

PHYSICS 1442-003

Fall 2011

Lecture 1

Electric Charge and

Electric Field

Properties of Electric Charges

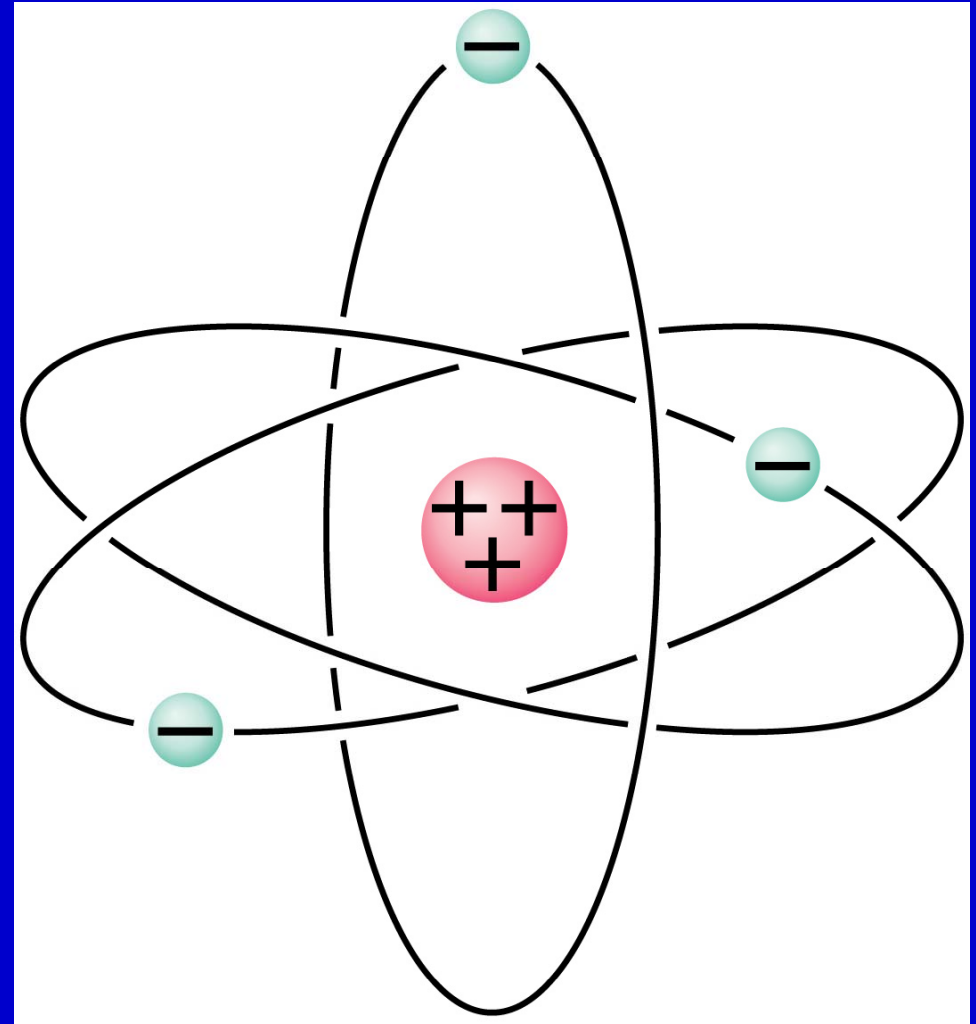
- Two types of charges exist
 - They are called positive and negative
 - Named by Benjamin Franklin
- Like charges repel and unlike charges attract one another
- Nature's basic carrier of positive charge is the proton contained in the nucleus of an atom
 - In solid materials the nuclei tend to remain close to fixed positions. Thus protons do not move from one material to another because they are held firmly in the nucleus

Properties of Charge

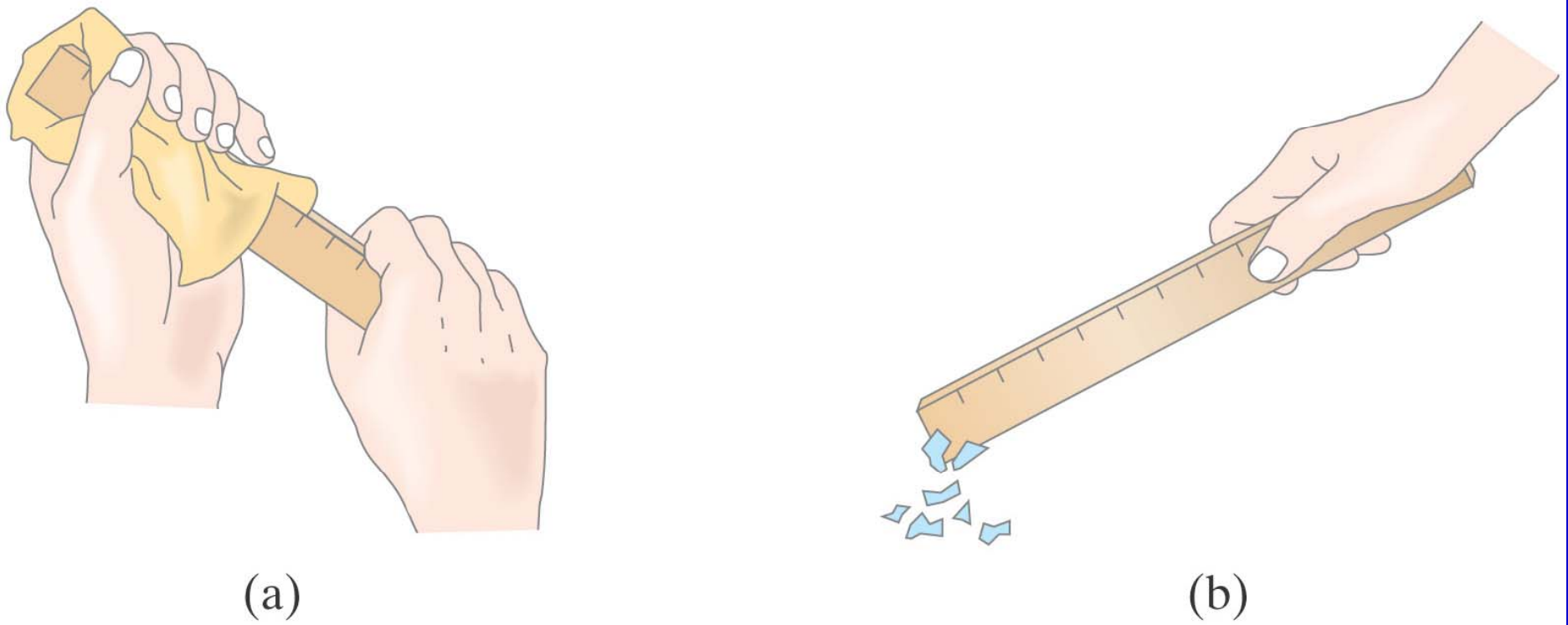
- Nature's basic carrier of negative charge is the electron
 - Gaining or losing electrons is how an object becomes charged
- Electric charge is always conserved
 - Charge is not created, only exchanged
 - Objects become charged because negative charge is transferred from one object to another

