Physics Notes – Chapter 17 – Electric Forces and Fields

I. Basic rules and ideas related to electricity

a. electricity is about charges or charged objects … where they are and how they move – electrostatics is about charges that are not continuously moving.

b. charges come in ***two kinds only*** they are: positive (due to Protons) and negative (due to electrons)

c. ***Charge on a proton exactly equals the magnitude of the charge of an electron – the type (or sign) of their charge is opposite.***

e = elementary charge (magnitude of the charge of a proton or electron)

e = 1.60 X 10^{-19} C

C = coulomb; SI unit for charge

the charge on one electron is -1.6 X 10^{-19} Coulombs

the charge on one proton is +1.6 X 10^{-19} Coulombs

d. Charges exert forces on other charges over a distance (without contact being necessary) **LIKE charges repel** each other and **UNLIKE or OPPOSITE charges attract**. (link to three video clips: like charges and unlike charges interacting in combinations) http://paer.rutgers.edu/pt3/experimentindex.php?topicid=10&cycleid=56

e. Electrons and Protons are charged electrically - we call them charged particles, BUT when an atom, or any object, has equal numbers of electrons and protons and carries zero net charge it is said to be ***electrically neutral.***

f. ***Charge is "quantized"***; - charge on a proton or electron , "e", is the smallest amount of free charge that has been discovered; any charge greater than "e" will be of some distinct whole number multiple of "e"; Robert Millikan first demonstrated this in his famous oil drop experiment

g. Conservation of Electric charge- electric charge is always conserved – never created or destroyed only transferred from one object to another.

h. ***ELECTRICITY is NOT the same thing as MAGNETISM*** and electricity does NOT involve North or South Poles!!!! BUT electricity and magnetism are related to each other…a relationship which we will investigate in Ch. 22.

II. Facts to remember about Matter or substances

a. Matter is made up of atoms and atoms contain equal numbers of protons and electrons. With equal numbers of positive protons and negative electrons atoms are neutral … **so matter is neutral in most circumstances.**

b. Matter can become charged if it loses or gains some electrons. An atom that has become charged is called an "ion". If an atom gains an electron it becomes negatively charged and if it loses an electron it becomes positive. ***NOTICE: ONLY THE ELECTRONS CAN BE LOST OR GAINED.*** Protons do not move from one atom to another unless it involves a nuclear reaction.

III. Charging an object by contact and by induction – 3 general ways that matter can become charged:

1. contact or conduction- touching a charged conductor to a neutral one

2. friction – rubbing electrons from one originally neutral object onto another (both objects become charged)

3. induction – holding a charged object near another object while providing a ground to the second object.

First some definitions:
Conductors – materials in which electric charges move freely; metals
Insulators – materials in which electric charges do not move freely; glass, rubber, wood

A surface charge can be induced on insulators <u>by charge polarization</u> –as shown here ->

