Lecture (1)

Electricity and Magnetism I

First Stage
Department of Physics
College of Science
Al-Muthanna University
2018-2019

Dr. Ahmed Almurshedi
Ph.D., M.Sc., B.Sc.
Medical Physics

Syllabus of Electricity and Magnetism I

Week	Topics Covered
1	Electric Charge, Electric Force
2	Coulomb law
3	Electric field
4	Electric field
5	Electric flux
6	Gauss law
7	Electrical potential of point charges
8	Potential of point charge

Week	Topics Covered
9	Energy stored in charged system
10	Capacitors
11	Polarization
12	Isolator Material
13	AC currents
14	Ohm's law
15	Kirshoff's law

References

1- Fundamentals of Physics, Halliday & Resnicle, John Wiley, 2011 9th edition.

2- University Physics by Francis and others.

3- Website

Electric Charge

The electrical charge is denoted by “**q**”. There are two kinds of electric charge: positive and negative charges. The net charge of a body is the algebraic sum of its positive and negative charges. A body having equal amounts of positive and negative charges (i.e. zero net charge) is called electrically neutral. A particle having a nonzero net charge is often called an ion.

The unit of electric charge is Coulomb. The coulomb, C , is derived from the fundamental SI unit of time, the second, s , and the fundamental SI unit of electric current, the ampere, A . It is the charge (Q or q) transported by a constant current of one ampere in one second.

Properties of electric charges

1. The like charges are repulsion and the unlike charges are attraction.

2. Electric charge is conserved.

When a glass rod is rubbed with silk, electrons are transferred from the glass to the silk in same magnitude, because of conservation of charge.

3. Electric charge is quantized.

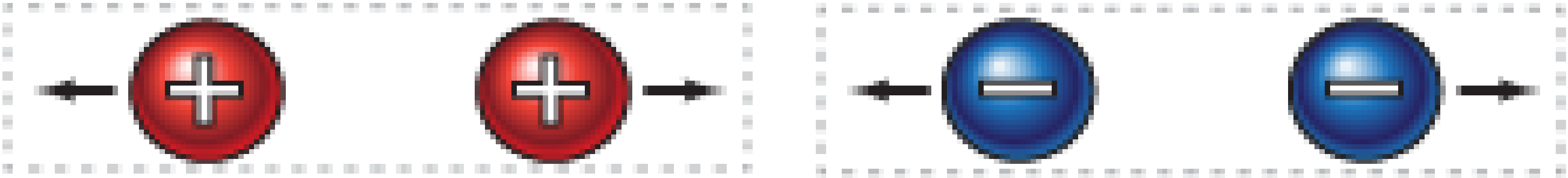
In 1909 Robert Millikan (1886–1953) discovered that charge, is always a multiple of a fundamental unit of charge, meaning that charge can't be subdivided. An object may have a charge of (±e, ±2e, ±3e, …) and so on, but never a fractional charge of (±0.5e or ±0.22e).

$$\boldsymbol{q = n\,e} \qquad\qquad \boldsymbol{n = 1, 2, 3, \ldots}$$

Attraction and repulsion of electric charges

Unlike charges attract.

Like charges repel.



Conductors, Insulators and Semiconductor

1. **A conductors** is the substance that permits electric charge to move freely, e.g. silver, copper and aluminum.

2. **Insulators** are the substance that does not permits electric charge to move, e.g. glass, plastic and rubber.

