PHYS 1444 – Section 001
Lecture #8

Thursday, June 13, 2019

Dr. Jaehoon Yu

- Chapter 23
  - Electric Potential Due to Electric Dipole
  - E Determined from V
  - Electrostatic Potential Energy
- Chapter 24 Capacitance etc..
  - Capacitors
  - Capacitors in Series or Parallel

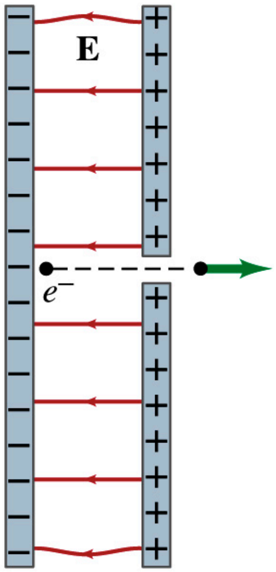
Today's homework is #6, due 11pm, Wednesday, June 19!!

Announcements

- Reading Assignment
  - CH 23.9
- Mid-term exam
  - In class Tuesday, June 18
  - Comprehensive exam which covers CH21.1 through what we learn Monday, June 17 plus appendices A and B the math refresher
  - BYOF: You may bring one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
  - No derivations, word definitions, setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!

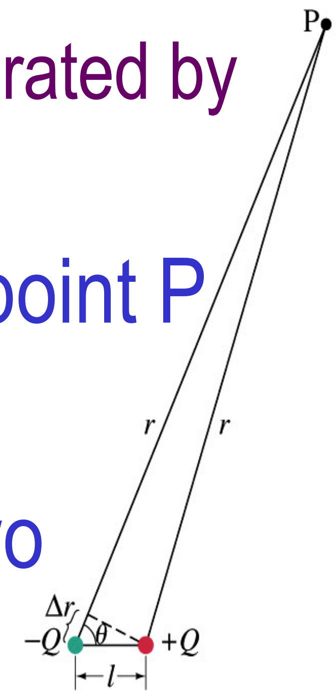
Reminder: Special Project #3

- **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



Electric Potential due to Electric Dipoles

- What is an electric dipole?
  - Two equal point charge Q of opposite signs separated by a distance ℓ and behaves like one entity: p=Qℓ
- For the electric potential due to a dipole at a point P
  - We take V=0 at r=∞
- The simple sum of the potential at p by the two charges is



$$V=\sum\frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}=\frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r}+\frac{(-Q)}{r+\Delta r}\right)=\frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r}-\frac{1}{r+\Delta r}\right)=\frac{Q}{4\pi\varepsilon_0}\frac{\Delta r}{r(r+\Delta r)}$$

- Since Δr=ℓcosθ and if r>>ℓ, r>>Δr, thus r+Δr~r and

$$V=\frac{Q}{4\pi\varepsilon_0}\frac{l\cos\theta}{r^2}=\frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r}$$

V by a dipole at a distance r from the dipole

$$V=\frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r}$$

E Determined from V

- Potential difference between two points under the electric field is $V_b - V_a = -\int_a^b \vec{E} \cdot d\vec{l}$
- So in a differential form, we can write

$$dV = -\vec{E} \cdot d\vec{l} = -E_l dl$$

  - What are dV and E_ℓ?
    - dV is the infinitesimal potential difference between the two points separated by a distance $d\ell$
    - E_ℓ is the field component along the direction of $d\ell$.
- Thus we can write the field component E_ℓ as

$$\boxed{E_l = -\frac{dV}{dl}}$$

Physical Meaning?

The component of the electric field in any direction is equal to the negative rate of change of the electric potential as a function of distance in that direction.!!

