•**How do we know there are two types of electric charge?**

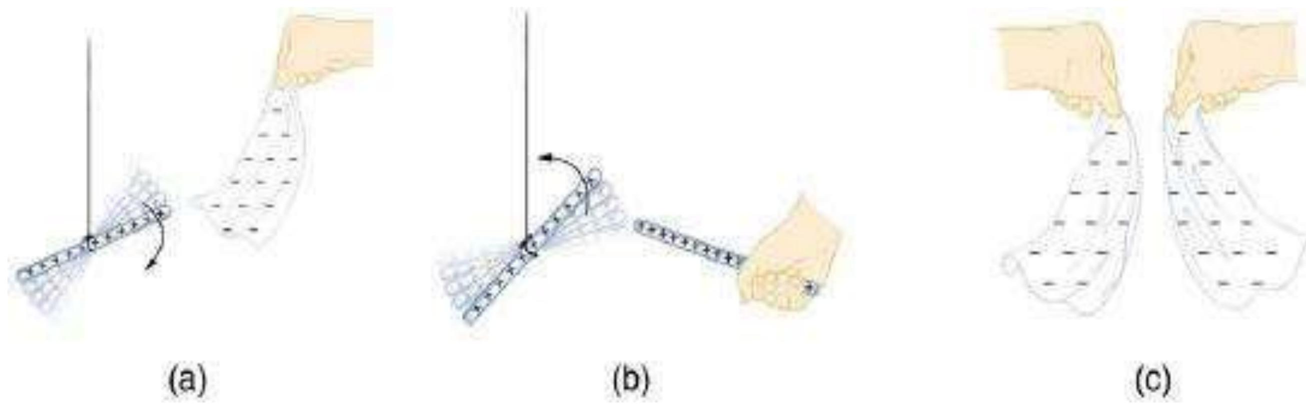
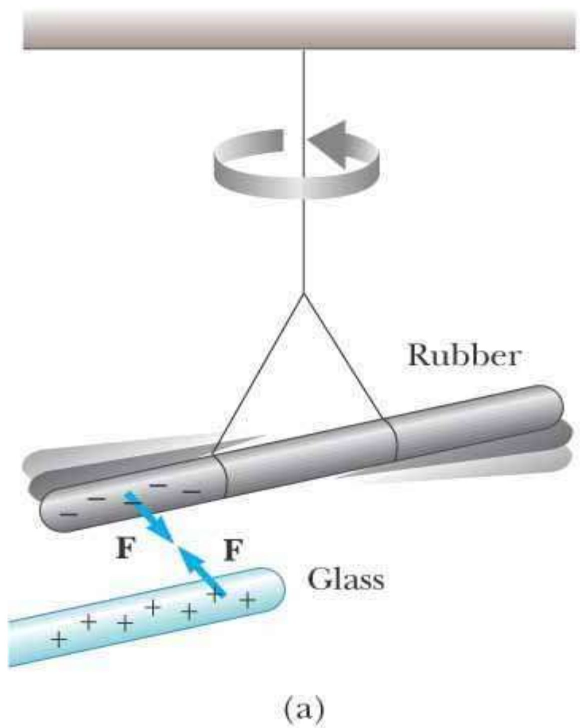


Figure .1 A glass rod becomes positively charged when rubbed with silk, while the silk becomes negatively charged. (a) The glass rod is attracted to the silk because their charges are opposite. (b) Two similarly charged glass rods repel. (c) Two similarly charged silk cloths repel.

Properties of Electric Charges

- Two types of charges exist: they are called positive and negative
- Unlike charges attract one another and Like charges repel



Electric Charge

Here are two demonstrations that seem to be magic, but our job here is to make sense of them. After rubbing a glass rod with a silk cloth (on a day when the humidity is low), we hang the rod by means of a thread tied around its center (Fig. 21-1*a*). Then we rub a second glass rod with the silk cloth and bring it near the hanging rod. The hanging rod magically moves away. We can see that a force repels it from the second rod, but how? There is no contact with that rod, no breeze to push on it, and no sound wave to disturb it.

