# Chapter 21

# Electric Charge and Electric Field

PowerPoint® Lectures for

***University Physics, 14th Edition, Global Edition***
***– Hugh D. Young and Roger A. Freedman***

**Lectures by Jason Harlow**

# Learning Goals for Lecture 1

***Looking forward at …***

- how objects become electrically charged, and how we know that electric charge is conserved.
- how to use Coulomb's law to calculate the electric force between charges.

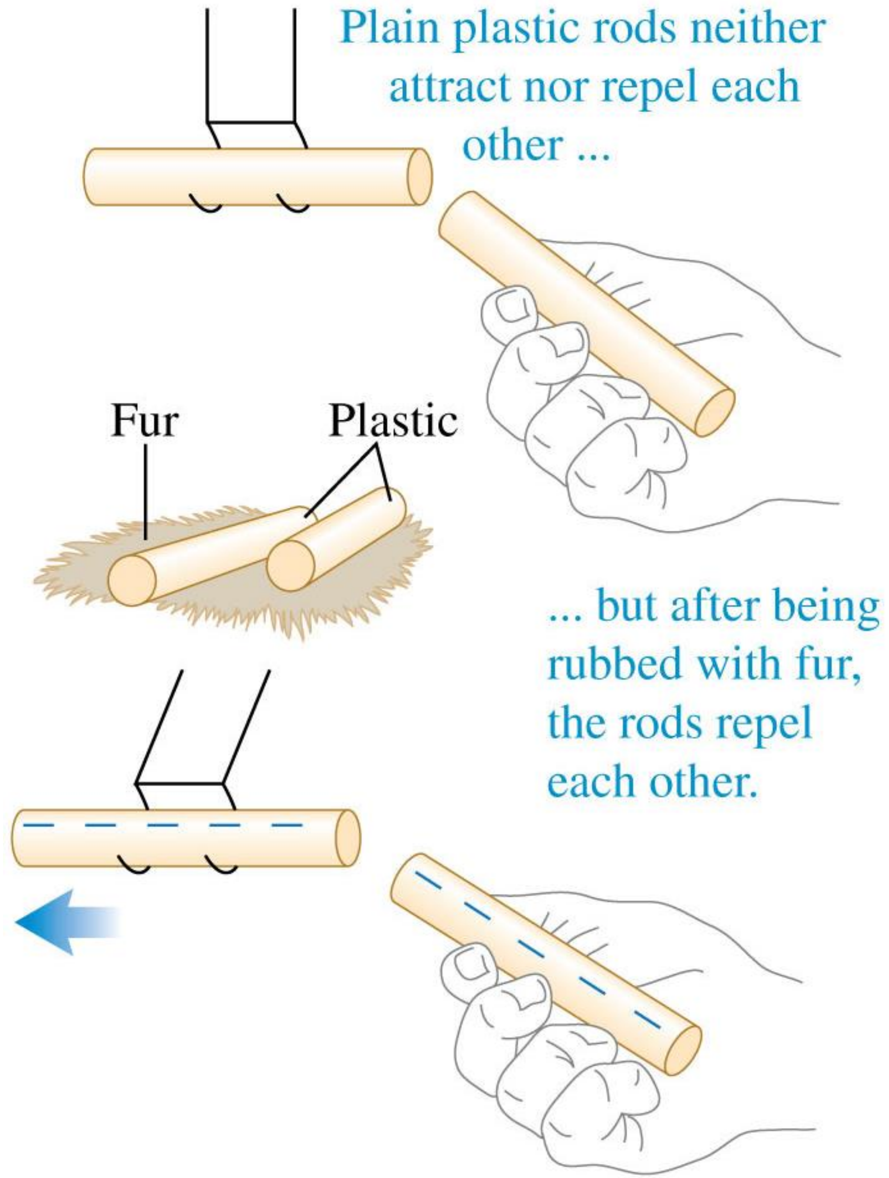
# Introduction

- Water makes life possible: The cells of your body could not function without water in which to dissolve essential biological molecules.

- What electrical properties of the water molecule allow it to be such a good solvent?
- We now begin our study of *electromagnetism*, one of the four fundamental forces.
- We start with electric charge and look at electric fields.

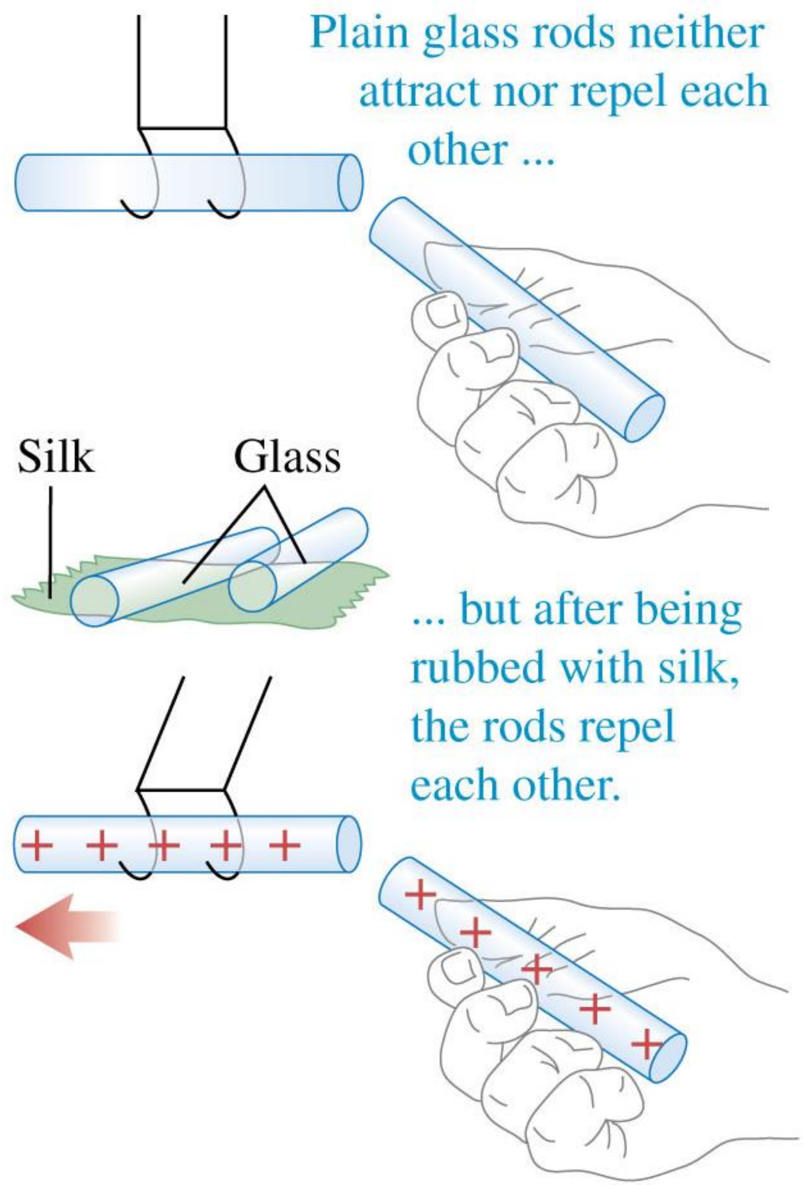
# Electric charge

- Plastic rods and fur (real or fake) are particularly good for demonstrating **electrostatics**, the interactions between electric charges that are at rest (or nearly so).
- After we charge both plastic rods by rubbing them with the piece of fur, we find that the rods *repel* each other.