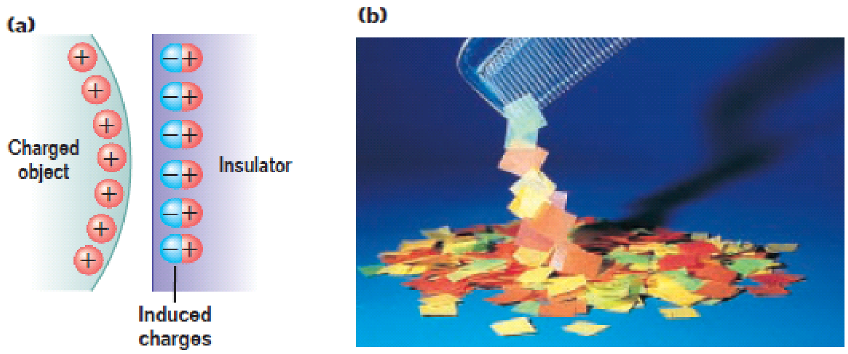


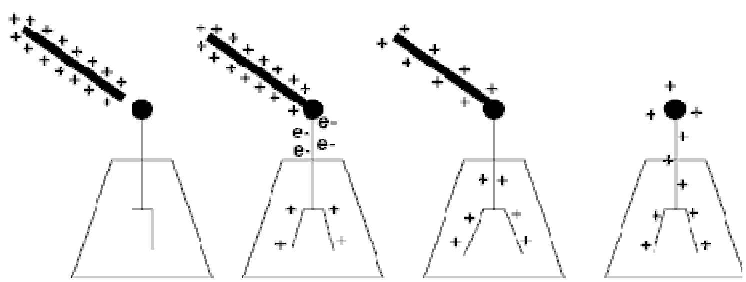
Figure 17-5
(a) The charged object on the left induces charges on the surface of an insulator, which is said to be *polarized.* **(b)** This charged comb induces a charge on the surface of small pieces of paper that have no net charge.

Semiconductors – conduct a moderately small amount of electricity (useful in electrical devices since their properties can be changed by adding small amounts of other atoms); silicon, germanium. In pure form they are actually insulators, but made to conduct by adding impurities (this is called "doping")

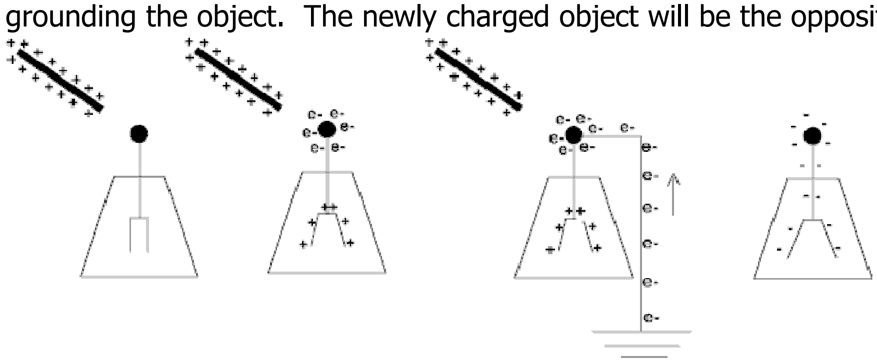
<u>Charging by contact -</u>

1. **Friction** - by rubbing two different neutral materials together, you can transfer some electrons from one surface to another. Ex: shoes on carpet – electrons move from the carpet to the shoes. **The two objects receive an opposite charge.**
2. **Conduction** - an already charged object can be brought <u>into contact</u> with something else and transfer electrons to or from the new object. **The two objects end up the same charge.**

This example is for an electroscope being charged by conduction.



<u>Charging by Induction -</u> an induced charge can be produced in a neutral object by bringing a charged object nearby <u>but not touching</u> the neutral one. You then attach a wire (or touch it with a finger) providing a path for electrons to move onto or off of the once neutral object. This is called grounding the object. The newly charged object will be the opposite charge of the original.



(link to five video clips: demos and questions on charging an electroscope)
http://paer.rutgers.edu/pt3/experimentindex.php?topicid=10&cycleid=50

IV. Coulomb's law - pronounced " cool' ahmz " law and electrostatic force (force between charged objects)

a. Coulomb's Law states that the force between 2 charged objects or particles is directly proportional to the product of their charges and is inversely proportional to the distance between them **SQUARED**.

b. The formula is:

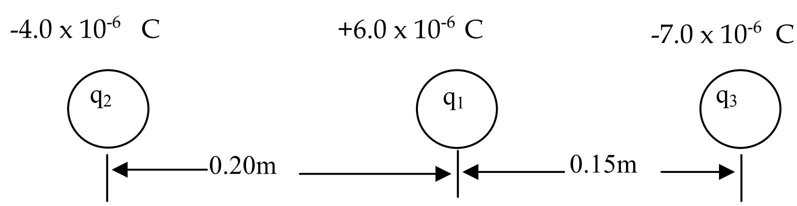
$$F = k\frac{q_1 q_2}{d^2}$$

where **q** is the amount of charge in coulombs, **d** is the distance in meters between them, and **k** is the electrical constant or Coulomb's constant and the value for **Coulomb's electrical constant is:**