Electric Charge in the Atom

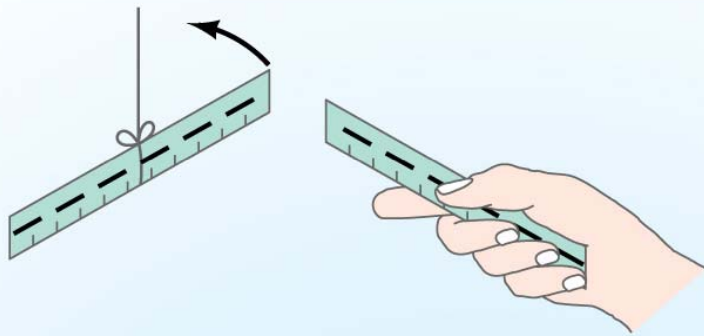
Atom has a tiny but heavy, positively charged nucleus surrounded by negatively charged electrons. The nucleus contains positively charged protons and neutrons, which have no net electric charge. All protons and electrons have the same magnitude of electric charge, but their signs are opposite. Neutral atoms contain equal numbers of protons and electrons.



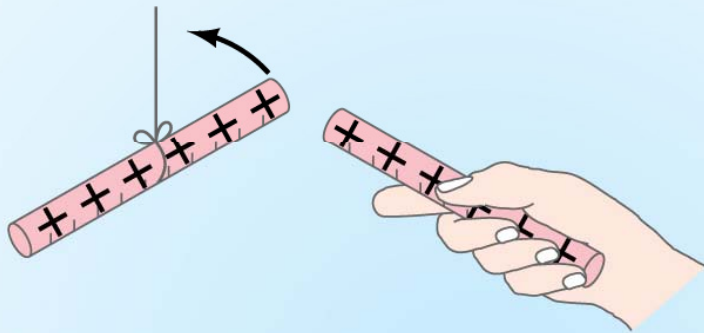
Objects become charged because negative charge is transferred from one object to another. Rubbing charges objects by moving electrons from one to the other.



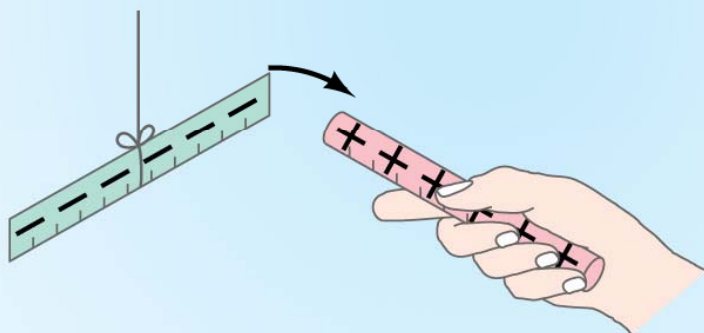
A plastic ruler rubbed with a cloth attracts tiny pieces of paper



(a) Two charged plastic rulers repel



(b) Two charged glass rods repel



(c) Charged glass rod attracts charged plastic ruler

Like charges repel
and opposite charges
attract one another

Properties of Charge

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

Conductors

- Conductors are materials in which the electric charges move freely
 - Copper, aluminum and silver are good conductors
 - When a conductor is charged in a small region, the charge readily distributes itself over the entire surface of the material

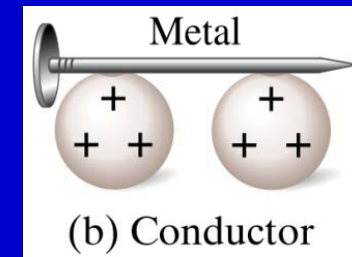
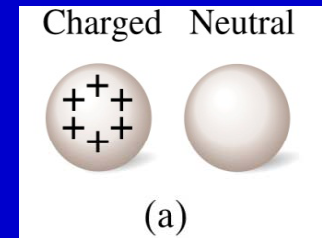
Insulators

- Insulators are materials in which electric charges do not move freely
 - Glass and rubber are examples of insulators
 - When insulators are charged by rubbing, only the rubbed area becomes charged
 - There is no tendency for the charge to move into other regions of the material

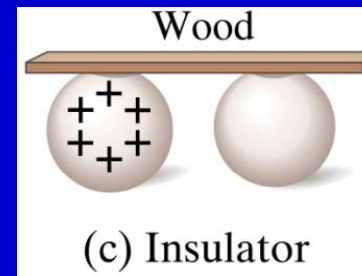
Semiconductors

- The characteristics of semiconductors are between those of insulators and conductors. They conduct only under certain conditions.
- Silicon and germanium are examples of semiconductors

- Let's imagine two metal balls of which one is charged
- What will happen if they are connected by
 - A metallic object ?
 - Some amount of charge is transferred.



