ELECTRIC CHARGE & COULOMB'S LAW

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The
BLACK
HOLE

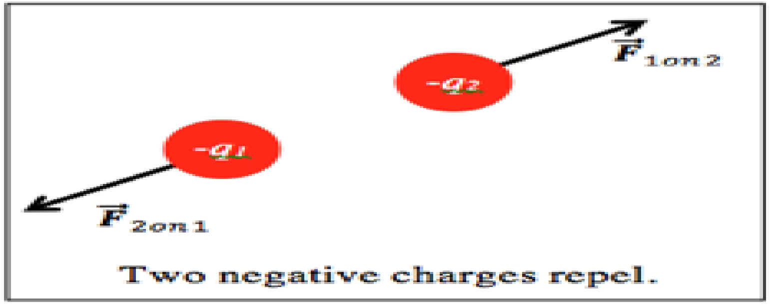
FUNDAMENTAL FORCES OF NATURE

- Gravitational Force
  - – Weakest force; but infinite range.
- Weak Nuclear Force
  - – Next weakest; but short range.
- Electromagnetic Force
  - – Stronger, with infinite range.
- Strong Nuclear Force
  - – Strongest; but short range.

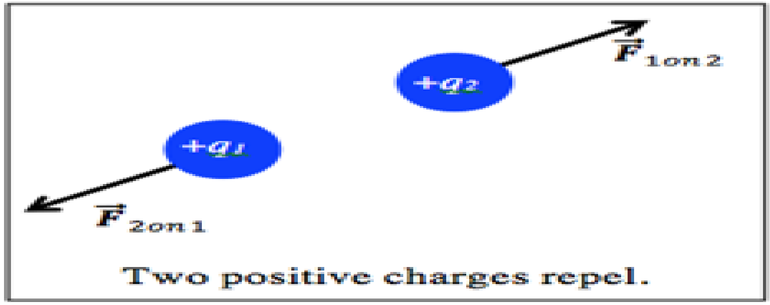
The <u>Electromagnetic Force</u> between charged particles is one of the fundamental forces of nature.

Properties of Electric Charges

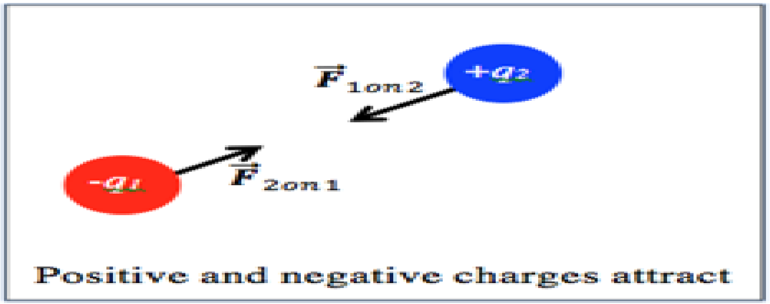
- It was found that there are two kinds of electric charges, which were given the names positive and negative by Benjamin Franklin(1706–1790)
- We identify negative charge as that type possessed by **electrons** and positive charge as that possessed by **protons**
- Charges of the same sign repel one another and,
- Charges with opposite signs attract one another.



Two negative charges repel.