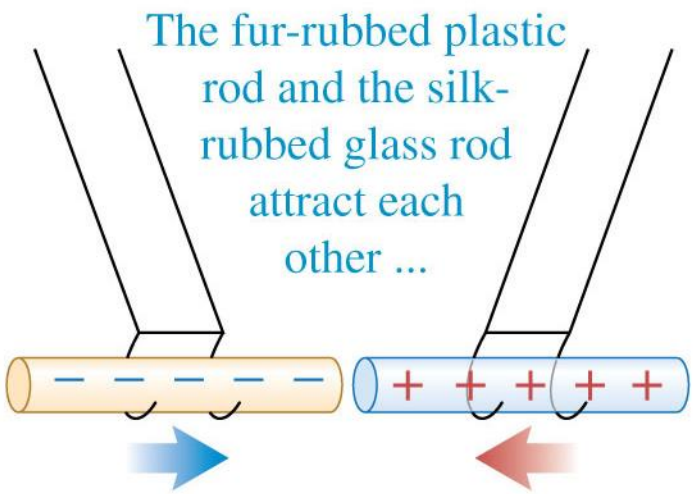
# Electric charge

- When we rub glass rods with silk, the glass rods also become charged and repel each other.

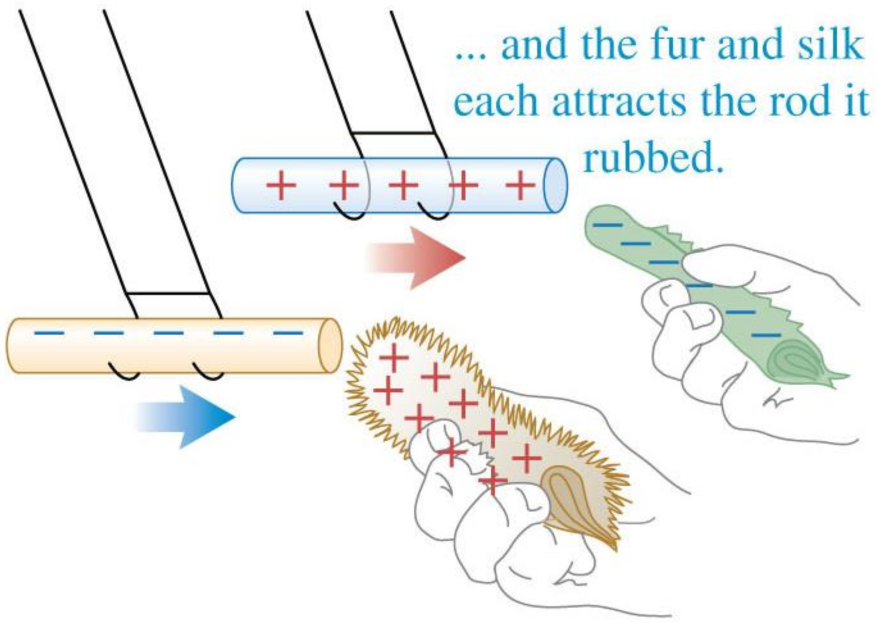


# Electric charge

- A charged plastic rod *attracts* a charged glass rod; furthermore, the plastic rod and the fur *attract* each other, and the glass rod and the silk *attract* each other.

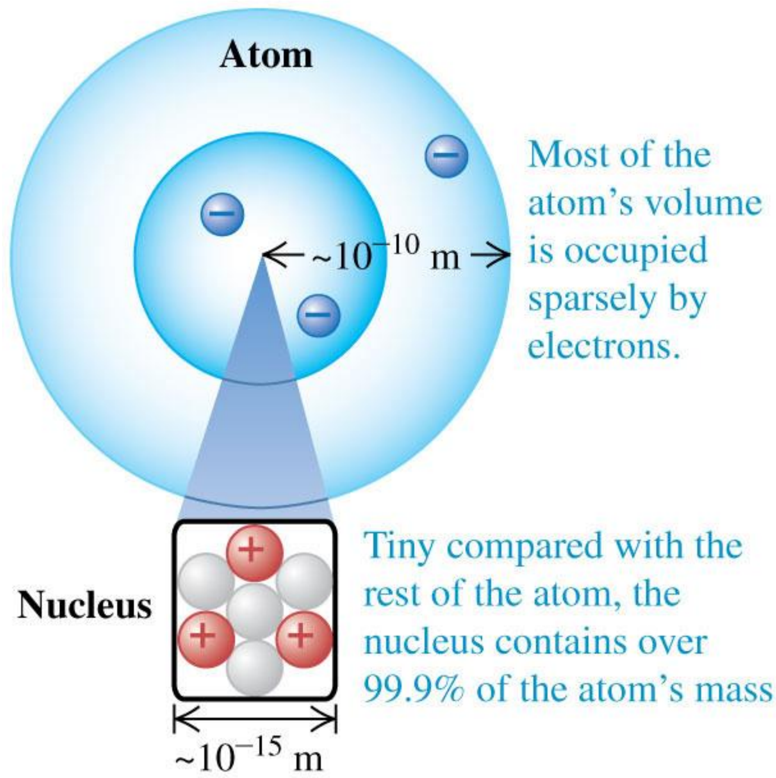



- These experiments and many others like them have shown that there are exactly two kinds of electric charge: The kind on the plastic rod rubbed with fur (*negative*) and the kind on the glass rod rubbed with silk (*positive*).



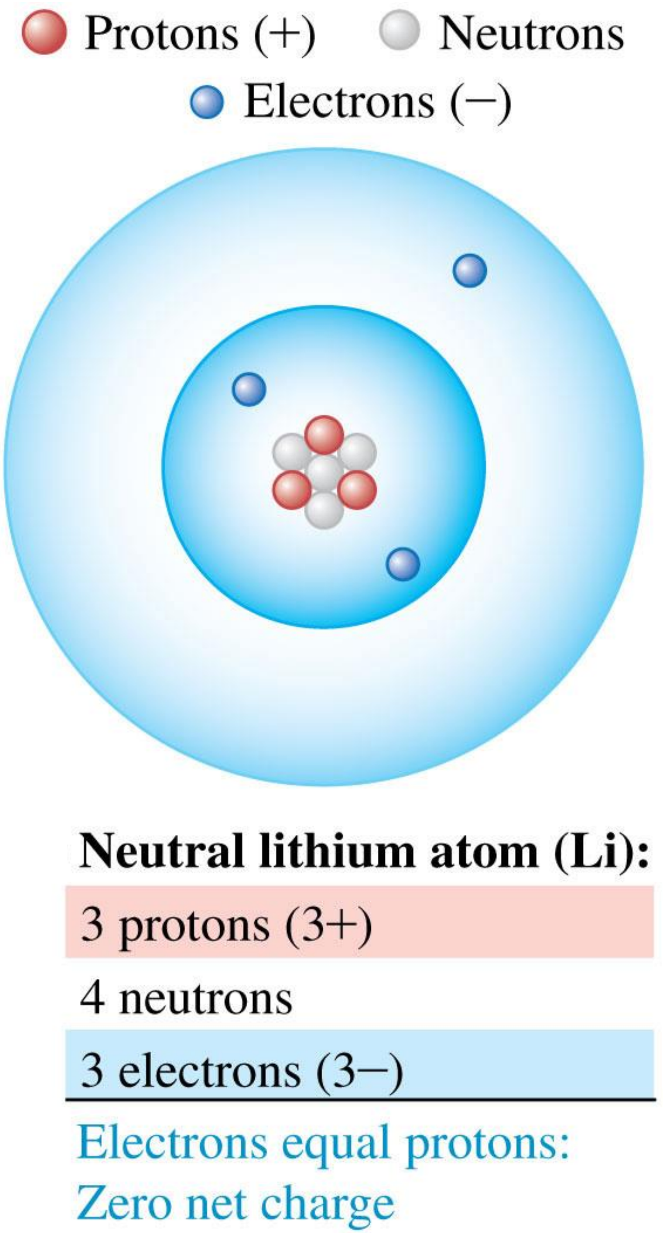
# Electric charge and the structure of matter

- The particles of the atom are the negative *electrons* (dark blue spheres in this figure), the positive *protons* (red spheres), and the uncharged *neutrons* (gray spheres).
- Protons and neutrons make up the tiny dense nucleus, which is surrounded by electrons.



