PHYS 1441 – Section 001
Lecture #5

Monday, June 10, 2019

Dr. Jaehoon Yu

- Chapter 22
  - Electric Dipole
- Chapter 23
  - Electric Potential Energy
  - Electric Potential due to Point Charges
  - Shape of the Electric Potential
  - V due to Charge Distributions

Today's homework is #4, due 11pm, Friday, June 14!!

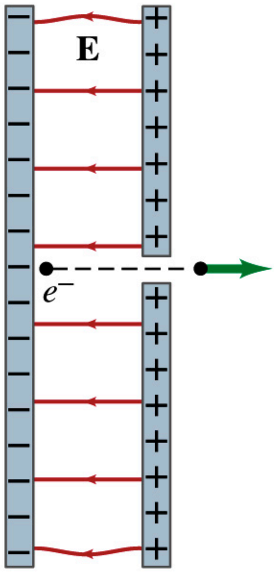
Announcements

- Reading Assignment
  - CH 23.9

Reminder: SP#2 – Angels & Demons

- Compute the total possible energy released from an annihilation of x-grams of anti-matter and the same quantity of matter, where x is the last two digits of your SS#. (20 points)
  - Use the famous Einstein's formula for mass-energy equivalence
- Compute the power output of this annihilation when the energy is released in x ns, where x is again the first two digits of your SS#. (10 points)
- Compute how many cups of gasoline (8MJ) this energy corresponds to. (5 points)
- Compute how many months of world electricity usage (3.6GJ/mo) this energy corresponds to. (5 points)
- Due by the beginning of the class Wednesday, June. 12

Special Project #3



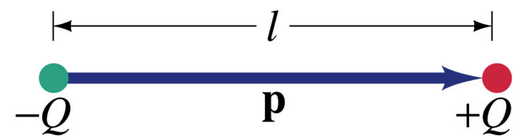
- **Particle Accelerator**. A charged particle of mass **M** with charge **-Q** is accelerated in the uniform field **E** between two parallel charged plates whose separation is **D** as shown in the figure on the right. The charged particle is accelerated from an initial speed $\mathbf{v_0}$ near the negative plate and passes through a tiny hole in the positive plate as shown in the figure right.
  - Derive the formula for the electric field E to accelerate the charged particle to a fraction f of the speed of light c. Express E in terms of **M, Q, D,** f, **c** and $\mathbf{v_0}$.
  - (a) Using the Coulomb force and kinematic equations. (8 points)
  - (b) Using the work-kinetic energy theorem. (8 points)
  - (c) Using the formula above, evaluate the strength of the electric field E to accelerate an electron from 0.1% of the speed of light to 90% of the speed of light. You need to look up the relevant constants, such as mass of the electron, charge of the electron and the speed of light. (5 points)
- Please do NOT copy but have your own handwritten answer!
- Due beginning of the class Monday, June 17

Gauss' Law Summary

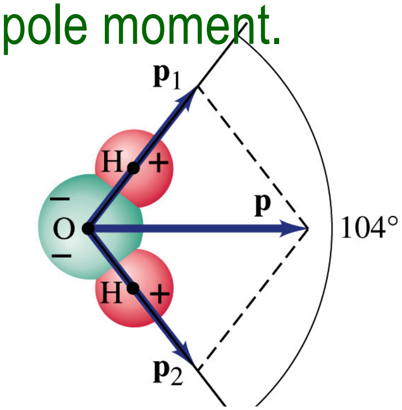
- The precise relationship between flux and the enclosed charge is given by Gauss' Law $\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$
  - ε_0 is the permittivity of free space in the Coulomb's law
- A few important points on Gauss' Law
  - Freedom to choose!!
    - The surface integral is performed over the value of **E** on a closed surface of your choice in any given situation.
  - Test of existence of electrical charge!!
    - The charge Q_{encl} is the net charge enclosed by the arbitrary closed surface of your choice.
  - Universality of the law!
    - It does NOT matter where or how much charge is distributed inside the surface. Gauss' law still applies!
  - The charge outside the surface does not contribute to Q_{encl}. Why?
    - The charge outside the surface might impact the field lines but not the total number of lines entering or leaving the surface.

Electric Dipoles

- An electric dipole is the combination of two equal charges of opposite signs, +Q and –Q, separated by a distance ℓ, which behaves as one entity.
- The quantity $Q\ell$ is called the electric dipole moment and is represented by the symbol p.

