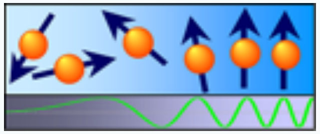
Experimental Physics EP2a

Thermodynamics & Electricity

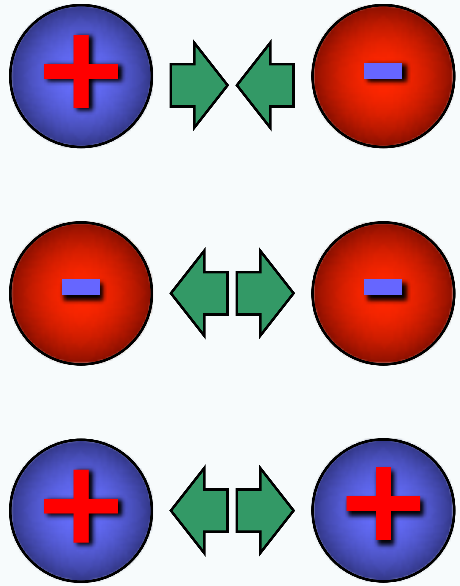
– Electric charge –
Conductors, Coulomb's law



https://bloch.physgeo.uni-leipzig.de/amr/

Electric charge

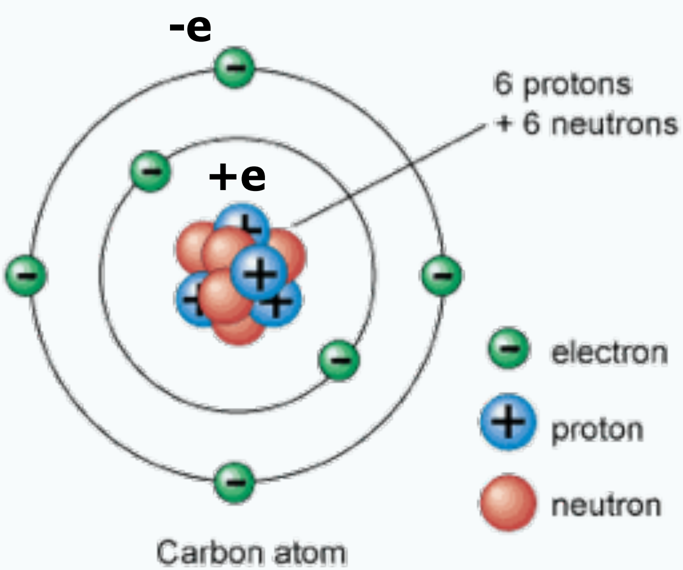
- Air
- Human Hands
- Asbestos
- Glass
- Human Hair
- Mica
- Nylon
- Wool
- Lead
- Silk
- Aluminum
- Paper
- Cotton
- Steel
- Wood
- Rubber balloon
- Hard rubber
- Nickel, Copper
- Brass, Silver
- Gold, Platinum
- Sulfur
- Celluloid
- Silicon
- Teflon



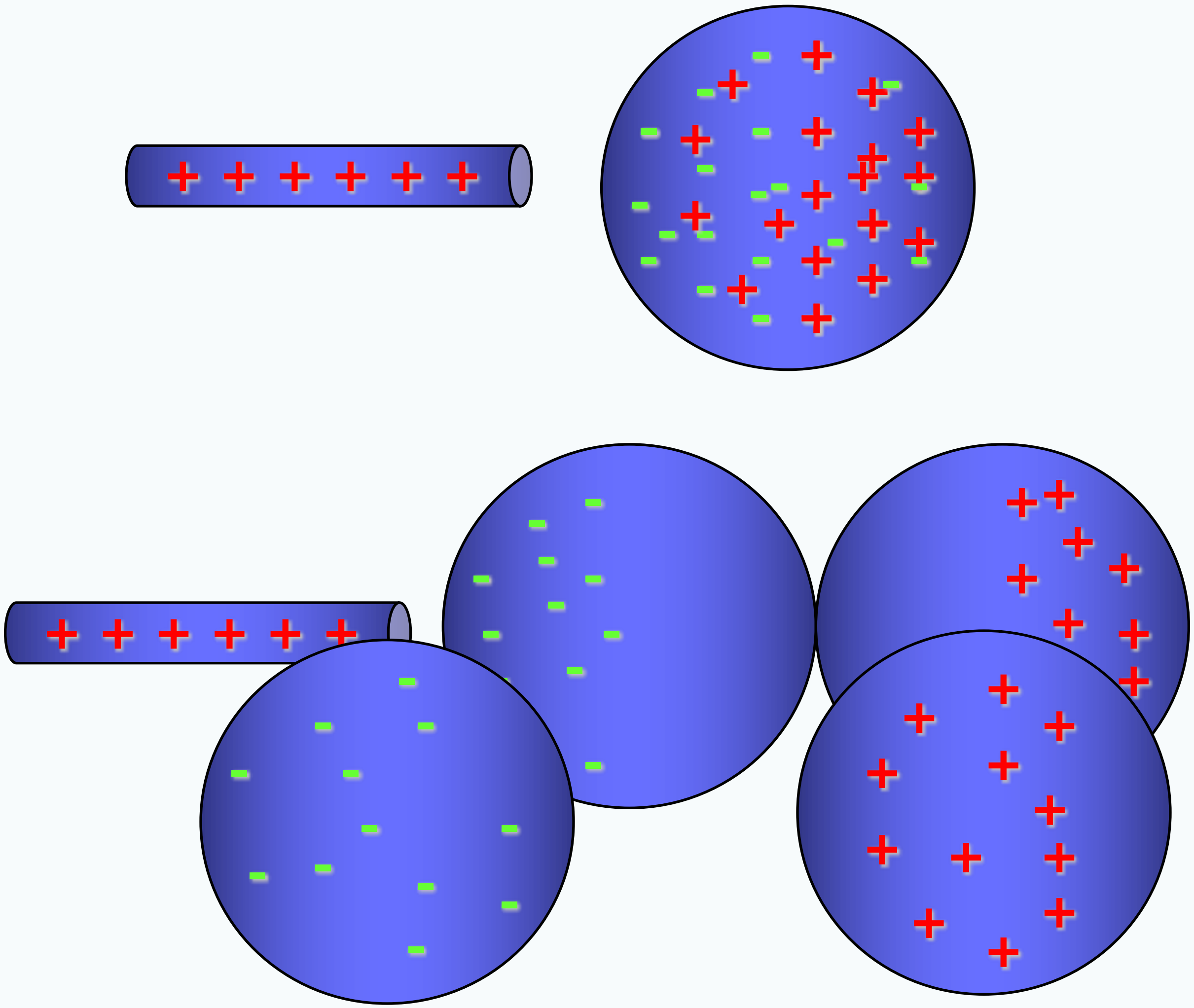
Benjamin Franklin
January 17, 1706 Boston
April 17, 1790 Philadelphia