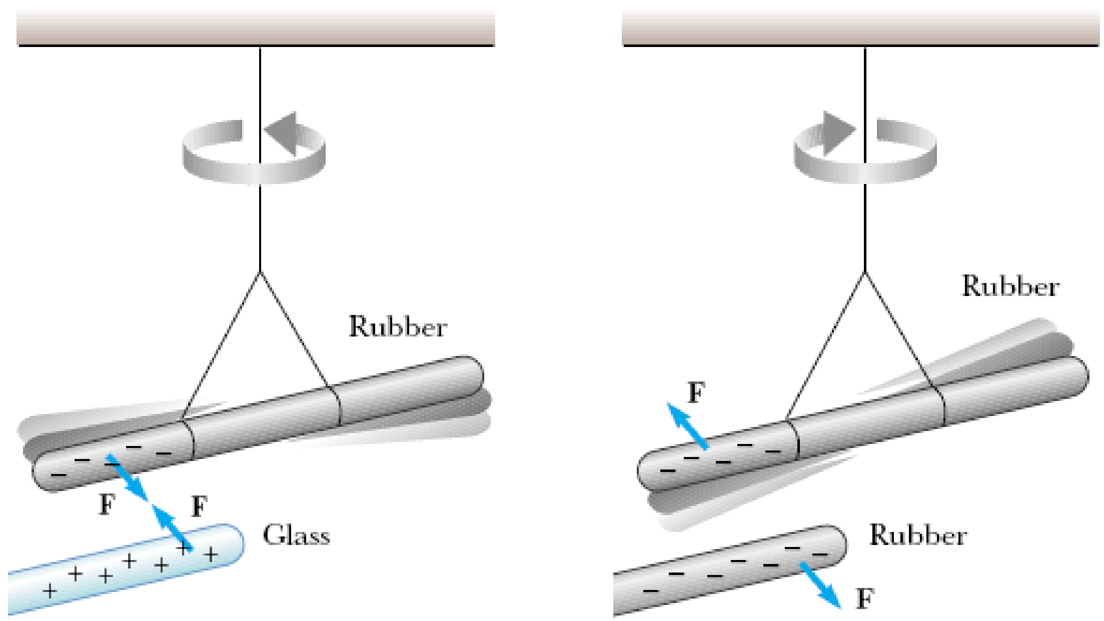


Two positive charges repel.



Positive and negative charges attract

- Using the convention suggested by **Franklin**, the electric charge **on the glass** rod is called **positive** and that on the **rubber rod** is called **negative.**
- Therefore, any charged object **attracted** to a charged **rubber rod** must have a **positive charge**, and any charged object **repelled** by a charged **rubber rod** must have a **negative** charge.



ELECTRIC CHARGE IS CONSERVED

- Another important aspect of electricity that arises from experimental observations is that **electric charge is always conserved in an isolated system**.
- That is, when one object is rubbed against another, **charge is not created in the process(electrified state)**.
- The **electrified state** is due to a ***transfer of charge from one object to the other.***

  One object gains some amount of negative charge while the other gains an equal amount of positive charge.

QUANTIZED ELECTRIC CHARGE

- In 1909, Robert Millikan (1868–1953) discovered that electric charge always occurs as some integral multiple of a fundamental amount of charge *e*
- In modern terms, the electric charge *q is said to be* ***quantized***
- where *q is the* standard symbol used for charge as a variable. That is, electric charge exists as discrete "packets," and we can write ***q = Ne, where N is some integer.***
- Magnitude of electron and proton is the same, but signs are different.
- Neutrons have no charge

SUMMARIZED

<u>Properties of Electric Charges:</u>

- There are two kinds of charges in nature; charges of opposite sign attract one another, and charges of the same sign repel one another.
- Total charge in an isolated system is conserved.
- Charge is quantized.

BRAINSTORMING

Question:

If you rub an inflated balloon against your hair, the two materials attract each other, as shown in Figure;

Is the amount of charge present in the system of the balloon and your hair after rubbing

(a) **less than** amount of charge present before rubbing?

(b) **the same** as amount of charge present before rubbing?

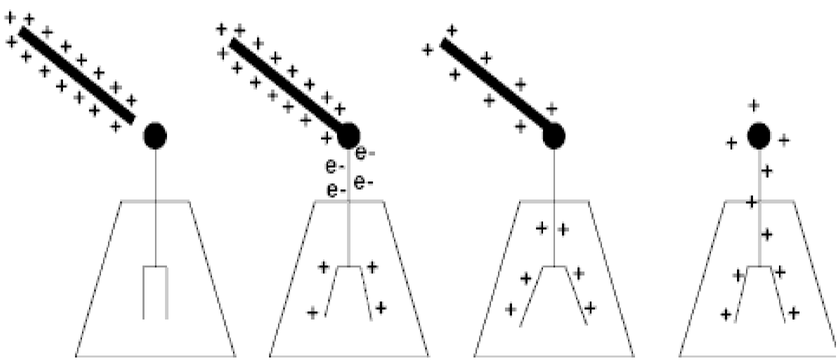
(c) **more than** the amount of charge present before rubbing?

- **Ans: The amount of charge present in the isolated system after rubbing <u>is the same</u> as that before because charge is conserved; it is just distributed differently.**

