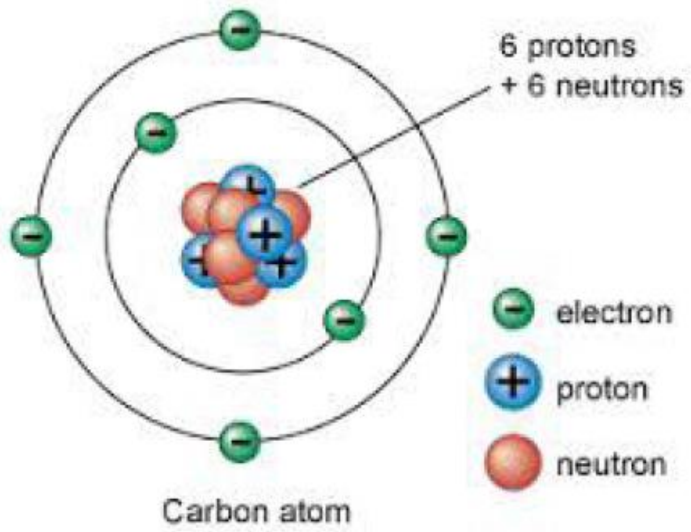
Chapter 21: Electric Charge and Electric Field

- What is the origin of the electric charge?
- How do the charges distribute in the charged objects?
- How to create charged objects?
- How much force could be induced by electric charges?
- What is electric field?
- What is an electric dipole?

What is the origin of the electric charge?

All the materials are made from atoms, and each atom is composed of nucleus (protons and neutrons) and electrons



Among them, the electrons are the ones that could possibly transferred from one atom to another.

How do the charges distribute in the charged objects?

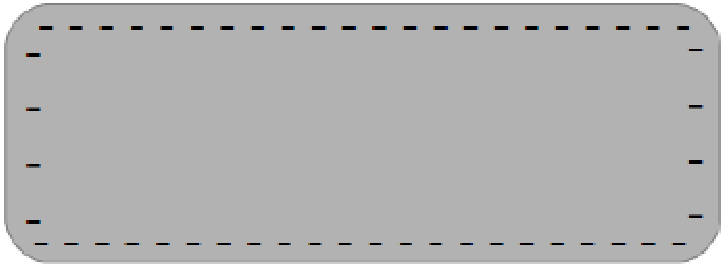
- Conductor: Charges/electrons could move freely inside it.
- Insulator: Charges/electrons could not move freely inside it. Charges/electrons will stay at where they are placed.

Insulator

Conductor

How do the charges distribute in the charged objects?

- Same sign of charges repel from each other; opposite sign of charges attract each other.
- Charges in conductor will try to repel each other until they reach the farthest distant.



Conductor

Charges in conductors will stay on SURFACE of the conductor.

How to create charged objects?

Three major ways to create charges onto materials

- Tribology/Rubbing (only works for insulators)
- Contact (Works for both insulators and conductors)
- Induction (Only work for conductors)

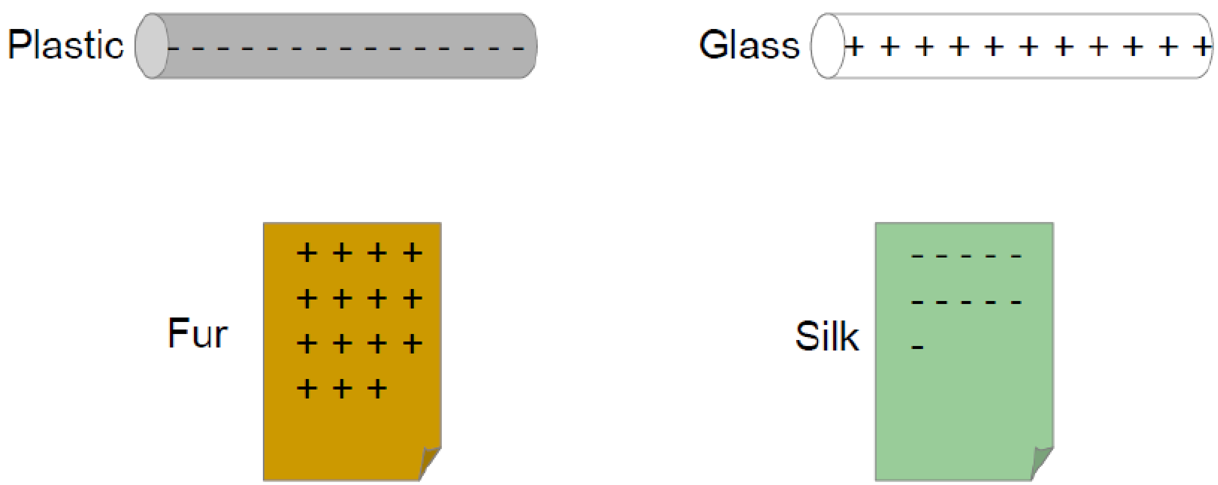
- "Electron Transfer" between materials is the main mechanism for the charges. The lack of electron infers to "positive" charge, since atoms are neutral to begin with.
- Electrons will not disappear, but just transferred, so the amount of charges is a conserved number.