k = 9.0 X 10^9 N·m^2/C^2

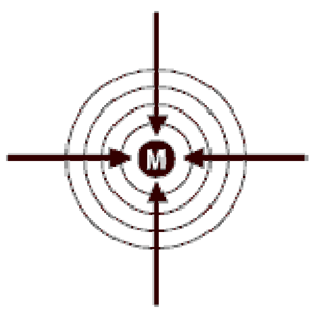
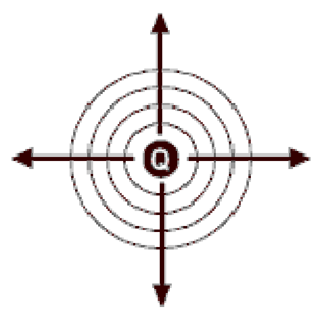
The force produced on some charged object by two or more other charged objects must be found by summing the forces **as vectors.**

Example #1: The figure below shows three point charges that lie along the x axis. Determine the magnitude and direction of the net electrostatic force on charge q_1.



Gravitational forces Vs. Electrical Forces

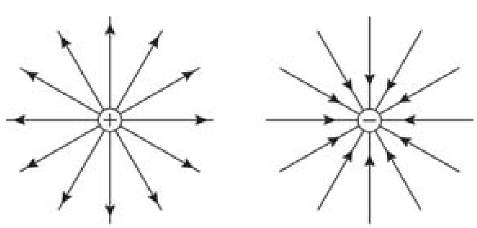
The electrostatic force is analogous to the gravitational force <u>except</u> that the electrostatic force can be either attractive or repulsive and it is MUCH stronger, while gravity only attracts (as far as we know) and it is comparatively weak. {Demo: charged balloon held above neutral pieces of paper (electric force overcomes gravity) and attraction of the neutral meter stick with charged rod.}

Gravitational Forces	Electrostatic Forces
$F = G\frac{M_1 M_2}{r^2}$ ▪ G = 6.67 x 10^{-11} Nm^2/kg^2 is VERY small ▪ gravity is a weak force ▪ inverse square force ▪ attractive only	$F = k\frac{Q_1 Q_2}{r^2}$ ▪ k = 9 x 10^9 Nm^2/C^2 is VERY large ▪ electrostatic forces are strong ▪ inverse square force ▪ attractive and repulsive
Gravitational Field	**Electrostatic Field (+ charge)**
 $F = mg = G\frac{mM}{r^2}$ $g = G\frac{M}{r^2}$ ▪ gravitational field strength, g ▪ g's vector nature points towards the center of the planet ▪ each surface represents a unique value for g ▪ g is measured in N/kg (or m/sec^2)	 $F = qE = k\frac{qQ}{r^2}$ $E = k\frac{Q}{r^2}$ ▪ electric field strength, E ▪ E's vector nature points away from a positive charge or towards a negative charge ▪ each surface represents a unique value for E ▪ E is measured in N/C

<u>{Do WS on Coulomb's Law – Parts 1 & 2 here}</u>

V. Electric Force Fields

a. A charged object has an area around it where it exerts a force on other charges that come into the field…(a lot like a massive object exerts a force due to gravity on other objects that come near)



(a) (b)

$$E = k\frac{q}{r^2}$$

b. any force field can be represented by force field lines. Electric force field lines are useful in visualizing the electric field in a region of space. Wherever the lines are close together the field is stronger. The direction is shown (see above) as an arrow pointing **away from a positive** charge and **toward a negative**. This is different from a gravity field, because gravity only attracts…so there is no "force field away from" in gravity.