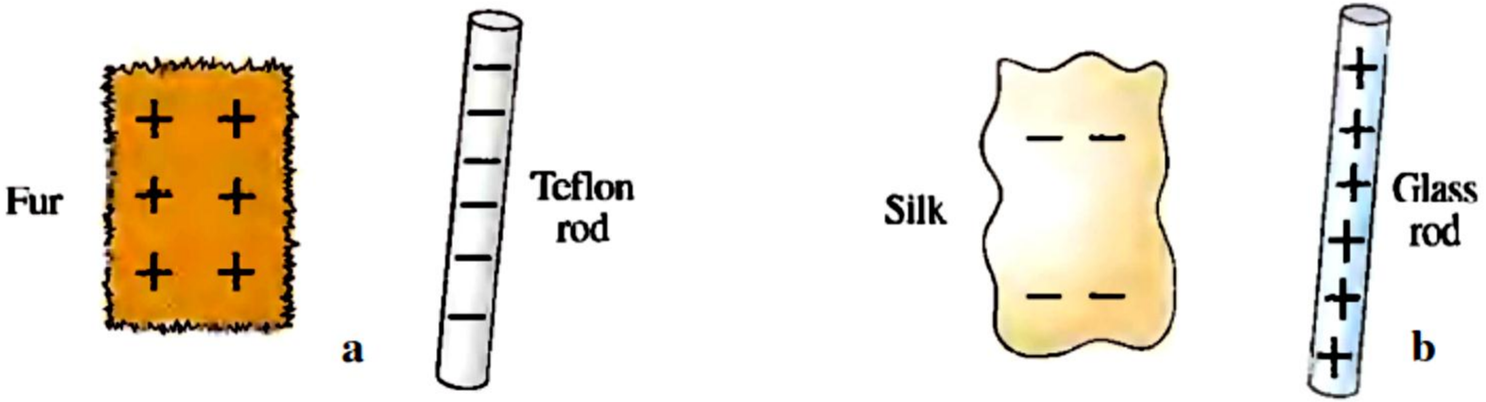
3. **Semiconductors** are the substance that an in intermediate position between conductor and insulator, e.g. silicon and germanium.

Types of Charging

In a neutral matter the numbers of electrons are equal the protons. We can transfer charges back and forth between different materials by using three different ways:

1. Charging by Friction

When you rub one material to another, they are charged by friction. When you rub the glass rod to a silk, glass lose electron and positively charged and silk gain electron and negatively charged. We can say the charged of the system are conserved (see figure below).



a) Teflon is rubbed against fur

b) glass is rubbed against silk.

2. Charging by Contact

When positively charged rod touches the neutral sphere, some of the electrons of the sphere pass through to the rod and when separate them, sphere becomes positively charged.

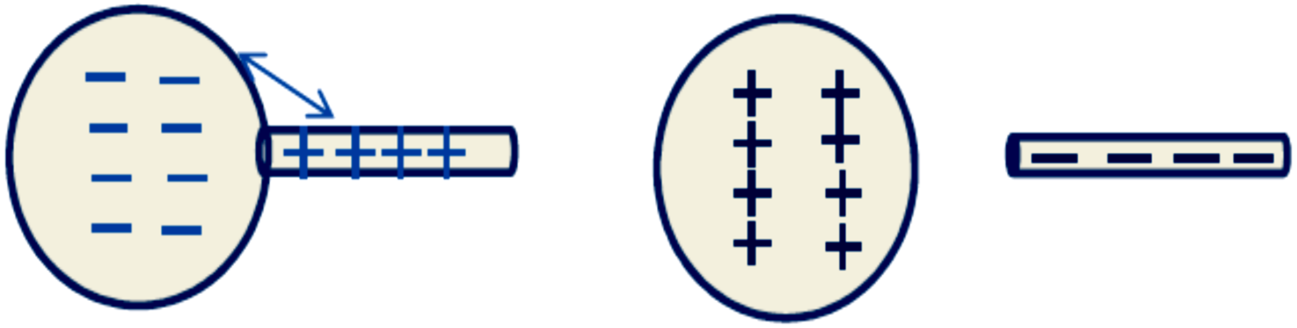


Figure charging by contact

3. Charging by Induction

If we bring a negatively charged Teflon rod close to one sphere, mobile electrons in the spheres move to the opposite side of the far sphere, leaving opposite charges on the two spheres. The spheres have a total charge of zero, but one is positive and the other negative. While the Teflon rod is still near, we separate the two spheres, leaving them oppositely charged. If we now remove the Teflon rod, the charges induced by the rod will remain on the two metal spheres. The spheres have been charged by induction.