How to create charged objects?

Three major ways to create charges onto materials

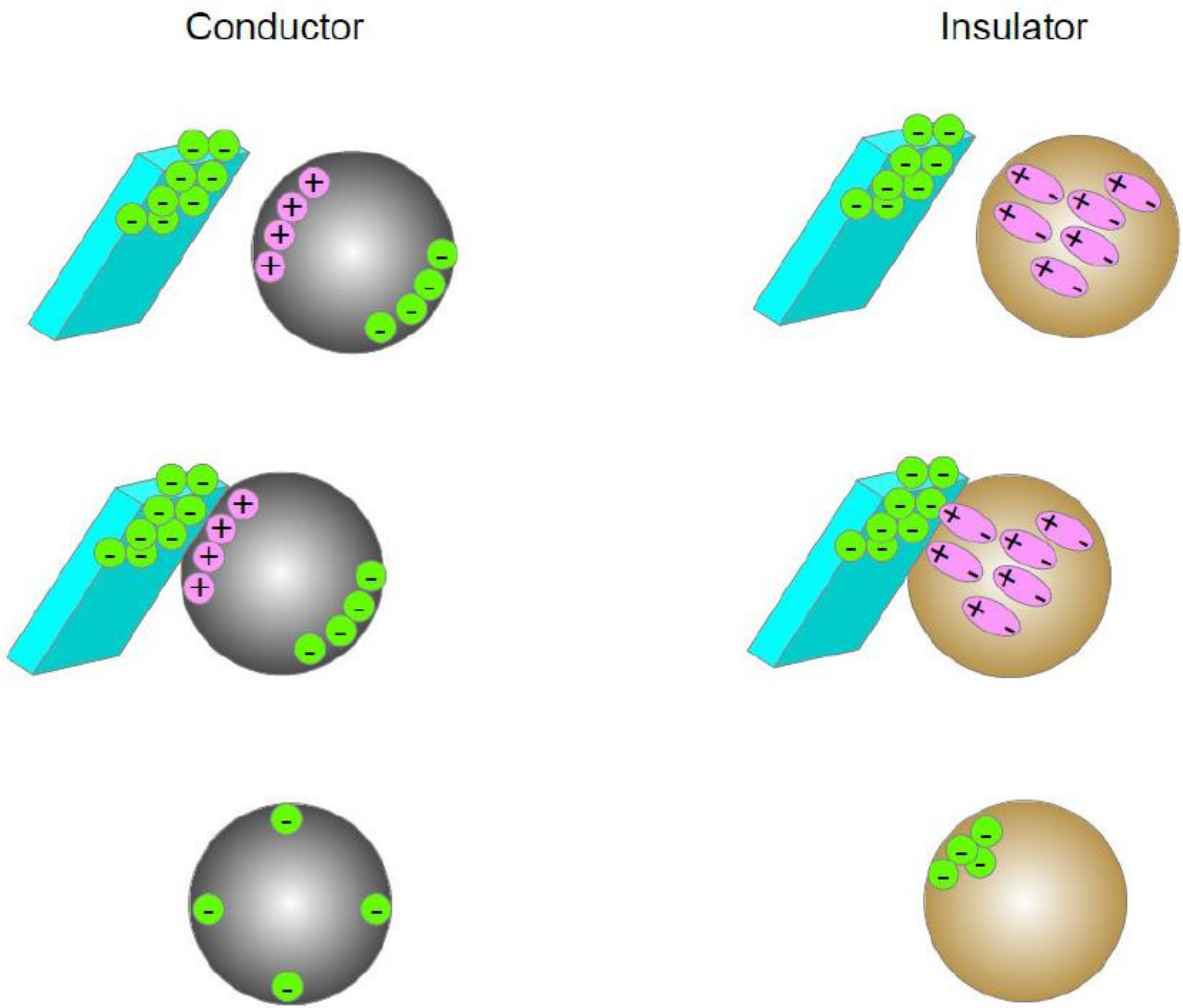
- Tribology/Rubbing (only works for insulators)
- Contact (Works for both insulators and conductors)
- Induction (Only work for conductors)

