Chapter 19
Electric Charges, Forces, and Fields

Outline

19-1 Electric Charge

Objectives:

- What is electric charge
- How it is created
- Electric charge properties

The effect of electric charge have been known for a long time.

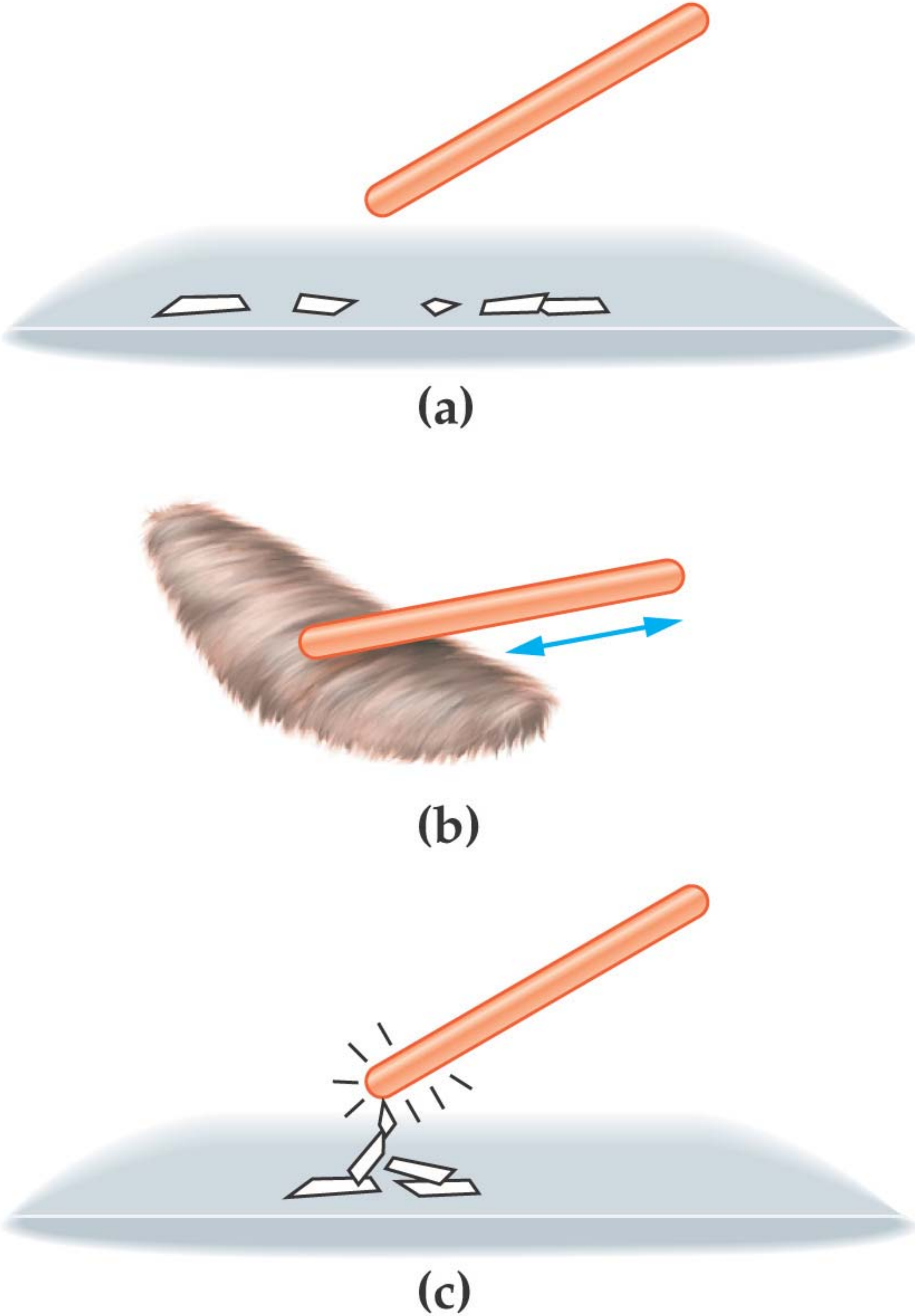


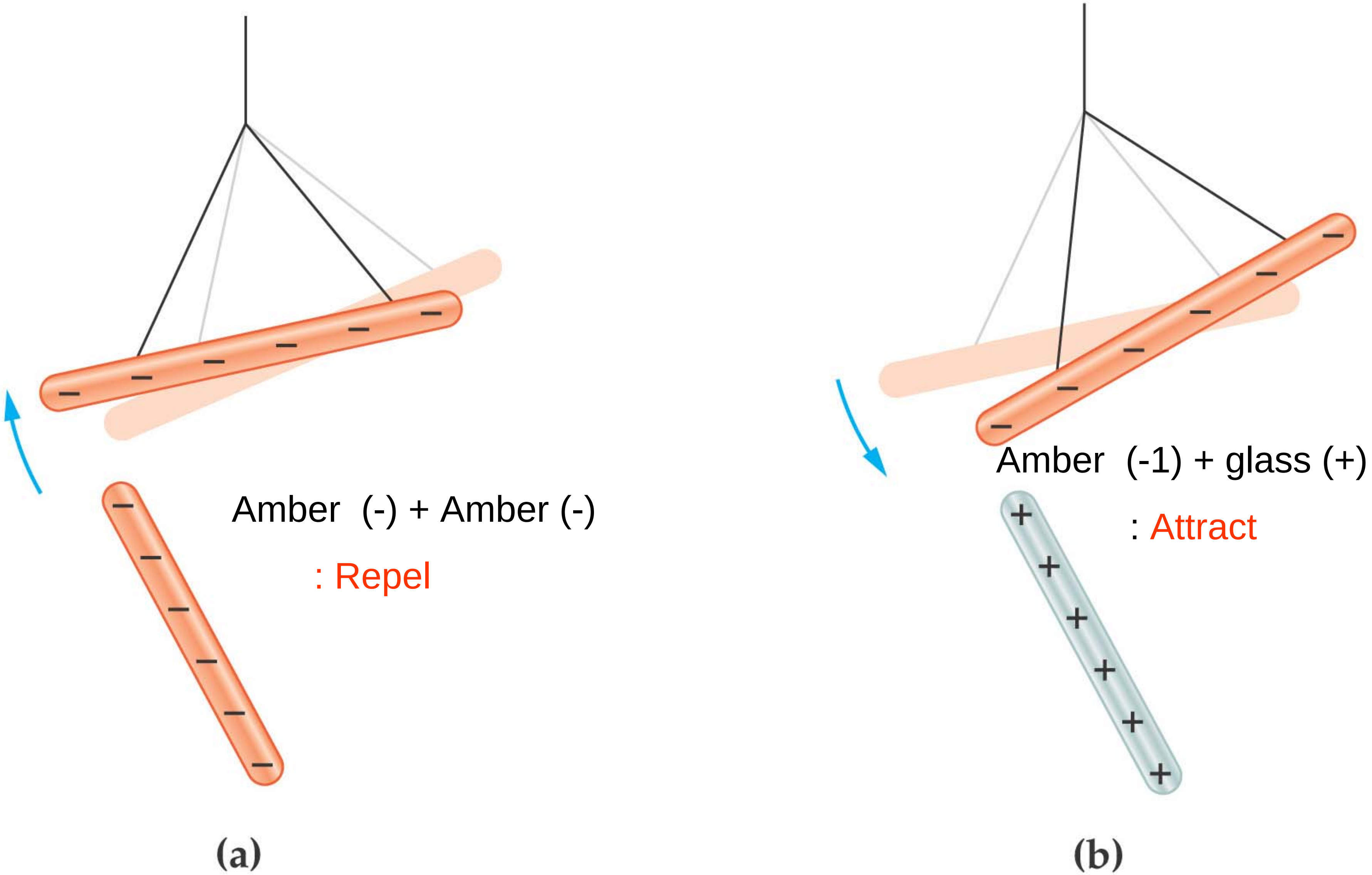
Figure 19-1
Charging an Amber Rod

(a). Uncharged amber exert no force on papers.

