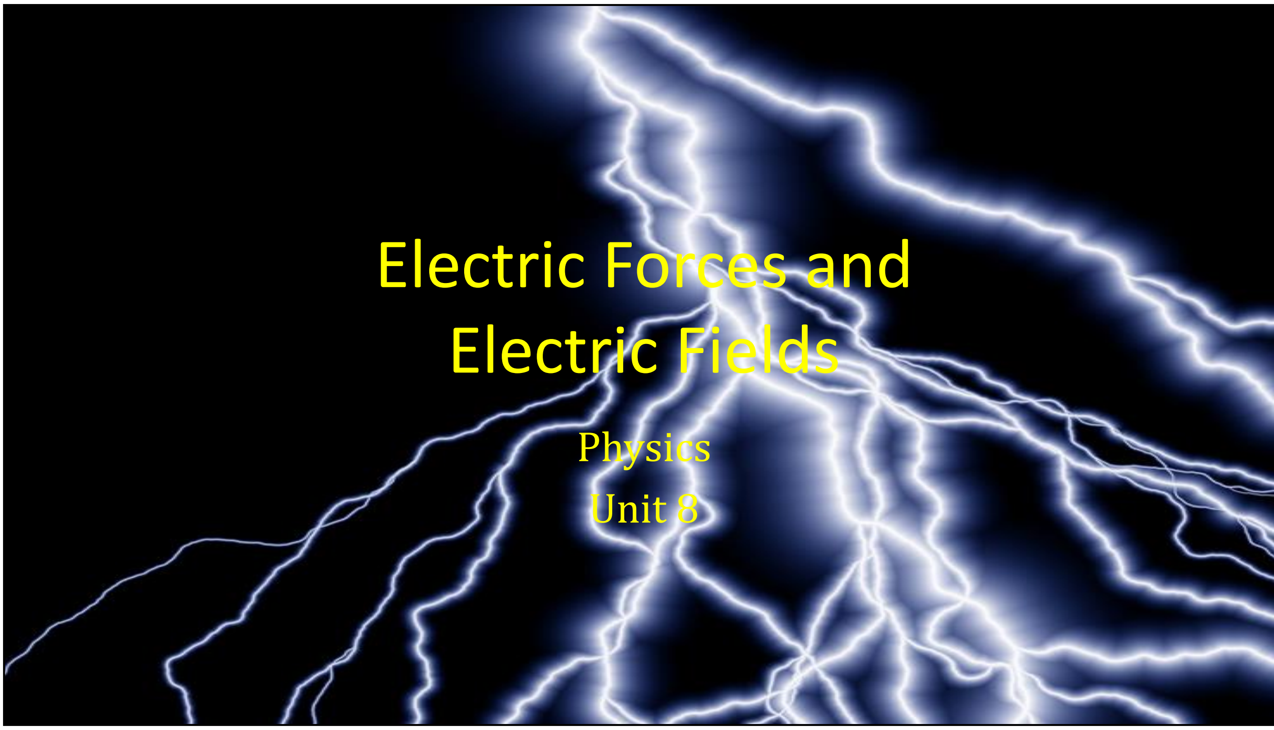

Physics Unit 8

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the textbook.

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In this lesson you will…

- Define electric charge, and describe how the two types of charge interact.
- State the law of conservation of charge.
- Define conductor and insulator, explain the difference, and give examples of each.
- Describe three methods for charging an object.
- Explain what happens to an electric force as you move farther from the source.

08-01 STATIC ELECTRIC CHARGE AND CONDUCTORS

08-01 Static Electric Charge and Conductors

- An atom
  - Nucleus
    - Protons – positive charge
    - Neutrons – no charge, but same mass as proton
  - Electron cloud
    - Electron – negative charge, little mass
    - $q_e = -1.60 \times 10^{-19}\ C$
      - Unit of charge: Coulomb (C)
      - q_e is the smallest charge discovered
      - Electricity is quantized → comes in discreet numbers
      - $|q_e|$ is the fundamental unit of charge
  - In nature atoms have no net charge
    - # protons = # electrons

Lab 08-01

- Determine what types of materials can create and hold static electricity.

08-01 Static Electric Charge and Conductors

- How many electrons does it take to make a charge of $-4 \times 10^{-6}\ C$? What is their mass ($m_e = 9.11 \times 10^{-31}\ kg$)?

- $N = 2.5 \times 10^{13}$ electrons (a lot)
- $m = 2.28 \times 10^{-17}$ kg (very small)

$$N = \frac{q}{e} \rightarrow N = \frac{4 \times 10^{-6}\ C}{1.6 \times 10^{-19}\ C} = 2.5 \times 10^{13}$$
$$m = 2.5 \times 10^{13}\ (9.11 \times 10^{-31}\ kg) = 2.28 \times 10^{-17}\ kg$$

08-01 Static Electric Charge and Conductors

- Law of Conservation of Charge
  - During any process, the net electrical charge of a closed system remains constant
- Like charges repel
- Unlike charges attract
  - The attraction and repulsion are forces and can be used with Newton's Laws and other dynamics problems

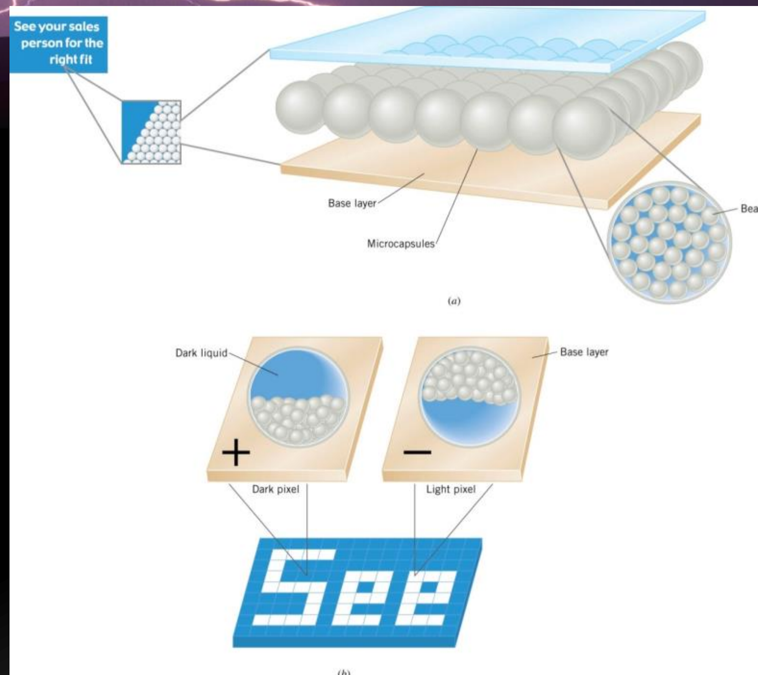
•When you rub a balloon on your hair, the balloon steals electrons from the hair. The balloon gets a negative charge and the hair gets a positive charge.

•When the balloon takes electrons from the hair, each hair is positively charged. It stands on end because the like positive charges repel

•The balloon with the extra electrons sticks to other objects because it has a charge and the other objects don't. The unlike charges attract

08-01 Static Electric Charge and Conductors

Electric Ink



This is different than LCD (in LCD the material is naturally transparent, the charge makes it become opaque)

•New Technology

•Made of two layers (base and transparent top)

•Microcapsules diameter of hair contain white charged beads and dark liquid.

