PHYS 1441 – Section 002
Lecture #8

Monday, Sept. 28, 2020
Dr. Jaehoon Yu

- CH22
  - Electric Dipole
- CH23
  - Electric Potential Energy
  - Electric Potential Due to Point Charges
  - Equi-potential Lines and Surfaces

Today's homework is #5, due 11pm, Tuesday, Oct. 6!!

Announcements

- Reading assignments: CH22 – 4 and CH23 – 9
- Course evaluation policy
  - Homework: 25%!!!
  - Exams
    - Final Comprehensive Exam (11am, Wed., 12/16/20): 23%
    - Mid-term Comprehensive Exam (1pm, Mon., 10/19/20): 20%
    - One better of the two term Exams (9/23/20 and 11/11/20): 12%
    - Missing an exam is not permissible unless pre-approved
  - Lab score: 10%
  - Pop-quizzes: 10%
  - Extra credit: 10% of the total
  - Grading done on a sliding scale, based on the final grades
- 1^{st} term results
  - Class average: 63.4/96
    - Equivalent to 66/100
  - Top score: 96/96

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. 7, 2020**
- 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

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

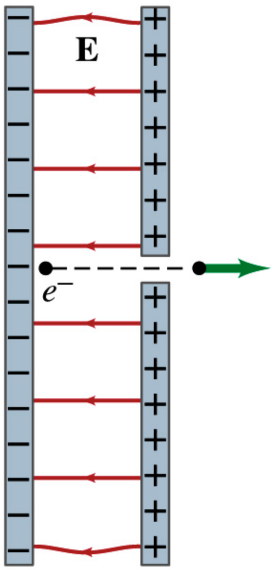
Upcoming Elections (Select Election for available polling information)

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

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

Special Project #4

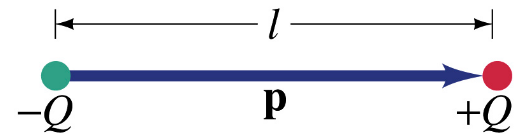
- **Particle Accelerator**. A charged particle of mass **M** with charge **-Q** is accelerated in the uniform field **E** between two parallel charged plates whose separation is **D** as shown in the figure on the right. The charged particle is accelerated from an initial speed $\mathbf{v_0}$ near the negative plate and passes through a tiny hole in the positive plate.



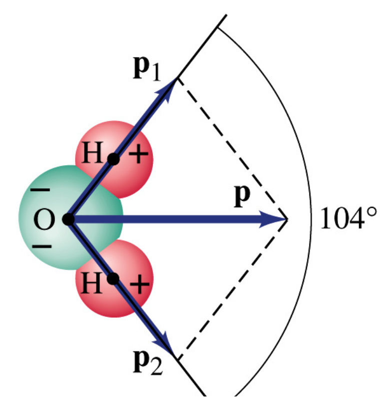
  - Derive the formula for the electric field E to accelerate the charged particle to a fraction *f* of the speed of light *c*. Express E in terms of **M, Q, D,** ***f*****, c** and $\mathbf{v_0}$.
  - (a) Using the Coulomb force and the kinematic equations. (8 points)
  - (b) Using the work-kinetic energy 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!

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.

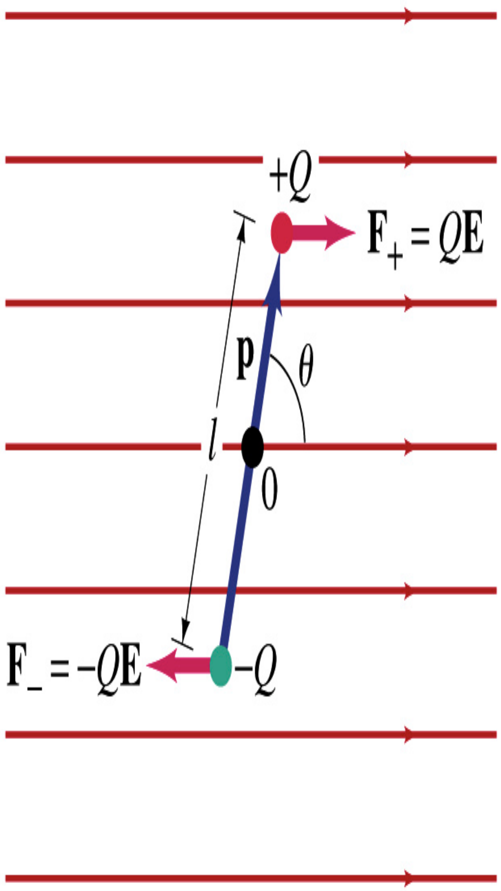


  - The dipole moment is a vector quantity *(poll 2)*
  - The magnitude of the dipole moment is $\mathbf{Q\ell}$. Unit? *(poll 3)* C-m
  - Its direction is from the negative charge to the positive charge.
  - Many of diatomic molecules like CO have a dipole moment. ➔ These are referred as polar molecules.
    - Even if the molecule is electrically neutral, their sharing of electrons causes separation of charges in a microscopic scale
    - 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.