(b). Rod amber is rubbed against a piece of fur.

(c). Amber become charged and then attracts the papers.

Figure 19-2
Likes Repel, Opposites Attract



Conclusions:

There are two type of charges (in amber and glass), which is illustrated in Fig. 19-2

- Positive charge (+)
- Negative charge (-)

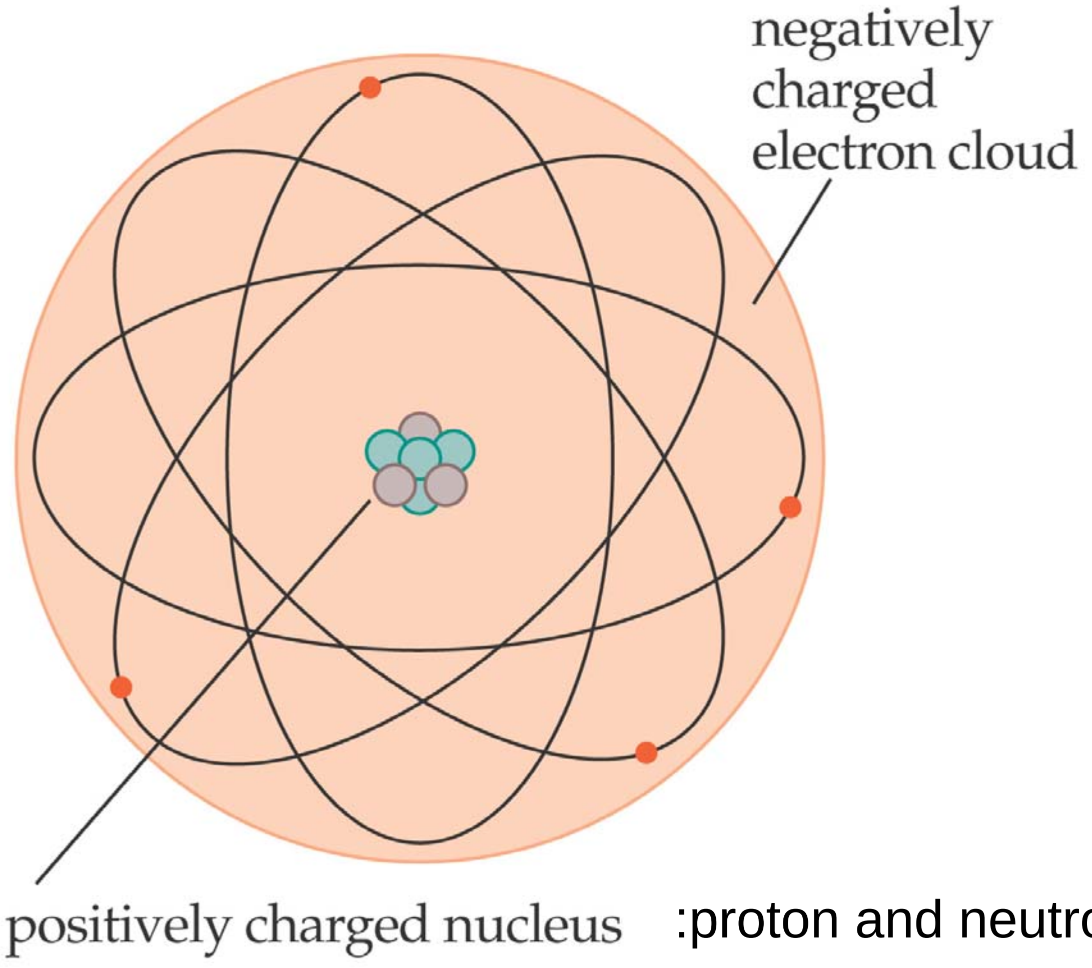
Properties

- The “like” or same charges repel.
- The opposite or different charges attract.