In the second demonstration we replace the second rod with a plastic rod that has been rubbed with fur. This time, the hanging rod moves toward the nearby rod (Fig. 21-1*b*). Like the repulsion, this attraction occurs without any

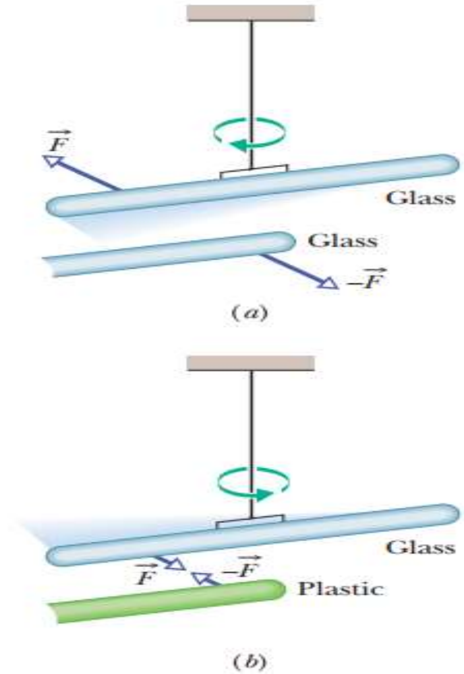


Figure 21-1 (*a*) The two glass rods were each rubbed with a silk cloth and one was suspended by thread. When they are close to each other, they repel each other. (*b*) The plastic rod was rubbed with fur. When brought close to the glass rod, the rods attract each other.

Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

In a moment we shall put this rule into quantitative form as Coulomb's law of *electrostatic force* (or *electric force*) between charged particles. The term *electrostatic* is used to emphasize that, relative to each other, the charges are either stationary or moving only very slowly.

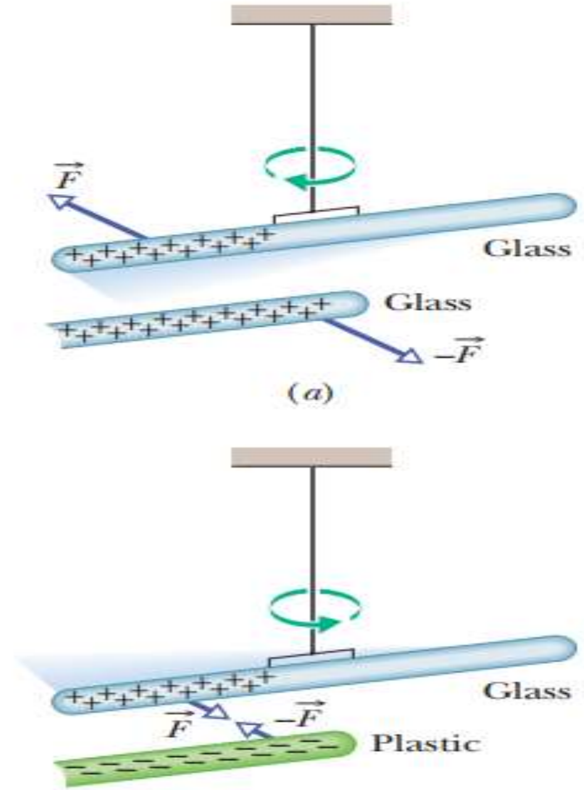


Figure (*a*) Two charged rods of the same sign repel each other. (*b*) Two charged rods of opposite signs attract each other.Plus signs indicate a positive net charge, and minus signs indicate a negative net charge.

- ## Conductors and Insulators

We can classify materials generally according to the ability of charge to move through them.
Conductors are materials through which charge can move rather freely; examples include metals (such as copper in common lamp wire), the human body, and tap water.
Nonconductors-also called **insulators**-are materials through which charge cannot move freely; examples include rubber (such as the insulation on common lamp wire), plastic, glass, and chemically pure water.
Semiconductors are materials that are intermediate between conductors and insulators; examples include silicon and germanium in computer chips.
Superconductors are materials that are *perfect* conductors, allowing charge to move without *any* hindrance.

