Physics 3204

UNIT 2: FIELDS

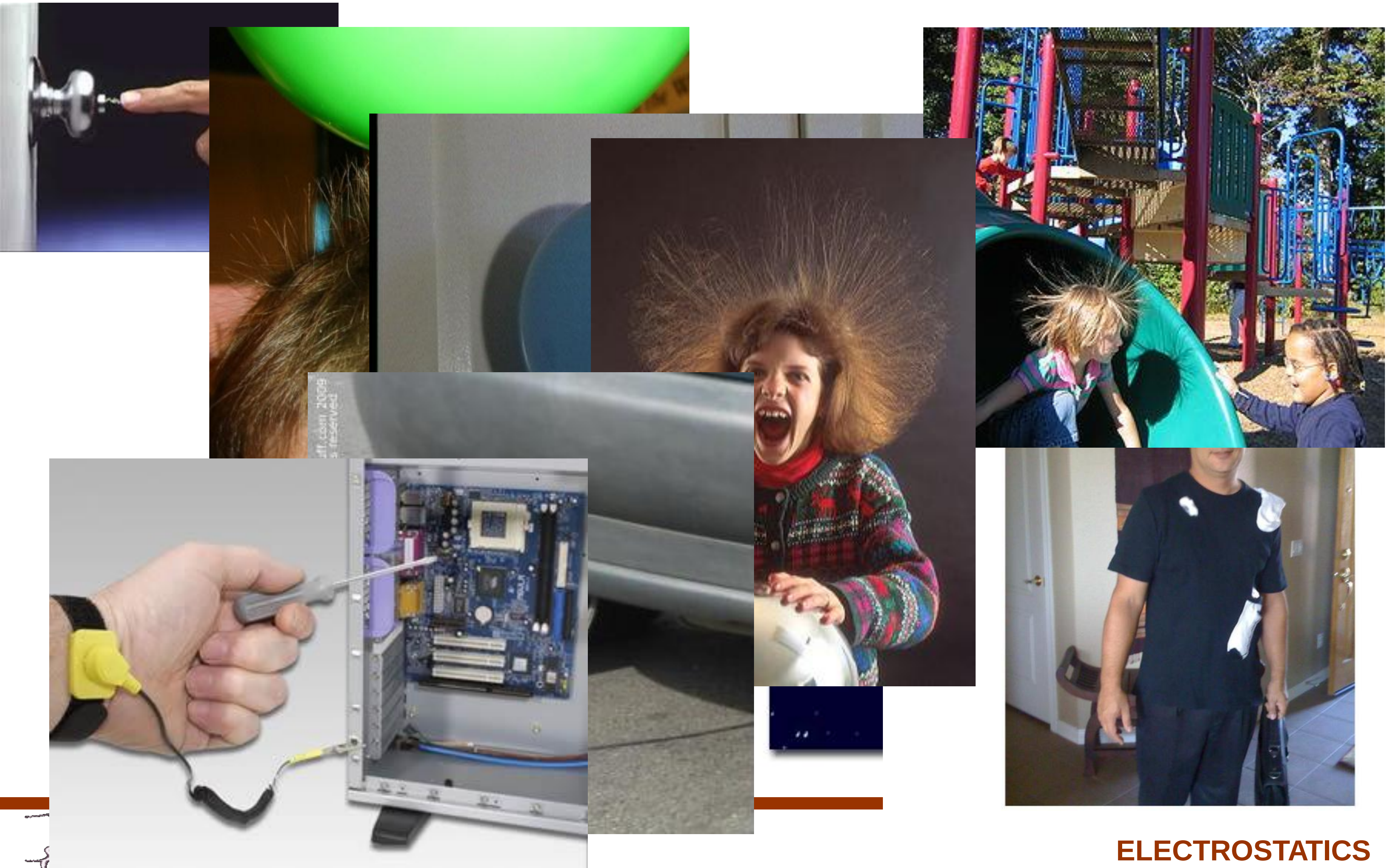
ELECTROSTATICS

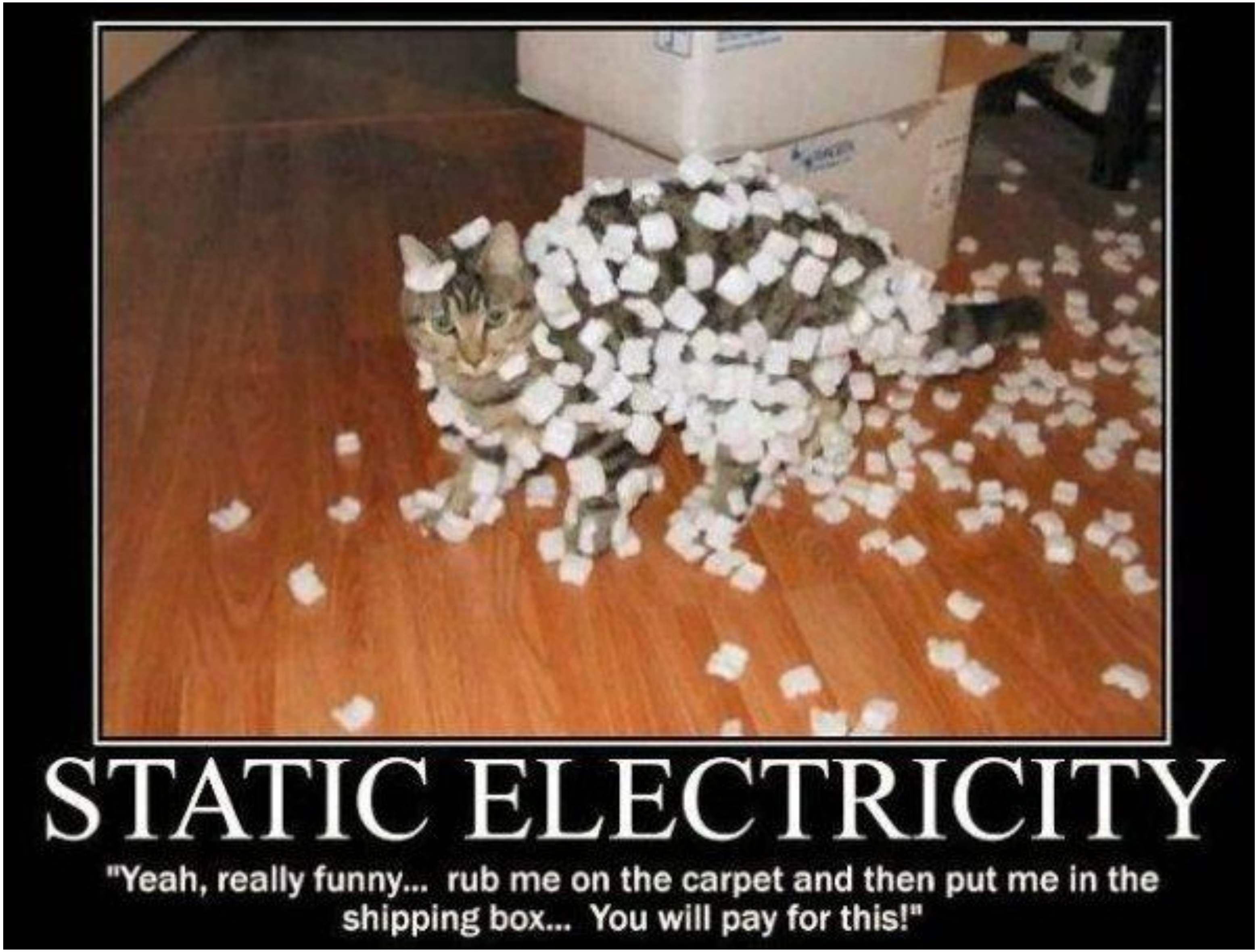
Section 13.1- 13.7

Key Question:

How can an object be charged and what effect does that charge have upon other objects in its vicinity?

There is a large overlap of the world of static electricity and the everyday world which you experience.




STATIC ELECTRICITY
"Yeah, really funny... rub me on the carpet and then put me in the shipping box... You will pay for this!"

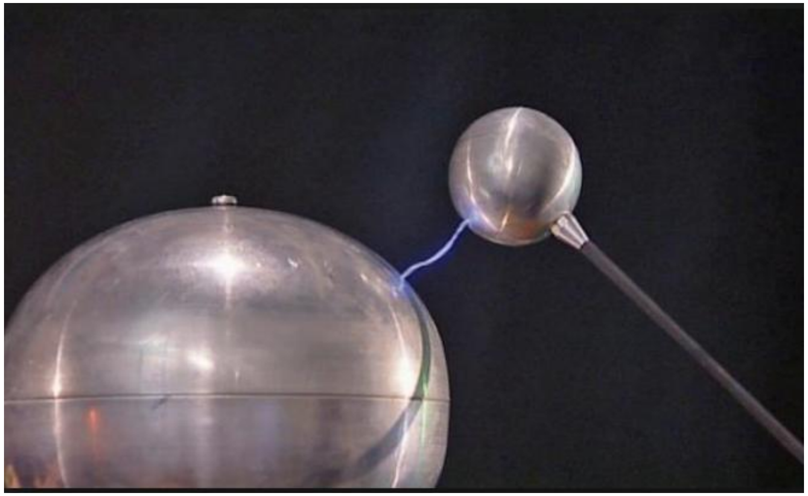
FRANKLIN'S KITE

On June 15, 1752, Benjamin Franklin launched his kite into the dark clouds of a *developing storm. He correctly assumed* that the thunderclouds would have a static charge before there was a lightning strike. His goal was to collect the electricity from these storm clouds. Had lightning actually struck his kite, the precautions that Franklin had put in place would not have been enough to prevent his being electrocuted.

After flying the kite for a few minutes, Franklin brought his knuckles close to the iron key and a spark jumped from the key to his knuckles. This static electricity spark was identical to those produced by friction. Benjamin Franklin had proved that lightning was caused by a build-up of static electricity in the storm clouds.

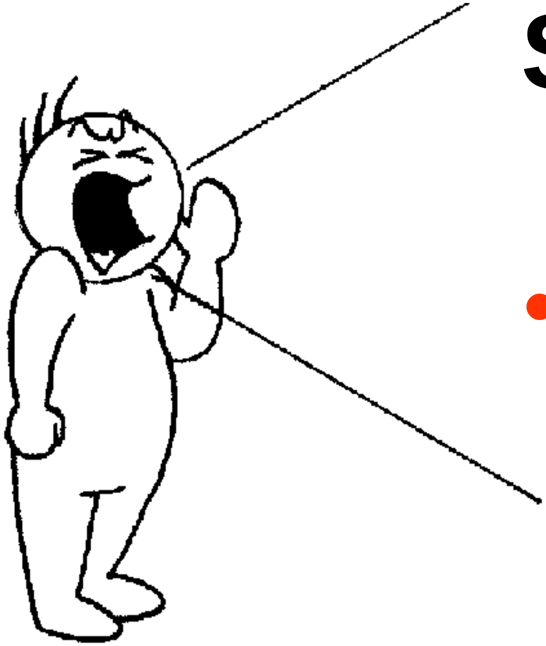
What Is Static Electricity?

Remember Static means at rest.



- **Static electricity** refres to stationary electrical charge that is built up on the surface of a material

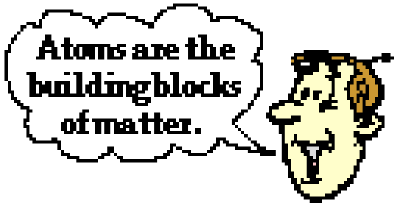
The interaction between static electric charges is called electrostatics.



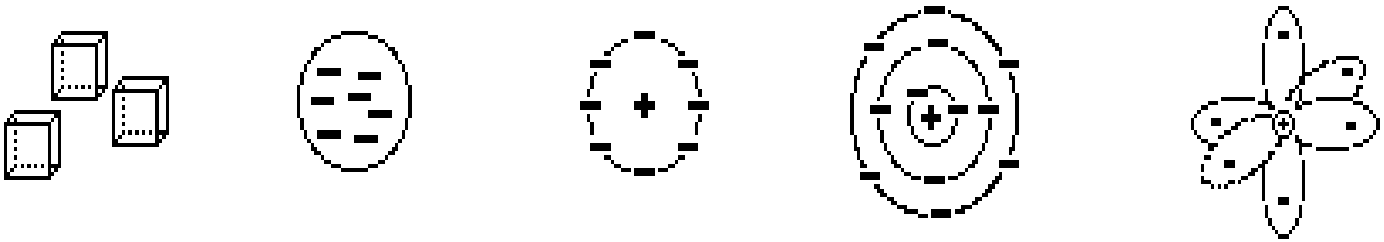
Section 1
Topic 1

- Electrostatics and the Atomic Theory

Text: 13.1 – 13.2



Our Changing View of the Atom



"Atomos" are the building blocks of matter.	Negative electrons are embedded in a sea of positive charge.	Positive charge is located within a central nucleus.	Electrons are in circular orbits with quantized energy levels.	Electrons occupy regions of space whose shape is described by complex mathematical equations.
Early Greek Philosophers	J.J. Thomson	Ernest Rutherford	Neils Bohr	Quantum Mechanics
400 B.C.	1898 - 1903	1911	1913	Modern Model

Atomic Theory

- Basic Atomic Theory is used to explain electrostatic effects.

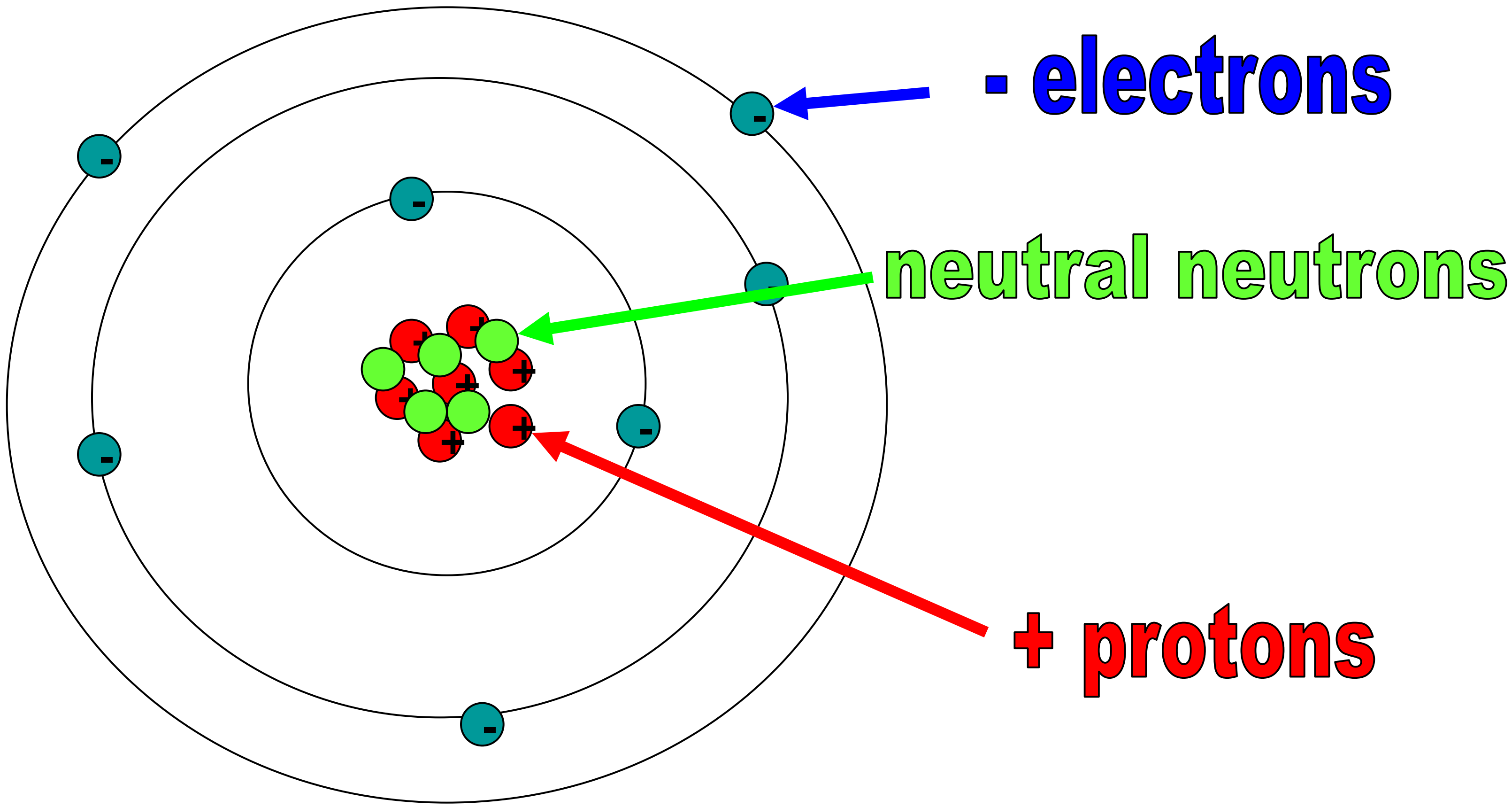
- The Bohr-Rutherford Atomic Model states:

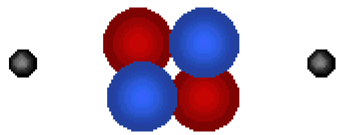
- All matter is made of tiny particles called atoms.
- Atoms can consist of three particles, the electron, proton, and neutron, each having a negative, positive and neutral electric charge, respectively.

- Protons and neutrons exist in the atomic nucleus, while electrons orbit around the nucleus in probability clouds.

Structure of Matter

- Fundamental building blocks of the matter are atoms.

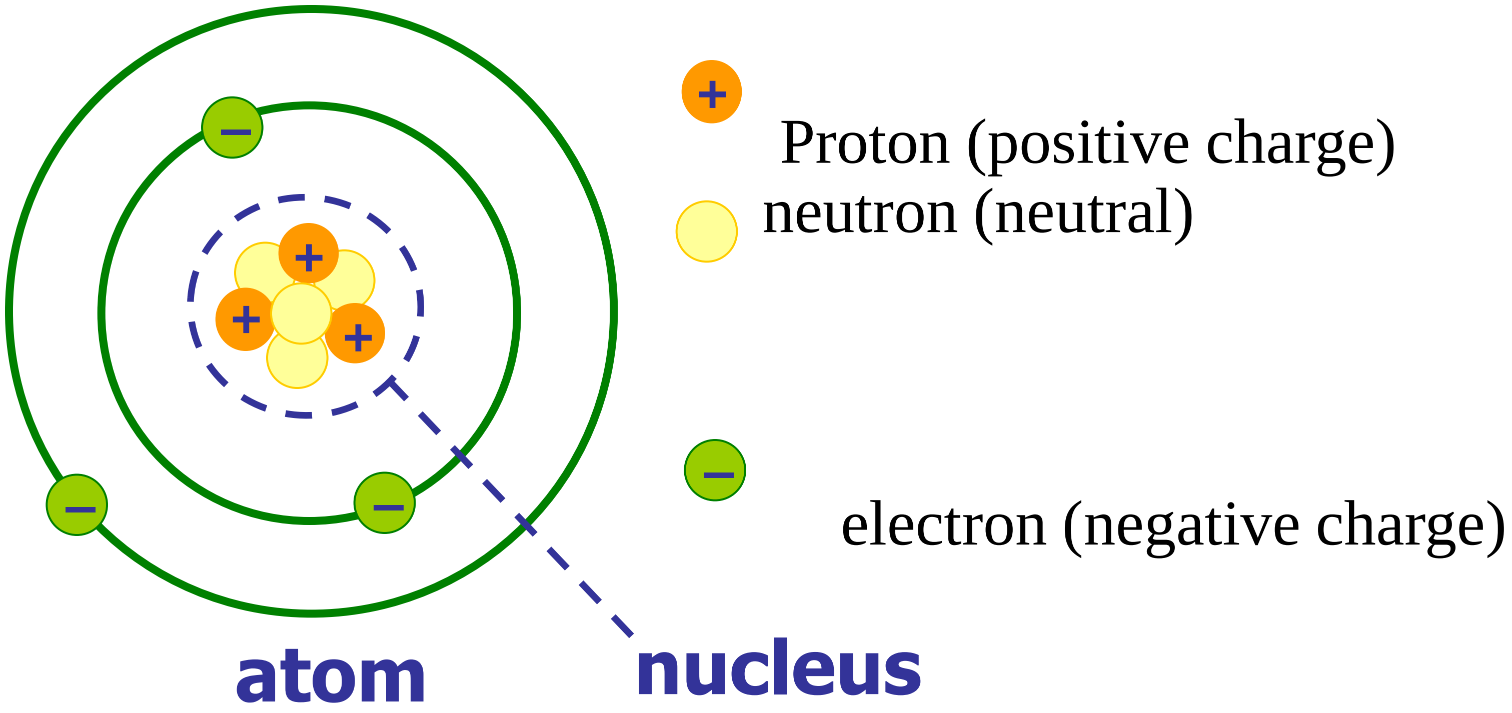




Summary of Subatomic Particles

Proton	Neutron	Electron
In nucleus	In nucleus	Outside nucleus
Tightly Bound	Tightly Bound	Weakly Bound
Positive Charge	No Charge	Negative Charge
Massive	Massive	Not very massive

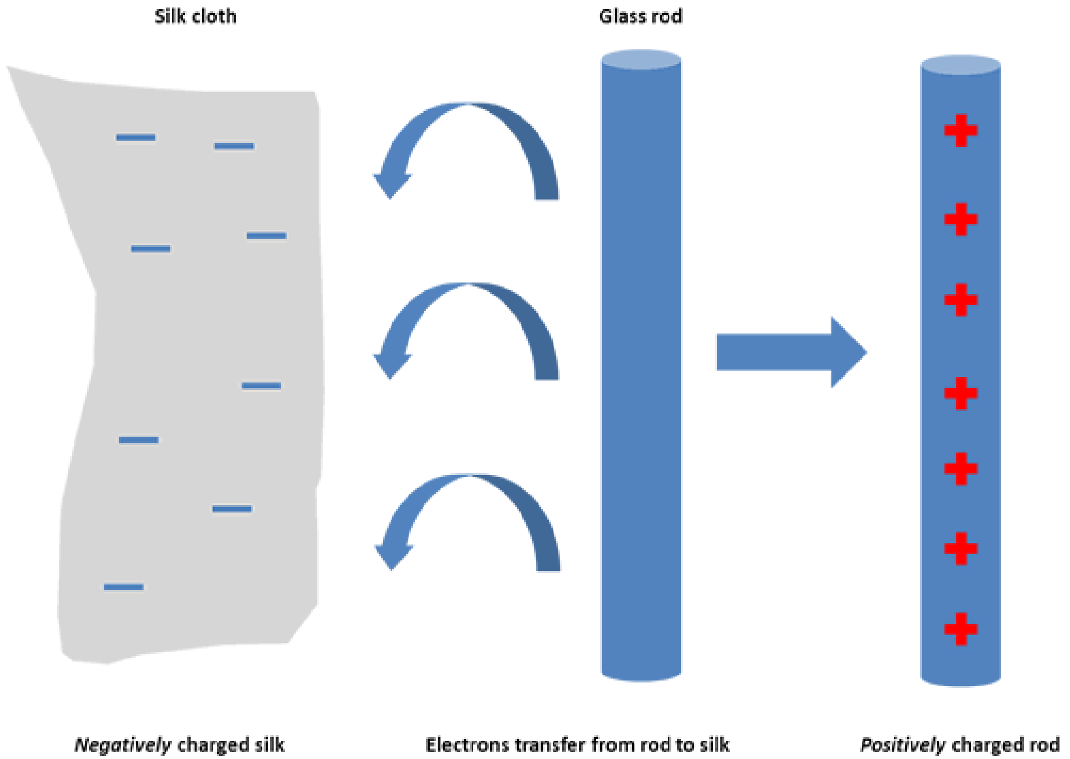
Matter is made up of atoms.