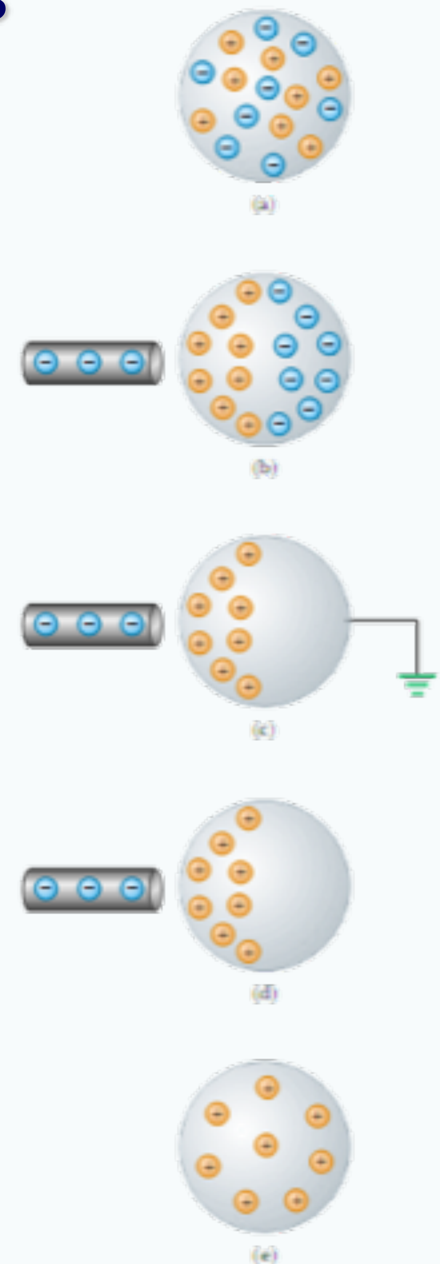
$$e = 1.602177 \times 10^{-19}\ \mathrm{C}$$

Charge is conserved.

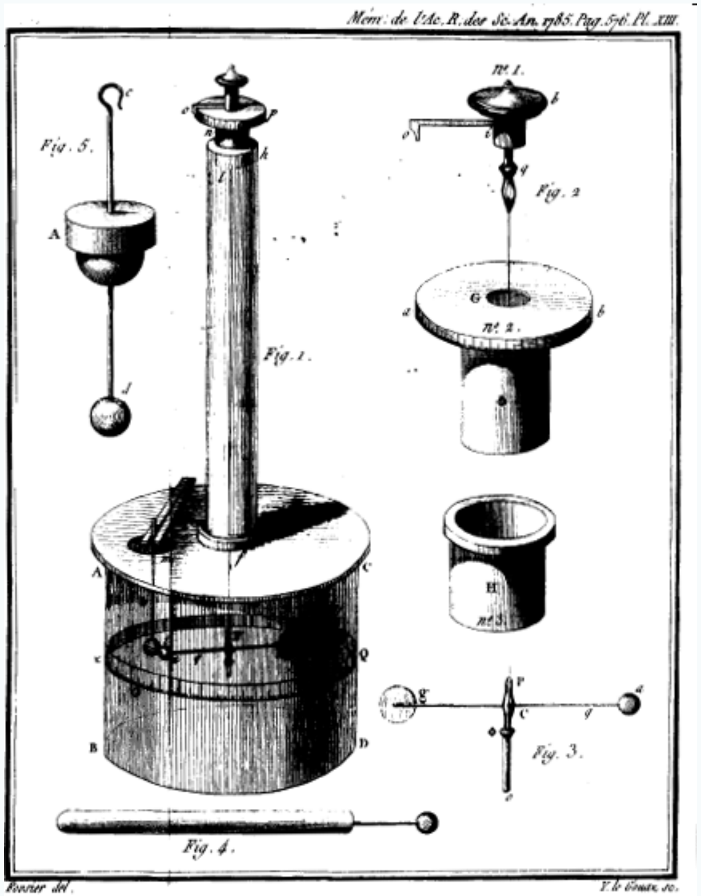


Conductors and insulators





Coulomb's law



The force exerted between two charges acts along the line connecting the charges.

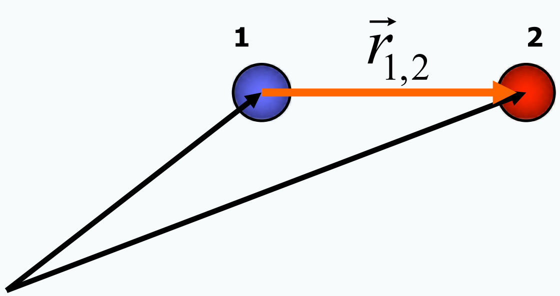
It varies inversely proportional to the square of the distance separating the charges.