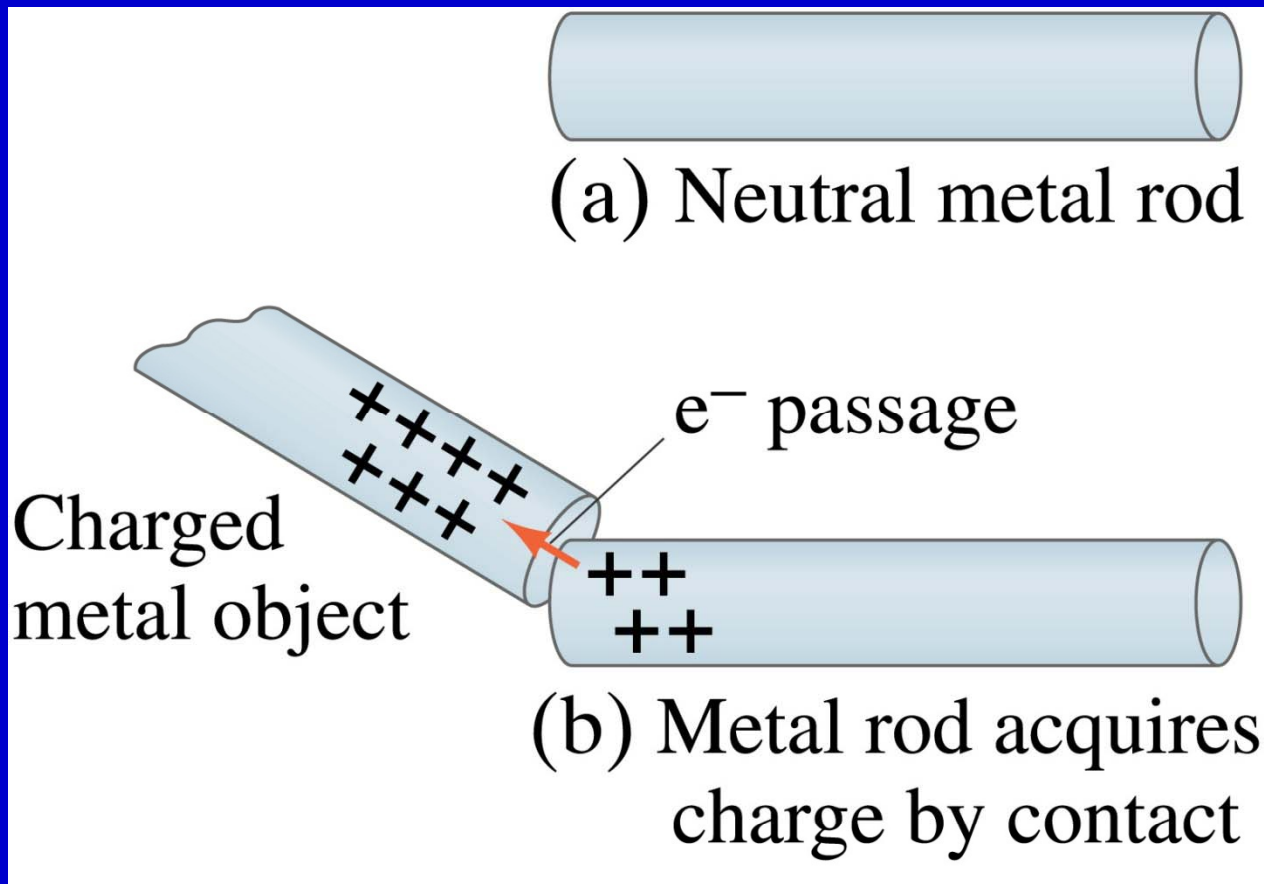
- A wooden object?
 - No charge is transferred



- Metals are generally good conductors whereas most other materials are insulators.
- Atomically, conductors have loosely bound electrons while insulators have them tightly bound!

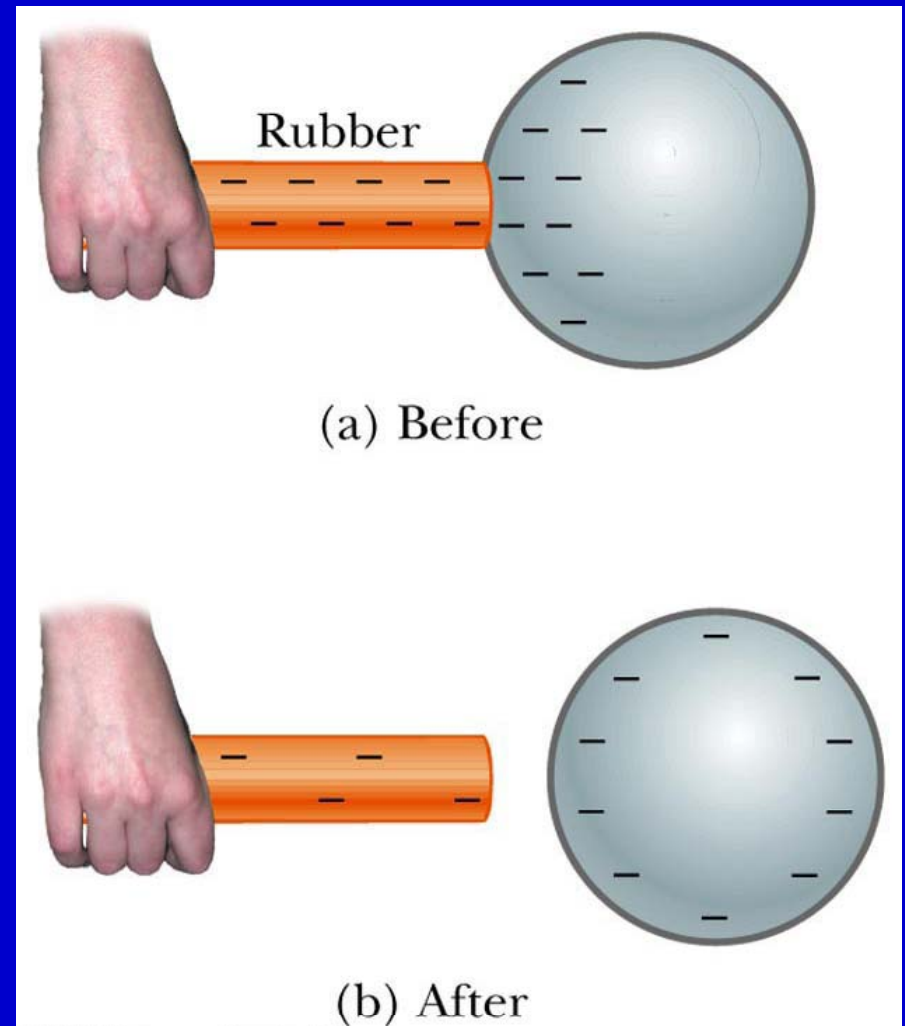
Induced Charge

Metal objects can be charged by conduction:



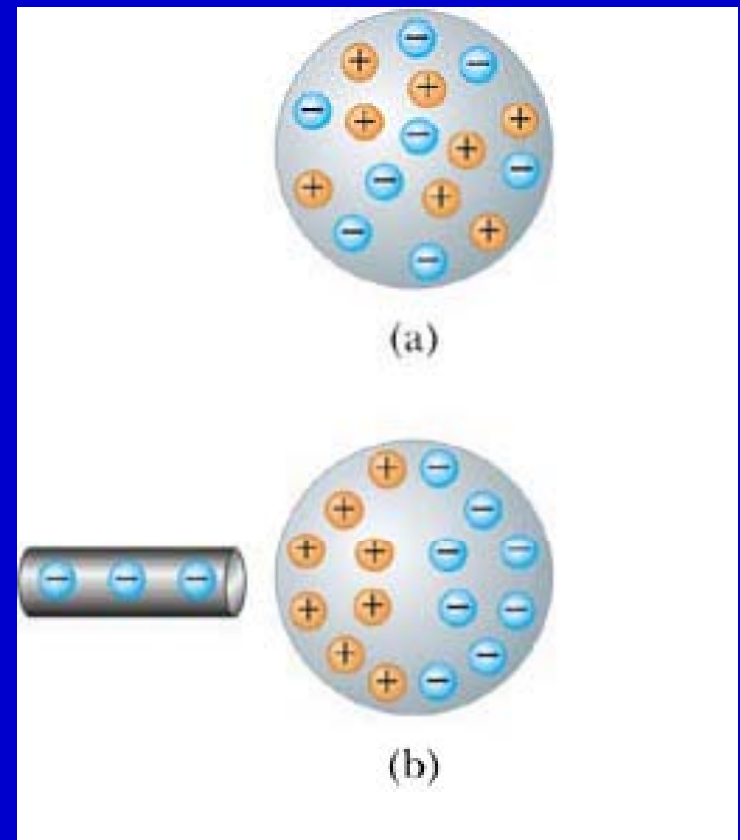
Charging by Conduction

- A charged object (the rod) is placed in contact with another object (the sphere)
- Some electrons on the rod can move to the sphere
- When the rod is removed, the sphere is left with a charge
- The object being charged is always left with a charge having the same sign as the object doing the charging