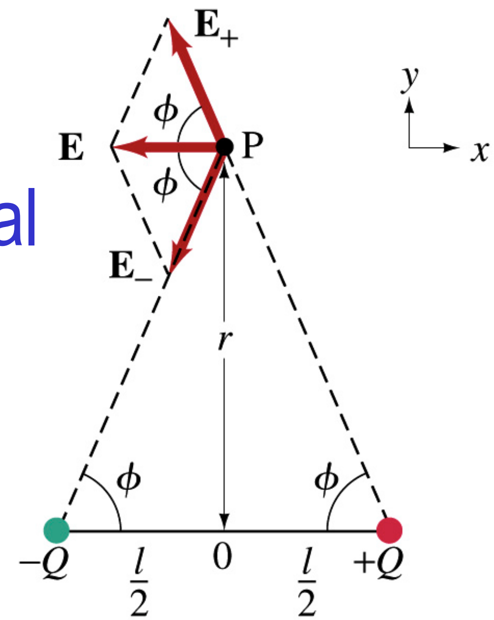


Dipoles in an External Field

- 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. (poll 7)
- 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?.

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

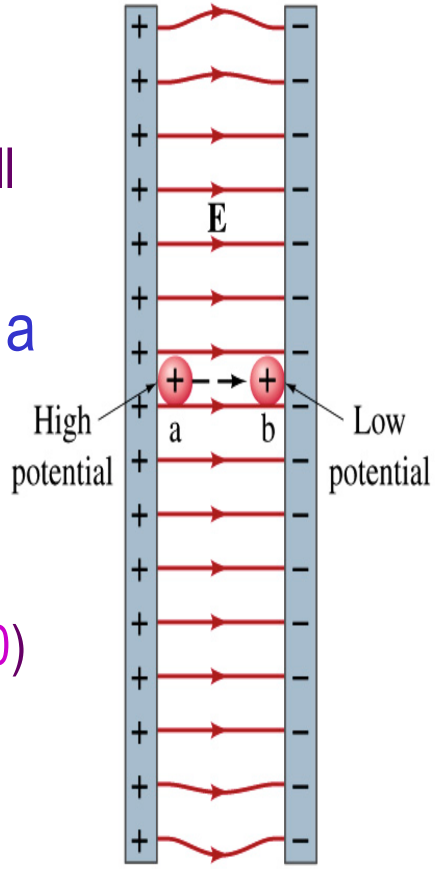
- Why does this make sense?
  - Since from a long distance, the two charges are very close so that the overall charge gets close to 0!!
  - This dependence works for the point not on the bisecting line as well

Electric Potential Energy

- Concept of energy is very useful solving mechanics problems
- Conservation of energy makes solving complex problems easier.
- When can the potential energy be defined? (Poll 2)
  - 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.

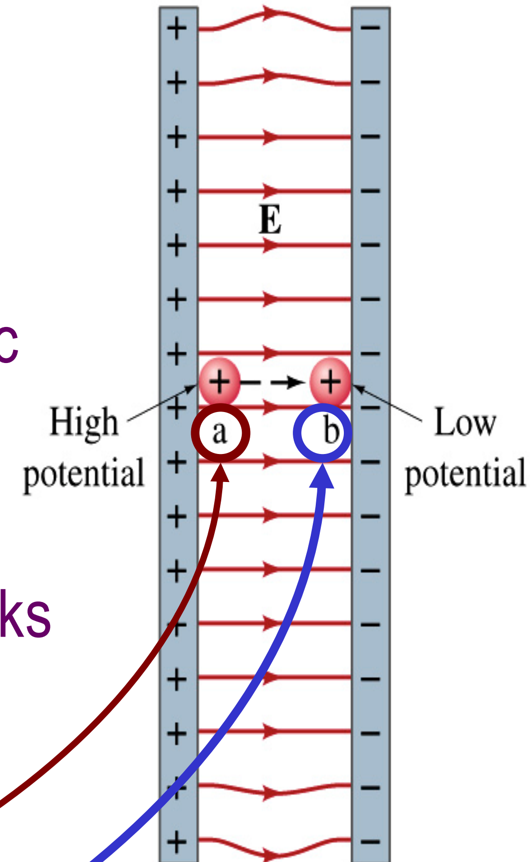
Electric Potential Energy

- How would you define the change in electric potential energy $U_b - U_a$?
  - The potential to work gained by the charge as it moves from point *a* to point *b*.
  - Negative of the work done on the charge by the electric force to move it from *b* to *a*.
- Let's consider an electric field between two parallel plates w/ equal but opposite charges
  - The field between the plates is uniform since the gap is small and the plates are infinitely long…
- What happens when we place a small charge, +q, on a point at the positive plate and let go?
  - The electric force will accelerate the charge toward the negative plate.
  - What kind of energy does this charged particle gain? (poll 10)
    - Kinetic energy



