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

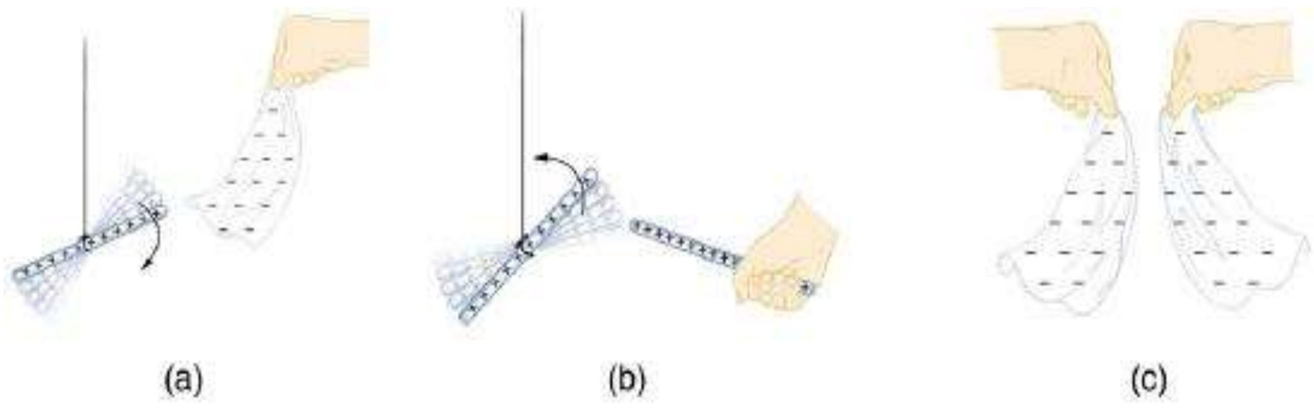
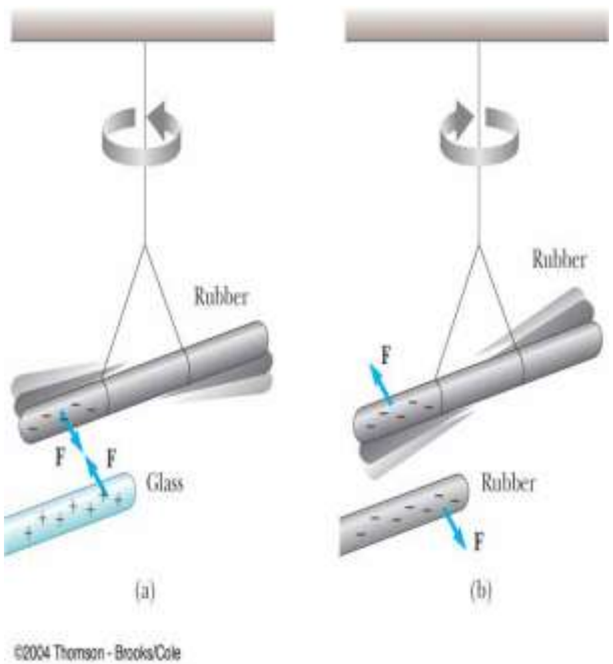
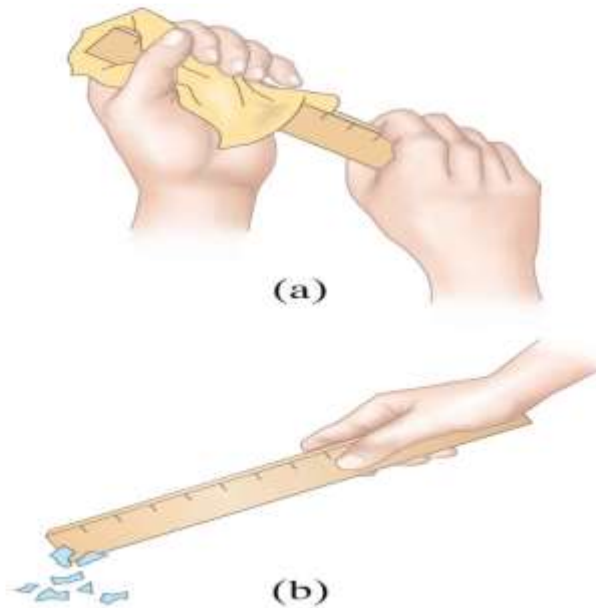


