PHYS 111

1ST semester 1446

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Lecture 2

Chapter 23: **Electric Fields**

23.1 Properties of Electric Charges

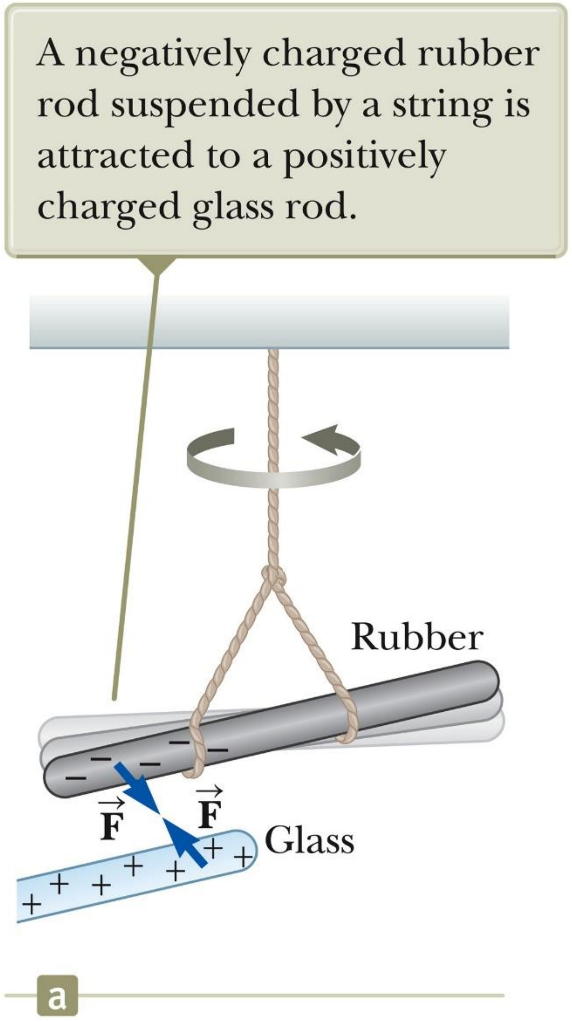
There are two kinds of electric charges: **positive** and **negative.** Charges of the **same** sign repel one another and charges with **opposite** signs attract one another.

Electric charge is always **conserved** in an isolated system.

The electric charge q is said to be **quantized.** That is, electric charge exists as discrete "packets," $q = Ne$, where N is some integer.

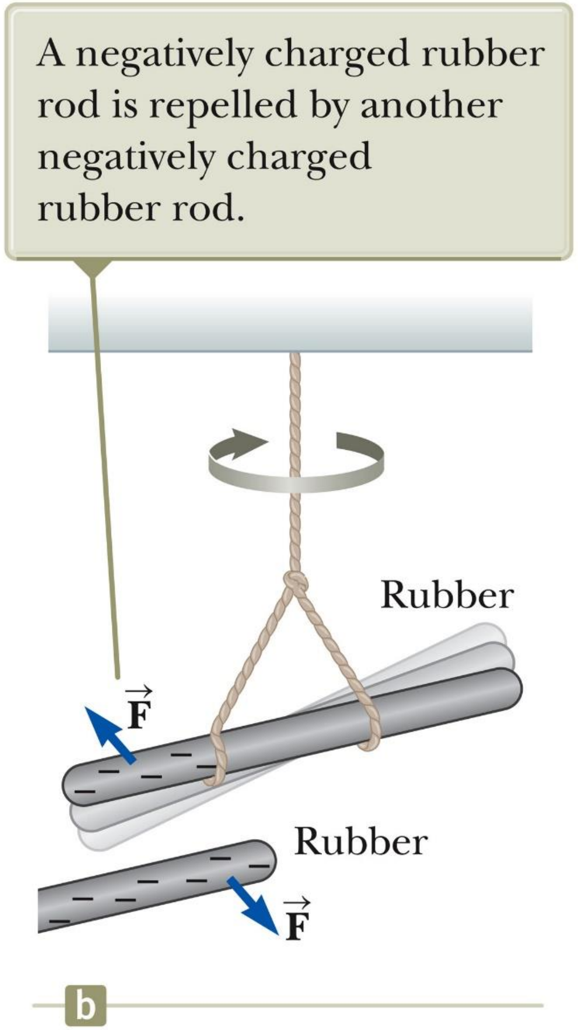
Electric Charges, 2

- The rubber rod is negatively charged.
- The glass rod is positively charged.
- The two rods will attract.