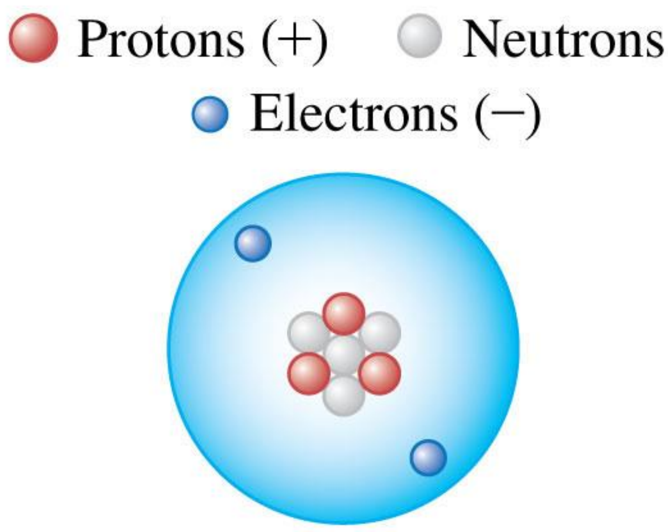
# Atoms and ions

- A neutral atom has the same number of protons as electrons.
- The electron "shells" are a schematic representation of the actual electron distribution, a diffuse cloud many times larger than the nucleus.



# Atoms and ions

- A *positive ion* is an atom with one or more electrons removed.




**Positive lithium ion ($Li^{+}$):**

3 protons (3+)

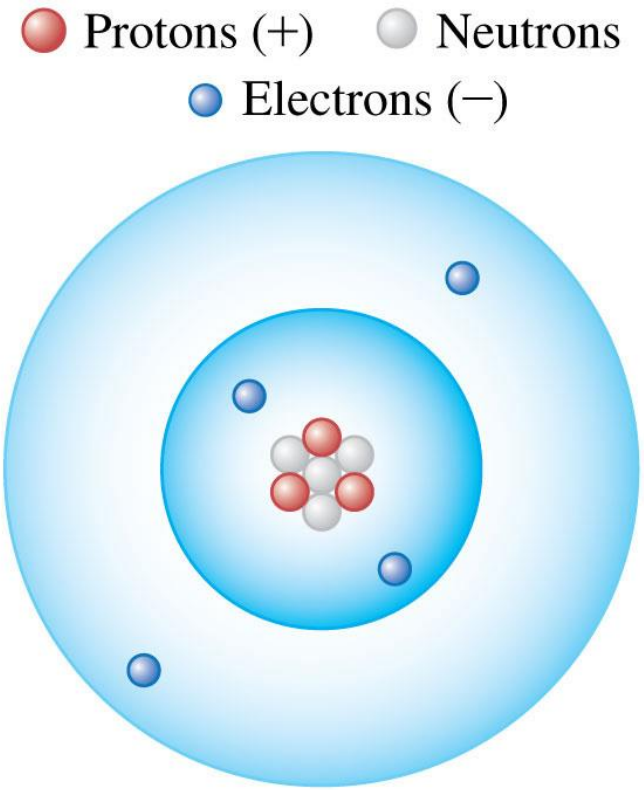
4 neutrons

2 electrons (2−)

Fewer electrons than protons:
Positive net charge

# Atoms and ions

- A *negative ion* is an atom with an excess of electrons.




**Negative lithium ion ($Li^-$):**

3 protons (3+)

4 neutrons

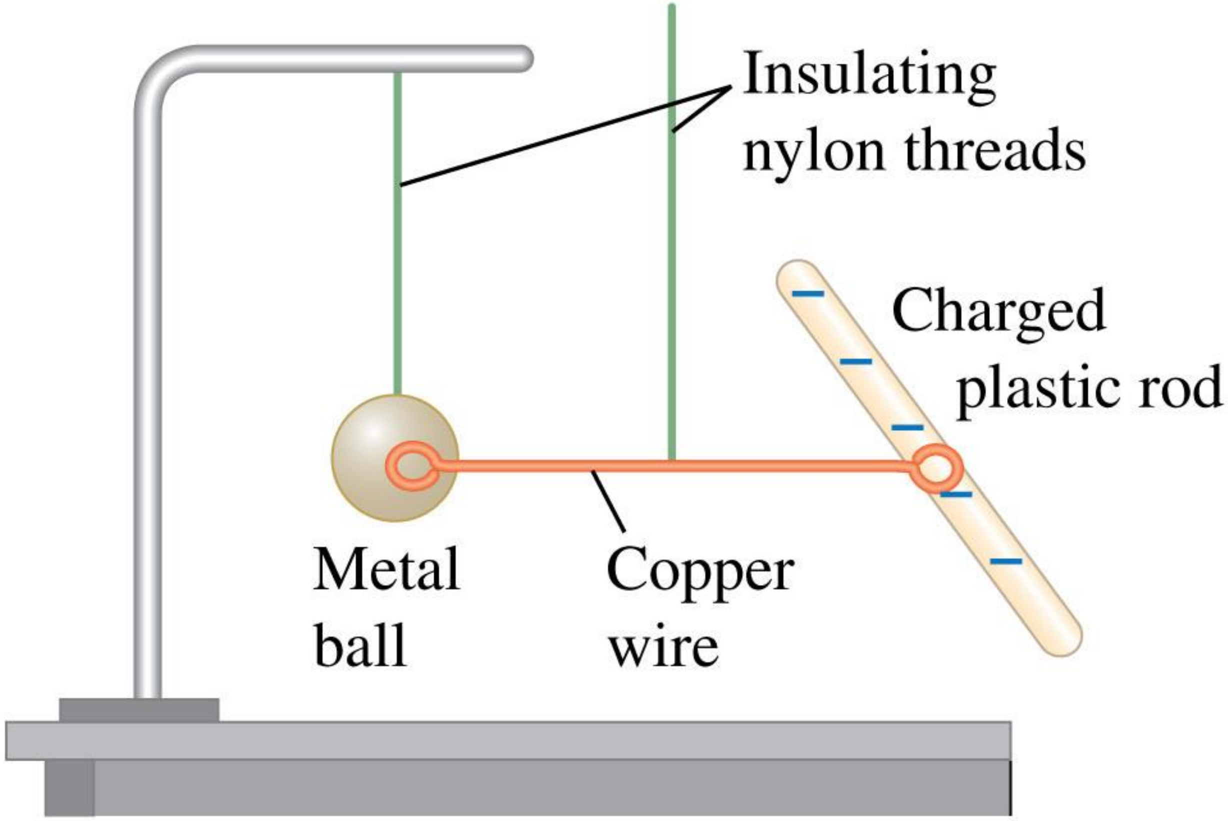
4 electrons (4−)

