Electricity is the flow of electric charge. The Greeks first observed electrical forces when early scientists rubbed amber with fur. They noticed they could attract small bits of straw with the amber. They called this the "amber effect". The Greek word for amber is "Elektron" and the effect was called "Elektrics", hence electricity.

**Renaissance period**

It was discovered that two objects rubbed by an identical third material would cause the two to experience a repulsive force. Conversely, if the two objects were rubbed by two different materials, an attractive force could be created. This is when the concept of two charge types, positive and negative, came about.

**Ben Franklin**: was credited with naming charges positive and negative. He believed electricity was a "fluid". Therefore, if a piece of amber was rubbed by fur, the fur would "absorb" this electric fluid, causing the amber to have a "deficit" of electric fluid, and hence a negative charge. His assumption turned out to be incorrect. In reality, electrons are deposited on to the amber from the fur. It is this reason why electrons were given a negative charge, simply because of an incorrect scientific assumption – an accident of history that has had a permanent impact on modern science and technology.

## Fundamental Law of Charges

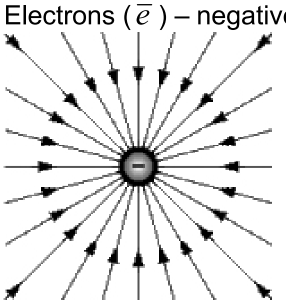
**Behaviour of charged particles**: Like charges repel, unlike attract. I.e. electrons repel other electrons, protons repel other protons, and electrons are attracted to protons. Charged particles can also attracted neutral particles.

- Opposite charges attract
- Similar charges repel
- Charged objects attract some neutral objects

## Basic structures of matter and their charges

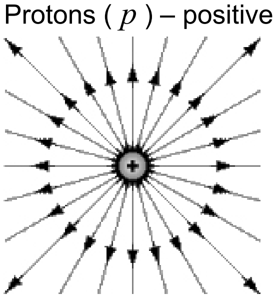
**Charge carriers**: There are two charge carriers, electrons ( $\bar{e}$ ) and protons ( $p$ ). Electrons are negatively charged (-1) and are found orbiting the nucleus of atoms. Protons (+1) are positively charged and are located within the nucleus of an atom. In general, electrons are the primary charge carriers since electrons are freer to move in solids. Protons are generally locked into place by molecular forces.

- Electrons ( $\bar{e}$ ) – negative charge $-1.6\times10^{-19}C$ or $-1e$



**Electric field** lines of force point toward the electrons: positive charges will move toward the electron along the paths indicated by the lines of force.

- Protons ( $p$ ) – positive charge $1.6\times10^{-19}C$ or $1e$



**Electric field** lines of force point away from the proton: positive charges will move away from the proton along the paths indicated by the lines of force.

- Neutrons ( $n$ ) – neutral charge $0C$

**No Electric field** lines of force are generated by neutral objects, therefore electrons and protons will pass unaffected.

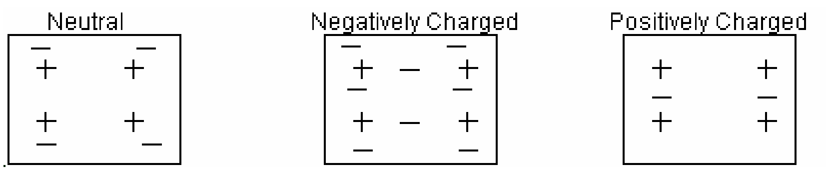
## Conductors and Insulators:

**Conductors:** Conductors are substances in which the electrons are loosely bound to the nuclei and hence are easily induced to flow. - e.g. Copper, aluminium, silver, gold, salt water, most metals are all highly conductive materials.