- Object with zero net charge are said to be electrically **neutral.**

A good example of neutral object is the atom, as shown in Fig. 19-3.

Figure 19-3
The Structure of an Atom



:proton and neutron.

All electrons have the same electric charge. Electron is negative, and is defined with a magnitude *e*, giving by:

Magnitude of an Electron's Charge, *e*

$$e = 1.60 \times 10^{-19} \quad C \qquad (19-1)$$

SI unit: coulomb, C

The electron has a mass:

$$M_e = 9.11 \times 10^{-31} \quad kg \qquad (19-2)$$

In contrast, the charge on proton (one constituent of the nucleus) is positive (+e). The mass of proton is

$$m_p = 1.673 \times 10^{-27} \quad kg \qquad\qquad (19-3)$$

The other constituent of the nucleus is the neutron, which has zero charge. Its mass is

$$m_n = 1.675 \times 10^{-27} \quad kg \qquad\qquad (19-4)$$

Charge Separation /Transfer

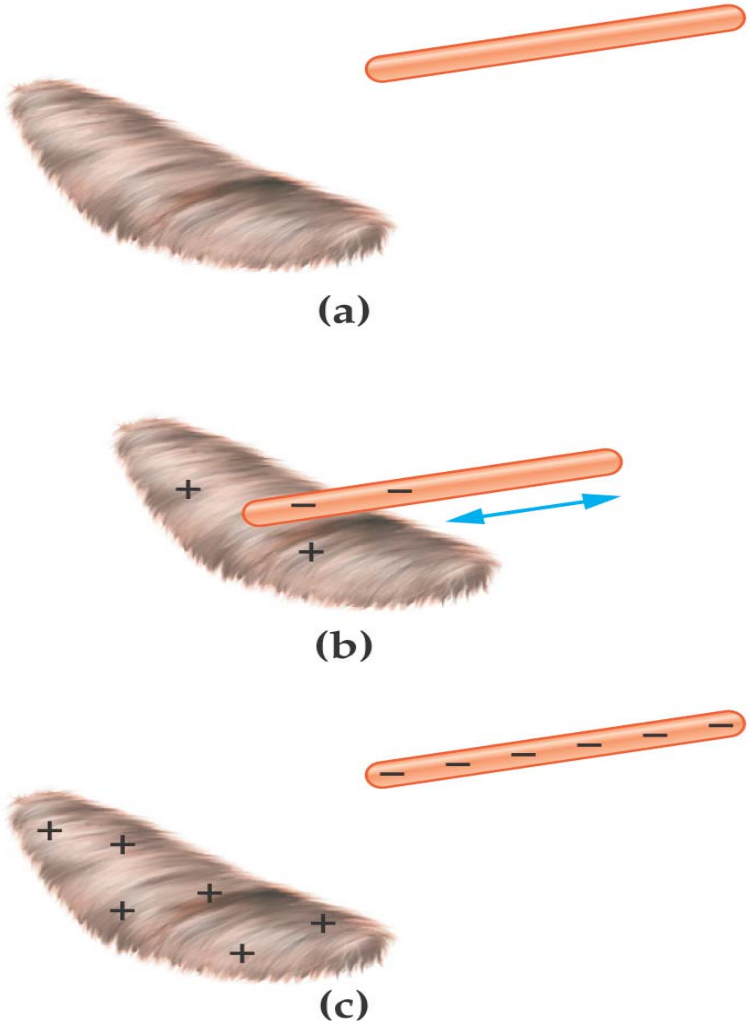


Figure 19-4
Charge Transfer

(a) Initially, an amber rod and a piece of fur is electrically neutral: no more negative/positive charge!

(b) Charges is transferred from one to the other.

(c) At the end, the fur and the amber have charges of equal magnitude, but opposite sign.

Conservation of Electric Charge

The total electric charge of the universe is constant:

No physical process can increase or decrease the total amount of electric charge.

Some concepts

Due to the movement of electrons, charge is transferred from one object to another.

Positive Ion: The atom that loses an electron is said to be a positive ion;

Negative Ion: The atom that receives an extra electron is said to be a negative ion;

19-2 Insulators and Conductors

- **Insulator:** Charges cannot move about freely on it.

    Examples: amber, glass, wood, rubber.

- **Conductor:** Charges can move freely on it.

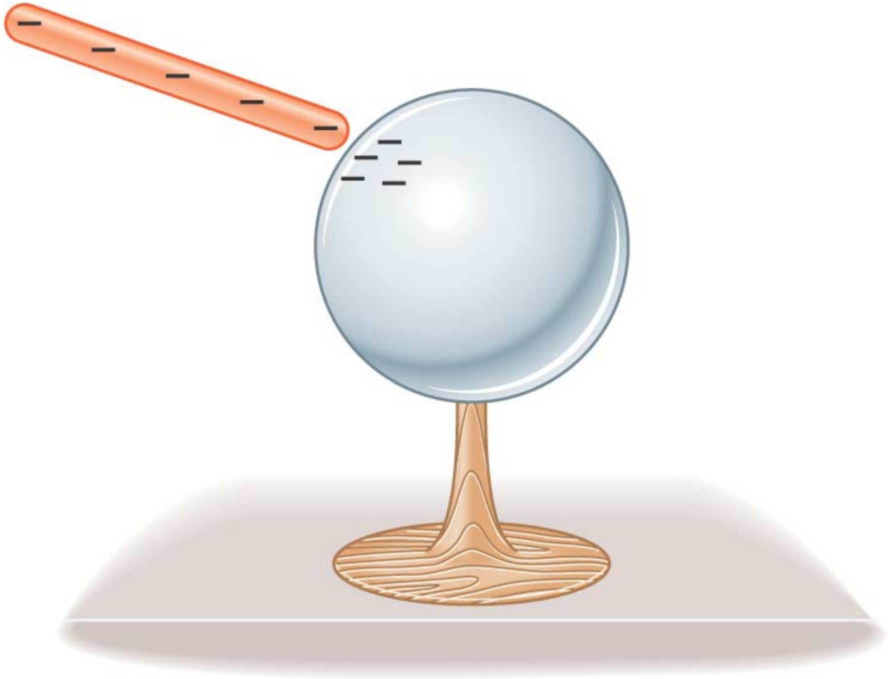
    Examples: different metals and metal wires.