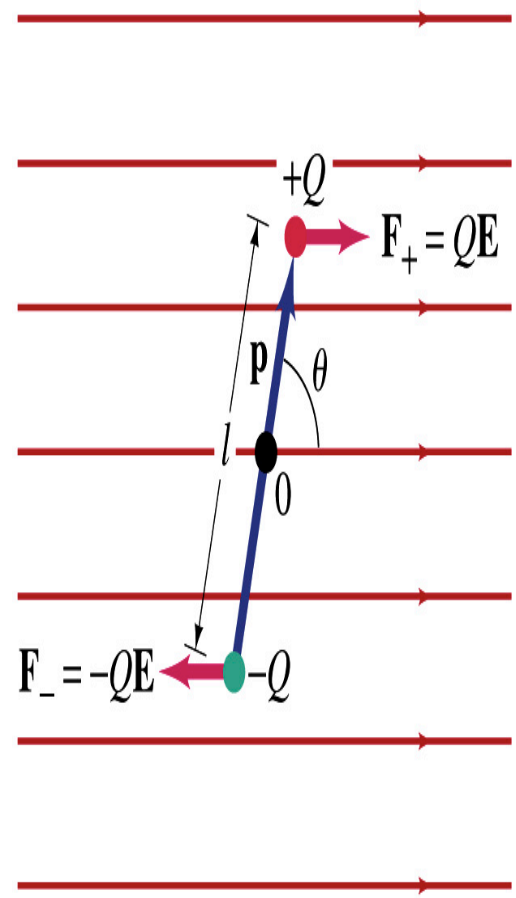


  - The dipole moment is a vector quantity, $\mathbf{p}$
  - The magnitude of the dipole moment is $\mathbf{Q\ell}$. Unit? C-m
  - Its direction is from the negative charge to the positive charge.
  - Many of diatomic molecules like CO have a dipole moment. ➔ These are referred as polar molecules.
    - Even if the molecule is electrically neutral, their sharing of electrons causes separation of charges
    - Symmetric diatomic molecules, such as O_2, do not have dipole moment.
  - The water molecule also has a dipole moment which is the vector sum of two dipole moments between Oxygen and each of Hydrogen atoms.

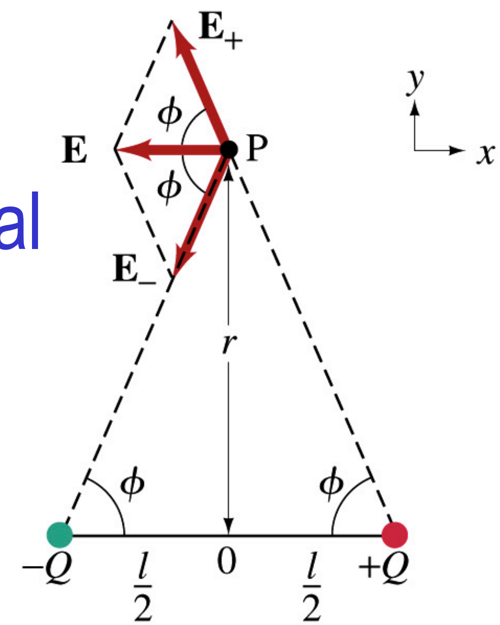


Dipoles in an External Field

- Let's consider a dipole placed in a uniform electric field **E**.
- What do you think will happen to the dipole in the figure?
  - Force will be exerted on the charges.
    - The positive charge will get pushed toward right while the negative charge will get pulled toward left.
  - What is the net force acting on the dipole?
    - Zero
  - So will the dipole not move?
    - Yes, it will.
  - Why?
    - There is a torque applied on the dipole.



Electric Field by a Dipole



- Let's consider the case in the picture.
- There are fields by both the charges. So the total electric field by the dipole is $\vec{E}_{Tot} = \vec{E}_{+Q} + \vec{E}_{-Q}$
- The magnitudes of the two fields are equal

$$E_{+Q} = E_{-Q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{\left(\sqrt{r^2+(l/2)^2}\right)^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2+(l/2)^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2+l^2/4}$$

- Now we must work out the x and y components of the total field.
  - Sum of the two y components is
    - Zero since they are the same but in opposite direction
  - So the magnitude of the total field is the same as the sum of the two x-components:

$$E = 2E_+\cos\phi = \frac{1}{2\pi\varepsilon_0}\frac{Q}{r^2+l^2/4}\frac{l}{2\sqrt{r^2+l^2/4}} = \frac{1}{4\pi\varepsilon_0}\frac{p}{\left(r^2+l^2/4\right)^{3/2}}$$

Dipole Electric Field from Afar

- What happens when r>>l?.

$$E_D = \frac{1}{4\pi\varepsilon_0}\frac{p}{\left(r^2 + l^2/4\right)^{3/2}} \approx \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3} \quad \left(\text{when } r \gg l\right)$$

- Why does this make sense?
  - Since from a long distance, the two charges are very close so that the overall charge gets close to 0!!
  - This dependence works for the point not on the bisecting line as well

Electric Potential Energy

- Concept of energy is very useful solving mechanical problems
- Conservation of energy makes solving complex problems easier.
- When can the potential energy be defined?
  - Only for a conservative force.
  - The work done by a conservative force is independent of the path. What does it only depend on??
    - The difference between the initial and final positions
  - Can you give me an example of a conservative force?
    - Gravitational force
- Is the electrostatic force between two charges a conservative force?
  - Yes. Why?
  - The dependence of the force to the distance is identical to that of the gravitational force.
    - The only thing matters is the direct linear distance between the objects not the path.