Properties of Electric Charges

- Nature’s basic carrier of positive charge is the proton
- Protons rarely move from one material to another because they are held firmly in the nucleus Exception: electrolytes

- Nature’s basic carrier of negative charge is the electron
  - Gaining or losing electrons is how an object becomes charged (typically)

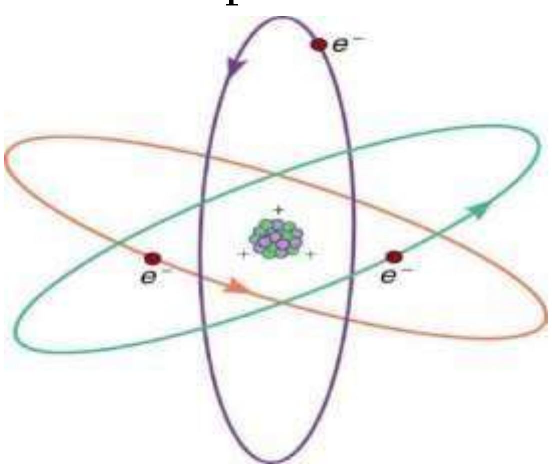
Properties of Electric Charges

- Charge is *quantized*
  - All charge is a multiple of a fundamental unit of charge e: $q=Ne$

    Quarks are the exception
  - Electrons have a charge of $-e$
  - Protons have a charge of $+e$

Charge Carried by Electrons and Protons

We have the advantage of knowing that normal matter is made of atoms, and that atoms contain positive and negative charges, usually in equal amounts. Figure shows a simple model of an atom with negative electrons orbiting its positive nucleus. The nucleus is positive due to the presence of positively charged protons. Nearly all charge in nature is due to electrons and protons, which are two of the three building blocks of most matter. (The third is the neutron, which is neutral, carrying no charge.) Other charge-carrying particles are observed in cosmic rays and nuclear decay, and are created in particle accelerators. All but the electron and proton survive only a short time and are quite rare by comparison.



- **Electric charge**

  a physical property of an object that causes it to be attracted toward or repelled from another charged object; each charged object generates and is influenced by a force called an electromagnetic force

- **Law of conservation of charge**

  states that whenever a charge is created, an equal amount of charge with the opposite sign is created simultaneously.

- **Electron**

  a particle orbiting the nucleus of an atom and carrying the smallest unit of negative charge.

- **Proton**

  a particle in the nucleus of an atom and carrying a positive charge equal in magnitude and opposite in sign to the amount of negative charge carried by an electron.

Elementary Particles: Charges and Masses

TABLE 15.1 **Charge and Mass of the Electron, Proton, and Neutron**

Particle	Charge (C)	Mass (kg)
Electron	-1.60×10^{-19}	9.11×10^{-31}
Proton	$+1.60 \times 10^{-19}$	1.67×10^{-27}
Neutron	0	1.67×10^{-27}

Coulomb's Law

- Now we come to the equation for Coulomb's law,

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

- This equation works for only charged particles. So, here we consider just **charged particles** and not, say, two charged cats.
- If two charged particles are brought near each other, they each exert an **electrostatic force** on the other. The direction of the force vectors depends **on the signs** of the charges.

If the particles have **the same sign** of charge, **they repel** each other. That means that the force vector on each is directly away from the other particle (Fig. *a* and *b*). If we release the particles, they accelerate away from each other. If, instead, the particles have **opposite signs** of charge, **they attract** each other. That means that the force vector on each is directly toward the other particle (Fig. *c*). If we release the particles, they accelerate toward each other