METHODS OF CHARGING

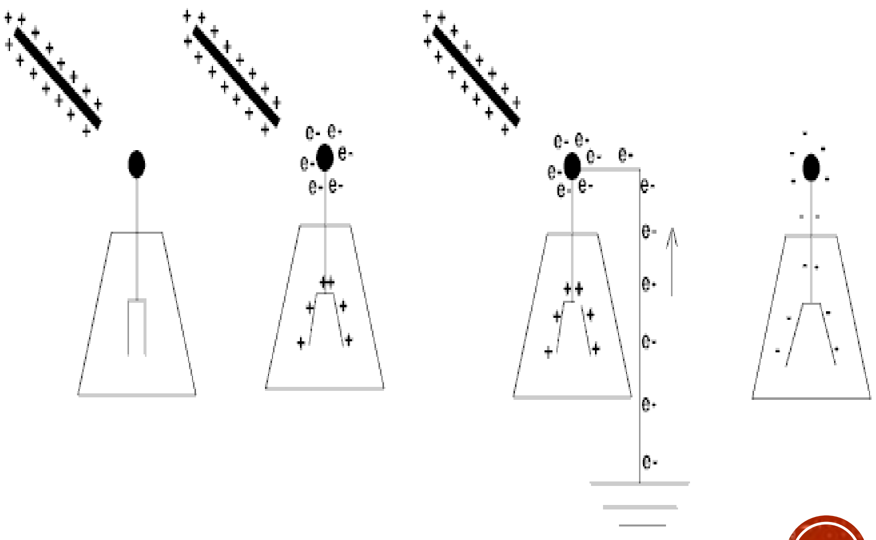
By conduction

- Charges are transferred from one body to another by physical contact.



By induction

- Charges are transferred from one body to another only when charged object comes closer to other object.



ELECTRICAL CONDUCTORS & INSULATORS

- **Electrical conductors** are materials in which some of the electrons are free electrons that are not bound to atoms and can move relatively freely through the material.
- Examples: Materials such as copper, aluminum, and silver are good electrical conductors
- **Electrical Insulators** are materials in which all electrons are bound to atoms and cannot move freely through the material.
- Examples: Materials such as glass, rubber, and wood fall into the category of electrical insulators.

SEMI CONDUCTORS & SUPER CONDUCTORS

- **Semiconductors** are a third class of materials, and their electrical properties are somewhere between those of insulators and those of conductors.
- Examples: Silicon and germanium are well-known examples commonly used in the fabrication of a variety of electronic chips used in computers, cellular telephones, and stereo systems.
- **Superconductors** are materials that are ***perfect conductors, allowing*** charge to move without *any hindrance.*

Coulomb's Law

From Coulomb's experiments, we can generalize the following properties of the **electric force** between two stationary charged particles. The electric force

- is inversely proportional to the square of the separation r between the particles and directed along the line joining them;
- is proportional to the product of the charges q_1 and q_2 on the two particles;
- is attractive if the charges are of opposite sign and repulsive if the charges have the same sign;
- is a conservative force.

Coulomb's law as an equation

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

$$k_e = \frac{1}{4\pi\epsilon_0}$$

Coulomb constant $k_e = 8.9875 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$

permittivity of free space $\epsilon_0 = 8.8542 \times 10^{-12} \ \mathrm{C^2/N \cdot m^2}$

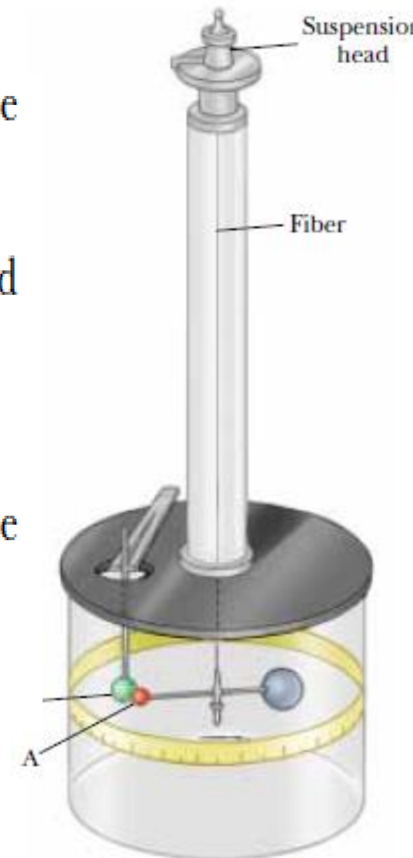
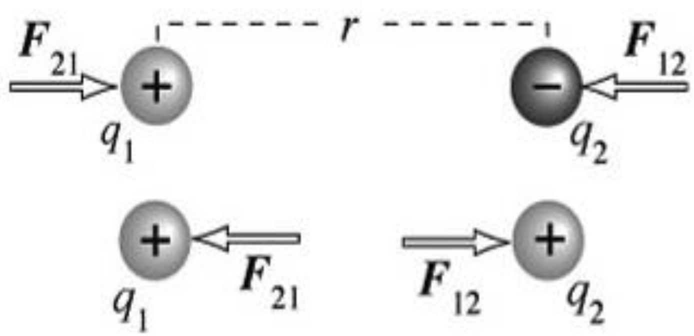


Figure 1 Coulomb's torsion balance, used to establish the inverse-square law for the electric force between two charges.