It is proportional to the product of the charges.

The force is repulsive if the charges have the same sign and attractive if they are opposite.

$$\vec{F}_{1,2} = \frac{k q_1 q_2}{r_{1,2}^2} \hat{r}_{1,2}$$

$$F_{1,2} = \frac{k |q_1 q_2|}{r_{1,2}^2}$$



$$k = 8.9875 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$$

$$k = (4\pi\varepsilon_0)^{-1}$$

Some examples

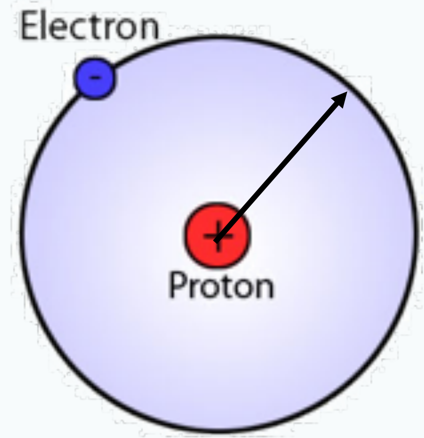
$e = 1.6 \times 10^{-19}$ C

$m_p = 1.67 \times 10^{-27}$ kg

$m_e = 9.11 \times 10^{-31}$ kg

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

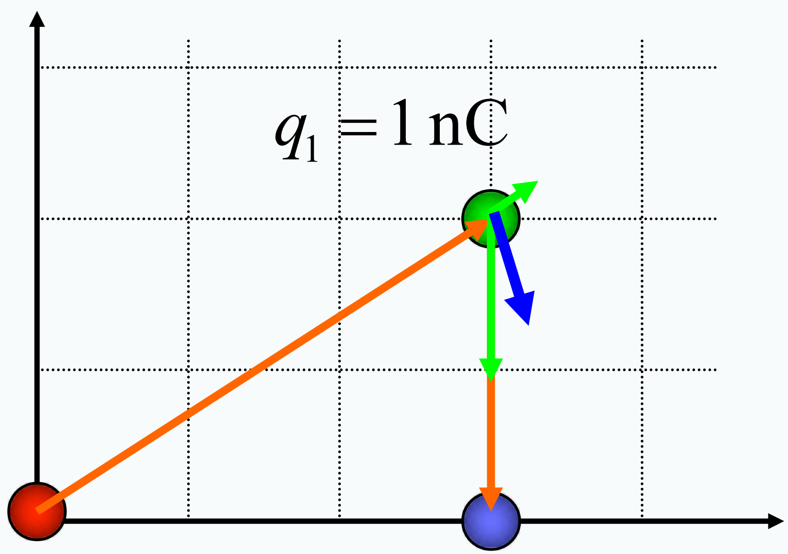
$$\frac{F_e}{F_g} - ?$$



$$r = 5.3 \times 10^{-11}\ \text{m}$$

$$F_e - ? \qquad a - ?$$

$$q_1 = 1\,\text{nC}$$



$$q_1 = 1\,\text{nC} \qquad q_1 = -2\,\text{nC}$$

To remember!

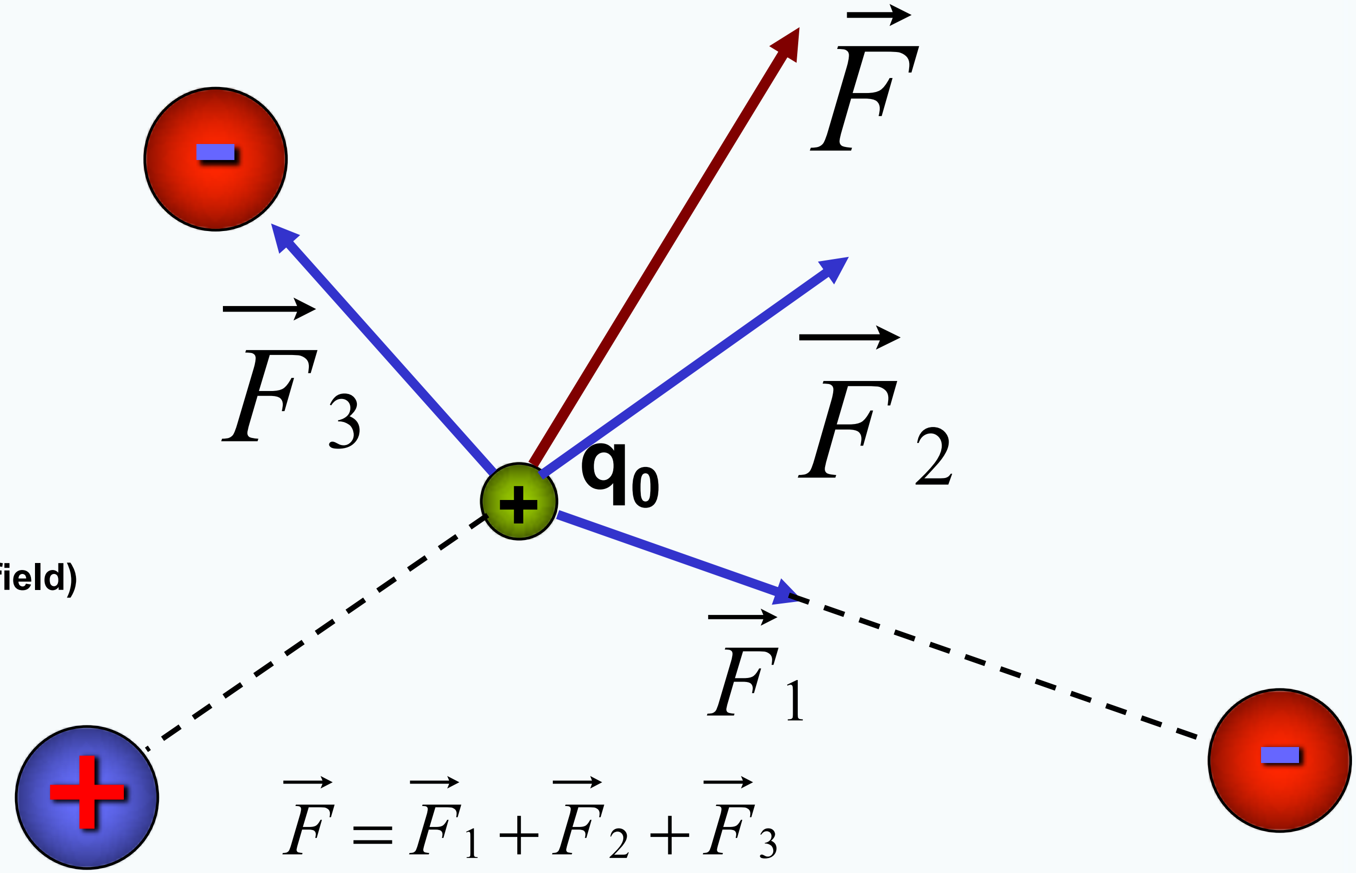
- Unlike charges attract one another, like charges repel.
- Charge is conserved.
- Charge is quantized – integer number of electronic charge.
- Conductors are materials in which electrons move freely.
- In insulator electrons do not move freely.
- Coulomb's law states that force due to charges:

(i) inversely proportional to square distance,

(ii) proportional to the product of charges,

(iii) the proportionality constant is called the Coulomb constant.

Electric field



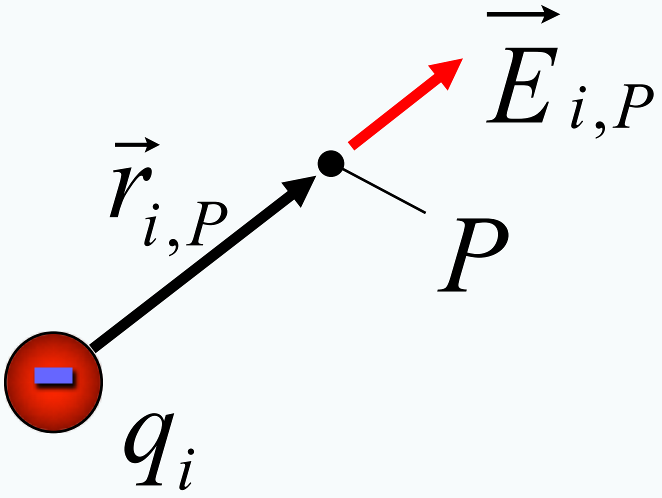
- q_0 is a **test charge**
(i.e. q_0 is small enough
to not alter the electric field)
- q_0 is **positive**

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

$$\vec{E} = \lim_{q_0 \to 0} \vec{F} / q_0 \qquad 1\,N/C = 1\,kg \cdot m \cdot s^{-3} \cdot A^{-1} = 1\,V/m$$

Electric field

Coulombs law:



electric field, due to charge q_i at point P

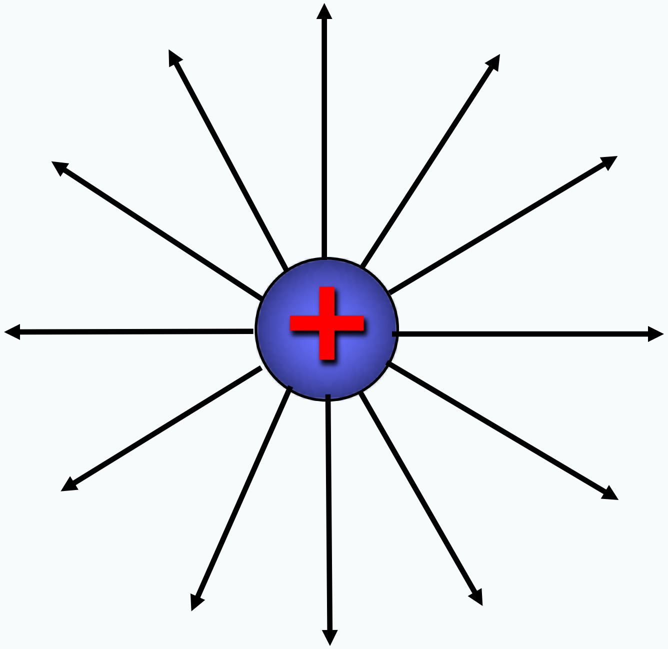
$$\vec{E}_{i,P} = \frac{kq_i}{r_{i,P}^{\ 2}} \hat{r}_{i,P}$$

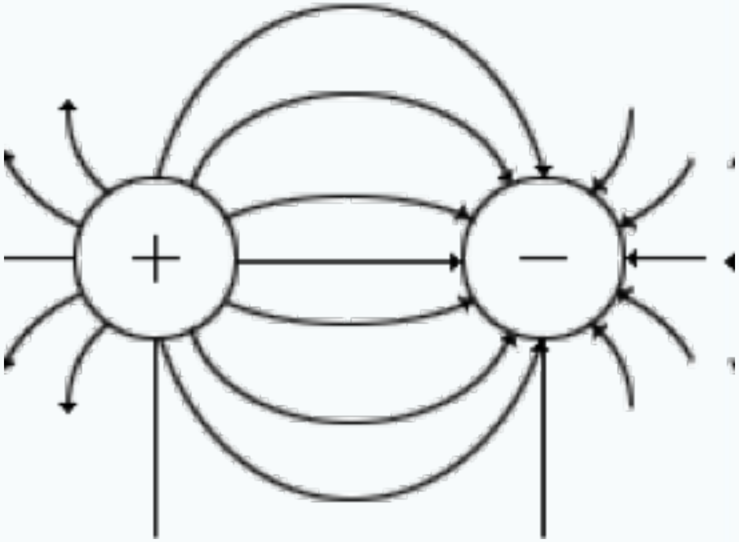
net electric field, due to a distribution of point charges

$$\vec{E}_P = \sum_i \vec{E}_{i,P} = \sum_i \frac{kq_i}{r_{i,P}^{\ 2}} \hat{r}_{i,P}$$

