Lecture 1:

Electrostatic force and charge density

Outlines

1) Introduction
2) Notion of electric charge
3) Properties of electric charge
4) Charging objects by induction
5) Coulomb law
6) Charge density
7) Complementary mathematics

What is Electromagnetism

- Electromagnetism covers electrostatic and magnetism.
- Electromagnetism is a branch of physics involving the study of electromagnetism force, a type of physical interaction that occurs between electrically charged particles.

Electric charge

- The Greeks first noticed electric charged by rubbing amber with fur, then picking up bits of matter. The Greek word for amber is elektron.
- Benjamin Franklin arbitrarily called the two kinds of charge positive and negative. In most cases, only the negative charge is mobile.

Methods of charging

The process of supplying the electric charge (electrons) to an object or losing the electric charge (electrons) from an object is called charging.

An uncharged object can be charged in different ways:

- ❖Charging by friction
- ❖Charging by conduction
- ❖Charging by induction

Charging by friction

When insulators are rubbed together, one gives up electrons and becomes positively charged, while the other gains electrons and becomes negatively charged.

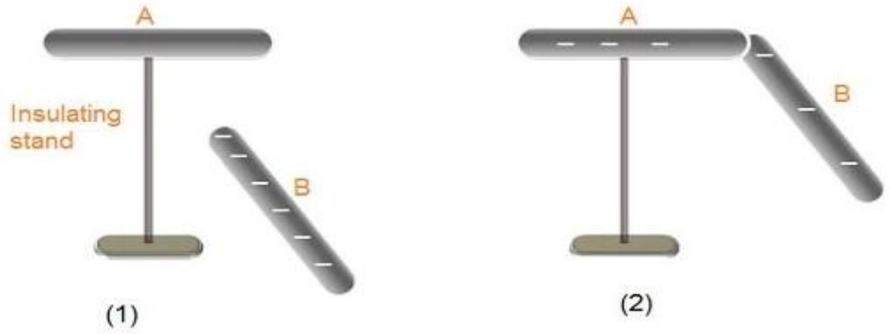
Common examples of charging by friction:

A. • Plastic food wrap that sticks to a container

B. • Laundry from the dryer that clings

Charging by conduction

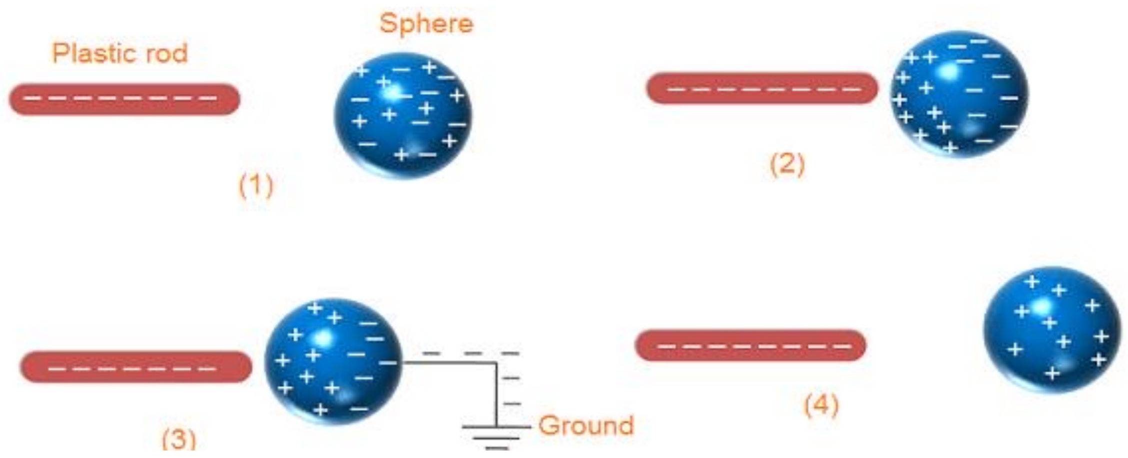
- The process of charging the uncharged object by bringing it in contact with another charged object is called charging by conduction.
- A charged object has unequal number of negative (electrons) and positive charges (protons). Hence, when a charged object is brought in contact with uncharged conductor, the electrons get transferred from charged object to the conductor.
-Consider an uncharged metal rod A kept on an insulating stand and a negatively charged conductor B as shown in below figure 1.