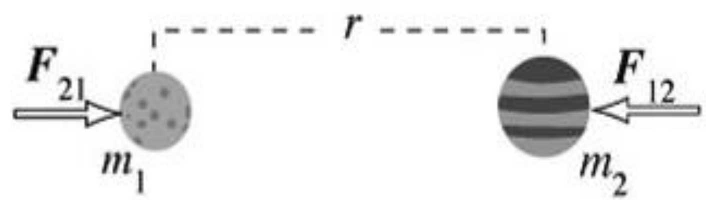
Electrostatic Force vs. Gravitational Force



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

Electrostatic Force

F	=	electrostatic force
q	=	electric charge
r	=	distance between centers of charge
k	=	Coulomb constant $9.0 \times 10^{9}\ \mathrm{N \cdot m^2/C^2}$



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

Gravitational Force

F	=	gravitational force
m	=	mass
r	=	distance between centers of mass
G	=	gravitational constant $6.7 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$

Example 1:

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

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

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

Using Newton's law of universal gravitation and
for the particle masses, we find that the magnitude of the gravitational force is $F_g = G\frac{m_e m_p}{r^2}$

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

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

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

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.

Class Activity:

Q.. 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?

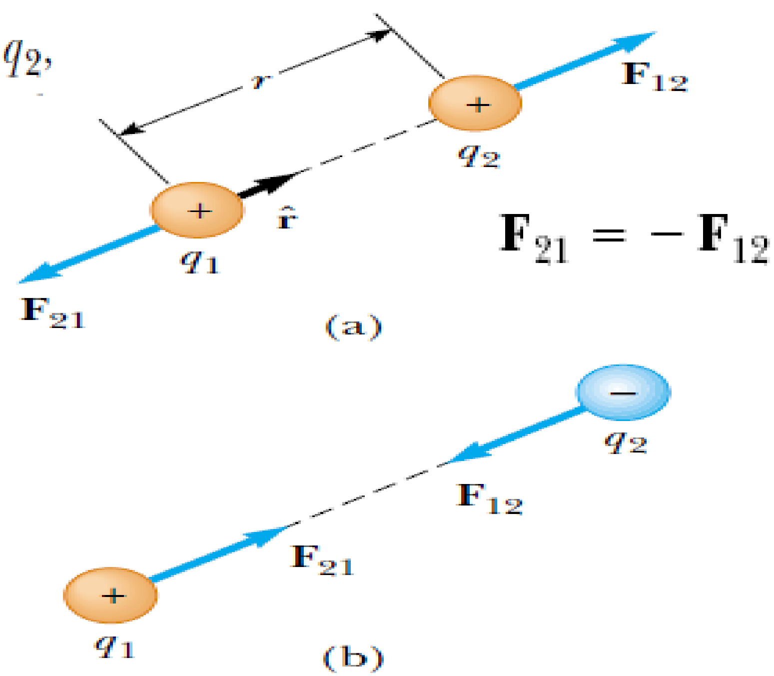
Coulomb’s Law in Vector Form

When dealing with Coulomb’s law, you must remember that force is a vector quantity and must be treated accordingly. The law expressed in vector form for the electric force exerted by a charge q_1 on a second charge q_2, written $\mathbf{F}_{12}$, is

$$\mathbf{F}_{12} = k_e \frac{q_1 q_2}{r^2}\,\hat{\mathbf{r}}$$

Vector form of Coulomb’s law

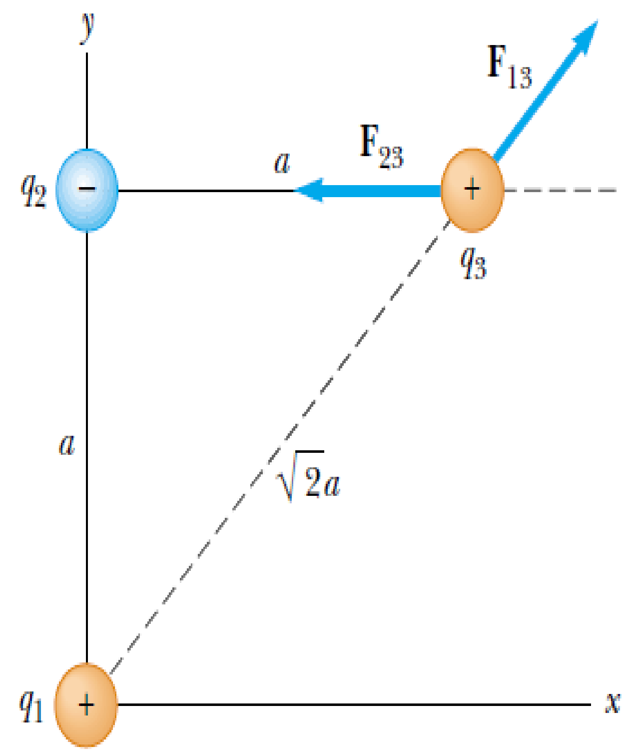
where $\hat{\mathbf{r}}$ is a unit vector directed from q_1 toward q_2,