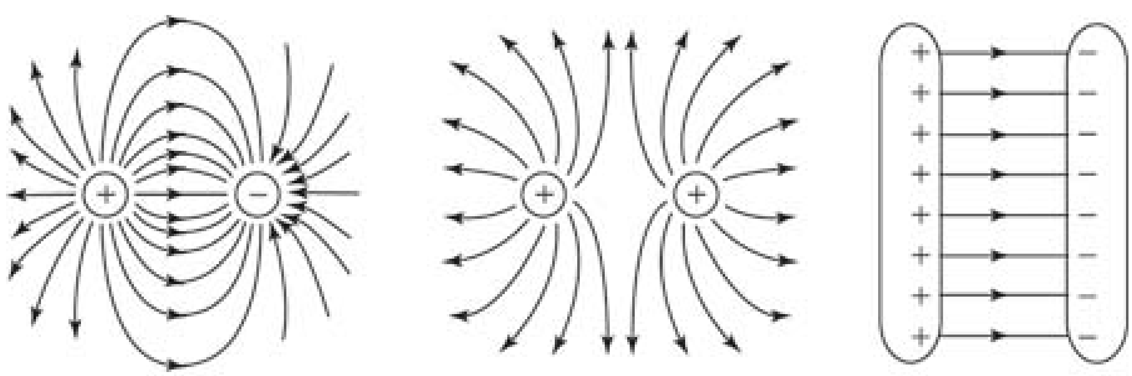
c. If a second charge is placed at some point in the field, the second charge interacts with the field at that point (this explanation does away with the idea of "action at a distance" because an interaction between particles separated by some distance is no longer required…They are interacting with a force field with which they are in contact)

- The direction of E is the same as the direction of the electric force that would be exerted on a small **positive** test charge that could be placed in the field. This direction was decided arbitrarily in order to make electric forces, current, and electric fields easy to describe and calculate consistently.

Electric field lines originate on a positive charge (or infinity) and terminate on a negative charge (or infinity) **so if the charge (Q) is positive, the field would point outward from it, If negative the field would point toward it.**

Rules for drawing electric field lines:

- Lines begin at positive charge (or infinity) and terminate on negative charge (or infinity) (away from + and toward -)
- Number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge present
- No two field lines can cross each other



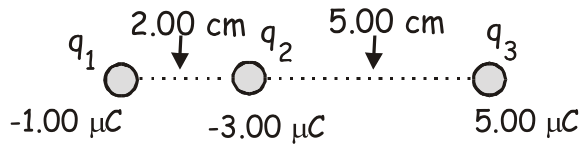
(a) (b) (c)

VI. Calculating the magnitude and direction of an electric force field

- **The magnitude is found using** $E = \frac{kq}{r^2}$ **E=Electric Field strength, r = distance between the charged object creating the force field and the point at which you are measuring the electric field strength**

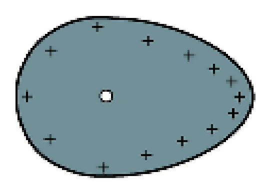
Example 2:

Three charges are arranged as shown below. Calculate the magnitude and state the direction of the net **electric field** (E) at a point 3.0 cm to the right of the 5.00 μC charge. Then calculate the force that would act on a proton if it were placed at that point in the field and its acceleration once it was released from that position.



Do worksheet – Coulomb's Law, Electrostatic Forces and Fields: Part 3

Characteristics of Conductors that are in electrostatic equilibrium (not grounded) - like the Van De Graaff generator (shown below) when charged up or an electroscope that is charged.



- Electric field is zero everywhere inside the conductor – so you are safe inside (see the Faraday Cage pictures at bottom of page)
- Any excess charge resides entirely on its outer surface – see diagram to right
- On irregular shaped objects, the excess charge accumulates where the radius of curvature is smallest (at sharp points). This is one of the reasons that lightning rods work to protect buildings. The charge accumulates at the somewhat sharp tip and then escapes into the atmosphere thereby discharging the building so the lightning will NOT strike.
- Lightning rods protect buildings in case the lightning still strikes because they ground the strike and take it into the ground.