More electrons than protons: Negative net charge

# Conservation of charge

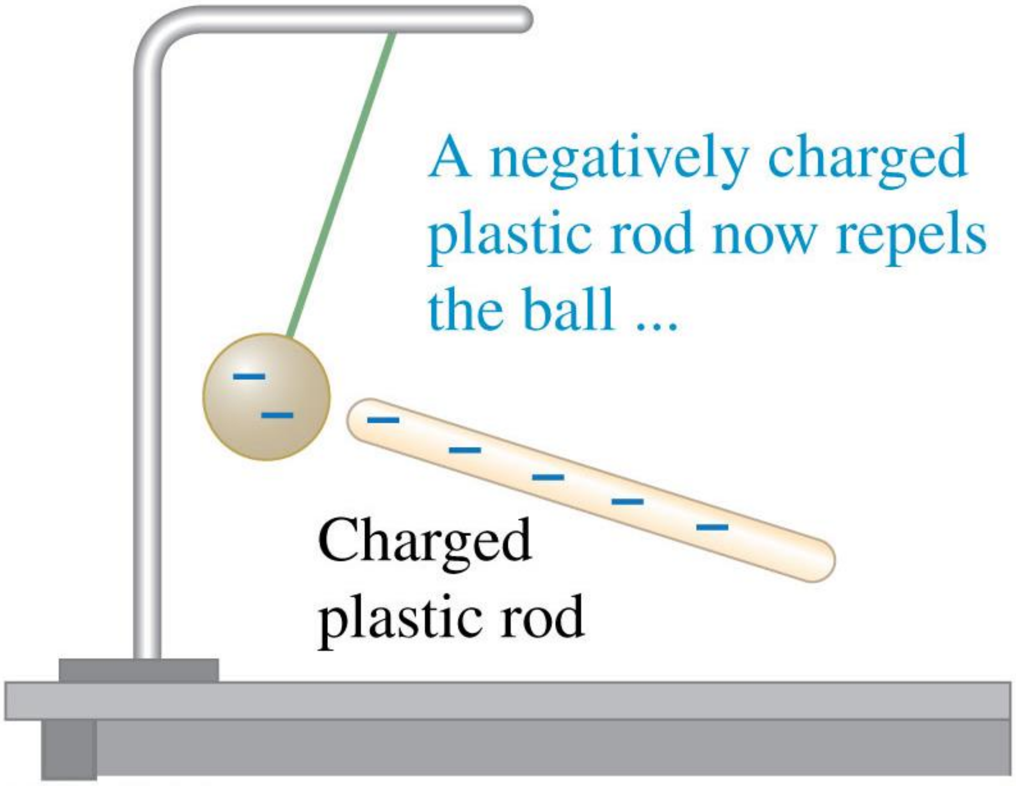
- The proton and electron have the same magnitude charge.
- The magnitude of charge of the electron or proton is a natural unit of charge. All observable charge is *quantized* in this unit.
- The universal **principle of charge conservation** states that the algebraic sum of all the electric charges in any closed system is constant.

# Conductors and insulators



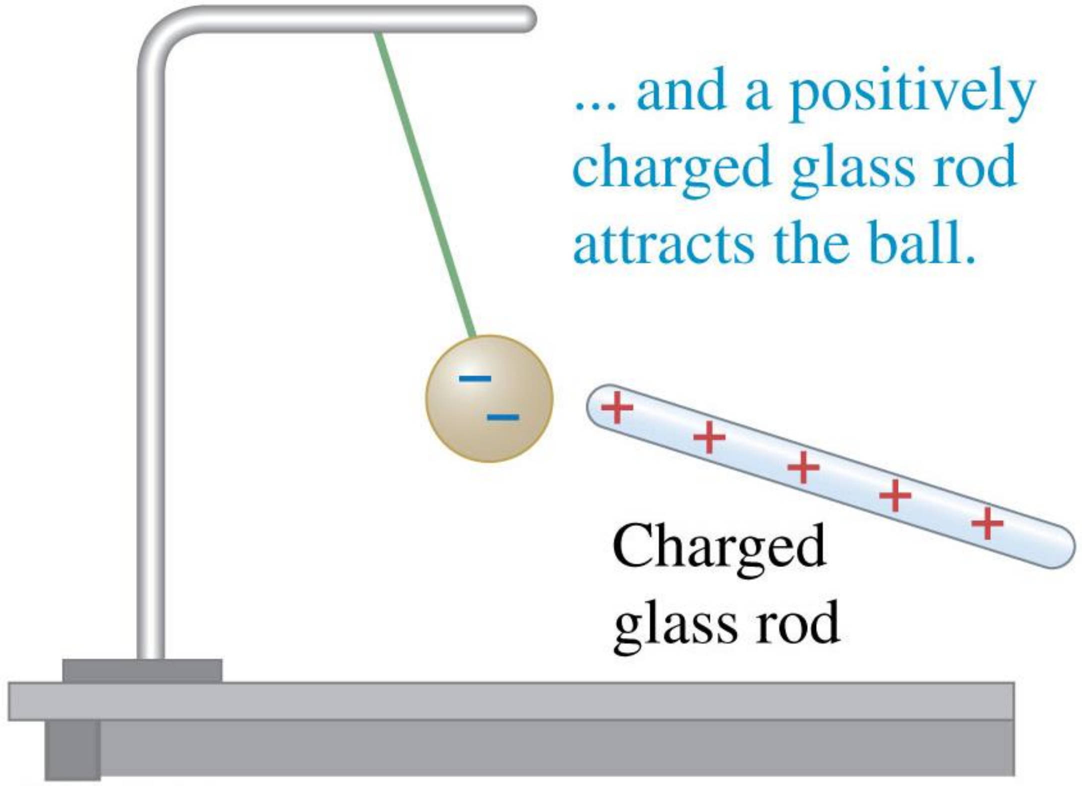

- Copper is a good conductor of electricity; nylon is a good insulator. The copper wire shown conducts charge between the metal ball and the charged plastic rod to charge the ball negatively.

# Conductors and insulators




- After it is negatively charged, the metal ball is repelled by a negatively charged plastic rod.

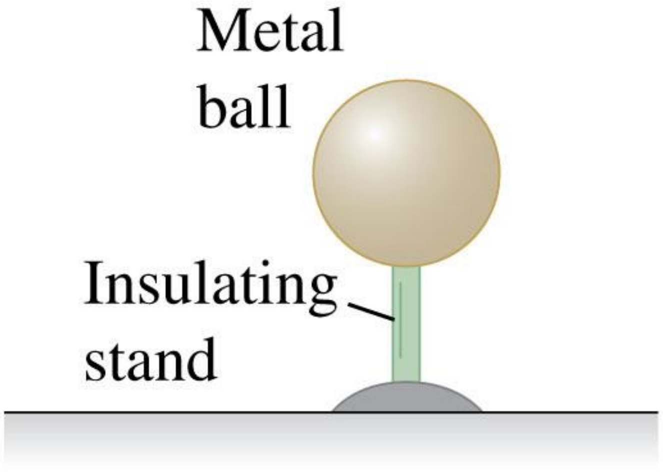
# Conductors and insulators



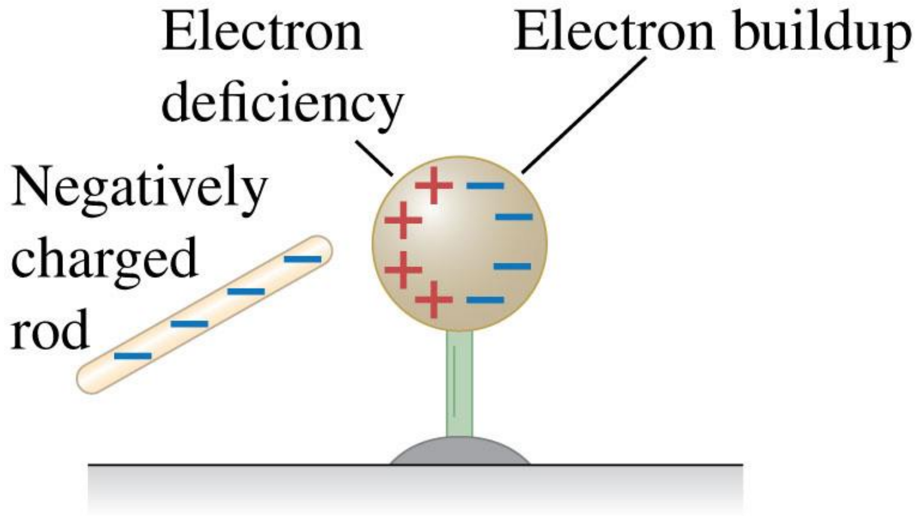

- After it is negatively charged, the metal ball is attracted by a positively charged glass rod.