- If charges are of same sign the product is positive.
- If charges of different signs, the product is negative.
- If the product is positive, charges repel.
- If the product is negative, charges attract.

Example: Find the resultant force

Consider three point charges located at the corners of a right triangle as shown in 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 q_3.



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

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

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

$$= 9.0\ \mathrm{N}$$

In the coordinate system shown in Figure 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

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

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

$$= 11\ \mathrm{N}$$

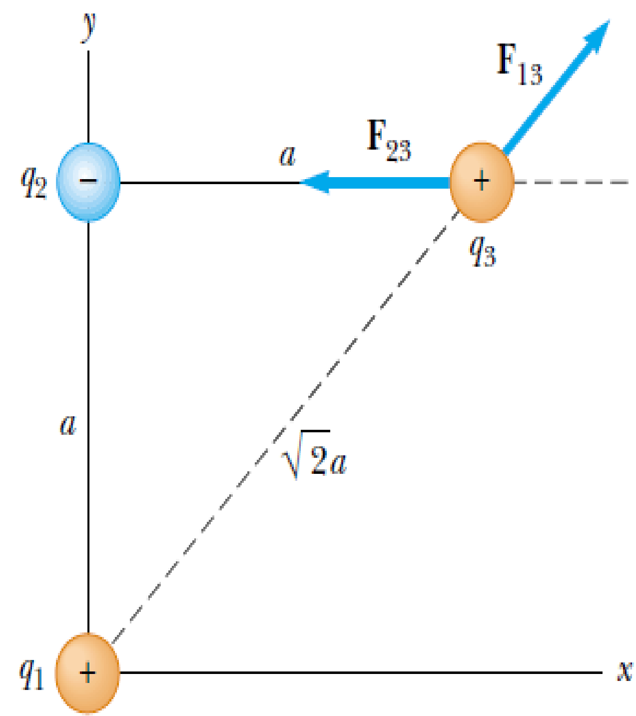
The repulsive force $\mathbf{F}_{13}$ makes an angle of 45° with the x axis. Therefore, the x and y components of $\mathbf{F}_{13}$ are equal, with magnitude given by $F_{13} \cos 45° = 7.9$ N.

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:

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

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

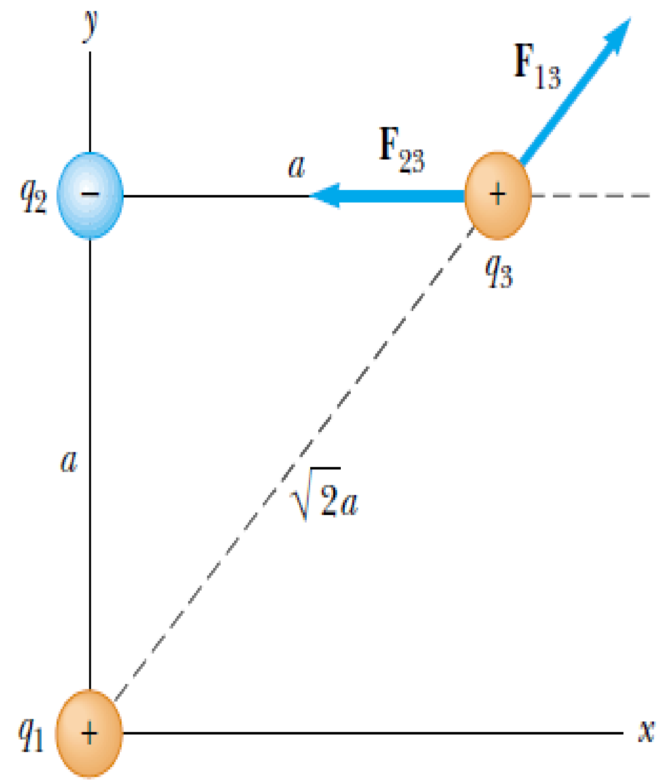
We can also express the resultant force acting on q_3 in unit-vector form as $\mathbf{F}_3 = (-1.1\hat{\mathbf{i}} + 7.9\hat{\mathbf{j}})$ N



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 $\mathbf{F}_{13} + \mathbf{F}_{23}$.

