PHYS 1441 – Section 002
Lecture #10

Monday, Oct. 5, 2020

Dr. Jaehoon Yu

- CH23
  - Potential due to Charge Distributions
  - Equi-potential Lines and Surfaces
  - Electro-static Potential Energy
- CH24
  - Capacitors
  - Capacitors in Series and Parallel

Today's homework is homework #6, due 11pm, Friday, Oct. 16!!

Announcements

- Reading assignments: CH22 – 4 and CH23 – 9
- Online Quiz 2 on Quest
  - Beginning of class this Wednesday, Oct. 7
  - Covers: CH22.1 through what we finish today, Monday, Oct. 5
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
  - No derivations, word definitions or setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
  - Must send me the photos of front and back of the formula sheet, including the blank, no later than 11am the day of the quiz
    - Once submitted, you cannot change, unless I ask you to delete some part of the sheet!
- Special seminar on COVID – 19: When best time?
  - Dr. Linda Lee

Reminder: SP#3 – Civic Duty I: Voter Registration

- **Voter registration in Texas ends on Monday, Oct. 5, 2020**
  - Registration can be done: https://www.votetexas.gov/register/index.html
  - Check your registration: https://teamrv-mvp.sos.texas.gov/MVP/mvp.do
- For those who are legal to take part in the election
  - Your own registration to vote: 10 points
    - Include the screen shot your own voter registration check
  - You can have up to 3 more people who are not registered to register: 5 points each
    - Must include before and after the registration screen shots of the same person next to each other to show these are newly registered
- For those who are not legal to take part in the election
  - You can have up to 5 people who are not registered to register: 5 points each
    - Must include before and after the registration screen shots of the same person next to each other to show these are newly registered
- **Deadline: 1pm Wednesday, Oct. 14, 2020← Note extended deadline**
- Put all screen shots in one pdf file following the naming convention – SP3-LastName-FirstName-Fall20.pdf and upload to the CANVAS assignment

SP#3 – Civic Duty I: Voter Registration – 2

TEXAS SECRETARY OF STATE

TEAM

AM I REGISTERED?

TEXAS ELECTIONET ADMINISTRATION SYSTEM

Voter Information

Name: JAEHOON YU

[redacted]

Gender: MALE

Valid From: 01/01/2020

Effective Date of Registration: 05/20/2004

Voter Status: ACTIVE

County: TARRANT

Precinct: 2266

VUID: 1050748339

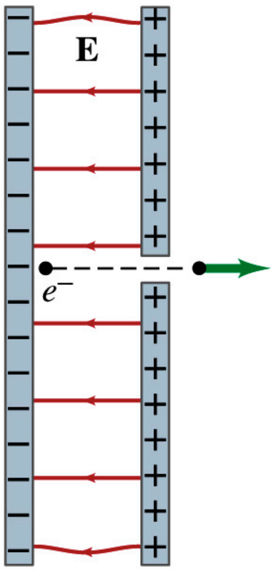
Change your Address

Upcoming Elections (Select Election for available polling information)

11/03/2020--2020 NOVEMBER 3RD GENERAL ELECTION

***Eligibility is determined by Effective Date of Registration (Must be on or before Election Day)

Reminder: Special Project #4



- **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.
  - 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 the 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 the initial speed of 0.1% to 90% of the speed of light. You need to look up and write down the relevant constants, such as mass of the electron, charge of the electron and the speed of light. (5 points)
- Must be handwritten and not copied from anyone else!
  - Follow the SP naming convention: SP4-first-last-fall20.pdf which includes all pages in one file ➔ Be sure to write your name onto all pages of the project report!
- Due beginning of the class **Monday, Oct. 12**, submitted on CANVAS!