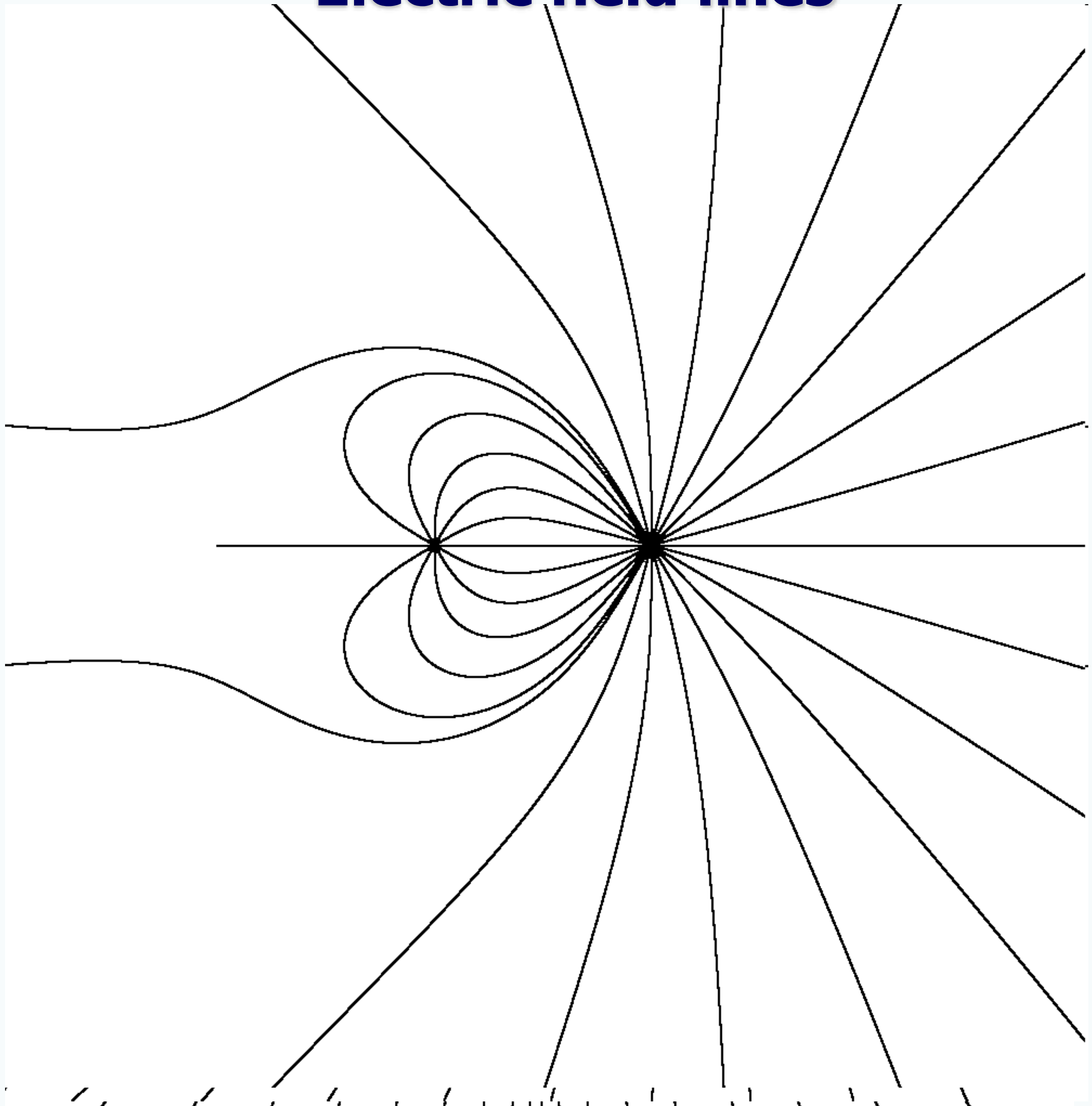
Electric field lines

- electric field lines (also lines of force) show the direction of the force exerted on a positive test charge
- electric field lines begin on positive charges (or infinity) and end on negative charges (or infinity)
- the electric field lines point radially away from positive charges and towards negative charges
- the density (spacing) of the lines is proportional to the electric field strenght at that point
- the number of lines leaving or entering a charge is proportional to the magnitude of the charge
- field lines do not cross





