PHYS 1444 – Section 002
Lecture 8

Monday, Sept. 23, 2019

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CH 23

- Electric Potential due to Point Charges
- Shape of the Electric Potential
- V due to Charge Distributions
- Equi-potential Lines and Surfaces

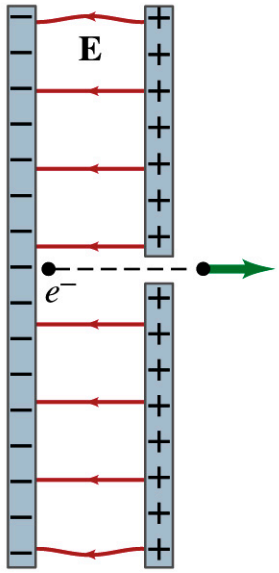
Today's homework is homework #6, due 11pm, Wednesday, Oct. 2!!

Announcements

- Submit special project #2
- Reading assignment: CH23.9
- Homework system
  - Please take the necessary actions regarding the homework page access as soon as possible!
    - You and I will lose access to your homework records!
- Today is the national voter registration day
  - fyi: To check your voting registration and register to vote
    - https://teamrv-mvp.sos.texas.gov/MVP/mvp.do
  - You can select criteria to check and register

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.
  - 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 0.1% of the speed of light 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!
- Due beginning of the class Monday, Sept. 30



Electric Potential

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

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

Electric Potential

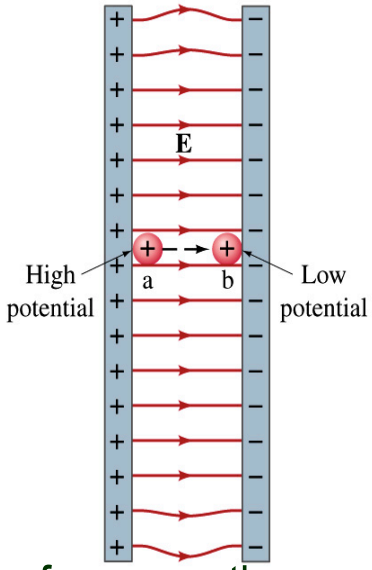
- Since only the difference in potential energy is meaningful, only the potential difference between two points is measurable
- What happens when the electric force does a "positive work"?
  - The charge gains kinetic energy
  - Electric potential energy of the charge decreases
- Thus the difference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

A Few Things about Electric Potential

- What does the electric potential depend on?
  - Other charges that create 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.

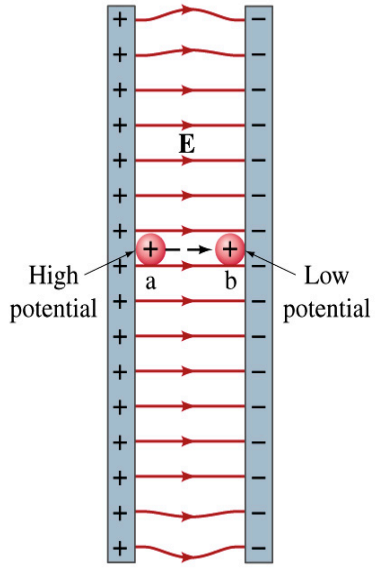


Zero point of electric potential can be chosen arbitrarily.

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

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

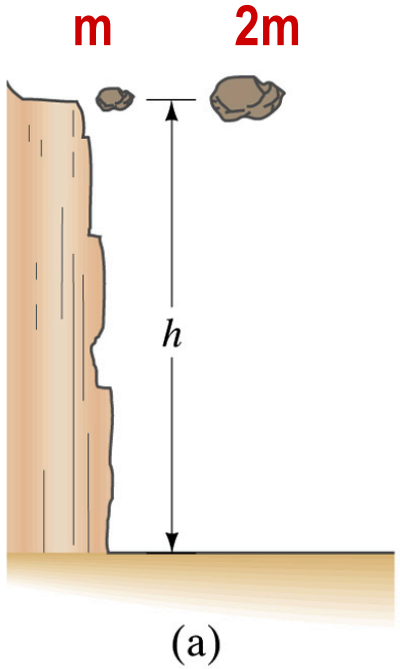
- OK, then, how would you express the potential energy that a charge q would obtain when it is moved between point *a* and *b* with the potential difference V_{ba}?