Refresher : Some Formula

- Electric potential (poll 2)

$$\boxed{V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}}$$

$$\boxed{V = Ed}$$

- Electric field (poll 2)

$$\boxed{\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}}$$

(Poll12)

Electric Potential by Charge Distributions

- Let's consider the case of **n** individual point charges in a given space and V=0 at r=∞.
- Then the potential V_{ia} due to the charge Q_i at point a, at a distance r_{ia} from Q_i is

$$V_{ia} = \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- Thus the total potential V_a by all **n** point charges is

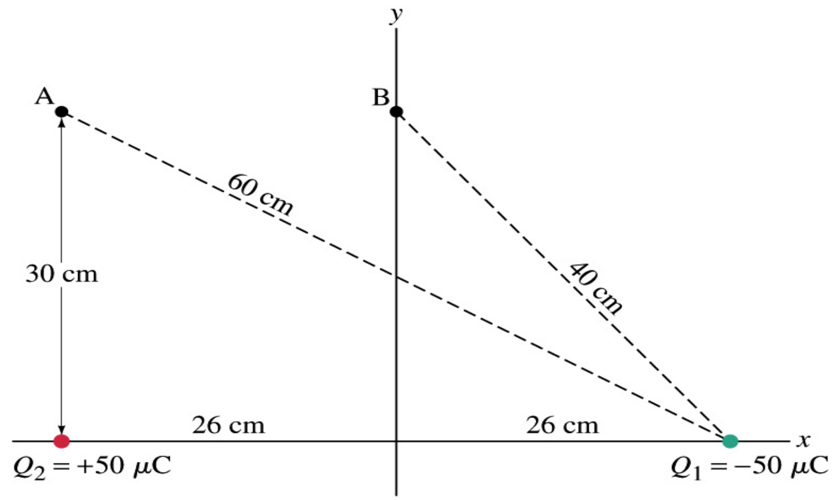
$$V_a = \sum_{i=1}^{n} V_{ia} = \sum_{i=1}^{n} \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- For a continuous charge distribution, we obtain

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$$

Example

- **Potential due to two charges**: Calculate the electric potential (a) at point A in the figure due to the two charges shown, and (b) at point B.



- Potential is a scalar quantity, so one adds the potential by each of the source charge, as if they are numbers.

(a) potential at A is $V_A = V_{1A} + V_{2A} = \sum \frac{Q_i}{4\pi\varepsilon_0} \frac{1}{r_{iA}} =$

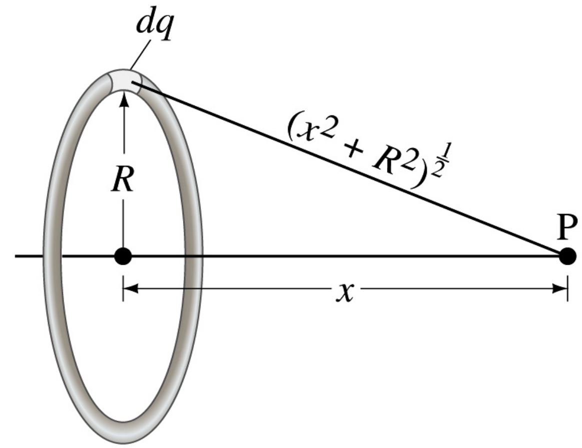
$$= \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r_{1A}} + \frac{1}{4\pi\varepsilon_0} \frac{Q_2}{r_{2A}} = \frac{1}{4\pi\varepsilon_0} \left(\frac{Q_1}{r_{1A}} + \frac{Q_2}{r_{2A}} \right)$$

$$= 9.0 \times 10^9 \left(\frac{-50 \times 10^{-6}}{0.60} + \frac{50 \times 10^{-6}}{0.30} \right) = 7.5 \times 10^5 V$$

(b) How about potential at B?

Example 23 – 8

- **Potential due to a ring of charge**: A thin circular ring of radius R carries a uniformly distributed charge Q. Determine the electric potential at a point P on the axis of the ring a distance x from its center.



- Each point on the ring is at the same distance from the point P. What is the distance?

$$r = \sqrt{R^2 + x^2}$$

- So the potential at P is

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r} = \frac{1}{4\pi\varepsilon_0 r}\int dq =$$

What's this?