•The base layer is electrically charged (some pixels (picture element) are dark because the beads are attracted to the base layer and some are white because the beads are repelled by the base layer)

08-01 Static Electric Charge and Conductors

- Electricity can flow through objects
- Conductors let electrons flow easily
  - Most heat conductors are also electrical conductors
  - Metals
- Insulators are very poor conductors
  - Rubber
  - Plastic
  - Wood

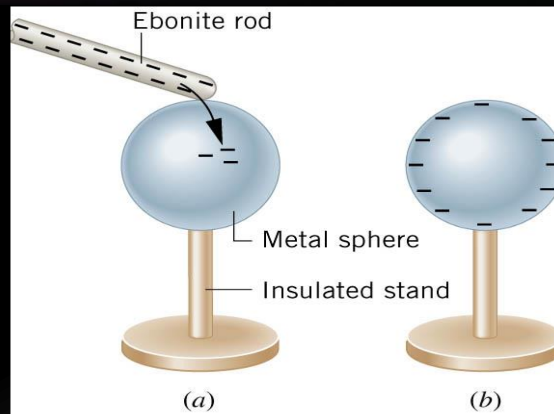
•Metals make good conductors because of metallic bonds (chemistry) where the electrons are not strongly attached to the individual nuclei. This happens partly because the outer most layer of electrons is so far away from the nucleus, there isn’t much attraction.

•Insulators are made of atoms that hold tightly to their electrons i.e. their electron shells are full or almost full.

•Hence electrical wires are coated in plastic

08-01 Static Electric Charge and Conductors

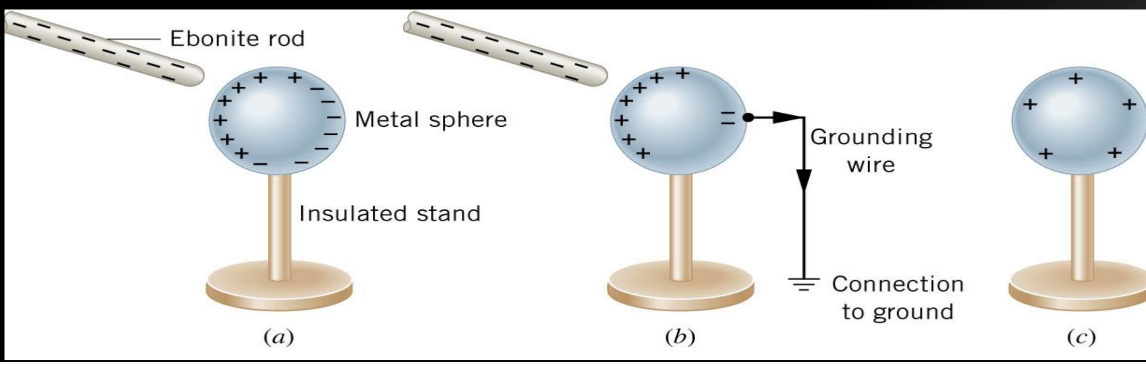
- Charging by contact
- Negative charged rod gives some electrons to sphere
- Sphere becomes negatively charged until charges are equal



08-01 Static Electric Charge and Conductors

Charge by Induction

- Charge without touching
- Charged rod comes near neutral sphere
- The like charges are repelled to other side of sphere
- A grounding wire lets the charges escape from the sphere
- The grounding wire is removed, then the charged rod
- Sphere is charged



- •Negative rod brought close to the sphere
- •Negative charge on rod repels electrons on sphere
- •Electrons move to other side
- •Electrons are bled off with a ground wire
- •Wire and rod removed

08-01 Static Electric Charge and Conductors

- If the sphere in the previous 2 slides was plastic instead of metal
- Electrons wouldn't flow
- The surface would become slightly charged as the electrons in each individual atom rearrange, but no overall effect
- Static cling is made by this effect

The electrons on one atom shift, this makes the electrons in the neighboring atom shift so that the closest parts have opposite charges and they attract

08-01 Homework

- Try charging your way through these problems
- Read 18.3

In this lesson you will…

- State Coulomb's law in terms of how the electrostatic force changes with the distance between two objects.
- Calculate the electrostatic force between two charged point forces, such as electrons or protons.
- Compare the electrostatic force to the gravitational attraction for a proton and an electron.

08-02 COULOMB'S LAW

08-02 Coulomb's Law

- Point charges exert force on each other
  - Related to the size of the charges and the distance between them
  - If the signs are same force repels
  - If the signs are opposite force attracts
  - Force of the first to the second is equal and opposite of the second to the first
    - Newton's Third Law

08-02 Lab

- Do the lab to observe properties of electric force

08-02 Coulomb's Law

- Coulomb's Law

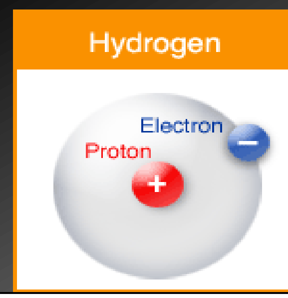
$$F = k\frac{|q_1 q_2|}{r^2}$$

- Where
  - F = electrostatic force
  - k = constant (8.99×10^9 Nm^2/C^2)
  - q = charge
  - r = distance between the charges

08-02 Coulomb's Law

- In a hydrogen atom, the electron ($q = -1.60 \times 10^{-19}$ C) is 5.29×10^{-11} m away from the proton of equal charge magnitude. Find the electrical force of attraction.