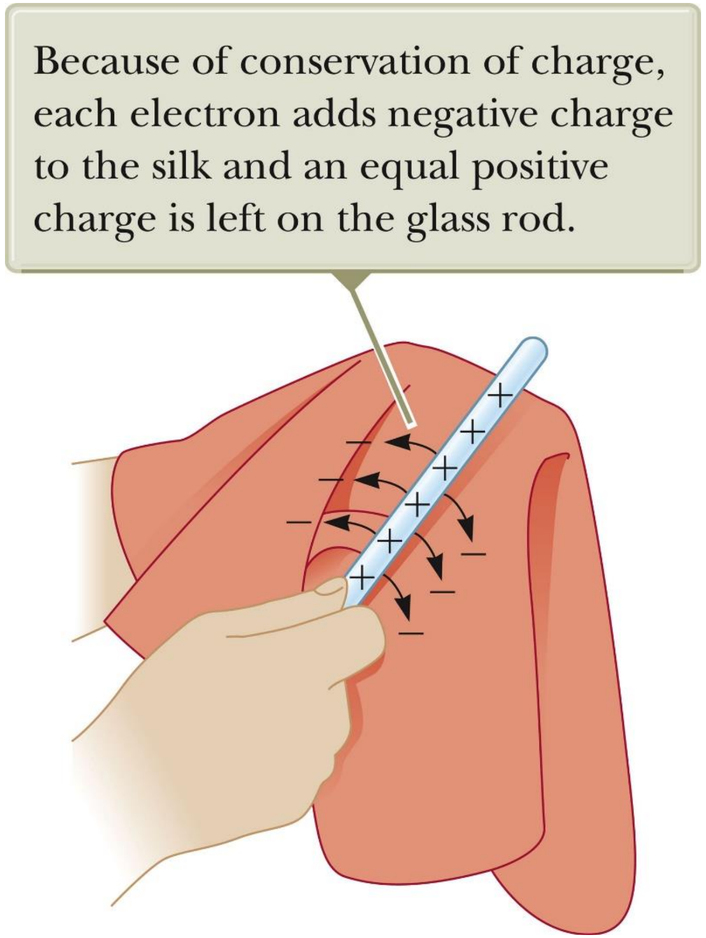
Electric Charges, 3

- The rubber rod is negatively charged.
- The second rubber rod is also negatively charged.
- The two rods will repel.



Conservation of Electric Charges

- A glass rod is rubbed with silk.
- Electrons are transferred from the glass to the silk.
- Each electron adds a negative charge to the silk.
- An equal positive charge is left on the rod.



Quantization of Electric Charges

- The electric charge, q, is said to be quantized.
  - q is the standard symbol used for charge as a variable.
  - Electric charge exists as discrete packets.
  - $q = \pm Ne$
    - N is an integer
    - e is the fundamental unit of charge
    - $|e| = 1.6 \times 10^{-19}$ C
    - Electron: $q = -e$
    - Proton: $q = +e$

Conductors

- Electrical conductors are materials in which some of the electrons are free electrons.
  - Free electrons are not bound to the atoms.
  - These electrons can move relatively freely through the material.
  - Examples of good conductors include copper, aluminum and silver.
  - When a good conductor is charged in a small region, the charge readily distributes itself over the entire surface of the material.

