Electricity

1. Current and Circuits

Remember that matter is usually electrically neutral, however, an object can be charged by losing or gaining electrons. The unit of charge is the coulomb (C).
When an electric charge is placed near by other electric charges, it feels a force that can displace it. An ordered movement of electric charge is called **current**.
Conductors allow the movement of electrons through them. Metals are good conductors and copper is the most commonly used conductor. However, insulators do not allow electrons to move freely, so they do not conduct electricity.

If we close the flow of electrons, we then have an electric circuit. A circuit is made of the following components connected among them: (A circuit is made of the following connected components)

- **Energy source** (such as an electric cell or battery) which provides the energy needed to move the electrons through the circuit, from the negative (-) terminal round to the positive (+) terminal.
- **Connecting wires** through which electric charges can flow.
- A **switch**, which allows or stops the electric current to flow.
- One or several **receptors (**lightbulbs, resistors,…) that use and transform the energy the electrons carry into a more useful type of energy such as electrical energy, heat energy, motion, sound, etc.

In a circuit, there are two basic ways of connecting bulbs, resistors and the other components together, series and parallel:

- In **series** circuits the different components are placed one after another, in the same line or branch.
- In **parallel** circuits, the different components will be in different lines or branches.

2. Physical Magnitudes

You must first understand a few electricity magnitudes in order to study how electric circuits work. We will start with current or intensity, potential difference or voltage, and resistance.

2.1 Current or Intensity (I)

The movement of electric charge is called current or intensity. Its symbol is I. The higher the current, the greater the flow of charge.
So, more specifically, current is defined as the amount of charge that passes a point in a given amount of time.

The SI unit for current is amperes (A). (An ampere is the current that flows through conductor when a charge of 1C passes through it each/per second; **A = C/s**

Currents can be measured with an ammeter or a milliammeter.

(By convention, current is considered the movement of positive charges. However, electric current is due to the movement of electrons. So, if you make a closed circuit by attaching wires to the two terminals of a battery, electrons will flow from the negative terminal to the positive terminal. The current, however, will be considered to move from the positive terminal to the negative terminal. (This is alright, because in terms of electric charge and electric fields, the movement of negative charges in one direction is equivalent as the movement of positive charges in the opposite direction).

2.2 Electrical Potential Difference or Voltage (V)

Potential difference is that which pushes electrons from one place to another. It is the potential energy a charge gains or loses as it moves between two points in a circuit. We can define voltage as the energy per charge at a particular position. The SI unit form potential difference or voltage is volts (V).

V = J/C Voltage can be measured with a voltmeter

2.3 Resistance (R)

It is how much a material resists the flow of charges. Its SI unit is the ohms (Ω)
(Understand that as electrons flow through any material, they ran into the atoms that make up the material itself!)
So,

Current tends to flow from a place of high voltage to a place of low voltage - just like water tends to flow from a place of higher elevation to a place of lower elevation. (Hence, elevation in water flow is analogous to voltage in current flow.) Resistance is simply how much the material resists the flow of charges and is measured in ohms [Ω]. (In our water analogy, water flowing through large pipes encounters very little resistance, while water flowing through a sponge or through sand encounters a higher resistance.) A voltage source (such as a battery or a power supply) is like a water pump: a water pump can move water from a lower place to a higher place; the voltage source moves the charge from a place of low voltage (negative terminal) to a place of high voltage (positive terminal). A circuit is simply a path for the charges to flow from the high voltage position to the low voltage position, just like pipes or rivers can form a "circuit" for water flow.

The individual circuit components are connected in such a way that the current flows through them, usually giving up energy in the process. As the charges give up energy, the potential energy of the charges (and hence the voltage) will decrease as they traverse the circuit. **Ohm's Law** states that for most common conductors the potential difference (V) across the conductor is proportional to the current (I) that flows through the conductor:

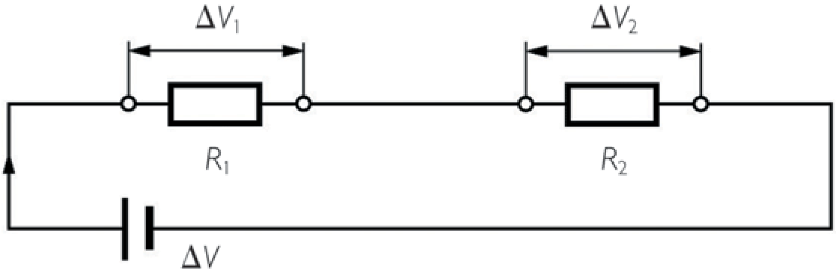
$$V = I R$$

The resistance is then simply the constant of proportionality and is a measure of how hard it is to force the current through the conductor: the bigger the resistance, the more voltage is needed to force a certain amount of current; and the other way around, the greater the resistance, the less current will flow through the resistance for a certain voltage.

3. Series and Parallel Circuits: solving problems

Series Circuits

The components are connected one after another, in the same line or branch:



The current going through the first resistor will also go through the second resistor. Therefore, the intensity or current going through all the resistors is the same.

$$I_1 = I_2$$

The PD across each resistor, will depend on the value of the resistor itself. And moving round a circuit, from one battery terminal to the other, the sum of the PD's across the components is equal to the PD across the battery.