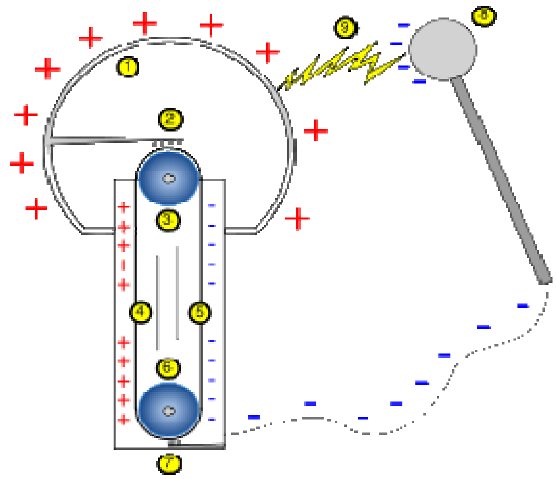
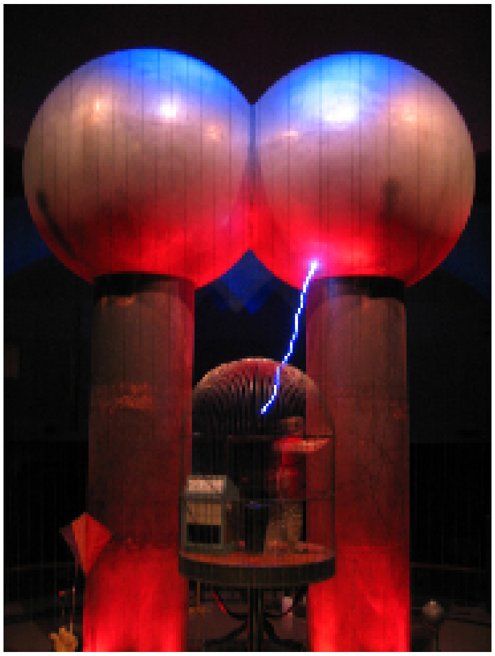


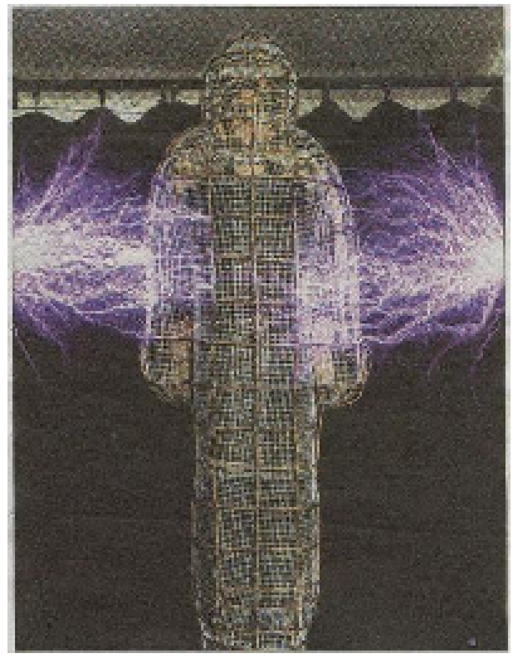
Diagram of a classical Van de Graaff generator.
1) hollow metallic sphere (with positive charges)
2) electrode connected to the sphere with a mesh or metal brushes in close proximity to the belt
3) upper roller (made of plexi-glass)
4) side of the belt with positive charges
5) opposite side of the belt with negative charges
6) lower roller (metal)
7) lower electrode (ground)
8) spherical device with negative charges, used to discharge the main sphere
9) spark produced by the difference of potentials (or Voltage)

Be able to describe these processes (Van De Graff, Lightning, lightning rods, Faraday cages) as shown here and discussed in class: Formation of Lightning! Lightning rods and how they work! Safety techniques: protection inside a Faraday Cage (see below), Car, or metal building…and Body position for safety.

(Demos of Van De Graff generator- Relate to Lightning and lightning rods and Faraday cages.)

The person is protected from shock inside the conductor due to the charge all positioned on the **outside** of the metal cage! The electric force field (E) is zero inside the conducting cage, but is very powerful on the outer surface and extends outward from that surface.





Left - Notice the person inside – touching the inner surface of the Faraday Cage!

Right - A person-shaped Faraday Cage – shielding him!

Homework problems p. 654-656 #'s 1-16, 19, 20, 28-30, 35-38 and 43.