Insulators

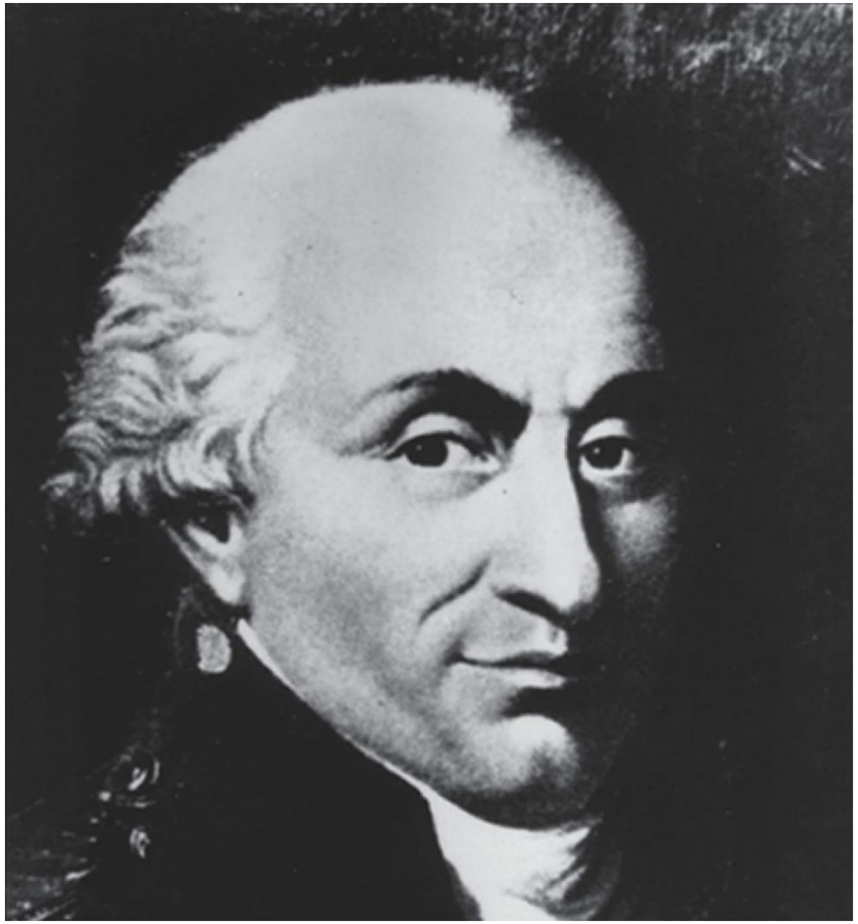
- Electrical insulators are materials in which all of the electrons are bound to atoms.
  - These electrons can not move relatively freely through the material.
  - Examples of good insulators include glass, rubber and wood.
  - When a good insulator is charged in a small region, the charge is unable to move to other regions of the material.

Semiconductors

- The electrical properties of semiconductors are somewhere between those of insulators and conductors.
- Examples of semiconductor materials include silicon and germanium.
  - Semiconductors made from these materials are commonly used in making electronic chips.
- The electrical properties of semiconductors can be changed by the addition of controlled amounts of certain atoms to the material.

Charles Coulomb

- 1736 – 1806
- French physicist
- Major contributions were in areas of electrostatics and magnetism
- Also investigated in areas of
  - Strengths of materials
  - Structural mechanics
  - Ergonomics



23.3 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;
- Proportional to the product of the charges $q1$ and $q2$ on the two particles;

- **Attractive** if the charges are of opposite sign
- **Repulsive** if the charges have the same sign; is a conservative force.

Coulomb's Law, Equation

- Mathematically,

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

- The SI unit of charge is the **coulomb** ©.
- k_e is called the **Coulomb constant.**
  - k_e = 8.9876 x 10^9 N·m^2/C^2 = $1/(4\pi\varepsilon_o)$
  - ε_o is the **permittivity of free space.**
  - ε_o = 8.8542 x 10^{-12} C^2 / N·m^2

Particle Summary

TABLE 23.1 *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	$1.674\,93 \times 10^{-27}$

