Go to: Course homepage, Lectures

Lecture 4 Sec 14.4-14.8, 15.1-15.3.

1. Review: Superposition principle. Dipole field pattern.
2. Dipole field E at large x (where x>>s), y=0.
3. Digression: Small epsilon-expansion
4. More on a dipole
   a. Field at large y, where x=0.
   b. Force on Q due to a dipole
   c. Dipole moment in a constant field. Torque.
5. Effect due to finite speed of light: $c=3 \times 10^8$ m/s.
   a. E spread out with speed of light. Traveling time over 1ft~0.3 m
   b. Is field real?
   c. E field pattern at high speed. (read on your own)
6. Field-matter interaction
   a. Charge in neutral matter. Charge separation: mechanical, rubbing ....
   b. Induced dipole moment in presence of E. p=(polarizability) E.
   c. F = constant/r^5

Class Announcements:

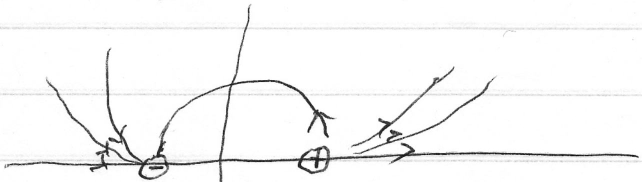
- Office hours MWF 9:15-10:15; other time by appointment.

- The EXTRA: A homework set is often accompanied by an extra set. The latter contains examples problems come with the solutions. They are intended to help you to study the materials. There are no grades or extra credit associated with them. Still, they you should work through these problems and understand them. We have just posted an extra-set of h0 (homework0) on review vector.

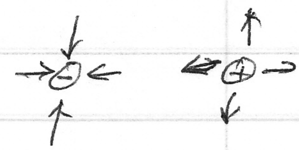
- TA sessions begin this week. See TA/LA homepage for TA session details. If you have any questions related to TA session, please contact your TA. Also the head-TA (Josh Hebert) may be able to help you.

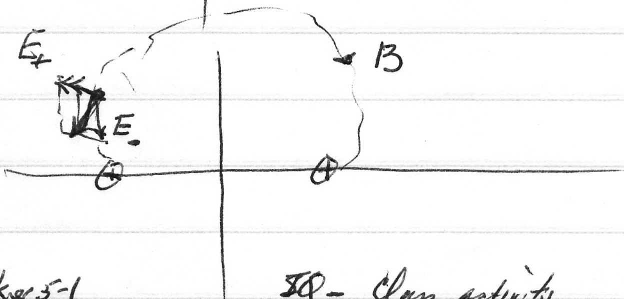
Lec 4

1. Review superposition principle & dipole field pattern

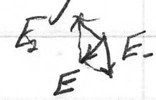


SSQ:



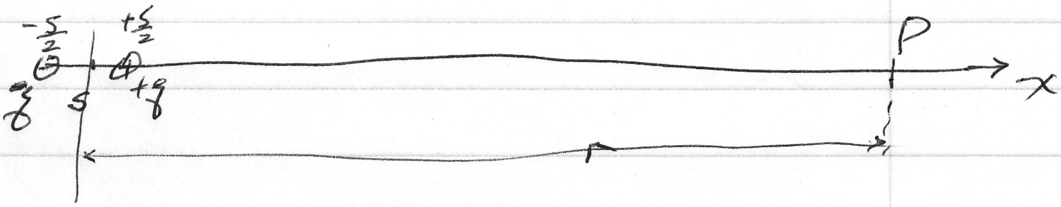


Method of ΣE:



checked 5-1   SQ - Class activity. This gives you

2. Field at P: Along x-axis, $x >> s$



$$E = E^{+} + E^{-}$$

$$= \frac{kq}{(r-\frac{s}{2})^2} - \frac{kq}{(r+\frac{s}{2})} = \frac{kq}{r^2}\left[\frac{1}{(1-\epsilon)^2} - \frac{1}{(1+\epsilon)^2}\right]$$

$$\epsilon = \frac{s}{2r} \ll 1$$

3. Digression on small ϵ expansion

$$(1-\epsilon)^2 = 1 - 2\epsilon + \epsilon^2 = 1 - 2\epsilon + O(\epsilon^2) \approx 1 - 2\epsilon$$

$$(1-\epsilon)^3 = 1 - 3\epsilon + 3\epsilon^2 + \epsilon^3 = 1 - 3\epsilon + O(\epsilon^2) \approx 1 - 3\epsilon$$