Tribology/Rubbing

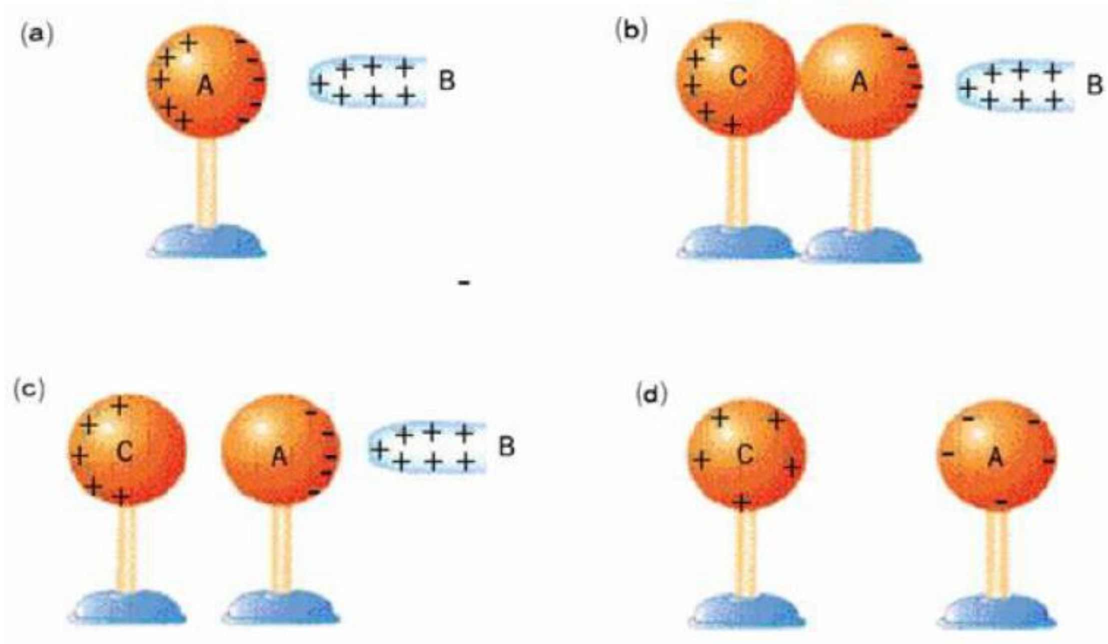


Different materials have different electron affinity

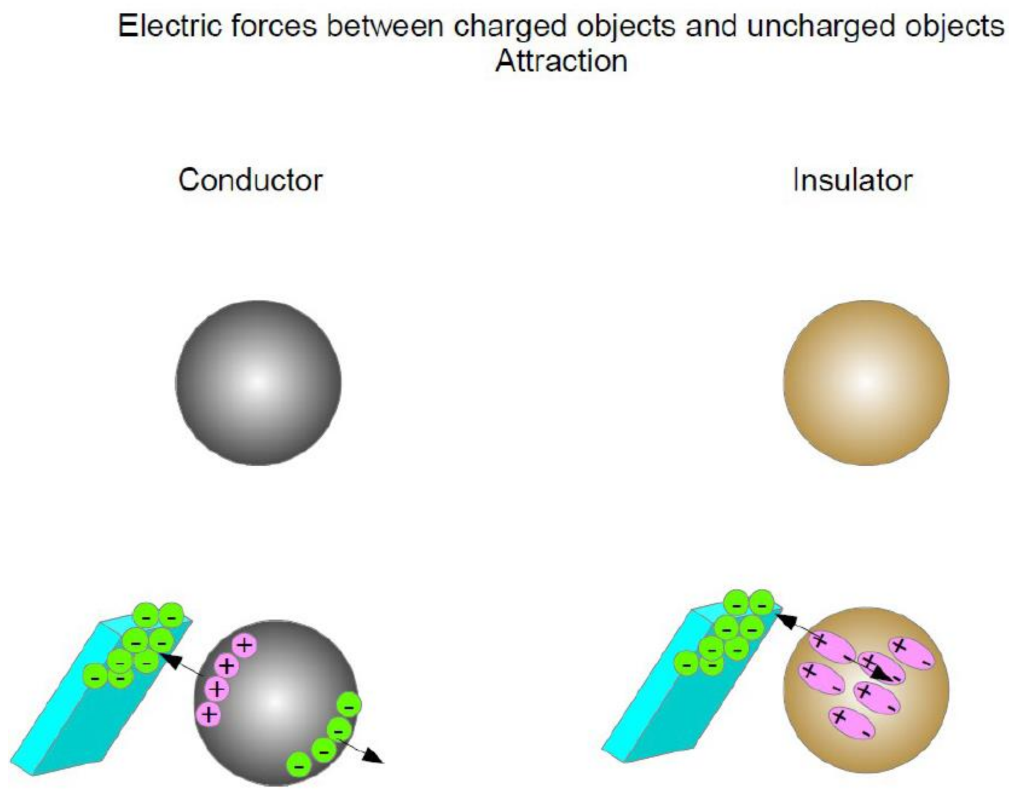
Contact



Induction



How much force could be induced by electric charges?



Electric Forces are larger when the separation is closer.
(What is the dependence on the distance?)

Coulomb’s Law

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

$\vec{F}$ is the electric force;

q_1 and q_2 are the amount of the charges of the two objects;

r is the distance between the two charged objects;