- **Semiconductor:** Materials have properties of electric conduction between insulator and conductor.

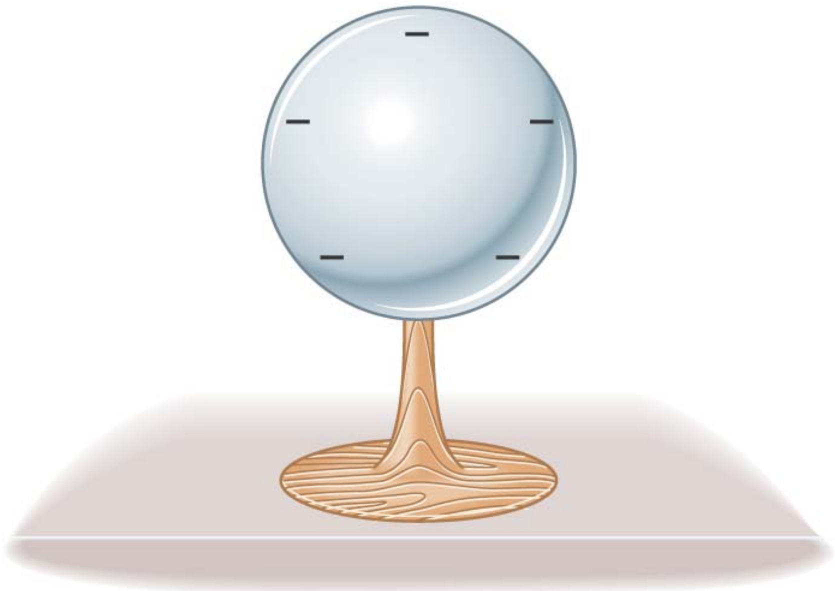
    And semiconductors have wide application in electronics!

Figure 19-6

Charging a Conductor



(a). An uncharged metal sphere is touched by a charged rod, and some charge is transferred to it.



(b). Charges move freely on a conductor, and spread out uniformly because of the same charge repel.

19-3 Coulomb's Law

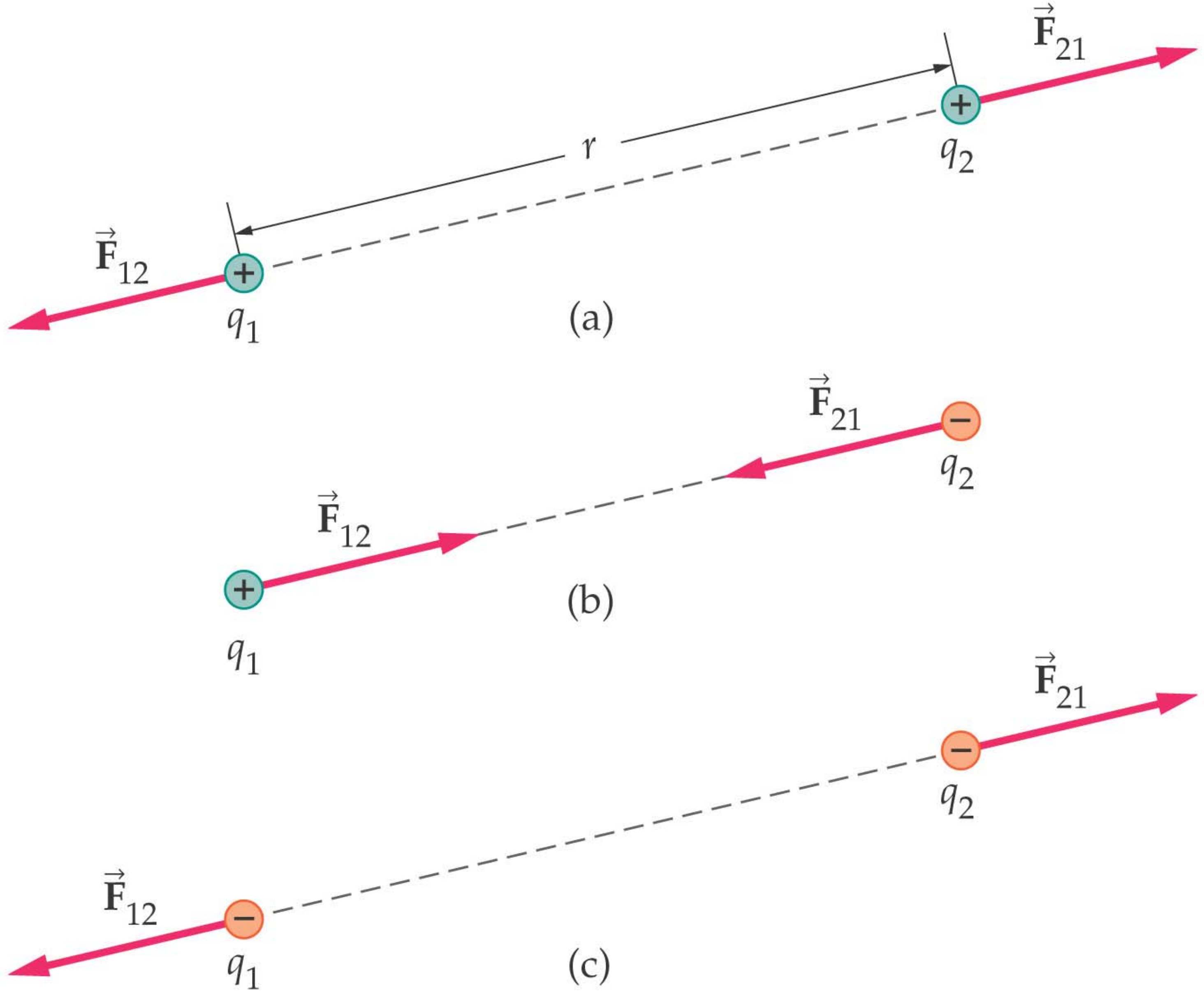
Coulomb's law for the magnitude of the electrostatic force between two point charges

