,r$

$\varepsilon = V + r\,I$

$V = -rI + \varepsilon$

$y = mx + c$

You can plot a graph of the terminal voltage against current. The y intercept will be the e.m.f and the gradient will be the negative internal resistance.
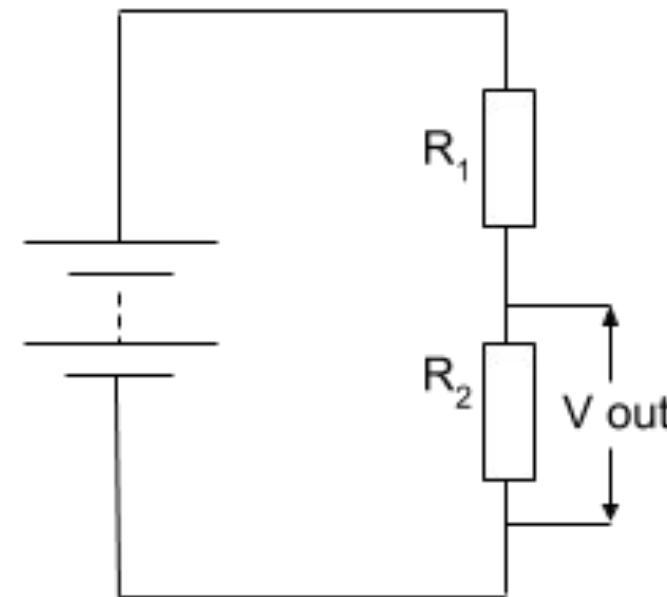
Potential Divider

A **potential divider** is a combination of two or more resistors in series, which results in the potential difference in the circuit being **split** into a specific **ratio**. By choosing the correct values of resistance for the resistors, a desired **output voltage (V-out)** can be obtained.

A component's pd as a fraction of the total e.m.f will be equal to its resistance as a fraction of the total resistance:

$$\frac{P.D_1}{\Sigma\varepsilon} = \frac{R_1}{\Sigma R}$$

Variable resistors in a potential divider are used to change the voltage supplied to something to a suitable voltage without using a transformer. However, this method wastes power.

Detecting circuits can also be constructed by using a semiconductor, such as an LDR, as the second resistor. This means that when light intensity increases, the output voltage (V-Out) over the LDR will drop below a certain desired level.