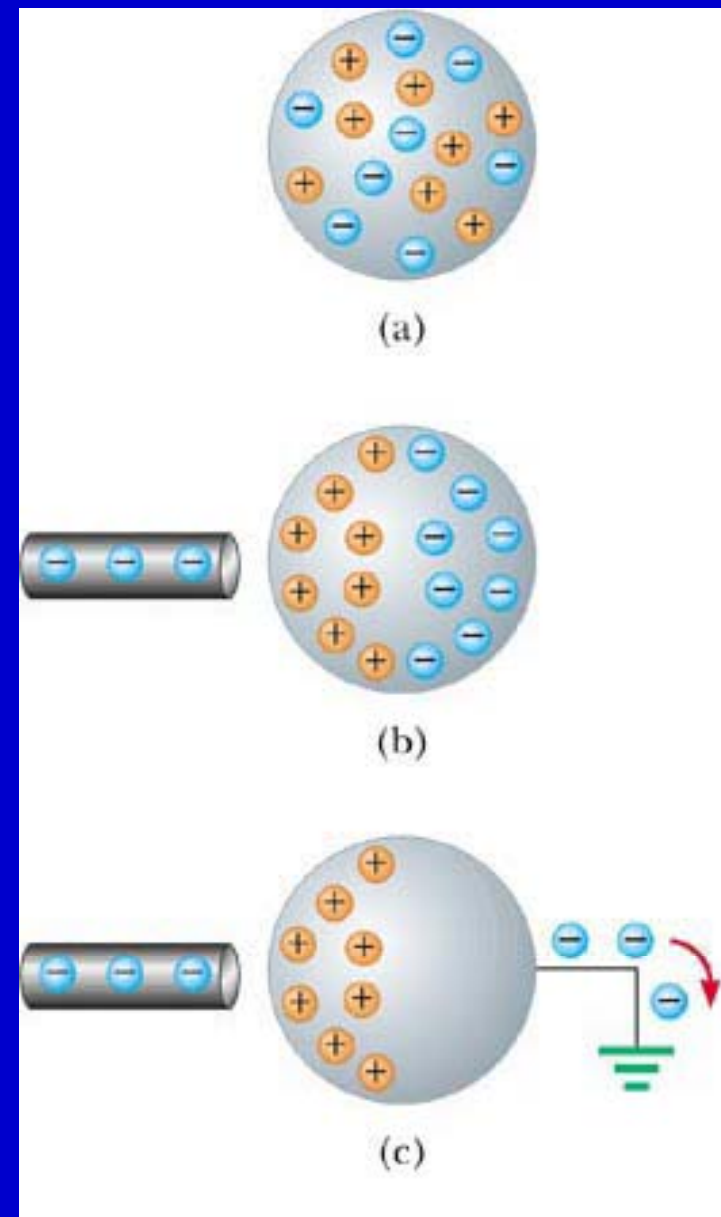


Charging by Induction

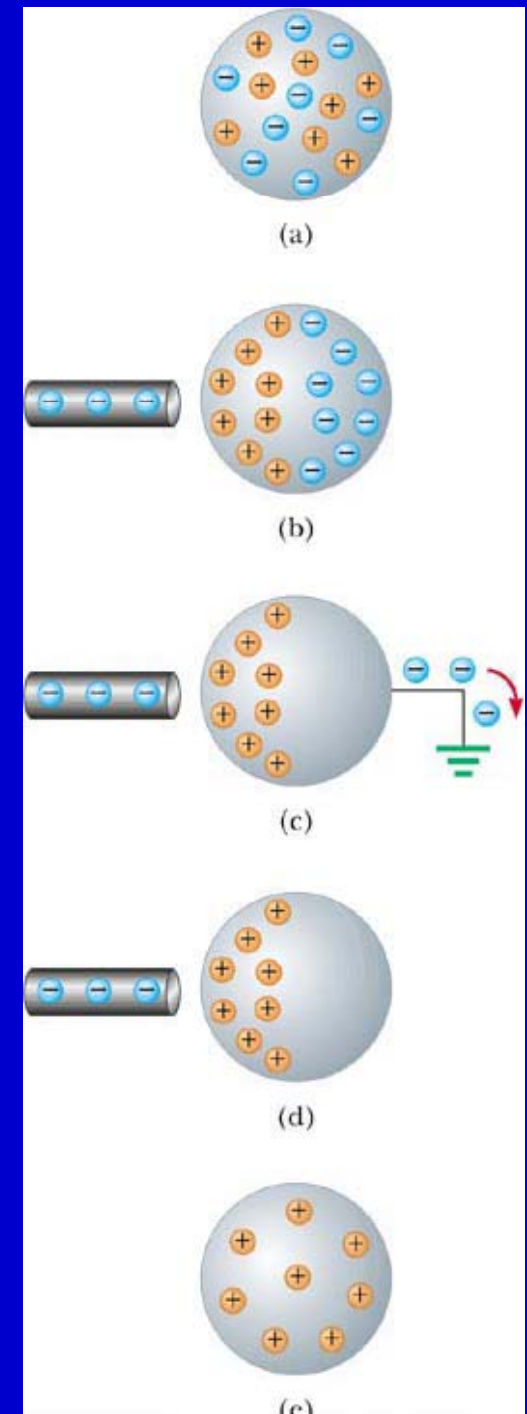
- When an object is connected to a conducting wire or pipe buried in the earth, it is said to be *grounded*
- A negatively charged rubber rod is brought near an uncharged sphere
- The charges in the sphere are redistributed
 - Some of the electrons in the sphere are repelled from the electrons in the rod



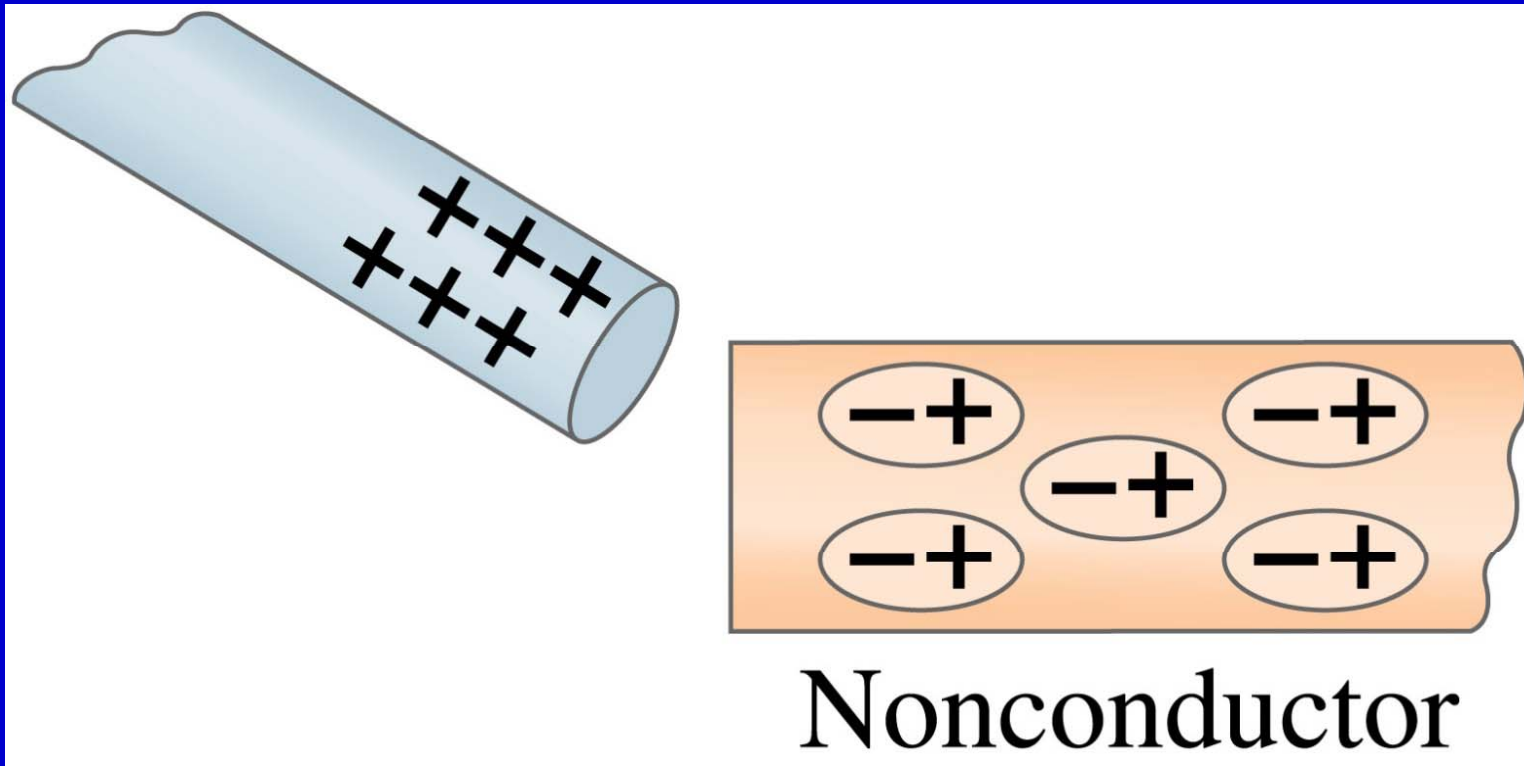
- The region of the sphere nearest the negatively charged rod has an excess of positive charge because of the migration of electrons away from this location
- A grounded conducting wire is connected to the sphere
 - Allows some of the electrons to move from the sphere to the ground



