Electric Fields

Charge

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

$q = Ne$ ↑ some integer

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

(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)
- Isulators – do not readily transport electrons

- Charging
  - Induction
  - Conduction
  - polarization

Coulomb's Law

- 1785 Charles Coulomb establishes this

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

q = charge (C)
magnitude

k = Coulomb constant $= 9.0\times10^{9}\,N\cdot\frac{m^2}{C^2}$

-or-

$$k = \frac{1}{4\pi\varepsilon_0}$$

ε_0 = permittivity of free space

$\varepsilon_0 = 8.85\times10^{-12}\,C^2/N\cdot m^2$

Side Note

If $|e|$ = charge of 1 electron or proton

$$1C = \frac{1}{e} = \frac{1C}{1.6\times10^{-19}C}$$

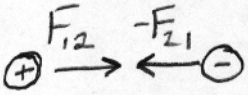
$1C = 6.3\times10^{18}$ electrons

-or-

6.3×10^{18} protons

Electric Force obeys Newton's 3rd law.

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

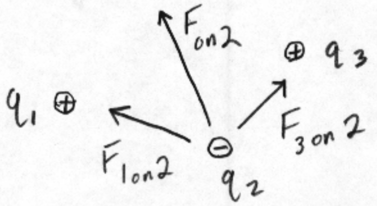


Also, if q_1 & q_2 have the same sign the force is repulsive.

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

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

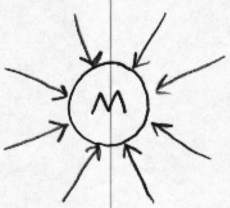
$$F_{on2} = F_{1on2} + F_{3on2}$$



The Electric Field

g = Earth's gravity field at surface

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



gravity field

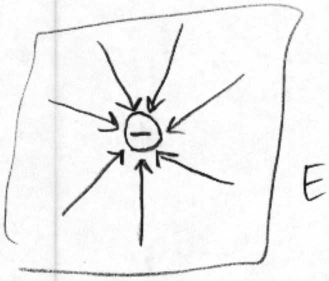
E-field is similar   replace mass w/ charge

$$\boxed{E = \frac{F_E}{\underset{\uparrow}{q}}}$$

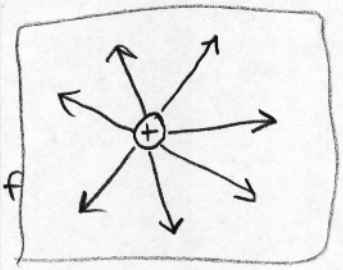
any charge q

SI unit

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



Electric field at position of q_1



$$F_E = k\frac{q_1 q_2}{r^2} \quad \text{since...} \quad E = \frac{F_E}{q_1}$$

$$\boxed{E = \frac{kq_2}{r^2} \quad \text{-or-} \quad \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{r^2}}$$

Electric field due to a group of charges

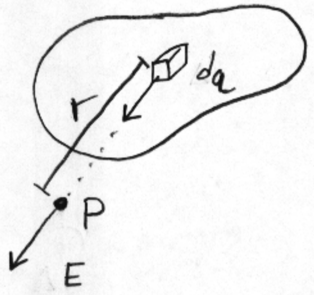
$$E = k\sum_i \frac{q_i}{r_i^2}$$

i = any charge

$$\text{-or-} \quad \Sigma E = E_1 + E_2 \ldots.$$

Electric Field and Continuous Charge Distribution

Same principle of multiple charges.



$$E = K\int \frac{dq}{r^2}\,\hat{r}$$

- Must use charge density

dQ
small charge

Uniform

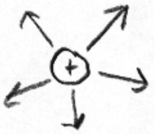
Charge per unit volume $\rho = \frac{Q}{V}$ $\left(\frac{C}{m^3}\right)$ $dQ = \rho\, dV$

Charge per surface area $\sigma = \frac{Q}{A}$ $\left(\frac{C}{m^2}\right)$ $dQ = \sigma\, dA$

Charge along a line $\lambda = \frac{Q}{L}$ $\left(\frac{C}{m}\right)$ $dQ = \lambda\, dl$

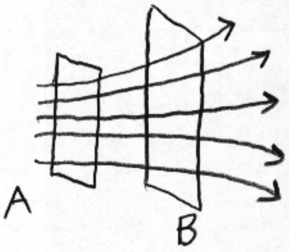
Electric Field Lines

- 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.