What If? What if the signs of all three charges were changed to the opposite signs? How would this affect the result for F_3?

Answer The charge q_3 would still be attracted toward q_2 and repelled from q_1 with forces of the same magnitude. Thus, the final result for $\mathbf{F}_3$ would be exactly the same.



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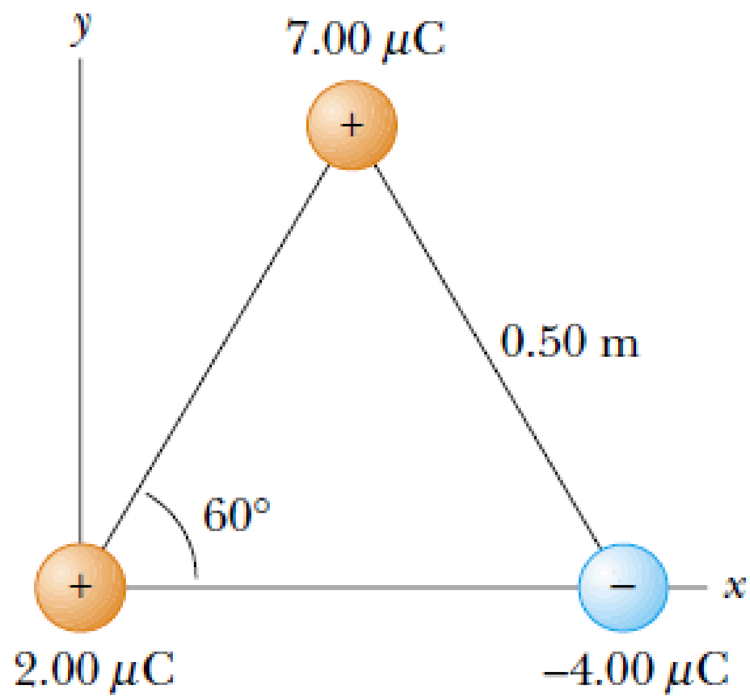
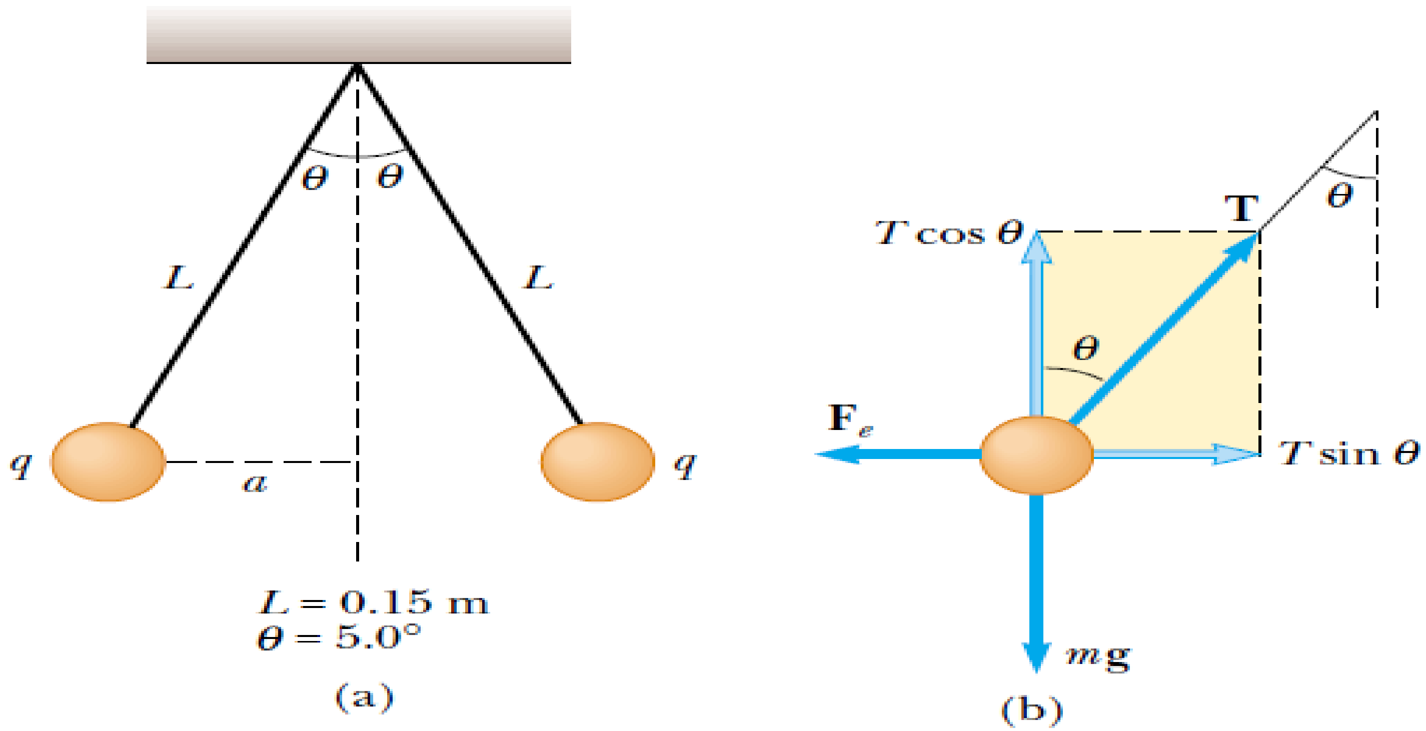
Home Work

