Colegio de
San Francisco de Paula
DEPARTAMENTO DE
CIENCIAS NATURALES

Unit 3. Electrostatics

Electricity throughout history

Even though electricity is present in nature in many ways lightning is probably the most spectacular one, it has not been easy to interpret and understand electrical phenomena.

The Ancient Greeks knew of the strange properties of amber. Tales de Mileto (625 a. C.-547 a. C.) proved that if amber was rubbed with wool it would attract dust and other small objects.

Our modern knowledge of electricity really began in the 1600s, when amber and other rubbed materials started to be investigated more closely. Scientists found that it was possible to produce repulsion as well as attraction, and that there were two different types of electric charge. In 1752 Benjamin Franklin (1706-1790) carried out an extremely dangerous experiment in which he flew a kite in a thunderstorm and got sparks to jump from a key attached to the line. The sparks were just like those produced by rubbing amber. Here was evidence that lighting and electricity were the same thing.

At this time, electrical experiments were with static electricity (charges on insulators that could be transferred in sudden jumps). However, in 1800 Alessandro Volta (1745-1827) discovered that two metals with salt water between them could cause a continuous flow of charge – in other words, an **electric current**. He had made the first battery. During this time, scientist kept going with their research. We can highlight different scientists and their inventions such as: Hans Christian, Michael Faraday, Thomas A. Edison, Samuel Morse and Heinrich Hertz. Within 60 years, the electric motor, generator, lamp, telegraph and radio had all been invented. However, it was not until J.J. Thomson discovered the electron in 1897, that there was any evidence to explain what electricity really was. From this discovery, we now know that the current in a circuit is a flow of electrons. It is because of the signs and conventions that Benjamin Franklin used that we say that the negative particle (electron) moves, and that current actually flows in the opposite direction from the electrons. In practice this does not make much difference, it is a convention.

The understanding of the nature and behavior of electrons allowed the development of electronic components, such as the vacuum tube and transistors. During the decade of 1960 integrated circuits were developed: it was the beginning of today's electronic era.

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Electric Charge

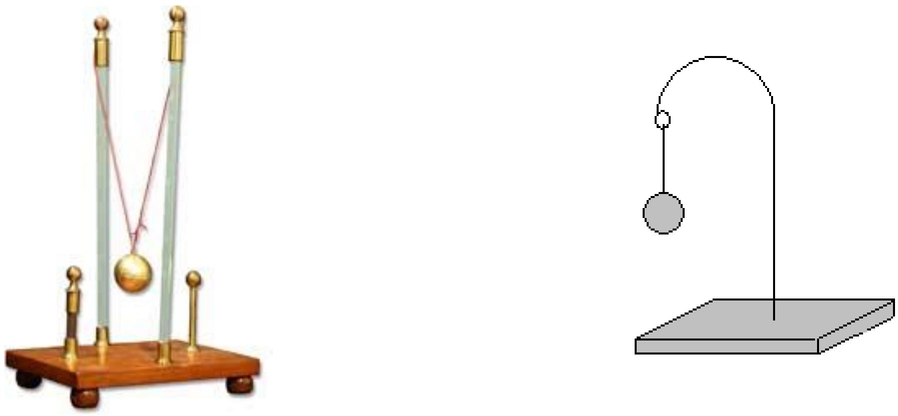
Electric charge or 'electricity', can come from batteries and generators. But some materials become charged when rubbed. Their charges are sometimes called **electrostatic charges** or 'static electricity'. It causes sparks and crackles when you take off a pullover, and if you slide out of a car seat and touch the door it may even give you a shock.

Glass rods or amber rods can be charged by rubbing them with a silk cloth. When you rub rods of glass or amber with a silk cloth, the rods will be able to attract small objects.

When two charged glass rods (or amber rods) are brought close together, they **repel** (try to push each other apart). However, if you bring close together a charged glass rod and a charged amber rod, they **attract** each other. This and similar experiments suggest that there are two different and opposite types of electric charge. We call them **positive (+) charge and negative (-) and charge**.

