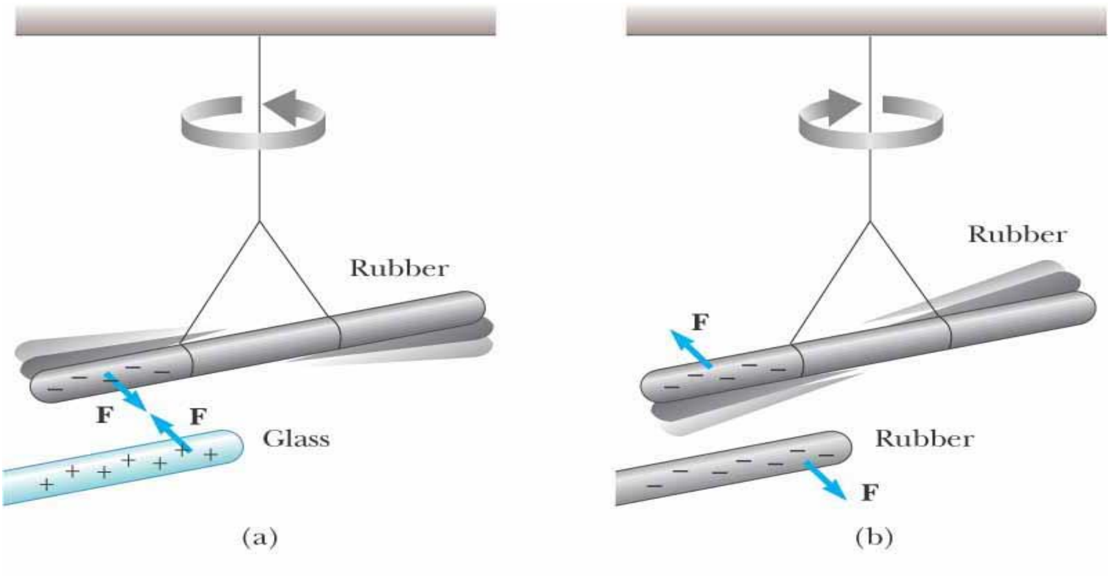
Chapter 23

Electric Field

23.1 Properties of electric charges

- Two types of charges exist in nature
  - They are called positive and negative
  - Named by Benjamin Franklin
- **Like** charges *repel* and **unlike** charges *attract* one another



(a) Negatively charged rubber rod suspended by a thread is attracted to a positively charged glass rod.

(b) A negatively charged rubber rod is repelled by another negatively charged rubber rod.

- Charge is quantized
  - All charge is a multiple of a fundamental unit of charge, symbolized by e
  - Electrons have a charge of –e
  - Protons have a charge of +e
- The SI unit of charge is the Coulomb (C)

$$e = 1.6 \times 10^{-19}\ C$$

Table 23.1

Charge and Mass of the Electron, Proton, and Neutron		
Particle	**Charge (C)**	**Mass (kg)**
Electron (e)	$-1.602\,191\,7 \times 10^{-19}$	$9.109\,5 \times 10^{-31}$
Proton (p)	$+1.602\,191\,7 \times 10^{-19}$	$1.672\,61 \times 10^{-27}$
Neutron (n)	0	$1.674\,92 \times 10^{-27}$