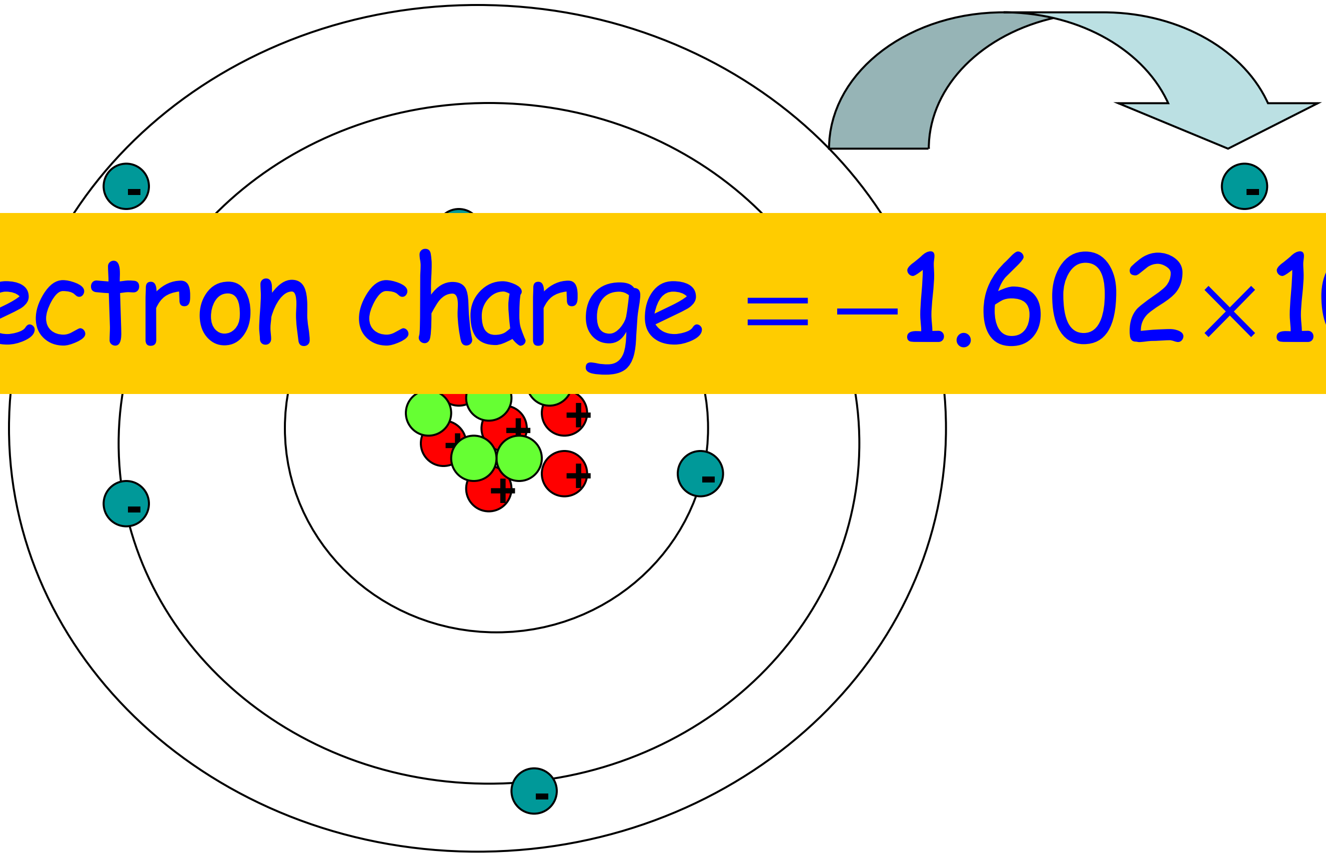
Electrostatic phenomenon can never be explained by the movement of protons and neutrons because they are trapped in the nucleus.

Movement of Electrons

- ***It is the movement of the electrons that is important***

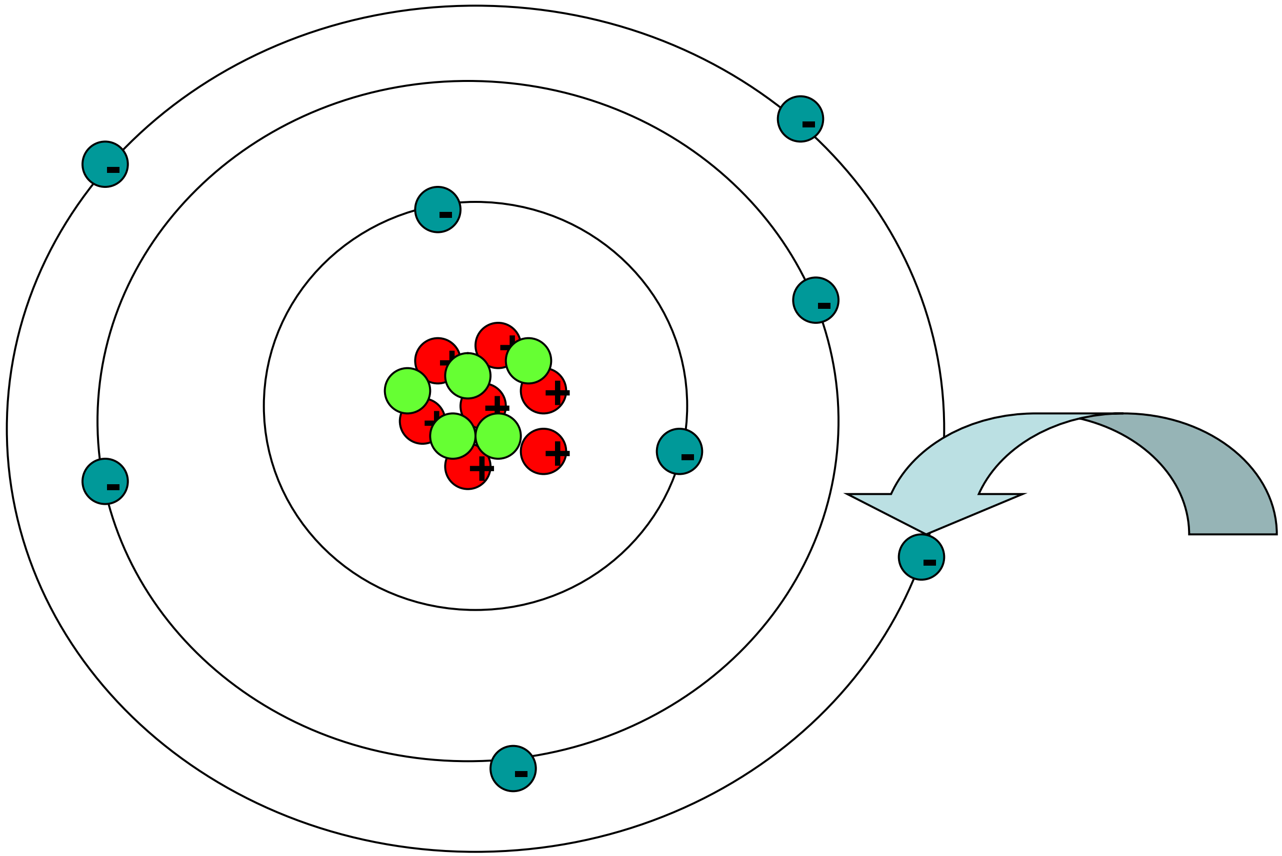


- Neutral atom -> electron = Positive ion

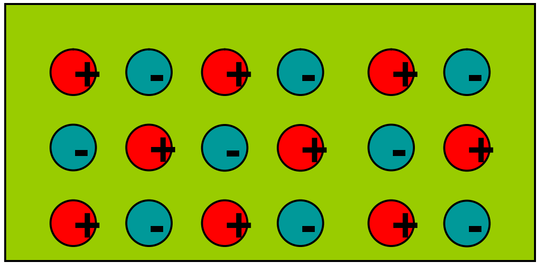


$$1\,\text{electron charge} = -1.602\times10^{-19}C$$

- Neutral atom + electron = negative ion.

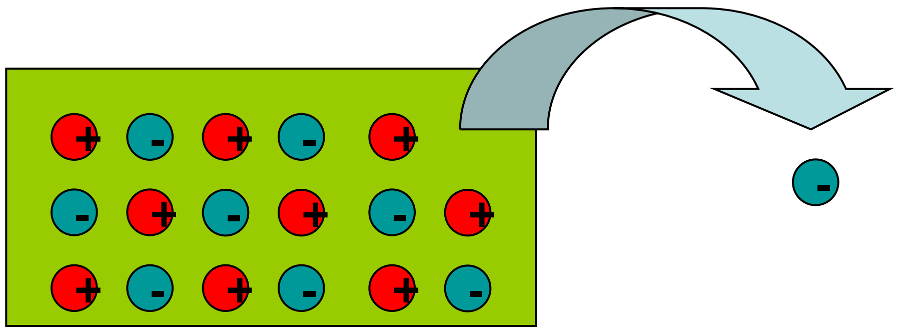


ELECTRICALLY CHARGING OBJECTS



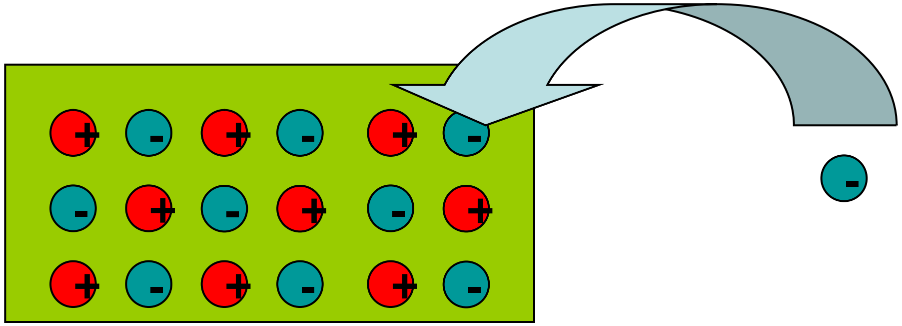
neutral object

ELECTRICALLY CHARGING OBJECTS



positive object

ELECTRICALLY CHARGING OBJECTS

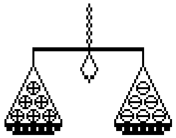


negative object

Summary Neutral vs. Charged Objects

- electrostatic phenomenon can never be explained by the movement of protons and neutrons because they are trapped in the nucleus. Therefore, it is the movement of the electrons that is important in explaining electrostatic phenomena:

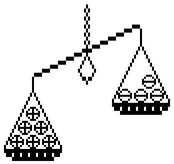
- **Neutral** refers to having equal number of protons and electrons



NEUTRAL
NO CHARGE

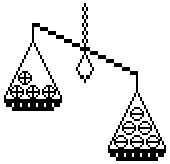
- **Charged** refers to having an imbalance of electrons. Two types:

1) **positively charged** having more protons than electrons.

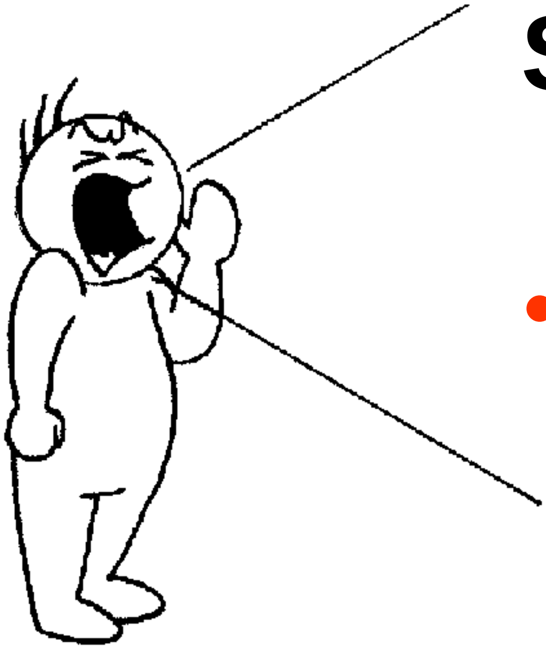


POSITIVE
CHARGE

2) **Negatively charged** having more electrons than protons



NEGATIVE
CHARGE

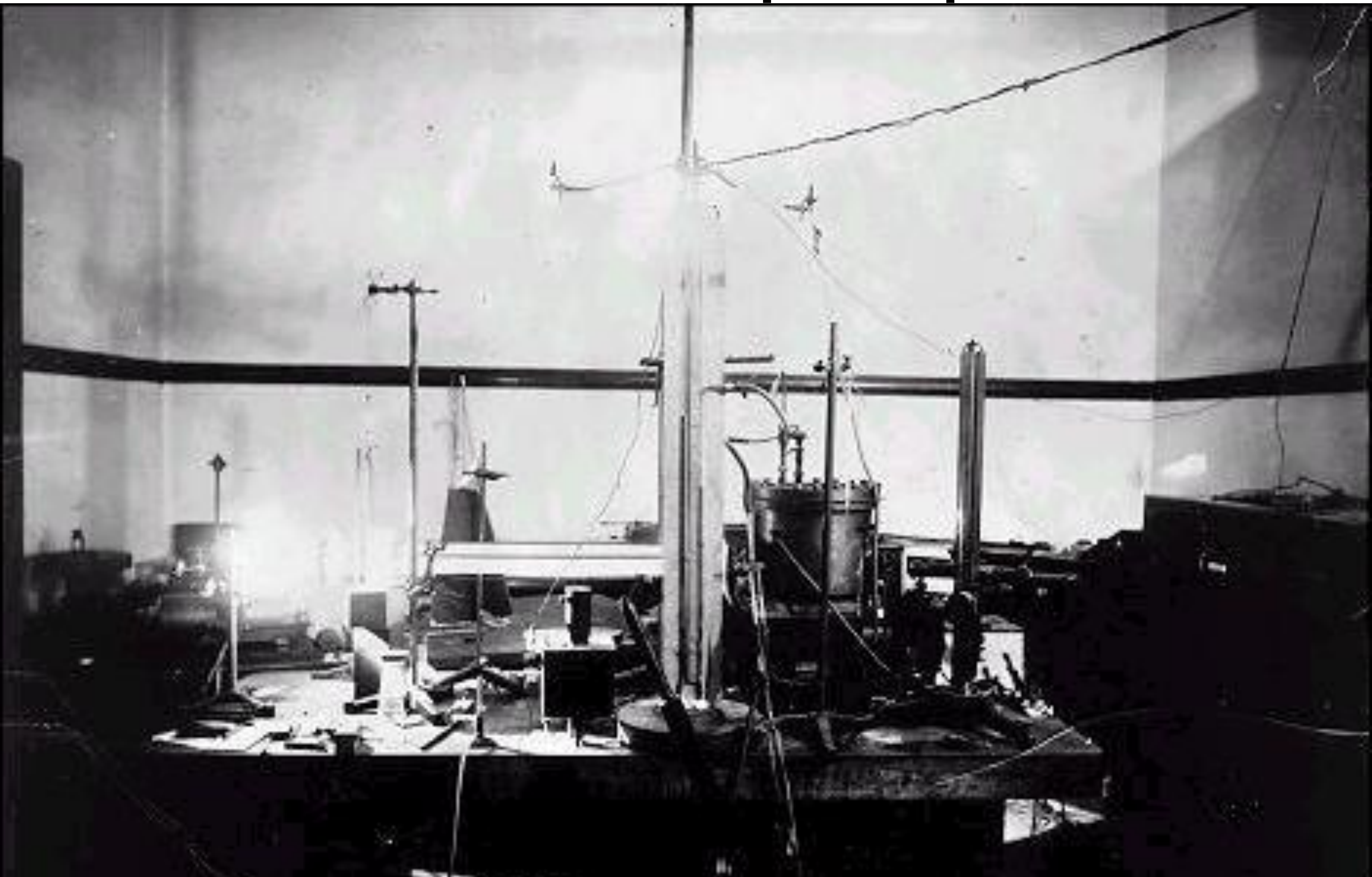


Section 1 Topic 2

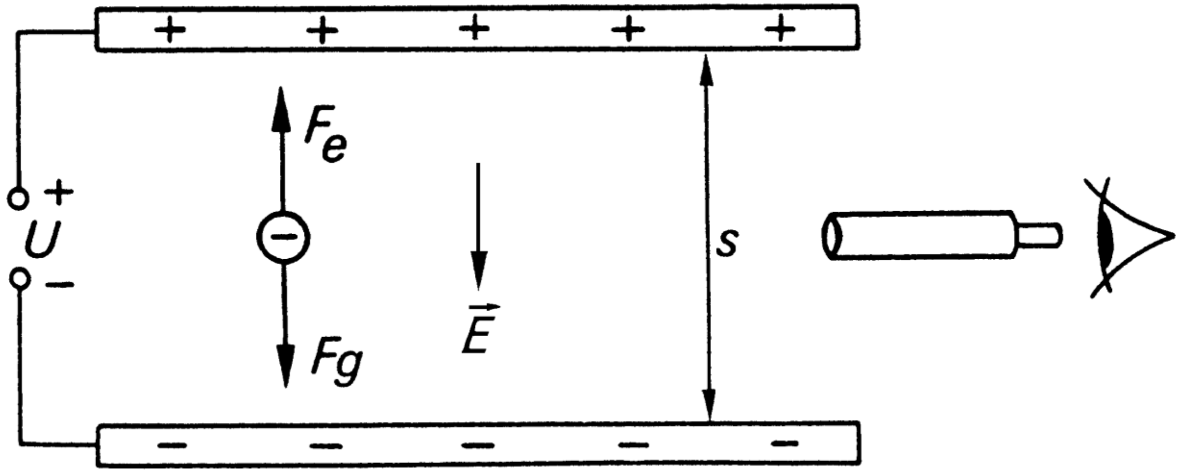
- Calculating Charge

Text: 13.1 – 13.2

Millikan's Oil Drop Experiment



Millikan’s Oil Drop Experiment



- **His earliest major success was the accurate determination of the charge carried by an electron, using the elegant "falling-drop method“**
- **Proved that this quantity was a constant for all electrons (1910), thus demonstrating the atomic structure of electricity**

Fundamental Charge

- Charge has a fundamental unit of a **Coulomb (C).**

Remember:

-*e* = an electron = -1.60×10^{-19} C
+*e* = a proton = $+1.60 \times 10^{-19}$ C

1*e*	1.602×10^{-19}
2*e*	3.204×10^{-19}
3*e*	4.806×10^{-19}
4*e*	6.408×10^{-19}
5*e*	8.010×10^{-19}

Calculating Total Charge

$$Q = Ne$$

- Q is total charge (Coulomb)
- N is number of electrons
- e is the fundamental charge (1.602 x 10 $^{-19}$ Coulomb)

Example 1

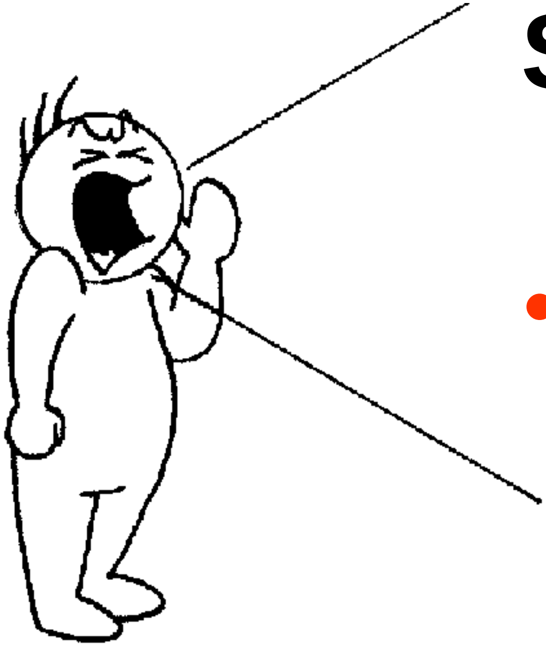
What is the charge on an object that has an excess of 4.0×10^{11} electrons?