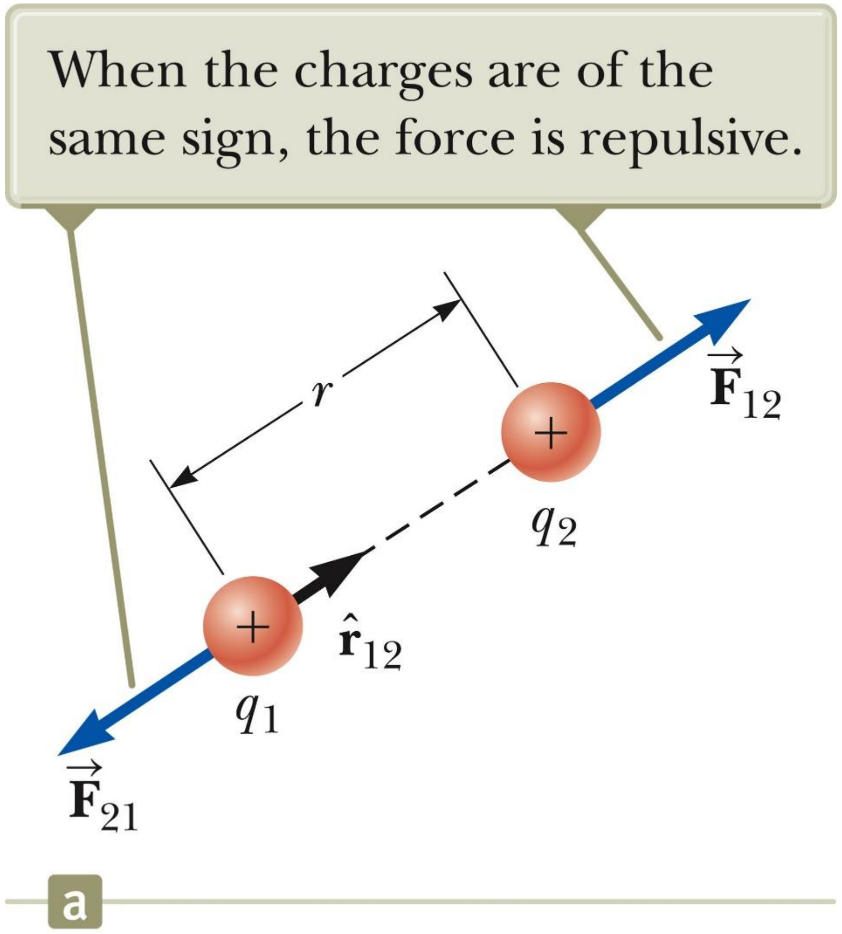
- The electron and proton are identical in the magnitude of their charge, but very different in mass.
- The proton and the neutron are similar in mass, but very different in charge.

Vector Nature of Electric Forces

- In vector form,

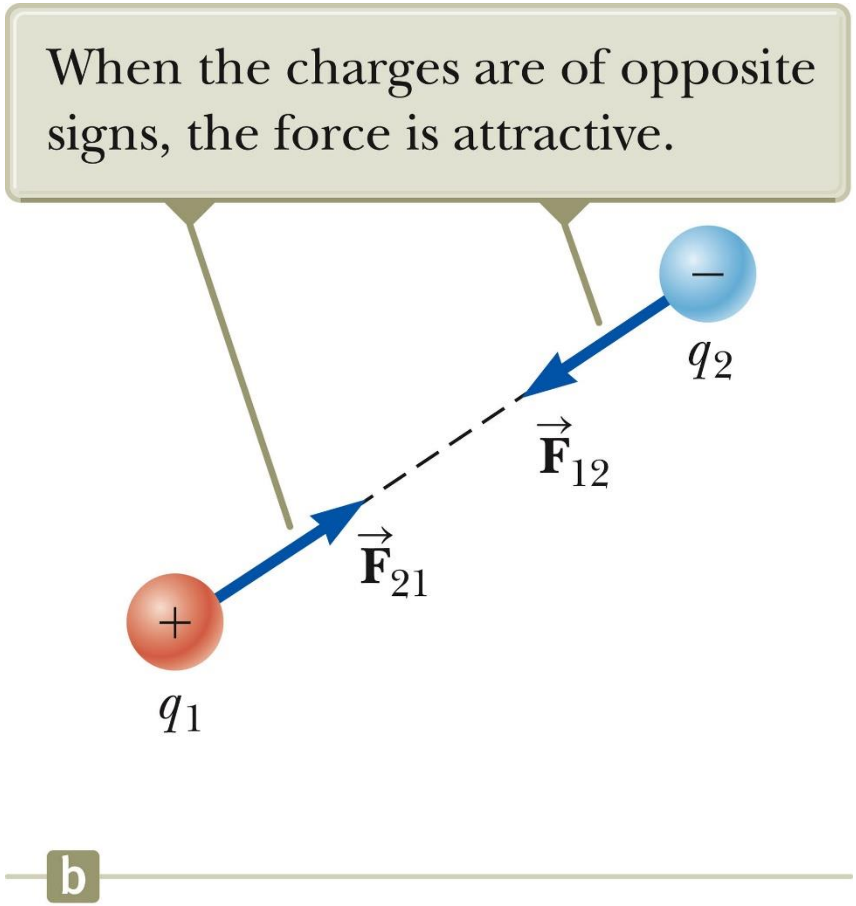
$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$