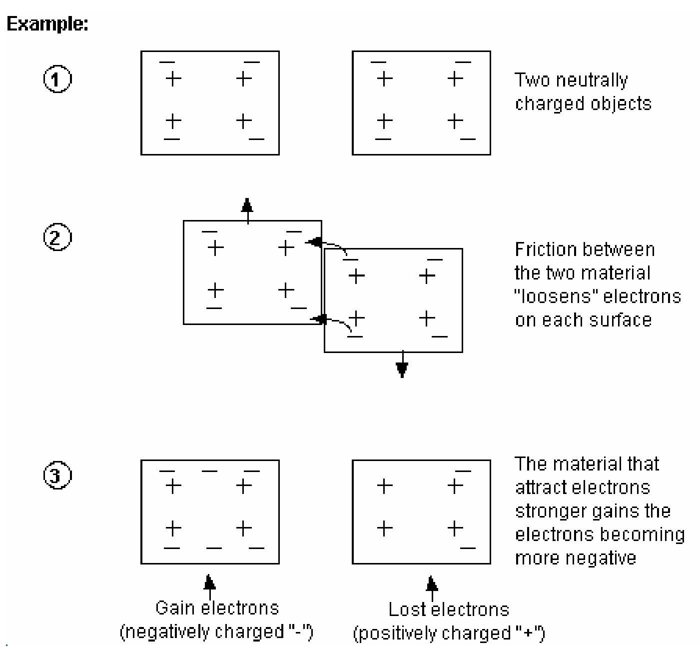
**Insulators:** Insulators are substances in which the electrons are tightly bound to the nuclei of there respective atoms. As a result, electrons do not flow easily. A large amount of energy is required before electrons can be induced to flow. - e.g. Pure water, rubber, most plastics, air, most non-metallic substances etc.

## Charging objects

**Net Charge:** The charge on any given object is determined by the net charge. Negatively charged objects have a surplus of electrons compared to the number of positive charge carriers. Positively charge objects have a deficit of electrons in compared to the number of positive charge carriers. Neutrally charged object have an equal numbers of positive charge and negative charge carriers.



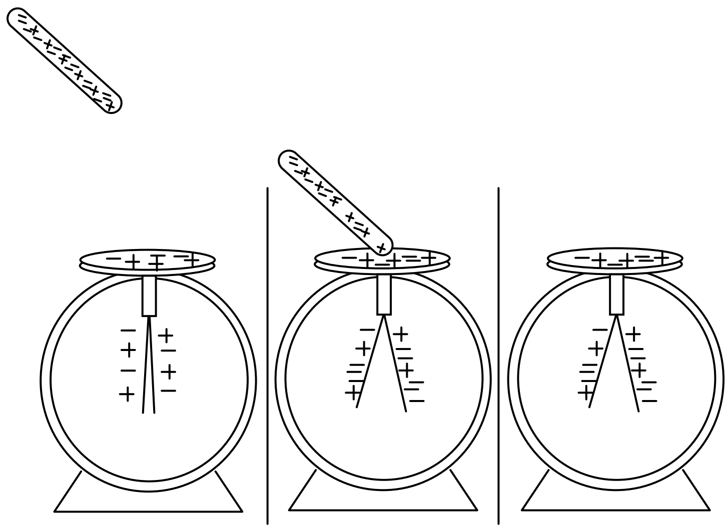

**Conservation of Charge / Charging by friction**: In any closed system, the number of positive and negative charge carriers is constant. Therefore, objects obtain charge by the transfer of charge carries from one substance to another. Most charge transfers occur by friction whereby one substance will gain electrons from another, leaving one substance with a surplus of electrons (overall negative charge) and the other a deficit (overall positive charge)




**Electronegativity**: The strength in which a substance holds on to its electrons is the measure of electronegativity. Substances with a greater electronegativity will steal electrons from substances with less electronegativity. Hence, this is how two neutrally charged substances can become charged when rubbed together. The neutral substance of greater electonegativity will steal electrons from the other neutral substance. The less electronegative substance becomes positively charged and the more electronegative substance becomes negatively charged.