# Charging by induction in 4 steps: Steps 1 and 2

1. Start with an uncharged metal ball supported by an insulating stand.

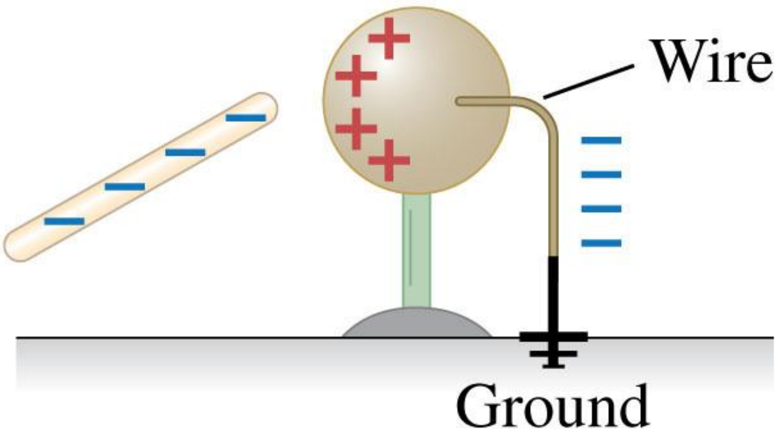



2. When you bring a negatively charged rod near it, without actually touching it, the free electrons in the metal ball are repelled by the excess electrons on the rod, and they shift toward the right, away from the rod.

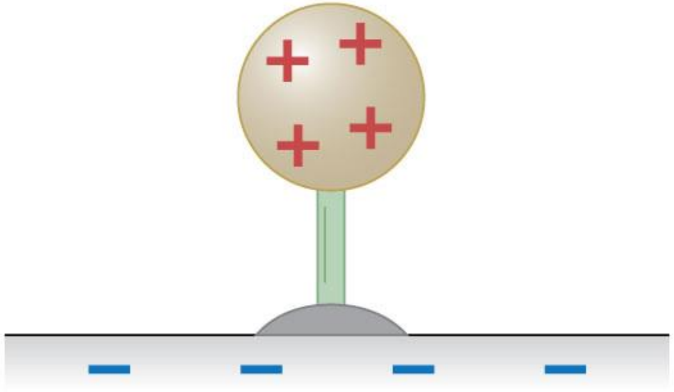


# Charging by induction in 4 steps: Steps 3 and 4

3. While the plastic rod is nearby, you touch one end of a conducting wire to the right surface of the ball and the other end to the ground.




4. Now disconnect the wire, and then remove the rod. A net positive charge is left on the ball. The earth acquires a negative charge that is equal in magnitude to the induced positive charge remaining on the ball.

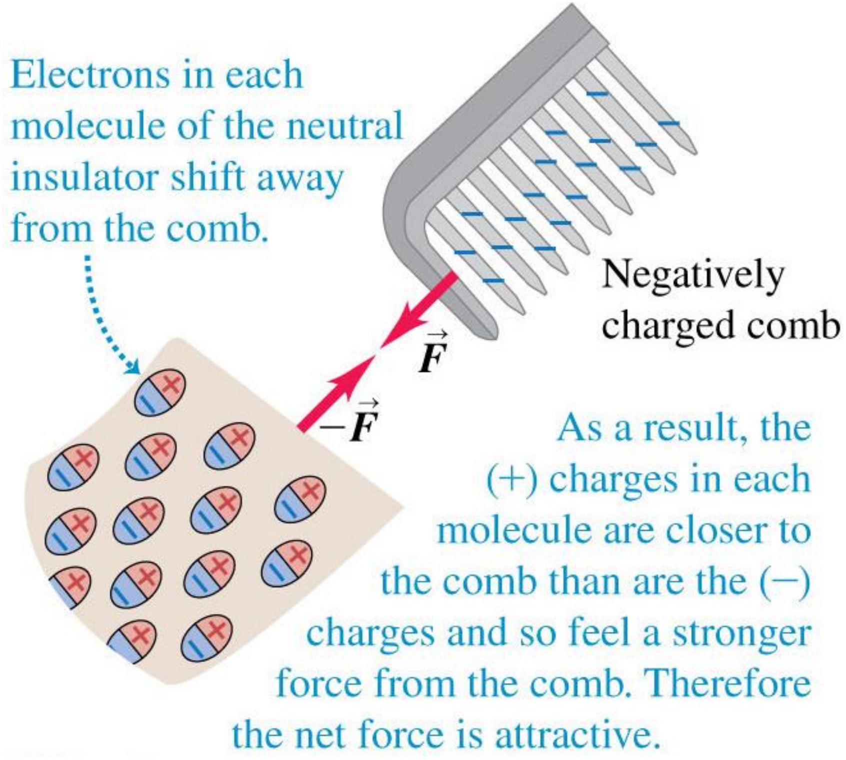


# Electric forces on uncharged objects

- A charged body can exert forces even on objects that are not charged themselves.
- If you rub a balloon on the rug and then hold the balloon against the ceiling, it sticks, even though the ceiling has no net electric charge.
- After you electrify a comb by running it through your hair, you can pick up uncharged bits of paper or plastic with it.
- How is this possible?

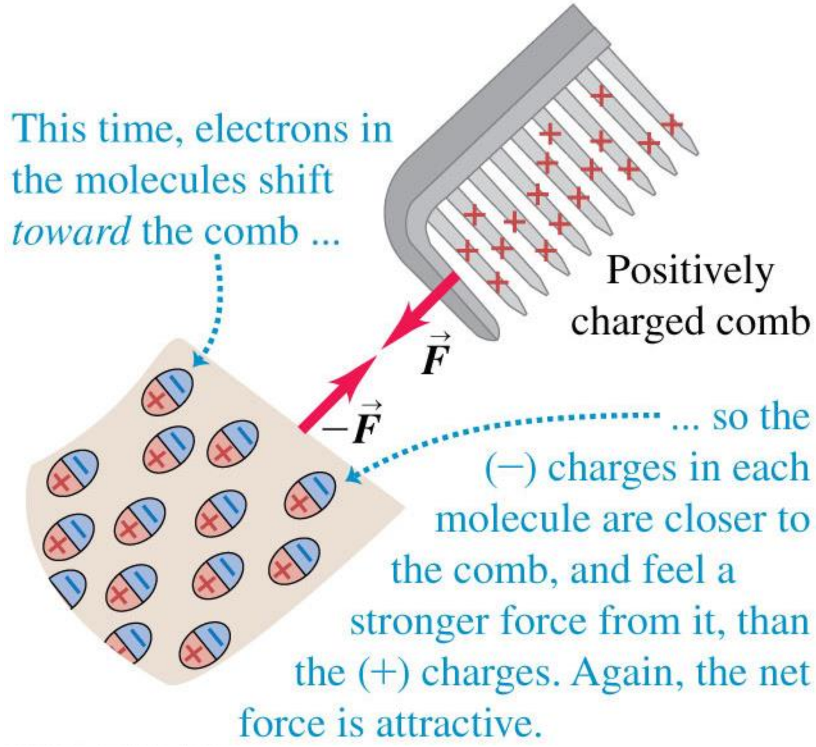
# Electric forces on uncharged objects

- The negatively charged plastic comb causes a slight shifting of charge within the molecules of the neutral insulator, an effect called **polarization**.