Charge by induction

- The process of charging the uncharged object by bringing another charged object near to it, without touching it, is called charging by induction.

- Consider an uncharged metal sphere and negatively charged plastic rod as shown in below figure (1). If, we bring the negatively charged plastic rod near to uncharged sphere as shown in below figure 2, charge separation occurs.



Properties of charge

▪ It exists two kinds of charges in nature:

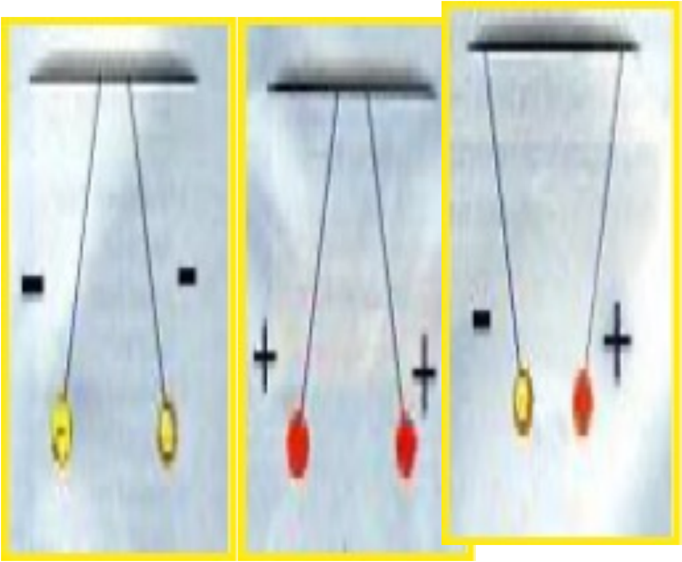
➢ Positive charge

➢ Negative charge

Benjamin Franklin (1706–1790)

▪ The negative charge is identified as electron.

▪ The positive charge is identified as proton.



• Like charges repel, and unlike charges attract (see, figure).

Neutral, uncharged matter contains as many positive charges (protons within atomic nuclei) as negative charges (electrons).

- The electric charge q is said to be quantized

$$q = ne,$$

where n is some integer, e is the electron charge. total charge = integer x fundamental unit of charge

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	$1.674\,92 \times 10^{-27}$

Materials

Electrical conductors:	*Semiconductors*	*Electrical insulators:*
Materials in which some of the electrons are free electrons that are not bound to atoms and can move relatively freely through the material (copper, aluminum, silver).	Materials in which their electrical properties are somewhere between those of insulators and those of conductors (Silicon, germanium)	Materials in which all electrons are bound to atoms and cannot move freely through the material (Glass, rubber, wood).

Coulomb's Law

Properties of the electric force between two stationary charged particles, Charles Coulomb (1736–1806)

- Inversely proportional to the square of the separation r between the particles and directed along the line joining them
- Proportional to the product of the charges q1 and q2 on the two particles
- Attractive if the charges are of opposite sign and repulsive if the charges have the same sign
- A conservative force

- q_1 is the charge on the first object
- q_2 is the charge on the second object
- r is the separation between the two objects
- $k_e = \frac{1}{4\pi\varepsilon_o}$, Coulomb constant
- $k_e = 8.9875 \times 109\ N.\frac{m^2}{C^2C2}$
- $\varepsilon_o = 8.8542 \times 1012\ C^2/N.m^2$
- ε_o = Vacuum permittivity/ Permittivity of free space

$$F_e = K_e \frac{q_1 q_2}{r^2}$$

Example 1

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

Example 23.1 The Hydrogen Atom

The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately 5.3×10^{-11} m. Find the magnitudes of the electric force and the gravitational force between the two particles.

