Introduction to electrostatics

Electrostatics is a branch of physics in which static electric field produced by static electric charges are studied.

Electrostatics plays a major role in everyday life. The various applications of electrostatics include photocopiers, defibrillator, paint spraying, electrostatic precipitator etc.

The computer peripheral devices include liquid crystal display (LCD), keyboard, touch pads works on the principle of electrostatics. Electrostatics is used in the agricultural activities like spraying to plants, sorting seeds etc. Electronic components such as capacitors, resistors etc. function based on electrostatics.

History of electrostatics

The natural phenomenon of static electricity has been known since ancient times. The credit of discovery of static electricity goes to Thales of Miletus, around 600BC.

Thales noticed that amber rubbed with wool or cloth attracts lighter objects. This is because amber gains electric charge by rubbing. Further experiments have revealed that, when one object is rubbed with other then both the objects will become charged.

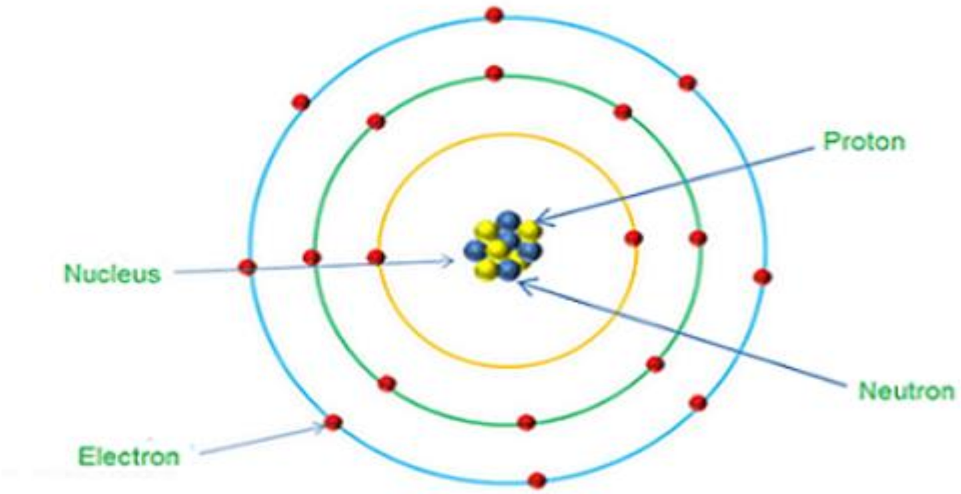
For many years Greeks thought that this phenomenon is due to the unique property of amber. What Thales noticed is nothing but static electricity. The word electricity is taken from the Greek word electron which means amber.

In normal state, all the atoms in an object contain equal number of electrons and protons. However, when one object is rubbed with other, few electrons from one object will moves to other. The object that received extra electrons has more number of electrons than protons. So, it becomes negatively charged. Similarly, the object that donates electrons loses few electrons and has less number of electrons than protons. So, it becomes positively charged.

Atom

Atoms are the basic building blocks of matter. Atom consists of three sub-atomic particles; they are protons, electrons and neutrons.

Electron is a negatively charged particle, proton is a positively charged particle and neutron is a particle that has no charge. The strong nuclear force between protons and neutrons stick them together to form a nucleus. Neutrons in the nucleus have no charge. So, the overall charge of nucleus is positive.



The negatively charged electrons are orbiting around the nucleus because of the electrostatic force of attraction present between electrons and protons. The number of electrons orbiting the nucleus is equal to the number of protons in the nucleus. Therefore, the overall charge of an atom is neutral.

Electric charge

Benjamin Franklin was the first American scientist who proved that there are two types of electric charges: positive charge and negative charge.

Electric charge is the property of sub-atomic particles particularly includes electrons and protons. Electrons have negative charge, protons have positive charge and neutrons do not have any charge.

The charge of electrons and protons is measured in coulombs, represented by C. Electron has a charge of -1.602×10^{-19} Coulombs (C) and proton has a charge of $+1.602 \times 10^{-19}$ Coulombs (C). The charge of an electron is equal to the charge of a proton. However, electron has a negative value of charge and proton has a positive value of charge.

Generally, the number of electrons and protons in the atom are equal in number. Due to the opposite charges of electrons and protons the charges get cancel each other and the atom remains neutral.

However, if the atom has unequal number of electrons and protons, then the atom is said to be a charged atom. If the atom has more number of electrons (negative charges) than protons (positive charges), then it is said to be negatively charged. Similarly, if the atom has more number of protons than electrons, then it is said to be positively charged.