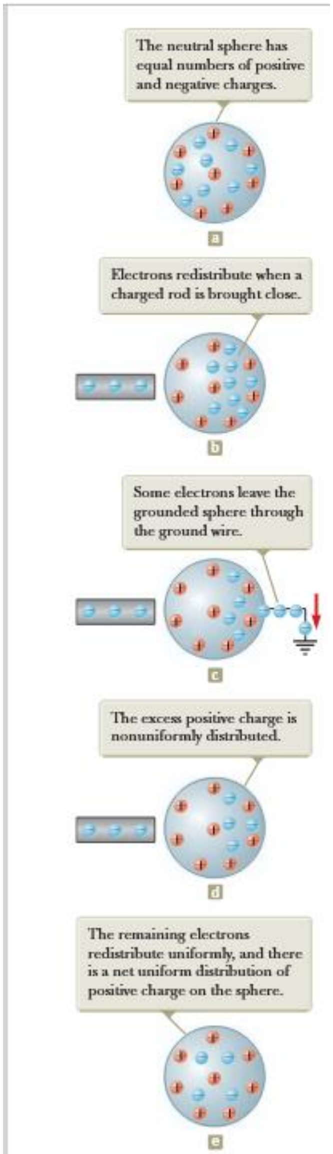
- In **conductors**, electrons can move easily because the outermost electrons in conductive materials (such as metals) are loosely bound to their parent atoms.
- An **insulator** is a material that resists the flow of electrical current because its electrons are tightly bound to their atoms and cannot move freely. This property makes insulators essential for protecting us from electrical hazards and for isolating electrical components in devices.
- A **semiconductor** is a material whose electrical conductivity falls between that of a conductor (like copper) and an insulator (like glass). Semiconductors can conduct electricity under certain conditions, making them crucial in electronic devices like diodes, transistors, and integrated circuits.

23.2 Charging objects by induction:

Remember ! charges are conservative, which means that electric charge cannot be created or destroyed; it can only be transferred from one object to another.

Charging by induction is a method of charging an object without direct contact between the object and a charge source.

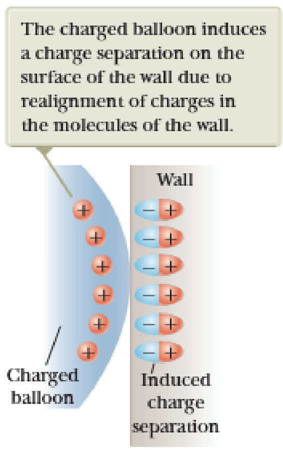
Charging a metallic object by *induction* (that is, the two objects never touch each other).
(a) A neutral metallic sphere, with equal numbers of positive and negative charges.
(b) The electrons on the neutral sphere are redistributed when a charged rubber rod is placed near the sphere.
(c) When the sphere is grounded, some of its electrons leave through the ground wire.
(d) When the ground connection is removed, the sphere has excess positive charge that is nonuniformly distributed.
(e) When the rod is removed, the remaining electrons redistribute uniformly and there is a net uniform distribution of positive charge on the sphere.



Check the following simulation:

http://phet.colorado.edu/en/simulation/balloons

- **How is charging by induction used in practical applications?**



- **<u>Here are some various materials and their tendency to lose or gain electrons:</u>**

Material	**Tendency to Lose Electrons**	**Tendency to Gain Electrons**
Rubber	High	Low
Glass	High	Low
Human Hair	High	Low
Silk	High	Low
Nylon	High	Low
Wool	High	Low
Cotton	High	Low
Wood	Moderate	Moderate
Steel	Moderate	Moderate
Copper	Moderate	Moderate
Aluminum	Moderate	Moderate
Plastic (e.g., PVC)	Low	Moderate
Polyester	Low	Moderate
Ebonite (hard rubber)	Low	High
Teflon	Low	High
Fur	Low	High
Polythene	Low	High

23.3 Coulomb's Law: (Charles Augustin de Coulomb, France, 1736)

#You can read about the experiment Charles Augustin de Coulomb performed to demonstrate that the force between two electric charges is affected by factors such as the magnitude of the charges, the distance between them, and the medium through which they interact.

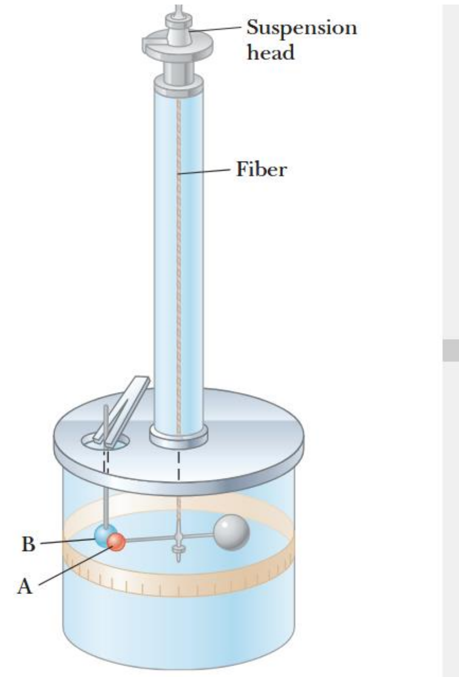


Figure 22.6 Coulomb's balance, used to establish the inverse-square law for the electric force.