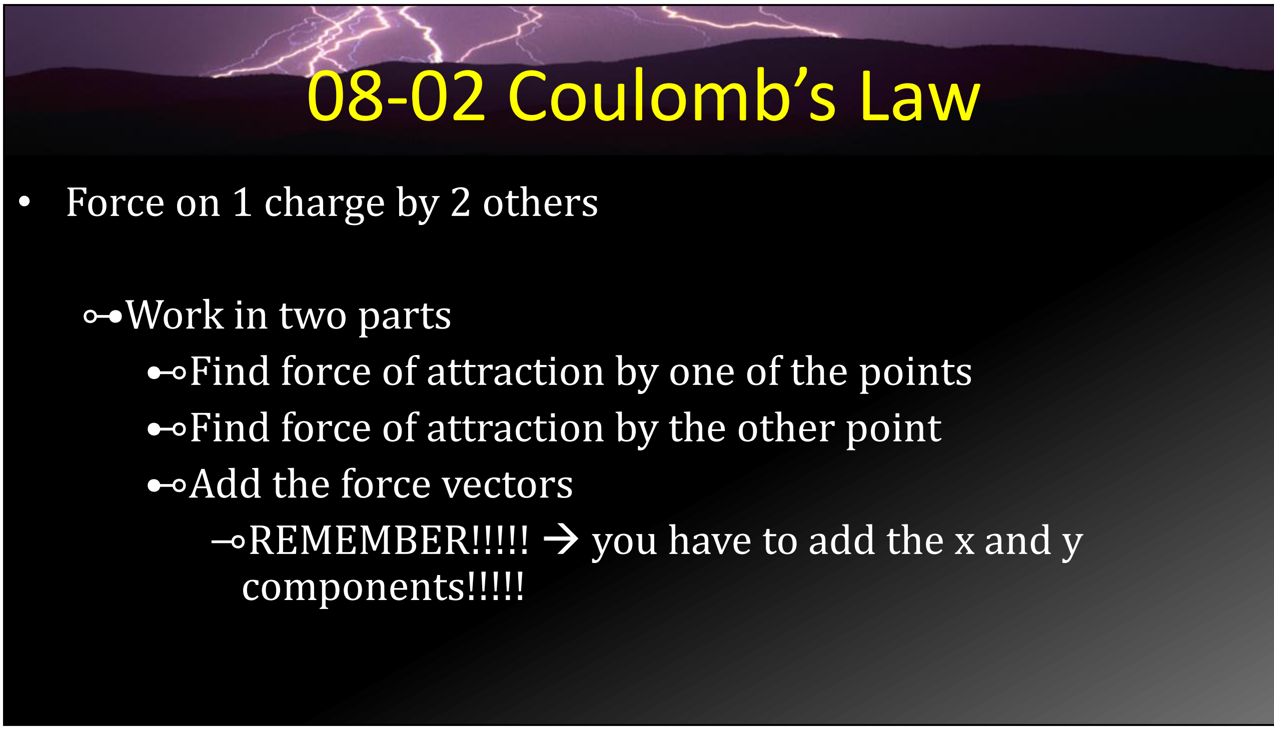
- $F = 8.22 \times 10^{-8}$ N



$$F = \frac{\left(8.99 \times 10^{9} \frac{Nm^2}{C^2}\right)\left((1.6 \times 10^{-19}\ C)(1.6 \times 10^{-19}\ C)\right)}{(5.29 \times 10^{-11}\ m)^2} = 8.22 \times 10^{-8}\ N$$

08-02 Coulomb's Law

- Coulomb's Law – other notes
  - Notice the similarity to Newton's Law of Universal Gravitation
  - Notice that $F \propto 1/r^2$
    - Distance increases by 4, force decreases by 16


08-02 Coulomb's Law
Force on 1 charge by 2 others
Work in two parts
Find force of attraction by one of the points
Find force of attraction by the other point
Add the force vectors
REMEMBER!!!!! → you have to add the x and y components!!!!!

08-02 Coulomb's Law

- There are three charges in a straight line
- q_1 = +2μC at x = -0.1 m
- q_2 = -3 μC at x = 0 m
- q_3 = +5 μC at x = 0.3 m
- What is the force on q_2?

- F = -3.89 N

$F_{12} = 8.99 \times 10^9 \frac{Nm^2}{C^2} \frac{(2\times10^{-6}\ C)(3\times10^{-6}\ C)}{(0.1\ m)^2} = -5.39\ N$ (neg because pulling in – direction)

$F_{23} = 8.99 \times 10^9 \frac{Nm^2}{C^2} \frac{(5\times10^{-6}\ C)(3\times10^{-6}\ C)}{(0.3\ m)^2} = 1.50\ N$ (pos because pulling in + direction)

$F = F_{12} + F_{23} = -5.39\ N + 1.50\ N = -3.89\ N$

08-02 Coulomb's Law

- There are three charges
- q_1 = +2μC at (0, 0.3) m
- q_2 = -3 μC at (0, 0) m
- q_3 = +5 μC at (0.1, 0.2) m
- What is the force on q_2?

- F = 3.247 N @ 68.1° above horizontal

$$F_{12} = 8.99 \times 10^9 \frac{Nm^2}{C^2} \frac{(2 \times 10^{-6}\ C)(3 \times 10^{-6}\ C)}{(0.3\ m)^2} = .599\ N$$

$$r = \sqrt{0.1^2 + 0.2^2} = .2236\ m$$

$$\theta = \cos^{-1}\left(\frac{.1}{.2236}\right) = 63.4 \text{ deg}$$

$$F_{23} = 8.99 \times 10^9 \frac{Nm^2}{C^2} \frac{(5 \times 10^{-6}\ C)(3 \times 10^{-6}\ C)}{(0.2236\ m)^2} = 2.70\ N$$

$$x - components\colon\ F_{12} = 0\ N, \qquad F_{23} = 2.70 \cos 63.4° = 1.209\ N$$

$$ADD\colon 0\ N + 1.209\ N = 1.209\ N$$

$$y - component\colon\ F_{12} = 0.599\ N, \qquad F_{23} = 2.70 \sin 63.4° = 2.414\ N$$

$$ADD\colon 0.599\ N + 2.414\ N = 3.013\ N$$

$$r = \sqrt{1.209^2 + 3.013^2} = 3.247\ N$$

$$\theta = \cos^{-1}\frac{1.209}{3.247} = 68.1°$$

08-02 Homework

- Charge these problems to your grade
- Read 18.4, 18.5

In this lesson you will…

- Describe a force field and calculate the strength of an electric field due to a point charge.
- Calculate the force exerted on a test charge by an electric field.
- Explain the relationship between electrical force (F) on a test charge and electrical field strength (E).
- Calculate the total force (magnitude and direction) exerted on a test charge from more than one charge
- Describe an electric field diagram of a positive point charge; of a negative point charge with twice the magnitude of
positive charge
- Draw the electric field lines between two points of the same charge; between two points of opposite charge.

08-03 ELECTRIC FIELD AND ELECTRIC FIELD LINES

08-03 Electric Field and Electric Field Lines

- We can use a ***test charge*** to determine how the surrounding charges generate a force
- Pick a small test charge so it doesn't change the surrounding charge orientation

08-03 Electric Field and Electric Field Lines

- A test charge ($q_0 = 1.0 \times 10^{-10}\ C$) experiences a force of $2 \times 10^{-9}\ N$ when placed near a charged sphere. Determine the Force per Coulomb that the charge experiences and predict the force on a $2\ C$ charge.

- $\frac{F}{q_0} = 20\ N/C$
- $F = 40\ N$

$$\frac{F}{q_0} = \frac{2 \times 10^{-9}\ N}{1 \times 10^{-10}\ C} = 20\frac{N}{C}$$

$$F = 20\frac{N}{C}\ (2\ C) = 40\ N$$

08-03 Electric Field and Electric Field Lines

- Electric Field Definition

$$E = \frac{F}{q_0} = \frac{kq_1}{r^2}$$

  - Force per charge
  - Vector
    - Same direction as the force on a positive test charge
    - Remember to add them as vectors!!!!
  - Unit: N/C

The surrounding charges create the electric field at a given point

As we will see, the test charge does not affect the electric field

08-03 Electric Field and Electric Field Lines

- Point Charges

$$E = \frac{F}{q_0}$$

$$F = \frac{kqq_0}{r^2}$$

$$E = \frac{\frac{kqq_0}{r^2}}{q_0}$$

$$E = \frac{kq}{r^2}$$

- Notice the q_0 does not affect the E-field

08-03 Electric Field and Electric Field Lines

- There is a point charge of $q = 2 \times 10^{-8}\ C$. Determine the E-field at 0.50 m away using a test charge of $1 \times 10^{-10}\ C$.

- E = 719 N/C

$$E = \frac{kq}{r^2}$$

$$E = \frac{\left(8.99 \times 10^{9} \frac{Nm^2}{C^2}\right)(2 \times 10^{-8}\ C)}{(0.50\ m)^2} = 719.2\ N/C$$

08-03 Electric Field and Electric Field Lines

- There are two point charges of q_1 = 4 C and q_2 = 8 C and they are 10 m apart. Find point where E = 0 between them.