- The wire to ground is removed, the sphere is left with an excess of induced positive charge
- The positive charge on the sphere is evenly distributed due to the repulsion between the positive charges
- *Charging by induction requires no contact with the object inducing the charge*



Nonconductors won't become charged by conduction or induction, but will experience charge separation:

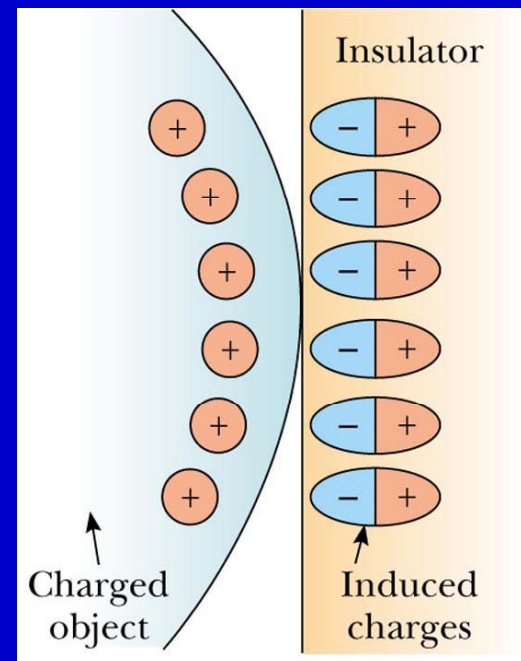


Polarization

- In most neutral atoms or molecules, the center of positive charge coincides with the center of negative charge
- In the presence of a charged object, these centers may separate slightly
 - This results in more positive charge on one side of the molecule than on the other side
- This realignment of charge on the surface of an insulator is known as *polarization*

Examples of Polarization

- The charged object (on the left) induces charge on the surface of the insulator
- A charged comb attracts bits of paper due to polarization of the paper



QUICK QUIZ 1

If a suspended object A is attracted to object B, which is charged, we can conclude that

- (a) object A is uncharged,
- (b) object A is charged,
- (c) object B is positively charged, or
- (d) object A may be either charged or uncharged.

Coulomb's Law

- Electric charge exerts a force of attraction or repulsion on other electric charges.
- It follows from studies performed by Coulomb that an electrical force has the following properties:
 - It is inversely proportional to the square of the separation between the two charged particles and is directed along the line joining them
 - It is proportional to the product of the magnitudes of the charges Q_1 and Q_2 on the two particles
 - It is attractive if the charges are of opposite signs and repulsive if the charges have the same signs

Coulomb's Law

- Mathematically,
$$F = k \frac{|Q_1| |Q_2|}{r^2}$$
- k is a proportionality constant
 - In SI units, k has the value
 - $k = 8.988 \times 10^9 \text{ N m}^2/\text{C}^2$
- Charges produced by rubbing ordinary objects (a comb or plastic ruler) are in the μC range ($1 \mu\text{C} = 10^{-6} \text{ C}$)
 - Remember, Coulombs must be used in the equation
- Remember that force is a *vector* quantity

Coulomb's Law

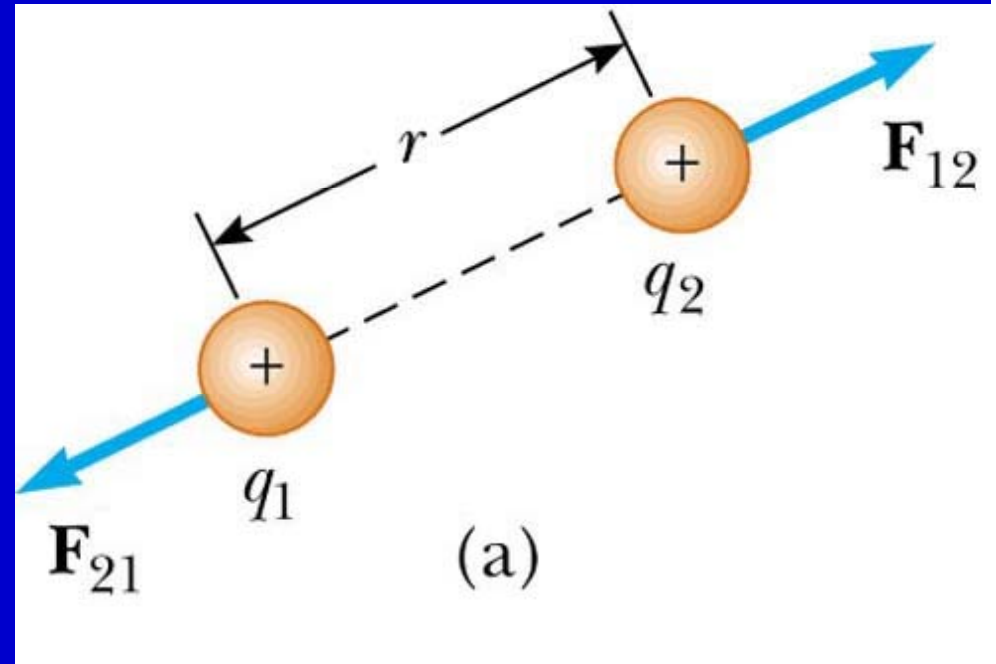
The proportionality constant k can also be written in terms of ϵ_0 , the permittivity of free space:

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$$

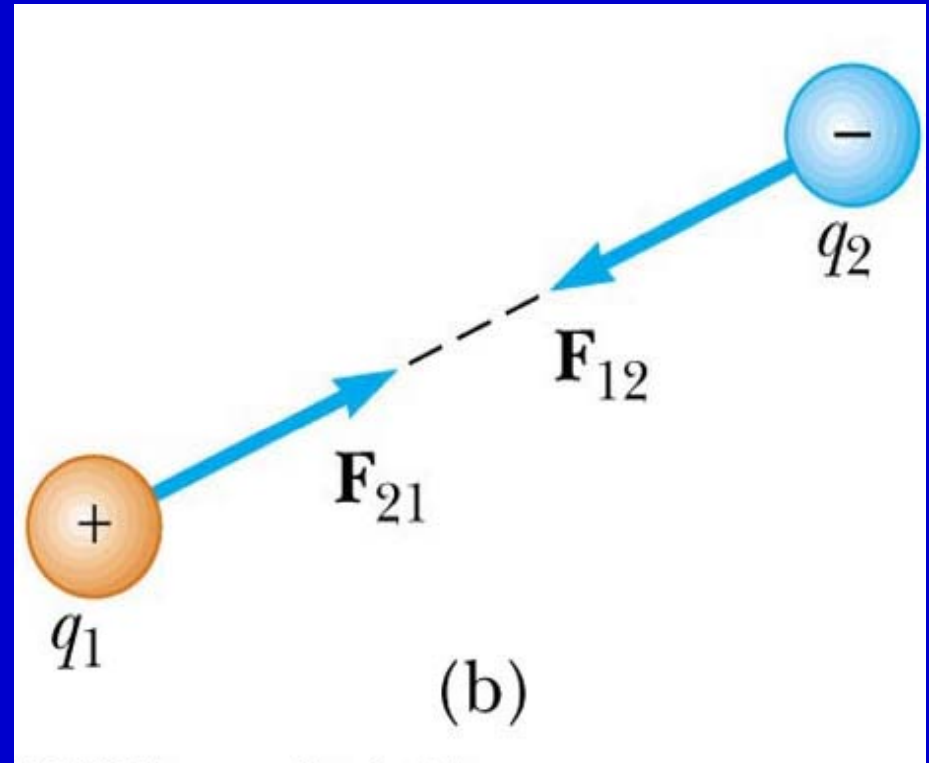
Vector Nature of Electric Forces

- Two point charges are separated by a distance r
- The like charges produce a repulsive force between them
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2



Vector Nature of Forces

- Two point charges are separated by a distance r
- The unlike charges produce an attractive force between them
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2



Electrical Forces are Field Forces

- This is the second example of a field force
 - Gravity was the first
- Remember, with a field force, the force is exerted by one object on another object even though there is no physical contact between them
- There are some important differences between electrical and gravitational forces

Electric Force and Gravitational Force

$$F = k \frac{Q_1 Q_2}{r^2} \quad \begin{array}{c} \text{Very} \\ \text{Similar} \end{array} \quad F = G \frac{M_1 M_2}{r^2}$$

- Does the electric force look similar to another force? What is it?
 - Gravitational Force
- What are the sources of the forces?
 - Electric Force: Charges, fundamental properties of matter
 - Gravitational Force: Masses, fundamental properties of matter
- What else is similar?
 - Inversely proportional to the square of the distance between the sources of the force
 - Inverse Square Law
- What is the difference?
 - Gravitational force is always attractive.
 - Electric force depends on the type of the two charges.

Electrical Force Compared to Gravitational Force

- Both are inverse square laws
- The mathematical form of both laws is the same
- Electrical forces can be either attractive or repulsive
- Gravitational forces are always attractive

QUICK QUIZ 2

Object A has a charge of $+2 \mu\text{C}$, and object B has a charge of $+6 \mu\text{C}$.

Which statement is true:

(a) $\mathbf{F}_{AB} = -3\mathbf{F}_{BA}$, (b) $\mathbf{F}_{AB} = -\mathbf{F}_{BA}$, or

(c) $3\mathbf{F}_{AB} = -\mathbf{F}_{BA}$

The Superposition Principle

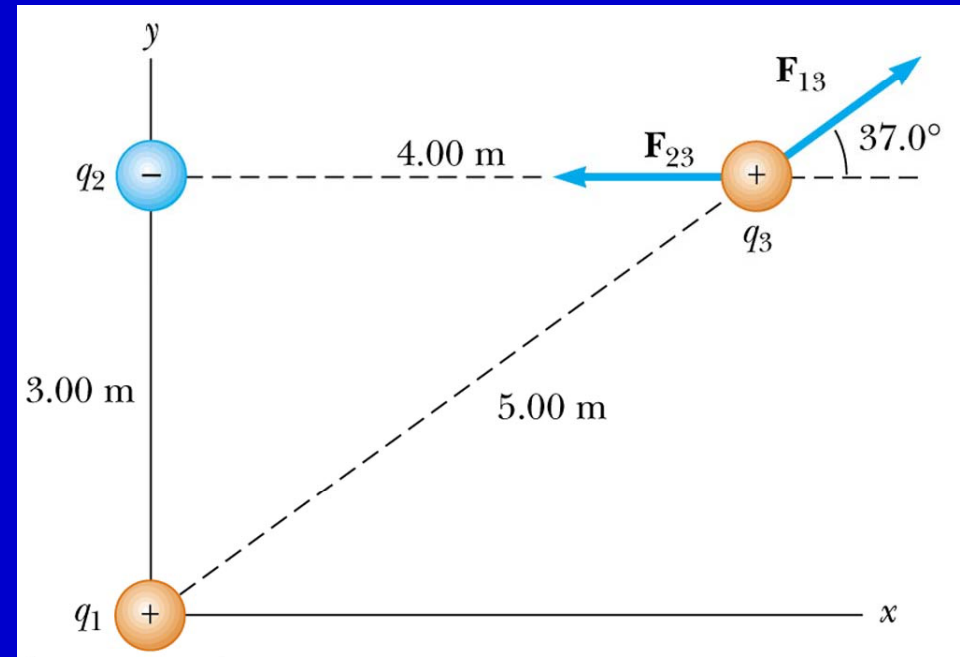
- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present.