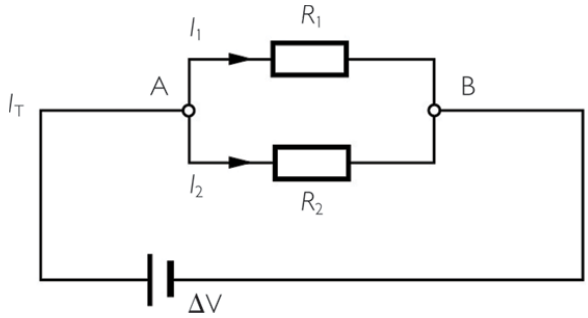
$$V = V_1 + V_2$$

If two or more resistors are connected in *series*, they give a *higher resistance,* than any of the resistors by itself. The effect is the same as joining several lengths of resistance wire to form a longer length

$$R_T = R_1 + R_2$$

Parallel Circuits

The different components are connected in different lines or branches, as the picture below shows:



Once the current gets to point A, it splits up and some will flow through the upper branch, going through R_1, and the rest will flow through the lower branch, where we find R_2. However, as electric charge is conserved, the total intensity is the sum of all of the individual intensities.

$$I_T = I_1 + I_2$$

However, current does not split randomly in a parallel circuit. More current will flow through the branch of the circuit with less resistance. As the potential difference across each resistor is directly proportional to the product of both magnitudes ($I \cdot R$), we can see that:

$$V_1 = V_2$$

If two or more resistors are connected in *parallel*, they give a *lower resistance,* than any of the resistors by itself.

$$1/R_T = 1/R_1 + 1/R_2$$

4. Electrical Power

In a circuit, all the charges that leave one terminal of the generator (battery,cell..) will come back to the other terminal but with less energy as they have been giving their energy to the different resistors.

The electrons that flow through a circuit have electrical potential energy, or electrical energy for short. This electric energy is transformed into other types of energy as it goes through the resistors (light energy, mechanical, heat…)

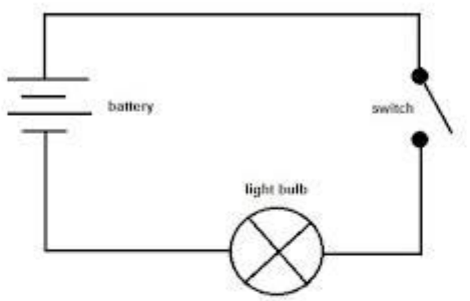
In the circuit below, the battery gives electrons potential energy. In the bulb, this is changed into thermal energy (heat) and then radiated.

So, **Power** is the rate at which energy is transformed (changed from one form to another) The SI unit is the watt (W)

Power = energy transformed/time taken

W = J/s

So if the battery on the below circuit is supplying 5 joules of energy every second, its power is 5 watts. The bulb in the circuit is taking energy at the same rate, so its power is also 5 watts.



Power of battery = 5 W

Battery supplies 5 J of energy per second

As well the bulb receives and radiates 5 J of energy per second;

So, Power of bulb = 5 W

Appliances such as toasters, irons, etc, have a power rating marked on them, either in watts or kilowatts.

Electrical power equation

For circuits, there is a more useful version of the power equation. If a battery, bulb, or other components has a PD (voltage) across it and a current through it, the power is given by this equation

P = PD x current

W = V x A

In symbols, **P = VI**

Power dissipated in a resistor- The Joule effect

When a current flows through a resistor, it has a heating effect. Electrons lose potential energy, which is changed into thermal energy. Scientifically speaking, energy is **dissipated** in the resistor.

For calculating the rate of energy dissipation, there is another useful version of the electrical power equation:

Power = PD x current

But: PD = (current) x (resistance)

So: power = (current) x (resistance) x (current)

So: **power = (current) ^{2} x (resistance)**

In symbols **$P = I^2R$**

(As we will see below, E = Pt, so we could derive the following formula for the Joule effect, where **$E = I^2 R t$**)

5. Electrical energy calculations

In a circuit, appliances such as kettles, toasters, and food mixers take energy from the supply and transform it. For example, appliances with heating elements change it into thermal energy (heat)

Energy and power are linked. If the power of an appliance is known, the energy transformed in any given time can be calculated with the following equation:

Energy transformed = power x time
(J) = (W) x (s)

In symbols **E = P t**

Where E is the energy (in joules) consumed by an appliance during the time it is on (in seconds).

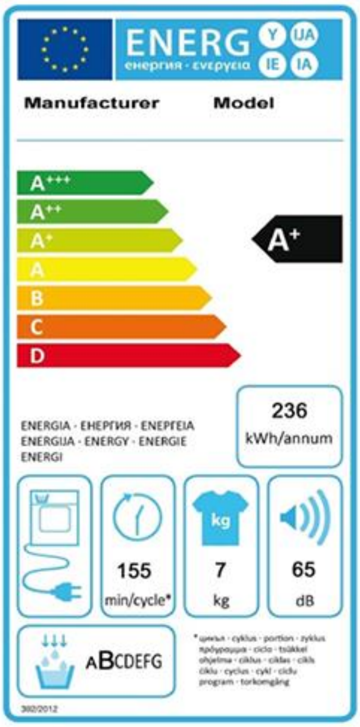
Example: If a 1000 W heating appliance is switched on for 5 seconds, the energy transformed would be: E = 1000 W x 5 s = 5000 J.

So, the heating appliance gives off 5000 J of thermal energy.

Electricity supply companies use the **kilowatt-hour (kWh)**, rather than the joule, as their unit of energy measurement:

One kilowatt-hour is the energy supplied when an appliance whose power is 1 kW is used for 1 hour.

$$E = P \cdot t = 1kW \cdot 1h = 1kW \cdot h$$



Energy labels

Energy labels tell the energetic efficiency of an appliance (7 levels) according to its annual energy consumption, as compare to the average.