$\hat{r}$ is the unit vector representing the direction of the force is along the direction of the two objects.

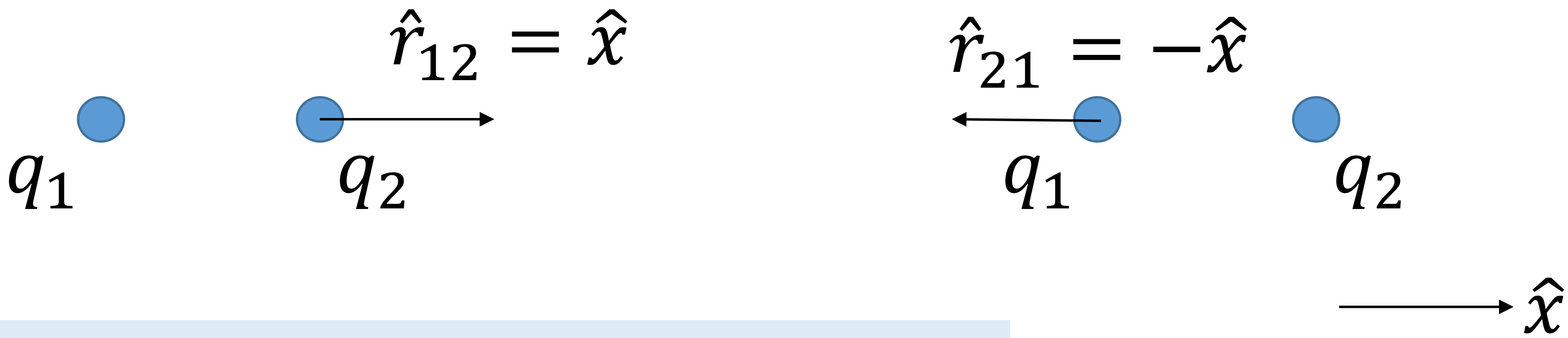
$k = \frac{1}{4\pi\epsilon_0} = 9.0\times10^9\, N\cdot m^2/C^2$

Some useful constants:

$\epsilon_0 = 8.854\times10^{-12}\, C^2/N\cdot m^2$

electron charge: $e = 1.6\times10^{-19}\, C$

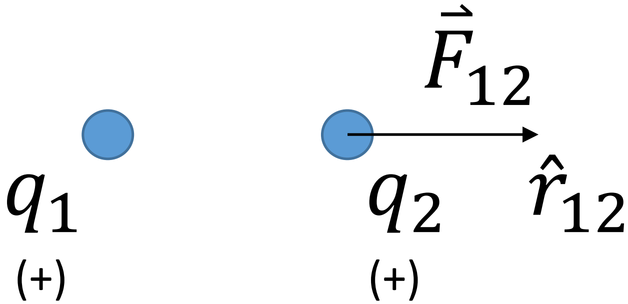
The vectors $\hat{r}$ and $\vec{F}$

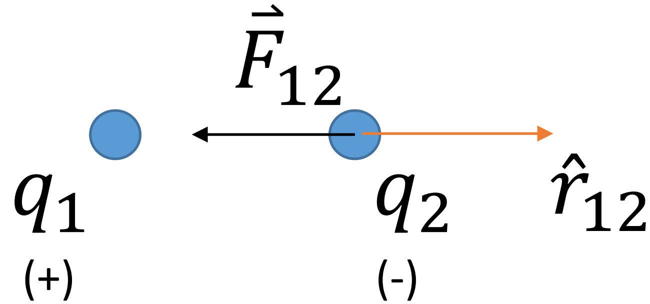


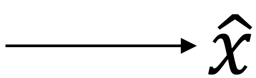
$$\hat{r}_{12} = \hat{r}_{1\ on\ 2} = \hat{r}_{source\ on\ object}$$