Example 2:

A wire passes a charge of 15.0 C. How many electrons pass through the wire?

Example 3

- **How many electrons would you have to remove from a sheet of paper to give it a net charge of 50 μC**



Section 1
Topic 2

- Laws of Electric Charge

Text: 13.1 – 13.2


BEWARE OF
STATIC
ELECTRICITY
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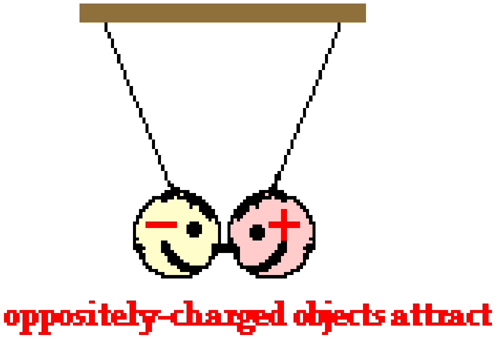
Law of Electric Charges:

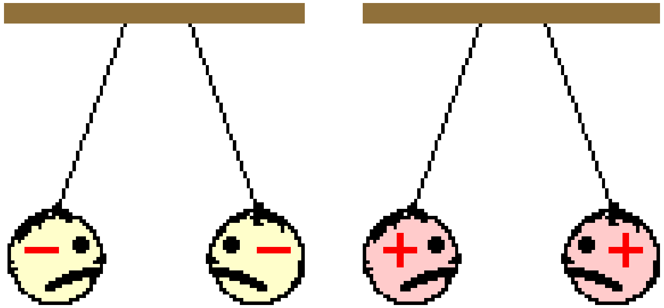
- Observation of electrostatic effects gives the **Law of Electric Charges**

1. Opposite charges attract.



Attractive forces act between opposite charged, pulling them towards each other.

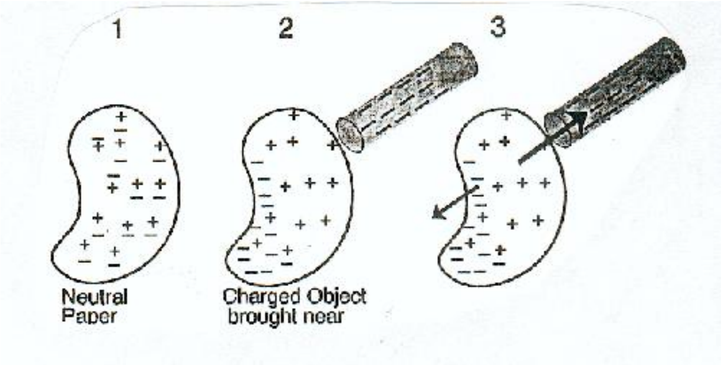
2. Like charges repel.



Repulsive forces act between like-charged objects, pushing them away from each other.

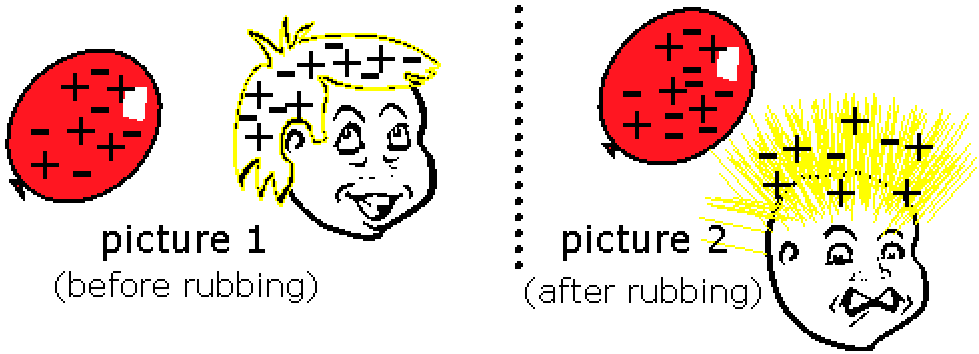
3. Charged objects can attract some neutral objects.

As shown in the picture 1 below, each piece of paper has equivalent numbers of positive and negative charges and is therefore neutral. Generally, the charge will be more or less evenly distributed throughout the paper.



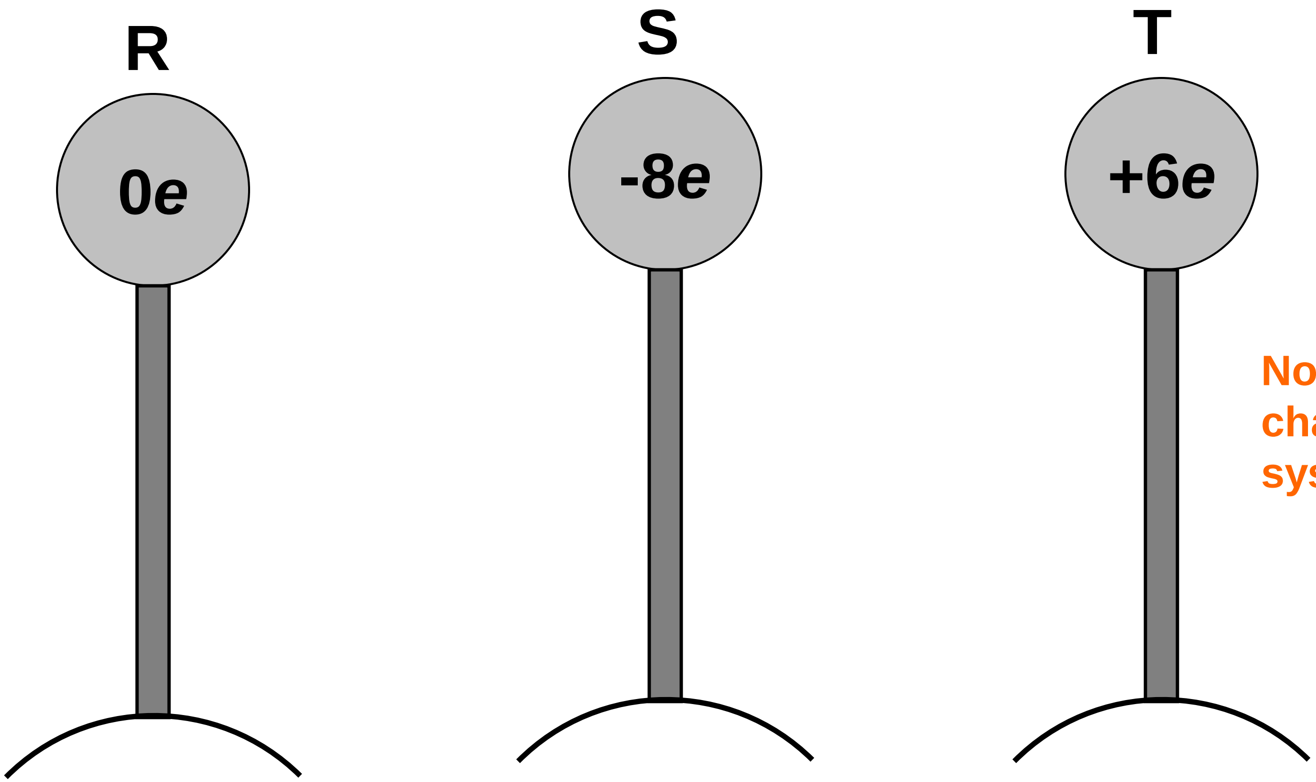
Then in picture 2 a negatively charged rod is brought near. (There are, of course, trillions of + charges on the balloon but usually we just show the excess charge, which in this case is a negative charge.) The negative charges on the rod push away the nearby negative charges on the paper. As shown in picture 3, this leaves the near side of the paper to be positive. So, there will be a force of attraction between the balloon and the near side of the paper, and the paper will be attracted to the balloon.

4. Charge is conservedCharges within a closed system may be transferred from one object to another, but charge is neither created nor destroyed.



The balloon has picked up 3 of the -'s from your hair. So, the balloon has an over-abundance of negative charge. But your hair now has 3 fewer -'s than +'s . Your hair has an over-abundance of positive charge.

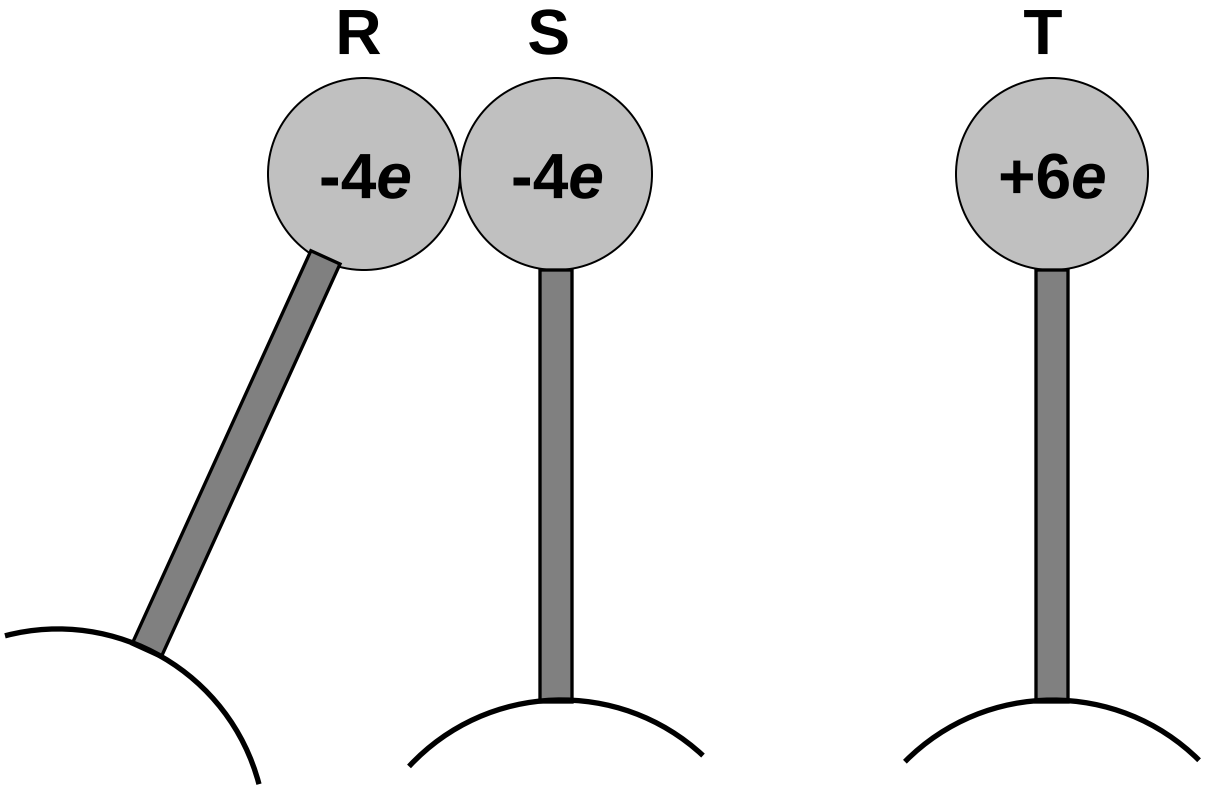
The diagram below shows the initial charges and positions of three metal spheres, R, S, and T, on insulating stands.

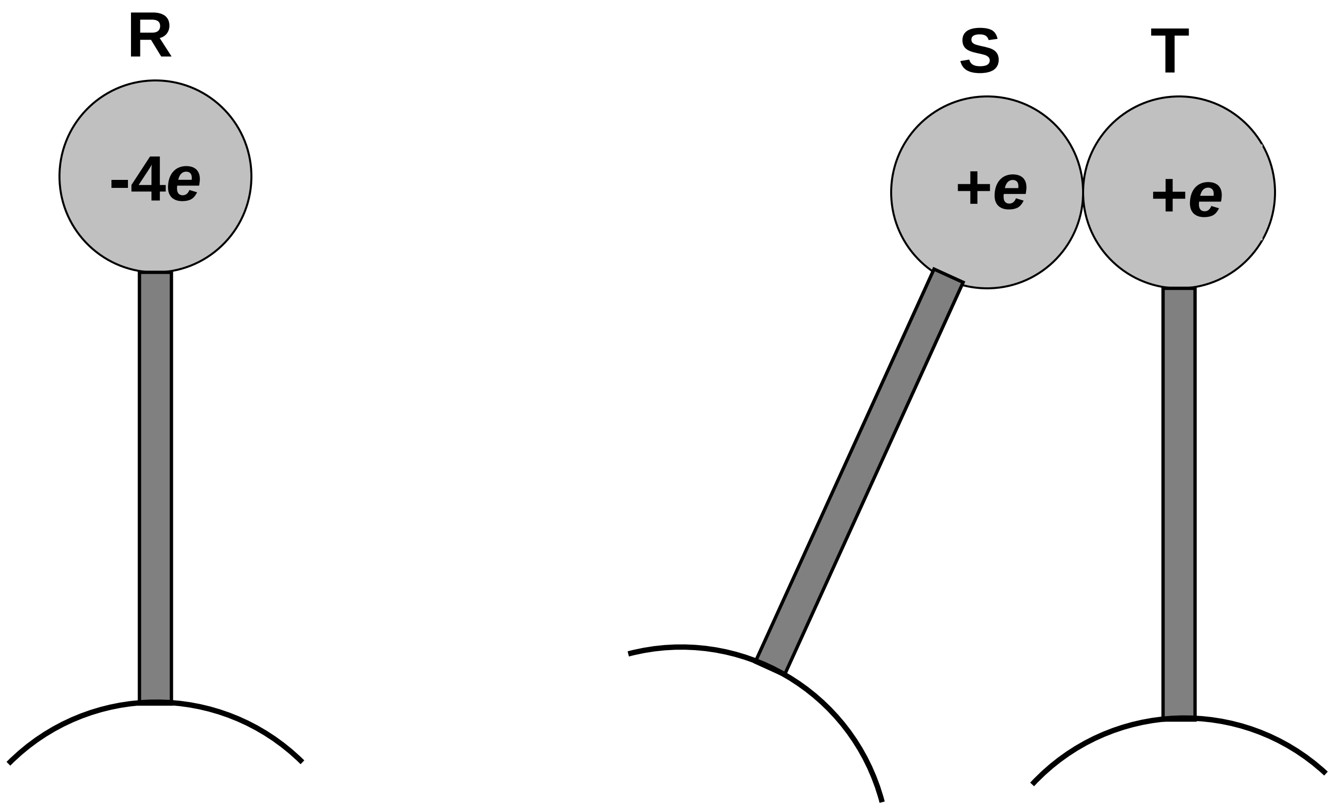


Note that the net charge of the system is -2*e*.

Sphere R is brought into contact with sphere S and then removed. Then sphere S is brought into contact with sphere T and removed. What is the charge on sphere T after this procedure is completed?

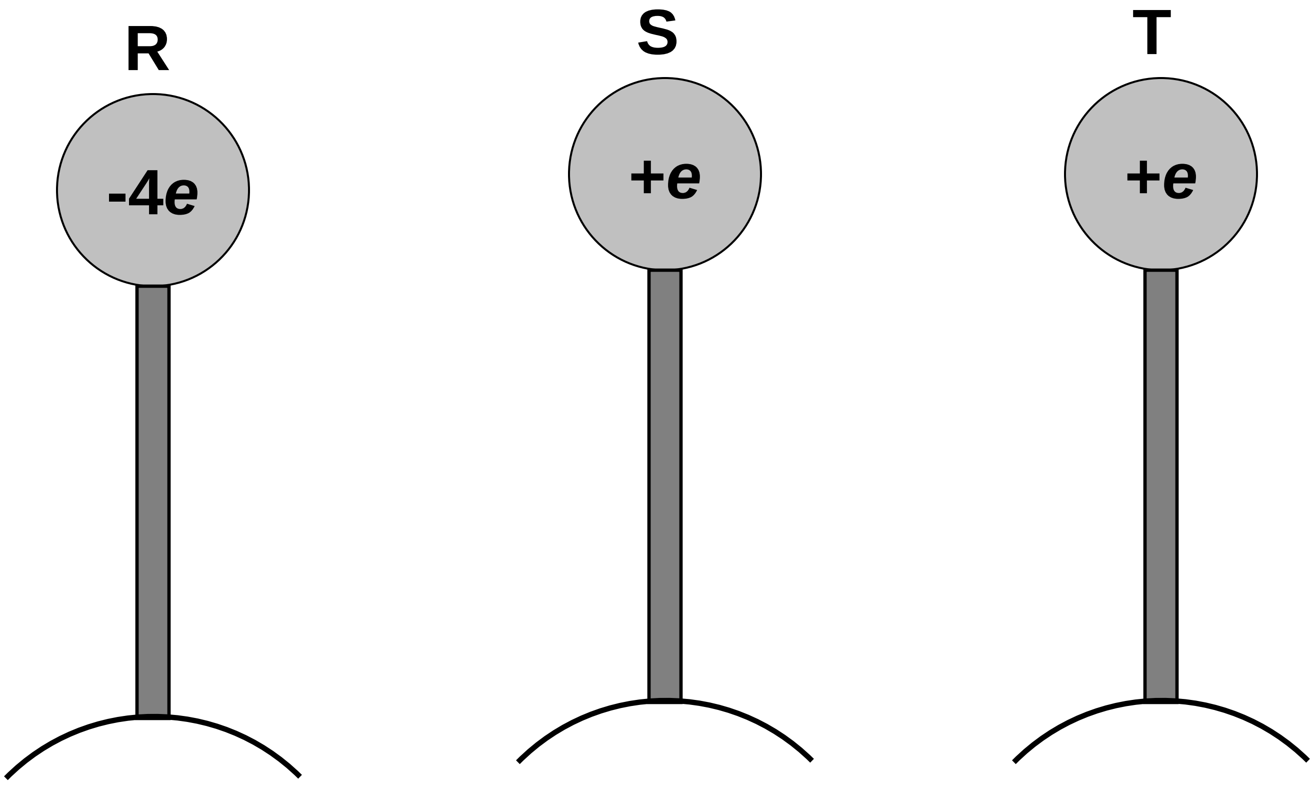
When the spheres come in contact the charge will be distributed evenly between both spheres.





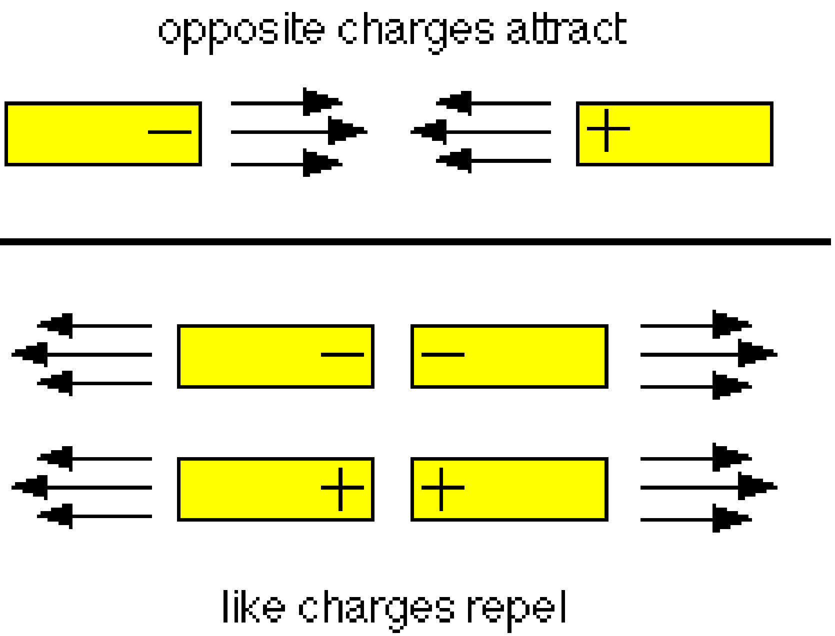
$$\frac{-4e + 6e}{2} = \frac{+2e}{2} = +e$$

Note that the charge of the system is conserved- the initial charge is the same as the final charge.

