Physics 1B
Electricity & Magnetism

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Outline of today

- Beginning of 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

- If I were to lift a mass up off of the floor and put it over my head, what have I done to that mass?
- I have increased the gravitational potential energy of the mass. If I let go of the mass it has the potential to move towards the floor.
- In order to increase the energy of the mass, I had to perform work on the mass.
- Since the gravitational force is a conservative force, the work I put into the mass is equivalent to the increase in its gravitational potential energy.

Electric Potential Energy

- If I were to move a negatively charged sphere away from a positively charged wall, what have I done to that sphere?
- I have increased the electric potential energy of the sphere. If I let go of the sphere it has the potential to move towards the wall.
- In order to increase the energy of the sphere, I had to perform work on the sphere.
- Since the electric force is a conservative force, the work I put into the sphere is equivalent to the increase in its electrical potential energy.

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.

Electric Potential Energy

- Example
- A proton is placed 3.0cm to the right of a +1.0nC charged sphere. It is then brought in to a distance of 1.0cm from the sphere. What is the change in potential energy of the proton?

Answer

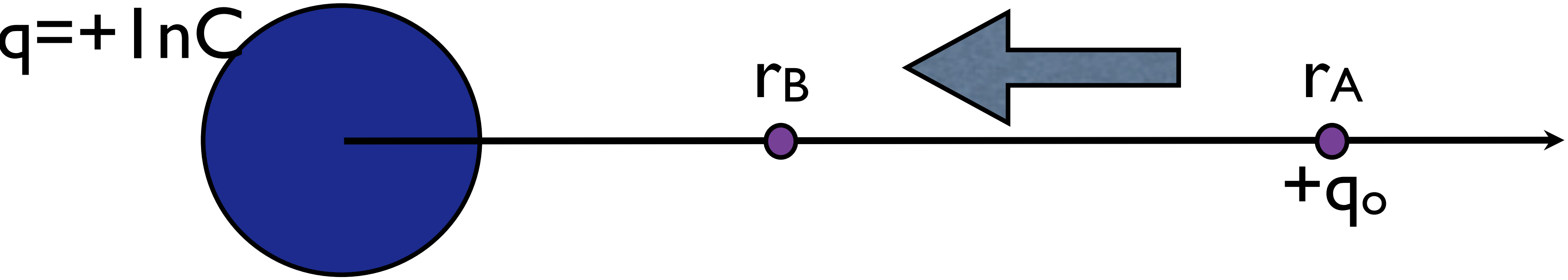
Define a coordinate system.

Choose the sphere as $r = 0$. Any outward distance would be positive.

Electric Potential Energy

<u>Answer</u>

Next, draw a picture of the situation:



List what quantities we know:

$q = +1.0\times10^{-9}C$

$q_o = +e = +1.602\times10^{-19}C$

$r_A = 0.03m$

$r_B = 0.01m$

Let's turn to the equation for change in electric potential energy.

Electric Potential Energy

Answer

Start with:

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

$$\Delta PE_{AB} = \left(8.99 \times 10^{+9}\ \mathrm{Nm^2/C^2}\right)\left(+1.602 \times 10^{-19}\mathrm{C}\right)\left(+1.0 \times 10^{-9}\mathrm{C}\right)\left(\frac{1}{0.01\mathrm{m}} - \frac{1}{0.03\mathrm{m}}\right)$$

$$\Delta PE_{AB} = 9.60 \times 10^{-17}\,\mathrm{J}$$

This is a positive value so potential energy increased.

What if we substituted in an electron for the proton?

The value would be the same, but the potential energy would have decreased instead of increased.