$$F = k\frac{|q_1||q_2|}{r^2}, \qquad (19-5)$$

$$with \quad k = 8.99 \times 10^9 \quad N.m^2/C^2$$

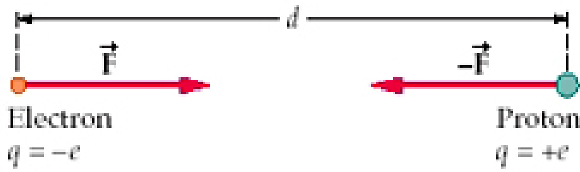
SI unit: newton, N

Figure 19-7
Forces Between Point Charges



CONCEPTUAL CHECKPOINT 19–2

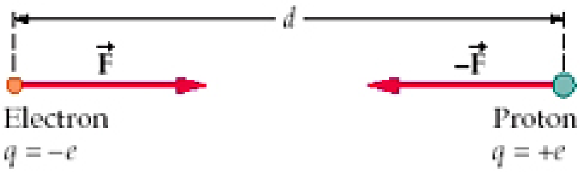
An electron and a proton, initially separated by a distance d, are released from rest simultaneously. The two particles are free to move. When they collide, are they **(a)** at the midpoint of their initial separation, **(b)** closer to the initial position of the proton, or **(c)** closer to the initial position of the electron?



Note: the mass of proton is ~ 2000 times that of the electron !

CONCEPTUAL CHECKPOINT 19–2

An electron and a proton, initially separated by a distance d, are released from rest simultaneously. The two particles are free to move. When they collide, are they **(a)** at the midpoint of their initial separation, **(b)** closer to the initial position of the proton, or **(c)** closer to the initial position of the electron?



Reasoning and Discussion

Because of Newton's third law, the forces exerted on the electron and proton are equal in magnitude and opposite in direction. For this reason, it might seem that the particles meet at the midpoint. The masses of the particles, however, are quite different. In fact, as mentioned in Section 19–1, the mass of the proton is about 2000 times greater than the mass of the electron; therefore, the proton's acceleration ($a = F/m$) is about 2000 times less than the electron's acceleration. As a result, the particles collide near the initial position of the proton. More specifically, they collide at the location of the center of mass of the system, which remains at rest throughout the process.

Answer

(b) The particles collide near the initial position of the proton.

Note: the mass of proton is ~ 2000 times of the electron !

An Example:

Calculate the magnitude of electric force between a electron and a proton at a distance of r= 5.29 x 10 $^{-11}$ m.

According to Coulomb's law

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

$$= (8.99\times10^{9}\,N.m^2/C^2)\frac{|-1.60\times10^{-9}\,C||1.60\times10^{-9}\,C|}{(5.29\times10^{-11}\,m)^2}$$

$$= 8.22\times10^{-8}\,N$$

An Example 19-9:

The attraction electrostatic force between the point charges $+8.44c10^{-6}$ C and Q has a magnitude of 0.975 N when the separation between the charges is 1.31 m. Find the sign and magnitude of the charge Q.

Negative charge and

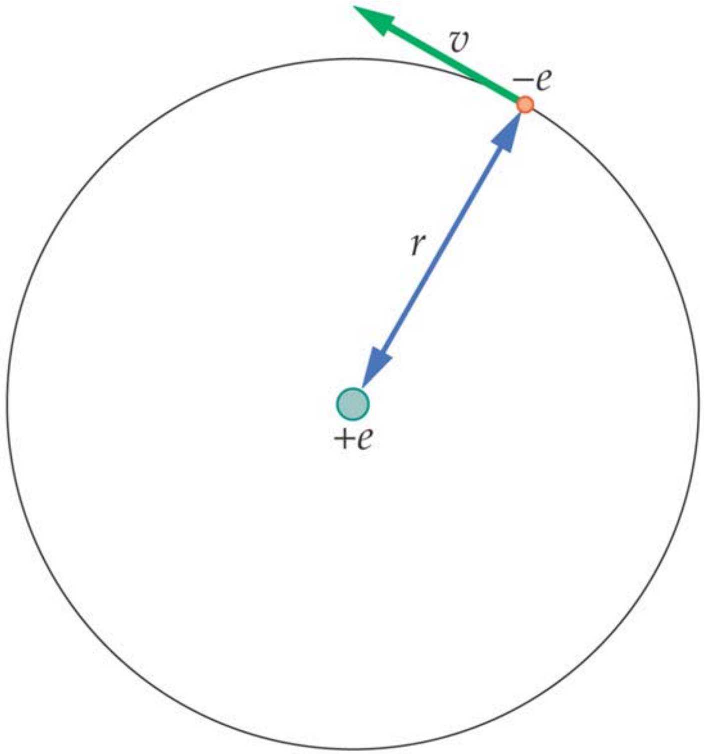
The magnitude of the charge Q is

$$Q = \frac{r^2 F}{kq} = \frac{(1.31\ \mathrm{m})^2 (0.975\ \mathrm{N})}{(8.99 \times 10^9\ \mathrm{N \cdot m^2 / C^2})(8.44 \times 10^{-6}\ \mathrm{C})} = \boxed{2.21 \times 10^{-5}\ \mathrm{C}}$$

Example 19-1: The Bohr Orbit

In the Borh's Hydrogen model, the electron is imagined to move in a circular orbit about a stationary proton. The force responsible for the electron circular motion is the electric force between the electron and the proton.

Given that the radius of the electron's orbit is 5.29×10^{-11}m, and its mass is $m_e = 9.11 \times 10^{-31}$km. Find the electron's speed.