Figure .1 A glass rod becomes positively charged when rubbed with silk, while the silk becomes negatively charged. (a) The glass rod is attracted to the silk because their charges are opposite. (b) Two similarly charged glass rods repel. (c) Two similarly charged silk cloths repel.

Properties of Electric Charges

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





Objects can be charged by rubbing

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)

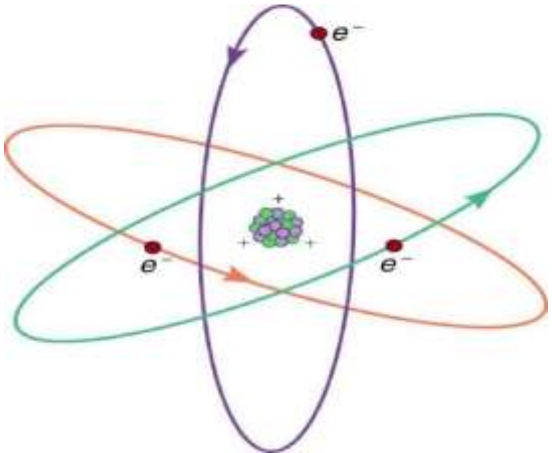
Properties of Electric Charges

- 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

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

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

- 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

  $k_e = 9 \times 10^9$ N $m^2/C^2 = 1/4\pi\varepsilon_0$

- Charges produced by rubbing are typically around:

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

$$1\ n\text{C} = 10^{-9}\ \text{C}$$

$$1\ p\text{C} = 10^{-12}\ \text{C}$$

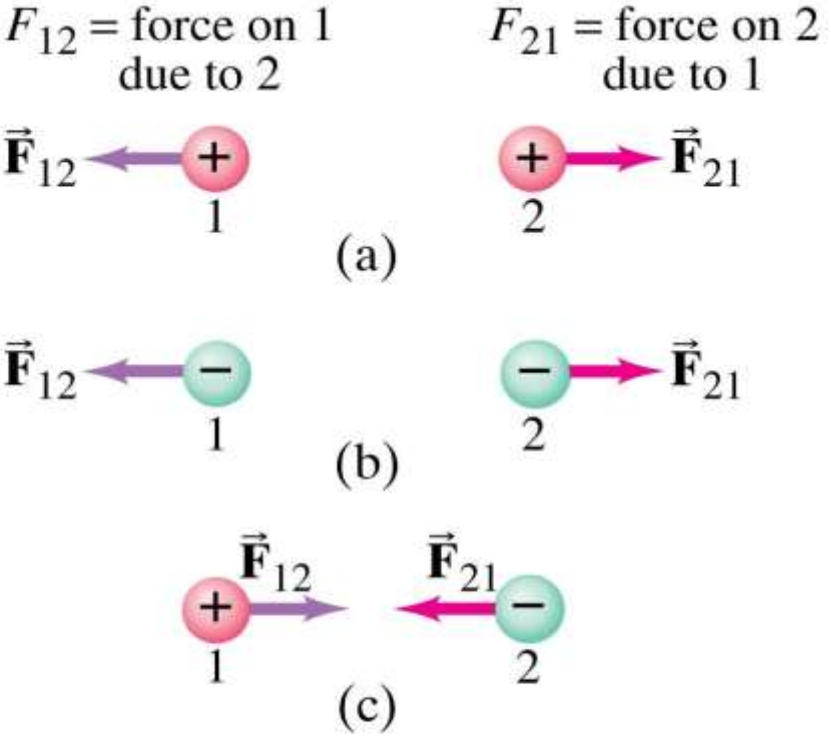
$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2.$$

