

AQA Physics A-level

Section 5: Electricity

Notes

3.5.1 Current electricity

3.5.1.1 - Basics of electricity

Electric current (I) - the flow of charge per unit time, or the **rate of flow of charge**.

$$I = \frac{\Delta Q}{\Delta t} \quad (\text{where } Q \text{ is charge})$$

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

$$V = \frac{W}{Q} \quad (\text{where } W \text{ is energy transferred})$$

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.

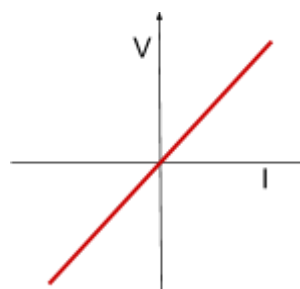
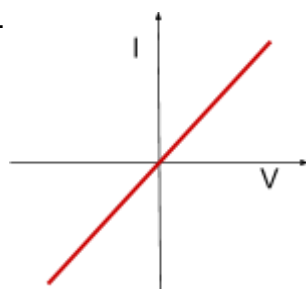
$$R = \frac{V}{I}$$

3.5.1.2 - Current-voltage characteristics

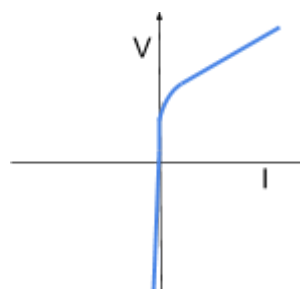
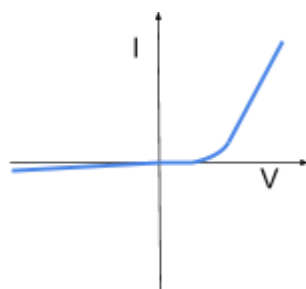
Ohm's law states that for an **ohmic conductor**, **current is directly proportional to the potential difference** across it, given that physical conditions (e.g temperature) are kept **constant**.

You must be able to recognise and understand the properties of certain components as demonstrated by current-voltage graph (where either current or voltage is on the y-axis):

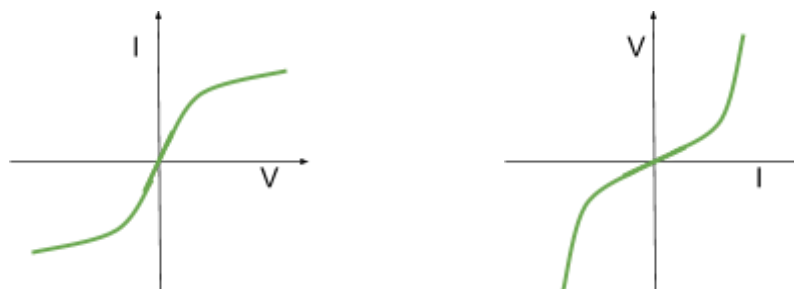
- **Ohmic conductor** - this component **follows Ohm's law** therefore its current-voltage graph will look like a straight line through the origin. (This is provided physical conditions are kept constant).



- **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 current increases (in either direction), the graph begins to curve due to the increasing resistance.



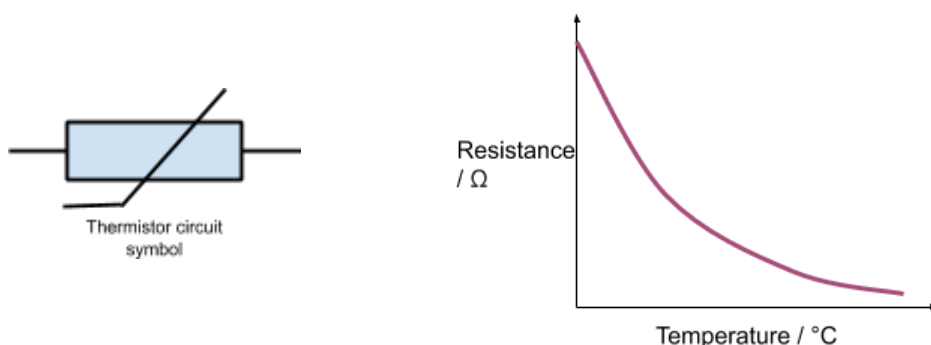
Unless a question states otherwise, **ammeters** can be assumed to have **zero resistance**, meaning they will not affect the measurement of current in a circuit at all, and voltmeters can be assumed to have **infinite resistance**, meaning **no current can flow** through them, meaning their measurement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