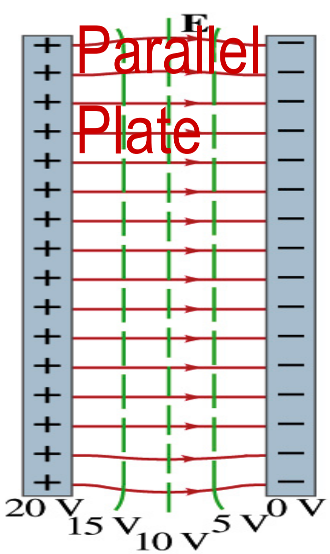
$$\frac{1}{4\pi\varepsilon_0\sqrt{x^2+R^2}}\int dq = \frac{Q}{4\pi\varepsilon_0\sqrt{x^2+R^2}}$$

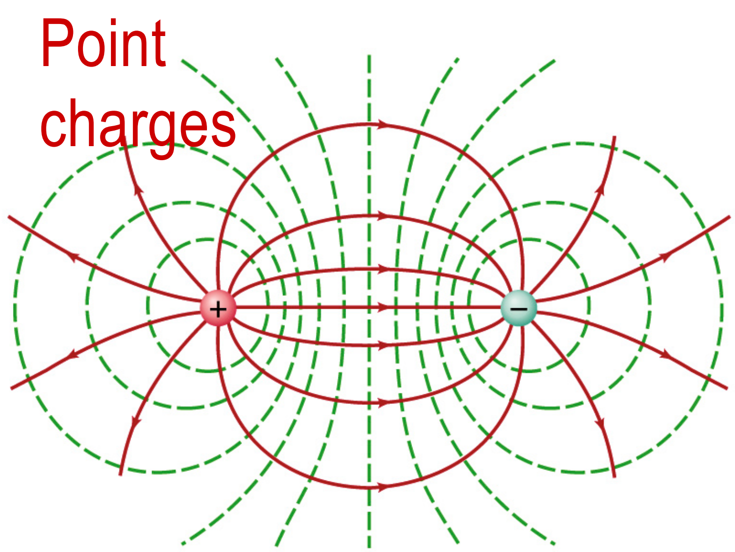
Equi-potential Surfaces

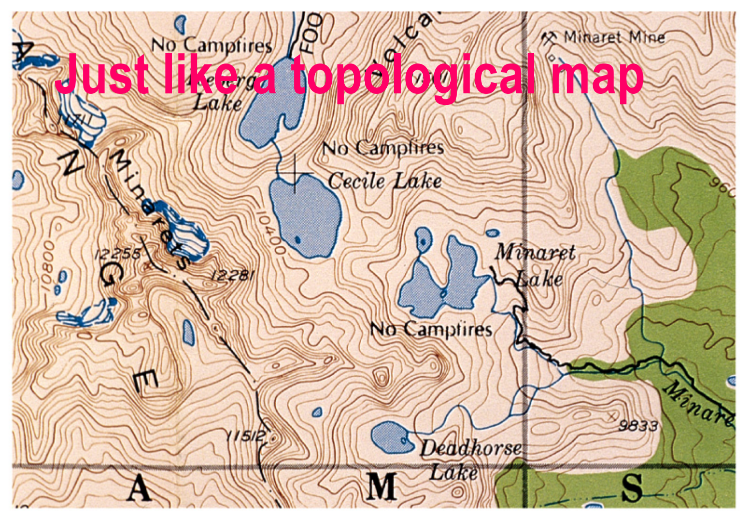
- Electric potential can be graphically shown using the equipotential lines in 2-D or the equipotential surfaces in 3-D
- Any two points on the equipotential surfaces (lines) are at the same potential
- What does this mean in terms of the potential difference?
  - The potential difference between any two points on an equipotential surface is 0. → unit? (poll 3)
- How about the potential energy difference?
  - Also 0. → unit? (poll 3)
- What does this mean in terms of the work to move a charge along the surface between these two points?
  - No work is necessary to move a charge between these two points.

Equi-potential Surfaces

- An equipotential surface (line) must be perpendicular to the electric field. Why?
  - If there are any parallel components to the electric field, it would require work to move a charge along the surface.
- Since the equipotential surface (line) is perpendicular to the electric field, we can draw these surfaces or lines easily.
- Since there can be no electric field within a conductor in a static case, the entire volume of a conductor must be at the same potential.
- So the electric field must be perpendicular to the conductor surface.