Vector Nature of Electric Forces

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 $9.0\times10^9\ \mathrm{N\cdot m^2/C^2}$.

$$\vec{F}_{12} = \frac{kq_1q_2}{r^2}\hat{r}$$

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

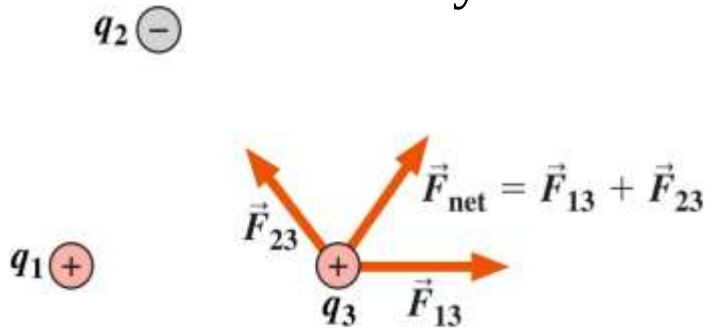


The superposition principle

- The electric force obeys the **superposition principle.**

$$\vec{\mathbf{F}}_i = k_e \sum_{j=1}^{N} \frac{q_i q_j}{r_{ij}^2} \hat{\mathbf{r}}_{ij}$$

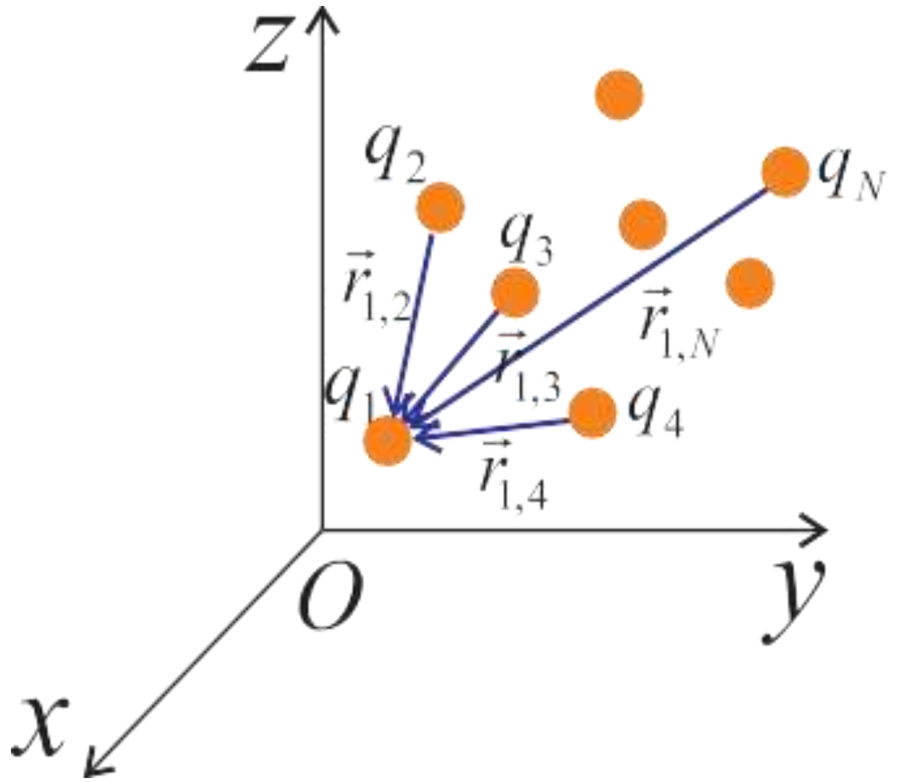
  - That means the force two charges exert on a third force is just the vector sum of the forces from the two charges, each treated without regard to the other charge.
  - The superposition principle makes it mathematically straightforward to calculate the electric forces exerted by distributions of electric charge.