$\hat{r}$ has the direction from the source to the object

The vectors $\hat{r}$ and $\vec{F}$





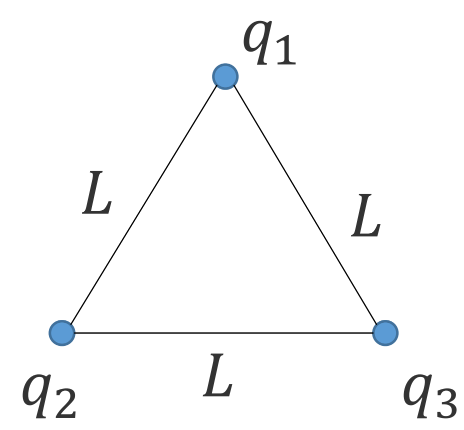


$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

$$\vec{F}_{12} = \vec{F}_{1\ on\ 2} = \vec{F}_{source\ on\ object}$$

Quiz

How to present the force on q_1? It is known that q_1 and q_2 are positive; q_3 is negative.



A. $\vec{F} = \left(k\frac{q_1q_2}{L^2}sin\frac{\theta}{2} - k\frac{q_1q_3}{L^2}sin\frac{\theta}{2}\right)\hat{x} + \left(k\frac{q_1q_2}{L^2}cos\frac{\theta}{2} + k\frac{q_1q_3}{L^2}cos\frac{\theta}{2}\right)\hat{y}$

B. $\vec{F} = \left(k\frac{q_1q_2}{L^2}sin\frac{\theta}{2} + k\frac{q_1q_3}{L^2}sin\frac{\theta}{2}\right)\hat{x} + \left(k\frac{q_1q_2}{L^2}cos\frac{\theta}{2} + k\frac{q_1q_3}{L^2}cos\frac{\theta}{2}\right)\hat{y}$

C. $\vec{F} = \left(k\frac{q_1q_2}{L^2}sin\frac{\theta}{2} - k\frac{q_1q_3}{L^2}sin\frac{\theta}{2}\right)\hat{x} + \left(k\frac{q_1q_2}{L^2}cos\frac{\theta}{2} - k\frac{q_1q_3}{L^2}cos\frac{\theta}{2}\right)\hat{y}$

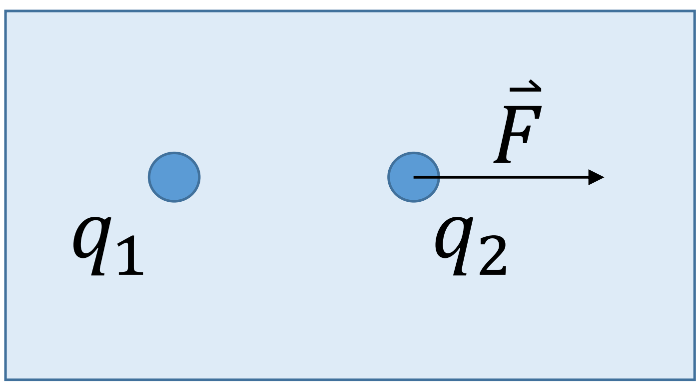
D. $\vec{F} = \left(k\frac{q_1q_2}{L^2}sin\frac{\theta}{2} - k\frac{q_1q_3}{L^2}sin\frac{\theta}{2}\right)\hat{x} - \left(k\frac{q_1q_2}{L^2}cos\frac{\theta}{2} + k\frac{q_1q_3}{L^2}cos\frac{\theta}{2}\right)\hat{y}$

E. $\vec{F} = \left(k\frac{q_1q_2}{L^2}sin\frac{\theta}{2} + k\frac{q_1q_3}{L^2}sin\frac{\theta}{2}\right)\hat{x} + \left(k\frac{q_1q_2}{L^2}cos\frac{\theta}{2} - k\frac{q_1q_3}{L^2}cos\frac{\theta}{2}\right)\hat{y}$

