PHYS 1444 – Section 004
Lecture #6

Monday, Feb. 6, 2012

Dr. Alden Stradling

- Chapter 23 Electric Potential
  - Electric Potential Energy
  - Electric Potential and Electric Field
  - Electric Potential due to Point Charges

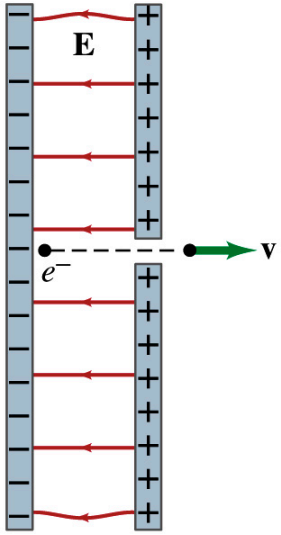
Today's homework is homework #4, due 10pm, Tuesday, Feb. 14!!

Announcements

- Quiz #2
  - Wednesday, Feb. 8
  - Beginning of the class
  - Covers: CH21.5 through what we learn today

Reminder: Special Project

- **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 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)



- Due beginning of the class Monday, Feb. 13

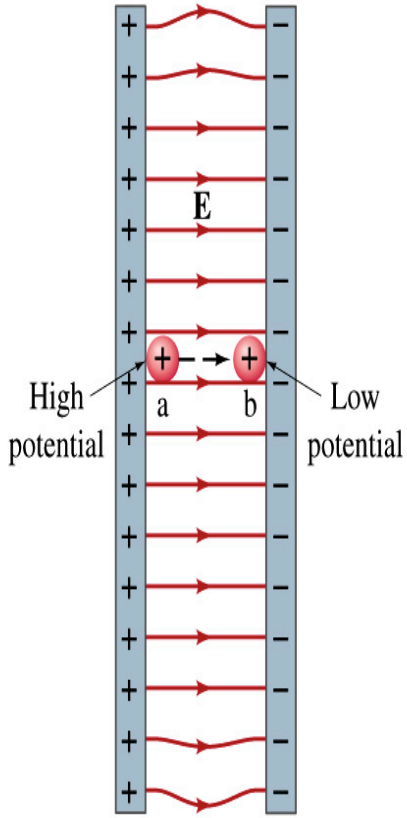
Electric Potential Energy

- 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 object not the path.

Electric Potential Energy

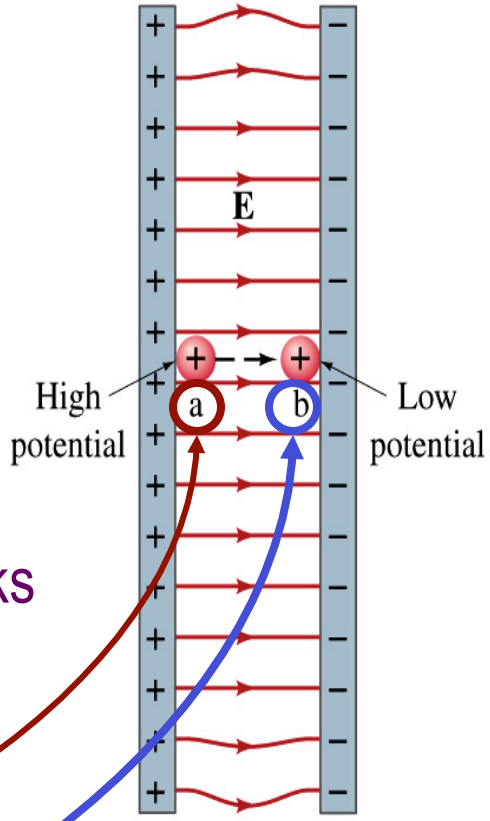
- How would you define the change in electric potential energy $U_b - U_a$?
  - The potential gained by the charge as it moves from point *a* to point *b*.
  - The negative work done on the charge by the electric force to move it from *a* to *b*.

- 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 negative plate.
  - What kind of energy does the charged particle gain?
    - 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 charged object has only the electric potential energy 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 greatest potential energy for
  - Positively charged object
  - Negatively charged object



PE= U 0
KE= 0 K
ME=U K
U+K

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 like the voltage of a battery…
- Electric potential is written with a symbol V
  - If a positive test charge q has potential energy U_a at a point *a*, the electric potential of the charge at that point is

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

Electric Potential

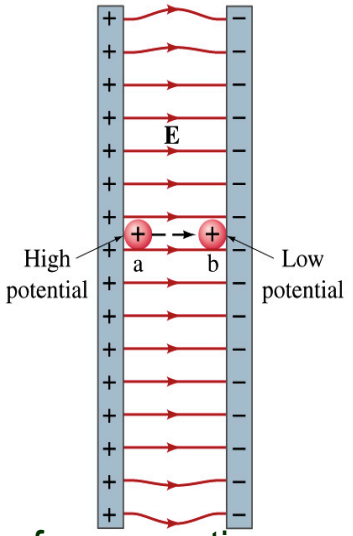
- Since only the difference in potential energy is meaningful, only the potential difference between two points is measurable
- What happens when the electric force does “positive work”?
  - The charge gains kinetic energy
  - Electric potential energy of the charge decreases
- Thus the difference in 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!!

A Few Things about 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 in the potential created by other charges
- Which plate is at a 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 a negative charge?
    - Its potential energy is higher on the negative plate. Thus, it moves from negative plate to positive. Potential difference is the same.
- The unit of the electric potential is Volt (V).
- From the definition, 1V = 1J/C.

