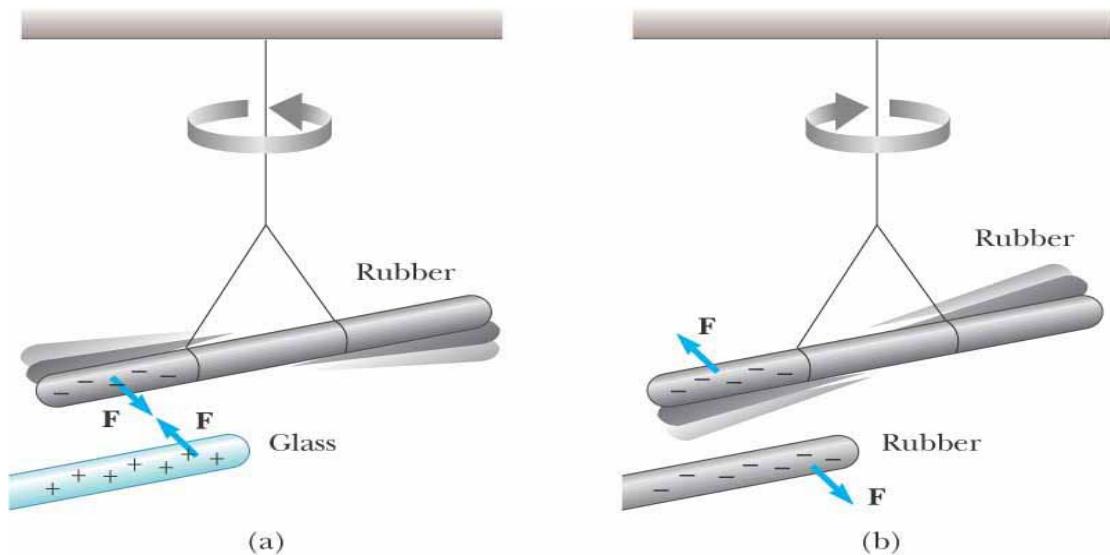


## Chapter 22

### Electric Field

#### 22.1 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



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- (a) 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)

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

**TABLE 22.1** Charge and Mass of the Electron, Proton, and Neutron

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.602\ 176\ 5 \times 10^{-19}$	$9.109\ 4 \times 10^{-31}$
Proton (p)	$+1.602\ 176\ 5 \times 10^{-19}$	$1.672\ 62 \times 10^{-27}$
Neutron (n)	0	$1.674\ 93 \times 10^{-27}$

- 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.

## 22.2 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.

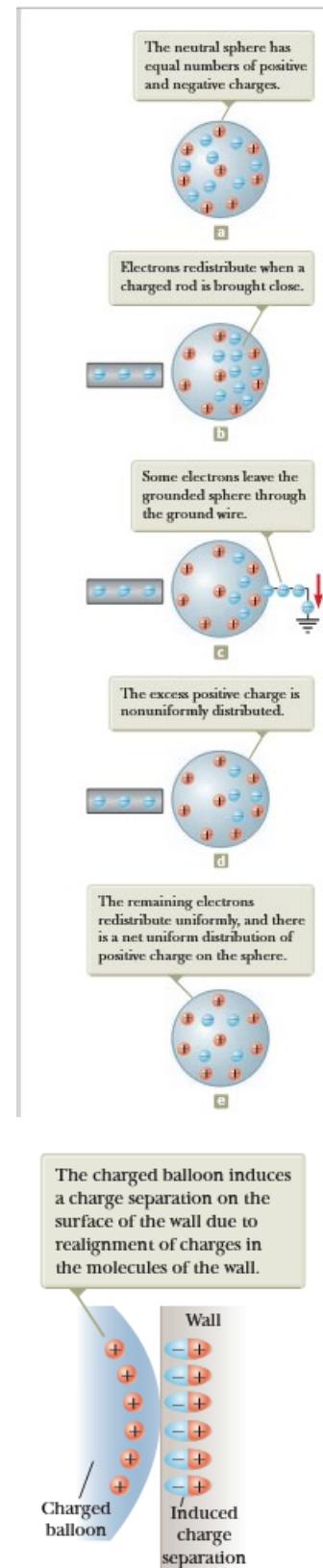
Charging a metallic object by induction (that is, the two objects never touch each other).

- A neutral metallic sphere, with equal numbers of positive and negative charges.
- The electrons on the neutral sphere are redistributed when a charged rubber rod is placed near the sphere.
- When the sphere is grounded, some of its electrons leave through the ground wire.
- When the ground connection is removed, the sphere has excess positive charge that is nonuniformly distributed.
- 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?**



## 22.3 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.

### Coulomb shows that an electrical force has the following properties:

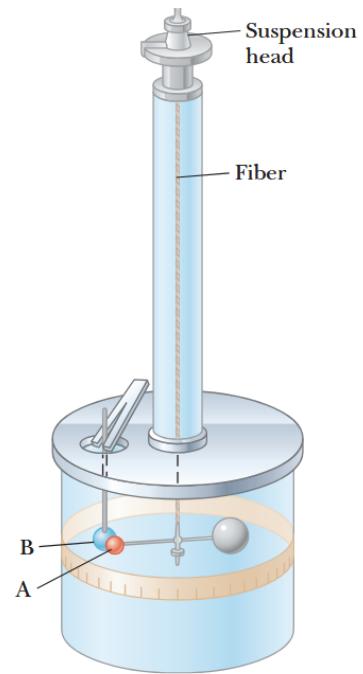
- It is along the line joining the two particles and inversely proportional to the square of the separation distance,  $r$ , between them,