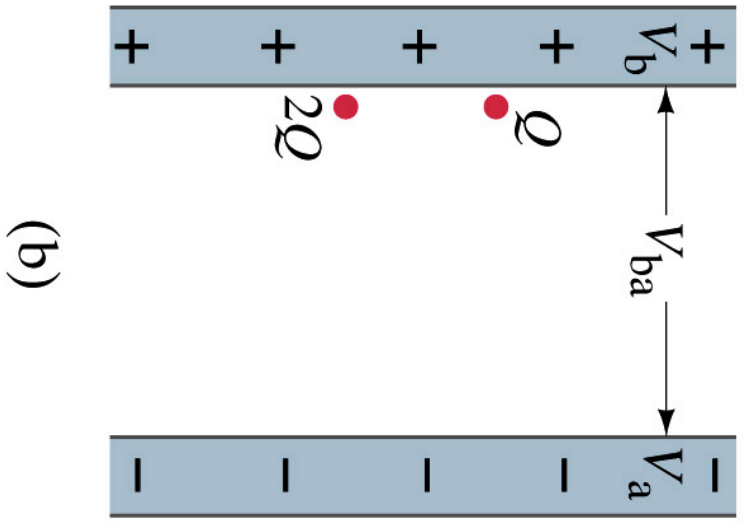
$$U_b - U_a = q(V_b - V_a) = qV_{ba}$$

  - 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 potential 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





- 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.
  - 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.

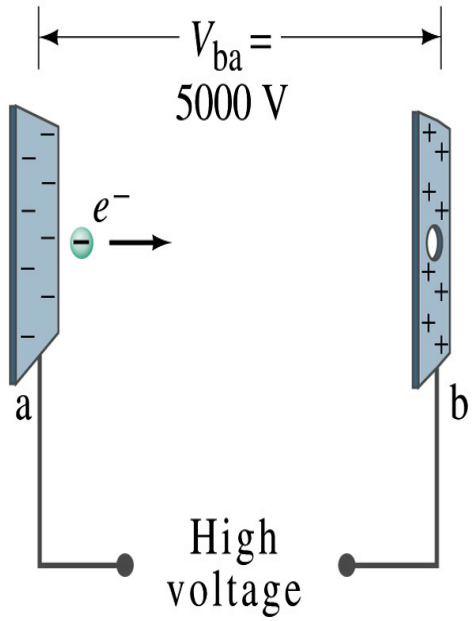
Some Typical Voltages

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

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?

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?
  - $e = -1.6 \times 10^{-19} C$

- So what is the change of its potential energy?

$$\Delta U = qV_{ba} = eV_{ba} = \left(-1.6 \times 10^{-19} C\right)\left(+5000V\right) = -8.0 \times 10^{-16} J$$

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?

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

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

Electric Potential and Electric Field

- The effect of the charge distribution can be described in terms of electric field or electric potential.
  - What kind of quantities are the electric field and the electric potential?
    - Electric Field: Vector
    - Electric Potential: Scalar
  - Since electric potential is a scalar quantity, it is often easier to handle.
- Well other than the above, how are these two quantities related?

Electric Potential and Electric Field

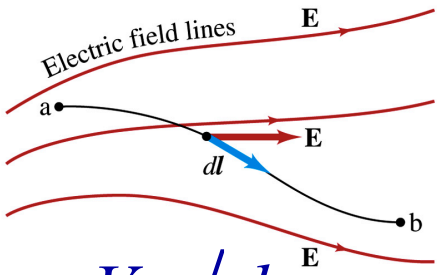
- **Potential energy** change is expressed in terms of a conservative force (point ***a*** at the higher potential)

$$U_b - U_a = -\vec{F} \cdot \vec{D} = -W_C$$

- For the electrical case, we are more interested in the **potential** difference:

$$V_{ba} = V_b - V_a = \frac{U_b - U_a}{q} = -\frac{\vec{F}}{q} \cdot \vec{D} = -\vec{E} \cdot \vec{D} = -ED\cos\theta$$

  - This formula can be used to determine V_{ba} when the electric field is given.



- When the field is uniform

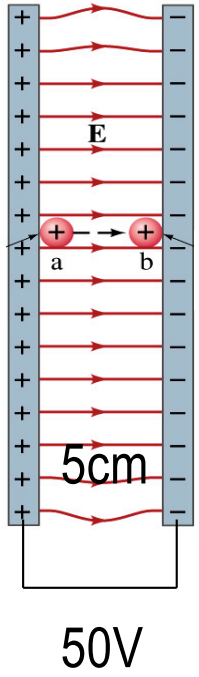
$$V_b - V_a = -\vec{E} \cdot \vec{D} = -ED\cos\theta = -Ed \quad \text{so} \quad E = -V_{ba}/d$$

What does "-" sign mean? The direction of E is along that of decreasing potential.

Unit of the electric field in terms of potential? V/m Can you derive this from N/C?

Example

Uniform electric field obtained from voltage:
Two parallel plates are charged to a voltage of 50V. If the separation between the plates is 5.0cm, calculate the magnitude of the electric field between them, ignoring any fringe effect.



What is the relationship between electric field and the potential for a uniform field?

$$V = Ed$$

Solving for E

$$E = \frac{V}{d} = \frac{50V}{5.0cm} = \frac{50V}{5\times10^{-2}\,m} = 1000V/m$$

Which direction is the field? Direction of decreasing potential!