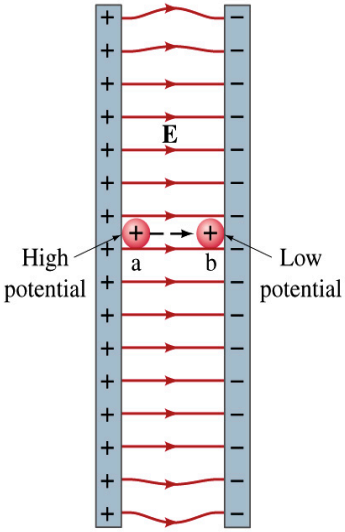


Zero point of electric potential can be chosen arbitrarily.

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

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

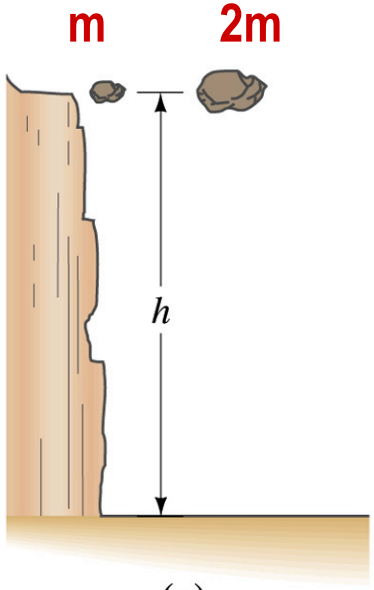
- OK, then, how would you express the potential energy that a charge q would obtain when it is moved between point *a* and *b* with the potential difference V_{ba}?

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

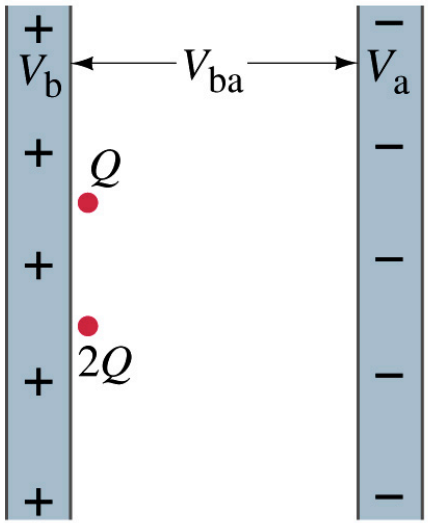
  - In other words, if an object with charge q moves through a potential difference V_{ba}, its potential energy changes by qV_{ba}.
- So based on this, how differently would you describe the electric potential in words?
  - A measure of how much energy an electric charge can acquire in a given situation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

Comparisons of Potential Energies

- Let's compare gravitational and electric potential energies



(a)



(b)

- 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

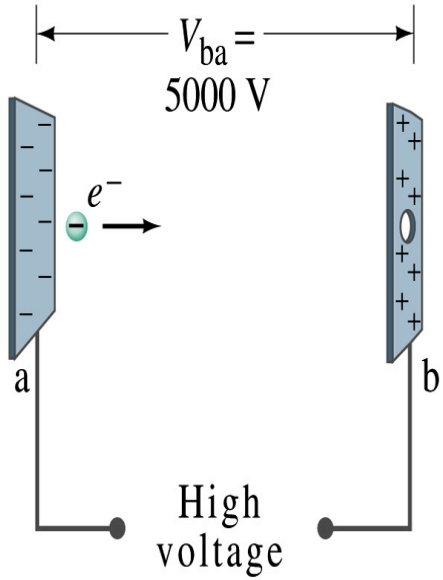
- The electric potential difference gives potential energy or the possibility to perform work based on the charge of the object.
- So what is happening in batteries or generators?
  - They maintain a potential difference.
  - The actual amount of energy used or transformed depends on how much charge flows.
  - How much 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? **Joules**
  - If it is left on twice as long? E_{tot}=10C*12V=120J.

Some Typical Voltages

Sources	Approximate Voltage
Thundercloud to ground	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

Example 23 – 2

Electrons in TV tube: Suppose an electron in the picture tube of a television set is accelerated from rest through a potential difference V_{ba}=+5000V. (a) What is the change in potential energy of the electron? (b) What is the speed of the electron (m=9.1x10^{-31}kg) as a result of this acceleration? (c) Repeat for a proton (m=1.67x10^{-27}kg) that accelerates through a potential difference of V_{ba}=-5000V.



- (a) What is the charge of an electron?
  - $e = -1.6\times10^{-19}\,C$

- So what is the change of its potential energy?

$$\Delta U = qV_{ba} = eV_{ba} = (-1.6\times10^{-19}\,C)(+5000V) = -8.0\times10^{-16}\,J$$

Example 23 – 2

- (b) Speed of the electron?
  - The entire potential energy of the electron turns to its kinetic energy. Thus the equation is

$$\Delta K = \frac{1}{2} m_e v_e^2 - 0 = W = -\Delta U = -eV_{ba} =$$
$$= -\left(-1.6\times10^{-19}\,C\right)5000V = 8.0\times10^{-16}\,J$$

$$v_e = \sqrt{\frac{2\times eV_{ba}}{m_e}} = \sqrt{\frac{2\times 8.0\times10^{-16}}{9.1\times10^{-31}}} = 4.2\times10^{7}\,m/s$$

- (C) Speed of a proton?

$$\Delta K = \frac{1}{2} m_p v_p^2 - 0 = W = -\Delta U = -\left\{\left(-e\right)\left(-V_{ba}\right)\right\} = -eV_{ba} = 8.0\times10^{-16}\,J$$

$$v_p = \sqrt{\frac{2\times eV_{ba}}{m_p}} = \sqrt{\frac{2\times 8.0\times10^{-16}}{1.67\times10^{-27}}} = 9.8\times10^{5}\,m/s$$