CAIE Physics A-level

Topic 9: Electricity

Notes

9 - Electricity

9.1 - Electric Current

Electric current (I) is the flow of charge (Q) per unit time (*t*), or the **rate of flow of charge**. Charge is carried by **charge carriers** in **quantised** amounts. Typically the charge carriers are **electrons**, which each carry the **elementary charge** $e = 1.60 \times 10^{-19}$ **C (coulombs)**.

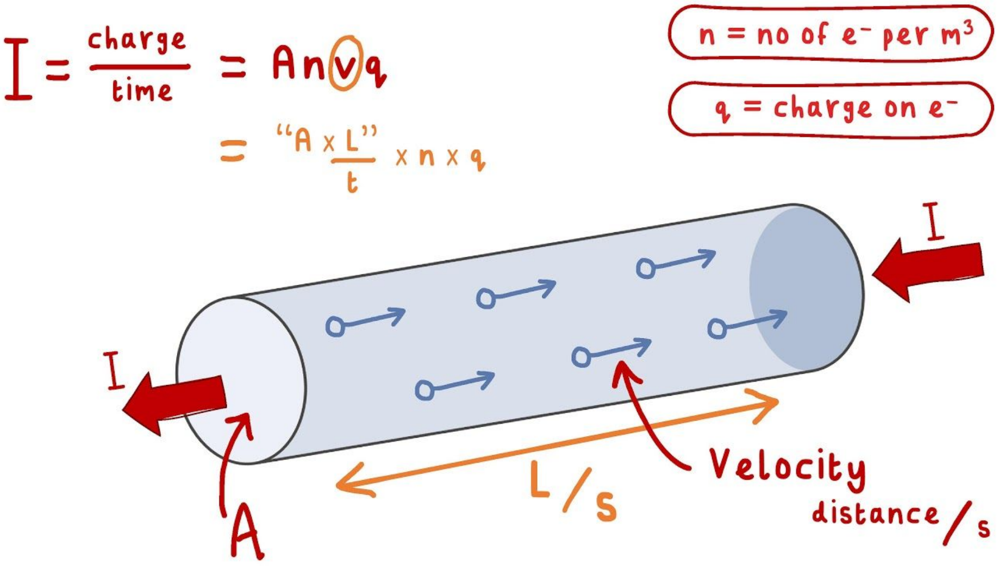
As suggested by the definition of electric current, the equation for the charge carried by a conductor is:

$$Q = It$$

For example, a conductor delivering a current of 5 amps for 10 seconds equals a total transferred charge of 50 coulombs.

Imagine a current carrying conductor (such as a wire) with a **cross-sectional area (A)**, with particles carrying charges of q with a **number density (n),** and mean **drift velocity (v)**. The current (I) being carried by the conductor is as follows:

$$I = Anvq$$



9.2 - Potential Difference and Power

Potential difference (V) - the energy transferred per unit charge between two points in a circuit.

$V = \frac{W}{Q}$ (where **W** is energy transferred/work done)

Power (P) is the energy transferred over time (rate of transfer of energy). $P = \frac{E}{t}$ where **E** is energy transferred and **t** is time. Another formula for power is $P = VI$, which can be combined with the formula $V = IR$, to form two variations:

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

Power is the energy transferred over time, so the product of power and time is the energy transferred, therefore $E = VIt$.

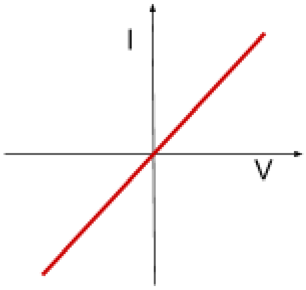
9.3 - Resistance and Resistivity

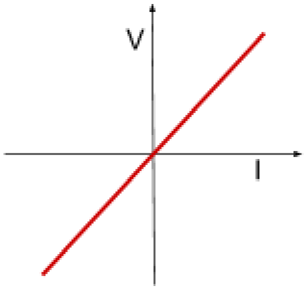
Resistance (R) - this is a measure of how difficult it is for charge carriers to pass through a component, and is measured by dividing the potential difference across a component by the current flowing through it.

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

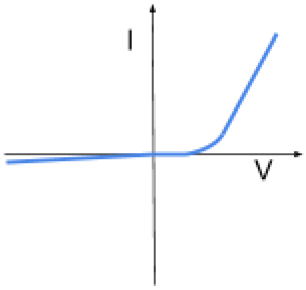
Ohm's law states that for an **ohmic conductor**, **current is directly proportional to the potential difference** across it, given that physical conditions (e.g temperature) are kept **constant**.

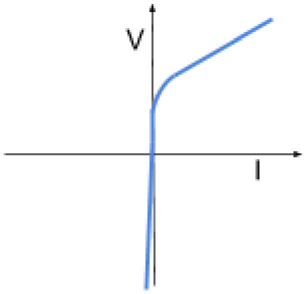
- **Ohmic conductor** - this component **follows Ohm's law,** therefore its current-voltage graph will look like a straight line through the origin (provided that physical conditions are kept constant).



