Physics 1B
Electricity & Magnetism

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Outline of today

- Continue Chapter 20.
- Electric potential (or voltage) and potential energy
- Remember:
  - Quiz 1 is next Friday, January 27th
  - It will cover only material from chapter 19.

Electric Potential Energy

- Recall that gravitational potential energy, PE_{grav}, for point masses (or spherically symmetric masses) was:

$$PE_{grav} = -G\frac{m_1 m_2}{r}$$

where zero potential energy was defined as having a separation distance of infinity.

Similarly, the electric potential energy, PE_{elec}, for point charges (or spherically symmetric charge distributions) is:

$$PE_{elec} = k_e\frac{q_o q}{r}$$

Electric Potential Energy

- As with all potential energy, it is far more useful to look at changes in electric potential energy as opposed to absolute electric potential energy.
- For a point charge, the change in potential energy between points A and B is given by:

$$\Delta PE_{AB} = PE_B - PE_A = k_e \frac{q_o q}{r_B} - k_e \frac{q_o q}{r_A}$$

$$\Delta PE_{AB} = k_e q_o q \left(\frac{1}{r_B} - \frac{1}{r_A} \right)$$

Note the lack of absolute value signs. The sign of the charge must be taken into account.

Voltage

- We define electric voltage as:

$$V \equiv \frac{PE_{elec}}{q_o}$$

Electric voltage is measured in Volts. Where: 1 Volt = 1 Joule/Coul. = 1 (Nm)/Coul

Voltage

- Again the far more useful quantity will be the change in voltage or what is referred to as the voltage difference.

$$\Delta V_{AB} = V_B - V_A = \frac{\Delta PE}{q_o}$$

This equation is always valid, independent of where you define your point of V=0.

This means that for a point charge we can say:

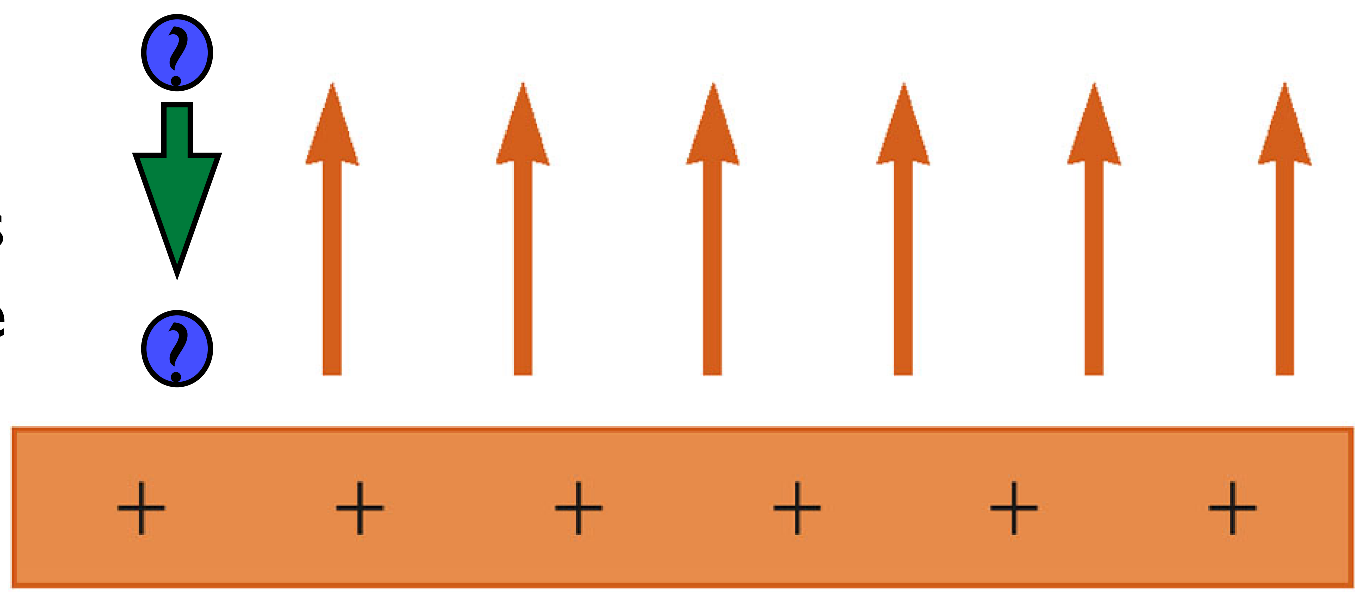
$$\Delta V_{AB} = \frac{\Delta PE}{q_o} = k_e q\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