3.5.1.3 - Resistivity

Resistivity (ρ) is a measure of how easily a material conducts electricity, it is defined as the **product of resistance and 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 m²** 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**.

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

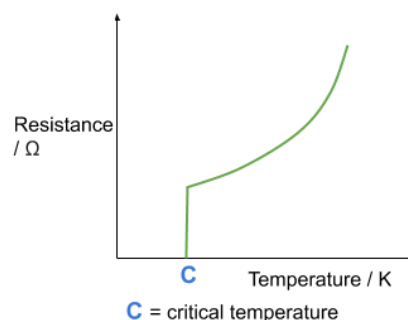
When the **temperature of a metal conductor increases, its resistance will increase**. This is because the atoms of the metal gain kinetic energy and move more, which causes the charge carriers (electrons) to collide with the atoms more frequently causing them to slow down, therefore current decreases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



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, therefore the number of charge carriers increases and so current increases causing resistance to decrease. On the left, is the temperature-resistance graph of thermistor.

One application of a thermistor in circuits is 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 lie close to 0 K (-273°C).



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

- **Power cables**, which would **reduce energy loss through heating to zero** during transmission.
- **Strong magnetic fields**, which would not require a constant power source. These could be used in **maglev trains**, where there would be no friction between the train and rail, and in certain **medical applications**.

3.5.1.4 - Circuits

There are two rules for adding the resistances of resistors in circuits, depending on whether the resistors are in series or in parallel:

- **In series** - $R_T = R_1 + R_2 + R_3 + \dots$ (Where R_T is total resistance and R_n is the resistance of resistor n).
- **In parallel** - $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$

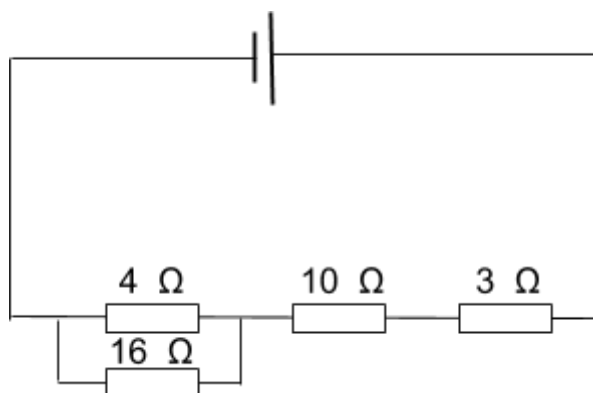
You may need to use both of these rules when calculating the resistance of one circuit, for example: Find the resistance of the circuit in the diagram to the right.

Firstly, find the resistance of the parallel combinations of resistors:

$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{16} = \frac{5}{16} \quad R_T = 3.2 \, \Omega$$

Then, use the series rule to add the remaining two resistors to the value calculated for the parallel combination.

$$R_T = 10 \, \Omega + 3 \, \Omega + 3.2 \, \Omega = 16.2 \, \Omega \quad \text{So the total resistance is } \mathbf{16.2 \, \Omega}.$$



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:

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

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

Below is an example in which you need to use the above formulas:

A lamp has a power of 60 W, and is connected to a power source of 240 V. Find the energy transferred by the lamp in 2 minutes and the current in the lamp.

To find the energy transferred you can use the (rearranged) formula $E = Pt$, making sure time is converted into seconds.