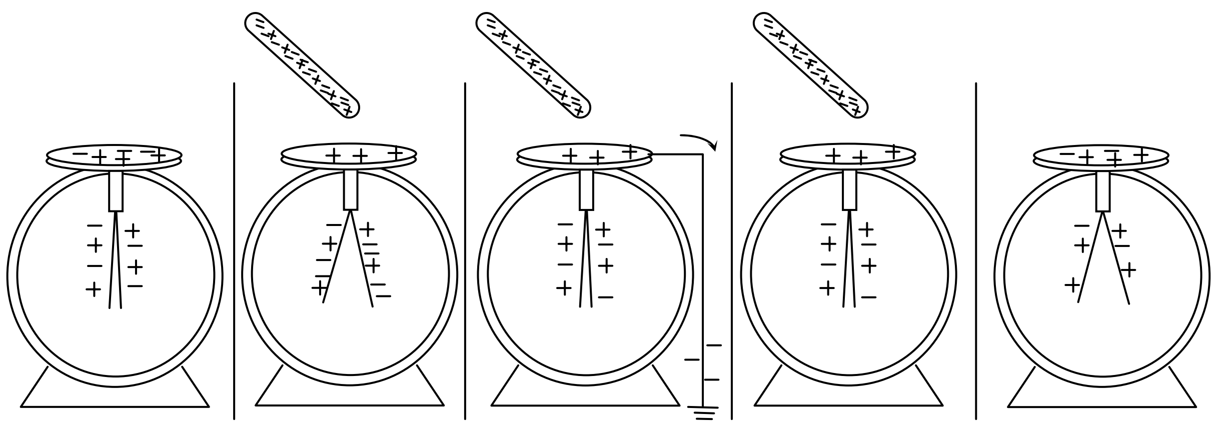
**Charging by Contact**

1. A charged rod comes in contact with the electroscope
2. Electrons from the charged rod migrate to the electroscope making the electroscope more negative and the charged rod less negative.
3. The leaves of the electroscope spread apart because of the net negative charge on them
4. The charged rod is removed leaving a net negative charge on the electroscope.



**Charging by Induction:**

1. A charged rod comes in close proximity to the electroscope but does not make contact.
2. Electrons move to the leaves of the electroscope. The unbalanced charge in the leaves cause the leaves to repel each other.
3. A ground is connected to the electroscope, draining electrons from the electroscope so that net charge in the leaves is zero allowing the leave to fall. Important to note that the net charge is positive at the top of the electroscope closest to the charged rod.
4. While the charged rod remains in close proximity, the ground is removed trapping the electrons in the ground.
5. Finally the charge rod is removed. The net charge on the electroscope is positive



## Electricity: A Review

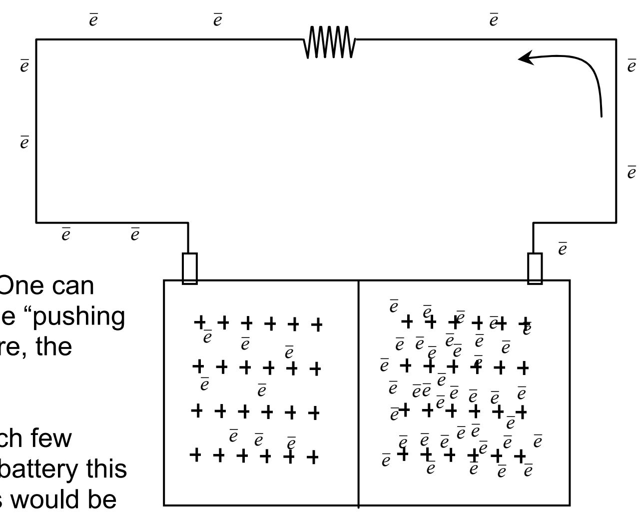
**Electricity:** There are two types of electricity, **static** and **current**. Both types of electricity involve electrons but with static electricity the electrons tend not to move easily where as with current electrons move quite easily.

As mentioned earlier: The reason why electrons were given a negative charge was completely an arbitrary decision that dates back to the days of Benjamin Franklin. In actual fact it was a mistake, because the theory of electricity came about before the discovery of the electron. Prior to the discovery, no one had any idea what caused electricity to flow. All they knew was that there was some kind of flow but had to guess what direction the electricity moved… they guessed wrong.

As a result of this historical error, the flow of electricity has two standards.