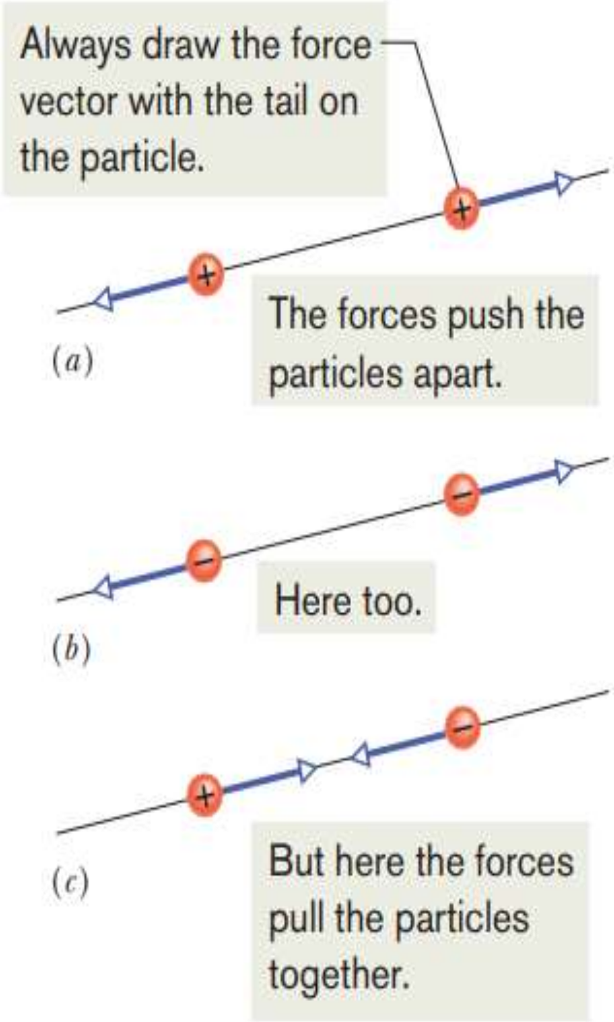
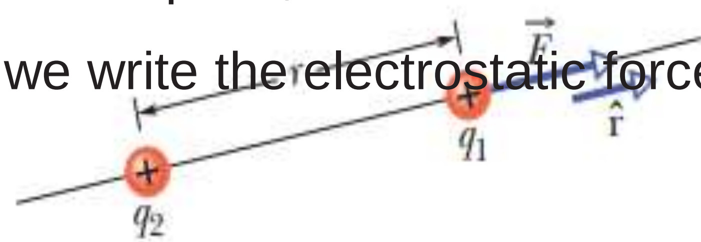


Figure. Two charged particles repel each other if they have the same sign of charge, either (*a*) both positive or (*b*) both negative. (*c*) They attract each other if they have opposite signs of charge

Vector Nature of Electric Forces

We write the equation in vector form and in terms of the particles shown in Fig. Where particle 1 has charge *q*1 and particle 2 has charge *q*2. (These symbols can represent either positive or negative charge.) Let's also focus on particle 1 and write the force acting on it in terms of a unit vector that points rˆ along a radial axis extending through the two particles, radially away from particle 2. (As with other unit vectors, has a magnitude of exactly 1 and no unit; its purpose is to point, like a direction arrow on a street sign.) With these decisions, we write the electrostatic force as



$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r} \quad \text{(Coulomb's law)},$$

Figure The electrostatic force on particle 1 can be described in terms of a unit vector along an axis through the two particles, radially away from particle 2

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

- An electrical force between two point charges has the following properties:

- It is inversely proportional to the square of the separation r between the particles and directed along the line joining them.

- It is proportional to the product 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,

k_e is called the *Coulomb Constant*

- The value of k_e depends on the choice of units

- The SI unit of charge is the Coulomb (C)

- The Coulomb constant k_e in SI

$$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \, \mathrm{N \cdot m^2/C^2}.$$

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

❑ Charges produced by rubbing are typically around:

$$1 \, \mu C = 10^{-6} \, C$$

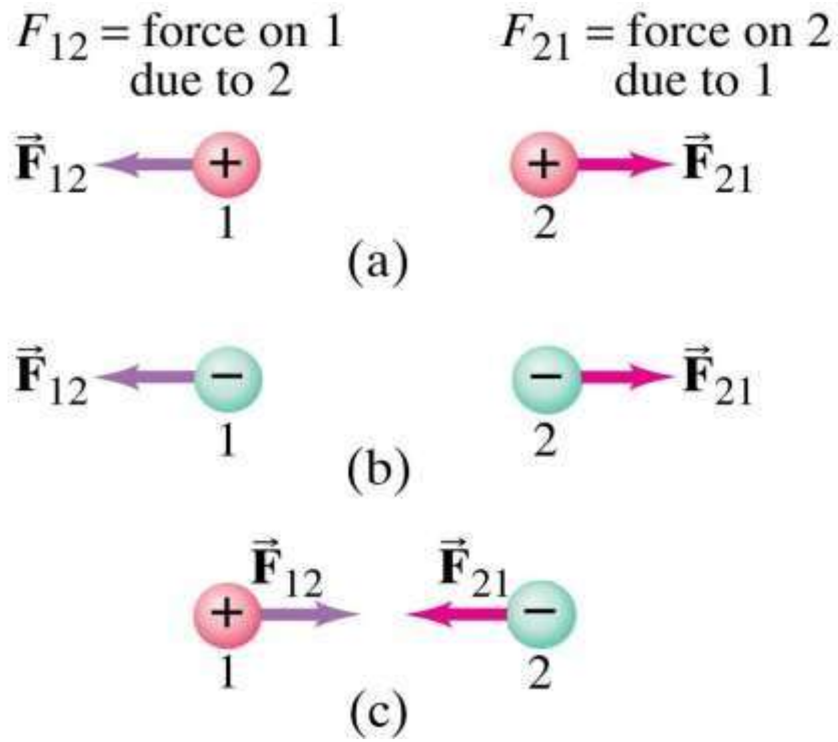
$$1 \, nC = 10^{-9} \, C$$

$$1 \, pC = 10^{-12} \, C$$

Here $\vec{F}_{12}$ is the force q_1 exerts *on* q_2 and $\hat{r}$ is a unit vector pointing *from* q_1 toward q_2.
k is the **Coulomb constant**, approximately $9.0 \times 10^9\ \text{N} \cdot \text{m}^2 / \text{C}^2$.

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

$F_{12} = - F_{21}$



The superposition principle

Multiple Forces.

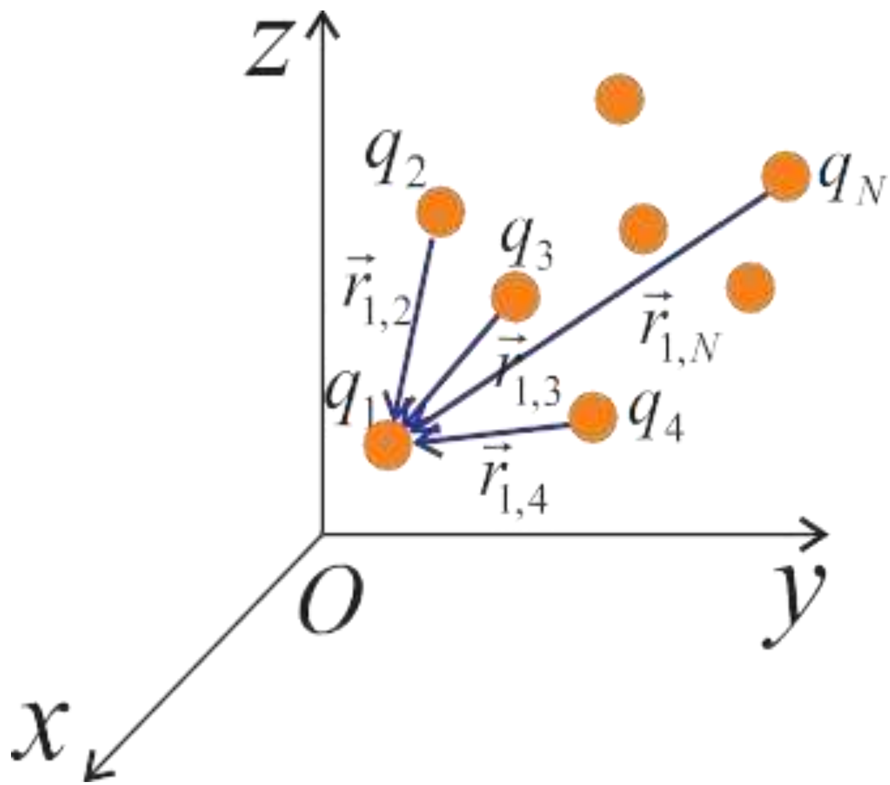
As with all forces, the electrostatic force obeys the principle of superposition. Suppose we have *n* charged particles near a chosen particle called particle 1; then tl $\vec{F}_{14}$ net force on particle 1 is given by the vector sum in which, for example, is the force on particle 1 due to the presence of particle 4.

$$\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n},$$

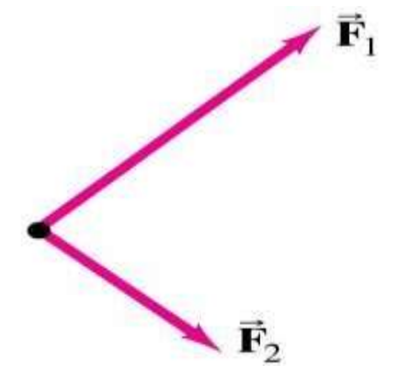
• The total force experienced by charge q_1 is the ***vector sum*** of the forces on q_1 exerted by other charges.