<u>Coulomb shows that an electrical force has the following properties:</u>

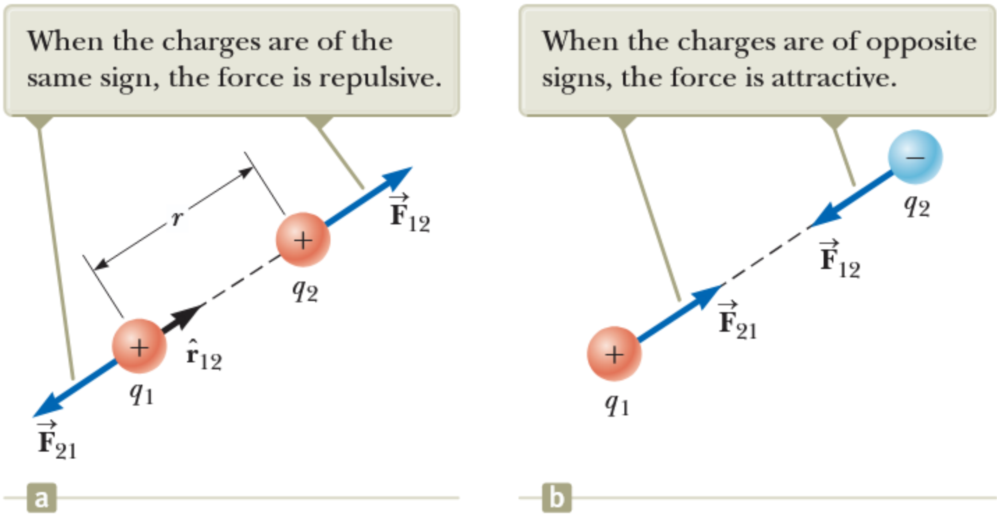
- It is along the line joining the two particles and inversely proportional to the square of the separation distance, r, between them,

$$\vec{F} \propto \frac{1}{r^2}$$

- It is proportional to the product of the magnitudes of the charges, $|q_1|$and $|q_2|$on the two particles

$$\vec{F} \propto |q_1| * |q_2|$$

- It is attractive if the charges are of opposite signs and repulsive if the charges have the same signs.



Mathematically:

$$\vec{F} = K_e \frac{|q_1||q_2|}{r^2}\hat{r}$$

- k_e is called the *Coulomb Constant*

$k_e = \frac{1}{4\pi\varepsilon_0}$ =8.9875 x 10^9 N m^2/C^2

ε_0 is the permittivity of free space ($\varepsilon_0 = 8.854x10^{-12}C^2/N.m^2$)

- q = n e

  q is the symbol used to represent total of charge, while n is a positive or negative integer, and e is the electronic charge, 1.6 x 10^{-19} Coulombs (C).

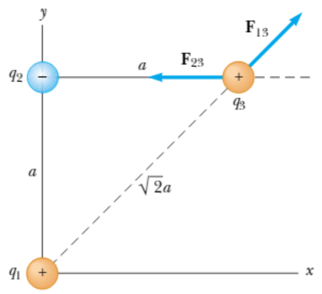
Example-1:

The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately 5.3 x10^{-11} m.

Find the magnitudes of the electric force.

$$F = k\frac{|e|^2}{r^2} = 9x10^9\frac{(1.6x10^{-19})^2}{(5.3x10^{-11})^2} = 8.2x10^{-8}\ N$$

Example-2 :



$$q_1 = q_3 = 5\ \mu C$$

$$q_2 = -2\ \mu C$$

$$a = 0.10\ m$$

Find the resultant force exerted on q_3?

The force $\vec{F}_{13}$ exerted by q_1 on q_3 is repulsive because both charges are positive. The repulsive force $\vec{F}_{13}$ makes an angle of 45.0^0 with the x axis. The magnitudes of the forces $\vec{F}_{13}$ and $\vec{F}_{23}$ are determined using the absolute magnitudes of the charges using Coulomb's law.