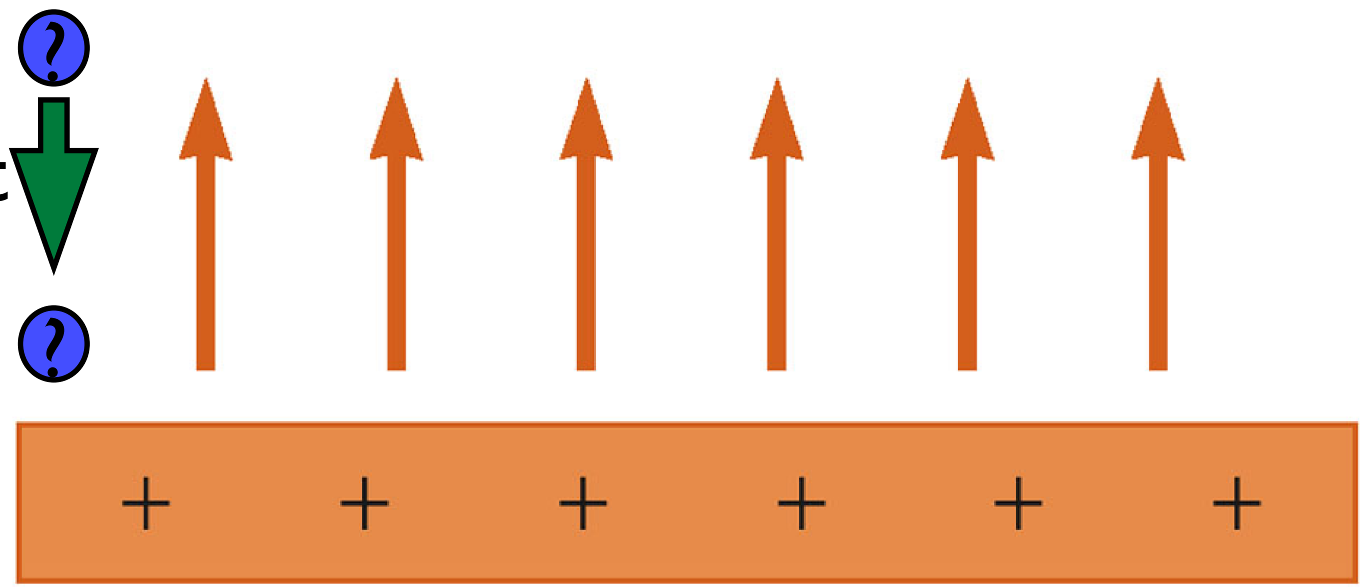
Electric Potential Energy

- Let's say we have a positively charged floor. What will the electric field look like?

Now let's say that an unknown charged object that is originally far away from the floor is brought in closer to the floor.

Has the electric potential energy of the object increased or decreased?

We are not sure. It is dependent on the sign of the test charge.



Electric Potential

- To solve this problem, we introduce a new variable, the electric potential, V.
- We define electric potential as:

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

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

DO NOT CONFUSE electric potential energy, PE_{elec}, and electric potential, V.

Many times electric potential will be referred to as voltage just to distinguish it further from electric potential energy.

Electric Potential

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

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

This equation is always valid.

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 electric potential difference is independent of the test charge, q_o.

