Chap 23 Electric fields
Chapter 22. Electric Charges

Electromagnetism
E + M

{ Electric (Electricity)
magnetic (magnetism)

Electricity   magnetism

1820
Oersted : moving current create magnetic field

↓

Michael Faraday
James C. Maxwell (put in Mathematic form)

↓

Maxwell's Equations (Table 32-1, P. 803)

1. Electric Charges — intrinsic Characteristic of the fundamental Charges
   - Static Cling
   - Spark between fingers and door knobs in a dry day
   - lightning in the sky

2. positive Charges — assigned arbitrarily by B. Franklin
   negative charges —
   electric neutral — balance between ~~postive~~ positive + negnative charges
   no net Charges.

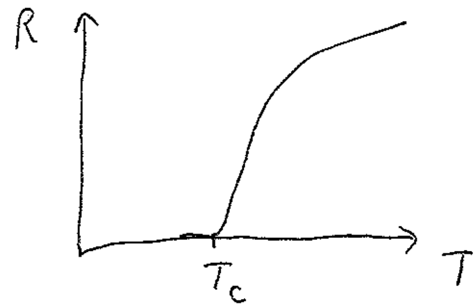
3. Interaction of Charged objects through electric force.
   - Charges with the same electrical sign repel each each other. Charges with the opposite sign attract each other.
   - Coulomb's law, (electro static force, electric force)

4. Conductor, – negative charge move freely

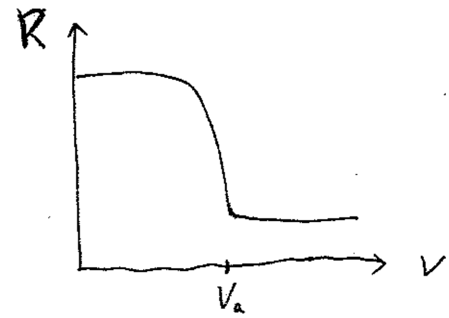
insulator – Charges don't move.

Semi Conductor – at some apply voltage Charge will move
Si. Ge. ...

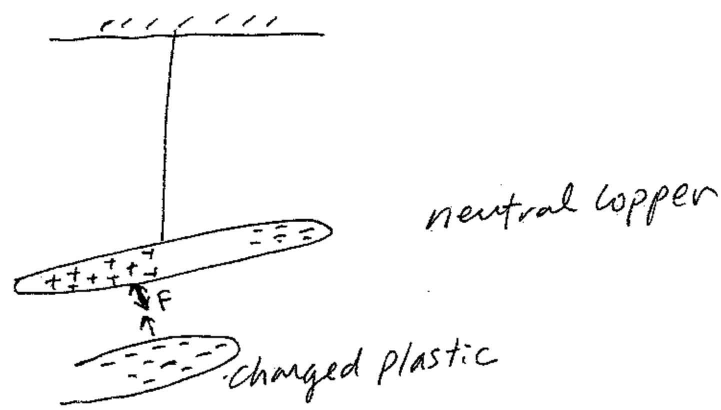
Super Conductor –



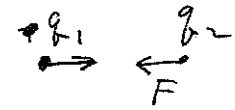
super conductor



Semi Conductor



5. Coulomb's law – Charles Augustin Coulomb,



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

$\rightarrow$ $F = k \dfrac{q_1 q_2}{r^2}$ compared with Newton's force $F = -G \dfrac{M_1 M_2}{R^2}$

$\rightarrow$ $F = \pm k \dfrac{|q_1||q_2|}{r^2}$ "+" repel, "–" attract

Compare All forces

k = electrostatic constant

$= \dfrac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \ N \cdot \dfrac{m^2}{C^2}$

$\epsilon_0 = 8.85 \times 10^{-12} \ C^2/N \cdot m^2$ = permittivity constant.

q : in Coulomb . SI unit.

q : SI unit, Coulomb

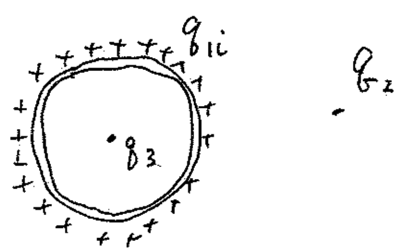
1 Coulomb = 1A  → 1A in one second.