Note that the voltage difference is independent of the test charge, q_o.

Electric Potential

- Electric potential difference is really a measure of how far you have moved in the electric field.
- Consider the case of an unknown charge above a positively charged floor, we see that, if voltage is really the electric potential energy per +1C of test charge then we can say something about the voltage knowing only the field.

If the charge was +1C, then the PE_{elec} and thus V would increase as we approach the positively charged wall.



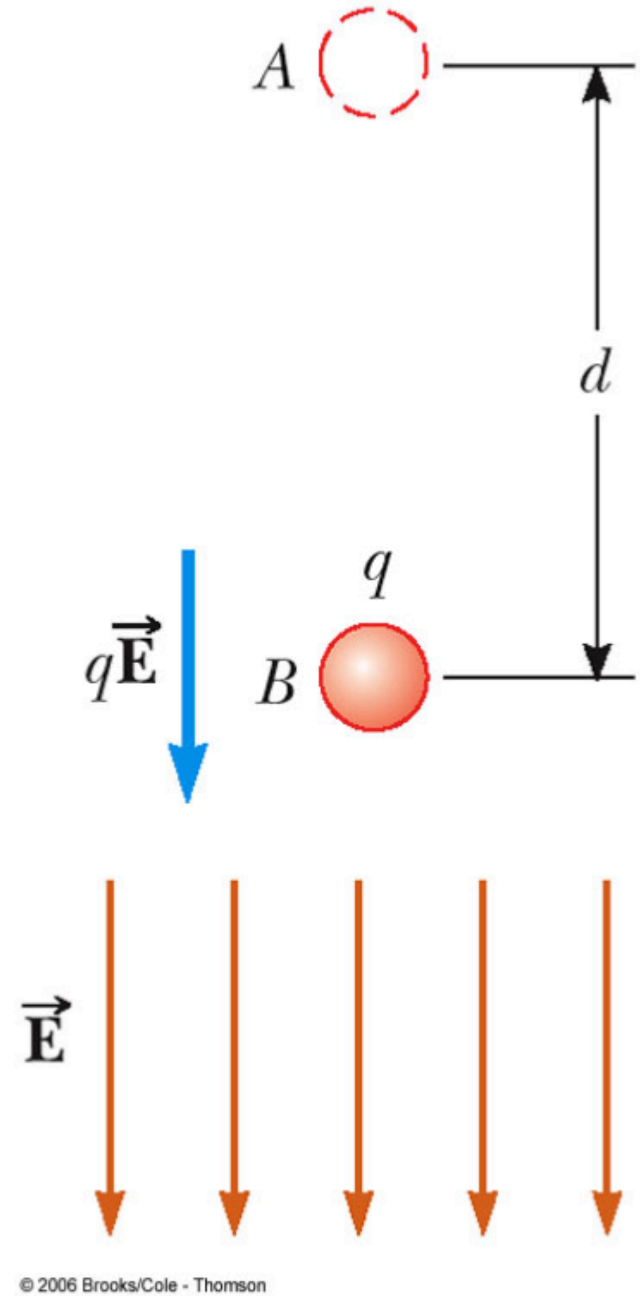
Electric Potential

Let' s say that we have an electric field that is directed downward.

How does the electric potential energy of a positive test charge change if it is moved from point A to point B?

The electric potential energy will decrease.