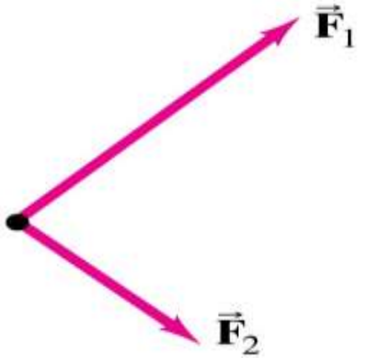
• The total force experienced by charge q_1 is the ***vector sum*** of the forces on q_1 exerted by other charges.

F_1= Force experienced by q_1 .

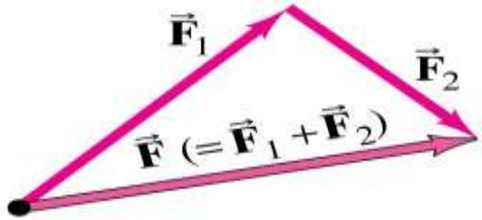
$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \cdot\cdot\cdot + \vec{F}_{1N} = \Sigma \vec{F}_{1j}$, j=2-N



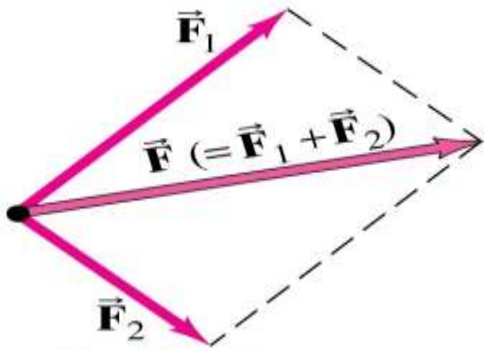
Vector addition review



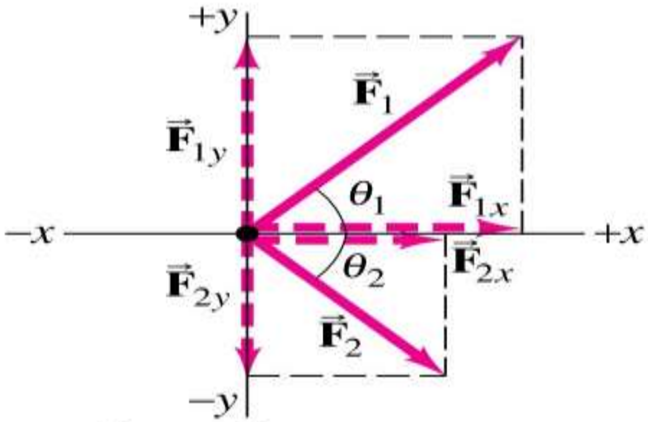
(a) Two forces acting on an object.