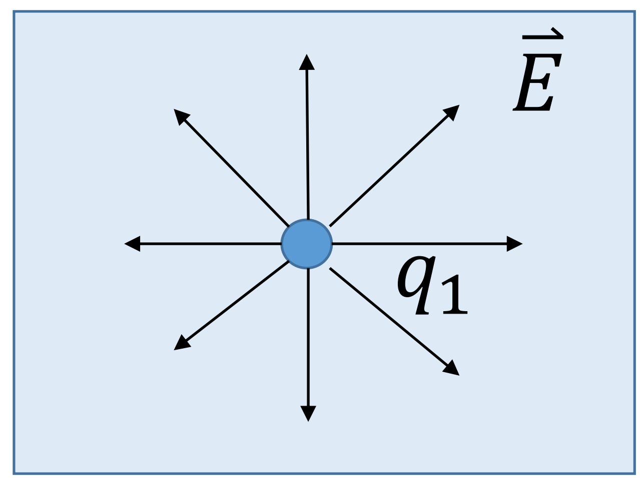
What is electric field?

$$\vec{F} = q_2\vec{E} \quad \Longleftrightarrow \quad \vec{E} = \frac{\vec{F}}{q_2}$$

$$\boxed{\vec{E} = k\frac{q_1}{r^2}\hat{r}}$$



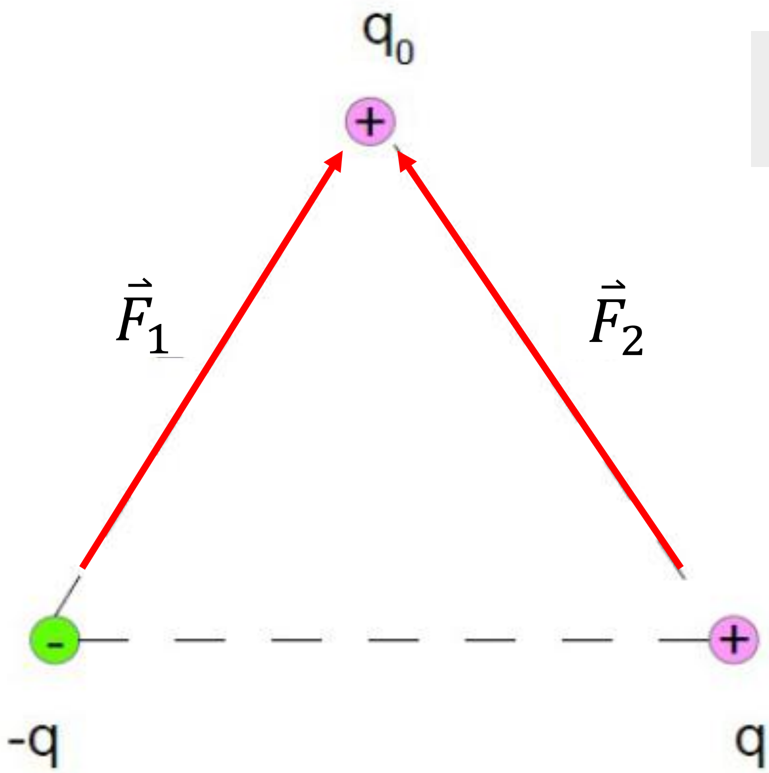
For one particular situation



Generalized situation

What is electric field?

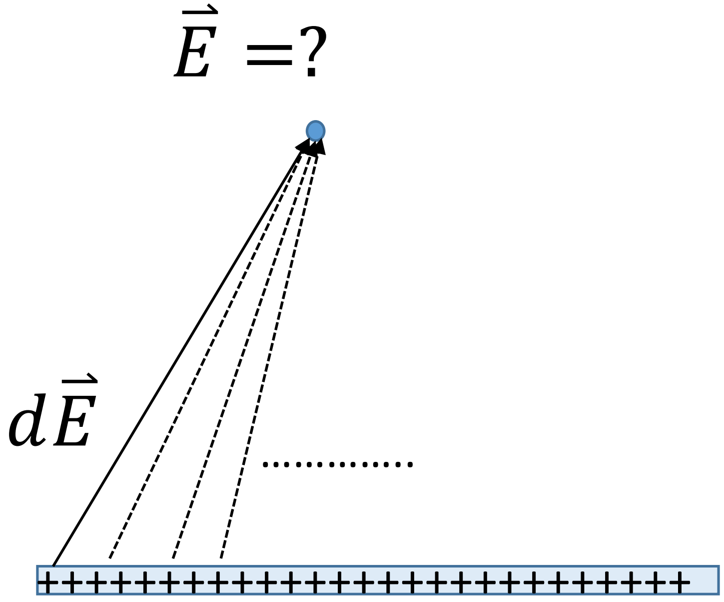
Forces could be added (as vectors), and so could Electric Field.