Solution From Coulomb's law, we find that the magnitude of the electric force is

$$F_e = k_e \frac{|e||-e|}{r^2} = (8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{(1.60 \times 10^{-19}\text{ C})^2}{(5.3 \times 10^{-11}\text{ m})^2}$$

$$= 8.2 \times 10^{-8}\text{ N}$$

Using Newton's law of universal gravitation and Table 23.1 for the particle masses, we find that the magnitude of the gravitational force is

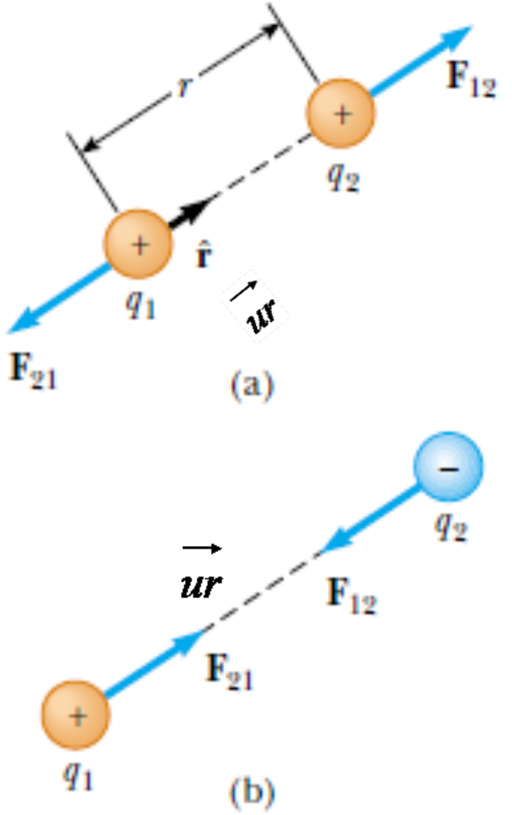
$$F_g = G\frac{m_e m_p}{r^2}$$

$$= (6.67 \times 10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2)$$

$$\times \frac{(9.11 \times 10^{-31}\text{ kg})(1.67 \times 10^{-27}\text{ kg})}{(5.3 \times 10^{-11}\text{ m})^2}$$

$$= 3.6 \times 10^{-47}\text{ N}$$

The ratio $F_e/F_g \approx 2 \times 10^{39}$. Thus, the gravitational force between charged atomic particles is negligible when compared with the electric force. Note the similarity of form of Newton's law of universal gravitation and Coulomb's law of electric forces. Other than magnitude, what is a fundamental difference between the two forces?



- Force is a vector quantity
- The law expressed in vector form for the electric force exerted by a charge q1 on a second charge q2, written F_{12}, is

$$\vec{F}_{12} = \frac{q_1 q_2}{4\Pi\varepsilon_0} \frac{\vec{r_{12}}}{\left\| \vec{r_2} - \vec{r_1} \right\|^3}$$

$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \vec{ur}$$

- where $\hat{r}$($\vec{ur}$) is a unit vector directed from q1 toward q2, as shown in Figure (a)
- The electric force exerted by q2 on q1 is equal in magnitude to the force exerted by q1 on q2 and in the opposite direction; that is,