Solution

1. Set the coulomb force between the electron and proton equal to the centripetal force required for the electro's circular orbit:

$$k\frac{|q_1||q_2|}{r^2} = m_e a_{cp}$$

$$k\frac{e^2}{r^2} = m_e\frac{v^2}{r}$$

2. Solve for the speed of the electron, *v*:

$$v = e\sqrt{\frac{k}{m_e r}}$$

3. Substitute numerical data:

$$v = (1.60\times10^{-19}C)\sqrt{\frac{8.99\times10^{9}N.m^2/C^2}{(9.11\times10^{-31}kg)(5.29\times10^{-11}m)}}$$

$$= 2.19\times10^{6}m/s$$

Superposition

The electric force, like all forces, is a vector. Hence, a charge experiences forces due to two or more charges is

<u>the vector sum</u> of all the forces.

For examples, in Fig. 19-8, the total force on charge 1 is the vector sum of the forces due to charges 2, 3 ,4

Vector sum/ Net force:

$$\overrightarrow{F}_1 = \overrightarrow{F}_{12} + \overrightarrow{F}_{13} + \overrightarrow{F}_{14}$$

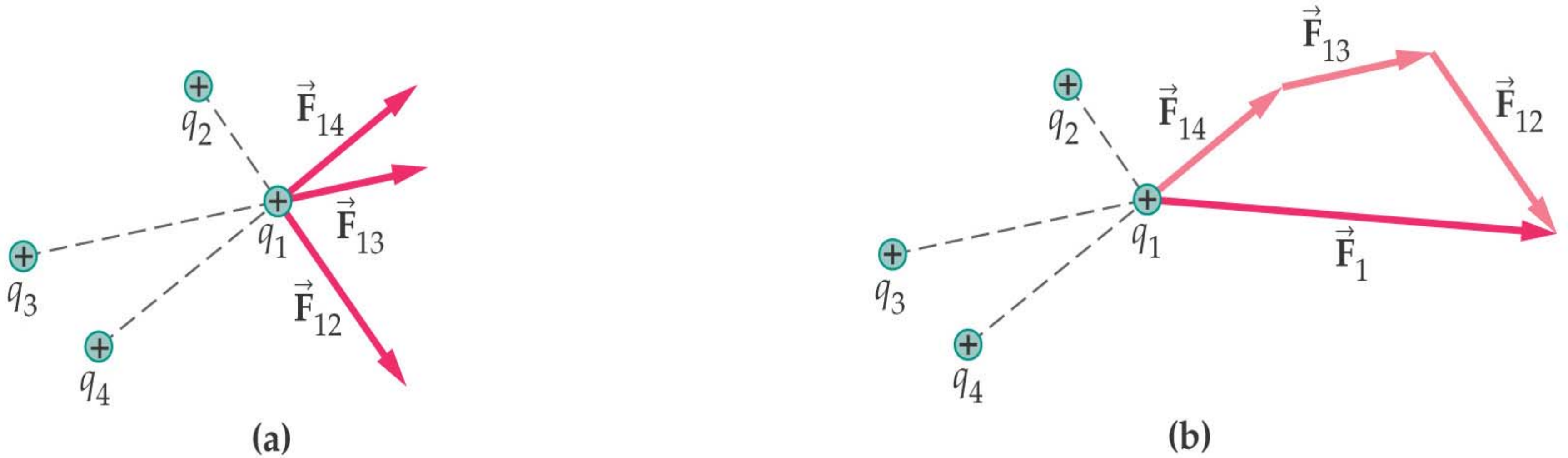


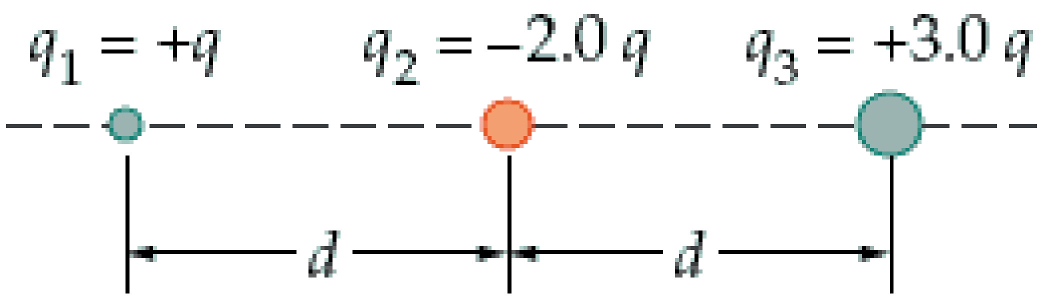
Figure 19-8
Superposition of Forces

Example 19-15: **Net Force**

For three charges, given q= +12 uC and d= 16 cm.

(a) Find the direction and magnitude of the net electrostatic force exerted on the point charge q_2 in the following figure.   (b) How will your answer change if the distance d were tripled?

Note: 1 uC=10^{-6} C



Solution

(a) Write Coulomb's law using vector notation:

$$\vec{\mathbf{F}}_2 = \vec{\mathbf{F}}_{21} + \vec{\mathbf{F}}_{23} = -k\frac{q_1 q_2}{d^2}\hat{\mathbf{x}} + k\frac{q_1 q_3}{d^2}\hat{\mathbf{x}}$$

Substitute the charge magnitudes given in the figure

$$\vec{\mathbf{F}}_2 = \frac{k}{d^2}\left[-q_1 q_2 + q_1 q_3\right]\hat{\mathbf{x}} = \frac{k}{d^2}\left[-q(2.0q) + (2.0q)(3.0q)\right]\hat{\mathbf{x}}$$