- $\hat{\mathbf{r}}_{12}$ is a unit vector directed from q_1 to q_2.
- The like charges produce a repulsive force between them.



Vector Nature of Electrical Forces, 3

- Two point charges are separated by a distance *r*.
- The unlike charges produce an attractive force between them.
- With unlike signs for the charges, the product $q_1 q_2$ is negative and the force is attractive.



Ex1. The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately 5.3 x 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

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

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

gravitational force is

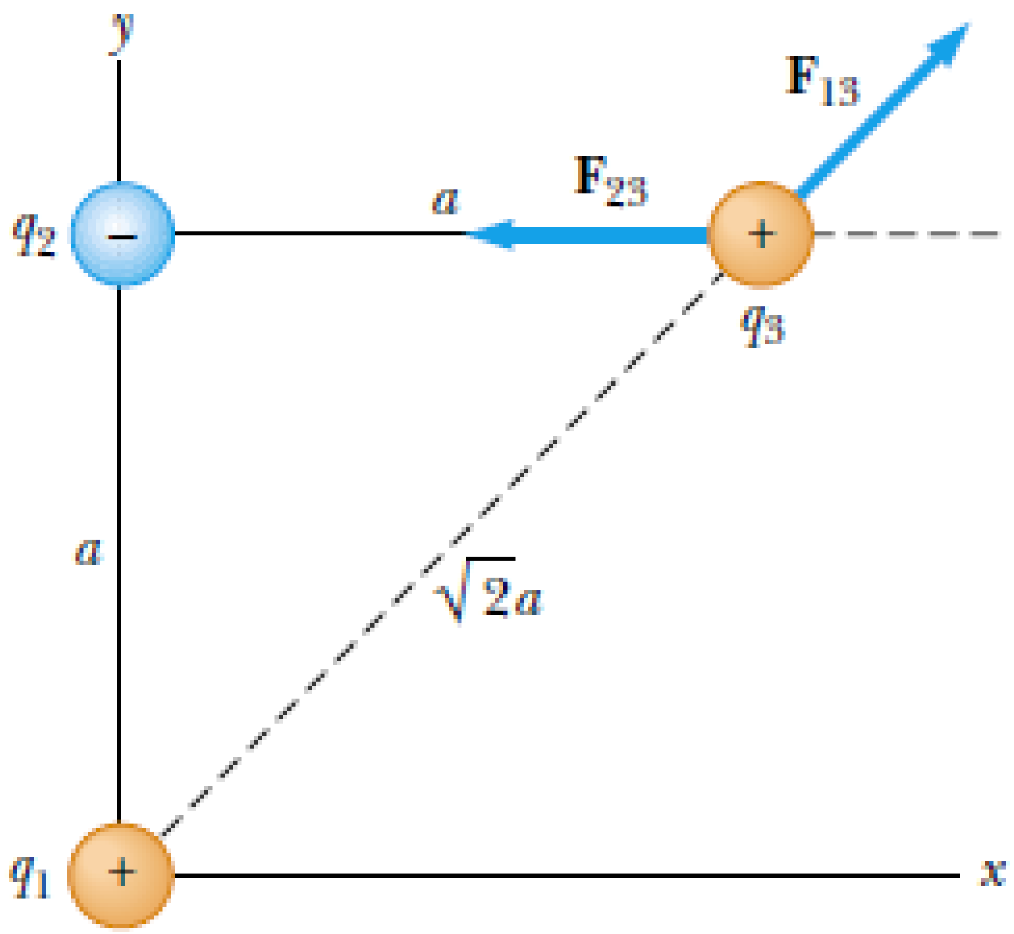
$$F_g = G\frac{m_e m_p}{r^2}$$

$$= (6.67 \times 10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2) \times \frac{(9.11 \times 10^{-31}\text{ kg})(1.67 \times 10^{-27}\text{ kg})}{(5.3 \times 10^{-11}\text{ m})^2}$$

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

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?