The force of the electric field is trying to decrease your potential energy.



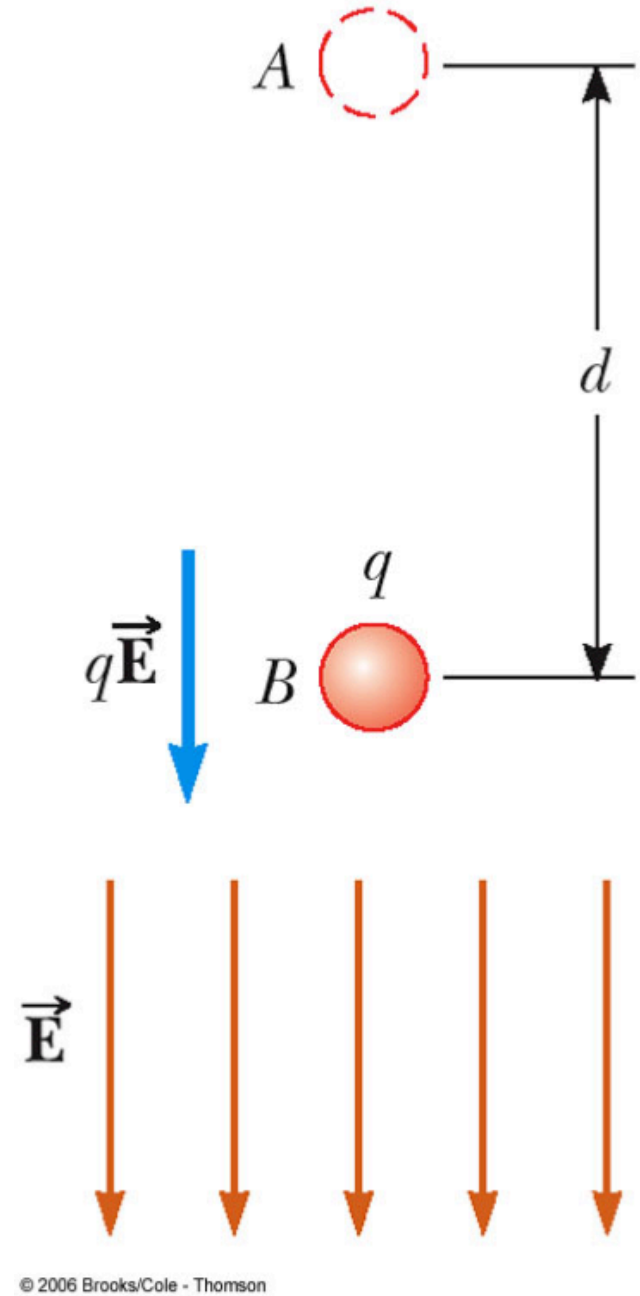
Electric Potential

How does the electric potential of a positive test charge change if it is moved from point A to point B?

The electric potential will also decrease.

The electric potential difference measures whether you are moving with the electric field or opposite the electric field.

Since the charge moves with the field it decreases.



Concept Question

- A proton is held 1m above a negatively charged floor. It is then moved to a distance of 2m above the floor. Which of the following is true regarding the proton?

A) Both the voltage and electric potential energy increased.

B) Both the voltage and electric potential energy decreased.

C) The voltage increased and the electric potential energy decreased.

D) The voltage decreased and the electric potential energy increased.

Electric Potential

- The lessons we have learned from examining electric potential energy and voltage are that:
- Voltage only depends on your position in the electric field.
- Electric potential energy will also depend on what your test charge is.
- No matter what, if a charge is free to move in an applied electric field, it will move in the direction that lowers its potential energy.

Electric Potential

- <u>Example</u>
- An electron in the picture tube of an older TV set is accelerated from rest through a potential difference $\Delta V = 5000V$ by a uniform electric field. What is the change in potential energy of the electron? What is the speed of the electron as a result of this acceleration (assume it started from rest)?