- d = 5.85 m from q_2 towards q_1

Pick the distance from the first as d and the distance from the second as 10 – d

Set E-fields equal to each other

$$\frac{k8\ C}{d^2} = \frac{k4\ C}{(10-d)^2}$$

$$\frac{8}{d^2} = \frac{4}{(10-d)^2}$$

$$8(10-d)^2 = 4d^2$$

$$2\sqrt{2}(10-d) = \pm 2d$$

$$28.2 - 2.82d = \pm 2d$$

$$Take +:\ 28.2 - 2.82d = 2d \lozenge 28.2 = 4.82d \rightarrow d = 5.85$$

$$Take -:\ 28.2 - 2.82d = -2d \rightarrow 28.2 = 0.82\ d \rightarrow d = 34.39$$

Answer is 5.85

08-03 Electric Field and Electric Field Lines

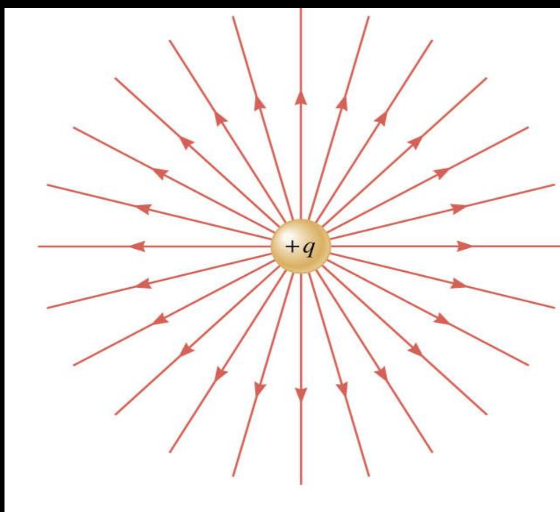
- It would be nice to have some kind of map to show the E-field in space
- Rules
  - Lines begin at positive charges only
  - Lines end at negative charges only
  - The number of lines entering or leaving a charge is proportional to the size of charge
  - Lines don’t cross each other
  - Lines leave surfaces at 90 degrees

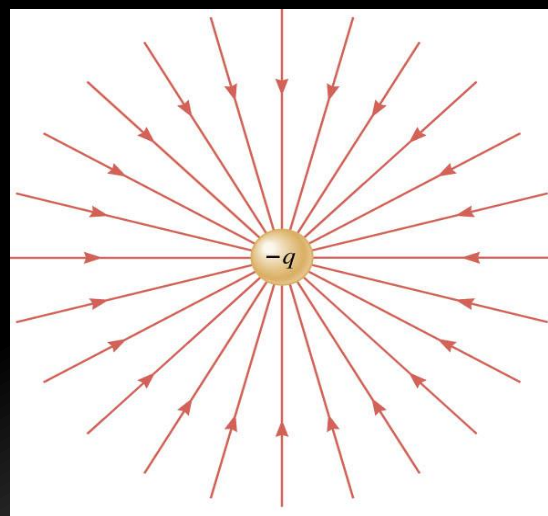
Spread out lines → weak E-field

Close lines → strong E-field

Lines don’t cross because there is only one value of E at one point

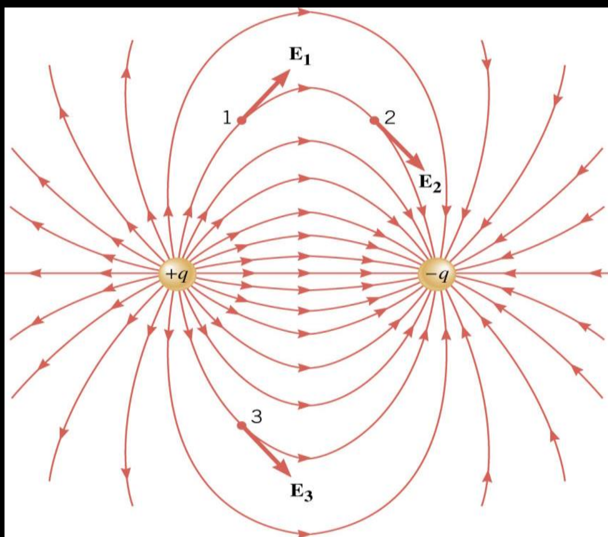
08-03 Electric Field and Electric Field Lines

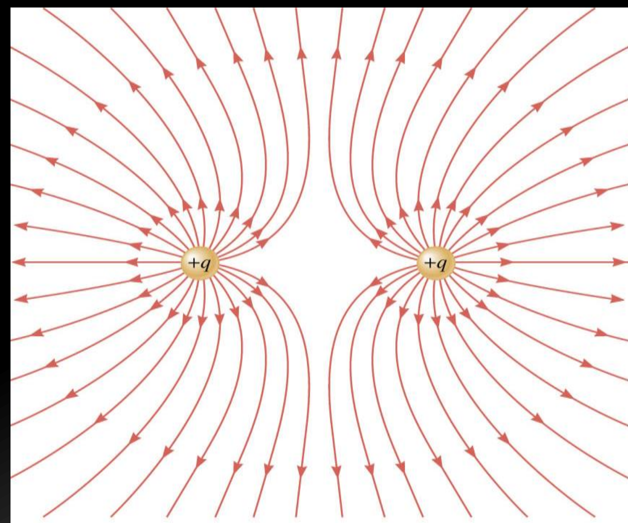




Made by putting test charge in points and seeing direction and strength of E-field

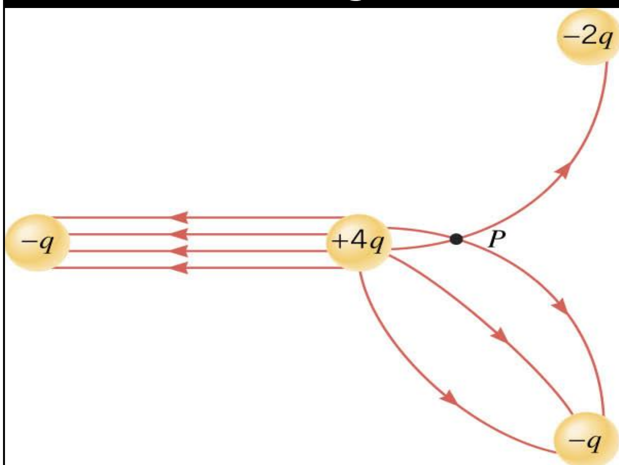
08-03 Electric Field and Electric Field Lines

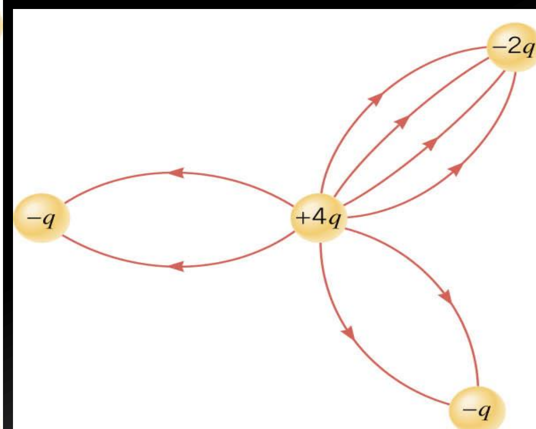




08-03 Electric Field and Electric Field Lines

What is wrong here?