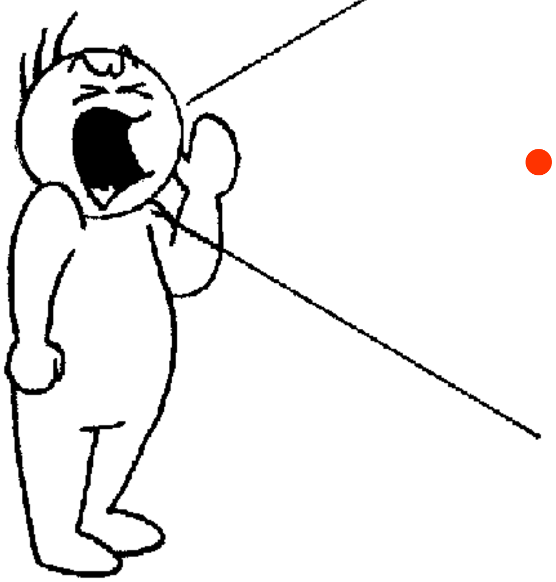


-4*e* + *e* + *e* = -2*e*

SUMMARY OF ELCTRIC CHARGE



The law of conservation of charge states that during the process of charging, the total number of charges exchanged between objects remains the same



Section 1
Topic 3

- Insulator and Conductors

Text: 13.3

Insulators vs. Conductors:

- The movement of charge is limited by the substance the charge is trying to pass through. There are generally 2 types of substances:

1) Insulators hold on to their outer electrons tightly. It prevents the flow of electrons

When charge is placed on an insulator, it stays in one region and does not distribute.

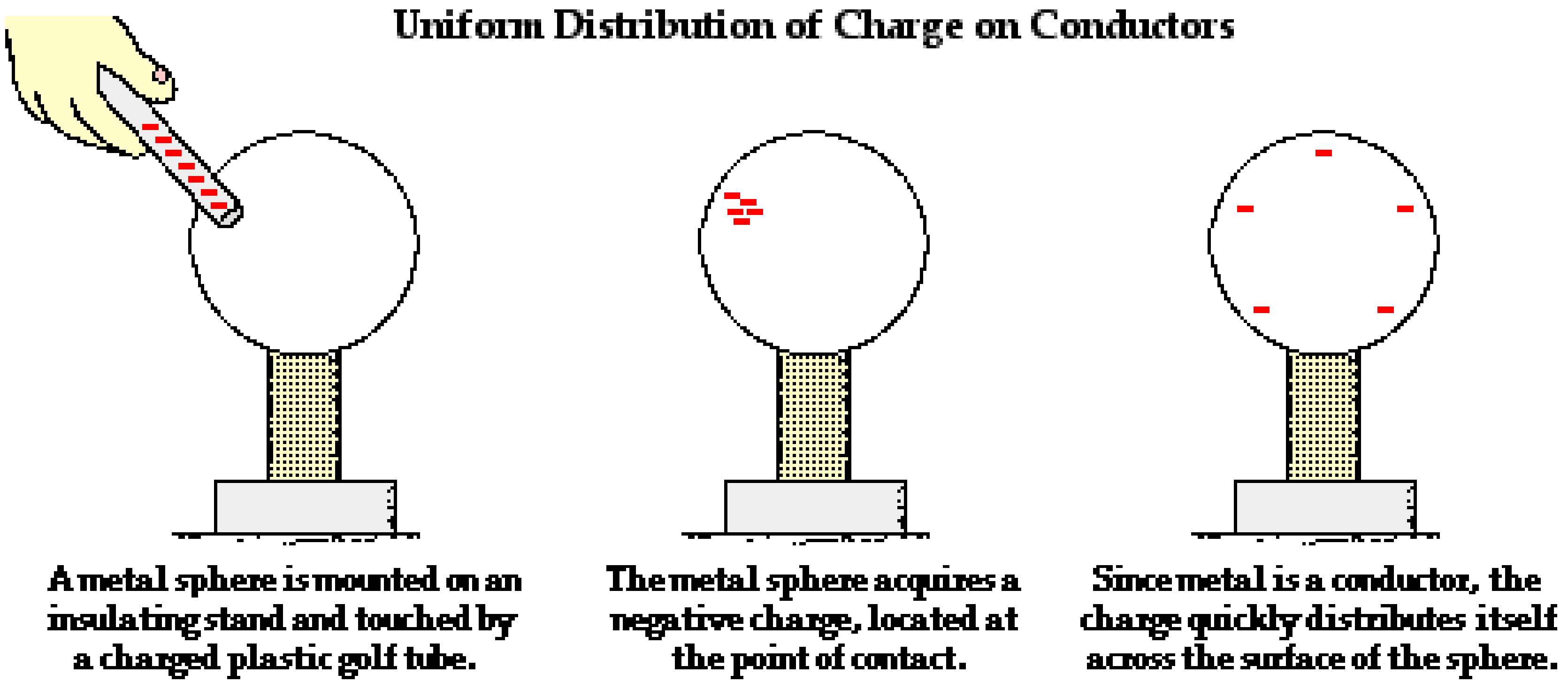
Wood, plastic, glass, air, and cloth are good insulators.

Charged Insulator

2) Conductors: hold on to their outer electrons rather loosely. It provides a good path for energy. It allows electrons to flow freely

When charge is placed on a conductor, it redistributes to the outer surface.

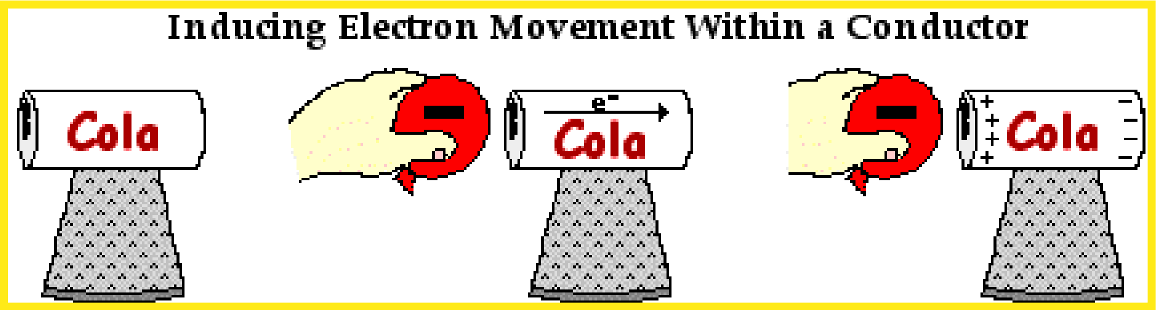
Metals (copper, gold, and aluminum) are good conductors.



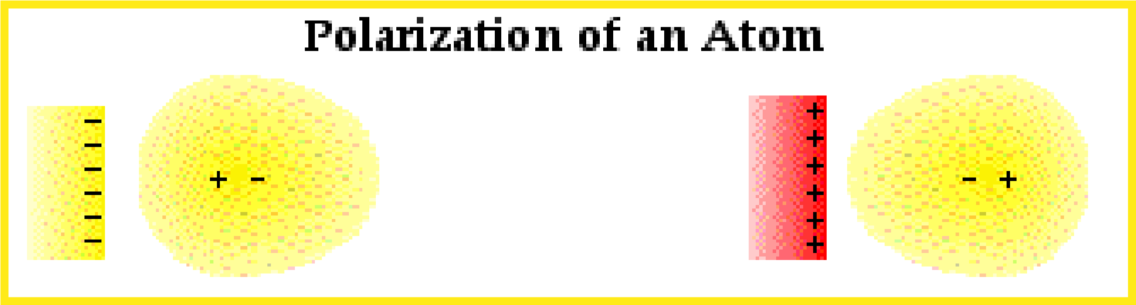
Polarization

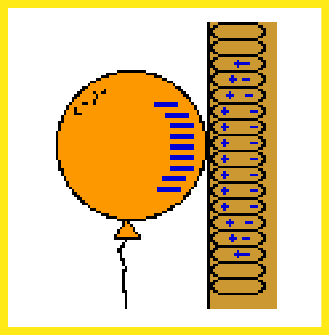
Polarization is the separation of charge

In a conductor, “free” electrons can move around the surface of the material, leaving one side positive and the other side negative.



In an insulator, the electrons “realign” themselves within the atom (or molecule), leaving one side of the atom positive and the other side of the atom negative.

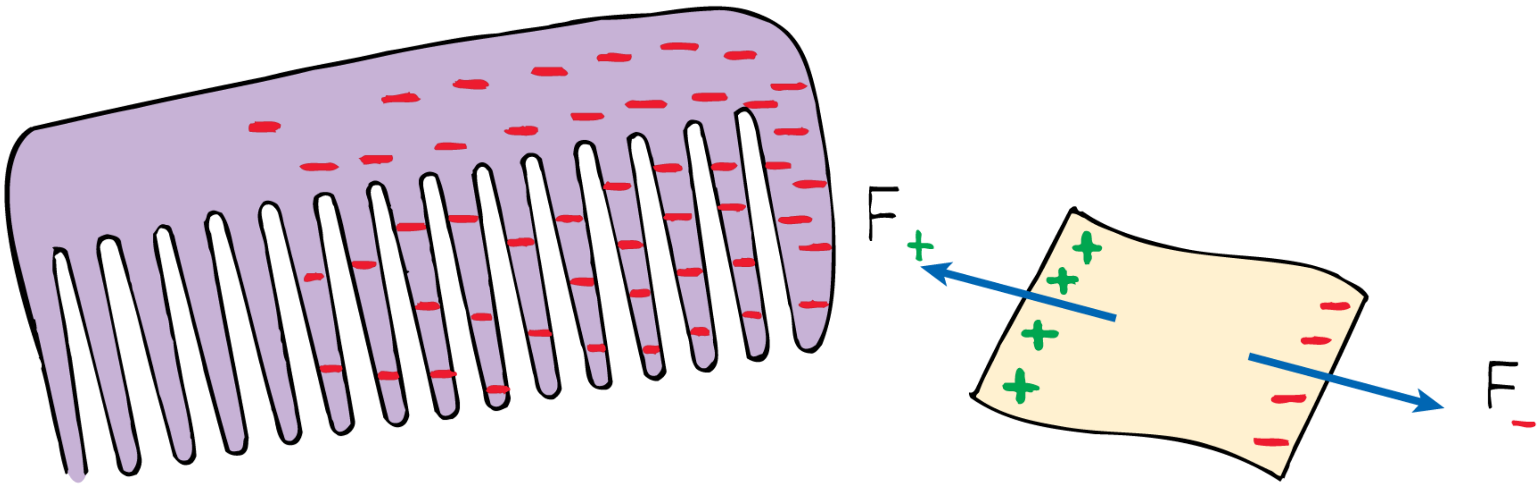




Polarization is not necessarily a charge imbalance!

Charge Polarization

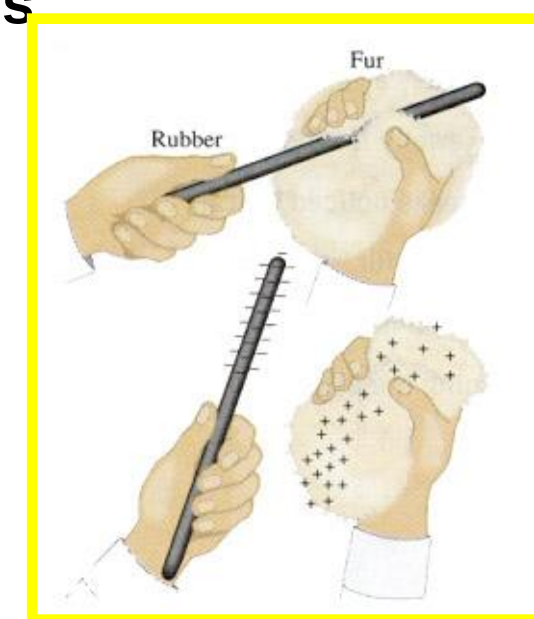
A charged comb attracts an uncharged piece of paper because the force of attraction for the closer charge is greater than the force of repulsion for the farther charge.

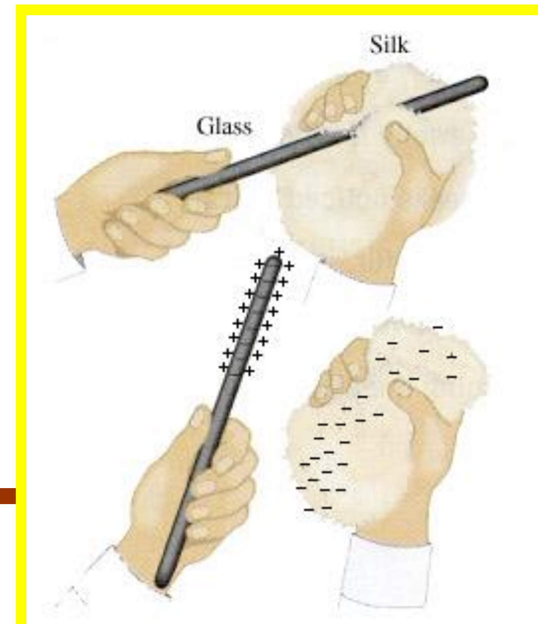


Every material has atoms with their own characteristic attraction for electrons. The STATIC ELECTRICITY SERIES (Electrostatic series) list several materials in order of increasing attraction for electrons

Table 13.1 p 530 contains the following listing:

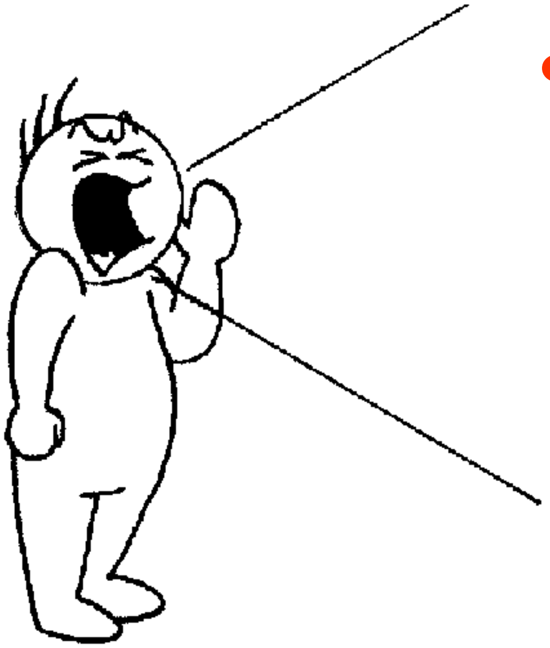
cat's fur	poor attraction for electrons
acetate	
glass	
wool	
silk	
wax	
Ebonite	
Copper	
rubber	good attraction for electrons

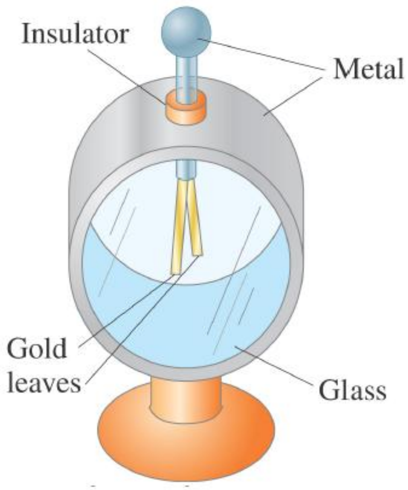




Section 1 Topic 4

- Detecting electric charge





Electroscopes- instruments used to detect charge

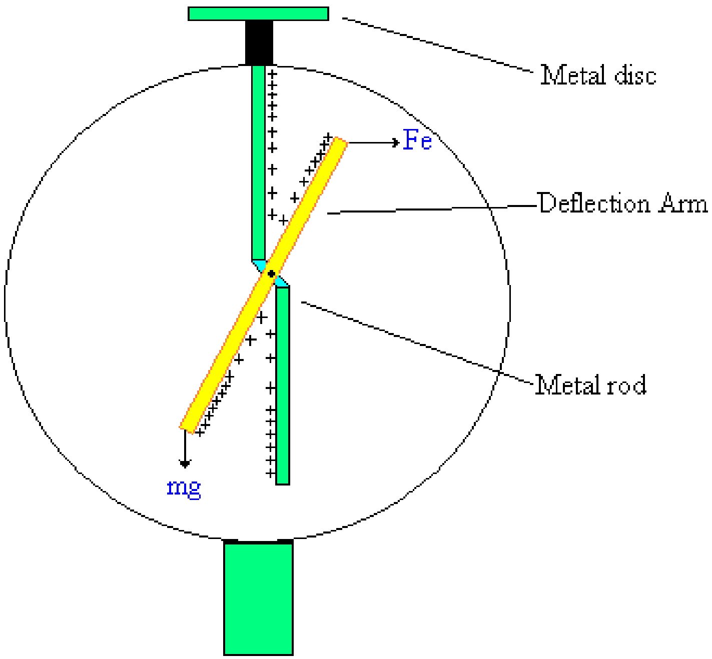


Figure 1: Electroscope

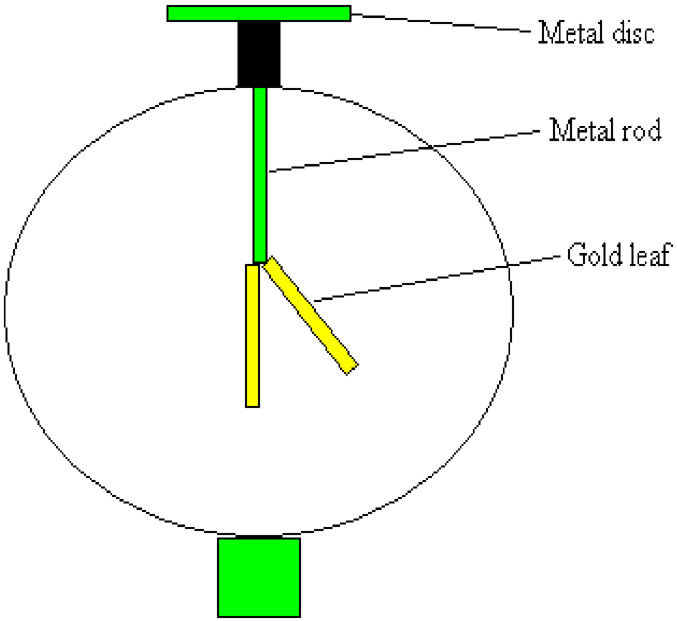
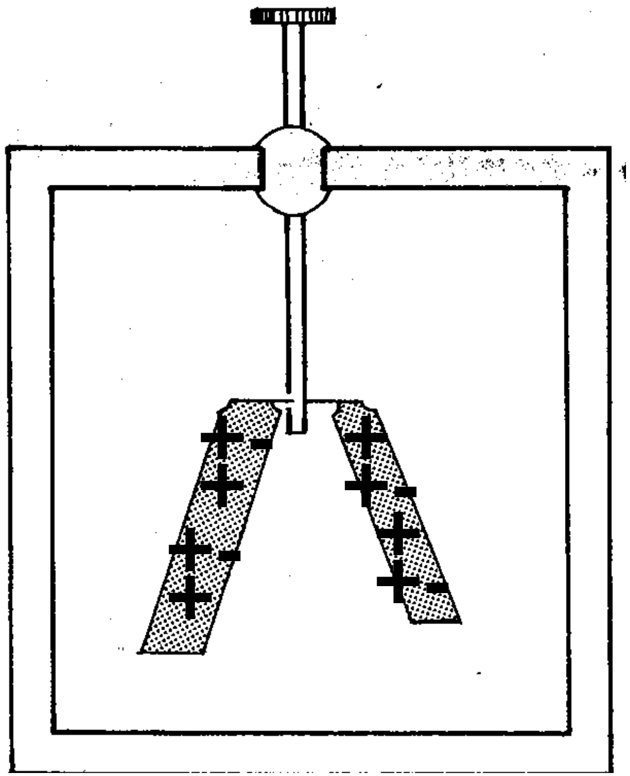


Figure 2: The classical electroscope

The yellow arms or leaves on both instruments will move to show the charge.

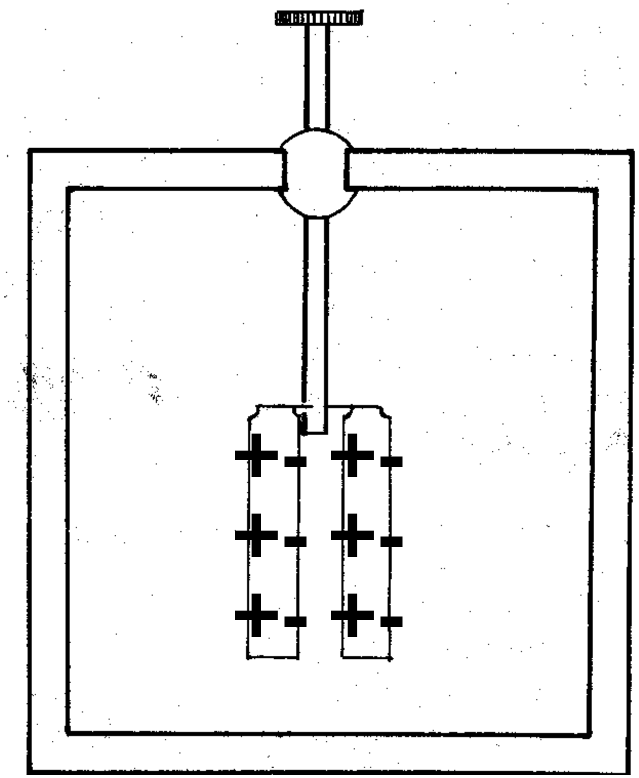
Charged Electroscope

When charged, the leaves repel each other and diverge. A larger divergence indicates a larger net charge.



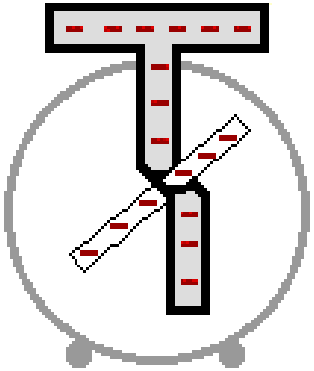
Uncharged Electroscope

When the electroscope is neutral, the leaves hang vertically.