<u>Answer</u>

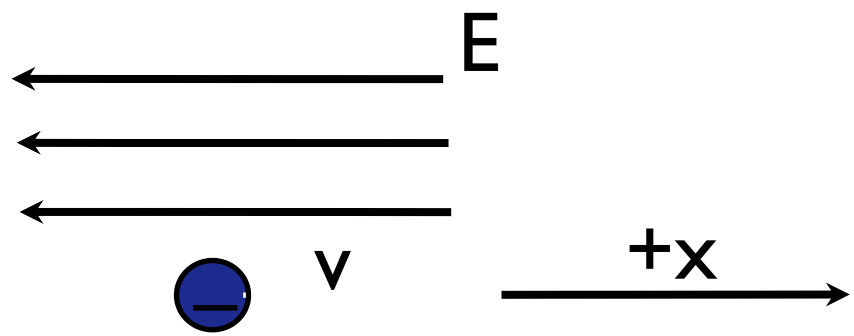
Define a coordinate system.

Choose where the electron starts it motion as $x = 0$ and its direction of motion as $+x$.

Electric Potential

<u>Answer</u>

Draw a quick picture of the situation:



Since the electron moves in the opposite direction as the electric field, its electric potential will increase as a result of this motion.

If this would have been a proton, then the electric potential would have decreased as a result of its motion.

Let's turn to the definition of electric potential:

$$\Delta V = \Delta PE/q_o$$

Answer

Electric Potential

$$\Delta PE = q_o(\Delta V)$$

$$\Delta PE = -1.602 \times 10^{-19}\text{C}(+5000V) = -8.0 \times 10^{-16}\text{J}$$

So, the electron lost potential energy by moving in this electric field.

Where did this energy go?

It went into the kinetic energy of the system, since the electric force is a conservative force.

We can then turn to conservation of energy to solve for the final velocity of the electron.

Did any energy leave the system?

No, it stays with the electron.

Electric Potential

<u>Answer</u>

$$0 = \Delta PE + \Delta KE$$

$$\Delta KE = -\Delta PE$$

$$\tfrac{1}{2} m v^2 = -\Delta PE \qquad v^2 = \frac{-2(\Delta PE)}{m}$$

$$v = \sqrt{\frac{-2(\Delta PE)}{m}} = \sqrt{\frac{-2(-8.0\times10^{-16}\,\mathrm{J})}{9.11\times10^{-31}\,\mathrm{kg}}} = 4.2\times10^{7}\,\mathrm{m/s}$$

Wow! The electron got almost close to the speed of light, with just a 5000V difference.

electron Volt

- It becomes very inconvenient to work with Joules when you are dealing with electrons or protons.
- We then introduce a new unit, the electron Volt.
- The electron Volt (eV) is defined as the energy that an electron gains when accelerated through a potential difference of 1Volt.
- $1eV = 1.602 \times 10^{-19} J$
- An electron in a normal atom has about 10 eV while gamma rays (light) may have millions of eV.