General: $(1-\epsilon)^a = 1 - a\epsilon + O(\epsilon^2) \approx 1 - a\epsilon.$

neg. a: $\frac{1}{1-\epsilon} \approx 1+\epsilon$

Proof: $(1-\epsilon)(1+\epsilon) = (1-\epsilon^2) \approx 1$

So the math form

$(1-\epsilon)^a \approx 1 - a\epsilon$ works where a can be positive or negative

$$\boxed{(1-\epsilon)^a \approx 1 - a\epsilon}$$

$$\frac{1}{(1-\epsilon)^2} = \frac{1}{1-(2\epsilon)} \approx 1+2\epsilon.$$

$$\frac{1}{(1+\epsilon)^2} = \frac{1}{(1+2\epsilon)} \approx 1-2\epsilon.$$

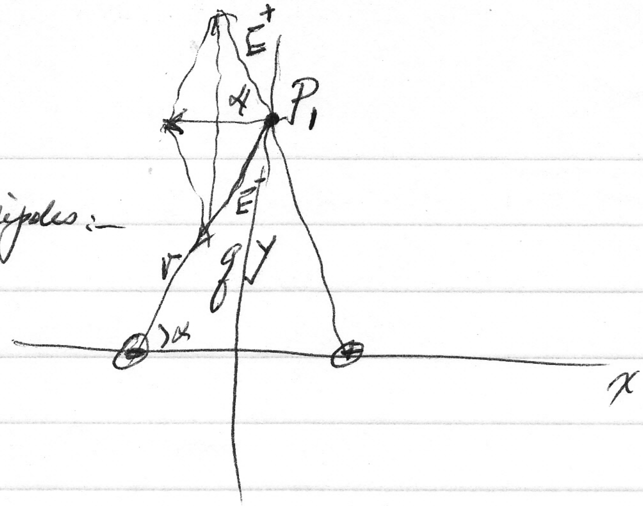
app $E = \frac{kq}{r^2}\left[\frac{1}{(1-\epsilon)^2} - \frac{1}{(1+\epsilon)^2}\right]$ $\qquad \epsilon = \frac{(s/2)}{x}$

$$[\;] = (1+2\epsilon) - (1-2\epsilon) = 4\epsilon = 4\left(\frac{s}{2x}\right) = \frac{2s}{x}.$$

$E = \frac{kq}{x^2} \cdot \frac{2s}{x} = \frac{2kqs}{x^3} = \frac{2kp}{x^3}$ ← Dipole mom. $p = qs$

4. More on dipoles:–

a)



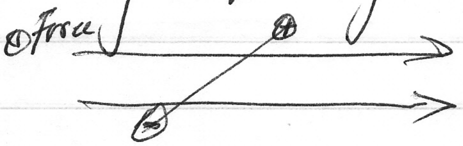
$$\vec{E}^{dipole}_{P_1} = \vec{E}^+_{P_1} + \vec{E}^-_{P_1}$$

Dir of $\vec{E}_{P_1}$: $(-\hat{x})$

$$Mag = 2E^+ \cos\alpha = 2 * \frac{kq}{r^2} \cdot \frac{\frac{s}{2}}{r} = \frac{kqs}{r^3}.$$

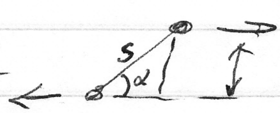
b) Uniform Dipole in uniform E

① Force



$$\vec{F}_{dipole} = \vec{F}_{+q} + \vec{F}_{-q}$$
$$= q\vec{E} - q\vec{E} = 0.$$

② Torque: Mechanical couple –

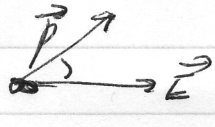


$$\tau = Fd = Eqd$$

$$= Eq\, s \sin\alpha$$

$$\vec{\tau} = \tau\hat{n} = \vec{p}\times\vec{E}$$
$$(E p \sin\alpha)\,\hat{n}$$

Dir: cw



cw.

5. Is E real?

a) Source creates field. Field spread out ~~with~~ speed of light.

Time taken to spread over 1 foot

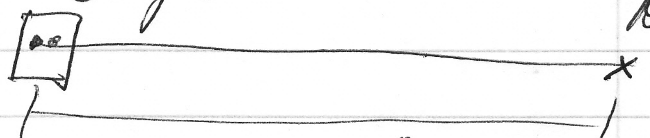
$$\Delta t \sim \frac{0.3}{3\times10^8} = 10^{-9}\,\text{sec} = \text{ns}.$$

b) $e^+ + e^- \to \gamma\gamma$

dipole field

e^+e^- system

Dipole field



r

$\frac{2kp}{r^3}.$

At $t=0$, reaction occurs

$\Rightarrow$ dipole system disappears

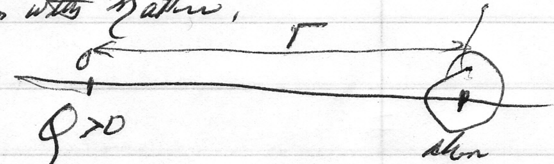
At P: E_p^{dipole} continues to be present for $t=0 \to t_1 = \frac{r}{c}$

then the field disappears.

NR description e^+e^- system has $v \ll c$.

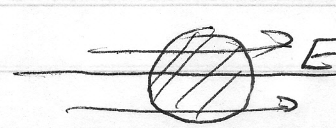
~~6~~. Preview ch 15. Field interaction with matter.

What is the force F^q_{atom}



r, $q>0$, atom

Polarization:



E

Atom

$E_r^q = \frac{kq}{r^2}$ polarize the medium

$$|F^q_{\text{atom}}| = |F_q^{\text{dipole}}| = Eq = \left(\frac{2kp}{r^3}\right)q = \frac{2kq}{r^3}\cdot p \propto r^{-5}$$

$\Rightarrow$ it induces a dipole $p \leftarrow \frac{kq}{r^2}$

attract