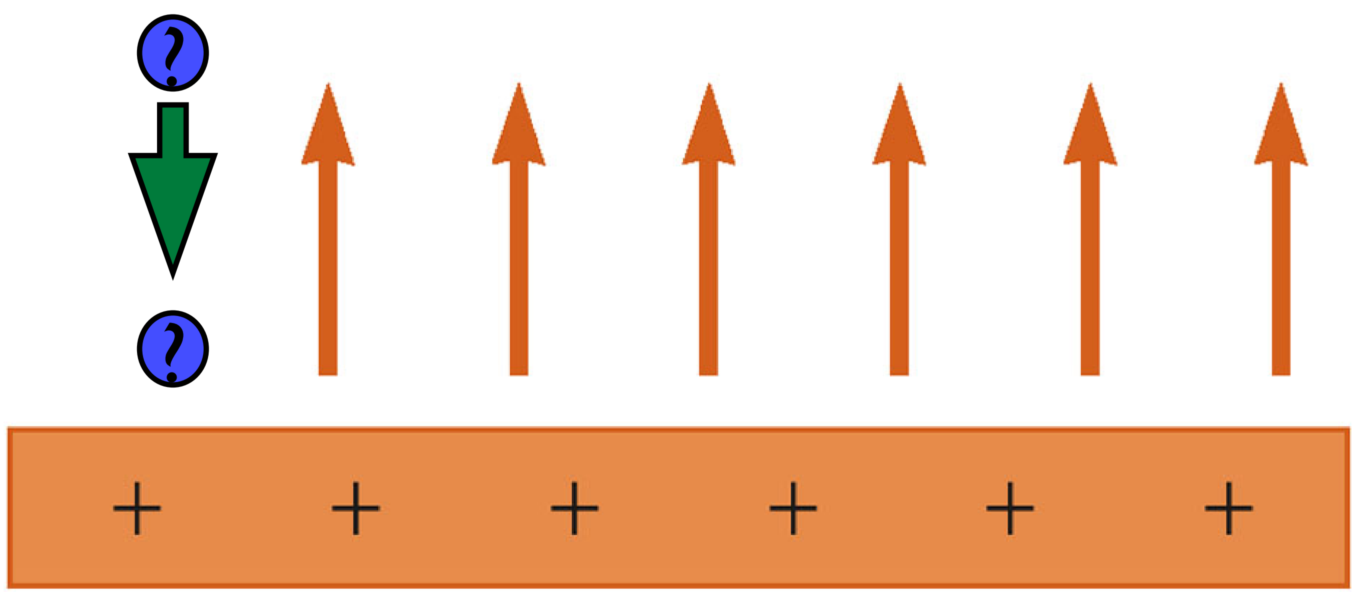
Electric Potential

- The electric potential at a location is the electric potential energy that a +1C charge would have due to outside charges if it were placed at that location.
- It is similar to the relationship that electric force and electric field have.
- Electric potential is a scalar quantity.
- Note that it really only depends on the outside charges, q, and the separation distance, r.
- If the outside charges are a distribution then, the electric potential will depend on the electric field, E, and the separation distance, r.

Electric Potential

- Electric potential difference is really a measure of how far you have moved in the electric field.
- If we go back to the case of the unknown charge above the positively charged floor, we see that, if electric potential is really what the electric potential energy would be for a +1C charge then we can say something about the charge.

If the charge was +1C, then the PE_{elec} would increase, so we say that V would increase as well.



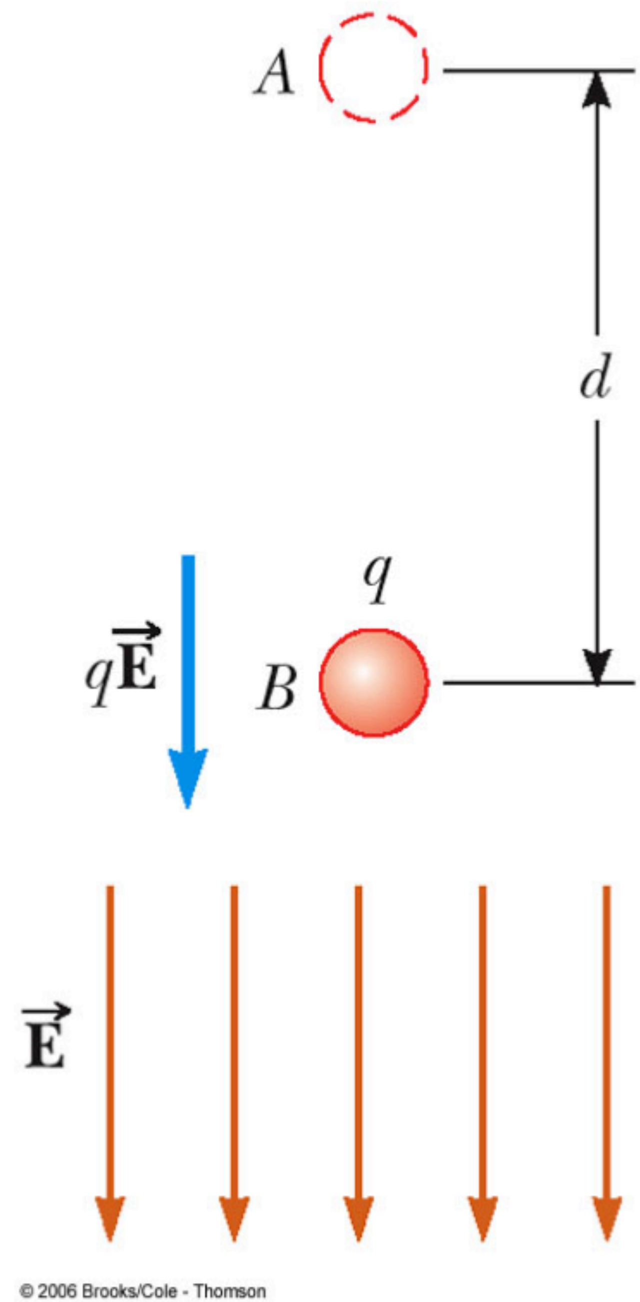
Electric Potential

Let' s say that we have an electric field that is directed downward created by other charges.

