

# Electric Fields

## Charge

- 2 kinds (Positive) & (negative) < unlike attract  
like repel
- Force between charges varies as  $F_c \propto \frac{1}{r^2}$
- Charge is conserved (electrons lost = electrons gained)
- Charge is quantized
  - Fundamental unit of charge ( $e$ )  
electron  $-e$       proton  $+e$

$$q = Ne$$

↑  
some integer

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

(C) Coulomb

## Neutrality and Charge

- Objects with equal #'s of (+) and (-) charges are neutral
- Removal of electrons = positive charge
- Addition of electrons = negative charge

## Insulators and Conductors

- Conductors - materials in which electrons move freely (metals)
- Insulators - do not readily transport electrons

### • Charging

- Induction
- Conduction
- Polarization

# Coulomb's Law

• 1785 Charles Coulomb establishes this

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

$q = \text{charge (C)}$   
magnitude

$$k = \text{Coulomb constant} = 9.0 \times 10^9 \text{ N} \cdot \frac{\text{m}^2}{\text{C}^2}$$

-or-

$$k = \frac{1}{4\pi\epsilon_0}$$

$\epsilon_0 = \text{permittivity of free space}$

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}$$

## Side Note

If  $|e| = \text{charge of 1 electron or proton}$

$$1\text{C} = \frac{1}{e} = \frac{1\text{C}}{1.6 \times 10^{-19}\text{C}}$$

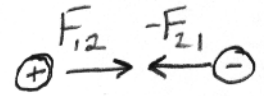
$$1\text{C} = 6.3 \times 10^{18} \text{ electrons}$$

-or-

$$6.3 \times 10^{18} \text{ protons}$$

Electric Force obeys Newton's 3rd law.

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

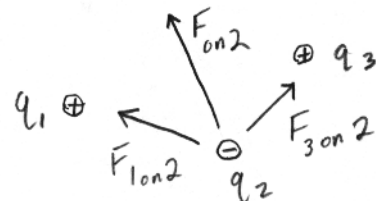


Also, if  $q_1$  &  $q_2$  have the same sign the force is repulsive.

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

• When more than two charges are present the force is equal to the vector sum of charges.

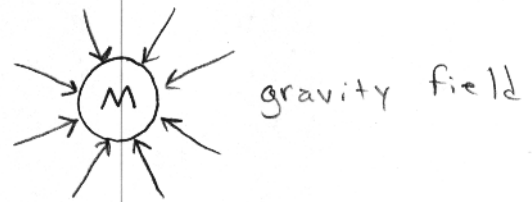
$$F_{on2} = F_{1on2} + F_{3on2}$$



# The Electric Field

$g$  = Earth's gravity field at surface

$$g = \frac{F_g}{m}$$



gravity field

E-field is similar

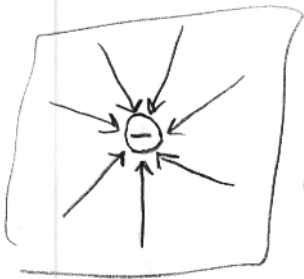
replace mass w/ charge

$$E = \frac{F_E}{q}$$

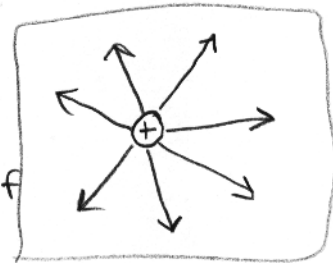
any charge  $q$

SI unit

$$\frac{N}{C}$$



Electric field at position of  $q_1$



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

since...  $E = \frac{F_E}{q_1}$

$$E = \frac{k q_2}{r^2} \text{ -or- } \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r^2}$$

Electric field due to a group of charges

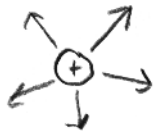
$$E = k \sum_i \frac{q_i}{r_i^2}$$

$i$  = any charge

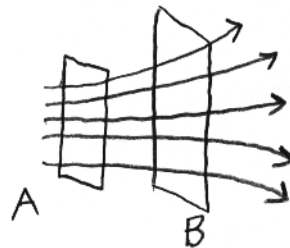
-or-  $\sum E = E_1 + E_2 + \dots$

# Electric Field Lines

- Make representing fields easier.



1. The electric field vector  $E$  is tangent to the field line at that point.
2. The # of lines per unit area through a surface perpendicular to the lines is proportional to the strength of the field at that point.



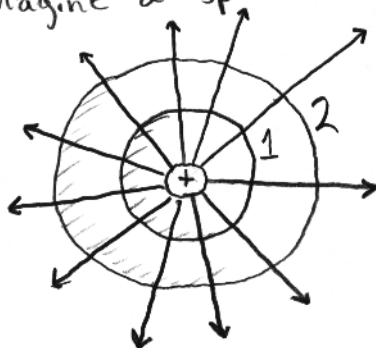
A has the greater magnitude of field  $E$

## ★ Rules for drawing Field Lines

1. Lines must go from positive to negative
2. # of lines leaving the positive must equal # of lines entering the negative of the same charge ( $q$ )
3. No two field lines can cross!