Lines on left should be curved→ as is the charge would constant between them, should depend on distance

Lines cross at point P

Number of lines should be proportional to charge 1:4:2:1 or 2:8:4:2 to make symmetry

08-03 Lab

- Create your own electric field map

08-03 Homework

- Electrify your brain and answer these problems
- Read 18.6, 18.7, 18.8

In this lesson you will…

- List the three properties of a conductor in electrostatic equilibrium.
- Explain the effect of an electric field on free charges in a conductor.
- Explain why no electric field may exist inside a conductor.
- Explain what happens to an electric field applied to an irregular conductor.
- Describe how a lightning rod works.
- Explain how a metal car may protect passengers inside from the dangerous electric fields caused by a downed line touching the car.
- Name several real-world applications of the study of electrostatics.

08-04 CONDUCTORS IN EQUILIBRIUM AND APPLICATIONS

08-04 Lab

- Discover something weird about phones in boxes and bags

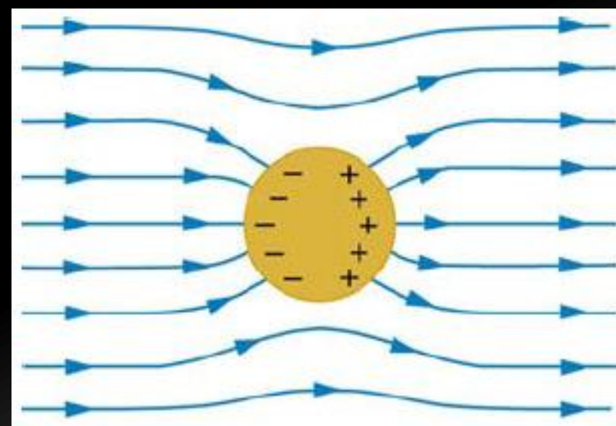
08-04 Conductors in Equilibrium and Applications

- Conductors contain free charges that move easily
- When extra charges are present, they quickly move to places where the electric field is ⊥ to the surface
- Then they stop moving
- This is electrostatic equilibrium

If there was a parallel component to the electric field, then they charges would move along the surface

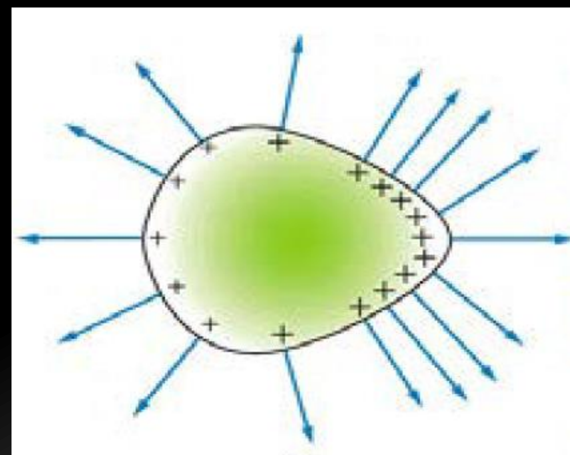
08-04 Conductors in Equilibrium and Applications

- Conductor in electric field will polarize
- Inside conductor, E-field = 0
- Just outside of conductor, E-field is ⊥ to surface
- Any excess charge resides on surface
  - They get as far apart as possible



08-04 Conductors in Equilibrium and Applications

- If the surface is uneven, more charge will collect near the area of most curvature
- If the curve is great enough, the E-field can be strong enough to remove excess charge
  - Lightning Rods

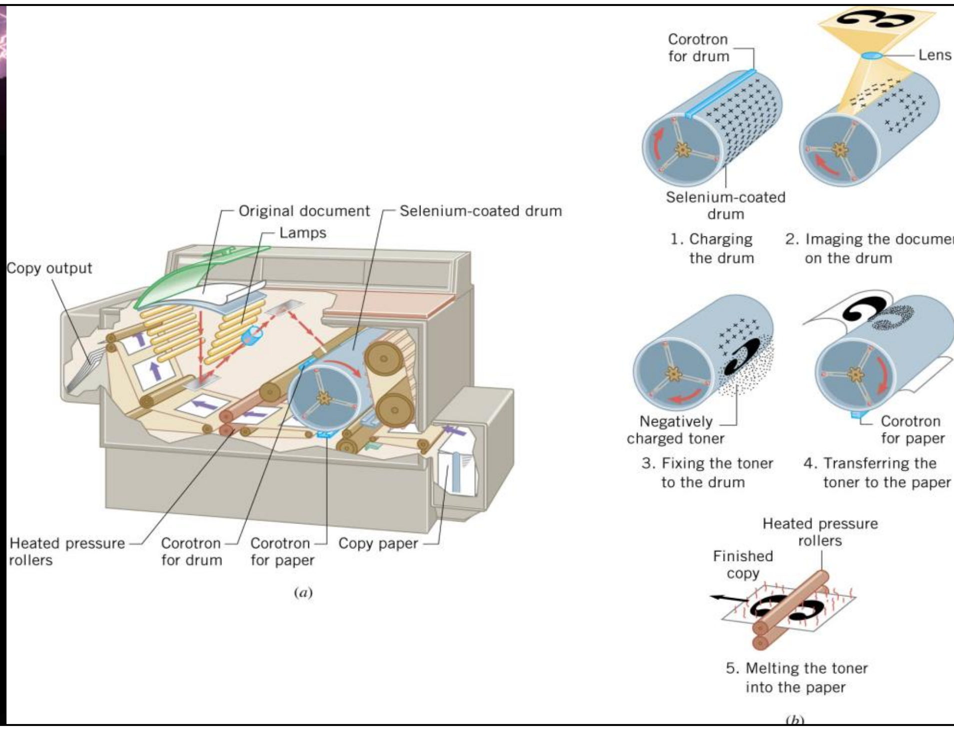


08-04 Conductors in Equilibrium and Applications

- Shielding
  - A conductor shields any charge within it from external electrical fields
  - Sensitive electrical equipment is shielded by putting in a metal box
    - Called Faraday Cage
  - Coaxial cable is shielded by a metal cylinder around the central metal wire. This reduces interference and signal loss

08-04 Conductors in Equilibrium and Applications

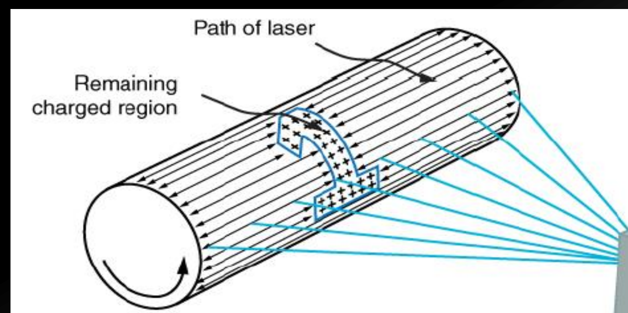
Copier



- Xerography (means dry writing in Greek)
- Xerographic drum is aluminum coated with selenium
    - Selenium is a photoconductor
    - Photoconductor is a conductor in light, but insulator in dark
- The drum is given a positive charge
- Lenses and mirrors shine the image onto the drum
- Where light hits the drum, selenium is conductor and becomes neutralized, where image is is dark so stays insulator and positive charge
- Toner given negative charge so it sticks to positive areas of drum
- Paper is give big positive charge so toner covering only the image sticks to the paper
- Paper is heated to melt in the toner