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



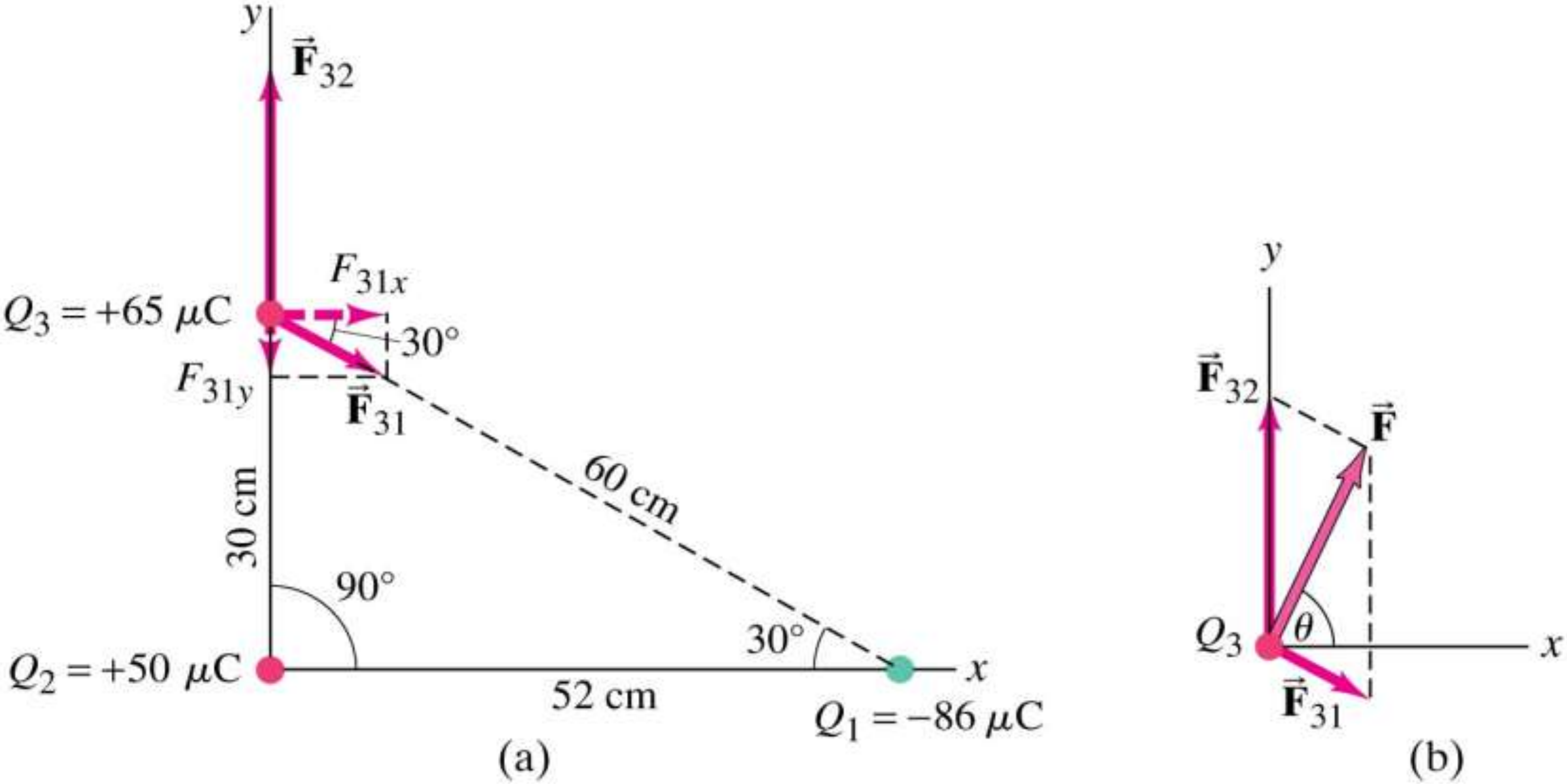
(c) $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the parallelogram method.