E Determined from V, cnt'd

- The quantity $dV/d\ell$ is called the **gradient of V** in a particular direction
  - If no direction is specified, the term gradient refers to the direction on which **V changes most rapidly** and this would be the direction of the field vector **E** at that point.
  - So if **E** and $d\ell$ are parallel to each other, $E = -\frac{dV}{dl}$
- If E is written as a function x, y and z, the ℓ refers to x, y and z $\quad E_x = -\frac{\partial V}{\partial x} \quad E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial z}$
- $\frac{\partial V}{\partial x}$ is the "partial derivative" of V with respect to x, while y and z are held constant
- In vector form, $\vec{E} = -gradV = -\vec{\nabla}V = -\left(\vec{i}\frac{\partial}{\partial x} + \vec{j}\frac{\partial}{\partial y} + \vec{k}\frac{\partial}{\partial z}\right)V$

$\vec{\nabla} = -\left(\vec{i}\frac{\partial}{\partial x} + \vec{j}\frac{\partial}{\partial y} + \vec{k}\frac{\partial}{\partial z}\right)$ is called ***del*** or the ***gradient operator*** and is a ***vector operator***.

Electrostatic Potential Energy

- Consider a case in which a point charge q is moved between points a and b where the electrostatic potential due to other charges in the system is V_a and V_b
- The change in electrostatic potential energy of q in the field by other charges is

$$\Delta U = U_b - U_a = q\left(V_b - V_a\right) = qV_{ba}$$

- Now what is the electrostatic potential energy of a system of charges?
  - Let's choose V=0 at r=∞
  - If there are no other charges around, single point charge Q_1 in isolation has no potential energy and is under no electric force

Electrostatic Potential Energy; Two charges

- If a second point charge Q_2 is brought close to Q_1 at a distance r_{12}, the potential due to Q_1 at the position of Q_2 is

$$V = \frac{Q_1}{4\pi\varepsilon_0}\frac{1}{r_{12}}$$

- The potential energy of the two charges relative to V=0 at r= ∞ is

$$U = Q_2 V = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r_{12}}$$

  - This is the work that needs to be done by an external force to bring Q_2 from infinity to the distance r_{12} from Q_1.
  - It is also a negative of the work needed to separate them to infinity.

Electrostatic Potential Energy; Three Charges

- So what do we do for three charges?
- Work is needed to bring all three charges together
  - Work needed to bring Q_1 to a certain location without the presence of any charge is 0.
  - Work needed to bring Q_2 to a distance to Q_1 is $U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r_{12}}$
  - Work need to bring Q_3 to certain distances to Q_1 and Q_2 is

$$U_3 = U_{13} + U_{23} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_3}{r_{13}} + \frac{1}{4\pi\varepsilon_0}\frac{Q_2Q_3}{r_{23}}$$

- So the total electrostatic potential energy of the three charge system is

$$U = U_{12} + U_{13} + U_{23} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1Q_2}{r_{12}} + \frac{Q_1Q_3}{r_{13}} + \frac{Q_2Q_3}{r_{23}}\right) \quad \left[V = 0 \text{ at } r = \infty\right]$$

  - What about a four charge system or N charge system?

Electrostatic Potential Energy: electron Volt

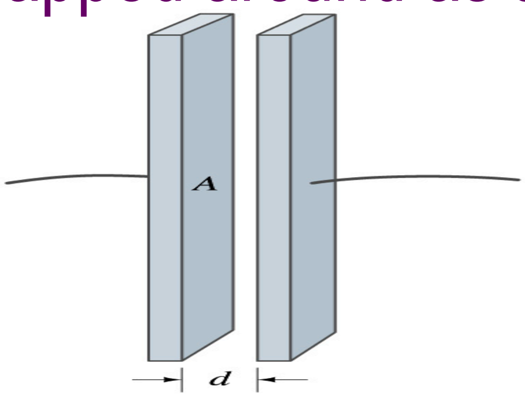
- What is the unit of electrostatic potential energy?
  - Joules
- Joules is a very large unit in dealing with electrons, atoms or molecules atomic scale problems
- For convenience a new unit, electron volt (eV), is defined
  - 1 eV is defined as the energy acquired by a particle carrying the charge equal to that of an electron (q=e) when it moves across a potential difference of 1V.
  - How many Joules is 1 eV then? $1eV = 1.6\times10^{-19}C\cdot 1V = 1.6\times10^{-19}J$
- eV however is **NOT a standard SI unit**. You must convert the energy to Joules for computations.
- What is the speed of an electron with kinetic energy 5000eV?