F_1= Force experienced by q_1 .

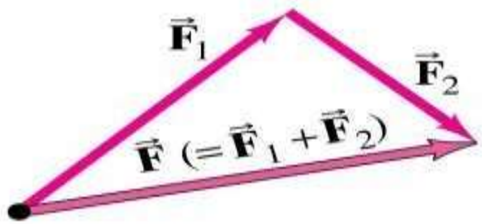
$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \cdot\cdot\cdot + \vec{F}_{1N} = \Sigma \vec{F}_{1j}$, j=2-N



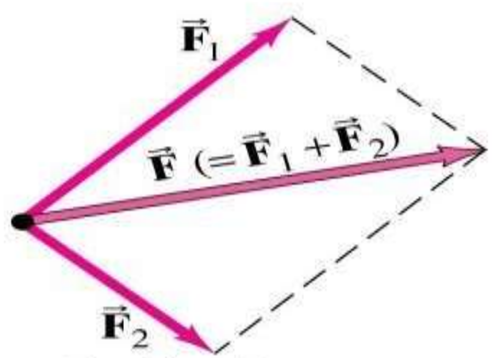
Vector addition review



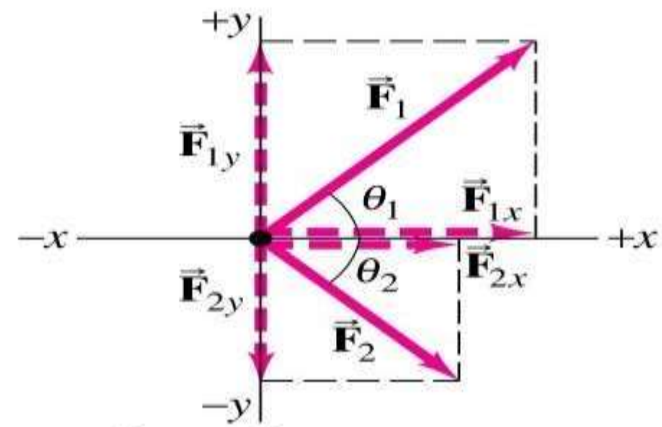
(a) Two forces acting on an object.



(b) The total, or net, force is $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the tail-to-tip method of adding vectors.



(c) $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the parallelogram method.



(d) $\vec{F}_1$ and $\vec{F}_2$ resolved into their x and y components.

Example1

This sample problem actually contains three examples, to build from basic stuff to harder stuff. In each we have the same charged particle 1. First there is a single force acting on it (easy stuff).Then there are two forces, but they are just in opposite directions (not too bad). Then there are again two forces but they are in very different directions.

$$\vec{F}_{12} = -(1.15 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{i}}.$$

$$\vec{F}_{1,\mathrm{net}} = \vec{F}_{12} + \vec{F}_{13}$$

$$= -(1.15 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{i}} + (2.05 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{i}}$$