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.



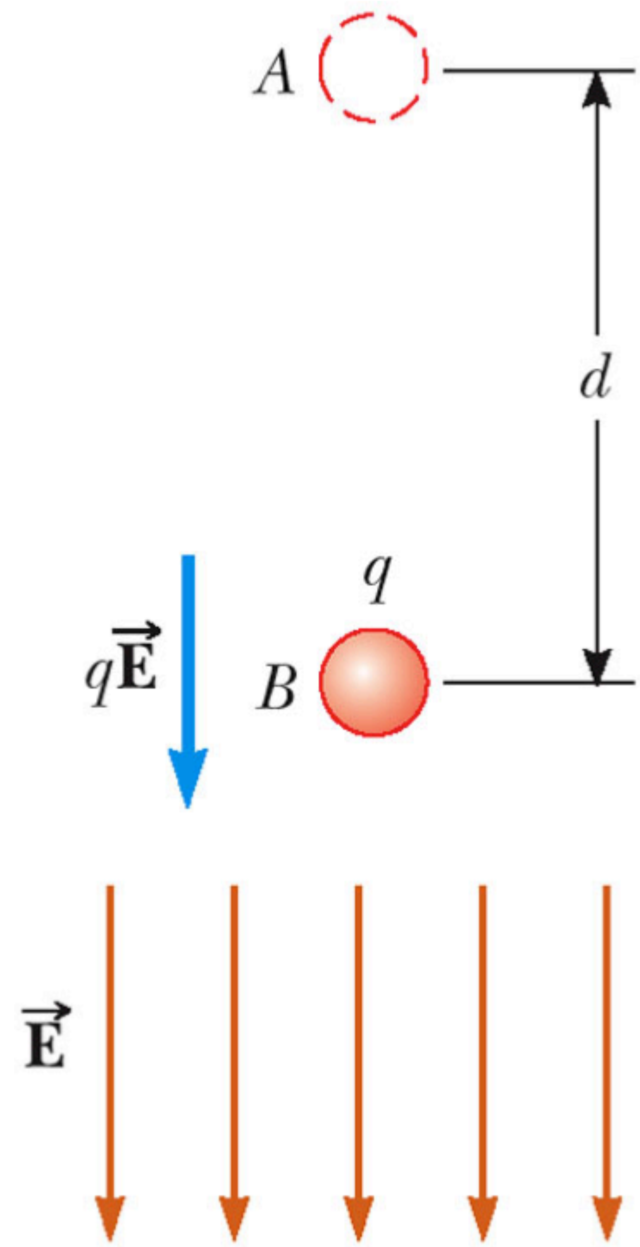
Electric Potential

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 electric potential and electric potential energy increased.

B) Both the electric potential and electric potential energy decreased.

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

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

Electric Potential

- The lessons we have learned from examining electric potential energy and electric potential are that:
- Electric potential 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>

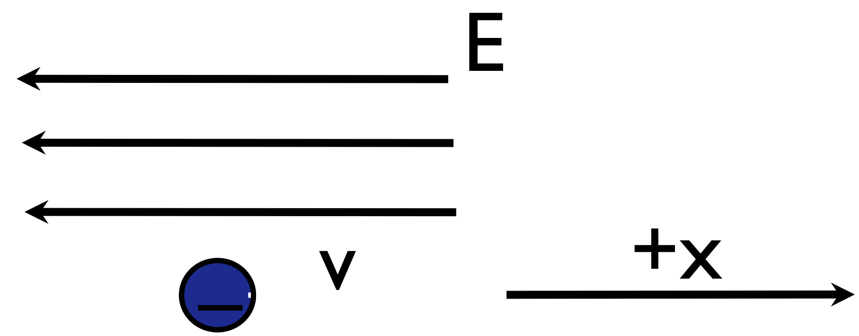
Define a coordinate system.

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

Electric Potential

Answer

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:

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

<u>Answer</u>

Electric Potential

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

$$\Delta PE = -1.602\times10^{-19}\text{C}(+5000V) = -8.0\times10^{-16}\text{J}$$

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 electron.