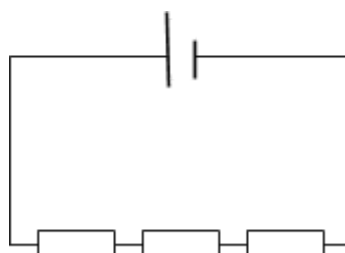
$$E = 60 \times 120 = \mathbf{7200 \text{ J}}$$

To find the current, you can use the (rearranged) formula $I = \frac{P}{V}$.

$$I = \frac{60}{240} = \mathbf{0.25 \text{ A}}$$

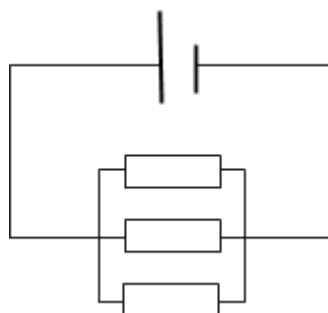
In a **series circuit**,

- The **current is the same** everywhere in the circuit.
- The battery p.d is shared across all elements in the circuit, therefore the **total sum of the voltages across all elements is equal to the supply p.d.**



In a **parallel circuit**,

- The **sum of the currents in each parallel set of branches is equal to the total current**.
- The **potential difference across each branch is the same**.



When joining together battery cells, you can use either a **series** or **parallel** configuration.

When joined **in series**, the total voltage across the cells is equal to the sum of the individual voltages of the cells:

$$V_T = V_1 + V_2 + V_3 + \dots$$

When **identical cells** are joined **in parallel**, the total voltage is equal to the voltage of one cell.

This is because the current is split equally between branches, therefore the overall potential difference is the same as if the total current was flowing through a single cell:

$$V_T = V_1 = V_2 = V_3 = \dots$$

In DC circuits, **charge and energy are always conserved**. Kirchoff's two laws describe how this is achieved:

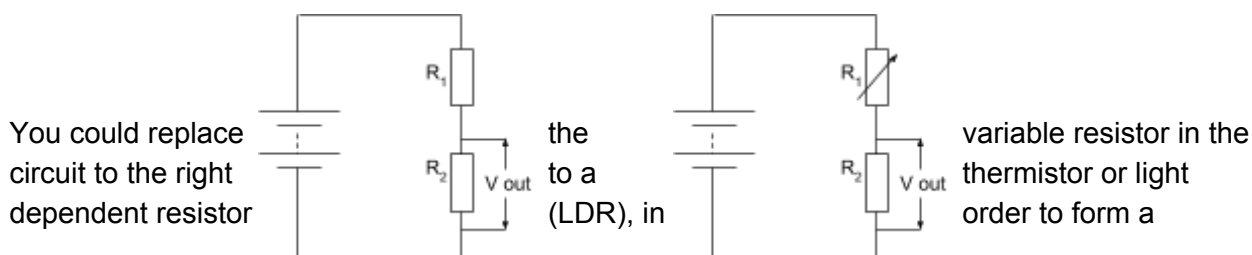
Kirchoff's first law - **the total current flowing into a junction is equal to the current flowing out of that junction**. This shows that no charge is lost at any point in the circuit.

Kirchoff's second law - **the sum of all the voltages in a series circuit is equal to the battery voltage**. This shows that no energy is lost at any point in a circuit.

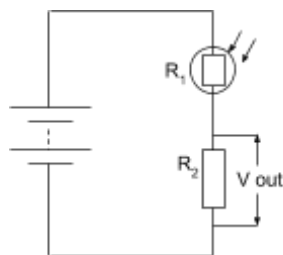
3.5.1.5 - Potential divider

A **potential divider** is a circuit with **several resistors in series connected across a voltage source**, used to **produce a required fraction of the source potential difference**, which remains constant.

You can also make a potential divider supply a **variable** potential difference by using a **variable resistor** as one of the resistors in series, therefore by varying the resistance across it, you can vary the potential difference output. For example, if the resistance across R_1 increases, the output p.d will decrease as circuit current has decreased and $V=IR$.



temperature or light sensor. A **light dependent resistor's** resistance decreases as light intensity increases.