$dq = i\,dt$

$$\rightarrow \boxed{F_{12} = k\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}}$$

Electric force follow the same vector sum as that of gravitational force, ie, $\vec{F_1} = F_{12} + F_{13} + \vec{F_{14}} + \cdots\cdots$, and the force ~~the~~ on one particle is the sum of all other particles force on this one.

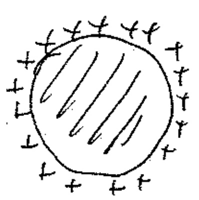
6. Shell :



the force on q_2 is the sum of all q_i's as if they were centered ~~on~~ the center of the shell

But q_3 will exert no force due to all q_is in the shell.

Sphere (conductor)



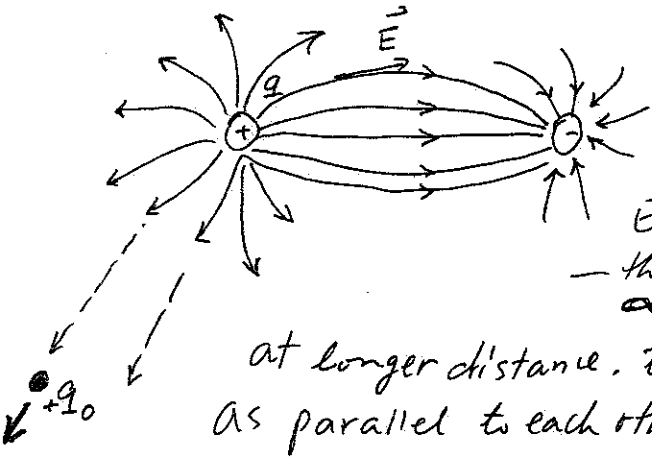
Charges will spread over the surface of a sphere uniformely. because changes will repel one another

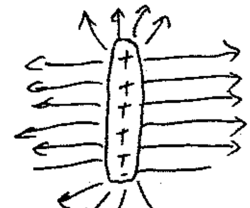
7 Charge is "Quantized" — ie. $q = ne$, e = charge of an electron $= 1.6\times10^{-19}$ Coulombs

e is the elementary charge.

8 Charge is conserved

Electric field — Set up by Charge, within it, another Change is subject to force according to Coulomb's law





Electric field line.
— the # of lines per unit area $\propto$ the electric field magnitute.

at longer distance, the lines can be considered as parallel to each other,

If we place a test charge q_0.

$$F = k \frac{q q_0}{r^2}$$

$$\vec{E} \equiv \frac{\vec{F}}{q_0} = k \frac{q}{r^2}, \quad \text{Electric field. } \left[\frac{N}{C} \right]$$

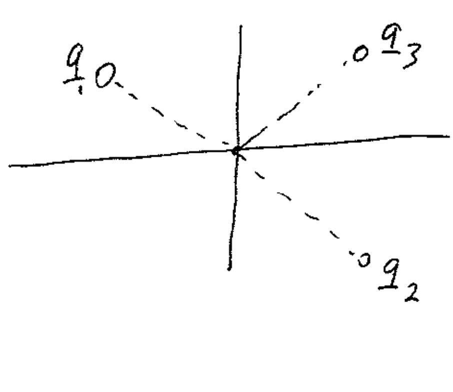
① Electric field lines are drawn from positive charge to negative charge

② The # density of lines is proportional to the magnitude of the electric field.