Answer

Electric Potential

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

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

$$\tfrac{1}{2}mv^2 = -\Delta PE$$

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

$$v = \sqrt{\frac{-2(\Delta PE)}{m}} = \sqrt{\frac{-2(-8.0\times 10^{-16}\,\mathrm{J})}{9.11\times 10^{-31}\,\mathrm{kg}}} = 4.2\times 10^{7}\,\mathrm{m/s}$$

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 = 1.602×10^{-19}J
- An electron in a normal atom has about 10 eV while gamma rays (light) may have millions of eV.

Equipotentials

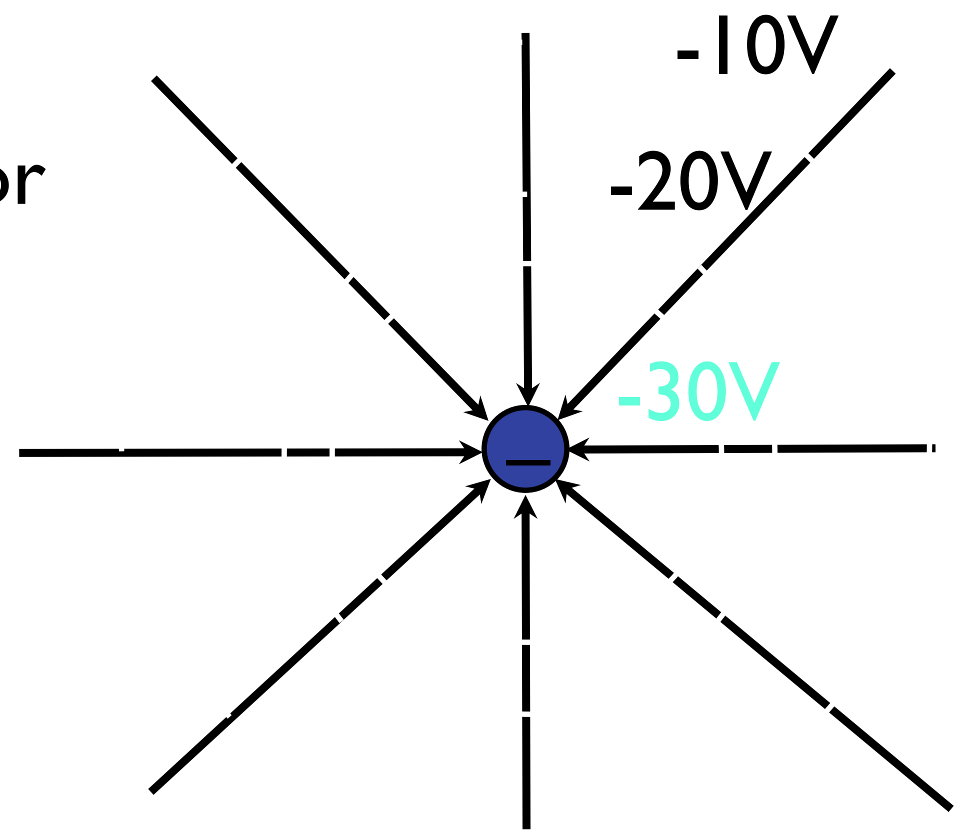
- An equipotential surface is a surface on which all points are the same potential.
- It takes no work to move a particle along an equipotential surface or line (assume speed is constant).
- The electric field at every point on an equipotential surface is perpendicular to the surface.
- Equipotential 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?