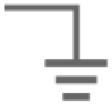
Grounding

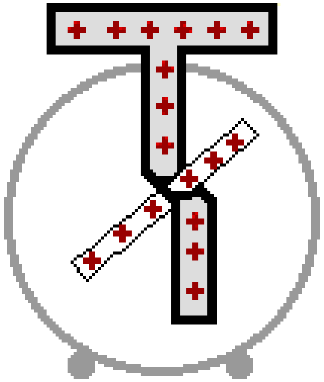
- **Grounding** is the process of *removing* the excess charge on an object by means of the transfer of electrons between it and another object of substantial size. When a charged object is grounded, the excess charge is balanced by the transfer of electrons between the charged object and a ground. A **ground** is simply an object which serves as a seemingly infinite reservoir of electrons; the ground is capable of transferring electrons to or receiving electrons from an object



Grounding a negatively-charged electroscope involves the transfer of electrons from the electroscope to "the ground."

Symbol for ground is

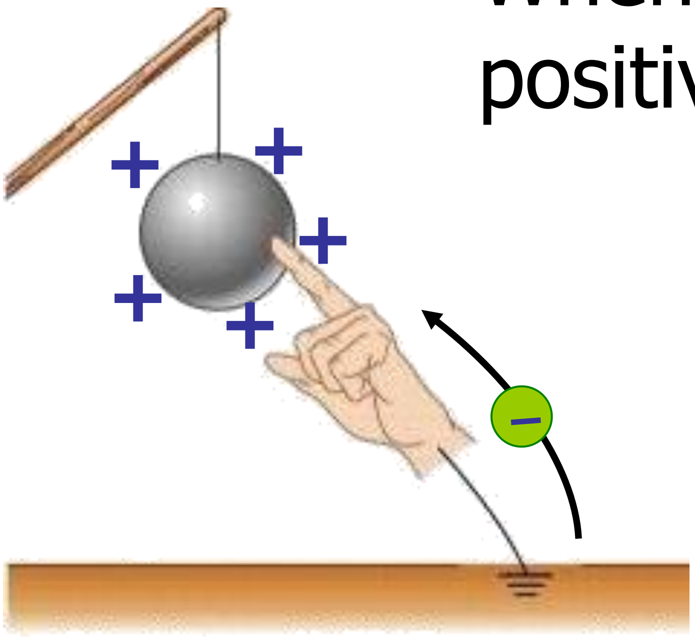




Grounding a positively-charged electroscope involves the transfer of electrons from "the ground" to the electroscope.

Grounding

b How does grounding occur?

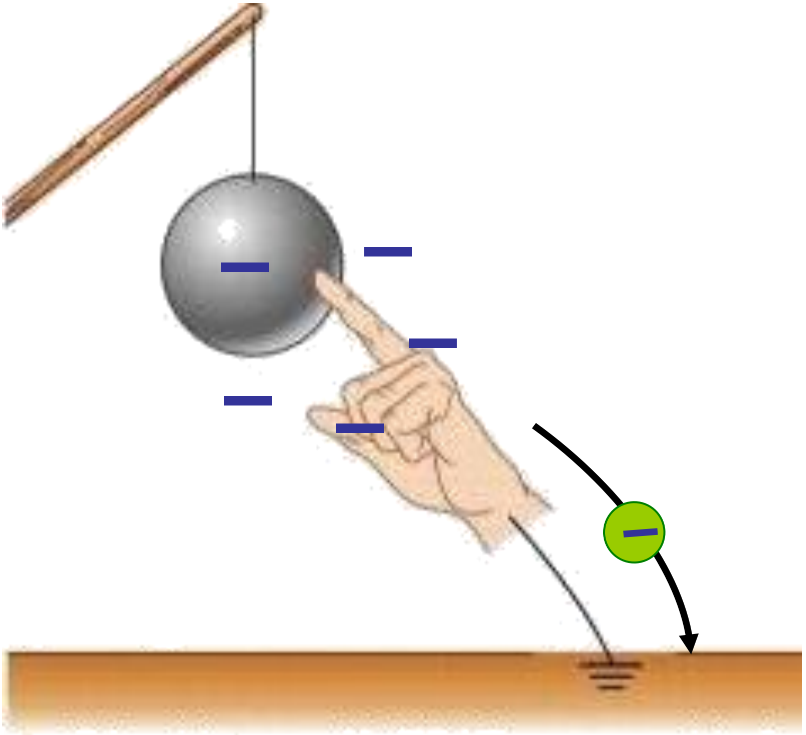


When we touch a metal ball of positive charge...

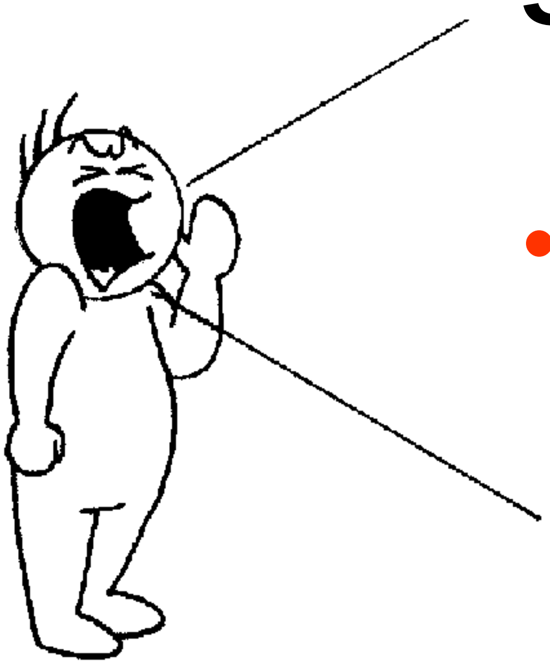
electrons flow from the earth to the metal ball to neutralize the metal ball.

Metal ball becomes neutral.

Similarly, if the metal ball is of negative charge...



•extra electrons flow from the metal ball to the earth and the ball becomes neutral.



Section 1
Topic 3

- The Creation and Transfer of charge

Text: 13.3

Charging Objects

- 3 Methods of charging objects

1) **Friction**
2) **Conduction**
3) **induction**

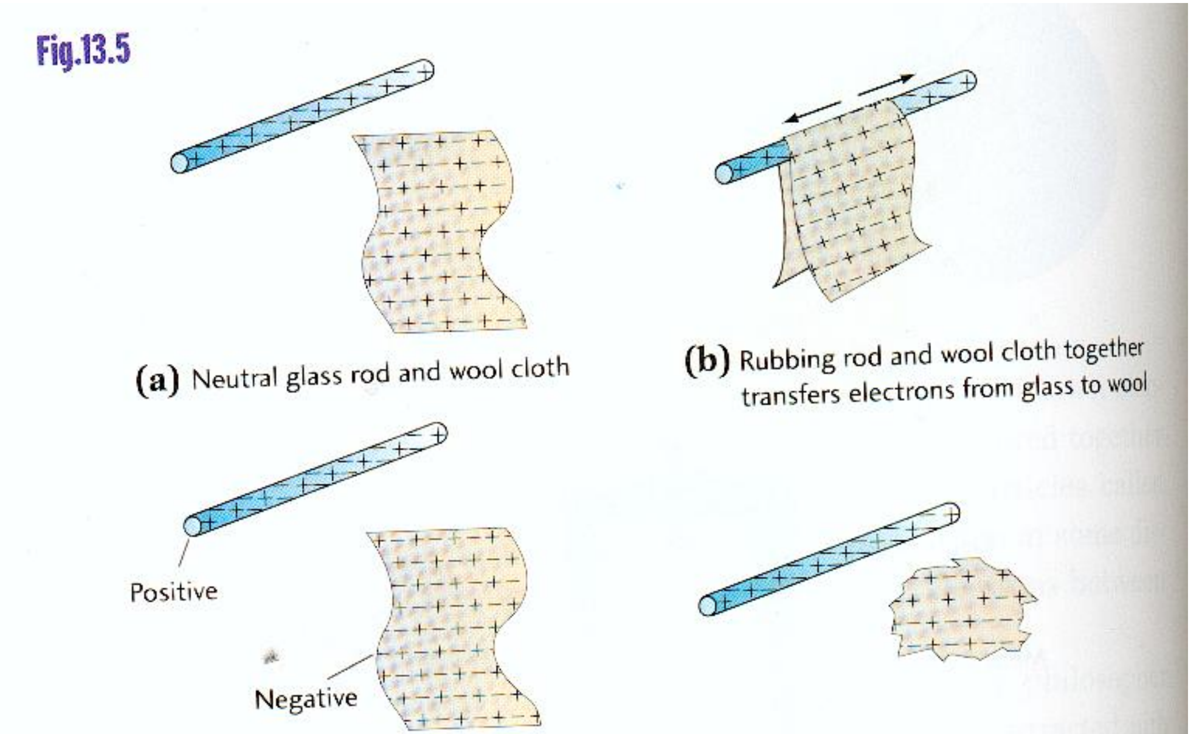
Remember:

Objects will lose or gain electrons to gain a net positive or negative charge, respectively.

- NOTE: protons are bound in the nucleus and thus NEVER NEVER move for electrostatic effects!

1) CHARGING BY FRICTION

- When insulators are rubbed together, one gives up electrons and becomes positively charged, while the other gains electrons and becomes negatively charged.



(a) Neutral glass rod and wool cloth

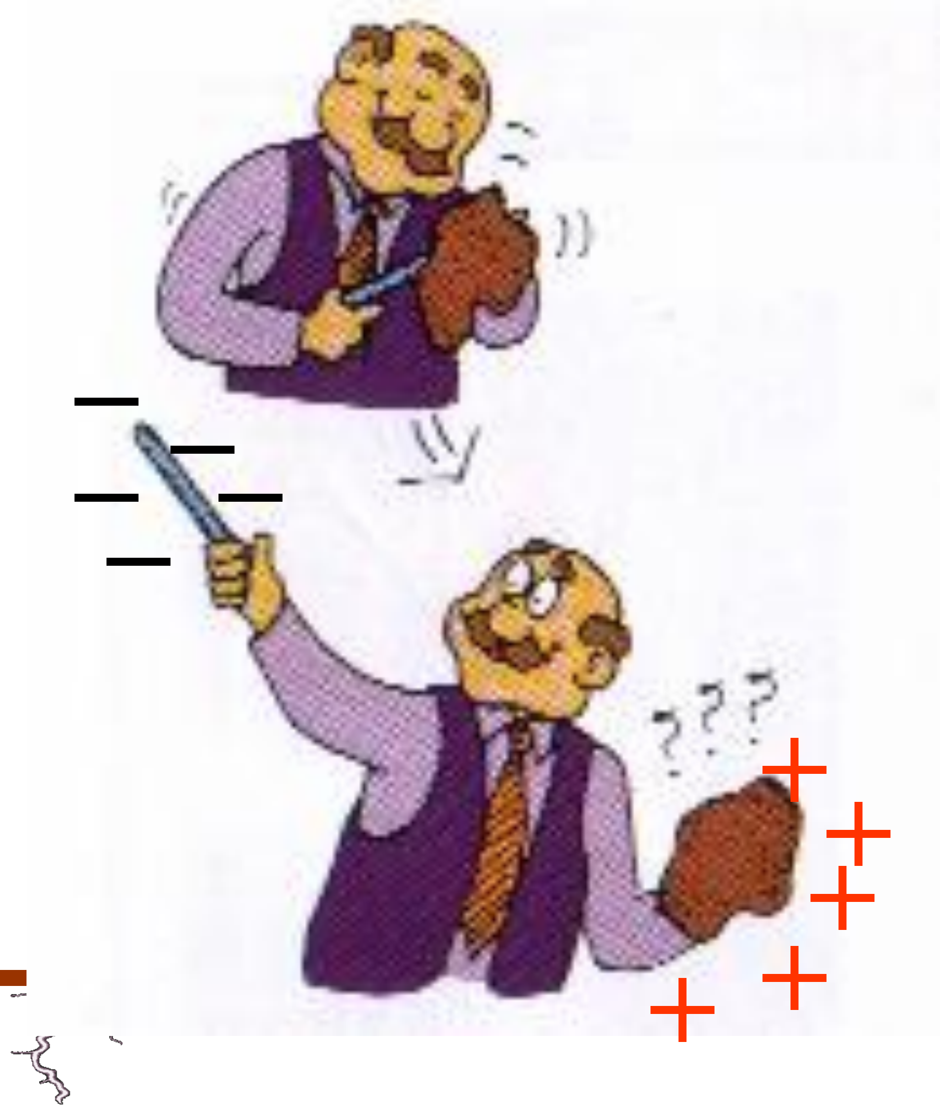
(b) Rubbing rod and wool cloth together transfers electrons from glass to wool

(c) Separate charged glass and cloth, cloth is more negative

(d) Charged rod attracts neutral paper

When objects rub together, electrons transfer from one to another as per the Electrostatic Series (See Table 13.1, pg. 530).

Stripping of electrons from one neutral object to another to make two <u>oppositely</u> charged objects



Wool loses electrons to hard rubber rod.

Wool is now positively charged and rod is negatively charged

Conductors **CANNOT** be easily charged by friction as the extra electrons gained can easily escape.

Electrostatic Series

Electrostatic series is a list of materials that are more likely to attract a negative charge when friction is applied to them.

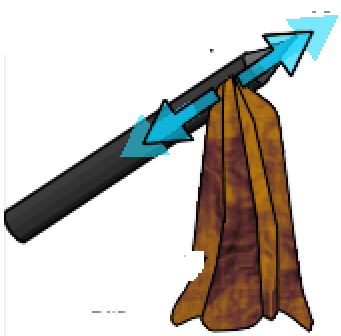
Relative charge		Tendency to attract electrons
Positive	Cat's fur	Weak attraction for electrons
↓	Acetate	↓
	Glass	
	Wool	
	Lead	
	Silk	
	Wax	
	Ebonite	
	Copper	
	Rubber	
	Amber	
	Sulphur	
negative	Gold	Strong attraction for electrons

Using the electrostatic series: look up the two materials being rubbed together. The one higher on the series will become postive, the other will become positive

Example 1:

What are the charges of wool and ebonite when they are rubbed together?

Referring to the electrostatic series, ebonite has the stronger attraction for electrons, so it would receive electrons from the wool. Therefore, the wool would become positive and the ebonite would be negative.



Example 2:

Using the electrostatic series: look up the two materials being rubbed together. The one higher on the series will become negative, the other will become positive

Try these:

a) rubber rubbed with silk

rubber = negative

silk = positive

b) wool rubbed on glass

wool = negative

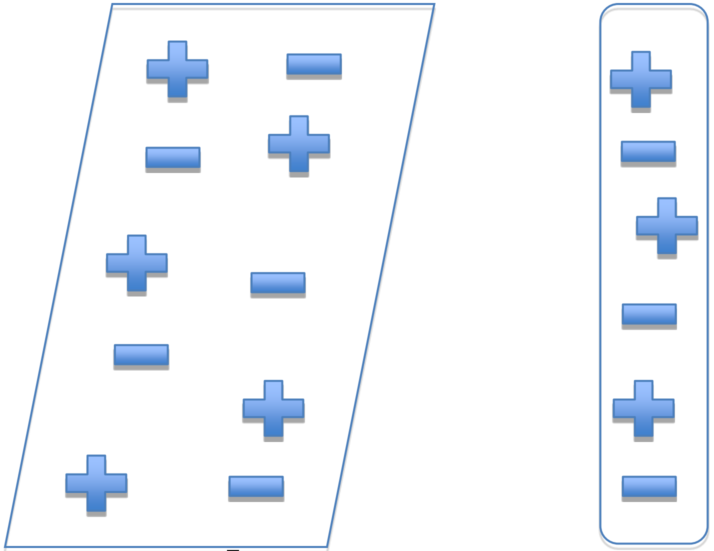
glass = positive

Example 3:

e.g. wool rubbed with glass

Before rubbing | **After rubbing**

wool | **Glass**



neutral | **neutral**

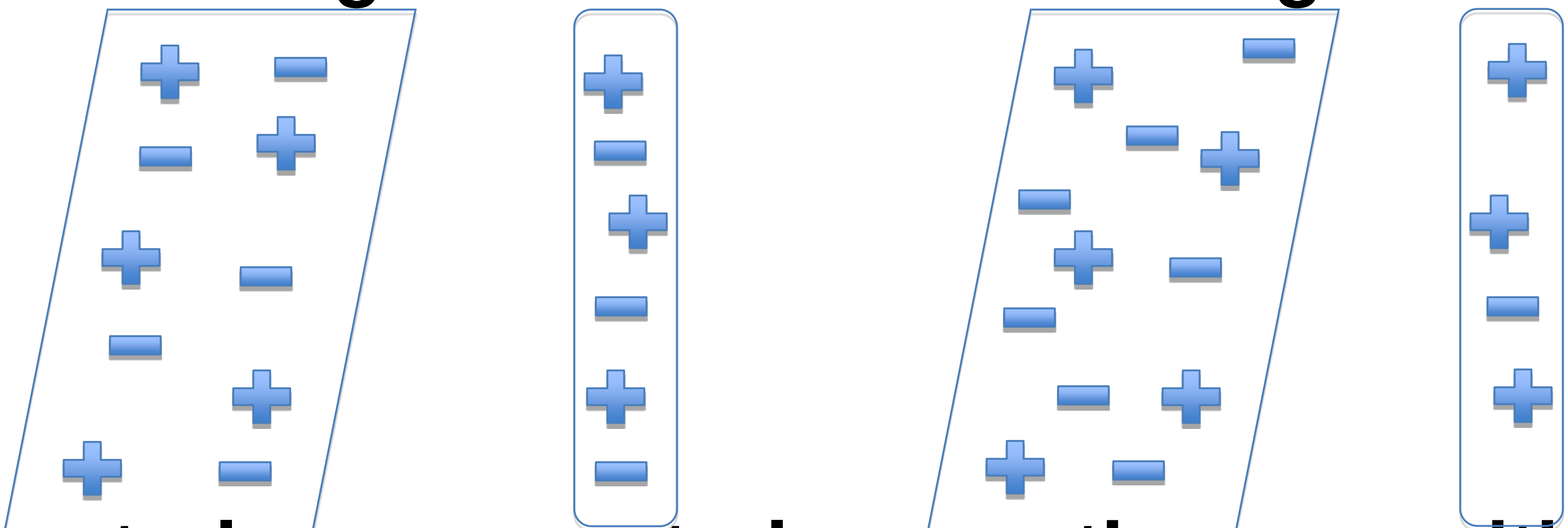
5+ | **3+**

5- | **3-**

e.g. **wool rubbed with glass**

Before rubbing | **After rubbing**

wool	glass	wool	glass



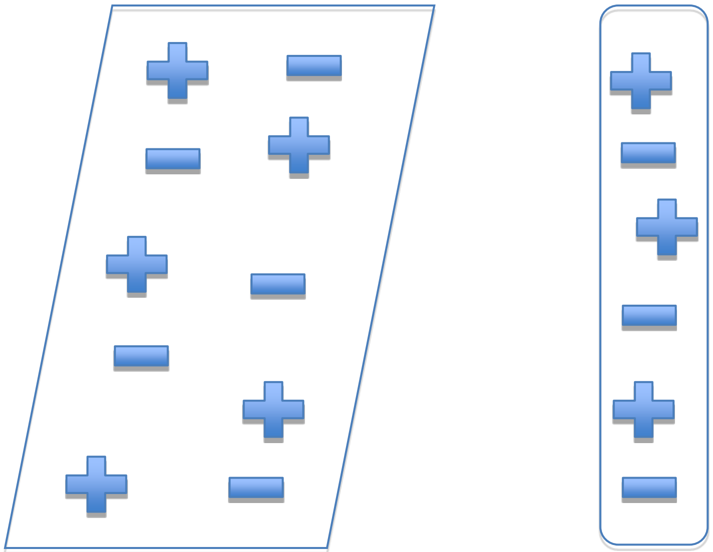
wool	glass	wool	glass
neutral	neutral	negative	positive
5+	3+	5+	3+
5-	3-	7-	1-