Q.1 Three point charges are located at the corners of an equilateral triangle as shown in Figure below Calculate the resultant electric force on the 7.00-μC charge.



Example: Find the Charge on Spheres

Two identical small charged spheres, each having a mass of 3.0×10^{-2} kg, hang in equilibrium as shown in Figure (a) The length of each string is 0.15 m, and the angle θ is 5.0°. Find the magnitude of the charge on each sphere.



(a) Two identical spheres, each carrying the same charge q, suspended in equilibrium. (b) The free-body diagram for the sphere on the left.

Solution Figure a helps us conceptualize this problem—the two spheres exert repulsive forces on each other. If they are held close to each other and released, they will move outward from the center and settle into the configuration in Figure a after the damped oscillations due to air resistance have vanished. The key phrase "in equilibrium" helps us categorize this as an equilibrium problem, with the added feature that one of the forces on a sphere is an electric force.

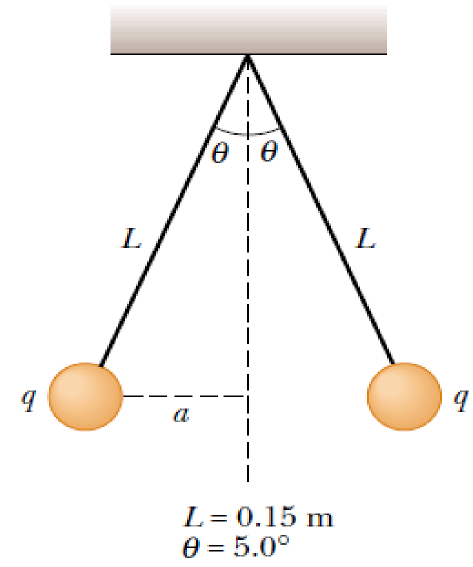
We analyze this problem by drawing the free-body diagram for the left-hand sphere in Figure b.

The sphere is in equilibrium under the application of the forces **T** from the string, the electric force $\mathbf{F}_e$ from the other sphere, and the gravitational force $m\mathbf{g}$.

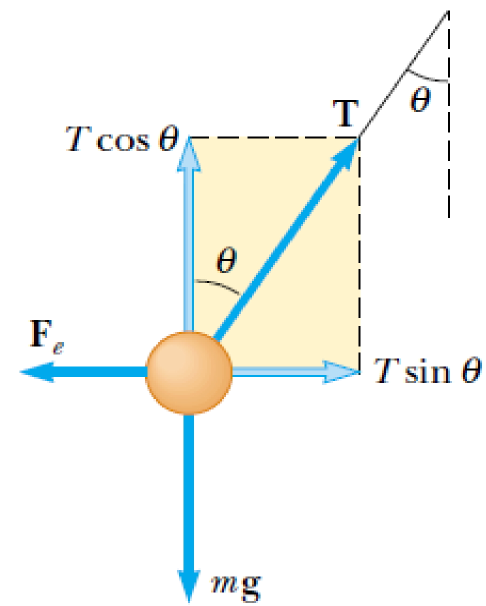
Because the sphere is in equilibrium, the forces in the horizontal and vertical directions must separately add up to zero:

$$(1) \qquad \sum F_x = T\sin\theta - F_e = 0$$

$$(2) \qquad \sum F_y = T\cos\theta - mg = 0$$



(a)