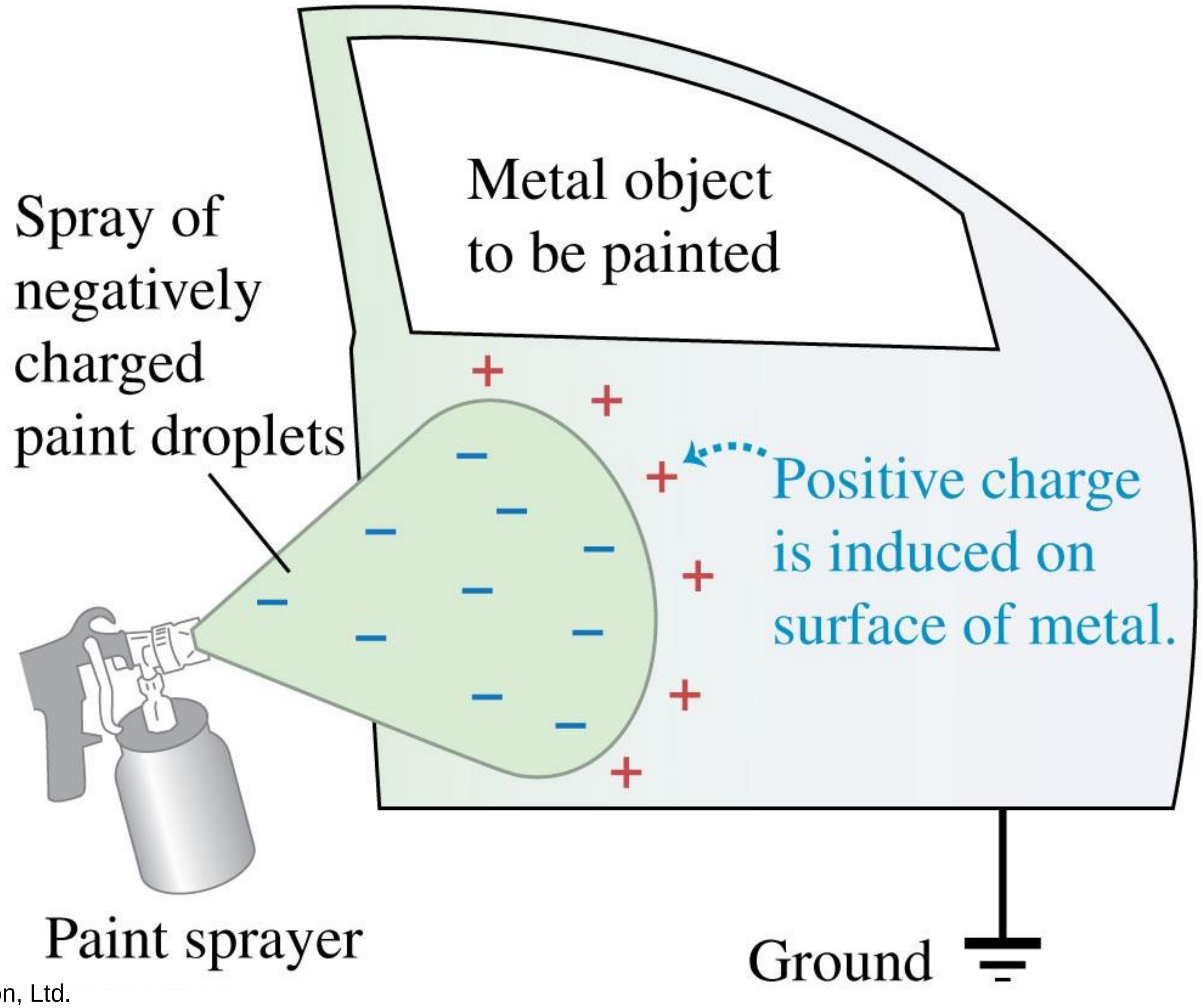
# Electric forces on uncharged objects

- Note that a neutral insulator is also attracted to a *positively* charged comb.
- A charged object of *either* sign exerts an *attractive* force on an uncharged insulator.



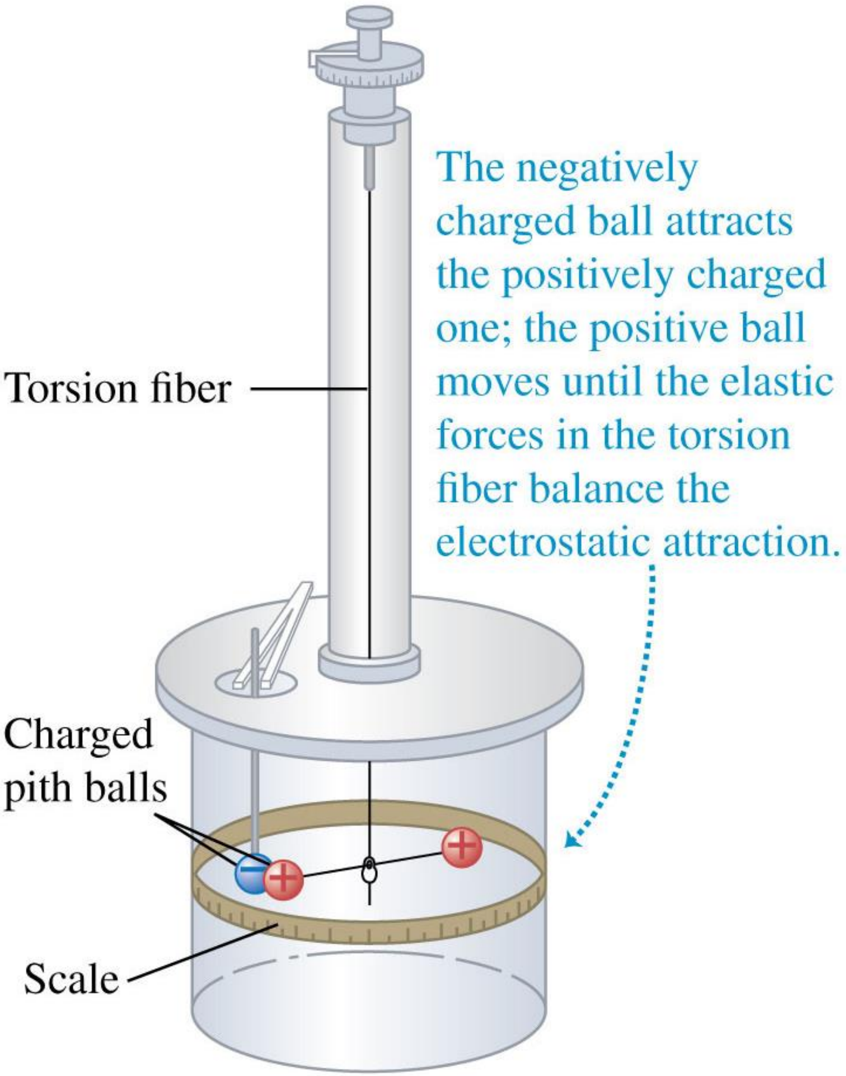
# Electrostatic painting

- Induced positive charge on the metal object attracts the negatively charged paint droplets.