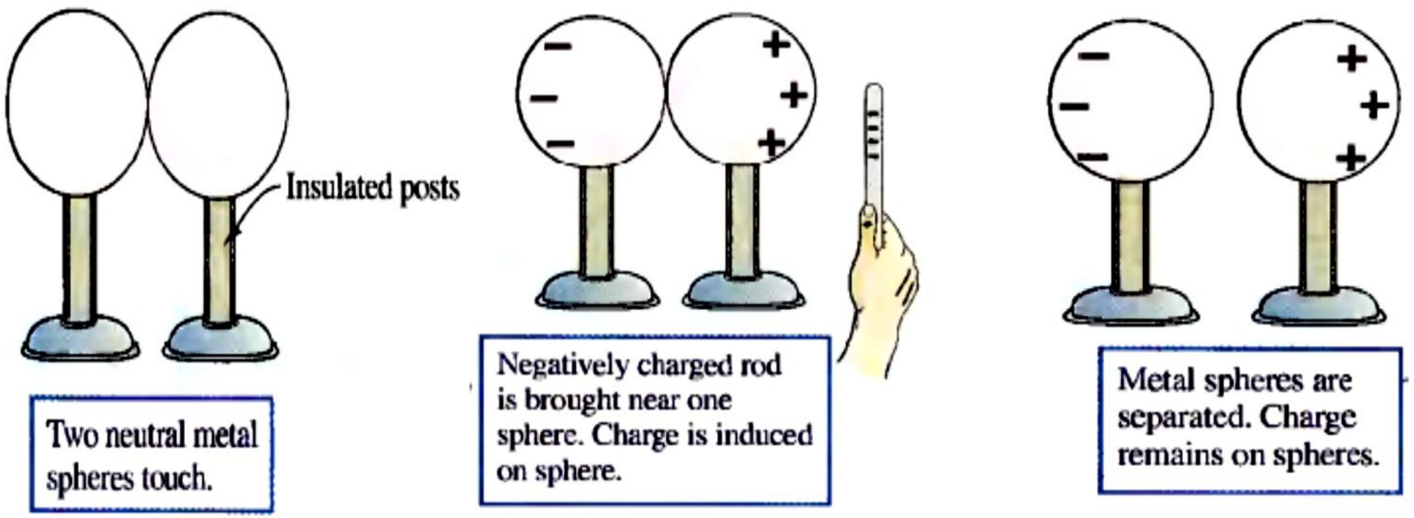


Figure charging by induction

Coulomb's Low

- The electrostatic interaction between two charged particles is proportional to their charges and to the inverse of the square of the distance between them, and its direction is along the line joining the two charges. This maybe expressed mathematically by:

$$\boldsymbol{F \propto \frac{q_1 q_2}{r^2} \qquad \Longrightarrow\ F = K\frac{q_1 q_2}{r^2}}$$

- Where r is the distance between the two charge $q_1 and\ q_2$. F is the force acting on either charge and K is the proportionality constant as Coulomb's constant to be determined by our choice of units. For practical and computational reasons, it is more convenient to express K in the form.

$$\boldsymbol{K = \frac{1}{4\,\pi\,\epsilon_\circ}}$$

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Where the new physical constant $\epsilon_\circ$ is called the vacuum permittivity.

$$\boldsymbol{\epsilon_\circ = 8.85 \times 10^{-12}\, N^{-1} m^{-2} C^{2}}$$

Accordingly, we shall normally write Coulomb’s law as:

$$\boldsymbol{F = \frac{q_1 q_2}{4\,\pi\,\epsilon_\circ\, r^2}}$$

- When using above equation we must include the charges sign. The direction of the force is determined according to the sign of the two charges. A negative value of force corresponds to attraction and a positive value of force corresponds to repulsion.

- If there are more than two charges, the total force acting on one charge due to the others is the sum of the forces due to the individual charges. For example if there are three charges, then the net force particles 1 due to the other two particles are given as:

$$\vec{\boldsymbol{F}} = \vec{\boldsymbol{F}}_{\mathbf{21}} + \vec{\boldsymbol{F}}_{\mathbf{31}}$$

Example 1: Compute the electrostatic force of repulsion between two **α**-particles at a separation of 10^{-11} cm, and compare with the force of gravitational attraction between them.