Electric Potential Energy

- What does this mean in terms of energies?
  - The electric force is a conservative force.
  - Thus, the mechanical energy (K+U) is conserved under this force.
  - The positively charged object has only the electric potential energy (no KE) at the positive plate.
  - The electric potential energy decreases and
  - Turns into kinetic energy as the electric force works on the charged object, and the charged object gains speed.
- Point of the greatest potential energy for
  - Positively charged object
  - Negatively charged object



PE= U_a 0

KE= 0 $K_b=(U_a)$

ME= U_a $K_b=(U_a)$

$U+K=(U_a)$

Electric Potential

- How is the electric field defined?
  - Electric force per unit charge: F/q
- We can define electric potential (potential) as
  - The electric potential energy per unit charge
  - This is the same as the voltage of a battery…
- Electric potential is written with the symbol V (poll 2)
  - If a positive test charge q has the potential energy U_a at the point *a*, the electric potential of the charge at that point is

$$V_a = \frac{U_a}{q}$$

Electric Potential, cont'd

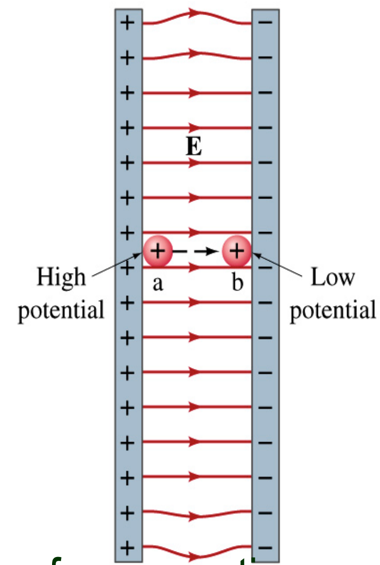
- Since only the difference in potential energy is meaningful, only the potential difference between two points is measurable
- What happens when the electric force does a "positive work"?
  - The charge gains kinetic energy
  - Electric potential energy of the charge decreases
- Thus the difference in potential energy is the same as the negative of the work, W_{ba}, done on the charge by the electric field to move the charge from point a to b.
- The potential difference V_{ba} is

$$V_{ba} = V_b - V_a = \frac{U_b - U_a}{q} = \frac{-W_{ba}}{q}$$

  - Electric potential is independent of the test charge!! Unit? (Poll 8)

A Few Things about the Electric Potential

- What does the electric potential depend on?
  - Other charges that creates the field
  - What about the test charge?
    - No, the electric potential is independent of the test charge
    - Test charge gains potential energy by existing within the potential created by other charges
- Which plate is at the higher **potential**?
  - Positive plate. Why?
    - Since positive charge has the greatest potential energy on it.
  - What happens to the positive charge if it is let go?
    - It moves from higher potential to lower potential
  - How about the negative charge?
    - Its potential energy is higher on the negative plate. Thus, it moves from negative plate to positive. **Potential difference is still the same**



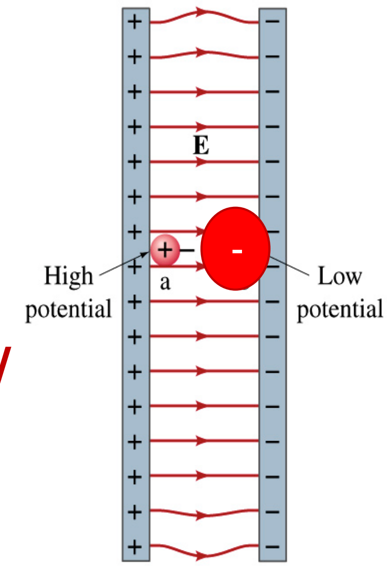
- The unit of the electric potential is Volt (V).
- From the definition, 1V = 1J/C.

Zero point of electric potential can be chosen arbitrarily.

Often the ground, a conductor connected to Earth, is zero.

Example 23 – 1

A negative charge: Suppose a negative charge, such as an electron, is placed at point *b* in the figure. If the electron is free to move, will its electric potential energy increase or decrease? How will the electric potential change?



- An electron placed at point *b* will move toward the positive plate since it was released at its highest **potential energy** point.
- It will gain kinetic energy as it moves toward left, decreasing its potential energy.
- The electron, however, moves from the point *b* at a lower potential to point *a* at a higher **potential**. $\Delta V = V_a - V_b > 0$.
- This is because the **potential is generated by the charges on the plates** not by the electron.