Equipotentials

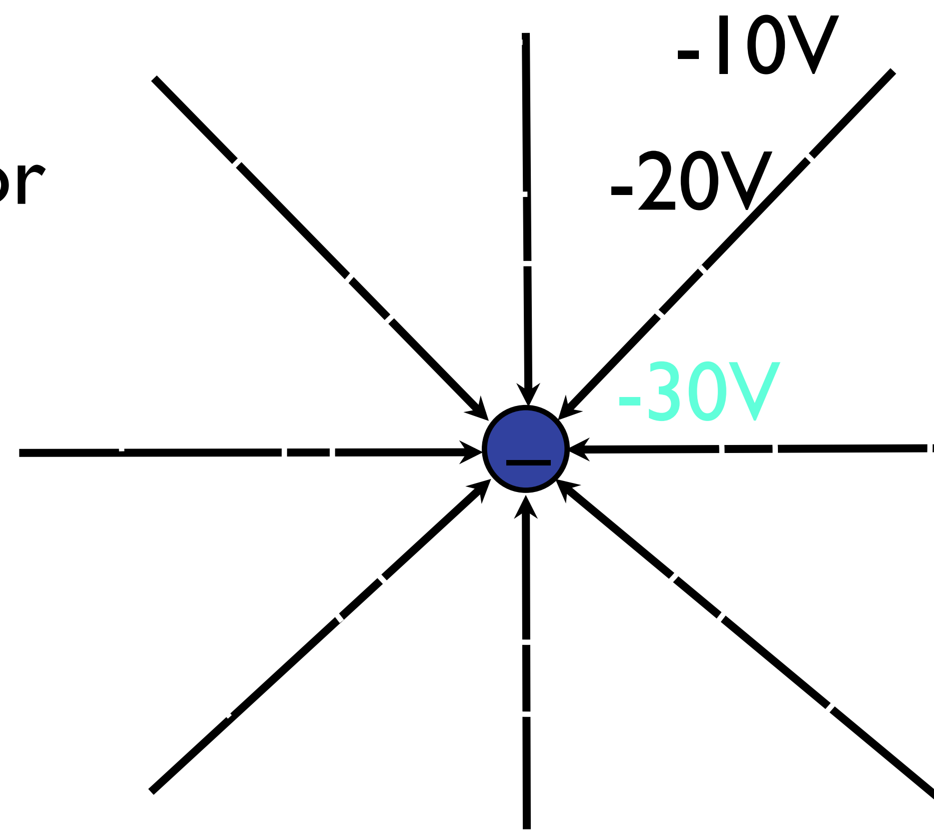
- An equipotential surface is a surface on which all points are the same potential.
- It takes no work to move a particle along an equipotential surface or line (assume speed is constant).
- The electric field at every point on an equipotential surface is perpendicular to the surface.
- Equipotential surfaces are normally thought of as being imaginary; but they may correspond to real surfaces (like the surface of a conductor).

Equipotentials

- Let's construct an equipotential surface for a lone negative charge.

First, draw the field lines for the charge.

If I move 1m away would it matter if it was up or down or left or right if I were to calculate potential?