Sol.

$$\boldsymbol{F = \frac{q_1 q_2}{4\,\pi\,\epsilon_\circ\, r^2}}$$

- Each **α**-particles has a charge of +2e or $2\times1.6\times10^{-19}=3.2\times10^{-19}$ C.

$$\boldsymbol{F = 9\times10^9\,\frac{(3.2\times10^{-19})^2}{(10^{-13})^2} = 9.18\times10^{-2}\ N}$$

$$\boldsymbol{F_g = G\ \frac{m_1 m_2}{r^2}}$$

The mass of an **α**-particles (2 proton + 2neutruns)

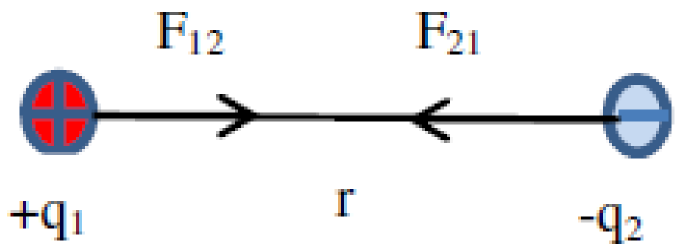
$$\mathbf{4 \times 1.87 \times 10^{-27} kgm = 6.68 \times 10^{-27} kgm}$$

$$\boldsymbol{F_g = 6.67 \times 10^{-11} \frac{(6.68 \times 10^{-27})^2}{(10^{-13})^2} N = 2.97 \times 10^{-27} N}$$

The gravitational force is evidently negligible in compare with the electrostatic force.

Example 2: Coulomb's law for two point charges. A point charge, q1 =2 μC is placed 0.5m from another point charge q2= -5μC. Calculate the magnitude and direction of the force on each charge.

Sol.



$$|\boldsymbol{F}_{1\,2}| = \frac{1}{4\,\pi\,\epsilon_\circ}\frac{|q_1||q_2|}{|r_{1\,2}^2|}$$

$$\boldsymbol{F}_{1\,2} = 8.99 \times 10^9 (N.m^2/C^2)\,\frac{(2 \times 10^{-6}\,C)(5 \times 10^{-6}\,C)}{(0.5\,m)^2}$$

$$\boldsymbol{F}_{1\,2} = 0.360\,N$$

$$\boldsymbol{F}_{2\,1} = -0.360\,N$$

$$F_R = (0.360\,N) + (-0.360\,N) = 0$$

Example 3: the force between two equal point charges 1 cm apart has a magnitude of 2 N. what is the magnitude of the point charge?

Sol.

$$F = K\frac{q^2}{r^2} \qquad q = \sqrt{\frac{F\,r^2}{K}}$$

$$q = \sqrt{\frac{(2\ N)\ (0.01\ m)^2}{8.99 \times 10^9 (N.m^2/C^2)}} = \pm 1.49 \times 10^{-7}\ C$$

Since the charges are equal, they are both positive or both negative. The force is repulsive in either case.

Example 4: Electrons are removed from an originally neutral sphere and placed on another originally neutral sphere. When 1 cm apart the small spheres attract each other with a force of 10^{-6} N. How many electron has transferred?

Sol.

$$\boldsymbol{F = K\frac{q_1 q_2}{r^2}}$$

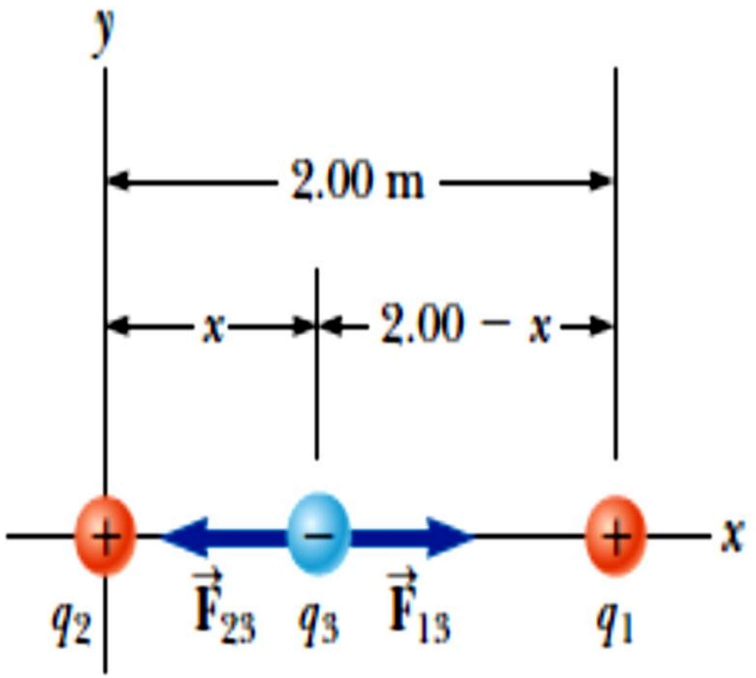
$$\boldsymbol{q_1 = -q_2 = ne} \qquad \boldsymbol{e = 1.6 \times 10^{-19}\ C}$$