1. Electric field — discrete charge

① point charge : $E = \frac{F}{q} = \frac{1}{4\pi\epsilon_0} \frac{|q|}{r^2}$

② multipule point charges

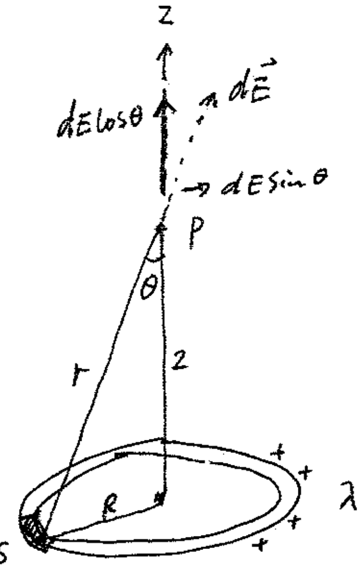


$\vec{E}_0$ at the origin

$$\vec{E}_0 = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$$

Charge distribution

④ Ring of charge distribution.



$$d\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{dq}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{\lambda\, ds}{(z^2+R^2)}$$

$dq = \lambda\, ds$

$$\vec{E} = \int dE\cos\theta = \int \frac{1}{4\pi\epsilon_0}\frac{\lambda\, ds}{(z^2+R^2)}\cdot\frac{z}{\sqrt{z^2+R^2}}\, ds$$

$$= \frac{\lambda}{4\pi\epsilon_0}\frac{z}{(z^2+R^2)^{3/2}}\cdot\int_0^{2\pi R} ds$$

$$\cos\theta = \frac{z}{r} = \frac{z}{\sqrt{R^2+z^2}}$$

$$= \frac{2\pi R\lambda}{4\pi\epsilon_0}\frac{z}{(z^2+R^2)^{3/2}} = \frac{1}{4\pi\epsilon_0}\frac{qz}{(z^2+R^2)^{3/2}}$$

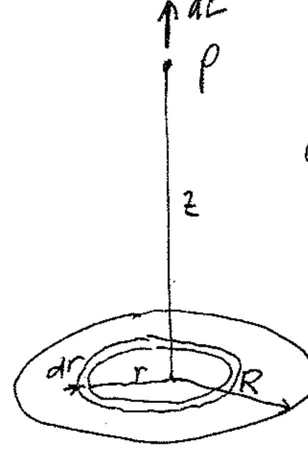
if $z \gg R$, $z^2+R^2 \approx z^2$

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{z^2}$$ ← At a large distance, a ring distribution can be approximate as the point charge.

Note: 1) Always check the answer at extreme case

2) Do Sample problem 23-5 for a section of ring distribution

⑤ Charged disk (Charge on it upper surface



σ = Charge density

$$dq = \sigma\, dA = \sigma(2\pi r\, dr)$$

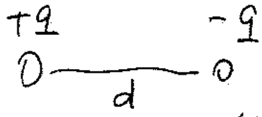
$$dE = \frac{z\,\sigma\, 2\pi r\, dr}{4\pi\epsilon_0 (z^2+r^2)^{3/2}}$$

$$= \frac{\sigma z}{4\epsilon_0}\frac{2r\, dr}{(z^2+r^2)^{3/2}}$$

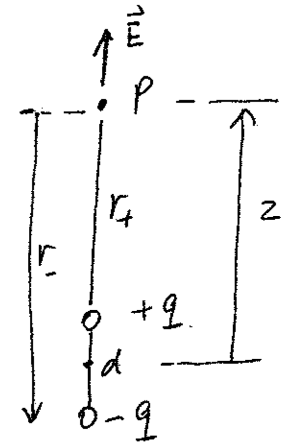
$$E = \int_{r=0}^{r=R} dE = \frac{\sigma z}{\epsilon 4}\int_0^R \frac{2r\, dr}{(z^2+r^2)^{3/2}}$$

$$= \frac{\sigma z}{4\epsilon_0}\left[\frac{(z^2+r^2)^{-1/2}}{-\frac{1}{2}}\right]_0^R = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{z}{\sqrt{z^2+R^2}}\right)$$

③ dipole —



two charges separated by a distance, have oppositive sign are called electric dipole



$$\vec{E} = \vec{E}_{(+)} + \vec{E}_{(-)} = \text{electric field @ pt. } P.$$

$$= \frac{1}{4\pi\epsilon_0}\left[\frac{q}{r_+^2} - \frac{q}{r_-^2}\right]$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{1}{[z-\frac{1}{2}d]^2} - \frac{1}{[z+\frac{1}{2}d]^2}\right]$$