$$\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \dots$$

- Remember to add the forces *vectorially*

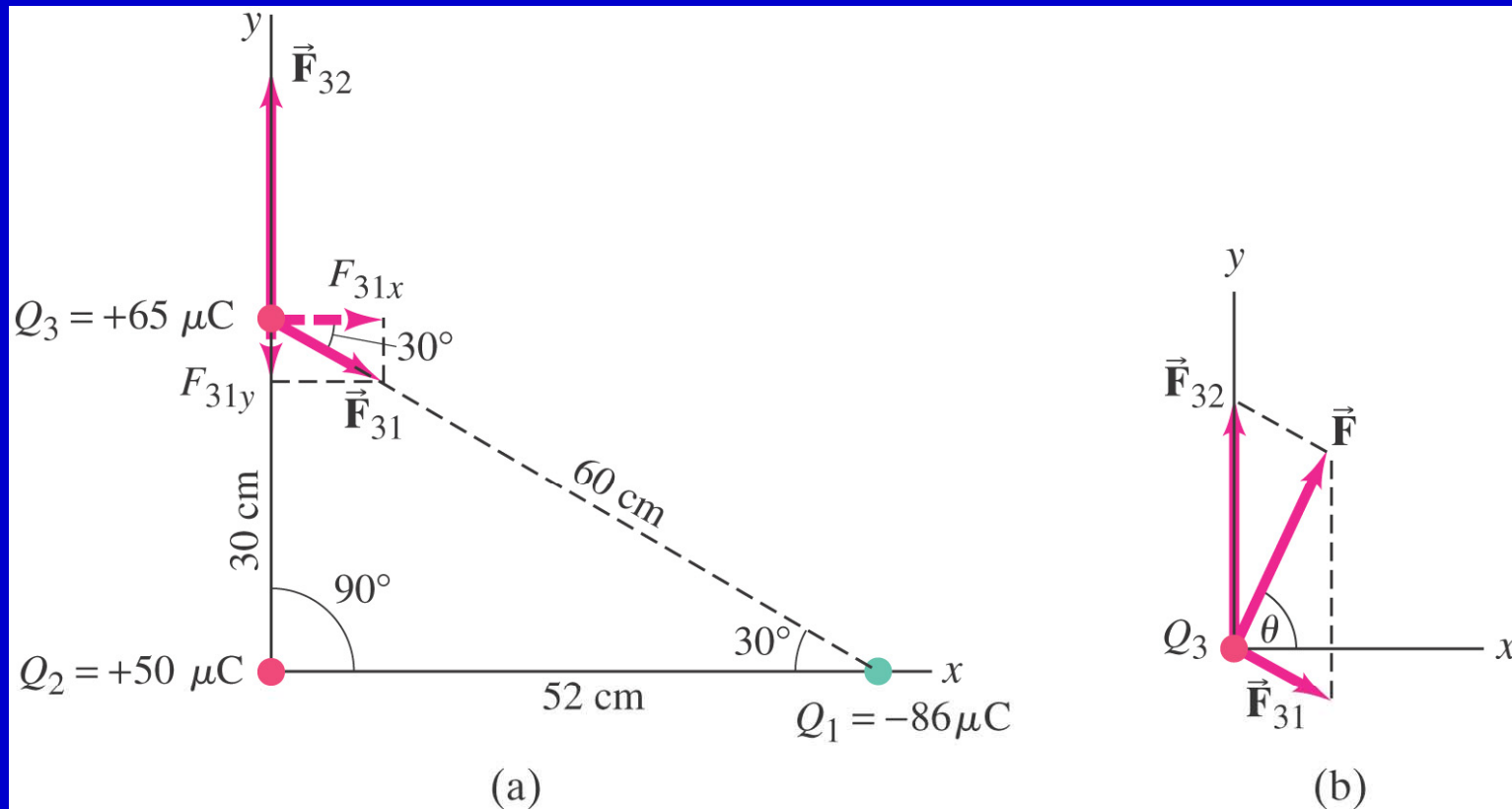
Superposition Principle Example

- 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 *total force* exerted on q_3 is the vector sum of \mathbf{F}_{13} and \mathbf{F}_{23}



Coulomb's law strictly applies only to point charges.

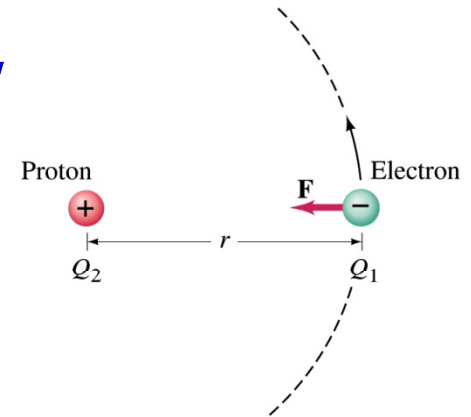
Superposition: for multiple point charges, the forces on each charge from every other charge can be calculated and then added as vectors.



■ **Electric force on electron by proton.**

Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the proton ($Q_2 = +e$) that is its nucleus.

- Assume the electron “orbits” the proton at its average distance of $r = 0.53 \times 10^{-10} \text{ m}$.



Using Coulomb's law
$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2} = k \frac{Q_1 Q_2}{r^2}$$

The charges are: $Q_1 = -e = -1.602 \times 10^{-19} \text{ C}$ and $Q_2 = +e = 1.602 \times 10^{-19} \text{ C}$

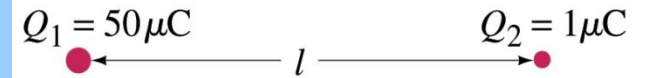
So the magnitude of the force is

$$F = \left| k \frac{Q_1 Q_2}{r^2} \right| = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2 \frac{(1.6 \times 10^{-19} \text{ C})(1.6 \times 10^{-19} \text{ C})}{(0.53 \times 10^{-10} \text{ m})^2} = 8.2 \times 10^{-8} \text{ N}$$

Which direction? Toward each other..

■ Which charge exerts greater force?

Two positive point charges, $Q_1=50\mu\text{C}$ and $Q_2=1\mu\text{C}$, are separated by a distance L . Which is larger in magnitude, the force that Q_1 exerts on Q_2 or the force that Q_2 exerts on Q_1 ?



What is the force that Q_1 exerts on Q_2 ?

$$F_{12} = k \frac{Q_1 Q_2}{L^2}$$

What is the force that Q_2 exerts on Q_1 ?

$$F_{21} = k \frac{Q_2 Q_1}{L^2}$$

Therefore the magnitudes of the two forces are identical!!

Well then what is different? The direction.

Which direction? Opposite to each other!

What is this law? Newton's third law, the law of action and reaction!!