$$F_{21} = -F_{12}$$

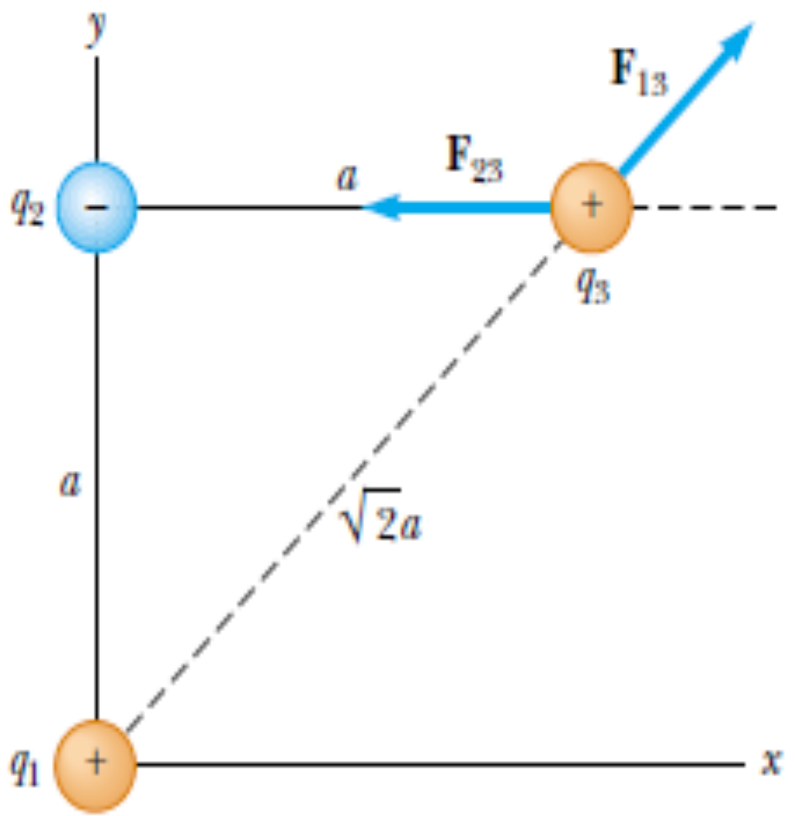
System of discrete charge

- The law of superposition allows Coulomb's law to be extended to include any number of point charges. The force acting on a point charge due to a system of point charges is simply the vector addition of the individual forces acting alone on that point charge due to each one of the charges. The resulting force vector is parallel to the electric field vector at that point, with that point charge removed.
- The force F on a small charge q at position r, due to a system of N discrete charges in vacuum is:

$$\boldsymbol{F}(\boldsymbol{r}) = \frac{q}{4\pi\varepsilon_0}\sum_{i=1}^{N} q_i \frac{\boldsymbol{r}-\boldsymbol{r}_i}{|\boldsymbol{r}-\boldsymbol{r}_i|^3} = \frac{q}{4\pi\varepsilon_0}\sum_{i=1}^{N} q_i \frac{\widehat{\boldsymbol{R}_i}}{|\boldsymbol{R}_i|^2}$$

where q_i and r_i are the magnitude and position of the i-th chargerespectively, $\widehat{R_i}$ is a unit vector in the direction of $R_i = r - r_i$ (a vector pointing from charges qi to q).

- Consider three-point charges located at the corners of a right triangle as shown in the figure, where $q_1 = q_3 = 5.0 \mu C$, $q_2 = -2.0\ \mu C$, and a=0.10 m. Find the resultant force exerted on q3



Example 23.2 Find the Resultant Force

Consider three point charges located at the corners of a right triangle as shown in Figure 23.8, where $q_1 = q_3 = 5.0\ \mu C$, $q_2 = -2.0\ \mu C$, and $a = 0.10$ m. Find the resultant force exerted on q_3.

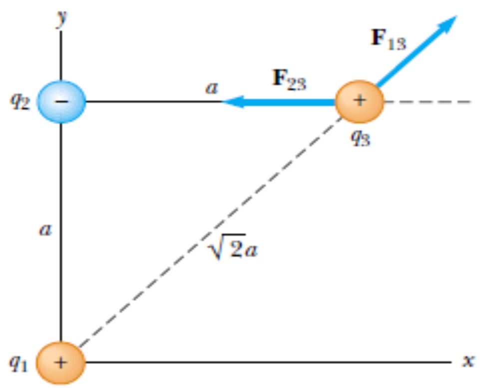


Figure 23.8 (Example 23.2) The force exerted by q_1 on q_3 is $\mathbf{F}_{13}$. The force exerted by q_2 on q_3 is $\mathbf{F}_{23}$. The resultant force $\mathbf{F}_3$ exerted on q_3 is the vector sum $\mathbf{F}_{13} + \mathbf{F}_{23}$.

Solution First, note the direction of the individual forces exerted by q_1 and q_2 on q_3. The force $\mathbf{F}_{23}$ exerted by q_2 on q_3 is attractive because q_2 and q_3 have opposite signs. The force $\mathbf{F}_{13}$ exerted by q_1 on q_3 is repulsive because both charges are positive.

The magnitude of $\mathbf{F}_{23}$ is

$$F_{23} = k_e \frac{|q_2||q_3|}{a^2}$$

$$= (8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(2.0 \times 10^{-6}\ \text{C})(5.0 \times 10^{-6}\ \text{C})}{(0.10\ \text{m})^2}$$

$$= 9.0\ \text{N}$$

In the coordinate system shown in Figure 23.8, the attractive force $\mathbf{F}_{23}$ is to the left (in the negative x direction).