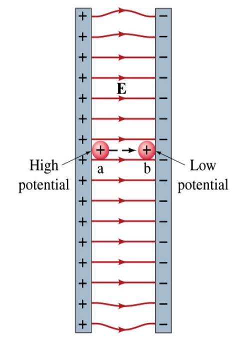
Electric Potential and Potential Energy

- What is the definition of the electric potential?
  - The potential energy difference per unit charge

$$V_{ba} = \frac{U_b - U_a}{q}$$

- OK, then, how would you express the potential energy that a charge q would obtain when it is moved between point *a* and *b* with the potential difference V_{ba}?

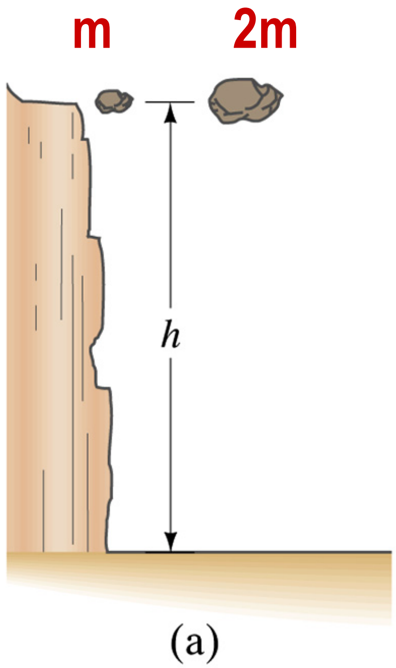
$$U_b - U_a = q\left(V_b - V_a\right) = qV_{ba}$$

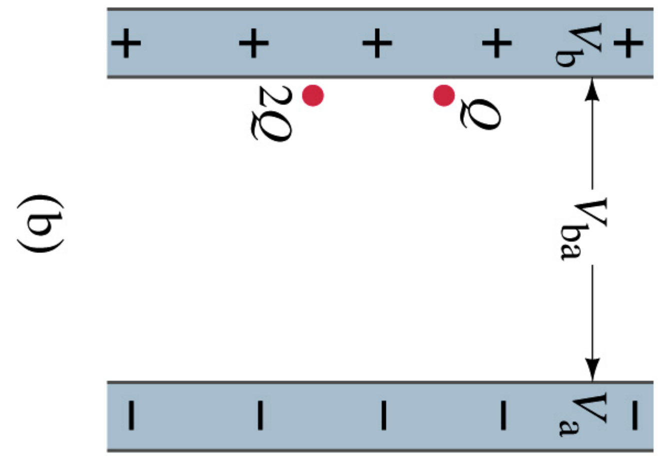


  - In other words, if an object with charge q moves through a potential difference V_{ba}, its potential energy changes by qV_{ba}.
- So based on this, how differently would you describe the electric potential in words?
  - A measure of how much kinetic energy an electric charge can acquire under the given field
  - A measure of how much work a given charge can do.

Comparisons of Potential Energies

- Let's compare gravitational and electric potential energies





- What are the potential energies of the rocks?
  - mgh and 2mgh
- Which rock has a bigger potential energy?
  - The rock with a larger mass
- Why?
  - It's got a bigger mass.

- What are the potential energies of the charges?
  - QV_{ba} and $2QV_{ba}$
- Which object has a bigger potential energy?
  - The object with a larger charge.
- Why?
  - It's got a bigger charge.

The potential is the same but the heavier rock or larger charge can do a greater work.

Electric Potential and Potential Energy

- The electric potential difference gives potential energy or the possibility to perform work based on the charge of the object.
- So what is happening in a battery or a generator?
  - They maintain a potential difference.
  - The actual amount of energy used or transformed depends on how much charge flows.
  - What is the potential difference maintained by a car's battery?
    - 12Volts
  - If for a given period, 5C charge flows through the headlight lamp, what is the total energy transformed?
    - E_{tot}=5C*12V=60 Umm… What is the unit? (poll 1) **Joules (J)**
  - If it is left on twice as long? E_{tot}=10C*12V=120J.

Some Typical Potential Differences

Sources	Approximate Voltage
Thundercloud to ground (~5km)	10^8 V
High-Voltage Power Lines	10^6 V
Power supply for TV tube	10^4 V
Automobile ignition	10^4 V
Household outlet	10^2 V
Automobile battery	12 V
Flashlight battery	1.5 V
Resting potential across nerve membrane	10^{-1} V
Potential changes on skin (EKG and EEG)	10^{-4} V

In a typical lightening strike, 15C of electrons are released in 500μs. What is the total kinetic energy of these electrons when they strike ground? What is the power released during this strike? What do you think will happen to a tree hit by this lightening?