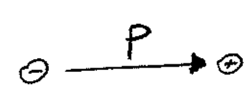
$$= \frac{q}{4\pi\epsilon_0 z^2}\left[\left(1-\frac{d}{2z}\right)^{-2} - \left(1+\frac{d}{2z}\right)^{-2}\right], \quad z \gg d. \quad \frac{d}{2z} \ll 1$$

$$= \frac{q}{4\pi\epsilon_0 z^2}\left[\left(1+\frac{2d}{2z(1!)}+\cdots\right] - \left(1-\frac{2d}{2z(1!)}+\cdots\right)\right]$$

$$\doteq \frac{q}{4\pi\epsilon_0 z^2} \quad \frac{2d}{z}$$

$$= \frac{1}{2\pi\epsilon_0}\frac{qd}{z^3}$$

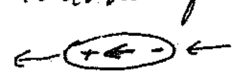
$$= \frac{1}{2\pi\epsilon_0}\frac{\vec{p}}{z^3} \qquad p \equiv qd = \text{electric dipole moment.}$$



in general

i) $E \propto \frac{1}{r^3}$ for all dipole at all distance

ii) The direction of the dipole is taken from the negative to the positive charge



iii) At a distane, $\vec{E}$ is the same direction of $\vec{p}$

iv) $E \propto \frac{1}{r^2}$ for a point charge.

v) H_2O. $p = 6.2 \times 10^{-30}$ C·m

for a charged disk $E = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{z}{\sqrt{z^2+R^2}}\right)$

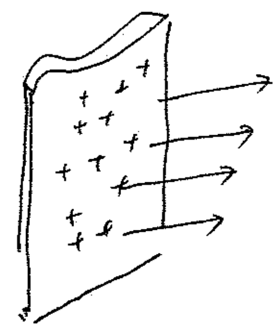
(6) Infinite large Sheet

from E for the disk, $E = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{z}{\sqrt{z^2+R^2}}\right)$

if $R \gg z$, $R \to \infty$, $\frac{z}{\sqrt{z^2+R^2}} \approx 0$

$E \to \frac{\sigma}{2\epsilon_0}$ — Electric field for a large sheet.

$E \propto \sigma$, from different pt of view.

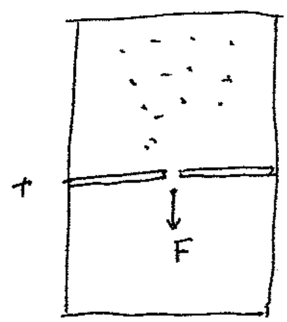


$\vec{E}$ must be uniform and $\propto \sigma$, the surface charge density.

2. Electric force — for a pt charge in an electric field

$\vec{F} = q\vec{E}$ Note: pt charge doesn't mean it is unit charge.

1) Millikan Oil drop exp.

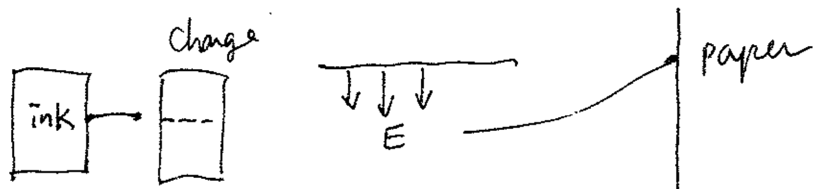


$F = qE$

$q = ne$

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

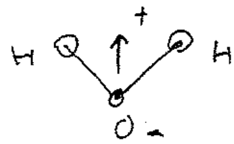
2),



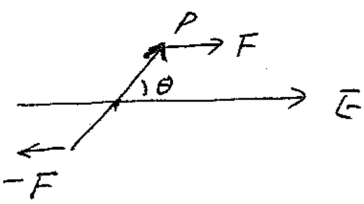
ink-jet.

3. dipole in an electric field.

H_2O



H_2O has permanent dipole.