The magnitude of the force $\mathbf{F}_{13}$ exerted by q_1 on q_3 is

$$F_{13} = k_e \frac{|q_1||q_3|}{(\sqrt{2}a)^2}$$

$$= (8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(5.0 \times 10^{-6}\ \text{C})(5.0 \times 10^{-6}\ \text{C})}{2(0.10\ \text{m})^2}$$

$$= 11\ \text{N}$$

The repulsive force $\mathbf{F}_{13}$ makes an angle of 45° with the x axis. Therefore, the x and y components of $\mathbf{F}_{13}$ are equal, with magnitude given by $F_{13}\cos 45° = 7.9$ N.

Combining $\mathbf{F}_{13}$ with $\mathbf{F}_{23}$ by the rules of vector addition, we arrive at the x and y components of the resultant force acting on q_3:

$$F_{3x} = F_{13x} + F_{23x} = 7.9\ \text{N} + (-9.0\ \text{N}) = -1.1\ \text{N}$$

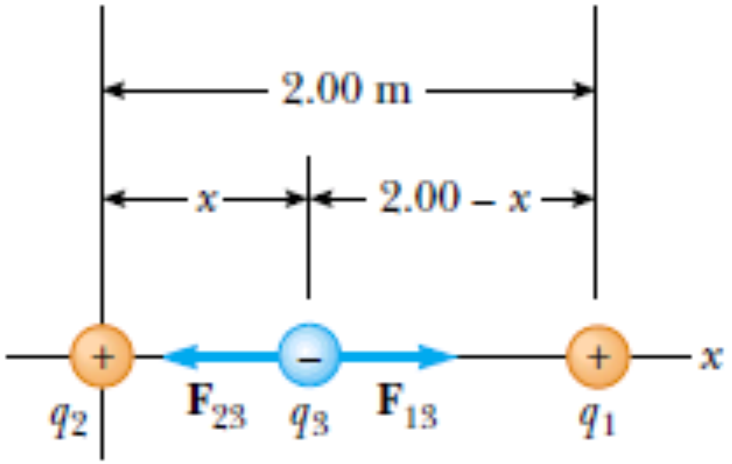
$$F_{3y} = F_{13y} + F_{23y} = 7.9\ \text{N} + 0 = 7.9\ \text{N}$$

We can also express the resultant force acting on q_3 in unit-vector form as

$$\mathbf{F}_3 = (-1.1\hat{\mathbf{i}} + 7.9\hat{\mathbf{j}})\ \text{N}$$

Homework 1

Three point charges lie along the x axis as shown in Figure 1. The positive charge $q_1 = 15.0\ \mu C$ is at $x = 2.00$ m, the positive charge $q_2 = 6.00\ \mu C$ is at the origin, and the resultant force acting on q_3 is zero. What is the x coordinate of q_3?



Object A has a charge of $+2\ \mu C$, and object B has a charge of $+6\ \mu C$. Which statement is true about the electric forces on the objects?

(a) $F_{AB} = -3F_{BA}$ (b) $F_{AB} = -F_{BA}$ (c) $3F_{AB} = -F_{BA}$ (d) $F_{AB} = 3F_{BA}$

(e) $F_{AB} = F_{BA}$ (f) $3F_{AB} = F_{BA}$

Explain what is meant by the term “a neutral atom.” Explain what “a negatively charged atom” means.

A balloon is negatively charged by rubbing and then clings to a wall. Does this mean that the wall is positively charged? Why does the balloon eventually fall?

A light, uncharged metallic sphere suspended from a thread is attracted to a charged rubber rod. After it touches the rod, the sphere is repelled by the rod. Explain.

A free electron and a free proton are released in identical electric fields. Compare the electric forces on the two particles.

Two protons in an atomic nucleus are typically separated by a distance of 2×10^{-15} m. The electric repulsion force between the protons is huge, but the attractive nuclear force is even stronger and keeps the nucleus from bursting apart. What is the magnitude of the electric force between two protons separated by 2.00×10^{-15} m?