Example 4:

try this one: ebonite rubbed with fur

<u>Before rubbing</u> **<u>After rubbing</u>**

fur **ebonite**



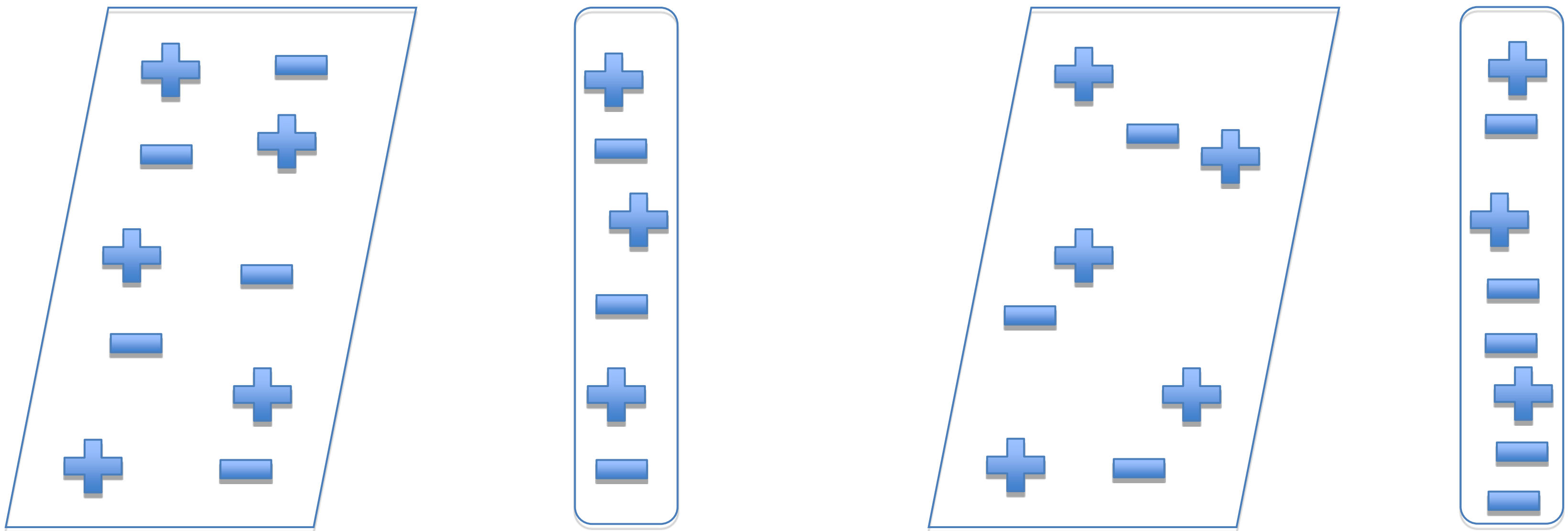
neutral **neutral**

5+ **3+**

5- **3-**

Before rubbing | **After rubbing**

fur	ebonite	fur	ebonite

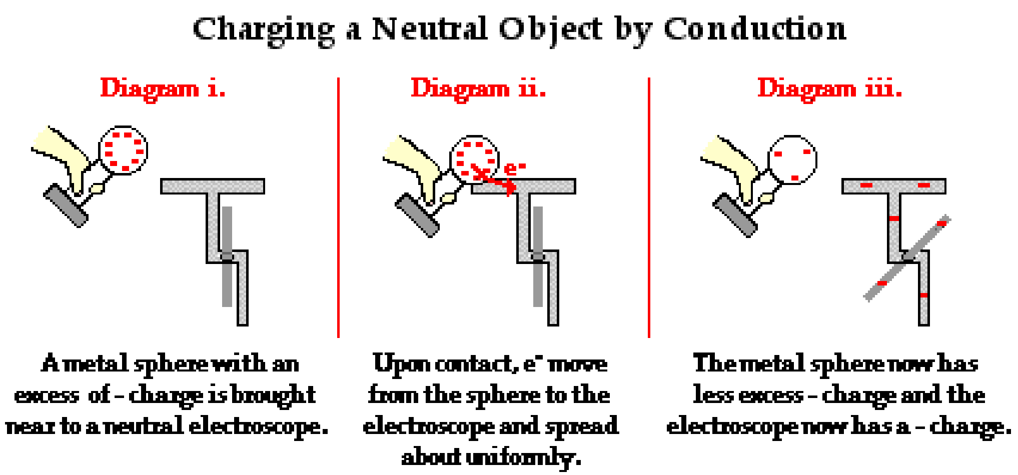


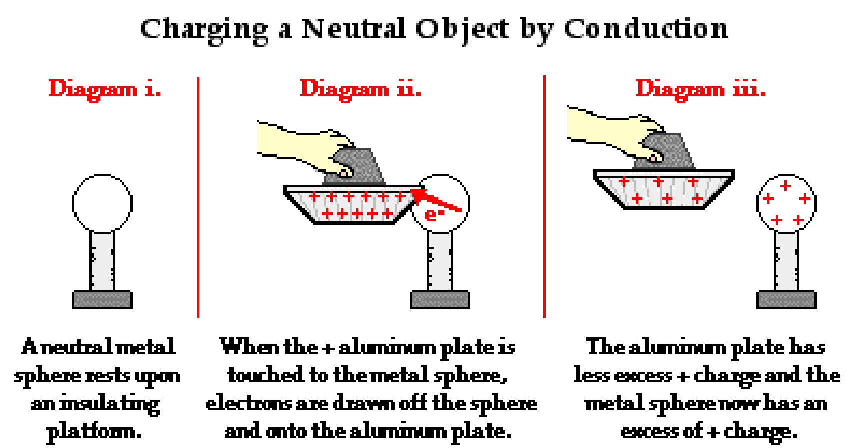
neutral	**neutral**	**positive**	**negative**
5+	**3+**	**5+**	**3+**
5-	**3-**	**3-**	**5-**

2) Charging by Conduction:

Charging by Contact

- When a charged object touches a neutral object (or with a different amount of charge), electrons transfer from the more negatively charged object in order to equally share the amount of charge.
- Refer to Fig 13.7, pg. 531

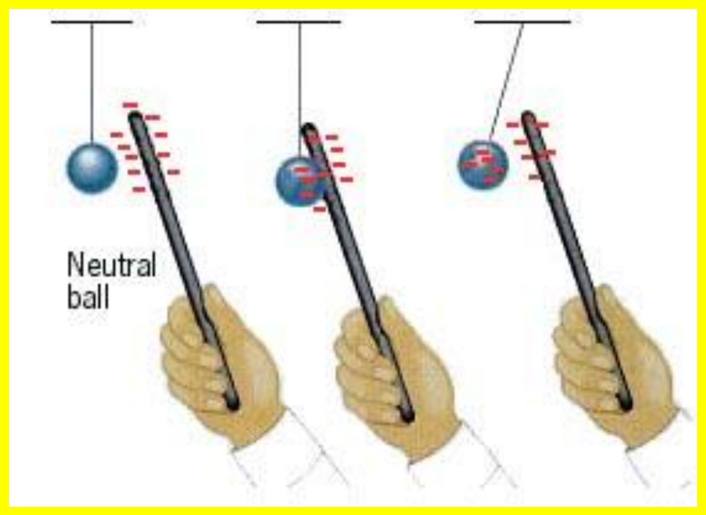




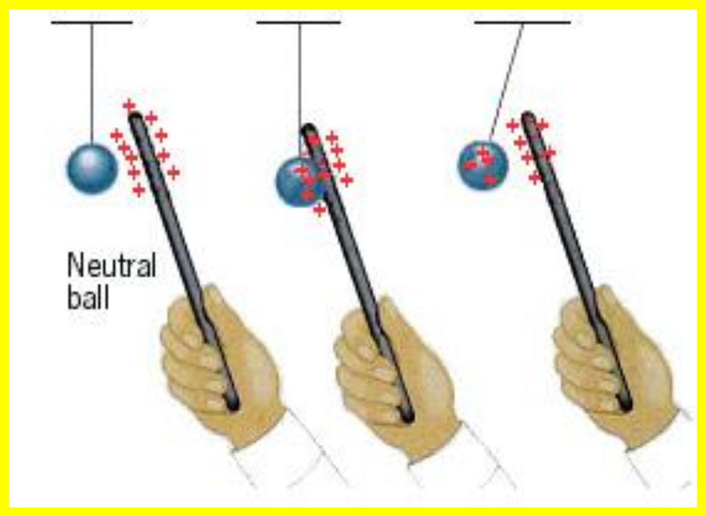
Charging by Conduction

When a charged conductor makes contact with a neutral conductor there is a transfer of charge.

CHARGING NEGATIVELY



CHARGING POSITIVELY



Electrons are transferred from the rod to the ball, leaving them both negatively charged.

Electrons are transferred from the ball to the rod, leaving them both positively charged.

Remember, only electrons are free to move in solids.

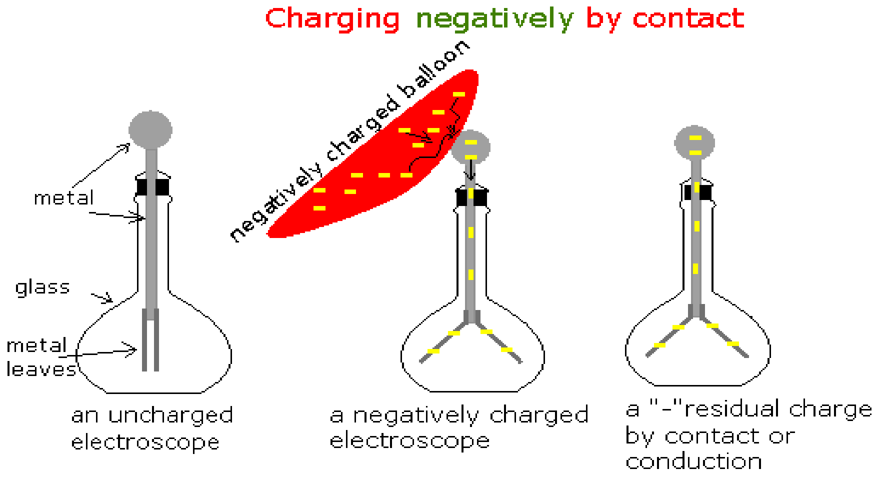
Notice that the original charged object loses some charge.

click for animation

Charging an Electroscope by Conduction

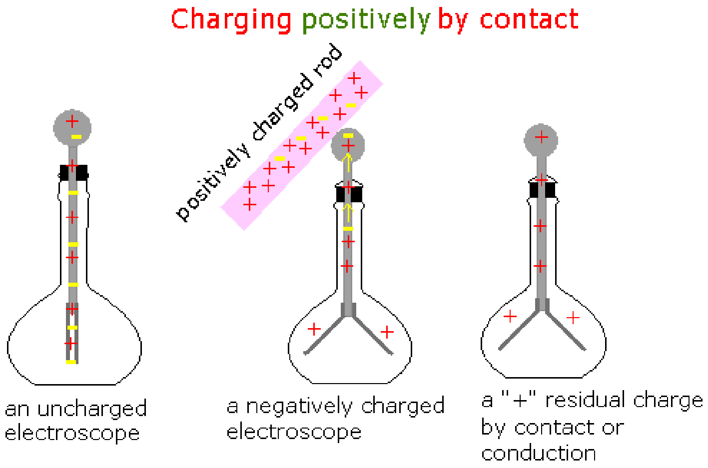
An electroscope can be charged by contact (both negatively or positively)

An electroscope being charged negatively by contact with a balloon that was rubbed with fur. Because the electrons repel each other they escape from the balloon to the knob of the electroscope where they still repel each other down the rod to the foil leaves. The negatively charged leaves then repel each other And spread apart. The electrons will flow until there is an equilibrium situation created with the electrons on the electroscope "pushing back“ with the same force as the electrons on the balloon are pushing down.
If the balloon is removed, the electrons will be trapped on the electroscope. We say that there is a residual (permanent) charge on the electroscope.



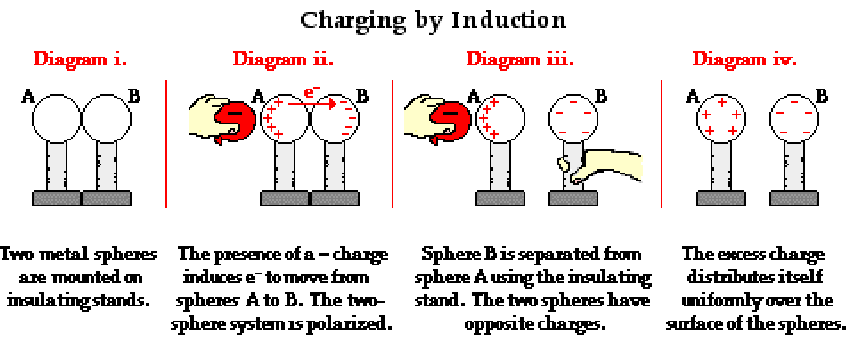
Charging positive by contact

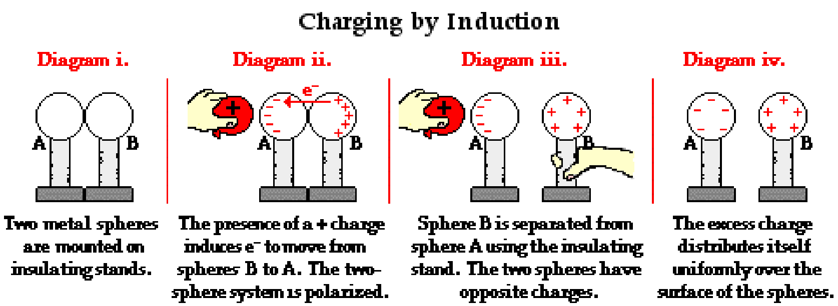
Electroscope is neutral (count 6 +'s and 6 -'s). But when the positive rod touches the metal knob of the electroscope the free electrons on the electroscope are attracted to the rod (opposite charges attract). Therefore, when the rod is removed, the electroscope has lost many of its free electrons and is left with an excess positive charge. (Remember, there are still trillions of negative charges on the electroscope, but there are even more positive charges, and it is only this excess positive charge that is shown). Did any positive charges move in all of this? No! Only the electrons moved.



Charging by Induction

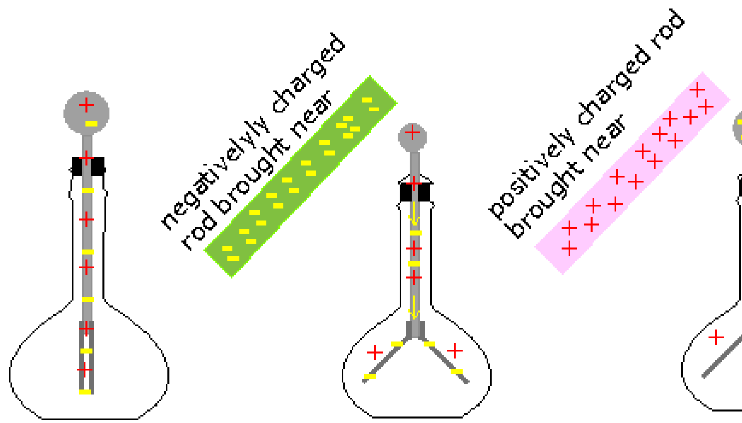
- the movement of electrons in an object due to a nearby charged object.
- the charged object attracts or repels electrons, causing them to move around in the first object





Charging An Electroscope by Induction (Temporary re-arrangement)

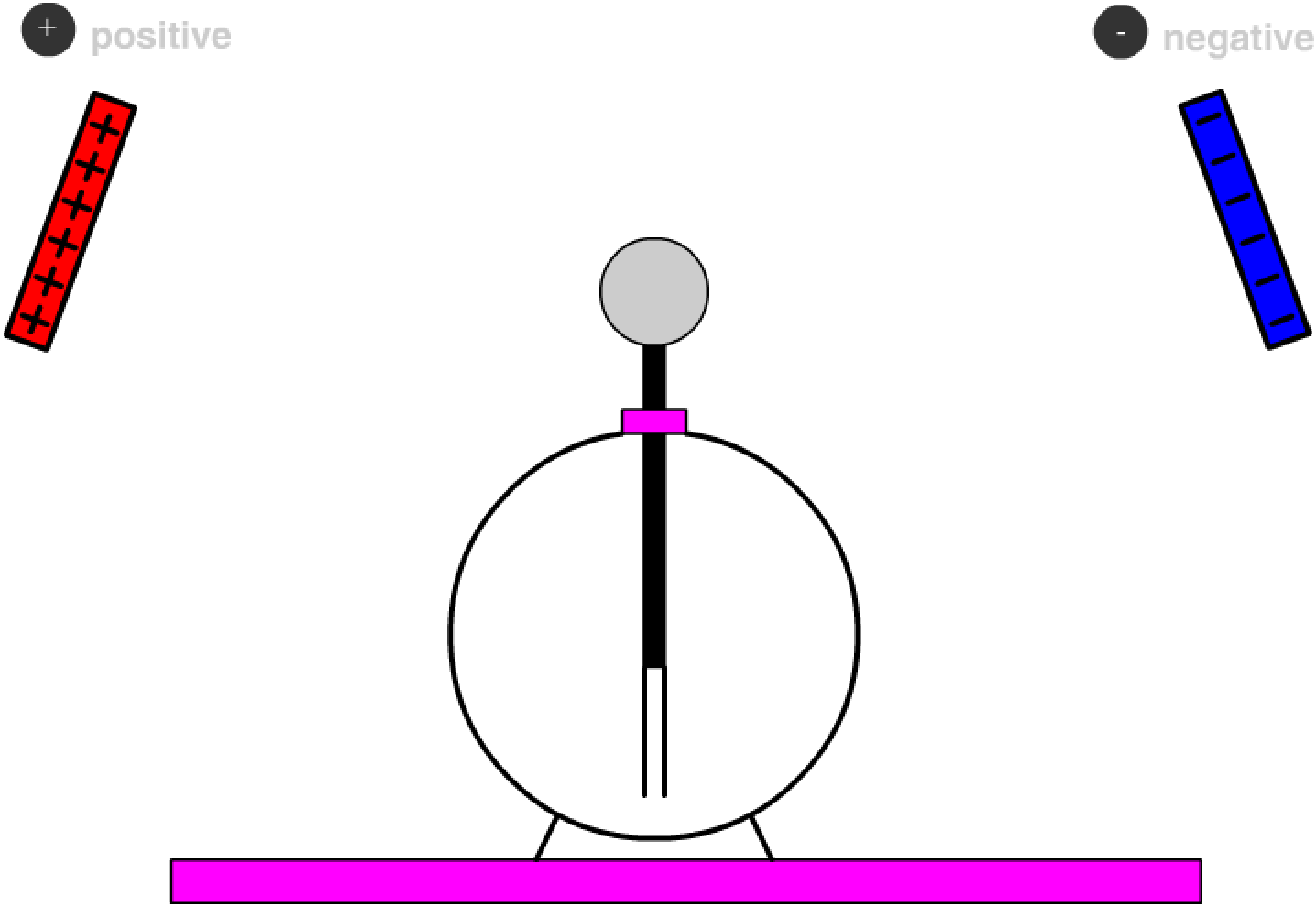
- A temporary charge can be induced on an electroscope. To do this, bring a charged object near the knob of the electroscope. Make sure that the charged object does not touch the knob. If it touches, you will be charging by contact or conduction, and not by induction. The picture below shows how to induce a temporary negative charge and a temporary positive charge on the leaves of an electroscope.



an uncharged electroscope (look for 6 +'s and 6 -'s)

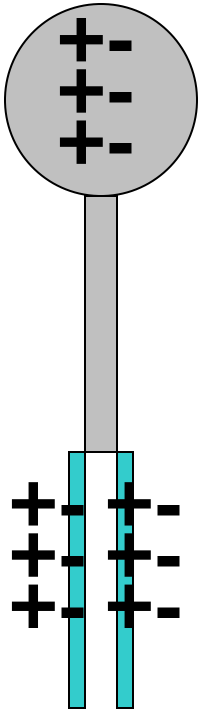
a negative charge is induced on the leaves, but the electroscope is overall neutral (6 +'s, 6 -'s)

a positive charge is induced on the leaves, but the electroscope is overall neutral (6 +'s, 6 -'s)


+ positive
- negative

Charging An Electroscope by Induction
(RESIDUAL CHARGE)

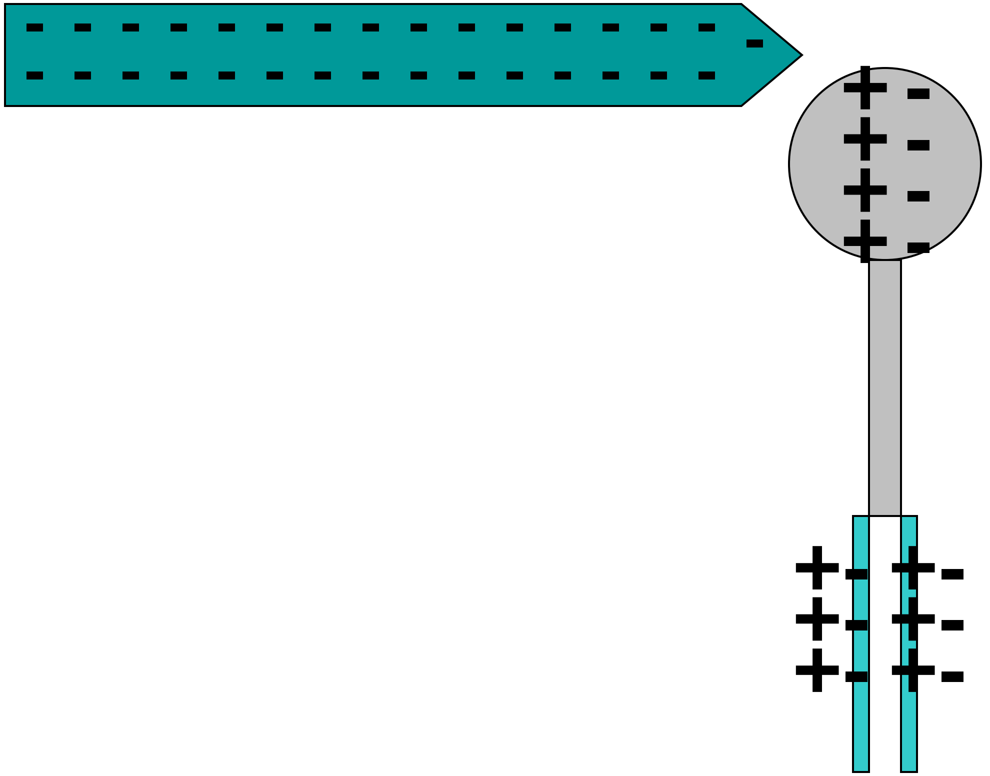
1. Uncharged (Neutral) electroscope:



Leaves are just hanging straight down.