The force felt by q_0 and the electric field at the position of q_0 are:

$$\vec{F} = \vec{F}_1 + \vec{F}_2 = q_0\vec{E}_1 + q_0\vec{E}_2$$
$$= q_0\left(\vec{E}_1 + \vec{E}_2\right) = q_0\vec{E}$$

Calculating Electric field



$$\vec{E} = \int d\vec{E}$$

Problem 21.32

At a distance of 2.2 cm from the center of a very long uniformly charged wire, the electric field has magnitude 2000 N/C and is directed toward the wire. What is the charge on a 1.0 cm length of wire near the center?

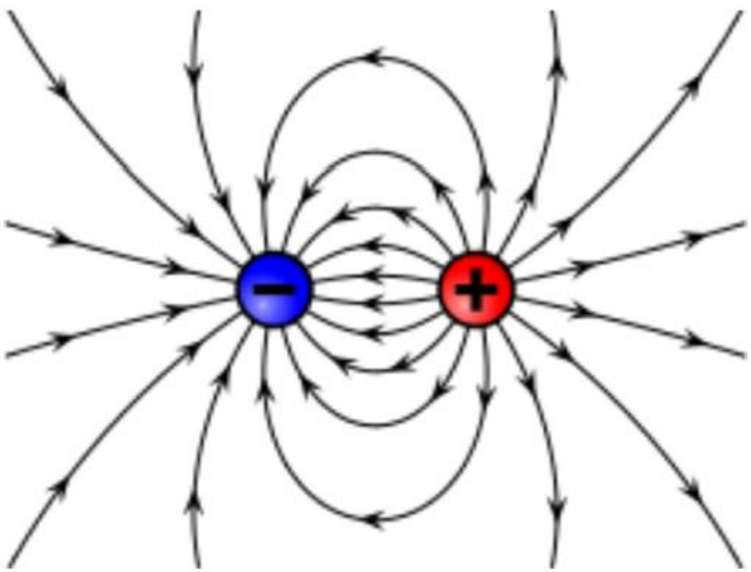
$(\varepsilon_0 = 8.85 \times 10^{-12} C^2/N \cdot m^2)$

Problem 21.96

A small sphere with mass m carries a positive charge q and is attached to one end of a silk fiber of length L. The other end of the fiber is attached to a large vertical insulating sheet that has a positive surface charge density σ.

Assume that the sphere is in equilibrium and find the angle that fiber makes with the vertical sheet.
Express your answer in terms of the variables q, σ, m and appropriate constants.

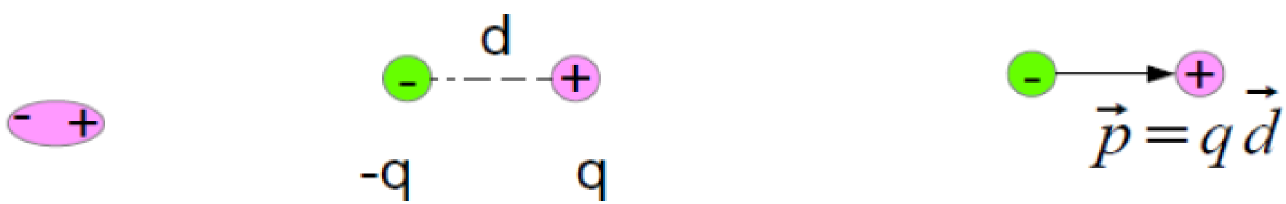
Visualizing Electric Field: The electric field lines



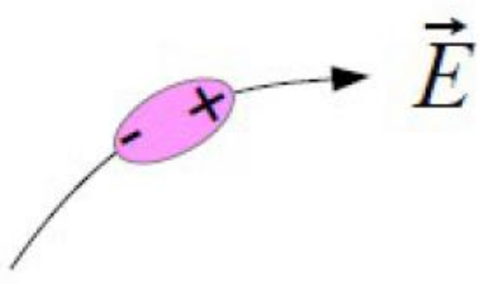
- Electric field lines start at (come out of) positive charges, and end at (going into) negative charges.
- Electric field lines do not intersect with each other.
- The electric field strength could be understood as the line density.
- The direction of the electric field at a certain point is the tangential direction of the electric field line at that location.

What is an electric dipole?