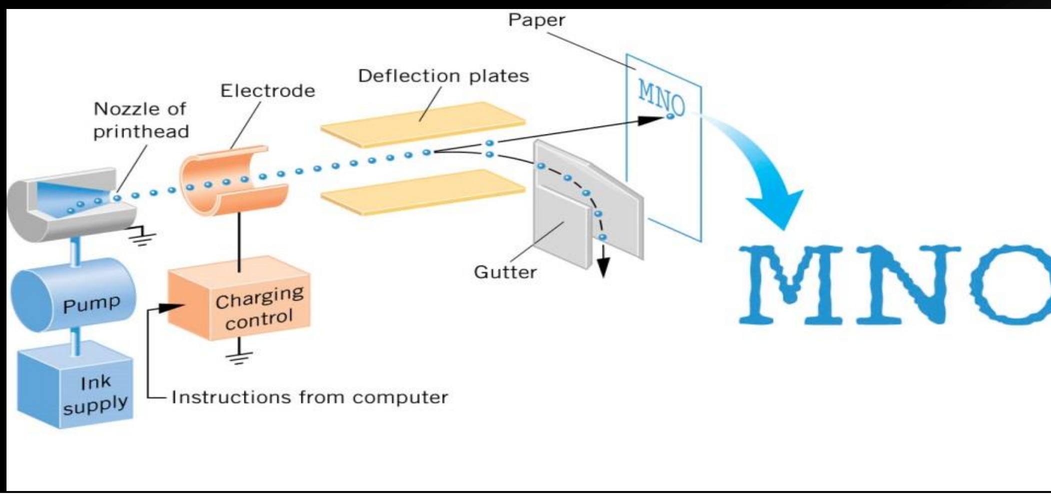
08-04 Conductors in Equilibrium and Applications

- Laser Printer
  - Similar to copier machine only the image is put on the drum using a laser
  - The laser scans the drum quickly
  - The computer turns the laser on and off at the right time to produce the image



08-04 Conductors in Equilibrium and Applications

- Inkjet printer



One type only!!!

•As print head shuttles back and forth across paper, ink is finely sprayed (extremely small drops)

•Where no ink wanted

  •Electrode gives the drops an electrical charge by induction

  •Deflection plates use the electrical charge to divert the ink into a gutter

•When want ink on paper

  •The Electrode is turned off, so no charge on ink

  •Ink goes straight to paper.

08-04 Homework

- Try going beyond the surface of these problems
- Read 19.1

In this lesson you will…

- Define electric potential and electric potential energy.
- Describe the relationship between potential difference and electrical potential energy.
- Explain electron volt and its usage in submicroscopic process.
- Determine electric potential energy given potential difference and amount of charge.

08-05 ELECTRIC POTENTIAL ENERGY: POTENTIAL DIFFERENCE

08-05 Electric Potential Energy: Potential Difference

- Change in PE due to Gravity
  - Force of gravity is conservative
  - $W = mgh_0 - mgh_f = PE_0 - PE_f$
- Change in PE due to Electrical Force
  - Electrical Force is conservative
  - $W = PE_0 - PE_f$

$$F_G = G\frac{m_1 m_2}{r^2}$$

$$F_E = k\frac{q_1 q_2}{r^2}$$

08-05 Electric Potential Energy: Potential Difference

- Since $E = \frac{F}{q_0}$ it is useful to have $\frac{W}{q_0} = \frac{EPE}{q_0}$
- Electric Potential (or Potential)
  - $V = \frac{EPE}{q_0}$
  - Unit: volt (V = J/C)

Point out that the **Electric Potential** and the **Electrical Potential Energy** are different

EPE → energy measured in joules

V → energy per unit charge measured in V

08-05 Electric Potential Energy: Potential Difference

- Electric Potential Difference

$$V_f - V_0 = \frac{PE_f}{q_0} - \frac{PE_0}{q_0} = -\frac{W}{q_0}$$

$$\Delta V = \frac{\Delta PE}{q_0} = -\frac{W}{q_0}$$

- V and EPE can only be measured in differences

08-05 Electric Potential Energy: Potential Difference

- Electric force moves a charge of 2×10^{-10} C from point A to point B and does 5×10^{-6} J of work.
- What is the difference in potential energies of A and B ($PE_A - PE_B$)?
  - $PE_A - PE_B = 5 \times 10^{-6}$ J
- What is the potential difference between A and B ($V_A - V_B$)?
  - V = 25000 V   Point A is higher potential

$$EPE\!: W_{AB} = -W_{BA} = EPE_A - EPE_B = 5 \times 10^{-6}\,J$$

$$V\!: V_A - V_B = -\frac{W_{BA}}{q_0} = \frac{5 \times 10^{-6}\,J}{2 \times 10^{-10}\,C} = 25000\,V$$

08-05 Electric Potential Energy: Potential Difference

- Electric Potential Difference and Charge Sign
  - Positive Charge
    - Moves from higher electrical potential toward lower electrical potential
  - Negative Charge
    - Moves from lower to higher electrical potentials

08-05 Electric Potential Energy: Potential Difference

- Points A, B, and C are evenly spaced on a line. A positive test charge is released from A and accelerates towards B, from B it decelerates, but doesn't stop at C. What happens when a negative charge is released at B?
- Accelerates towards A

B has the lowest potential. (positive accelerate to it and slows after passing)

C has next lowest potential. (while the distance was the same, the charge didn't stop)

A has the highest potential.

Negative charge will accelerate towards the highest potential

08-05 Electric Potential Energy: Potential Difference

- Batteries
  - Even though it is the negative electrons that actually move, tradition says that we talk about moving positive charges
  - Positive charge repelled by positive terminal
  - Moves through light bulb and energy converted to heat
  - By the time the positive charge reaches the negative terminal, it has no potential energy left

08-05 Electric Potential Energy: Potential Difference

- Volts and Energy
  - $V = \frac{EPE}{q_0}$
  - $EPE = q_0 V$
  - Use this when solving conservation of energy problems

  - Unit for small energy is electron volts (eV)
    - $eV = (1.60 \times 10^{-19}\ C)(1\ V) = 1.6 \times 10^{-19}\ J$

If you are looking for the change in electrical potential energy multiply the potential difference by the charge

Conservation of energy is where the initial E = final E of all types including GPE, EPE, KE, etc

08-05 Electric Potential Energy: Potential Difference

- When lightning strikes, the potential difference can be ten million volts between the cloud and ground. If an electron is at rest and then is accelerated from the ground to the cloud, how fast will it be moving when it hits the cloud 0.5 km away (ignore relativity effects)?
- $v = 1.87 \times 10^{9}\ m/s$

Conservation of Energy

$$E = KE + GPE + EPE$$

$$Final = initial$$

$$KE_f + (9.11 \times 10^{-31}\ kg)\left(9.8\frac{m}{s^2}\right)(500m) + (1 \times 10^{7}\ V)(-1.6 \times 10^{-19}\ C) = 0 + 0 + 0$$

$$KE_f + 4.46 \times 10^{-27}\ J - 1.6 \times 10^{-12}\ J = 0$$

$$KE_f - 1.6 \times 10^{-12}\ J = 0 \quad KE_f = 1.6 \times 10^{-12}\ J$$

$$KE = \frac{1}{2}mv^2 \rightarrow 1.6 \times 10^{-12}\ J = \frac{1}{2}(9.11 \times 10^{-31}\ kg)v^2 \rightarrow 3.51 \times 10^{18} = v^2 \rightarrow v = 1.87 \times 10^{9}\frac{m}{s}$$

Faster than speed of light so must use relativity which we will study later

08-05 Homework

- Try these potential puzzling problems
- Read 19.2

In this lesson you will…

- Describe the relationship between voltage and electric field.
- Derive an expression for the electric potential and electric field.
- Calculate electric field strength given distance and voltage.

