Lecture 20 Gary Shiu 3/16/07 (1)

Physics 248

Introduction to Electric Field: Discrete Charges

Notes:

Historical Note: Ancient greeks noticed that after amber was rubbed, it attracted small objects such as straw or feathers. The word electric comes from the greek word for amber, elektron.

Define:

- **Electrostatics:** The study of electrical charges at rest.
- **Atoms:** Nucleus contains protons. The number of protons designated by Z, the atomic number, and designates what type of atom it is. The charge on the proton is termed positive in accordance with Ben Franklin's original designation. Around the nucleus of an electrically neutral atom are Z electrons, considered negatively charged. Both protons and electrons carry the same amount of charge, but opposite in sign.
- **Fundamental Unit of Charge:**

Quantization of Electric Charge

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

$eg = \frac{1}{2}\hbar c$ Dirac

but no experimental evidence

Where C is the unit of charge called the Coulomb, after Charles Coulomb (1736-1806) who studied the force exerted by one charge on another using a torsion balance.

- The discrete nature of charge is rarely noticed at our macroscopic level. Typical charges on the glass rode Coulomb was using would have been on the order of 10^{10} e. However, other phenomena such as shot noise (variation in the current in a circuit due to the discrete charge of the electron) exhibit the discrete nature of charge.

- **Conductor:** A material where some of the electrons are free to move about the volume of the material.
- **Insulator:** A material where all the electrons are bound to nearby atoms and not free to move about th ematerial.

- **Coulomb's Law: The force exerted by one point charge on another acts along the line between the charges. It varies inversely as the square of the distance separating the charges and is proportional to the product of the charges. The force is repulsive if the charges have the same sign and attractive if the charges have opposite signs. (The reason for the $1/r^2$ force is because photons are massless)**

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

$k = 8.98755 \times 10^9\ Nm^2/C^2$

Electric Field lines

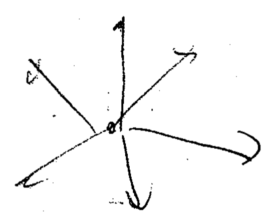
$$\vec{E} = \frac{\vec{F}}{q_0} \leftarrow \text{test charge}$$

$$= \frac{kq}{r^2}\hat{r}$$

Many charges.

$$\vec{E} = \sum_i \frac{k q_i}{|\vec{r}-\vec{r}_i|^2}\left(\frac{\vec{r}-\vec{r}_i}{|\vec{r}-\vec{r}_i|}\right)$$

Graphical representation : Field lines (line of force)



closer the lines
stronger the force

Rules : ① begin on ⊕ end on ⊖

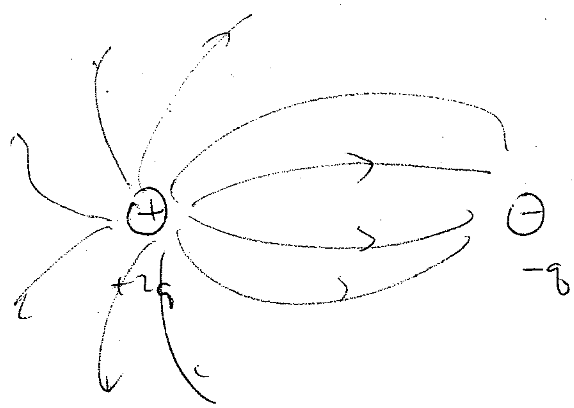
② uniform spacing leaving & entering an isolated charge