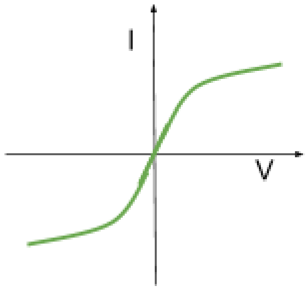


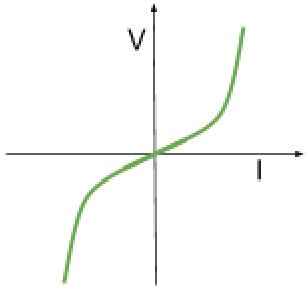
- **Semiconductor diode** - when looking at the current-voltage graph of this component you must consider its forward and reverse bias. The forward bias of a diode is the direction in which it will allow current to flow easily past the **threshold voltage**, which is the smallest voltage needed to allow current to flow. In the direction of the reverse bias, the resistance of the diode is extremely high meaning that only a very small current can flow.





- **Filament lamp** - this component contains a length of metal wire, which heats up as current increases, therefore the resistance of this component increases as current increases. At low currents the metal wire will not heat up significantly, therefore for very **low currents**, **Ohm's law is obeyed**. However, as the magnitude of the current increases, the graph begins to curve due to the increasing resistance.



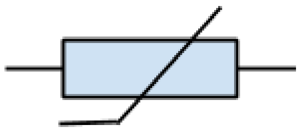


Unless a question states otherwise, **ammeters** can be assumed to have zero resistance, meaning they will not affect the measurement of current in a circuit at all, and voltmeters can be assumed to have infinite resistance, meaning no current can flow through them, so their measurement of potential difference across a component is exact.

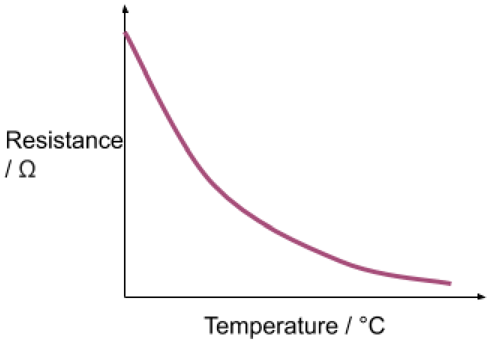
Resistivity, ρ is a measure of how easily a material conducts electricity. It is defined as the product of resistance and the cross-sectional area, divided by the length of the material. Resistivity will give the value of resistance through a material of length 1 m and cross-sectional area 1 m^2 which is useful when you need to compare materials even though they may not be the same size, however resistivity is also dependent on environmental factors, such as temperature.

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

When the **temperature of a metal conductor increases, its resistance will increase**. This is because the atoms of the metal gain kinetic energy and move more, which causes the charge carriers (electrons) to collide with the atoms more frequently, causing them to slow down. Therefore, as temperature increases, current decreases and so resistance increases ($R = \frac{V}{I}$).



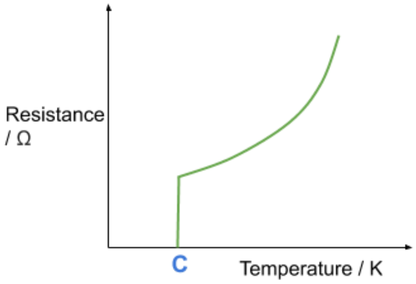
Thermistor circuit symbol



However, the opposite is true for **thermistors**: **as the temperature of a thermistor increases, its resistance decreases**. This is because increasing the temperature of a thermistor causes electrons to be emitted from atoms. This causes the number of charge carriers to increase and so current increases, meaning the resistance will decrease. Above on the right, is the temperature-resistance graph of a thermistor.

One application of a thermistor in circuits is to act as a temperature sensor, which can trigger an event to occur once the temperature drops or reaches a certain value. For example, it could be used to turn on the heating once room temperature drops below a specific value.

A **superconductor** is a material which, below a certain temperature, known as the **critical temperature**, has zero resistivity. The critical temperature of a superconductor depends on the material it is made out of, and most known superconductors have an extremely low critical temperature which lies close to 0 K (-273°C).



C = critical temperature

With a resistivity of zero, resistance also drops to zero, therefore applications of superconductors include

- **Power cables**, where superconductors would reduce energy loss through heating to zero during transmission.
- **Strong magnetic fields**, which would no longer require a constant power source. These could be used in maglev trains, where there would be no friction between the trains and rails, and in certain medical applications.

A **light dependent resistor (LDR)** is one whose resistance decreases with **increasing light intensity**. These types of sensors can be used to **trigger certain events**, for example in the circuit on the next page, a light dependent resistor is used. If the light intensity falls, resistance across R_1 will increase. This will cause the total circuit resistance to increase and so the circuit current will decrease. Using Ohm's law (**V = IR**), you can see that this means that the voltage across R_2 decreases, so the p.d out decreases. If you want this effect to be **reversed**, you can **switch the position of the LDR and resistor**, meaning that the p.d out would increase as light intensity decreases. This circuit, for example, could be used to switch on a light bulb depending on the light intensity of its environment, due to a certain threshold voltage (from p.d. out) being met.