Like charges repel; unlike charges attract. The closer the charges, the greater the force between them

The electrostatic pendulum is a device in common use for electrostatic experiments. It is made of a light-weight ball, of polystyrene or aluminium, hung by a silk thread from an insulating stand.



Two different electrostatic pendulums

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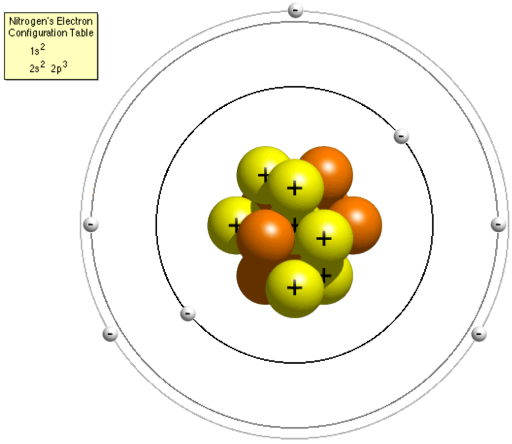
The Electric Nature of Matter

But where do charges come from?

As you already know, matter is made of tiny particles called **atoms**. Remember that atoms contain electric charges inside them. Atoms have a small central **nucleus** made up of **protons** and **neutrons,** and the much lighter **electrons** are found orbiting around it.

- Electrons have a negative (-) charge.
- Protons have an equal positive (+) charge.
  (the nuclear forces of attraction between these positive protons are much stronger than the repulsion forces which exist between the particles)
- Neutrons have no charge.



Normally, atoms have the same number of electrons and protons, so the net (or overall) charge on a material is zero. However, when two materials are rubbed together, electrons may be transferred from one to the other. One material ends up with more electrons than normal and the other with less. So one will have a net negative charge and the other is left with a net positive charge.

Understand that rubbing materials together does not create electric charge, it just separates charges that are already there.

Three different ways to charge an object:

By **rubbing or friction**, as we have already mentioned:

One of the objects gains electrons and the other one loses electrons. So both objects will have the same amount of charge but of different signs.

By **contact or conduction**:

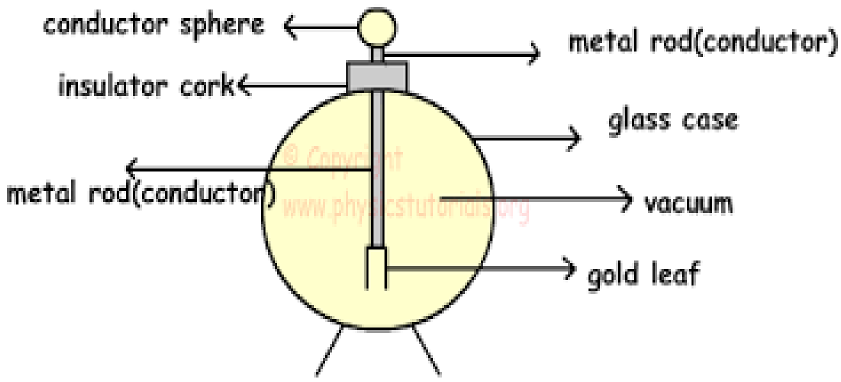
When a neutral object is touched with a charged object (either positive or negative) and some of the charges move onto the neutral object. Both objects will end up with the same sign.

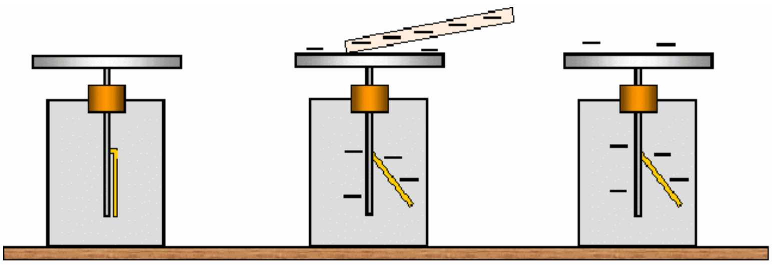
By **induction**:

Charges that appear on an uncharged object because of a charged object nearby are called **induced charges.** When placing a charged rod next to, but not touching, a neutral object this will become charged by induction. The neutral object will end up with an opposite charge to that on the rod.