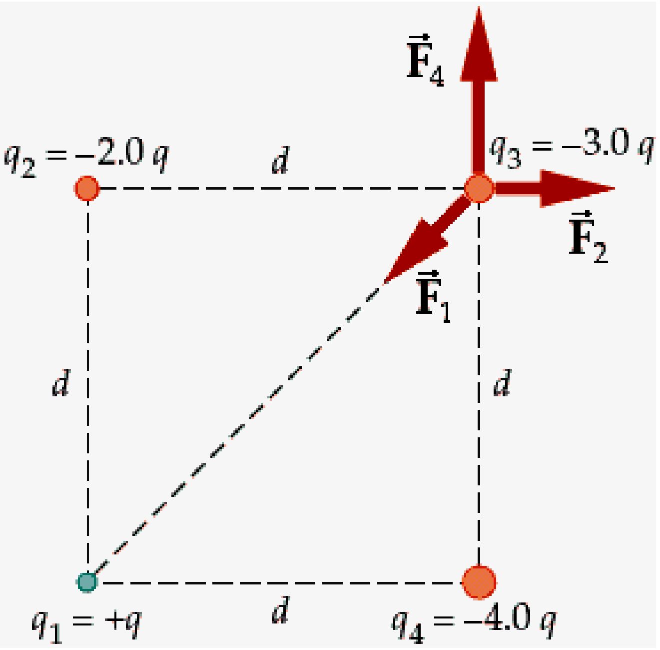
$$= \frac{kq^2}{d^2}[4.0]\hat{\mathbf{x}} = [4.0]\frac{\left(8.99\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\left(12\times10^{-6}\ \mathrm{C}\right)^2}{(0.16\ \mathrm{m})^2}\hat{\mathbf{x}} = \underline{\underline{(200\ \mathrm{N})\hat{\mathbf{x}}}}$$

The net electrostatic force on q_2 is $200\ \mathrm{N} = \boxed{0.20\ \mathrm{kN\ toward}\ q_3}$

(b) If the distance *d* were tripled, the magnitude would be cut to a ninth and the direction would be unchanged.

Example 19-21: Superposition

(a) Find the direction and magnitude of the net force exerted on the point charge q_3 in the figure. Let q= +2.4 uC and d= 33cm.
(b) How would your answer change if the distance d were double?



Picture the problem

Solution

1. (a) Find

$$\vec{\mathbf{F}}_2 = \frac{k|q_2||q_3|}{d^2}\hat{\mathbf{x}} = \frac{k(2.0q)(3.0q)}{d^2}\hat{\mathbf{x}} = \frac{6.0kq^2}{d^2}\hat{\mathbf{x}}$$

2. Find $\vec{\mathbf{F}}_4$

$$\vec{\mathbf{F}}_4 = \frac{k|q_3||q_4|}{d^2}\hat{\mathbf{y}} = \frac{k(3.0q)(4.0q)}{d^2}\hat{\mathbf{y}} = \frac{12kq^2}{d^2}\hat{\mathbf{y}}$$

3. Find $\vec{\mathbf{F}}_1$

$$\vec{\mathbf{F}}_1 = \frac{k|q_1||q_3|}{\left(\sqrt{2}d\right)^2}\left(-\cos 45°\hat{\mathbf{x}} - \sin 45°\hat{\mathbf{y}}\right) = \frac{k(q)(3.0q)}{\left(\sqrt{2}d\right)^2}\left(-\frac{\hat{\mathbf{x}}}{\sqrt{2}} - \frac{\hat{\mathbf{y}}}{\sqrt{2}}\right)$$

$$= \frac{3.0\sqrt{2}kq^2}{4d^2}\left(-\hat{\mathbf{x}} - \hat{\mathbf{y}}\right)$$

4. Find the vector sum of the three forces:

$$\vec{\mathbf{F}}_{\text{net}} = \left(\frac{6.0kq^2}{d^2} - \frac{3.0\sqrt{2}kq^2}{4d^2} \right) \hat{\mathbf{x}} + \left(\frac{12kq^2}{d^2} - \frac{3.0\sqrt{2}kq^2}{4d^2} \right) \hat{\mathbf{y}}$$

$$= \frac{3.0kq^2}{d^2} \left[\left(2.0 - \sqrt{2}/4\right) \hat{\mathbf{x}} + \left(4 - \sqrt{2}/4\right) \hat{\mathbf{y}} \right]$$

$$= \frac{3.0\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(2.4\times10^{-6}\ \text{C}\right)^2}{\left(0.33\ \text{m}\right)^2} \left[\left(2.0 - \sqrt{2}/4\right) \hat{\mathbf{x}} + \left(4 - \sqrt{2}/4\right) \hat{\mathbf{y}} \right]$$

$$\vec{\mathbf{F}}_{\text{net}} = \left(2.3\ \text{N}\right)\hat{\mathbf{x}} + \left(5.2\ \text{N}\right)\hat{\mathbf{y}}$$

5. Find the direction of $\vec{\mathbf{F}}_{\text{net}}$ from the $+x$ axis:

$$\theta = \tan^{-1} \frac{F_{\text{net},\,y}}{F_{\text{net},\,x}} = \tan^{-1} \frac{5.2\ \text{N}}{2.3\ \text{N}} = \boxed{66^\circ}$$

6. Find the magnitude of $\vec{\mathbf{F}}_{\text{net}}$

$$F_{\text{net}} = \sqrt{F_{net,x}^2 + F_{net,y}^2} = \sqrt{\left(2.3\ \text{N}\right)^2 + \left(5.2\ \text{N}\right)^2} = \boxed{5.7\ \text{N}}$$

7. (b) If the distance *d* were doubled, the magnitude of the force would be cut to one-fourth and the direction would be unchanged.