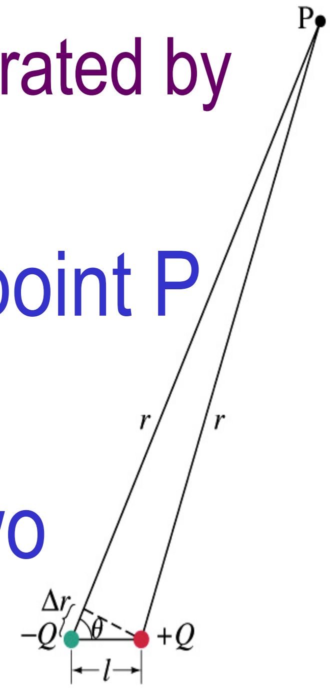






Electric Potential due to Electric Dipoles

- What is an electric dipole?
  - Two equal point charge Q of opposite signs separated by a distance ℓ and behaves like one entity: $p=Q\ell$
- 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 $\Delta r=\ell\cos\theta$ and if $r \gg \ell$, $r \gg \Delta r$, thus $r+\Delta r \sim r$ and

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

V by a dipole at a distance r from the dipole

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

E Determined from V

- Potential difference between two points under an 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

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

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

- 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 in 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 $E_x = -\frac{\partial V}{\partial x}$ $E_y = -\frac{\partial V}{\partial y}$ $E_z = -\frac{\partial V}{\partial z}$
- $\frac{\partial V}{\partial x}$ 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 the 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 $U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r_{12}}$
  - Work need to bring Q_3 to certain distances to Q_1 and Q_2 is

$$U_3 = U_{13} + U_{23} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_3}{r_{13}} + \frac{1}{4\pi\varepsilon_0}\frac{Q_2 Q_3}{r_{23}}$$

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

$$U = U_{12} + U_{13} + U_{23} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1 Q_2}{r_{12}} + \frac{Q_1 Q_3}{r_{13}} + \frac{Q_2 Q_3}{r_{23}}\right) \quad \left[V = 0 \text{ at } r = \infty\right]$$

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

Electrostatic Potential Energy: electron Volt

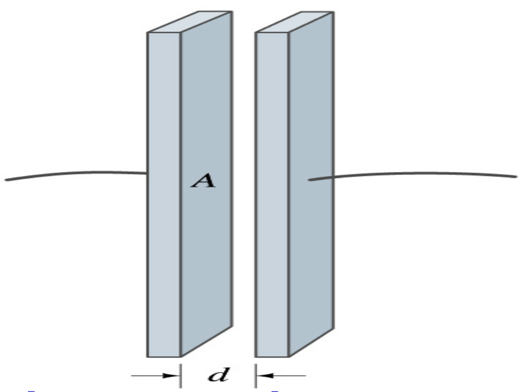
- What is the unit of the electrostatic potential energy? (poll 3)
  - Joules
- Joules is a very large unit in dealing with electrons, atoms, molecules or any atomic scale problems
- For convenience a new unit, electron volt (eV), is defined
  - 1 eV is defined as the energy acquired by a particle carrying the magnitude of 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? $1eV = 1.6\times 10^{-19}C\cdot 1V = 1.6\times 10^{-19}J$
- Note that 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?

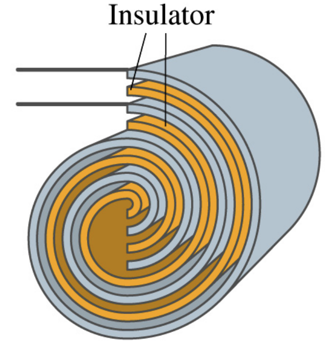
Capacitors (or Condensers)

- What is a capacitor?
  - A device that can store electric charge
  - But does not let them flow through
- What does a capacitor 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, 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 capacitor is essentially parallel plates wrapped around as a cylinder.





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