The Electroscope

The electroscope, also known as an electrometer, is a device used to detect **electrostatic charge**.





Electrostatic charge can be detected by using a **leaf electroscope** like the one shown here. If a charged object is placed near the cap, charges are induced in the electroscope. Those in the gold leaf and metal plate repel, so the leaf rises, the greater the movement, the stronger the charge. However, it is not possible to directly find out the sign of the charge, as two positive as well as two negative charges will bring about the rising of the gold leaf.

A metal-leaf electrometer is shown at the left, and one can easily be constructed, using a) a conductor (a nail will do), b) a rubber stopper, c) a flat-bottom flask, and d) two thin leaves of gold (or, less expensive) aluminium foil, fastened to the end of the conductor. When we touch the upper part (the conductor) with an electrically charged object, the electrical charge will be distributed along the conductor to the thin leaves of foil, which thus obtain a charge of the same sign and repel each other. The movement of the metal foil indicates if there is a charge.

Conductors and Insulators
When some materials gain charges, like a glass or amber rod, these charges remain localised. However, this does not happen in other materials, such as metals. These other materials will lose the gained charges almost immediately. This is because electrons flow through them or the surrounding material until the balance of negative and positive charge is restored.

If we rub a metal rod with wool or fur and bring it close to an electrostatic pendulum, we will see that the ball of the pendulum is not attracted to the rod. But, if we insulate the metal rod with a wooden handle, it will be easily charged by rubbing. This phenomenon is characteristic for metals and is due to the fact that electric charges easily move along the metal, and if it is not insulated, the charges will flow from the metal, passing through the hand and finally to the earth.

Conductors are materials that let electrons pass through them. Metals are the best electrical conductors. Some of their electrons are so loosely held to their atoms that the can pass freely between them. (These free electrons also make metals good thermal conductors).

Examples of good conductors: metals (especially silver, copper and aluminium), carbon.
Examples of poor conductors: water, human body, earth.
Note: most non-metals are poor conductors or don't conduct charge at all, except for carbon.

Insulators are materials that hardly conduct at all. Their electrons are tightly held to atoms and are not free to move; although they can be transferred by rubbing. Insulators are easy to charge by rubbing because any electrons that get transferred tend to stay where they are.

Examples of good insulators: plastics (PVC, polythene, Perspex).
Examples of poor insulators: glass, rubber, dry air.

We could also talk about **semiconductors** which are 'in-between' materials. They are poor conductors when cold, but much better conductors when warm. An example of a good semiconductor is silicon, and of a bad one germanium. Semiconductors are incredibly important in computing, 'silicon valley' ,in southern California, is named after the semiconductor responsible for the revolution in computing. Now many others semiconductors are also used, and we all know how important computers have become.

Unit of Charge

When an object is charged is because it has gained or lost electrons. The electron is an extremely small unit of charge, and difficult to manage individually. That is why the SI unit of charge is a much bigger arbitrary unit, the **coulomb (C)**. It is equal to the charge on about 6 million million million electrons.

The coulomb is defined as an electric charge equal to $6,24 \cdot 10^{18}$ electrons.

So, the charge of one electron is $-1.6 \cdot 10^{-19}$ C

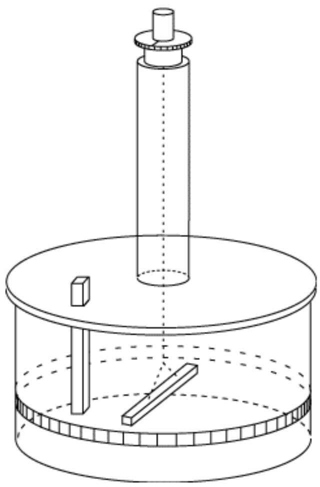
But since a coulomb is a relatively large quantity of charge, we often measure charge in microcoulombs.