Properties of electric charge

The various properties of electric charge include:

- Additivity of charges
- Charge is conserved

- Quantization of charge

Additivity of charges

If a system contains two point charges q_1 and q_2, then the total charge of the system is obtained by simply adding q_1 and q_2, i.e., charges add up like real numbers.

If a system contains n number of charges q_1, q_2, q_3, q_4, - - - - - - ,q_n, then the total charge of the system is $q_1 + q_2 + q_3 + q_4 + \text{- - - - - - - - -} + q_n$.

Charge is a scalar quantity; it has magnitude but no direction, similar to mass. However, there is one difference between charge and mass. Mass of a body is always positive whereas charge can be either positive or negative.

Let us take for example, the system containing four charges q_1 = +2C, q_2 = +3C, q_3 = -3C, q_4 = +4C, then the total charge of the system is

$$q = q_1 + q_2 + q_3 + q_4$$

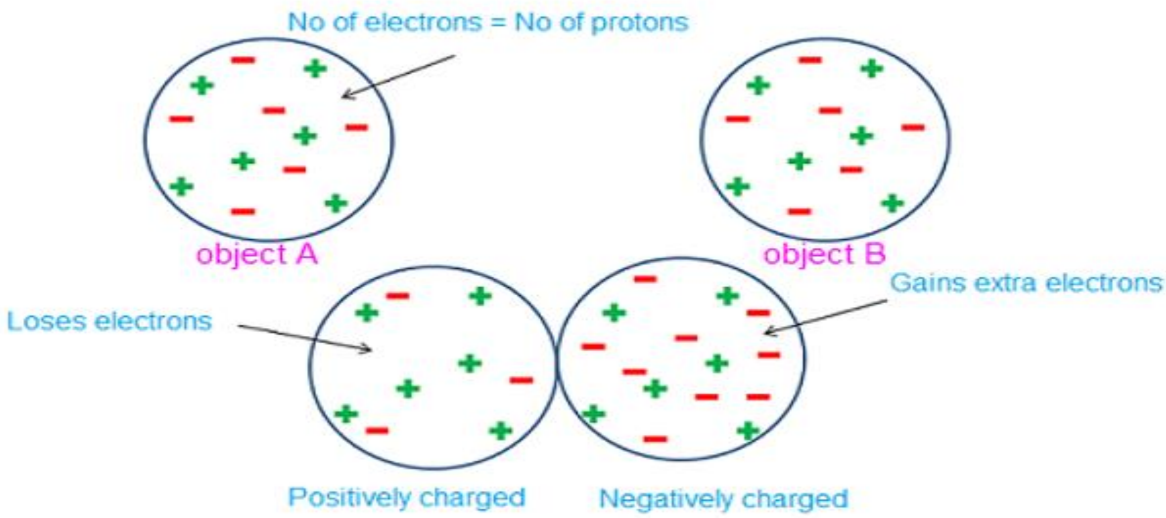
$$= (+2) + (+3) + (-3) + (+4)$$

$$= +6C$$

Therefore, the total charge of the system is +6C and it is positively charged.

Charge is conserved

The law of conservation of charge states that charge cannot be created or destroyed. However, a charge can be transferred from one object to other. Let us consider two objects, object A and object B. Object A has equal number of electrons and protons. So, it is electrically neutral. Similarly, object B has equal number of electrons and protons. So, it is also electrically neutral.



When object A and object B are rubbed with each other, negative charges from object A can be transferred to object B. Hence, object B has more number of electrons than protons due to gaining of extra electrons. Similarly, object A has lesser number of electrons than protons due to losing of some electrons.

Therefore, object A becomes positively charged and object B becomes negatively charged. However, the total charge of an isolated system remains constant.

Quantization of charge

The charge of any object is equal to integer multiples of the elementary charge. This is known as quantization of charge. It is given by

$$q = ne \quad \text{(or)} \quad n(-e)$$

Where

q = electric charge of any object or body

n = any integer positive or negative

-e = elementary charge = charge carried by a single electron.

e = elementary charge = charge carried by a single proton.

The charge on an electron is written as *-e* and the charge on a proton is written as *+e*. The quantization of charge was first suggested by the experimental laws of electrolysis discovered by Faraday. It was experimentally proved by Millikan. The total charge on an object is equal to the algebraic sum of individual charges present within the object.

If an object contains n_1 electrons and n_2 protons, then the total charge on the object is $n_1 \times (-e) + n_2 \times e$. For example, if the object contains 150 electrons and 200 protons, then the total charge on the object is $-150e + 200e = 50e$. Hence, the object is positively charged. The object charge can be exactly $0e$ or $1e$, $2e$ - - - or $-1e$, $-2e$ - - - but not 1/2, 1/4 etc.