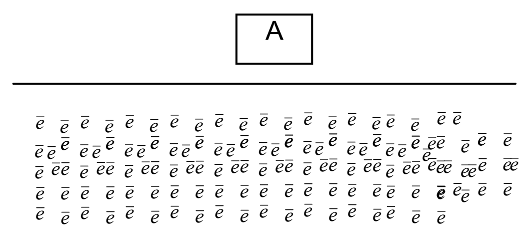
1. Electricity as the flow of positive charge (physically incorrect but the standard for all electronics in the world)
2. Electricity as the flow of negative charge (the correct model but discovered too late, the first standard had already been set)

**So what causes electricity?:** Going back to our knowledge of chemistry, electrons repel each other as do protons but electrons are attracted to protons. This is the essential nature of electricity. Refer to the diagram of a simplified battery. All matter is made up of electrons and protons. In general, there are equal numbers of protons and electrons in everyday objects. However, in the case of batteries, we have an imbalance. Take for instance our simplified battery. There are equal numbers protons on both sides of the batteries but the right side of the battery has significantly more electrons than the left side. Since electrons repel each other, the electrons are highly motivated to move as far away from each other as possible. Think of electrons as highly claustrophobic and very anti-social towards other electrons. One can see that a high concentration of electrons would result in some "pushing and shoving" between electrons. The more electrons there are, the more pushing and shoving there is.

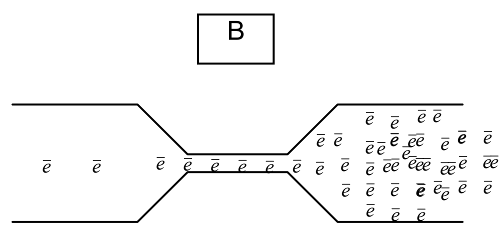


Now consider the other side of the battery were there are much few electrons. To the electrons stuck on the negative side of the battery this would be like a paradise for them. Therefore, these electrons would be highly motivated to go to the other side. As a result, the electrons will flow through the wire, through the resister, to the other side of the battery. The greater the difference between the number of electrons on both sides of the battery, results in a greater flow of electricity. This difference is called **potential difference** or **voltage**. The higher the voltage, the greater the flow of electricity. The flow of electricity is called **current** and is related to the number of electrons that flow through the wire over a period of time.

Now lets consider the resistor in our circuit. The resister acts like a constriction in the wire. This is similar to what happens when you pinch a water hose. The more you pinch the hose, the slower the water comes out. To get the same about of water to come out of the hose after it has been pinched requires more pressure. Therefore, the more resistance there is in an electronic circuit, more voltage is required to get the same amount of flow.




No restriction, high electricity flow
=
Low resistance, high current



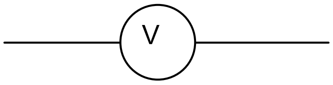

Significant restriction, lower electricity flow
=
High resistance, low current

In circuit A, the electrons have little or no restriction, as a result the flow free, easily and quickly. In circuit B, the electrons have a more constricted path to move through, as a result, few electrons can flow past the restriction over the same time period.

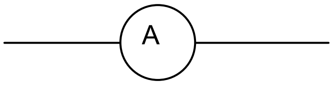
To match the flow of current of circuit B with circuit A, the pressure in B would have to be increase significantly, to *push* the electrons through the constriction faster. Therefore and increase in **voltage** would be required.

**The Symbols**

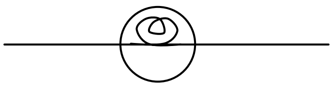
V = voltage measured in Volts (V) or the number of Joules of energy per Coulomb or (J/C)
I = current measured in Amperes or Amps (A) or the number of Coulombs per second.
R = resistance measured in Ohms ( $\Omega$ )



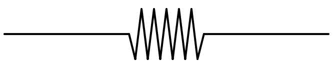

Voltage meter: measures voltage




Ammeter: measures current



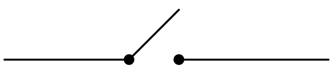
Lamp



Resistor: measured in Ohms ( $\Omega$ )



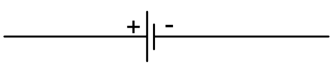
Conducting wire



Open switch: (no current flows)



Closed switch: (current flows)