1μC = 0,000001 C = 10^{-6} C (one millionth of a coulomb)

A body acquires a charge of +1 C if it loses $6,24 \cdot 10^{18}$ electrons with respect to its neutral state, and gets a charge of –1 C if it gains $6,24 \cdot 10^{18}$ electrons with respect to its neutral state.

<u>Coulomb's law</u>

The French physicist Charles A. Coulomb (1736-1806) studied the forces of attraction and repulsion between electric charges. In order to do this he used a **torsion balance,** which he invented. With this instrument, the force exerted can be measured through the torsion produced on a thin and rigid wire. The bigger the force, the bigger the torsion produced on the wire.



Coulomb's torsion balance.

In the picture, a bipolar magnet, hanging from a wire, is put under the influence of a positively or negatively charged vertical rod. The charge attracts one of the poles of the magnet and repels the other pole, producing a twist in the wire from which the magnet is hung.

Two electric charges will attract or repel each other with a force that is directly proportional to the product of the charges and inversely proportional to the squared distance which separates them.

$$F = K\frac{q_1 \cdot q_2}{d^2}$$

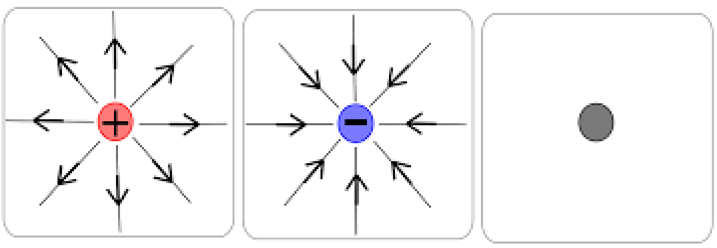
If the charges are expressed in coulombs (C), and the distances in meters (m), the force will be expressed in newtons (N).

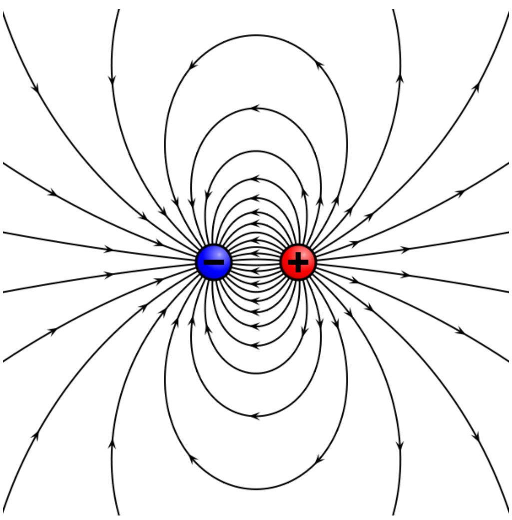
The value of the constant K depends on the medium between the charges. For a vacuum, $K = 9 \cdot 10^9 N \cdot m^2/C^2$.

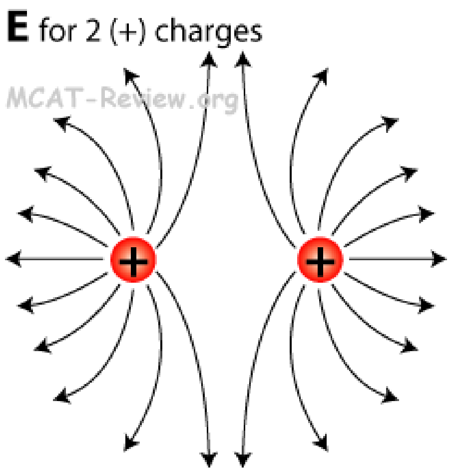
Electric Fields

To help visualize how a charge, or a collection of charges, influences the region around it, the concept of an electric field is used. If electric charges feel a force, then, scientifically speaking, they are in an electric field.

An electric field is a region or space where we can feel the influence of a charge that is making that field.







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