Electric field lines



Motion of a Point Charge in the Electric Field

$$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{q}{m}\vec{E}$$

the rest is mechanics…

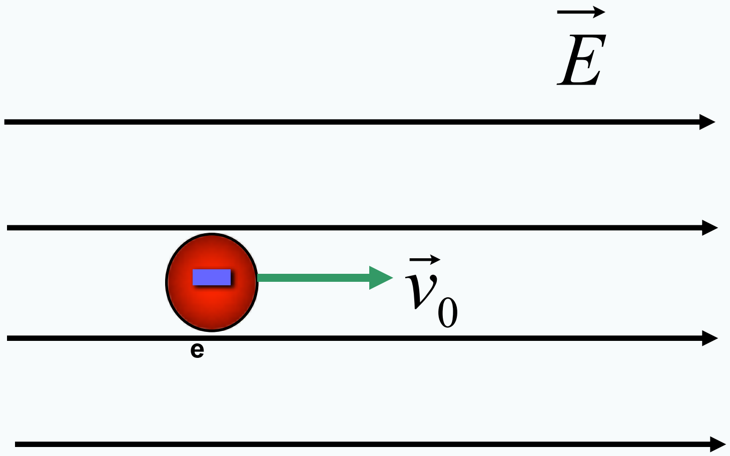
<u>example:</u> electron in uniform electric field

How far can it travel until it is momentarily stopped?

$$E_x = 1kN/C$$

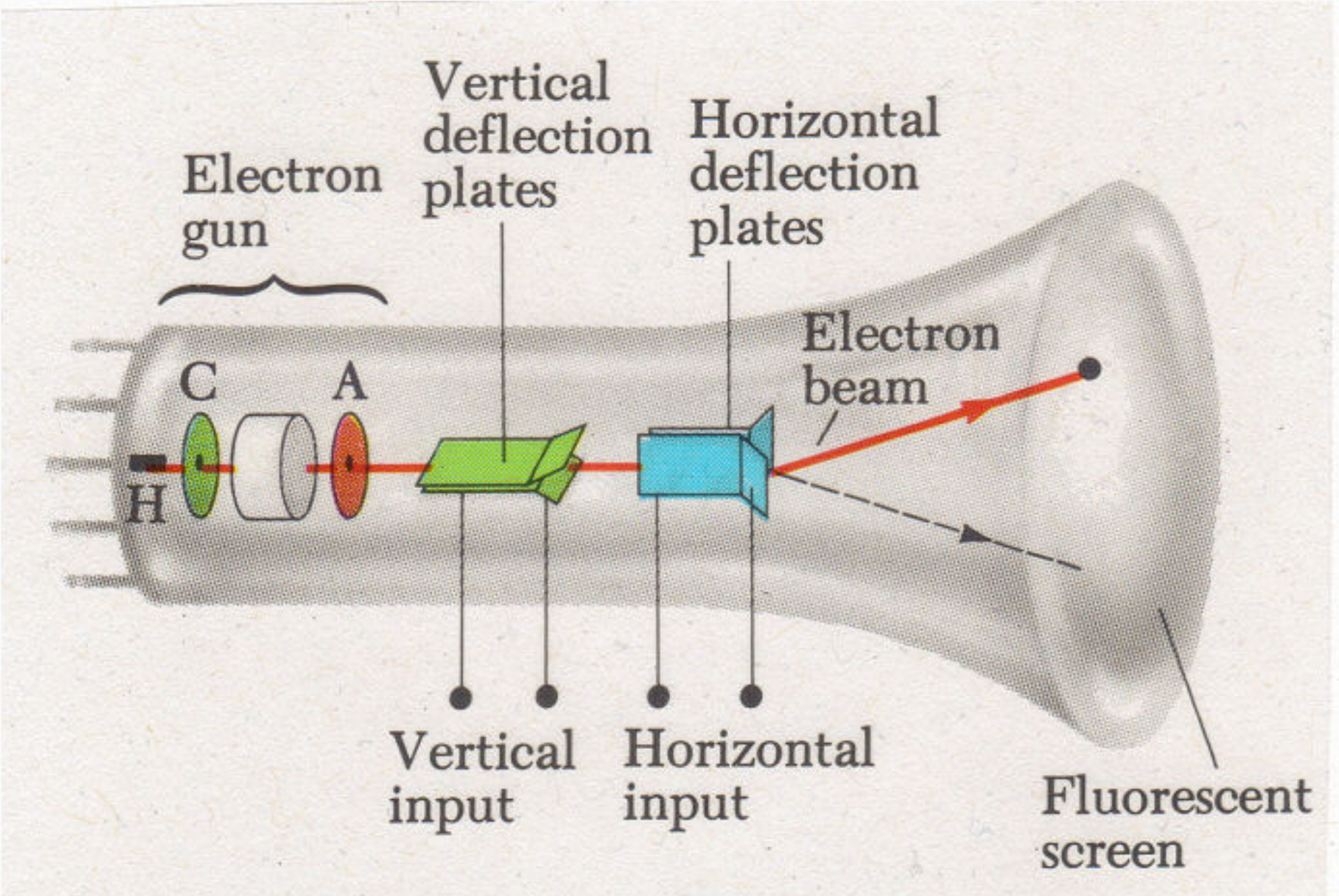
$$v_{0,x} = 2 \cdot 10^6 m/s$$

$$a_x = \frac{F_x}{m} = \frac{-eE}{m}$$



$$\Delta x = \frac{v^2{}_x - v_{0,x}^2}{2a_x} \longrightarrow v_x = 0 \longrightarrow \Delta x = \frac{mv_{0,x}^2}{2eE} = 1.14cm$$

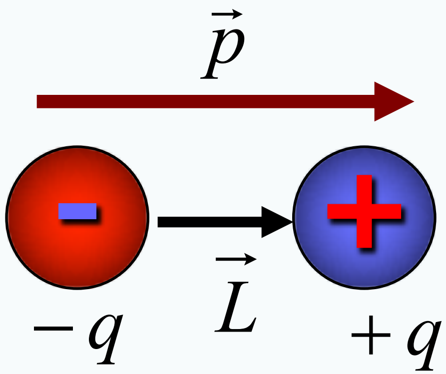
Motion of point-like charges in electric fields