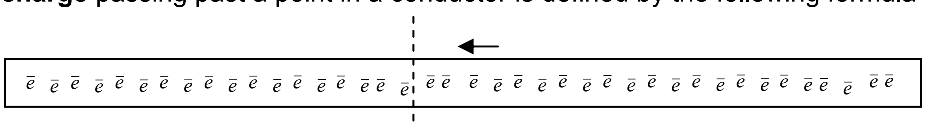

Single voltage cell (usually 1.5 volts)


Battery (made of several voltage cells)

# Formulae:

## Total Charge:

**The total charge** passing past a point in a conductor is defined by the following formula



$$\boxed{Q = Ne}$$

Where $Q$ is the charge in Coulombs ( $C$ ), $N$ is the number of charges and $e = 1.6 \times 10^{-19} C$

**Example:** 10,000 charges pass past a point in the conductor. Find the total charge.

$$\begin{aligned} Q &= Ne \\ &= 10000 \times 1.6 \times 10^{-19} \\ &= 1.6 \times 10^{-15} C \end{aligned}$$

# Current:

**Current** is defined at the amount charge that flows past any given point in a conductor over time.

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

Where $Q$ is the charge in Coulombs ($C$), and $t$ is time in seconds, and $I$ is in Amperes or Amps (A)

**Example:** Find the current if 10C of charge pass through a conductor in 50s.

$$I = \frac{Q}{t}$$
$$I = \frac{10}{50}$$
$$I = 0.2A$$

---

# Voltage:

Voltage is defined as the amount of energy that is delivered per unit charge. Historically, students have difficulty conceptualizing voltage. Voltage can be related to medication. When a doctor prescribes a medication for a patient, there are two things to consider, A) The dosage per pill and B) the number of pills that are to be taken in total for the prescription. The dosage refers to the strength of each pill where the number of pills taken will indicate how much medicine the patient will consume in total, depending on the dosage.

Voltage is the amount of **energy** per **charge**… like the dosage. The higher the voltage, the more energy that can be delivered per Coulomb of charge.

$$\boxed{V = \frac{E_e}{Q}}$$

Where $E_e$ is the amount of energy delivered to a load in Joules ($J$) and $Q$ represents the number of charges that passed through the load in Coulombs ($C$)

---

# Ohm's Law:

As discussed earlier, the flow of electricity is dependent on two factors, the amount of voltage and the amount of resistance. The relationship is as follows

$$\boxed{V = IR}$$

Where V is the voltage (V), I is the current in Amps (A) and R is the resistance in Ohms ($\Omega$).

---

# Power and Electrical Energy:

Work is defined as a change in energy, albeit gravitational ( $E_g$ )or kinetic ( $E_k$ ). Electricity also is capable of doing work therefore work done by electricity is found by the following equation

$$W = \Delta E_e$$

where $\Delta E_e$ is the change in electrical energy in Joules ( $J$ )

**Relating Work, Current and Power**

Work is define as $W = \Delta E_e$ and power is defined as $P = \frac{W}{t}$

Therefore $P = \frac{\Delta E_e}{t}$. $\Delta E_e$ ,however, is difficult calculate so voltage is used instead. Since $V = \frac{E_e}{Q}$, $\therefore E_e = VQ$

**Important:** Voltage in electronics is actually referred to as the ***potential difference*** which means that $V$ actually means $\Delta V$ ,but like many measurements, we only care about relative amounts. For example the height of a building is measured with respect to the ground as opposed to something like sea level.

Now $P = \frac{\Delta E_e}{t}$ becomes $P = \frac{VQ}{t} \rightarrow P = V\frac{Q}{t} \rightarrow P = VI$

$$P = VI$$

where, $P$ is the power in Watts (W), $V$ is the voltage in Volts (V), and $I$ is the current in Amps (A)

## Power and Ohm's Law

Combining $P = VI$ and $V = IR$

$$P = VI \qquad P = VI$$
$$P = (IR)I \quad \text{and} \quad P = V(V/R)$$
$$P = I^2R \qquad P = V^2/R$$

$$P = I^2R \qquad\qquad P = V^2/R$$