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

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

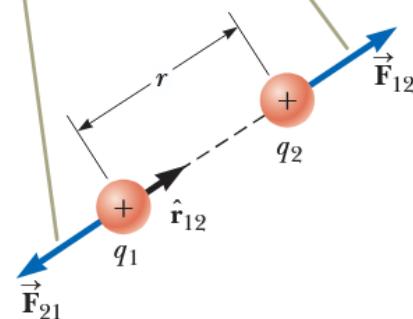
$$F \propto |q_1| * |q_2|$$

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

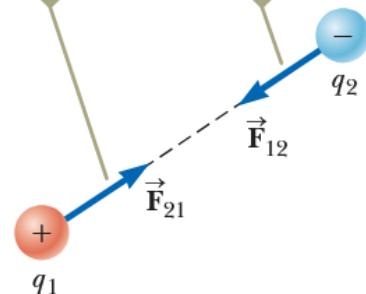


**Figure 22.6** Coulomb's balance, used to establish the inverse-square law for the electric force.

When the charges are of the same sign, the force is repulsive.



When the charges are of opposite signs, the force is attractive.



**Mathematically:**

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

■  $k_e$  is called the *Coulomb Constant*

$$k_e = \frac{1}{4\pi\epsilon_0} = 8.9875 \times 10^9 \text{ N m}^2/\text{C}^2$$

$\epsilon_0$  is the permittivity of free space ( $\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2/\text{N.m}^2$ )

■  $q = n e$

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

### Example-1:

The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately  $5.3 \times 10^{-11} \text{ m}$ .

**Find** the magnitudes of the electric force.

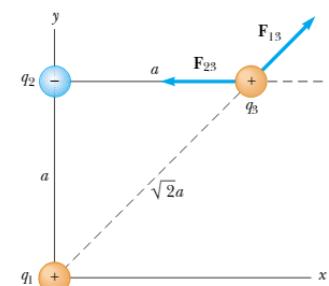
$$F = k \frac{|e|^2}{r^2} = 9 \times 10^9 \frac{(1.6 \times 10^{-19})^2}{(5.3 \times 10^{-11})^2} = 8.2 \times 10^{-8} \text{ N}$$

### Example-2 :

$$q_1 = q_3 = 5 \mu\text{C}$$

$$q_2 = -2 \mu\text{C}$$

$$a = 0.10 \text{ m}$$



**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  $45.0^\circ$  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  $q_3$  as follows:

$$F_3 = (F_{13x} - F_{23x})\hat{i} + F_{13y}\hat{j}$$

So, we will go to determine these quantities.

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

$$|F_{13}| = K \frac{|q_1||q_3|}{(\sqrt{2}a)^2} \quad \cos \theta = \frac{a}{\sqrt{2}a} \quad \sin \theta = \frac{a}{\sqrt{2}a}$$

$$F_{13x} = K \frac{|q_1||q_3|}{(\sqrt{2}a)^2} \frac{a}{\sqrt{2}a} = 9 \times 10^9 \frac{5 \times 10^{-6} \times 5 \times 10^{-6}}{2(0.1)^2} \frac{1}{\sqrt{2}} = 7.94 \text{ N}$$

$$F_{13y} = K \frac{|q_1||q_3|}{(\sqrt{2}a)^2} \frac{a}{\sqrt{2}a} = 9 \times 10^9 \frac{5 \times 10^{-6} \times 5 \times 10^{-6}}{2(0.1)^2} \frac{1}{\sqrt{2}} = 7.94 \text{ N}$$

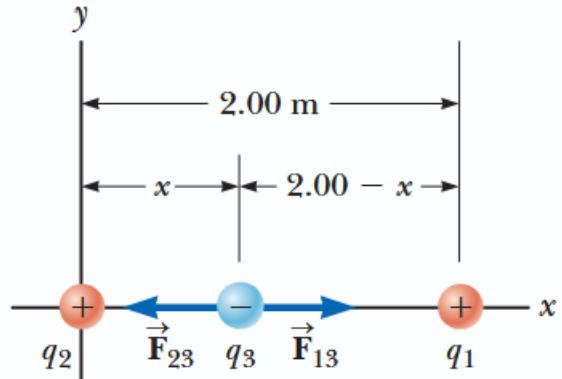
Simply,  $F_{23x} = K \frac{|q_2||q_3|}{(a)^2} = 9 \times 10^9 \frac{2 \times 10^{-6} \times 5 \times 10^{-6}}{(0.1)^2} = 8.99 \text{ N}$

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

### Example – 3:

#### Example 23.3 (usually exam question!)

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



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

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

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

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

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

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

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

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

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

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

choosing the plus sign,

$$x = 0.775 \text{ m}$$

### 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  $x=-3.44 \text{ m}$ . 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.