Where n is the number of electrons removed and e is the electronic charge.

$$\boldsymbol{F = K\frac{(ne)^2}{r^2}} \qquad n = \sqrt{\frac{F\,r^2}{K\,e^2}}$$

$$n = \sqrt{\frac{(10^{-6}\ N)\ (0.01\ m)^2}{8.99\times10^{9}(N.m^2/C^2)\ (1.6\times10^{-19}\ C)^2}} \qquad \boldsymbol{n = 6.59 \times 10^{8}}$$

Example 5: Three point charges lie along the x-axis as showing in the figure below the positive charge q1=15 μC is at x=2 m, the positive charge q2=6 μC is at the origin and the net force acting on q3 is zero. What is the x coordinate of q3?



Sol.

- $\overrightarrow{F_3} = \overrightarrow{F_{23}} + \overrightarrow{F_{13}} = -k\frac{|q_2||q_3|}{x^2} + k\frac{|q_1||q_3|}{(2-x)^2} = 0$

- $k\frac{|q_2||q_3|}{x^2} = k\frac{|q_1||q_3|}{(2-x)^2}$ $\qquad \frac{|q_2|}{x^2} = \frac{|q_1|}{(2-x)^2}$

- $x = \frac{2\sqrt{|q_2|}}{\sqrt{|q_2|}\pm\sqrt{|q_1|}}$ $\qquad x = \frac{2\sqrt{6\times10^{-6}\ C}}{\sqrt{6\times10^{-6}\ C}+\sqrt{15\times10^{-6}\ C}} = 0.775\ m$

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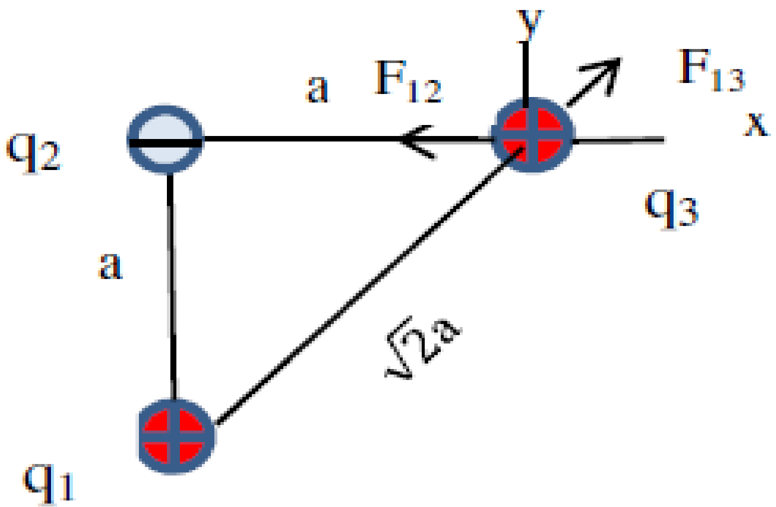
H.W 1: Consider three point charges located at the corners of a right triangle as shown in Figure, where q1 = q3 =5.0 μC, q2=-2.0 μC, and a=0.1 m. Find the resultant force exerted on q3?



H.W 2: Positive point charges of equal magnitude $Q = 10^{-8} C$ are distributed at the points (0,a) and(0,-a) in the x-y plane with a=1 cm, find the total charge of these two charges exert on a negative charge –Q located on the x-axis at (x,0). Evaluate this force for (x=0) and (x=a).