# Measuring the electric force between point charges

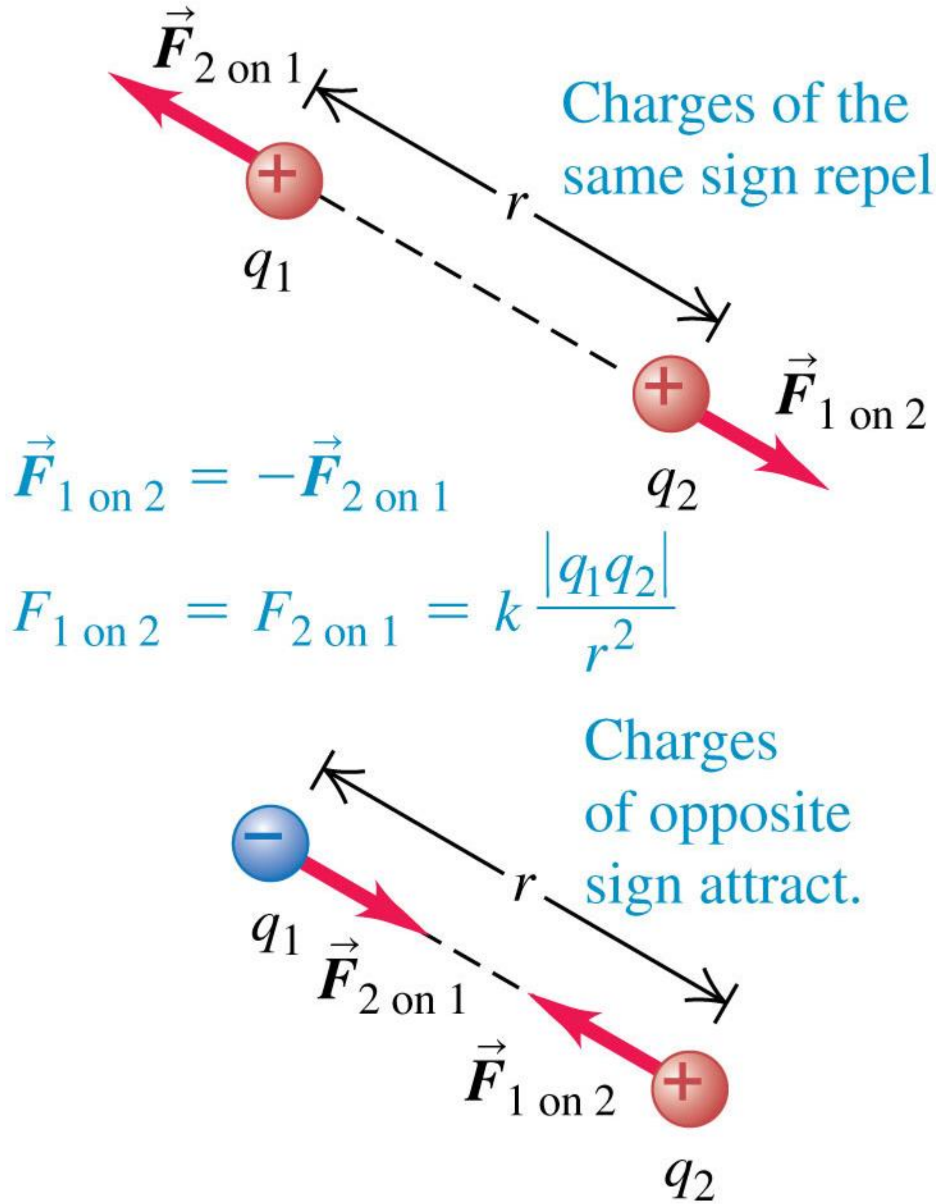
- Coulomb studied the interaction forces of charged particles in detail in 1784.
- He used a torsion balance similar to the one used 13 years later by Cavendish to study the much weaker gravitational interaction.
- For point charges, Coulomb found that the magnitude of the electric force is inversely proportional to the square of the distance between the charges.



# Coulomb's Law

- **Coulomb's Law**: The magnitude of the electric force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

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



## EXAMPLE 21.2 FORCE BETWEEN TWO POINT CHARGES

SOLUTION

Two point charges, $q_1 = +25\text{ nC}$ and $q_2 = -75\text{ nC}$, are separated by a distance $r = 3.0\text{ cm}$ (**Fig. 21.12a**). Find the magnitude and direction of the electric force (a) that $q_1$ exerts on $q_2$ and (b) that $q_2$ exerts on $q_1$.

$$F_{1\text{ on }2} = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$

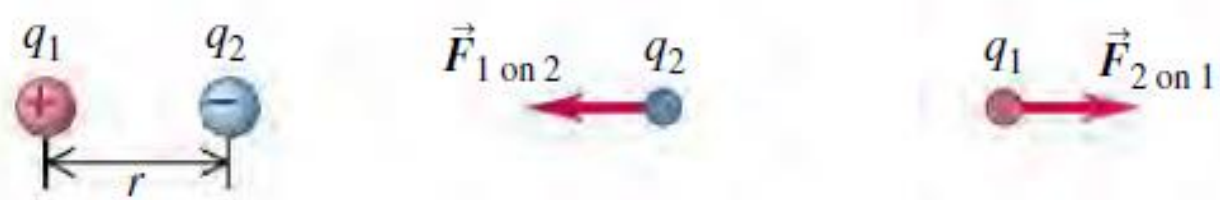
$$= (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)\frac{|(+25 \times 10^{-9}\text{ C})(-75 \times 10^{-9}\text{ C})|}{(0.030\text{ m})^2}$$

$$= 0.019\text{ N}$$

(a) The two charges

(b) Free-body diagram for charge $q_2$

(c) Free-body diagram for charge $q_1$

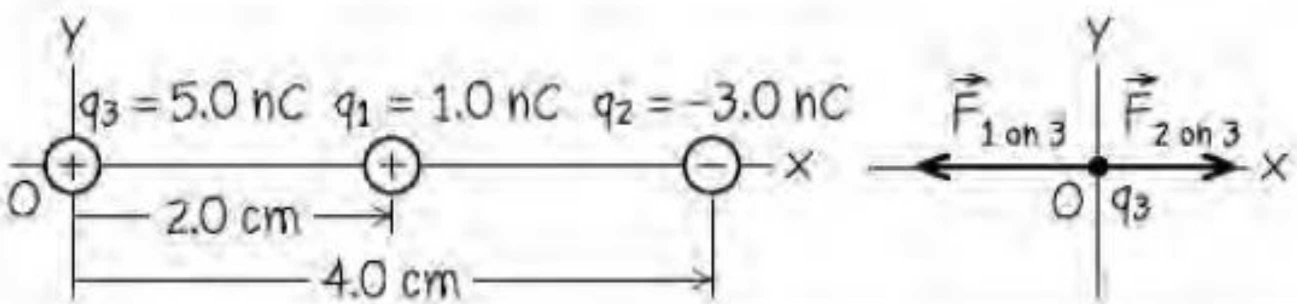


## EXAMPLE 21.3 VECTOR ADDITION OF ELECTRIC FORCES ON A LINE

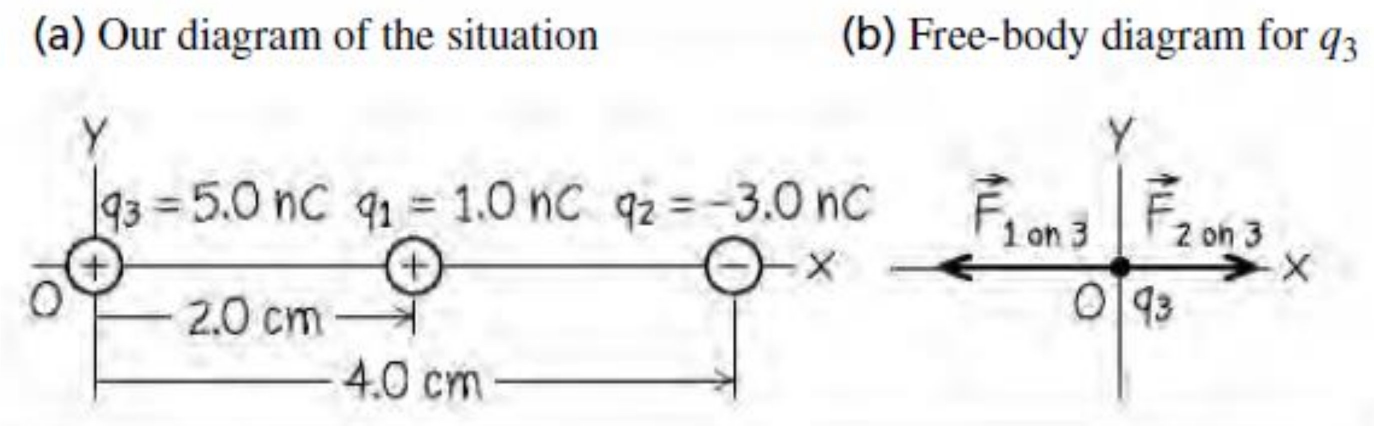
Two point charges are located on the $x$-axis of a coordinate system: $q_1 = 1.0\ \text{nC}$ is at $x = +2.0\ \text{cm}$, and $q_2 = -3.0\ \text{nC}$ is at $x = +4.0\ \text{cm}$. What is the total electric force exerted by $q_1$ and $q_2$ on a charge $q_3 = 5.0\ \text{nC}$ at $x = 0$?