→ **compare with physics of throws (mechanics, EP1)**

Electric dipoles

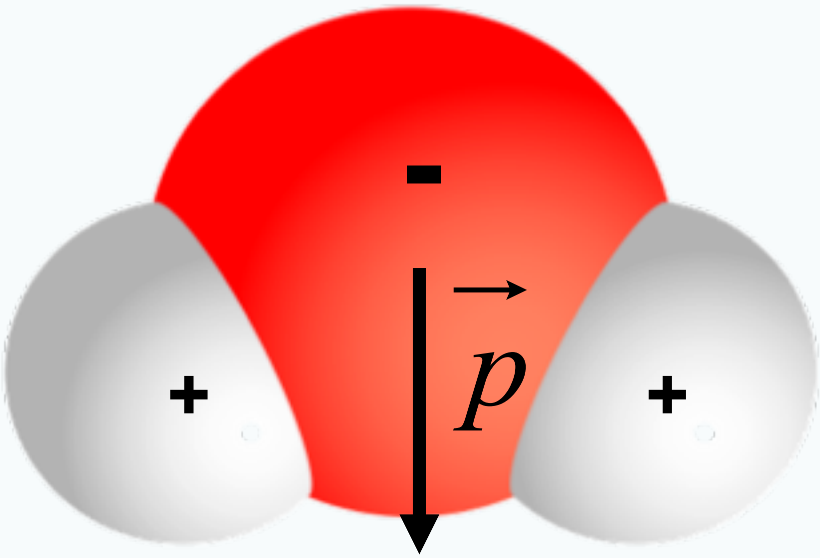
A system of two equal and opposite charges q separated by a small distance L ia called an electric dipole

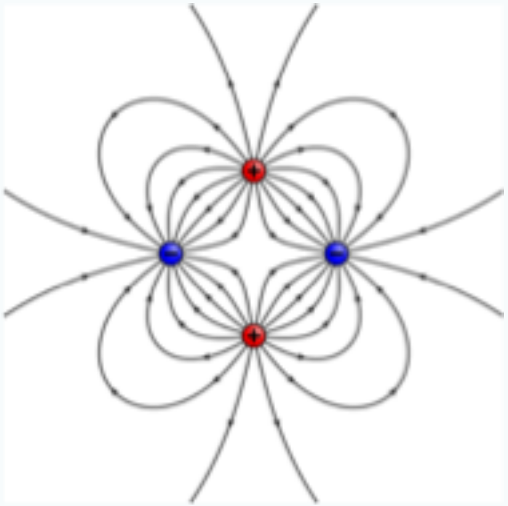


the electric dipole moment:

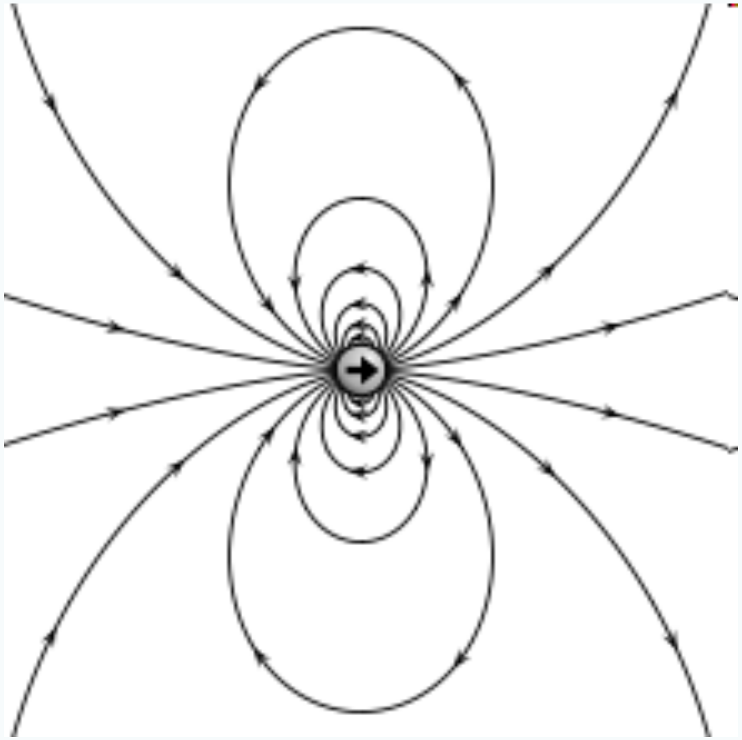
$$\vec{p} = q\vec{L}$$

$\vec{p}$ points from the negative to the positive charge and has the length $|q\vec{L}|$