These types of sensors can be used to trigger certain events, for example in the circuit above, a light dependent resistor is used. If the light intensity falls, resistance across R_1 will increase so the circuit current decreases and resistance across R_2 decreases, so the p.d out decreases. If you want this effect to be reversed, switch the position of the LDR and resistor, therefore the p.d out would increase as light intensity decreased and the circuit could go on to cause a light bulb to be switched on because a threshold voltage has been met.

3.5.1.6 - Electromotive force and internal resistance

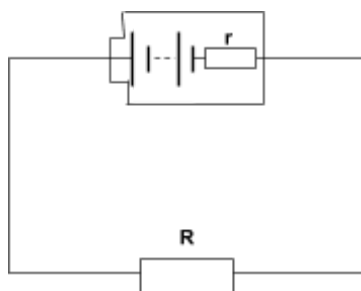
Batteries have an **internal resistance (r)** which is **caused by electrons colliding** with atoms inside the battery, therefore some energy is lost before electrons even leave the battery. It is represented as a small resistor inside the battery.

Electromotive force (emf / ε) is the **energy transferred by a cell per coulomb of charge** that passes through it:

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

As you can see in the circuit below, the sum of the internal resistance (r), and load resistance (R) is the total resistance (R_T) in the circuit.

$$R_T = R + r$$



And so emf is the product of the total resistance and the current of the circuit, because $V = IR$.

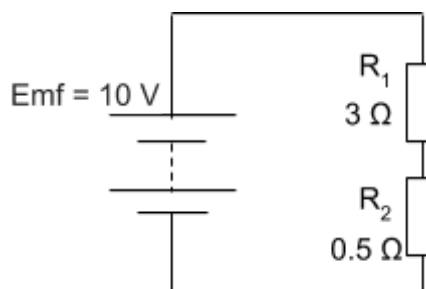
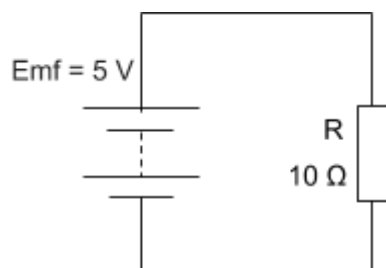
$$\varepsilon = IR + Ir \quad \varepsilon = I(R + r)$$

The p.d across the resistor R , is known as the **terminal p.d (V)**, whereas the p.d across the resistor r , is known as **lost volts (v)** because this value is equal to the **energy wasted by the cell per coulomb of charge**.

$$V = IR \quad v = Ir$$

Therefore, emf is the sum of the terminal p.d and lost volts: $\epsilon = V + v$.

The emf of a battery can be measured by measuring the voltage across a cell using a voltmeter when there is **no** current running through the cell, which means it is in an open circuit.



Here are two example questions where you need to use the above formulas:

A cell has an emf of 5 V, the value of lost volts is 2 V, and the resistance of R is 10 Ω. Find the current in the circuit.

Firstly, write down what you know.

$$\text{Lost volts} = Ir = 2 \text{ V} \quad \text{Emf} = 5 \text{ V}$$

Next, find the p.d across R using $\epsilon = IR + Ir$.

$$5 = IR + 2 \quad IR = 3 \text{ V}$$

Using $V = IR$, find the current.

$$3 = I \times 10 \quad I = \mathbf{0.3 \text{ A}}$$

A cell has an emf of 10 V, the current flowing through the circuit is 2 A, the resistance of R_1 is 3.5 Ω and the resistance of R_2 is 0.5 Ω. Find the value of lost volts and the internal resistance of the cell.

Firstly, find the terminal p.d (sum of the potential differences across R_1 and R_2/V).

$$V = IR \quad V_1 = 2 \times 3.5 = 7 \text{ V} \quad V_2 = 2 \times 0.5 = 1 \text{ V} \quad V = 7 + 1 = 8 \text{ V}$$

Find the lost volts using $\epsilon = V + v$.

$$10 = 8 + v \quad v = \mathbf{2 \text{ V}}$$

Finally find internal resistance using $v = Ir$.

$$2 = 2 \times r \quad r = \mathbf{1 \Omega}$$