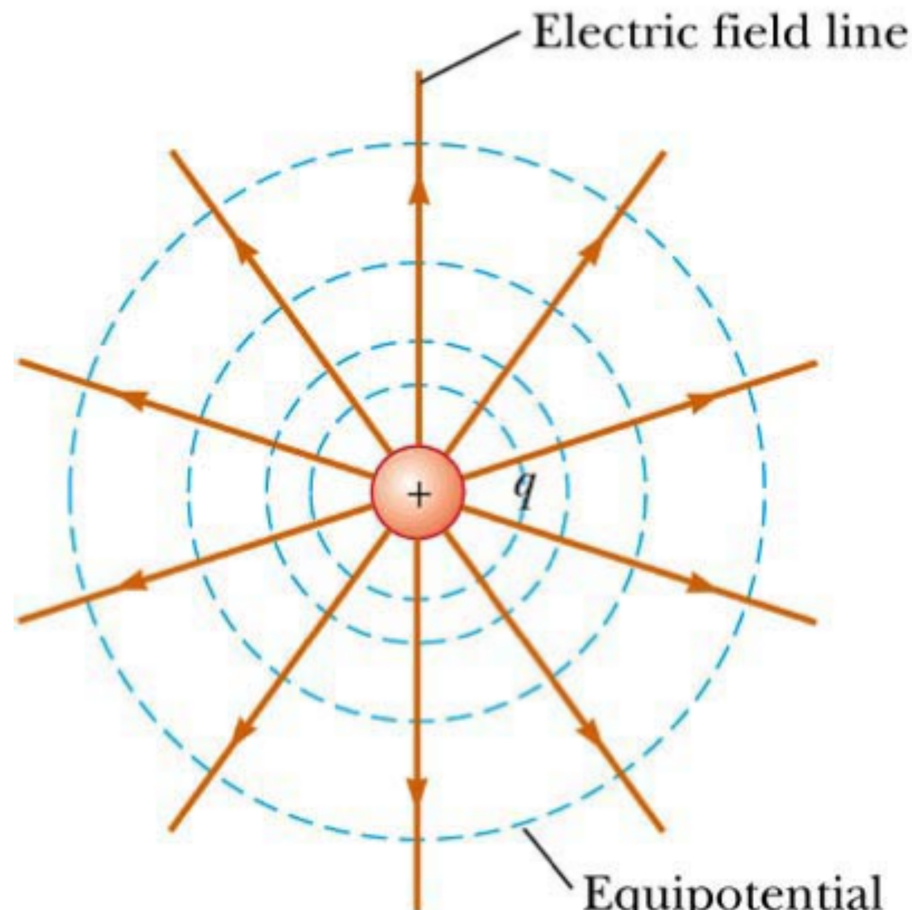


No, so our equipotential surface would be a sphere.

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.

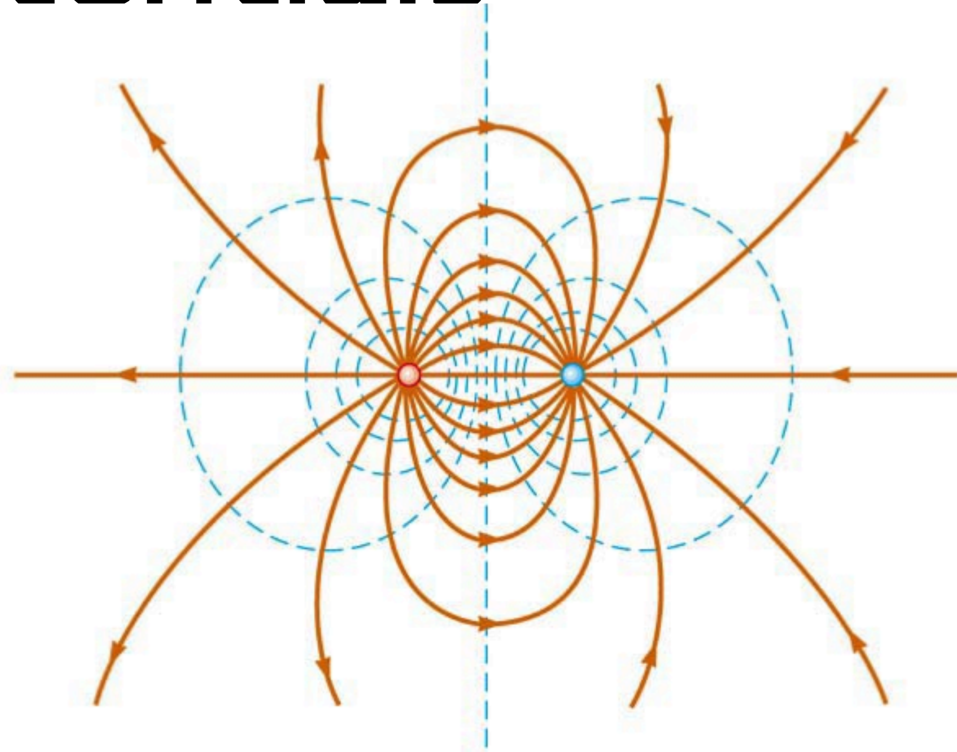


Equipotential lines are shown in blue, electric field lines are shown in red.

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
- Start the homework for Chapter 20
- Keep reading Chapter 20