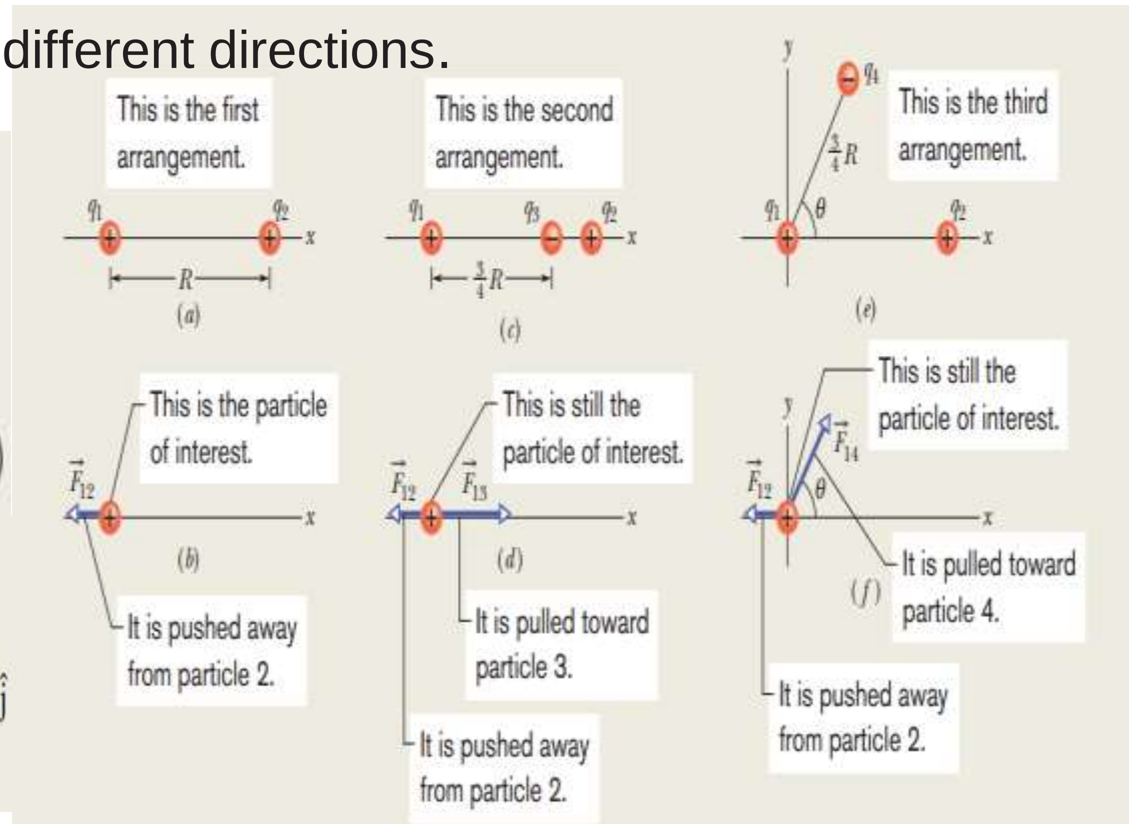
$$= (9.00 \times 10^{-25}\,\mathrm{N})\hat{\mathrm{i}}. \qquad \text{(Answer)}$$

$$\vec{F}_{1,\mathrm{net}} = \vec{F}_{12} + \vec{F}_{14}$$

$$= -(1.15 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{i}}$$

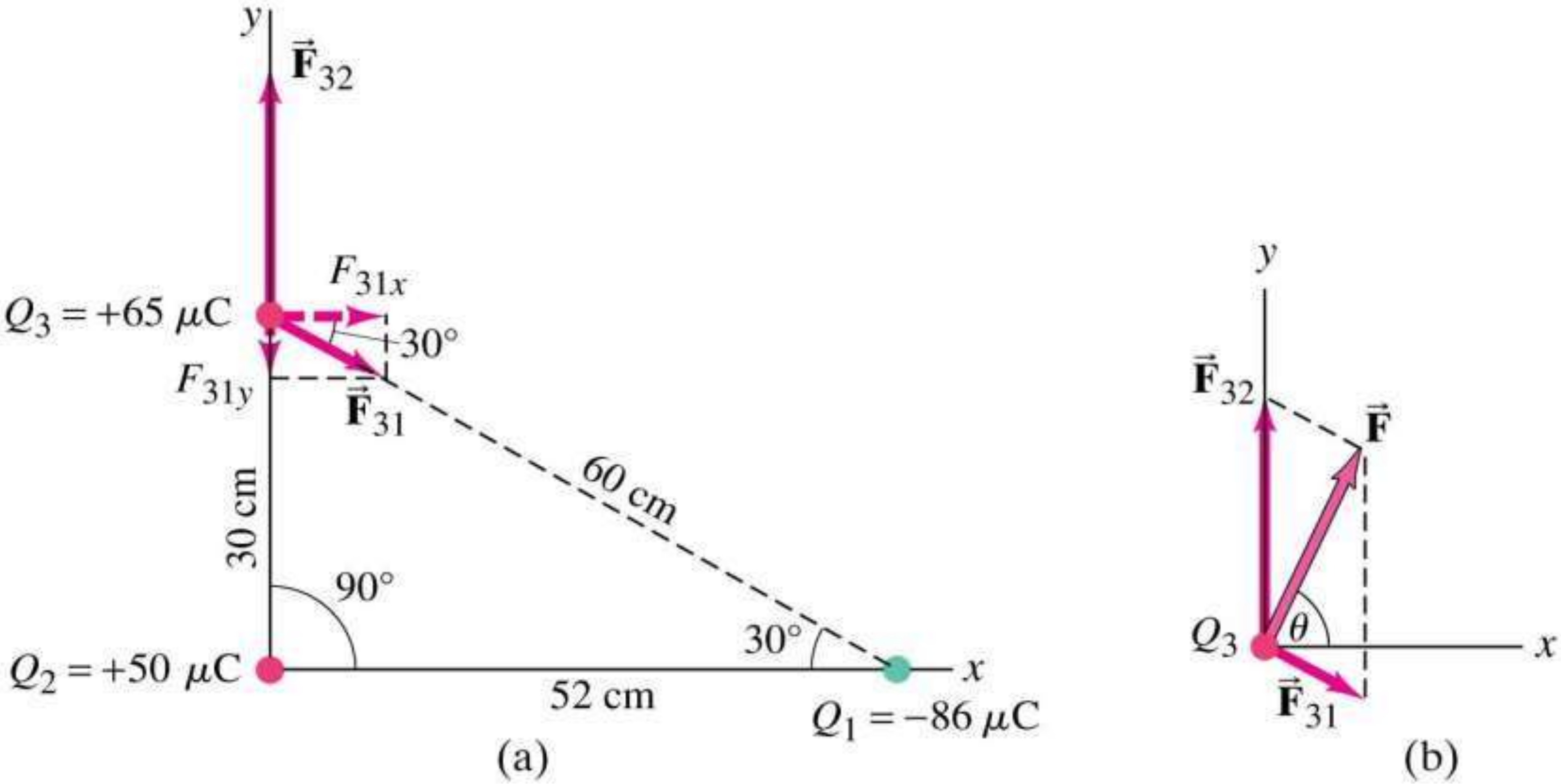
$$+ (1.025 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{i}} + (1.775 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{j}}$$