Coulomb's law

The study of electrostatics begins with Coulomb's law. Coulomb's law is an experimental law published in 1785 by French physicist Charles Augustin de Coulomb. This law is very important for the development of theory of electromagnetism.

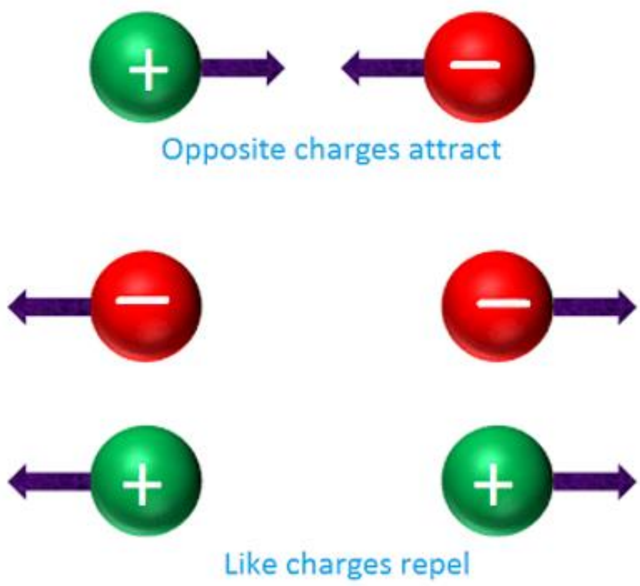
Charles Coulomb observed that when two electric charges are placed close to each other, they experience a force. He used a torsion balance to measure the repulsive and attractive forces between charged particles.

Statement of Coulomb's law

Charles coulomb has developed the two laws on the basis of his experiments, which are known as Coulomb's law of electrostatics.

First law

Coulomb's first law states that two charged particles of same charge (positive or negative) will repel each other and two charged particles of opposite charges (one positive and one negative) will attract each other.

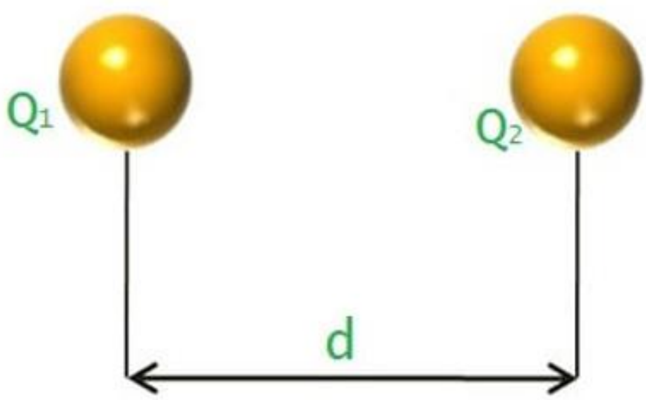


In other words, if two positively or negatively charged particles are placed close to each other, they get repelled. On the other hand, if one positively charged particle and one negatively charged particle is placed close to each other, they get attracted.

Second law

Coulomb's second law states that, the force of attraction or repulsion between the two electrically charged particles is directly proportional to the product of magnitudes of two charges and inversely proportional to the square of the distance between two charges.

This force of attraction or repulsion between two charges is also depends on the medium in which charges are placed.



If we increase the distance between two point charges, the force of attraction or repulsion present between them will decrease. In the similar way, if we decrease the distance between two point charges, the force of attraction or repulsion present between them will increase.

Coulomb's law can be mathematically written as

$$F \propto \frac{Q_1 Q_2}{d^2} \text{ (OR) } F = k\frac{Q_1 Q_2}{d^2}$$

Where,

F = Force of attraction or repulsion between the charges Q_1,

Q_2 = Magnitude of charge 1 and charge 2

d = Distance between two charges.

k = Constant whose value depends on the medium in which charges are placed.

$$k = \frac{1}{4\pi\varepsilon}$$

Where $\varepsilon = \varepsilon_0\varepsilon_r$

$$k = \frac{1}{4\pi\varepsilon_0\varepsilon_r}$$

Where,

ε_0 = permittivity of vacuum = 8.854×10^{-12} F/m

ε_r = relative permittivity of medium with respect to free space.

For vacuum, the relative permittivity $\varepsilon_r = 1$,

Hence $\varepsilon = \varepsilon_0$

Therefore, the force of attraction or repulsion between two electric charges that are placed in vacuum and medium is given by

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 d^2} \quad \text{in vacuum}$$

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0\varepsilon_r d^2} \quad \text{in medium}$$