Do field lines explain Coulomb's Law?

imagine a sphere around a point charge



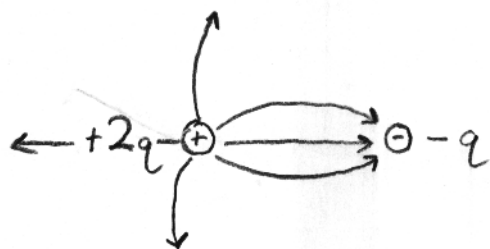
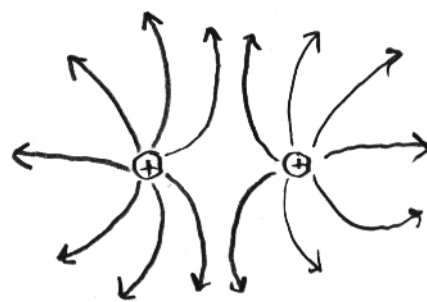
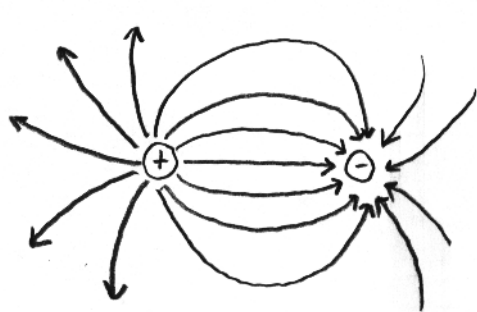
$$SA = 4\pi r^2$$

$N$  = # of lines that pass the sphere

$$\text{lines per surface area} = \frac{N}{4\pi r^2}$$

$F$  and  $E$  is proportional to  $N$  so

$$F_E \propto \frac{1}{r^2} \quad E \propto \frac{1}{r^2}$$



2 lines leave  $+2q$  for every 1 entering  $-q$

### Motion of Charged Particle in a uniform E-field

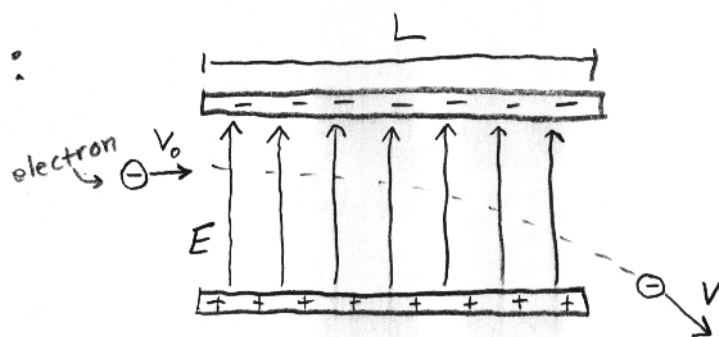
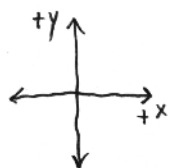
$$F = qE$$

$$F = ma$$

$$qE = ma$$

$$a = \frac{qE}{m}$$

Classic Ex:



$$a = -\frac{eE}{m}$$

$$v_x = v_0 = \text{constant}$$

$$v_y = v_{0y} + at = -\frac{eE}{m}t$$

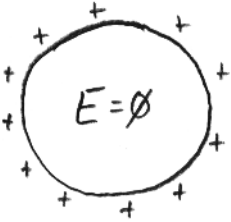
$$x = v_0 t$$

$$y = v_{0y}t + \frac{1}{2}at^2 = -\frac{1}{2}\frac{eE}{m}t^2$$

# Conductors vs. Insulators

## Conductor sphere

Actually electrons re-distributing  
Protons don't move!

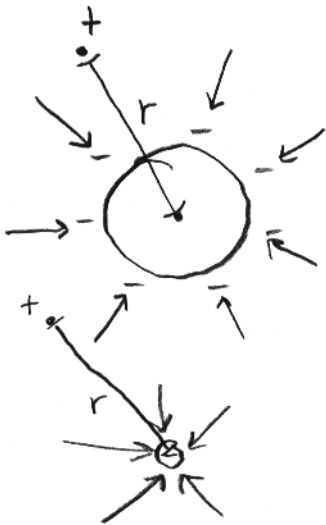


When charged, the charges will repel to the surface

This means there is no electrostatic field inside.

In fact it becomes a shell that shields from outside charges

- Faraday Cage



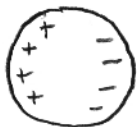
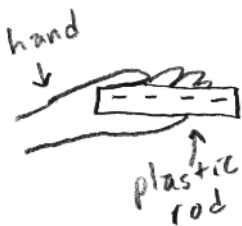
Outside it behaves like a point charge.

The distance is measured from the center of the sphere

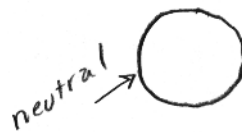
Insulators can be easily polarized



However, conductors can be polarized by induction



but if the rod is removed



Could you get the charge to stay?  
If so, how?