③ # of lines $\propto$ Q

④ Density of lines $\propto |\vec{E}|$

⑤ At large distance, equally spaced and radial w N = net charge

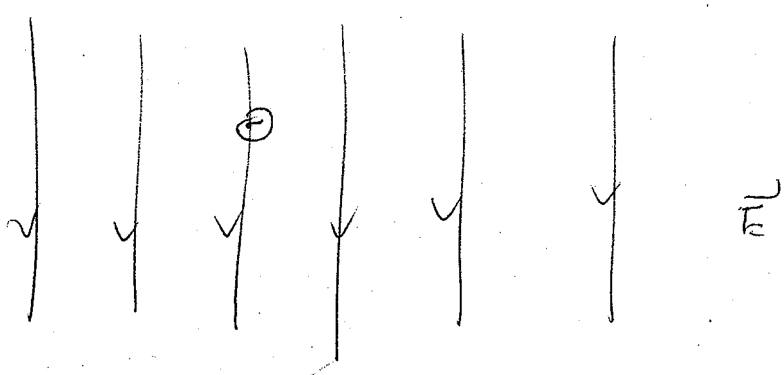
⑥ Field lines do not cross



Motion of Pt charges in $\vec{E}$ field

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

Constant $\vec{E}$ $\Rightarrow$ constant $\vec{a}$



What is direction of $\vec{a}$ of electron ? up.

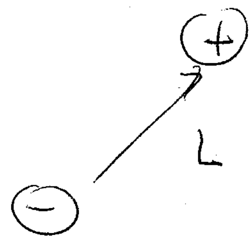
Comparing with gravitational force

$$\frac{F_e}{F_g} = \frac{eE}{mg} = \frac{(1.6\times10^{-19}C)(2000\,N/C)}{(9.11\times10^{-31}kg)(9.81\,N/kg)} = 3.6\times10^{13}$$

much bigger than mg

Electric Dipoles in E field

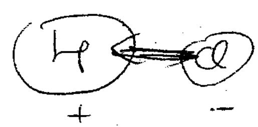
What is a dipole? A system of two equal & opposite charges that are close together



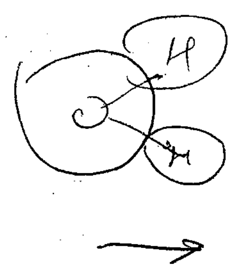
$\vec{P} = q\vec{L}$

Some molecules have permanent dipole moments: polar molecules

e.g. HCl

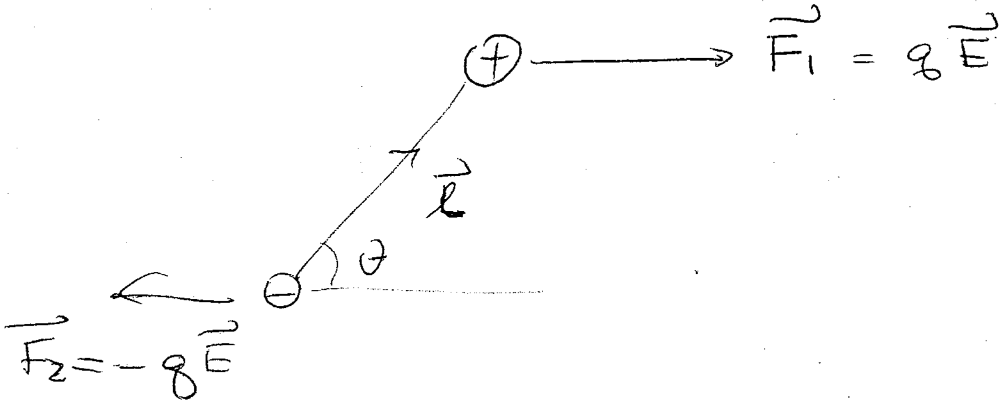


H_2O



What does a uniform electric field do to a dipole?

No net force, but torque



Torque about -ve charge $= F_1 l \sin\theta$

$= qEl\sin\theta$

$= pE\sin\theta$

Taking into account direction (Right handed rule)

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

into paper
align $\vec{p}$ along $\vec{E}$

When dipole rotates thru $d\theta$, the electric field does work

$dW = -\tau\, d\theta$ — sign because torque opposes increase in θ

$= -pE\sin\theta\, d\theta$

$dU = -dW = pE\sin\theta\, d\theta$

$$\boxed{U = -pE\cos\theta = -\vec{p}\cdot\vec{E}}$$

choose $U = 0$ at $\theta = 90^\circ$

Microwave oven : use electric dipole moment to cook food.

Oscillating electric field exert torque on dipoles, causing water molecules to rotate with significant rotational kinetic energy

EM energy ⇒ water molecules