$$\approx (-1.25 \times 10^{-25}\,\mathrm{N})\hat{\mathrm{i}} + (1.78 \times 10^{-24}\,\mathrm{N})\hat{\mathrm{j}}.$$



Example 2

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.

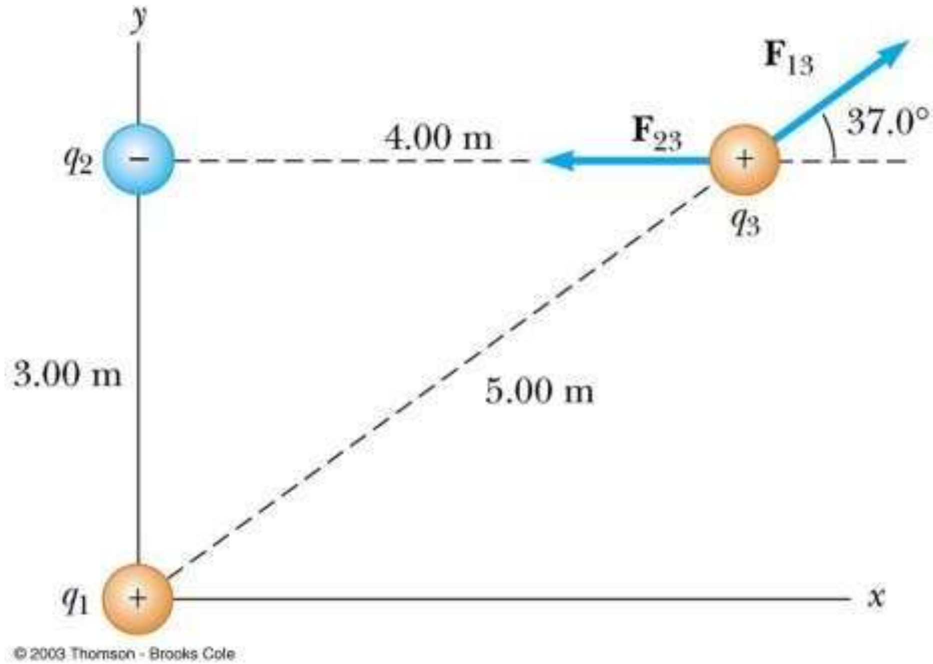


Example 3

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



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