Ex.2 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 = 0.10 m. Find the resultant force exerted on q3.



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

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

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

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

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

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

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

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

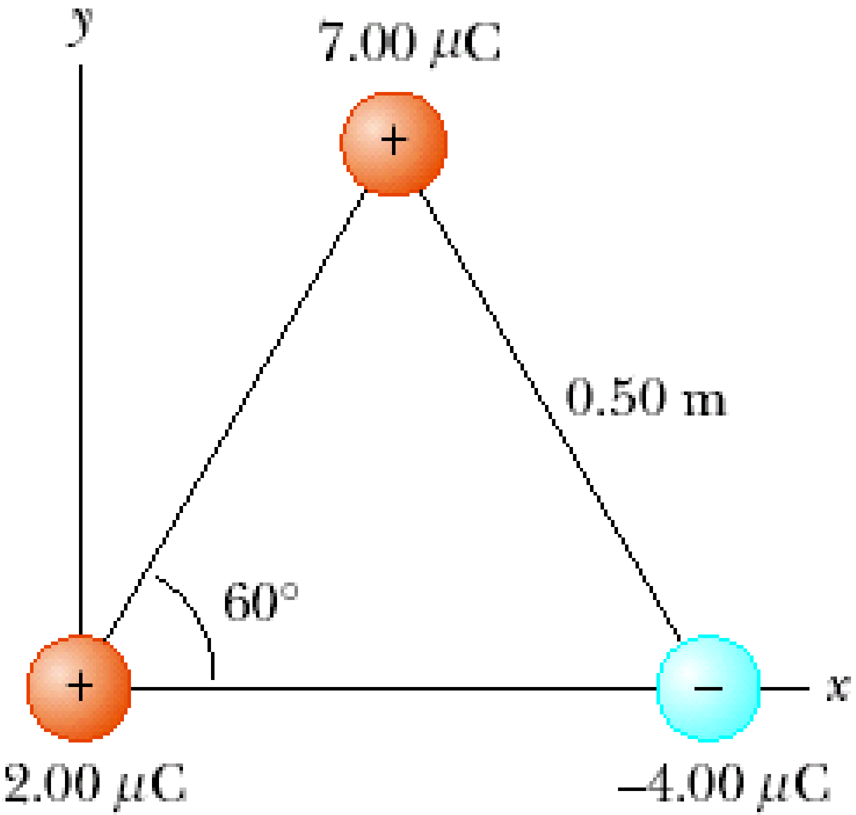
$$F_{3x} = F_{13x} + F_{23x} = 7.9 \text{ N} + (-9.0 \text{ N}) = -1.1 \text{ N}$$

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

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

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

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



$$F_1 = k_e \frac{q_1 q_2}{r^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(7.00\times10^{-6}\ \text{C}\right)\left(2.00\times10^{-6}\ \text{C}\right)}{(0.500\ \text{m})^2} = 0.503\ \text{N}$$

$$F_2 = k_e \frac{q_1 q_2}{r^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(7.00\times10^{-6}\ \text{C}\right)\left(4.00\times10^{-6}\ \text{C}\right)}{(0.500\ \text{m})^2} = 1.01\ \text{N}$$

$$F_x = 0.503\cos 60.0^\circ + 1.01\cos 60.0^\circ = 0.755\ \text{N}$$

$$F_y = 0.503\sin 60.0^\circ - 1.01\sin 60.0^\circ = -0.436\ \text{N}$$

$$\mathbf{F} = (0.755\ \text{N})\hat{\mathbf{i}} - (0.436\ \text{N})\hat{\mathbf{j}} = \boxed{0.872\ \text{N at an angle of } 330^\circ}$$