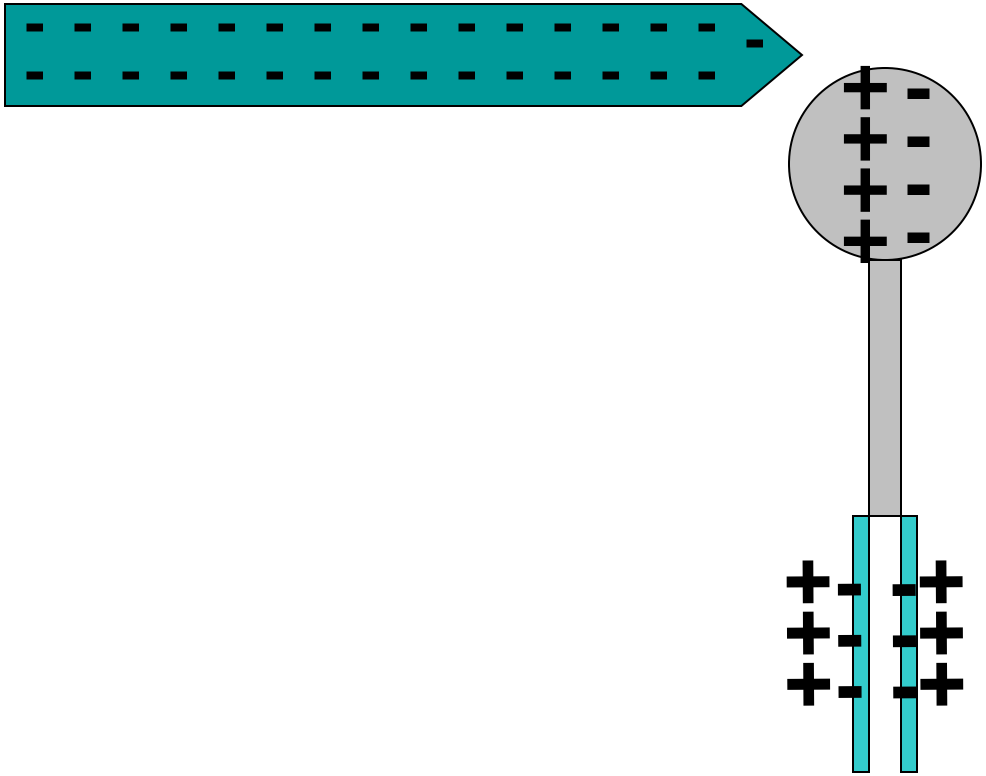
Net charge is zero.

2. A negatively charged rod is brought near the electroscop



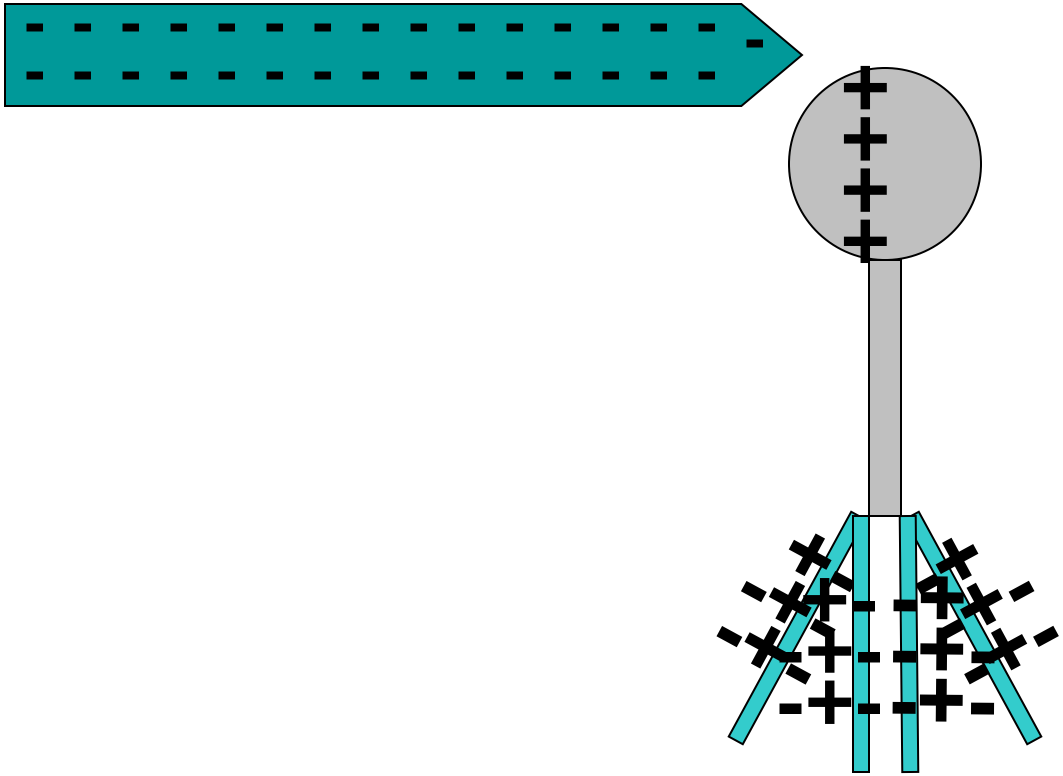
Net charge is zero

3. Electrons move to the leaves:



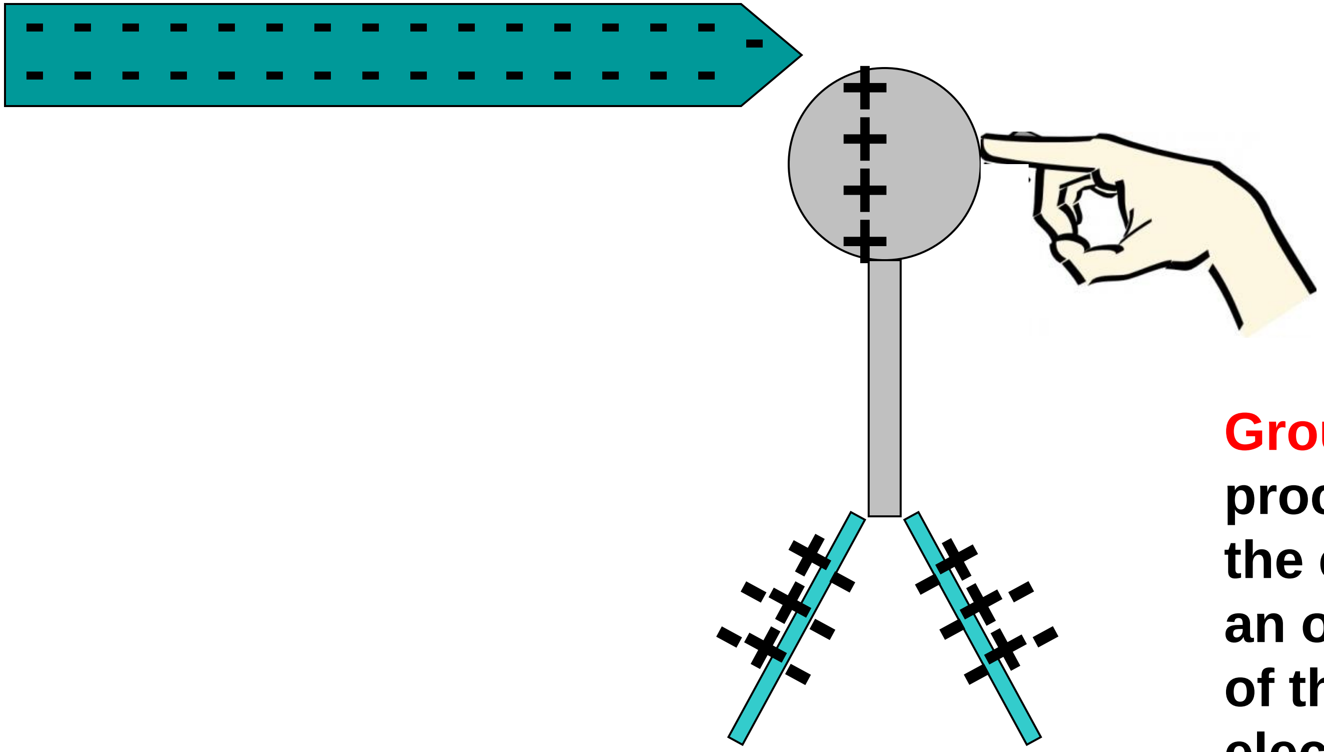
Net charge is still zero

4. Leaves diverge:



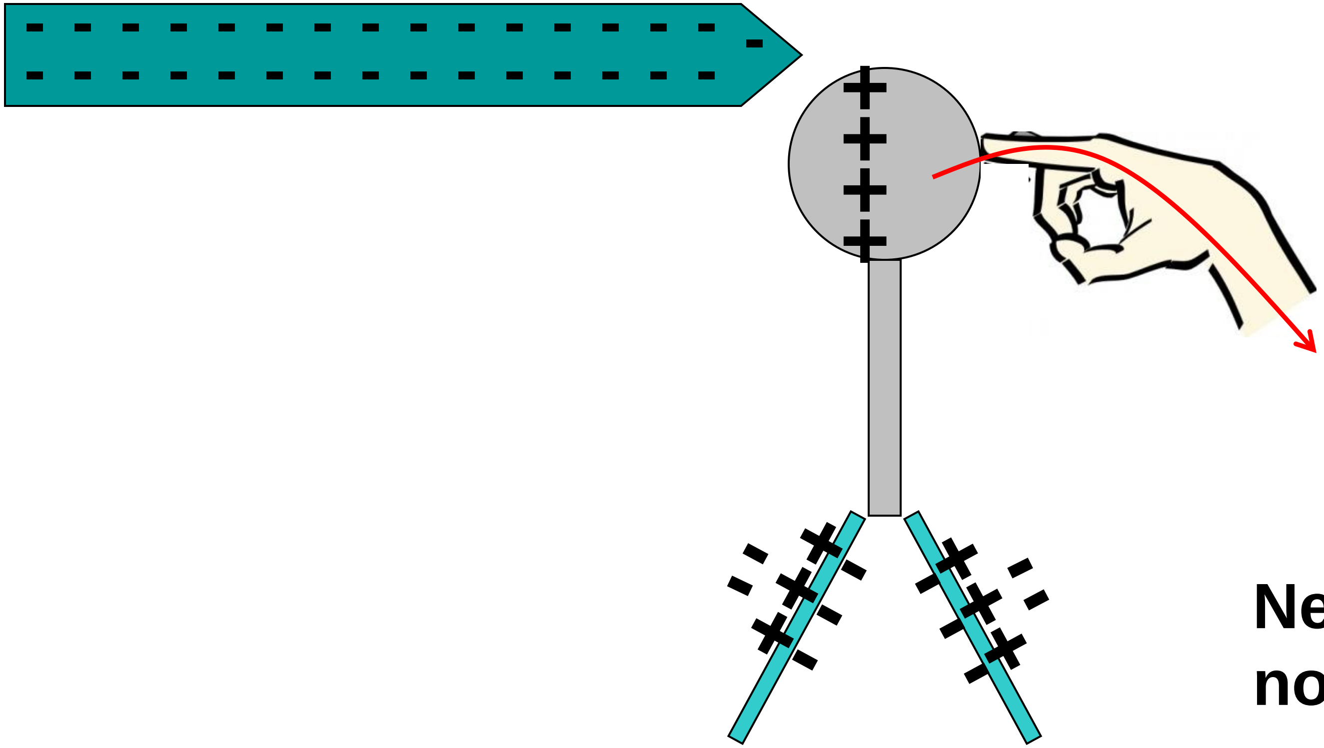
Net charge of zero

5. The electroscope is grounded:



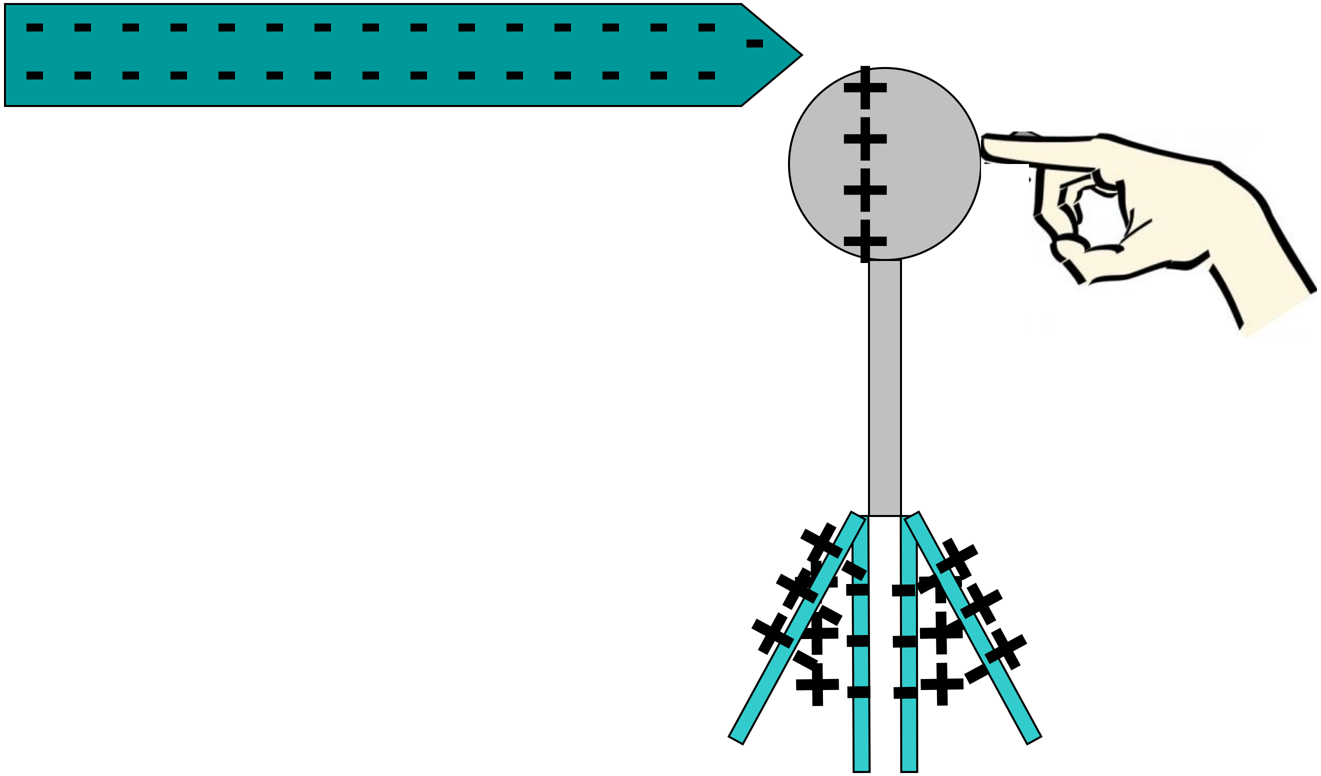
Grounding is the process of *removing* the excess charge on an object by means of the transfer of electrons between it and another object of substantial size.

6. Electrons go to the ground:

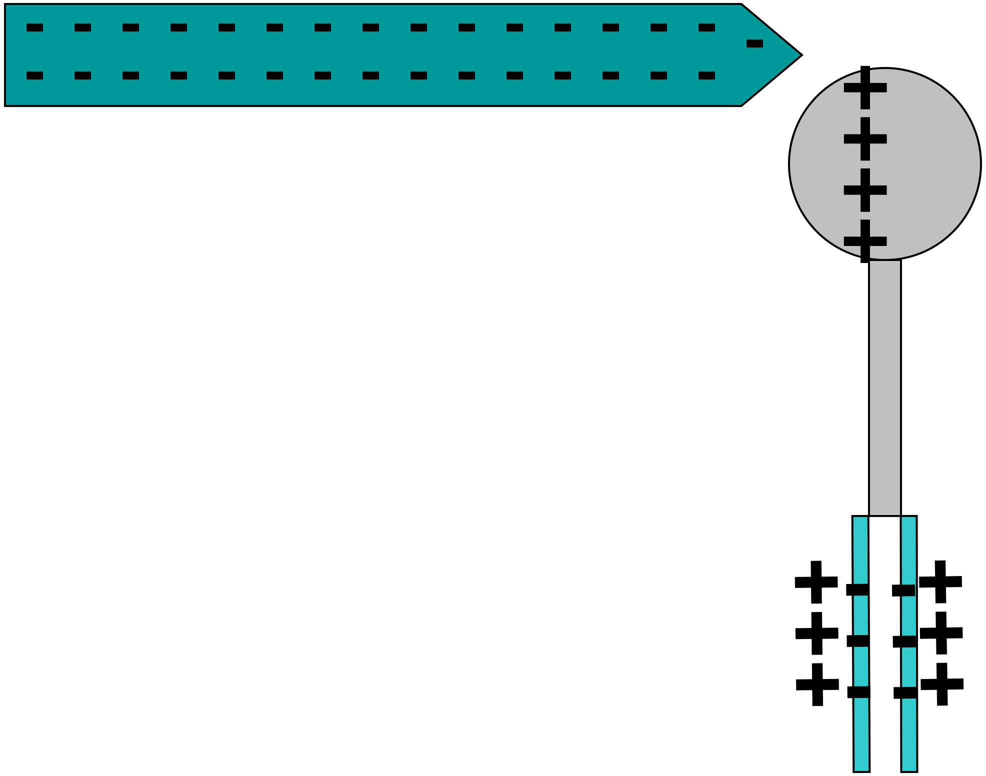


Net charge is now positive

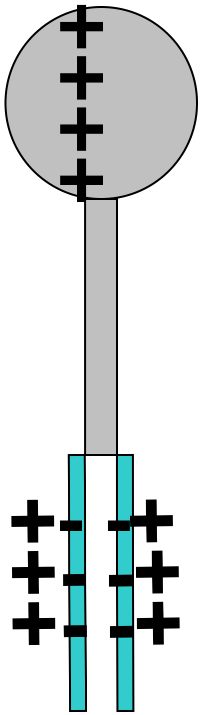
7. Leaves converge and ground is removed:



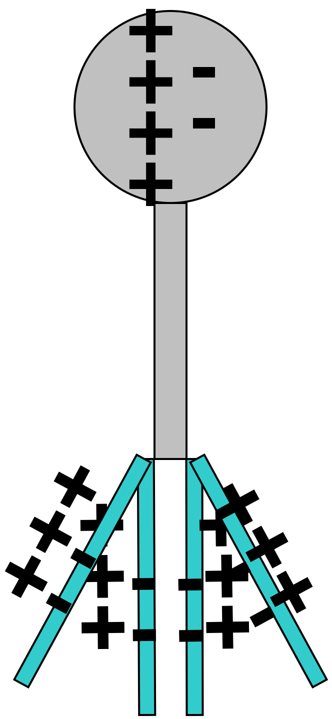
8. Negatively charged rod is removed:



9. **Electrons redistribute throughout the electroscope and move up toward the top:**

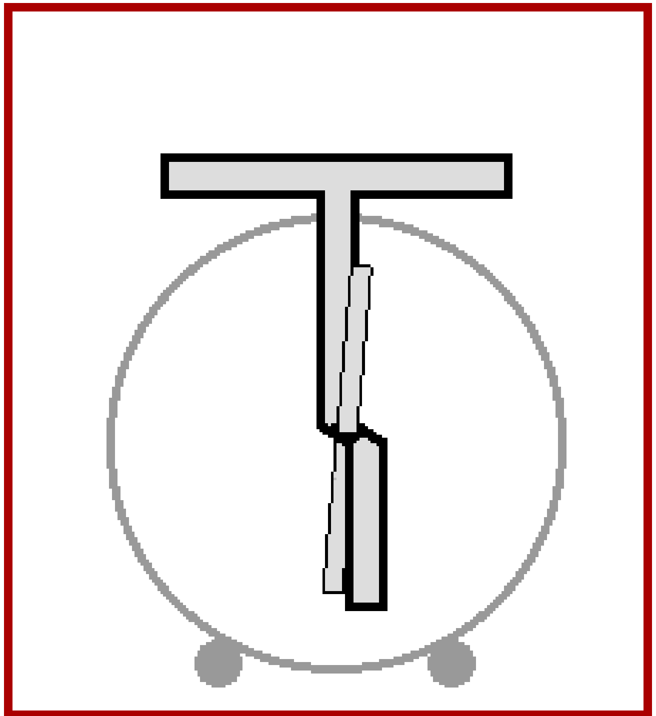


10. Leaves now have the same charge and diverge:



RULE

When an object Is charged by induction, the residual charge (permanent) left on the object is always opposite to the charge on the object that was bought near it.

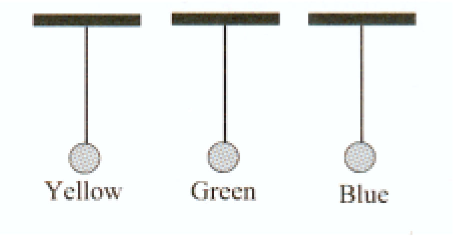


The electroscope is neutral as evidenced by the needle in a relaxed position.

Question for Students

Three different pit balls are suspended by separate strings. Use this information below to determine the charges on the blue and the green balls. Explain.