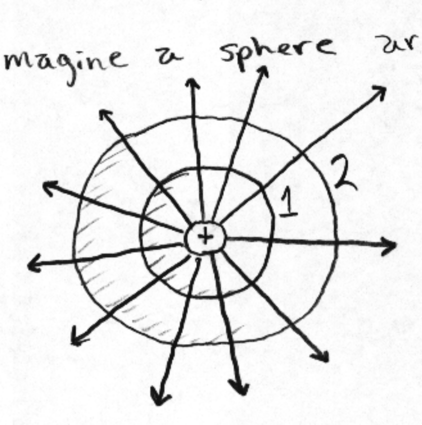
A has the greater magnitude of field E

☆ 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



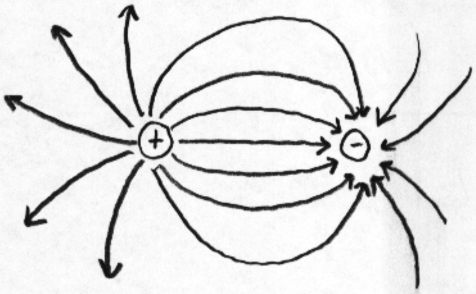
$SA = 4\pi r^2$

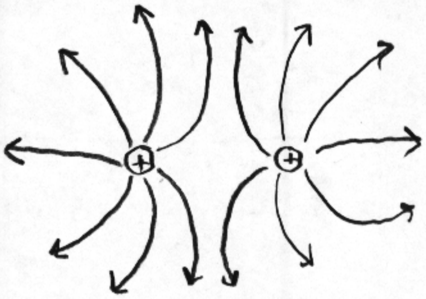
N = # of lines that pass the sphere

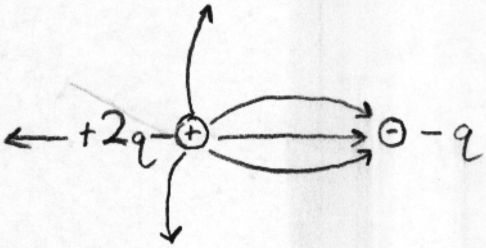
lines per surface area $= \frac{N}{4\pi r^2}$

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 $-q$

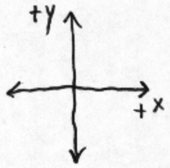
Motion of Charged Particle in a uniform E-field

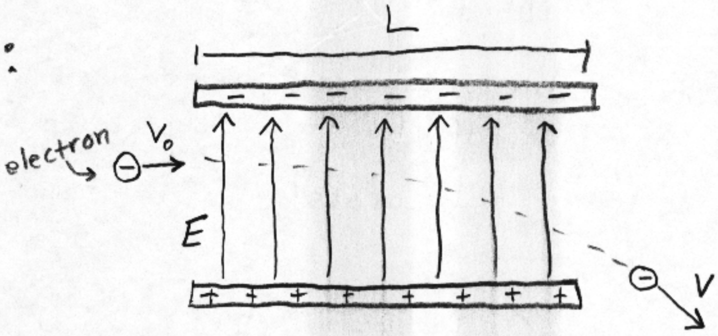
$$F = qE \qquad F = ma$$

$$qE = ma$$

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

Classic Ex:





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

$$V_x = V_0 = \text{constant}$$

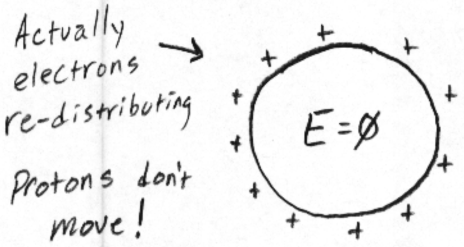
$$V_y = V_{0y} + at = -\frac{eE}{m}t$$

$$x = V_0 t$$

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

Conductors vs. Insulators

Conductor sphere

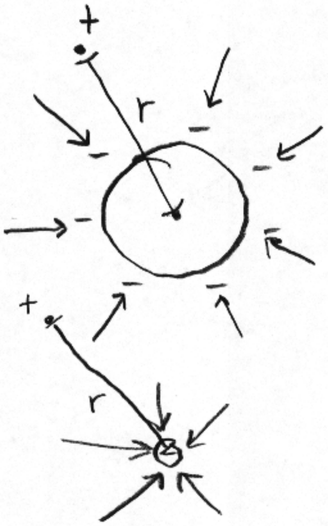


When charged, the charges will repel to the surface

This means there is no electrostatic field inside.

In fact it becomes a shell that shields from outside charges

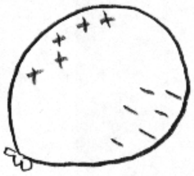
-Faraday Cage



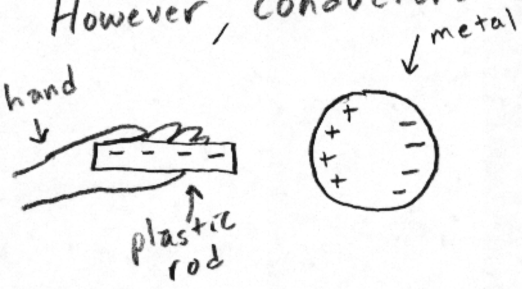
Outside it behaves like a point charge.

The distance is measured from the center of the sphere

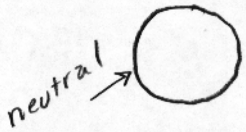
Insulators can be easily polarized



However, conductors can be polarized by induction



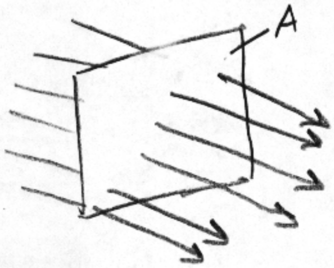
but if the rod is removed



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

Gauss' Law

Electric Flux: measure of # of field lines passing some surface area.



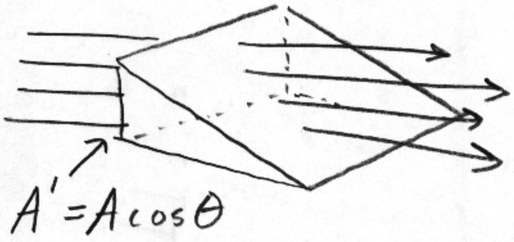
$$\boxed{\Phi = EA}$$

SI unit

$N \cdot m^2/C$

If the surface area is not perpendicular the # of lines (flux) must be less.

$A' < A$



$$\boxed{\Phi = EA\cos\theta}$$