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

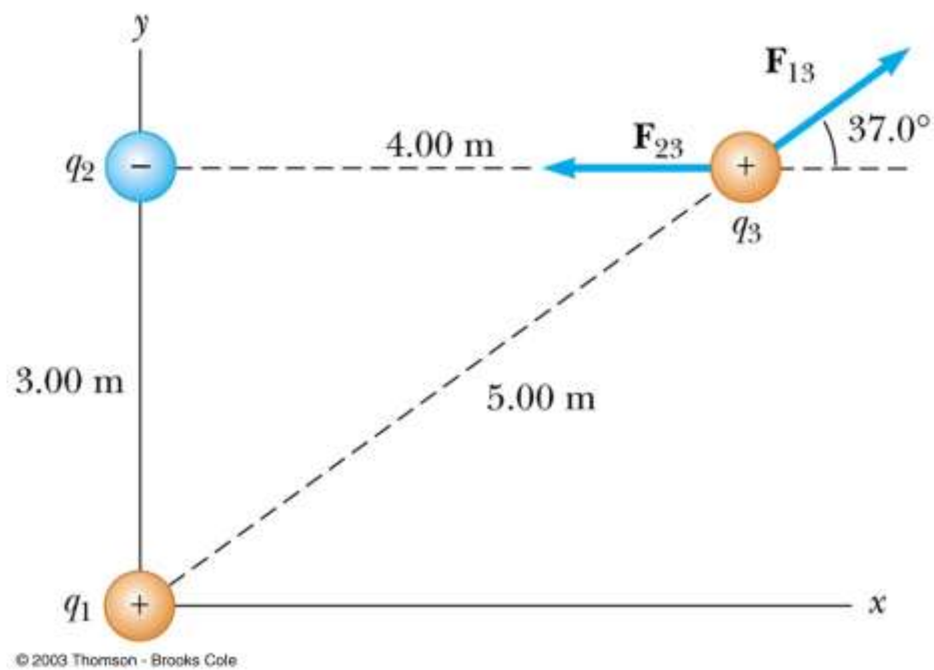
Example 1

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 2

- 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 $\mathbf{F}_{23}$



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

Electric Field

- Definition of the electric field:
  - The concept of an electric field surrounding the electric charge eliminates the problems of "action at a distance."
  - The *electric field vector* ***E*** at a point in space is the electric force ***F***$_e$ acting on a positive test charge q_0 placed at that point divided by the test charge.

The electric field vector $\vec{E}$

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}_e}{q_0}.$$

- the units in SI: Newton per Coulomb (N/C=V/m)

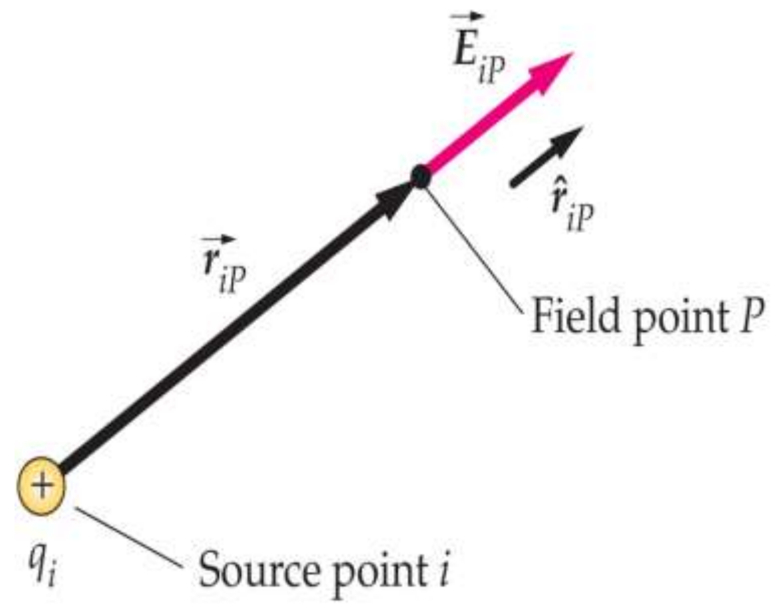
Electric Field, Vector Form

- Remember Coulomb's law, between the source and test charges, can be expressed as