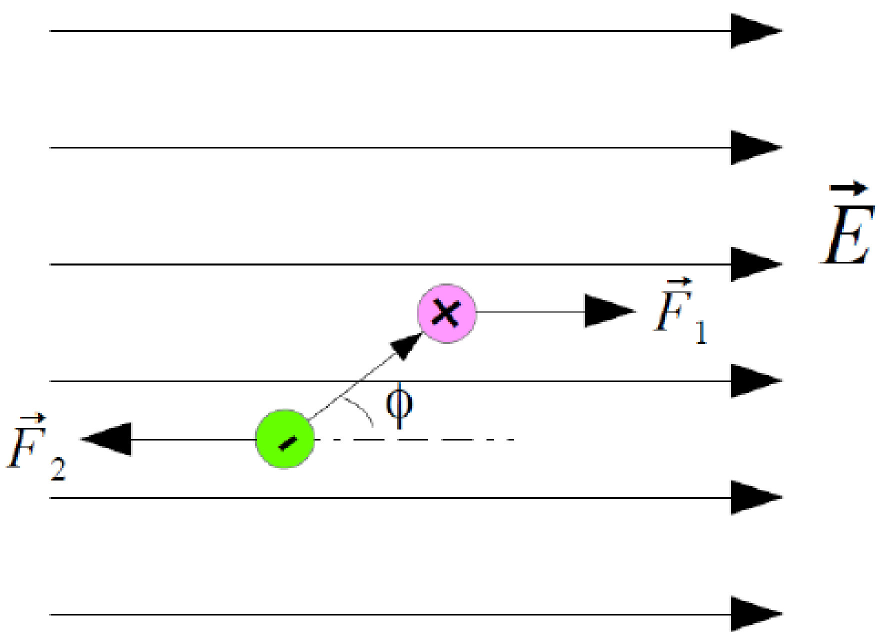
Electric Dipole: A pair of point charges with equal amount and opposite sign. (*q* and –*q* with distance of *d*)



Electric dipoles will align with electric field due to the electric force.



How much torque the electric dipole has if it is not align with electric field?

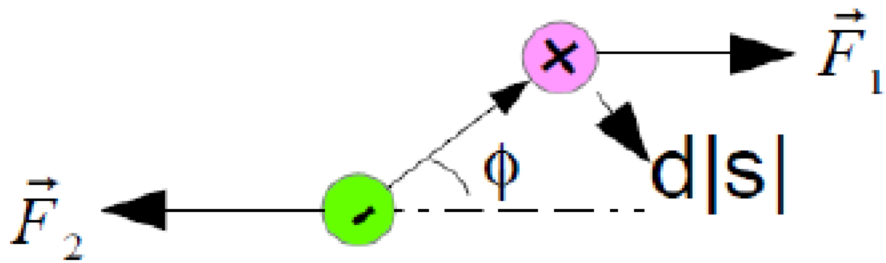


$$\vec{F}_1 = q\vec{E} \quad ; \quad \vec{F}_2 = -q\vec{E}$$

$$\vec{\tau} = \vec{r} \times \vec{F} = \frac{d}{2} \cdot |\vec{F}_1| \cdot \sin(\phi) + \frac{d}{2} \cdot |\vec{F}_2| \cdot \sin(\phi) = qd\,|\vec{E}| \sin(\phi) = |\vec{p}||\vec{E}| \sin(\phi) = \vec{p} \times \vec{E}$$

$$\vec{\tau} = \vec{p} \times \vec{E}$$

How much potential energy the electric dipole has if it is not align with electric field?



$$W=\vec{F}\cdot\vec{s}=\int q\,|\vec{E}|\cdot\sin(\phi)\cdot d\,|\vec{s}|+q\,|\vec{E}|\cdot\sin(\phi)\cdot d\,|\vec{s}|=\int 2q\,|\vec{E}|\cdot\sin(\phi)\cdot d\,|\vec{s}|$$

$$d\,|\vec{s}|=\frac{d}{2}\cdot d\,|\phi|=-\frac{d}{2}\cdot d\,\phi$$

$$W=-2q\,|\vec{E}|\int_{\phi_1}^{\phi_2}\sin(\phi)\frac{d}{2}\,d\,\phi=qd\,|\vec{E}|(-\cos(\phi_2)-(-\cos(\phi_1)))=qd\,|\vec{E}|\cos(\phi_2)+qd\,|\vec{E}|\cos(\phi_1)$$

$$W=|\vec{p}||\vec{E}|\cos(\phi_2)-|\vec{p}||\vec{E}|\cos(\phi_2)$$

$$U=-\vec{p}\cdot\vec{E}$$