**21.13** Our sketches for this problem.

(a) Our diagram of the situation (b) Free-body diagram for $q_3$



**21.13** Our sketches for this problem.




$$F_{1 \text{ on } 3} = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_3|}{r_{13}^2}$$

$$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)\frac{(1.0 \times 10^{-9} \text{ C})(5.0 \times 10^{-9} \text{ C})}{(0.020 \text{ m})^2}$$

$$= 1.12 \times 10^{-4} \text{ N} = 112\ \mu\text{N}$$

In the same way you can show that $F_{2 \text{ on } 3} = 84\ \mu\text{N}$.

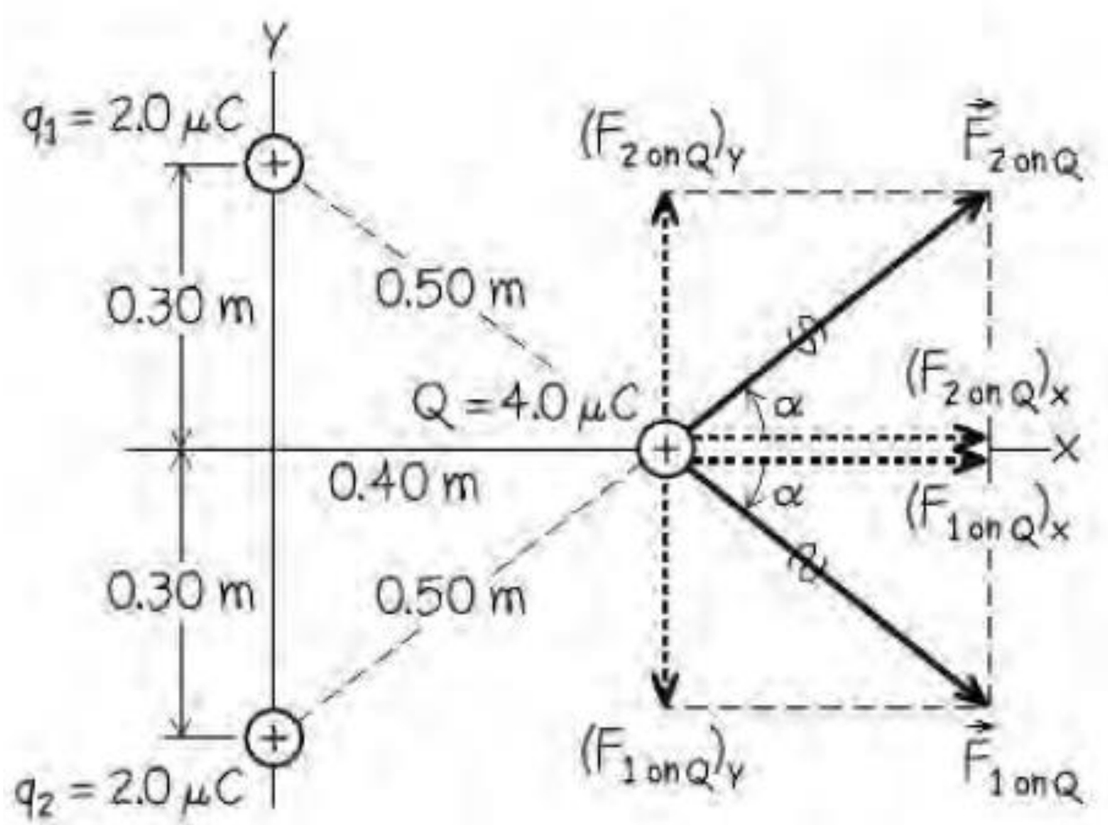
$\vec{F}_{1 \text{ on } 3} = (-112\ \mu\text{N})\hat{\imath}$ and $\vec{F}_{2 \text{ on } 3} = (84\ \mu\text{N})\hat{\imath}$

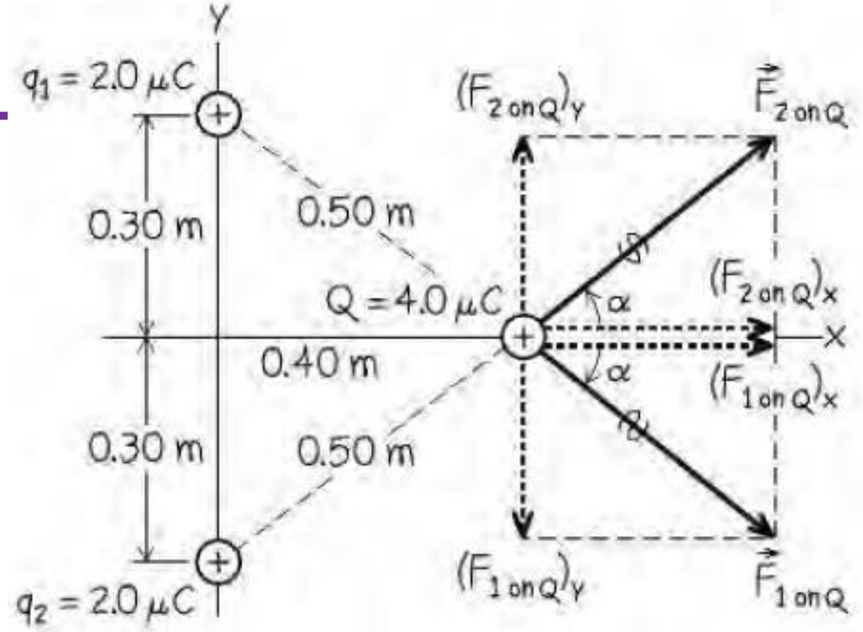
$$\vec{F}_3 = \vec{F}_{1 \text{ on } 3} + \vec{F}_{2 \text{ on } 3} = (-112\ \mu\text{N})\hat{\imath} + (84\ \mu\text{N})\hat{\imath} = (-28\ \mu\text{N})\hat{\imath}$$

## EXAMPLE 21.4 VECTOR ADDITION OF ELECTRIC FORCES IN A PLANE

SOLUTION

Two equal positive charges $q_1 = q_2 = 2.0\ \mu\text{C}$ are located at $x = 0, y = 0.30$ m and $x = 0, y = -0.30$ m, respectively. What are the magnitude and direction of the total electric force that $q_1$ and $q_2$ exert on a third charge $Q = 4.0\ \mu\text{C}$ at $x = 0.40$ m, $y = 0$?






$$F_{1 \text{ or } 2 \text{ on } Q} = (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2) \times \frac{(4.0 \times 10^{-6}\ \text{C})(2.0 \times 10^{-6}\ \text{C})}{(0.50\ \text{m})^2} = 0.29\ \text{N}$$

The $x$-components of the two forces are equal:

$$(F_{1 \text{ or } 2 \text{ on } Q})_x = (F_{1 \text{ or } 2 \text{ on } Q})\cos\alpha = (0.29\ \text{N})\frac{0.40\ \text{m}}{0.50\ \text{m}} = 0.23\ \text{N}$$

The total force on $Q$ is in the $+x$-direction, with magnitude 0.46 N.

# Summary

- The directions of the forces the two charges exert on each other are always along the line joining them.

(b) Interactions between point charges