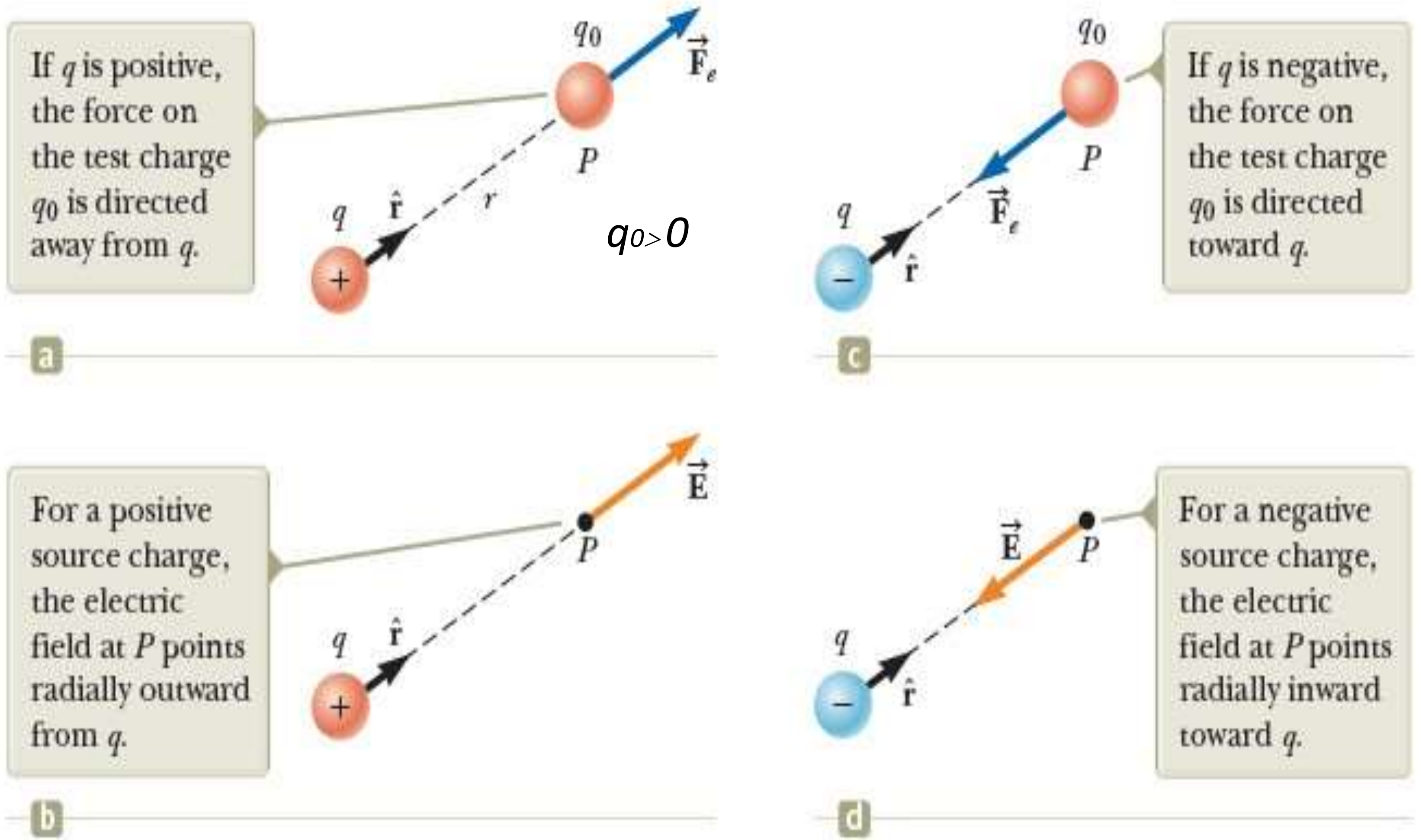
$$\vec{\mathbf{F}}_{i0} = k_e \frac{q_i\, q_o}{r_{ip}^2}\, \hat{\mathbf{r}}_{ip}$$

- Then, the electric field will be

$$\vec{\mathbf{E}}_{ip} = \frac{\vec{\mathbf{F}}_{i0}}{q_o} = k_e \frac{q_i}{r_{ip}^2}\, \hat{\mathbf{r}}_{ip}$$



More About Electric Field Direction



Superposition with Electric Fields

- At any point P, the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges.

$$\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r_i^{\,2}} \hat{\mathbf{r}}_i$$