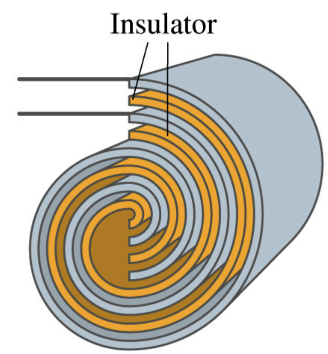
Capacitors (or Condensers)

- What is a capacitor?
  - A device that can store electric charge
  - But does not let them flow through
- What does it consist of?
  - Usually consists of two conducting objects (plates or sheets) placed near each other without touching
  - Why can't they touch each other?
    - The charge will neutralize…
- Can you give some examples?
  - Camera flash, UPS, Surge protectors, binary circuits, memory, etc…
- How is the capacitor different than the battery?
  - Battery provides potential difference by storing energy (usually chemical energy) while the capacitor stores charges but very little energy.

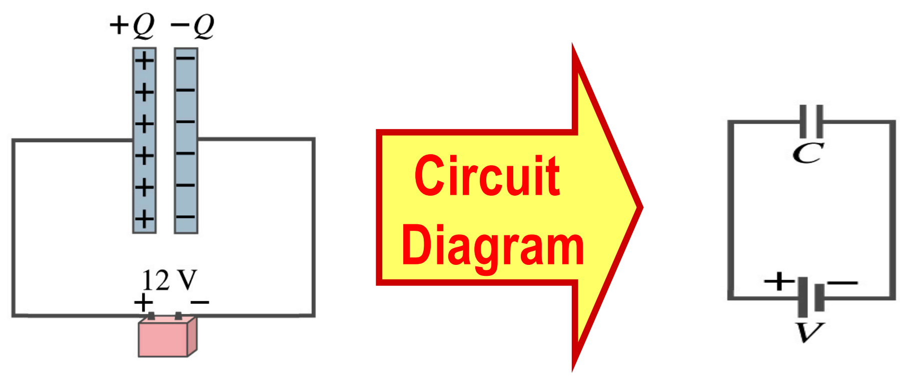
Capacitors

- A simple capacitor consists of a pair of parallel plates of area $\mathcal{A}$ separated by a distance d.
  - A cylindrical capacitors are essentially parallel plates wrapped around as a cylinder.



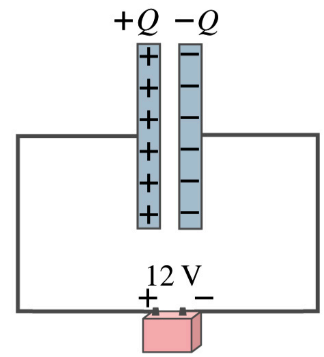


- How would you draw symbols for a capacitor and a battery in a circuit diagram?
  - Capacitor -||-
  - Battery (+) -|ı- (-)



Capacitors

- What do you think will happen if a battery is connected (or the voltage is applied) to a capacitor?
  - The capacitor gets charged quickly, one plate positive and the other negative in equal amount.



- Each battery terminal, the wires and the plates conductors. What does this mean?
  - All conductors are at the same potential. And?
  - So the full battery voltage is applied across the capacitor plates.
- So for a given capacitor, the amount of charge stored on each capacitor plate is proportional to the potential difference V_{ba} between the plates. How would you write this formula?

$$\boxed{Q = CV_{ba}}$$

C is a property of a capacitor so does not depend on Q or V.

  - C is a proportionality constant, called the capacitance of the device.
  - What is the unit? C/V or Farad (F) Normally use μF or pF.