Superposition

For case of more than two forces, the net force vector is

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ...$$

The X and Y components of the net force are

$$F_{net,x} = F_{1,x} + F_{2,x} + F_{3,x} + ...$$

$$F_{net,y} = F_{1,y} + F_{2,y} + F_{3,y} + ...$$

The magnitude and direction of the net force are

$$F_{net} = \sqrt{F_{net,x}^2 + F_{net,y}^2}$$

$$\theta = \tan^{-1}(F_{net,y} / F_{net,x})$$

Summary

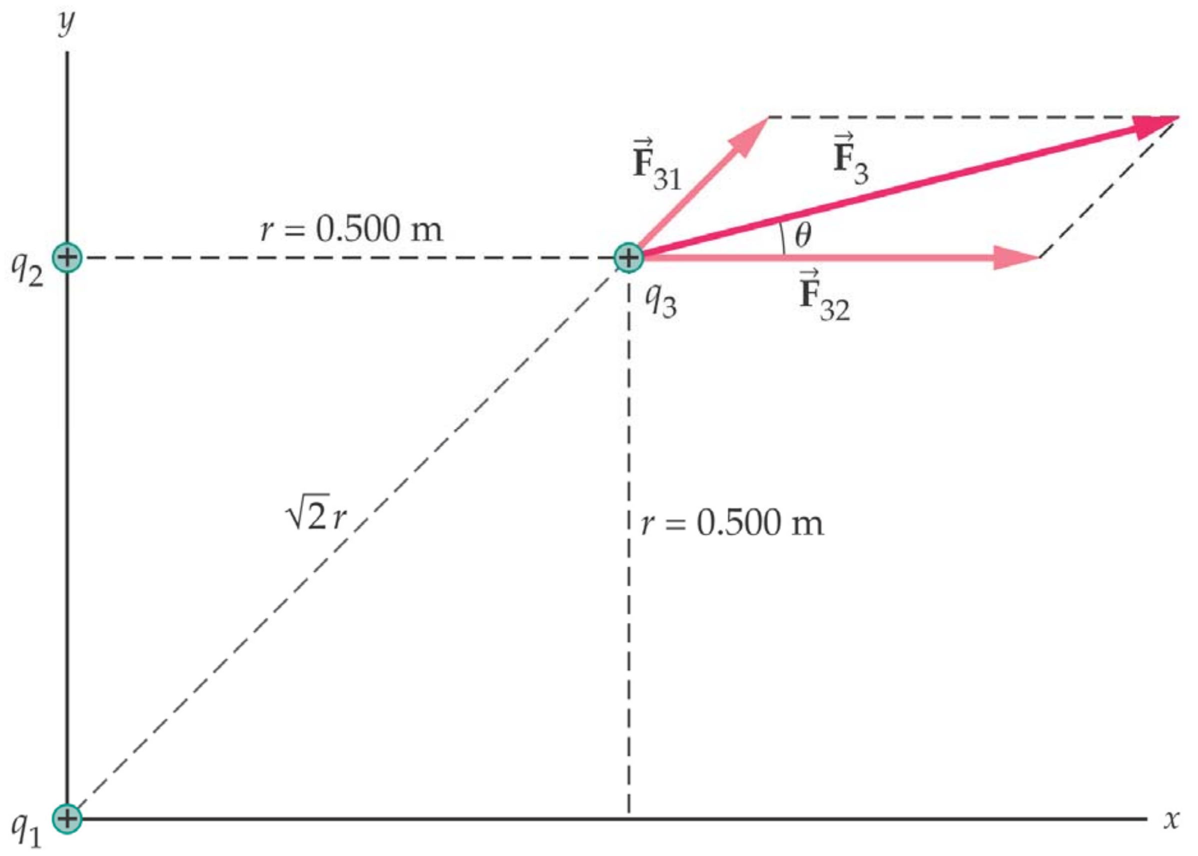
1) There are two kinds of charge: positive (+) and negative (-) charges.
2) Like charges repel; different charges attract.
3) Electric charge conservation: the total charges are constant in the universe.
4) Insulator, semiconductor, and conductor.
5) Coulomb's law

$$F = k\frac{|q_1||q_2|}{r^2}, \qquad (19-5)$$

6) Superposition (based on Coulomb's law): net vector force.

Example 19-3: Superposition

Three charges, each equal to +2.90 uC, are placed at three corners of a square 0.500 m on a side, as shown in the diagram. Find the magnitude and direction of the net force on charge number 3



Picture the problem

Solution

1. Find the magnitude of $\vec{F}_{31}$

$$F_{31} = k\frac{|q_1||q_3|}{(\sqrt{2}r)^2}$$

$$= (8.99\times10^9\ N.m^2/C^2)\times\frac{(2.9\times10^{-6}C)^2}{2(0.500m)^2}$$

$$= 0.151\quad N$$

2. Find the magnitude of $\vec{F}_{32}$

$$F_{32} = k\frac{|q_2||q_3|}{(r)^2}$$

$$= (8.99\times10^9\ N.m^2/C^2)\times\frac{(2.9\times10^{-6}C)^2}{(0.500m)^2}$$

$$= 0.302\quad N$$

3. Calculate the two orthogonal components of $\vec{F}_{31}$ and $\vec{F}_{32}$

$$F_{31,x} = F_{31} \cos 45.0^\circ = (0.151N)(0.707) = 0.107 \quad N$$

$$F_{31,y} = F_{31} \sin 45.0^\circ = (0.151N)(0.707) = 0.107 \quad N$$

$$F_{32,x} = F_{32} \cos 0^\circ = (0.302N)(1) = 0.302 \quad N$$

$$F_{32,y} = F_{32} \sin 0^\circ = (0.302N)(0) = 0 \quad N$$

4. Calculate the net force $\vec{F}_3$

$$F_{3,x} = F_{31,x} + F_{32,x} = 0.107N + 0.302N = 0.409 \quad N$$

$$F_{3,y} = F_{31,y} + F_{32,y} = 0.107N + 0N = 0.107 \quad N$$

$$F_3 = \sqrt{F_{3,x}^2 + F_{3,y}^2} = \sqrt{(0.409)^2 + (0.107N)^2} = 0.423 \quad N$$

5. Find the direction of $\vec{F}_3$

$$\theta_3 = \tan^{-1}\left(\frac{F_{3,y}}{F_{3,x}}\right) = \tan^{-1}\left(\frac{0.107N}{0.409N}\right) = 14.7^\circ$$