Force due to the interaction of Electric field and charge in a dipole, the net force is zero. but exert a net torque aloud its center of mass.

$$\tau = F\frac{d}{2}\sin\theta + F\frac{d}{2}\sin\theta = Fd\sin\theta$$

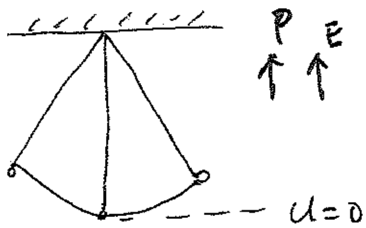
$$= qEd\sin\theta$$

$$\tau = pE\sin\theta = \vec{p}\times\vec{E} = -pE\sin\theta \quad (\text{negative torque})$$

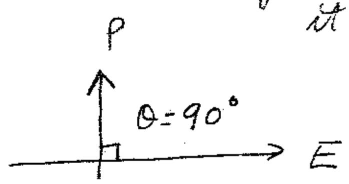
→ this give rise to the rotation of the molecules.

But the potential energy is minium when the dipole is linedup along the external field. i.e. $\tau = p\times E = 0$, $U = 0$

Compared to a pendulum, at this point, the dipole is at its equilibrium position it has the least potential.



$U=0$
$v = max$



$U = max$
$\tau = max$.

defined potential = ~~define the potential~~.

$$\therefore U = -W = -\int_{90°}^{\theta}\tau\, d\theta = +\int_{90°}^{\theta} pE\sin\theta\, d\theta$$ — potential at any other angle

$= PE(-\cos\theta)$
$= -PE(\cos\theta - 0)$

$$\therefore U = -p\cdot E\cos\theta = -\mathbf{p}\cdot\mathbf{E}$$

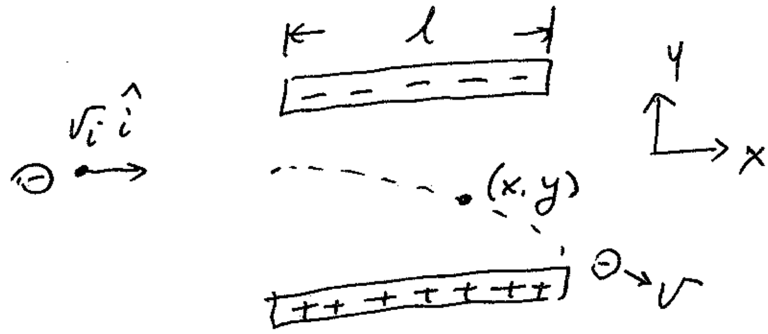
4. Micro waver.

Note: $\tau = -pE\sin\theta$
negative ~~tork~~ torque
as in the figure,
it gives rise to a clockwise rotation

23.7

Motion of a change particle in a Uniform electric field

$$F_e = qE = ma \rightarrow a_y = \frac{qE}{m}$$



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

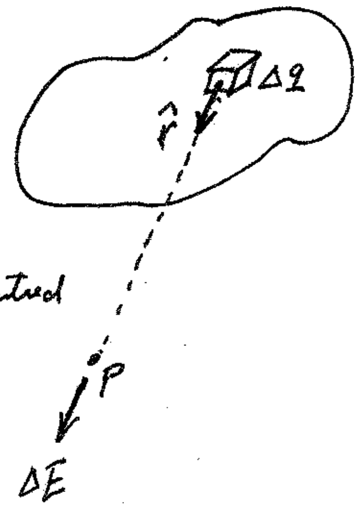
$$v_y = a_y t = -\frac{eE}{m_e} t$$

$$x_f = v_i t$$

$$y_f = \frac{1}{2} a_y t^2 = -\frac{1}{2} \frac{eE}{m_e} t^2$$

23.5. Electric field of a Continuous Charge distribution

$$\Delta\vec{E} = k_e \frac{\Delta q}{r^2}\hat{r}$$



$$\therefore \vec{E} \sim k_e \sum_i \frac{\Delta q_i}{r_i^2}\hat{r}_i$$

if the charge is continuous distributed

$$\vec{E} = k_e \lim_{\Delta q_i \to 0} \sum_i \frac{\Delta q_i}{r_i^2}\hat{r}_i$$

$$= k_e \int \frac{dq}{r^2}\hat{r}$$