Electric dipoles



$$\vec{E}(\vec{r}) = \frac{k}{r^3}(3p\hat{r}\cdot\cos\vartheta - \vec{p})$$

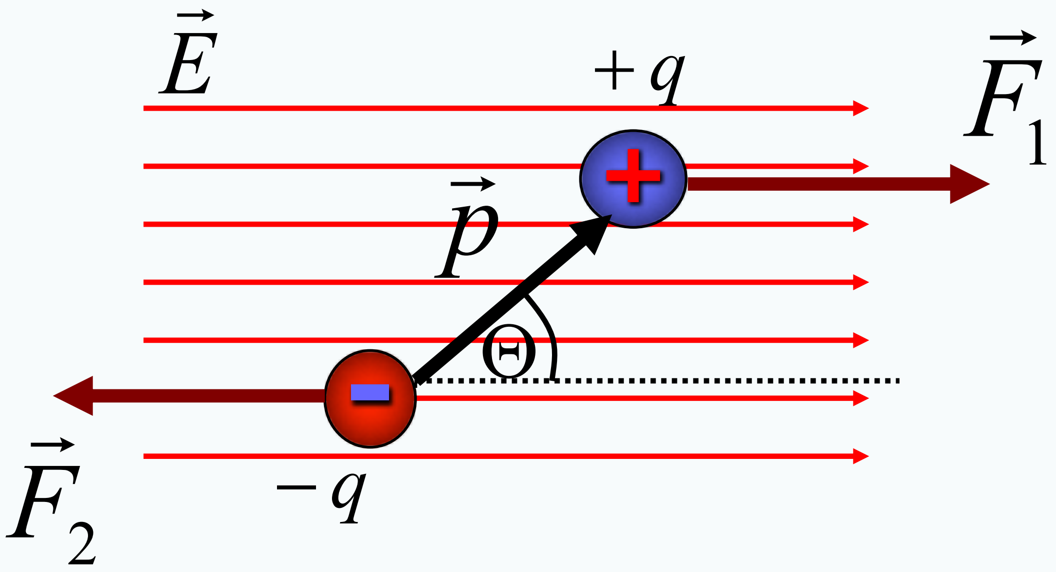
the field of an electric dipol

Electric dipoles in external electric fields

uniform electric field:

torque on the dipole

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



work done by electric field, when the dipol rotates:

$$dW = \tau d\Theta = pE \sin\Theta d\Theta$$

potential energy:

$$U = -pE\cos\Theta = -\vec{p}\vec{E}$$

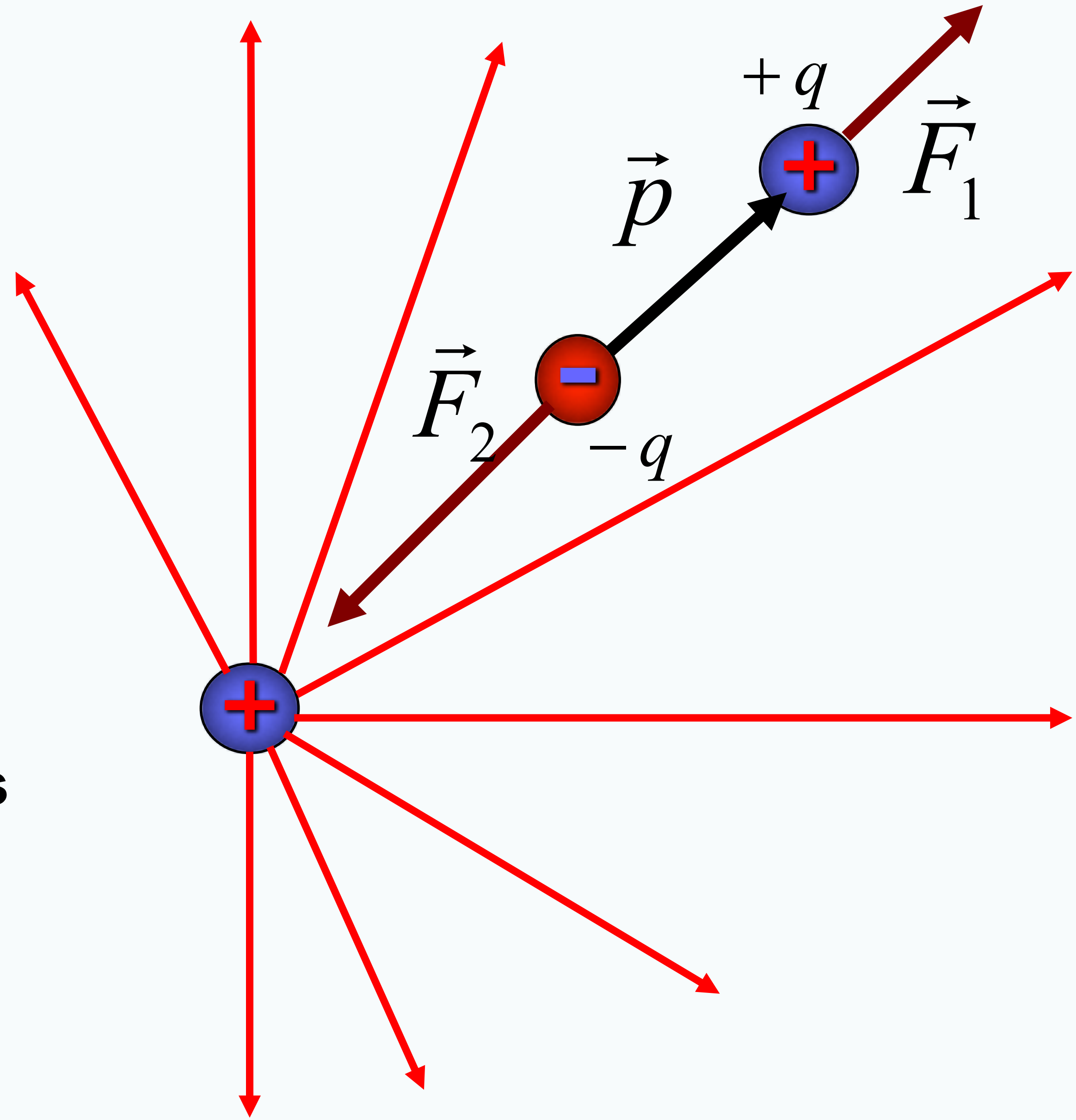
Electric Dipoles in External Electric Fields

<u>nonuniform electric field:</u>

<u>example</u>: a dipole in the field of a positive point charge

$$\left|\vec{F}_2\right| > \left|\vec{F}_1\right|$$

a net force acts on the dipole



To remember!

- Charges produce electric fields .
- Electric field exerts force on (other) charges.
- Electric field is defined by measuring the force on a test charge with an infinitely small charge.
- Electric field lines are used to visualize the electric field
- Dipoles have no net charge.
- Dipoles have an electric dipole moment p.
- Electric field of a dipole is proportional p/r^3.
- In electric fields a torque may act on dipoles .