From the figure, we can analyze the net force on the q3 as follows:

$$F_3 = (F_{13x} - F_{23x})\hat{\imath} + F_{13y}\,\hat{\jmath}$$

So, we will go to determine these quantities.

$$F_{13x} = |F_{13}|\cos\theta \qquad ; \qquad F_{13y} = |F_{13}|\sin\theta$$

$$|F_{13}| = K\frac{|q_1||q_2|}{(\sqrt{2}a)^2} \qquad \cos\theta = \frac{a}{\sqrt{2}a} \qquad \sin\theta = \frac{a}{\sqrt{2}a}$$

$$F_{13x} = K\frac{|q_1||q_3|}{(\sqrt{2}a)^2}\frac{a}{\sqrt{2}a} = 9x10^9\frac{5x10^{-6}x5x10^{-6}}{2(0.1)^2}\frac{1}{\sqrt{2}} = 7.94\ N$$

$$F_{13y} = K\frac{|q_1||q_3|}{(\sqrt{2}a)^2}\frac{a}{\sqrt{2}a} = 9x10^9\frac{5x10^{-6}x5x10^{-6}}{2(0.1)^2}\frac{1}{\sqrt{2}} = 7.94\ N$$

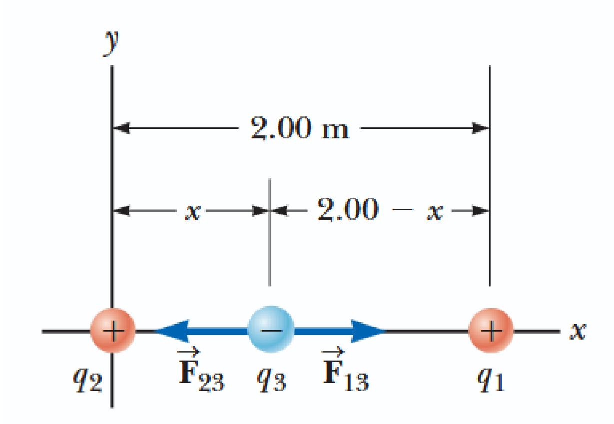
Simply, $F_{23x} = K\frac{|q_2||q_3|}{(a)^2} = 9x10^9\frac{2x10^{-6}x5x10^{-6}}{(0.1)^2} = 8.99\ N$

Then, $F_3 = (F_{13x} - F_{23x})\hat{\imath} + F_{13y}\,\hat{\jmath} = (7.94 - 8.99)\hat{\imath} + 7.94\,\hat{\jmath} = -1.04\hat{\imath} + 7.94\hat{\jmath}$

Example – 3:

Example 23.3 (usually exam question!)

Three point charges lie along the x axis as shown in the Figure . The positive charge q_1=15.0 µC is at x=2.00 m, the positive charge q_2=6.00 µC is at the origin, and the net force acting on q3 is zero. What is the x coordinate of q_3 ?



By analyzing the net force on q_3, we conclude that:

$$F_3 = (F_{13} - F_{23})\hat{\imath}$$

At an equilibrium situation, $\sum F_3 = 0 \quad ==== > \quad F_{13} = F_{23}$

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

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

$$\frac{15x10^{-6}}{(2-x)^2} = \frac{6x10^{-6}}{(x)^2}$$

$$\frac{15}{(2-x)^2} = \frac{6}{(x)^2}$$

$$6(2-x)^2 = 15x^2$$

$$2-x = \pm\sqrt{\frac{15}{6}}x$$

$$2-x \mp \sqrt{\frac{15}{6}}x = 0$$

choosing the plus sign,

$$x = 0.775\,m$$

Think about it !!

Notice that the movable charge is indeed closer to q_2 as we predicted. Notice that the result in Columb's law is independent of both the magnitude and the sign of charge q_3. If q_3 increases, both forces in the Figure increase in magnitude but still cancel. If q_3 changes sign, both forces reverse direction but still cancel.

The second solution to the equation (if we choose the negative sign) is x=-3.44 m. That is another location where the magnitudes of the forces on q_3 are equal, but both forces are in the same direction, so they do not cancel.