08-06 ELECTRIC POTENTIAL IN A UNIFORM ELECTRIC FIELD

08-06 Electric Potential in a Uniform Electric Field

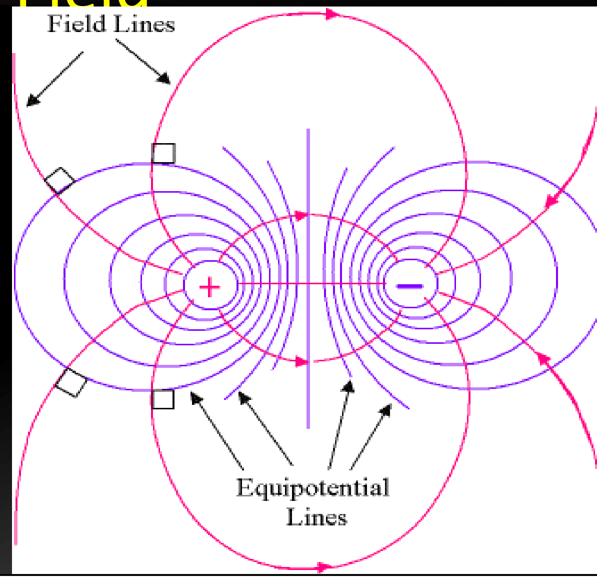
- Both electric field and electric potential can be used to describe charges
- E
  - deals with force
  - vector
- V
  - deals with energy
  - scalar

08-06 Electric Potential in a Uniform Electric Field

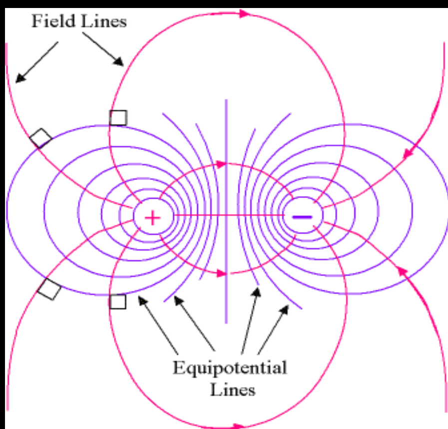
- Uniform Electric Field
- $W = -\Delta PE = -q\Delta V$
- $-\Delta V = -(V_B - V_A) = (V_A - V_B) = V_{AB}$
- $W = qV_{AB}$
- $W = Fd$
- $Fd = qV_{AB}$
- $F = qE$
- $qEd = qV_{AB}$
- $V_{AB} = Ed$ or $E = \frac{V_{AB}}{d}$

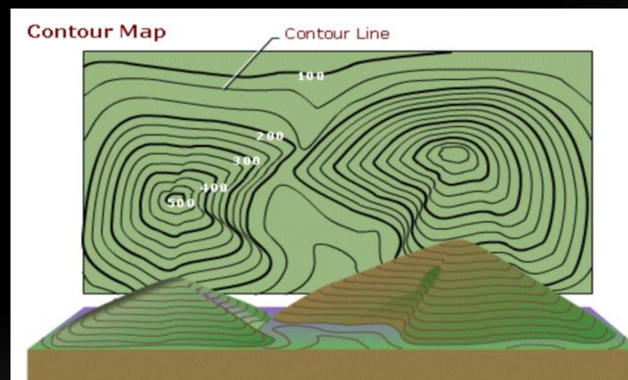
08-06 Electric Potential in a Uniform Electric Field

- In general
$$E = -\frac{\Delta V}{\Delta s}$$
- E is gradient (slope) of V vs. s (displacement)
- On picture, E-field lines show force. V lines are where V are same
- The closer V lines are, the stronger E is.



08-06 Electric Potential in a Uniform Electric Field





Field lines and equipotential lines like topographic map where altitudes are equipotential lines and slopes are like field lines

08-06 Electric Potential in a Uniform Electric Field

- How far apart are two conducting plates that have an electric field strength of 4.50×10^3 V/m between them, if their potential difference is 15.0 kV?

- D = 3.33 m

$$E = \frac{V_{AB}}{d}$$

$$4.50 \times 10^3 \frac{V}{m} = \frac{15000\ V}{d}$$

$$d = \frac{15000\ V}{4.50 \times 10^3 \frac{V}{m}} = 3.33\ m$$

08-06 Electric Potential in a Uniform Electric Field

- A doubly charged ion is accelerated to an energy of 15.0 keV by the electric field between two parallel conducting plates separated by 3.00 mm. What is the electric field strength between the plates?
- $E = 2.5 \times 10^6\ N/C$

$$15\ keV \left(\frac{1000\ eV}{1\ keV}\right)\left(\frac{1.60 \times 10^{-19}\ J}{1\ eV}\right) = 2.4 \times 10^{-15}\ J$$

$$E = \frac{V_{AB}}{d} \rightarrow Ed = V_{AB}$$

$$W = qV_{AB}$$

$$W = qEd$$

$$E = \frac{W}{qd}$$

$$E = \frac{2.4 \times 10^{-15}\ J}{(2 \cdot 1.60 \times 10^{-19}\ C)(0.003\ m)} = 2.5 \times 10^6\ N/C$$

08-06 Homework

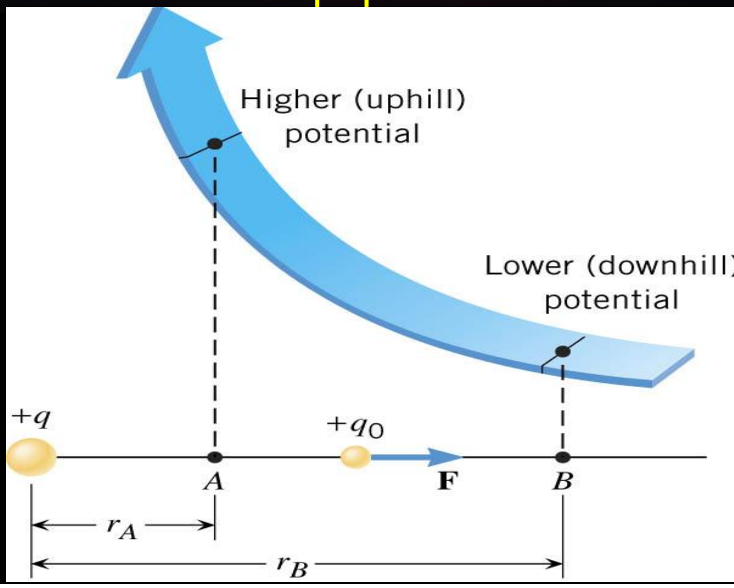
- You have the potential to succeed.
- Read 19.3, 19.4

In this lesson you will…

- Explain point charges and express the equation for electric potential of a point charge.
- Distinguish between electric potential and electric field.
- Determine the electric potential of a point charge given charge and distance.
- Explain equipotential lines and equipotential surfaces.
- Compare electric field and equipotential lines.