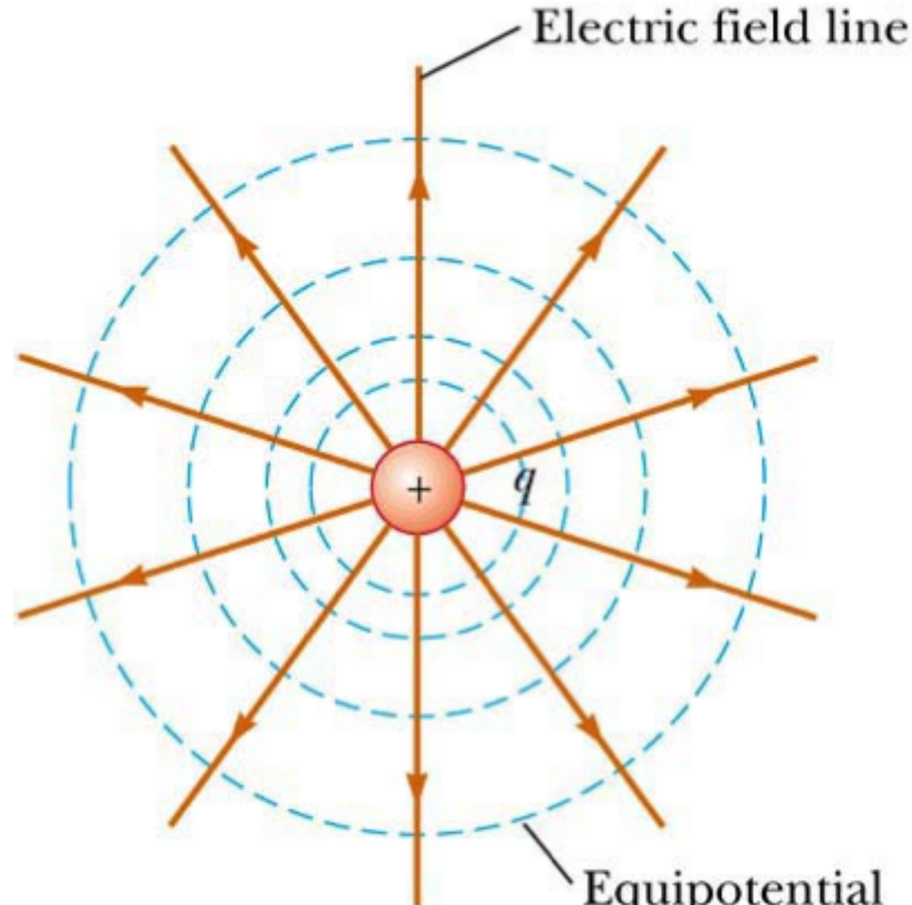


No, so our equipotential surface would be a sphere.

Also, since V goes as (1/r), the spacing would increase between equipotential surfaces.

Equipotentials

- For a lone positive charge, the equipotential surfaces are all spheres centered on the charge.
- We represent these spheres with equipotential lines.

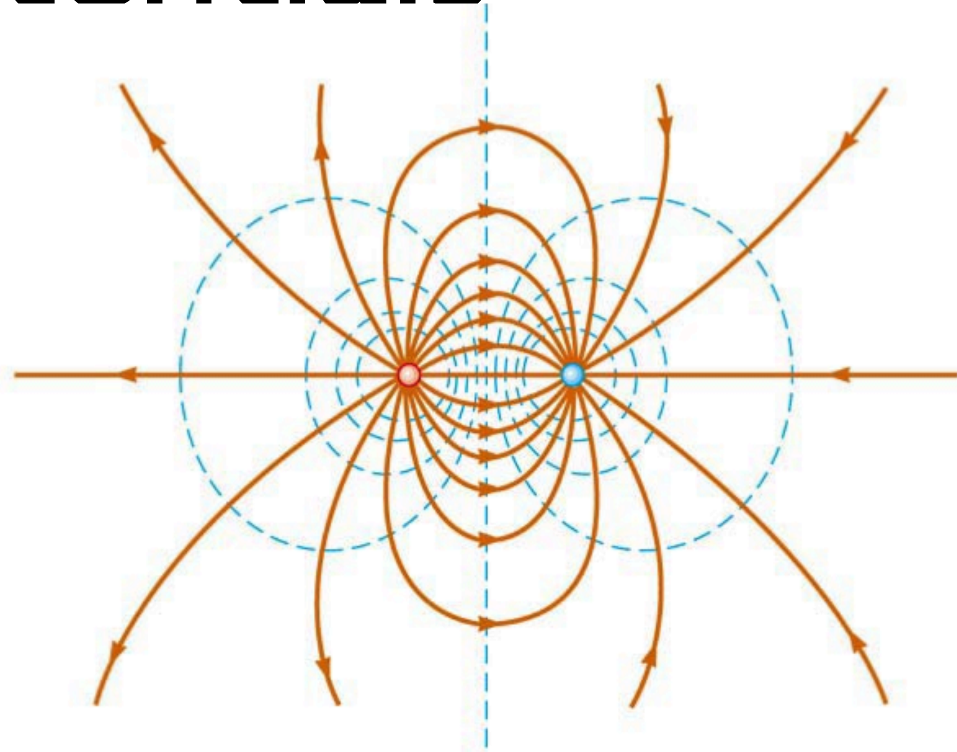


Equipotential lines are shown in blue, electric field lines are shown in red.

Note that the field lines are perpendicular to the equipotential lines at every crossing.

Equipotentials

- As you increase the number of charges in the distribution the equipotential lines get more complicated.
- Take the electric dipole composed of a positive and a negative charge.



For Next Time (FNT)

- Prepare for the Quiz on Friday
- Continue homework for Chapter 20
- Keep reading Chapter 20