(b)

$$(2) \qquad \sum F_y = T\cos\theta - mg = 0$$

From Equation (2), we see that $T = mg/\cos\theta$; thus, T can be eliminated from Equation (1) if we make this substitution. This gives a value for the magnitude of the electric force F_e:

$$F_e = mg\tan\theta = (3.0\times10^{-2}\text{ kg})(9.80\text{ m/s}^2)\tan(5.0°)$$
$$= 2.6\times10^{-2}\text{ N}$$

Considering the geometry of the right triangle in Figure a, we see that $\sin\theta = a/L$. Therefore,

$$a = L\sin\theta = (0.15\text{ m})\sin(5.0°) = 0.013\text{ m}$$

The separation of the spheres is $2a = 0.026$ m.

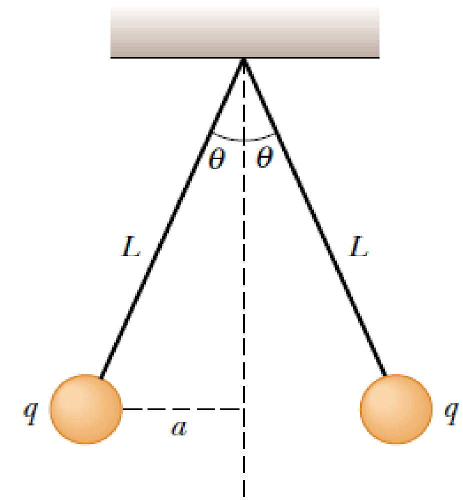
From Coulomb's law, the magnitude of the electric force is

$$F_e = k_e\frac{|q|^2}{r^2}$$

where $r = 2a = 0.026$ m

$$|q|^2 = \frac{F_e r^2}{k_e} = \frac{(2.6\times10^{-2}\text{ N})(0.026\text{ m})^2}{8.99\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2} = 1.96\times10^{-15}\text{ C}^2$$

$$|q| = \boxed{4.4\times10^{-8}\text{ C}}$$



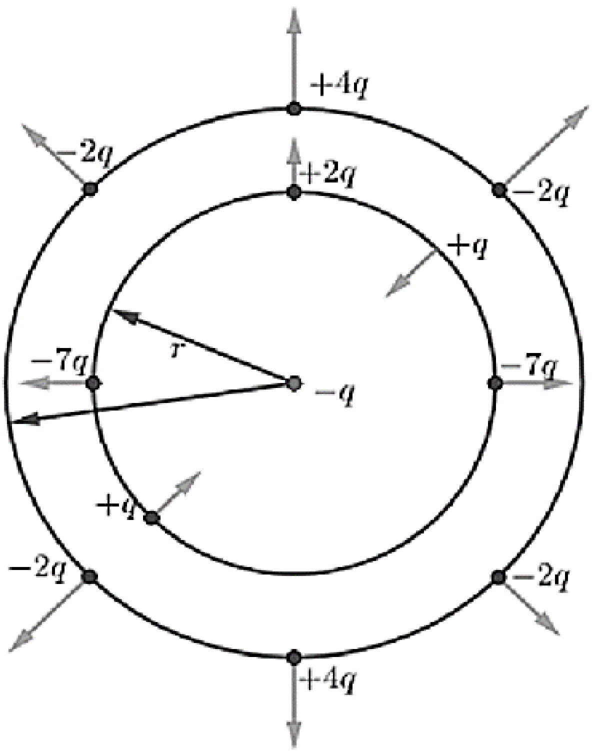
(a)

Home Work

Q 2. In the Bohr theory of the hydrogen atom, an electron moves in a circular orbit about a proton, where the radius of the orbit is 0.529×10^{-10} m. (a) Find the electric force between the two. (b) If this force causes the centripetal acceleration of the electron, what is the speed of the electron?

Brain Storming:

In Figure, shown, a central particle of charge *-q* is surrounded by two circular rings of charged particles. What are the magnitude and direction of the net electrostatic force on the central particle due to the other particles? (*Hint:* Consider symmetry.



From the picture, we can see that each force has the opposite direction but the same charge.

Each of these forces has an oppositely directed electrostatic force of the same intensity, and this means that we can shorten them.

So we have only one electrostatic force that comes from the charge $+2q$.

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{|q_1||q_2|}{r^2}$$

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{|2q||-q|}{r^2}$$

$$F = \boxed{2k \cdot \frac{q^2}{r^2}, \text{ directed upwards}} \qquad \left(k = \frac{1}{4\pi\varepsilon_0}\right)$$