08-07 ELECTRIC POTENTIAL DUE TO A POINT CHARGE AND EQUIPOTENTIAL LINES

08-07 Electric Potential Due to a Point Charge and Equipotential Lines



- Charge at q
- Two points at distances rA and rB
- At both these points a small positive test charge is repelled by the force F = (kqq/r^2)
- This force does work to move the test charge from A to B
- Since r varies from A to B and the force varies also, so must use calculus integrals to find the work done
  - $W_{AB} = kqq_0/rA - kqq_0/rB$
- The potential difference can be found
  - $V_B - V_A = -W_{AB}/q_0 = kq/rB - kq/rA$
- If we make rB very large (infinite) then kq/rB = 0 and $V_B = 0$
- For convenience we always set $V_B = 0$ so
  - $V = kq/r$

08-07 Electric Potential Due to a Point Charge and Equipotential Lines

- Potential of a Point Charge

$$V = \frac{kq}{r}$$

- V is NOT the absolute potential
- V IS the potential difference if a test charge were moved to a distance of r from infinity

08-07 Electric Potential Due to a Point Charge and Equipotential Lines

- Two or more charges
  - Find the potentials due to each charge at that location
  - Add the potentials together to get the total potential

08-07 Electric Potential Due to a Point Charge and Equipotential Lines

- Two charges are 1 m apart. The charges are +2 μC and -4 μC. What is the potential 1/3 of the way between them?
- 0 V

$$V = \frac{kq}{r}$$

$$V = \frac{\left(8.99 \times 10^9 \frac{Nm^2}{C^2}\right)(2 \times 10^{-6}\ C)}{0.333333\ m} + \frac{\left(8.99 \times 10^9 \frac{Nm^2}{C^2}\right)(-4 \times 10^{-6}\ C)}{0.666667\ m} = 0\ V$$

08-07 Electric Potential Due to a Point Charge and Equipotential Lines

- How much work is done ($-W = PE_f - PE_0$) to bring two electrons to a distance of $5.3 \times 10^{-11}\ m$ to the nucleus of a Helium atom ($q = 3.2 \times 10^{-19}\ C$)?
- $W = 1.52 \times 10^{-17}\ J$

Start by saying that the potential at infinity is 0.

Find the potential at the orbit due to the nucleus:

$$V = \frac{kq}{r} = \frac{\left(8.99 \times 10^{9} \frac{Nm^2}{C^2}\right)(3.2 \times 10^{-19}\ C)}{5.3 \times 10^{-11}\ m} = 54.3\ V$$

Find the work done to bring the first electron in from infinity:

$$EPE = qV = (1.6 \times 10^{-19}\ C)(54.3\ V) = 8.68 \times 10^{-18}\ J$$

Find the new potential at the orbit (new electron will want to come into the opposite side of the orbit):

$$V = \frac{kq}{r} + \frac{kq}{r}$$

$$= \frac{\left(8.99 \times 10^{9} \frac{Nm^2}{C^2}\right)(3.2 \times 10^{-19}\ C)}{5.3 \times 10^{-11}\ m} + \frac{\left(8.99 \times 10^{9} \frac{Nm^2}{C^2}\right)(-1.6 \times 10^{-19}\ C)}{10.6 \times 10^{-11}\ m}$$

$$= 40.7\ V$$

Find the work to bring in the second electron

$$EPE = qV = (1.6 \times 10^{-19}\ C)(40.7\ V) = 6.51 \times 10^{-18}\ J$$

Find the Total

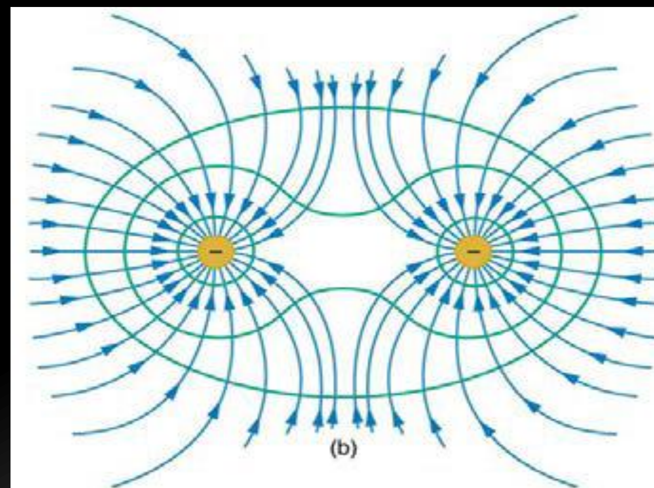
$$EPE_{total} = 8.68 \times 10^{-18}\ J + 6.51 \times 10^{-18}\ J = 1.52 \times 10^{-17}\ J$$

08-07 Lab

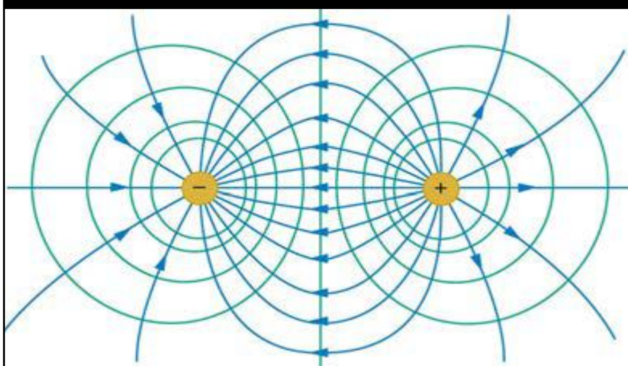
- Create a map of equipotentials

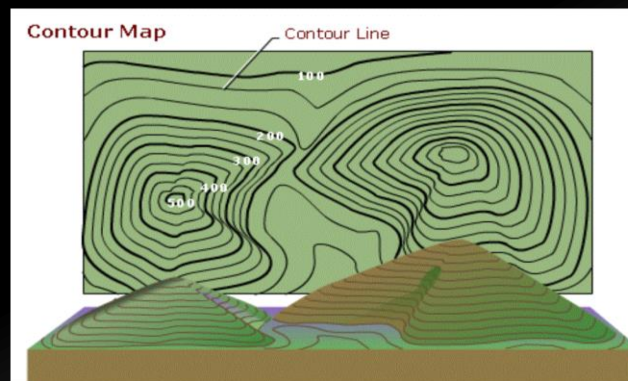
08-07 Electric Potential Due to a Point Charge and Equipotential Lines

- Equipotential Lines
  - Lines where the electric potential is the same
  - Perpendicular to E-field
  - No work is required to move charge along equipotential line since $q\Delta V = 0$



08-07 Electric Potential Due to a Point Charge and Equipotential Lines

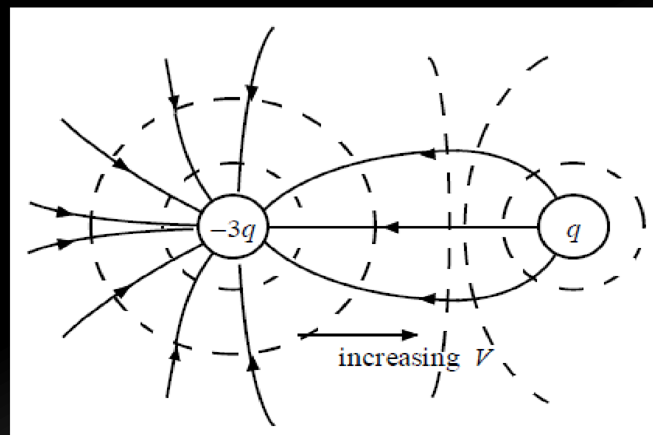




Field lines and equipotential lines like topographic map where altitudes are equipotential lines and slopes are like field lines

08-07 Electric Potential Due to a Point Charge and Equipotential Lines

- Sketch the equipotential lines in the vicinity of two opposite charges, where the negative charge is three times as great in magnitude as the positive.



08-07 Homework

- Let me charge you with this point: You can reach your potential.