- **The yellow ball was charged by induction using a negatively charged rod.**
- **The blue ball repels the green ball**
- **The blue ball is attracted to the yellow ball**

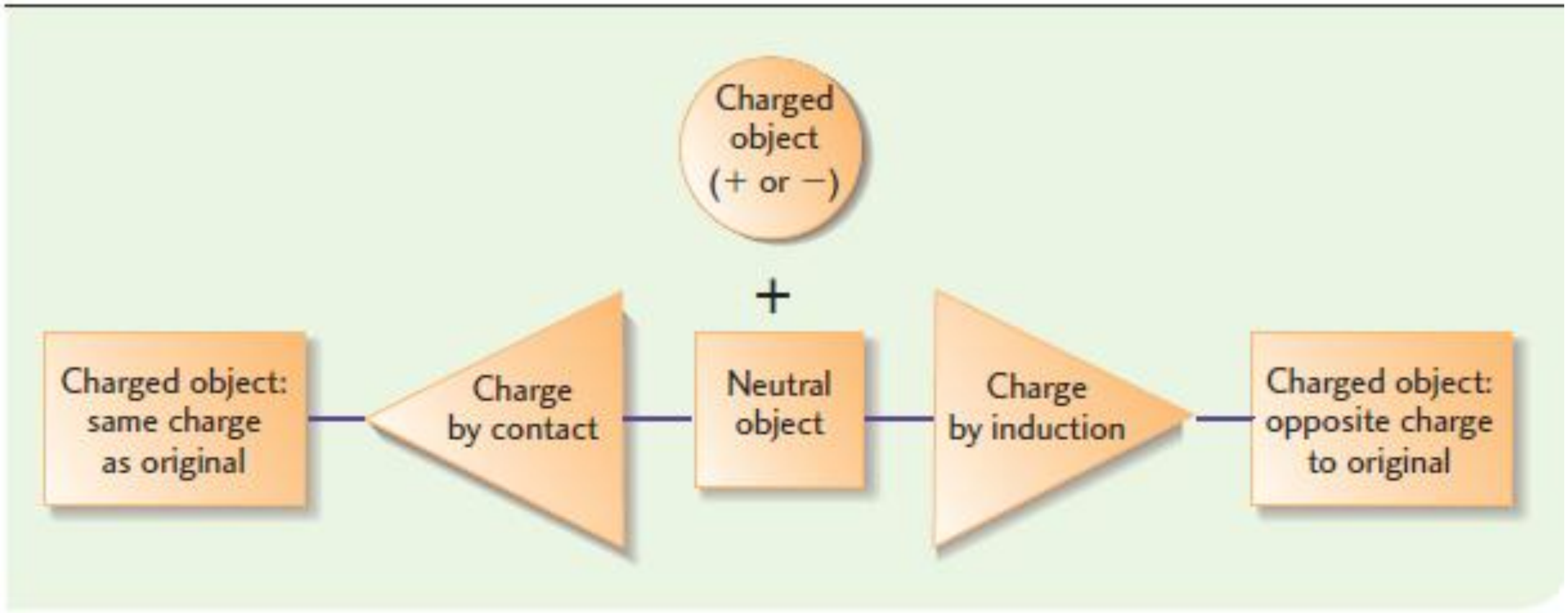


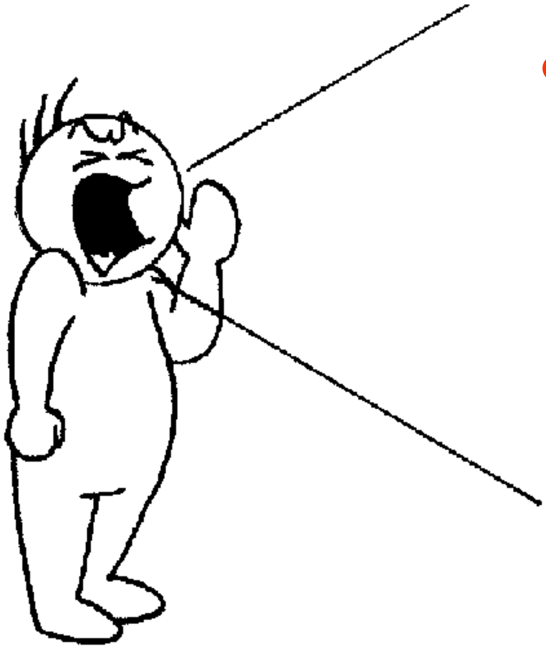
The yellow ball has a positive charge on it because it was initially charged by induction using a negatively charged rod. When an object is charged by induction, the residual charge left on object is always opposite to the object that was bought near.

The blue ball is attracted to the yellow ball. We know that they have opposite charges because of the electric law that "opposites attract". Therefore, we can assume the charge on the blue ball is negative

The blue ball repels the green. Remembering the Electric Law that like charges repel. This indicates that they have the same charge. Hence, we know previously that the blue ball is negative, so, the green ball is negative to0

Summary: Charging by Conduction or Induction

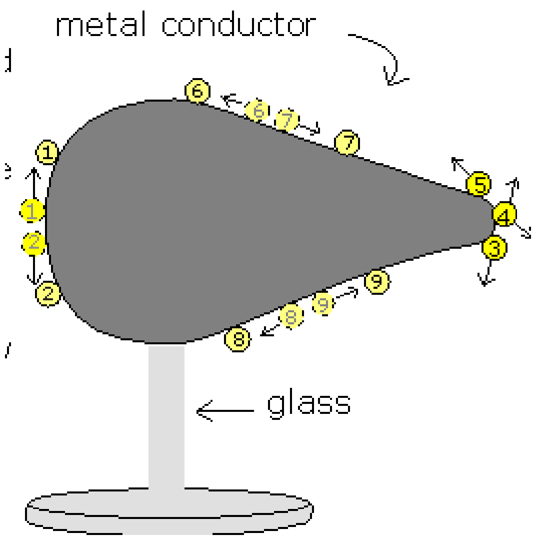




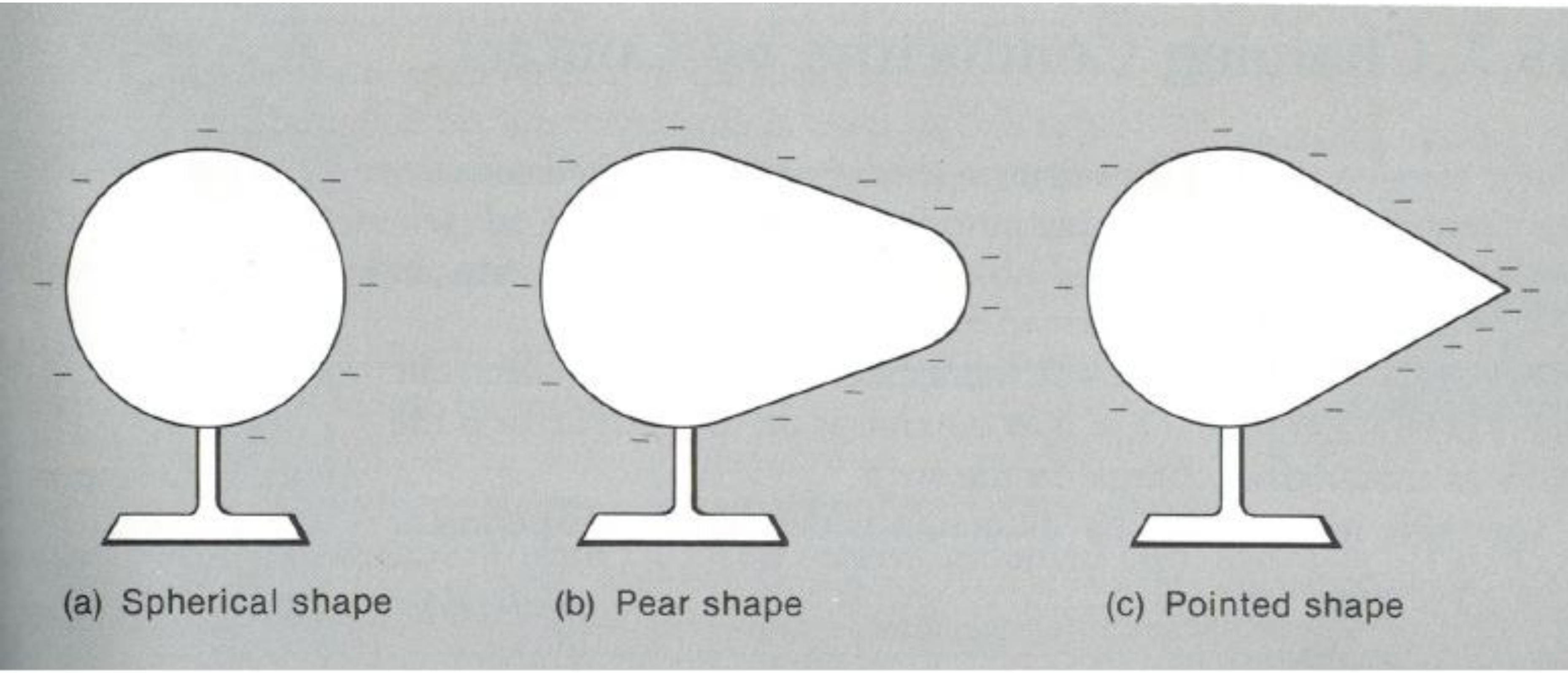
Section 1
Topic 4

- Distribution of charge

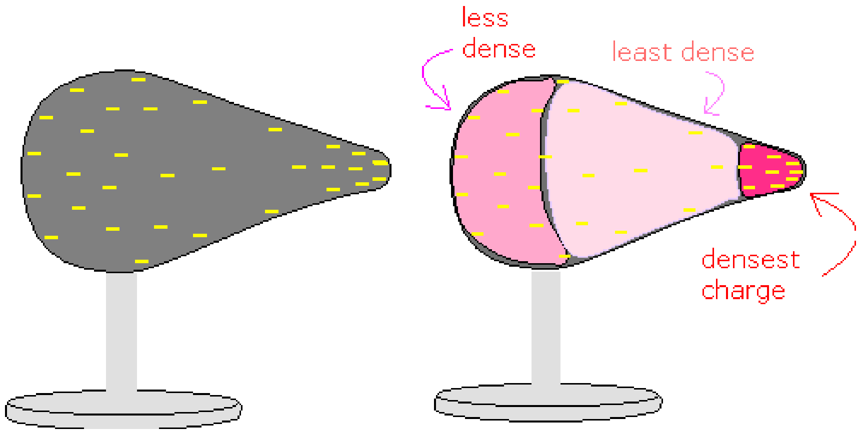
Where a conductor has less curvature, the repelling forces are more parallel to the surface and the electrons are forced apart. Where there is more curvature (pointy areas) the repelling forces are not parallel with the surfaces, so the electrons don't require as much "elbow room".



Of course you must realize that excess electrons are all over the surface of a 3-dimensional object.


(a) Spherical shape
(b) Pear shape
(c) Pointed shape

Notice that the region of highest density charge is on the end of greatest curvature.



Question

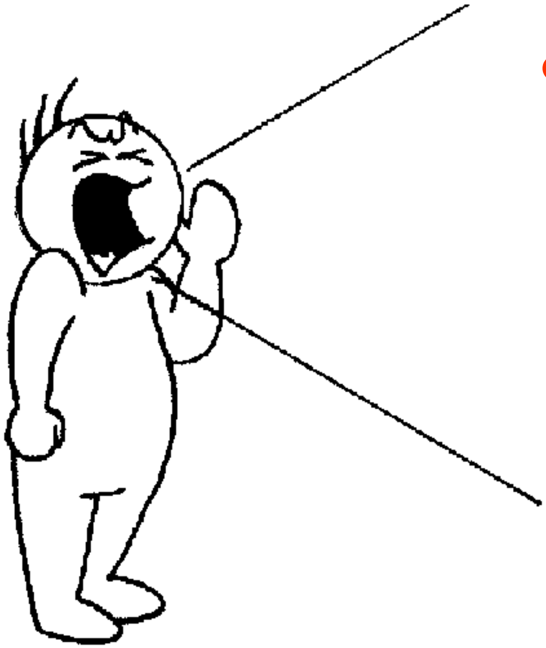
In the pictures above the electrons are shown to be on the surface of the conductor. Are there any electrons inside the conduct?

Answer

Of course, there are zillions of electrons in the interior of the conductor--BUT such electrons are all counterbalanced by the positive charge on zillions of protons. There is no excess charge inside the conductor. All excess charge is on the surface!

Section 1 Topic 4

- Electric Discharge

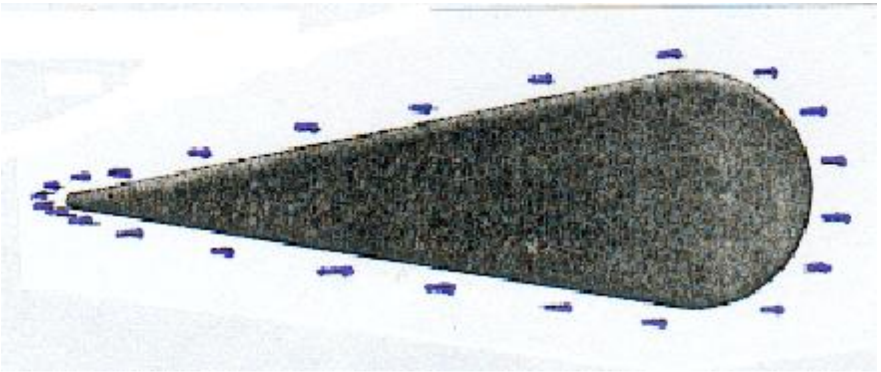


ELECTRICAL DISCHARGE

- You are more familiar with fast electrical discharge than slow electrical discharge. For example, the "prickle" that you feel when reach out to a door knob on a dry day, or the little "snaps" that you hear when removing clothes from an electric dryer are examples of fast discharge. Lightning is the Granddaddy of fast discharges.

- Electric charge "jumps" or discharges due to repulsion forces when too many electrons build up in one place. The discharge is more likely to take place from pointy areas than from flat ones. This is why you are warned to stay away from trees in a thunderstorm.

The picture below suggests that electrical discharge is more likely to occur from places of high curvature (i.e., pointy places).



This phenomenon of discharge from surfaces of high curvature is the basis of the operation of lightning rods. Instead of charge increasing to large amounts and subsequently discharging rapidly and dangerously from buildings during thunderstorms, the lightning rod protruding from the roof permits a continuous but safe, slower discharge. Or, according to some writers, even if lightning does strike, it will be more likely to hit the lightning rod and be safely transferred to ground via a cable.

ELECTRICAL STORMS (LIGHTNING)

Rapid heating and the formation of large rain drops from smaller ones in the atmosphere causes clouds to become electrically charged. A charged cloud induces a strong opposite charge on the surface of the earth directly beneath it.

If the charge on the cloud increases beyond a certain point, a gigantic discharge occurs in the form of lightning. Surplus electrons from a negatively charged cloud may jump across the air gap to earth; or electrons may jump from ground across the air gap to neutralize the deficit of electrons on a positively charged cloud.

Lightning is dangerous! The discharge follows the shortest possible path to the earth and therefore usually strikes the tallest structure in the vicinity. Pointed lightning rods are attached to tall buildings to attract lightning and carry it toward the ground.

Lightning stroke data

length:150 m - 3 km   width:1 cm - 30 cm

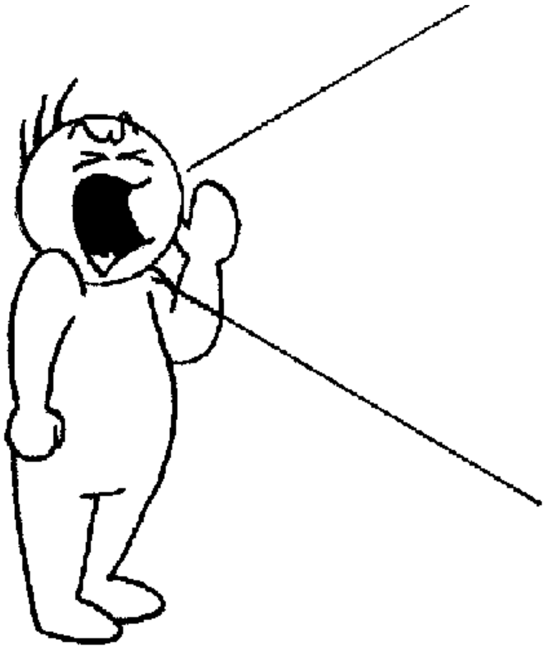
temperature:< 30 000oC   power:billions of kilowatts

time:0.002 s - 1.6 s

Activity

- Read Text: Sec 13.1 – 13.3, Pages 527-534
- Worksheet: Electrostatics
- DO Extra Practice Questions: Text In your textbook:
- p. 582: do #33 to #35
- p. 534--do #1 and #2.
- p. 579--do #1 -#6
- p. 582--do #33 - #45

- Core Lab : The law of Electric Charge



Section 1 Topic 3

- **Coulomb's Law**

Charles Augustin Coulomb (1736 - 1806)

Coulomb's Law

This law was created by Charles- Augustin Coulomb (1736-1806) who experimented with forces that existed between any two electrical point charges.

- **Describes the electric force that exists between two charged objects:**

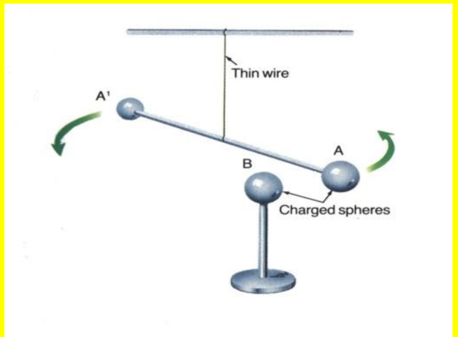
- **"The electric force between two charged objects:**

  1) directly related to the product of the charges

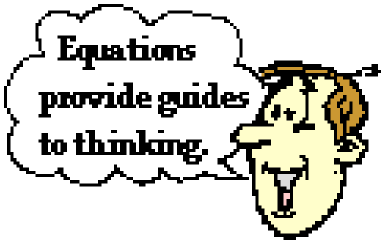
$$F_e \propto \frac{1}{d^2}$$

  2) inversely related to the square of the distance between them."

$$F_e \propto Q_1 \cdot Q_2$$



COULOMB'S LAW OF ELECTROSTATIC FORCE



constant

charges

$$F_e = k\frac{Q_1 Q_2}{d^2}$$

electrostatic force

distance

Where k = Coulomb's Constant

$k = 9.0 \times 10^9$ N m^2 / C^2

A negative force is attractive, and a positive force is repulsive.

Coulomb's Law- formula for electrostatic force

Again this is similar to the gravitational force…

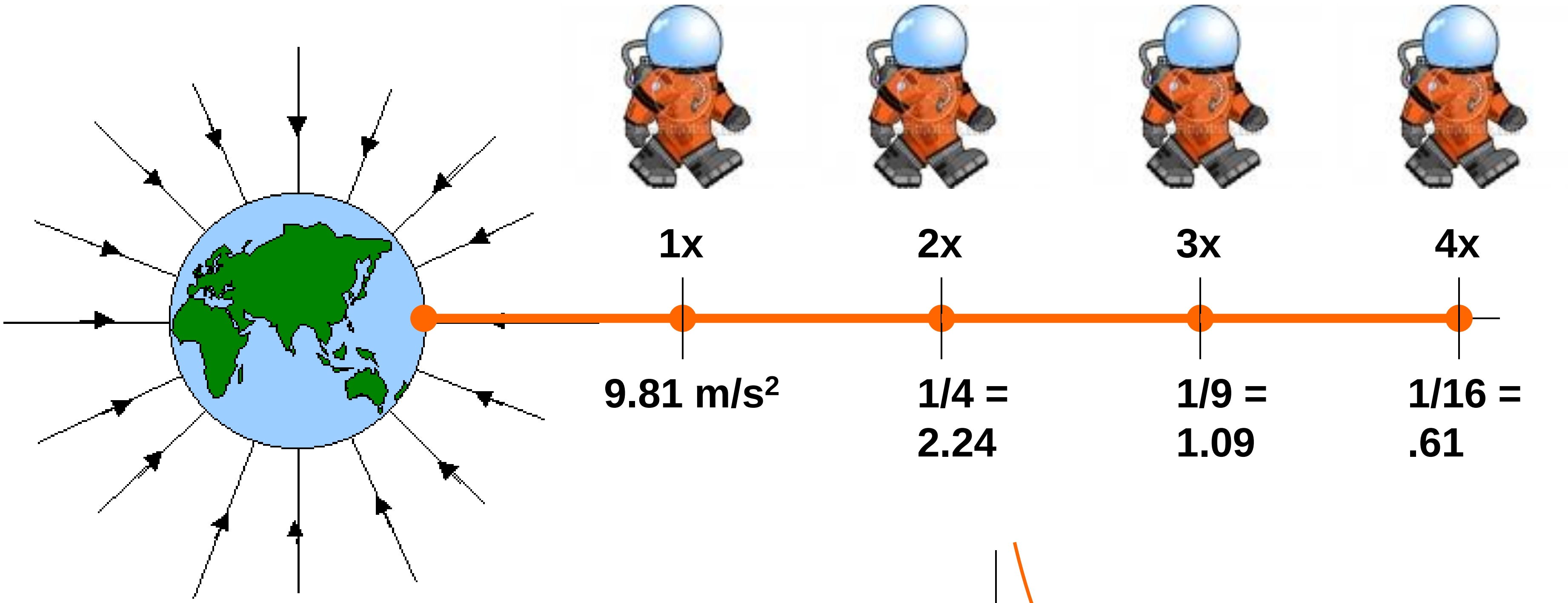
$$F_g = \frac{GmM}{r^2}$$

charge (q) is now responsible for the force

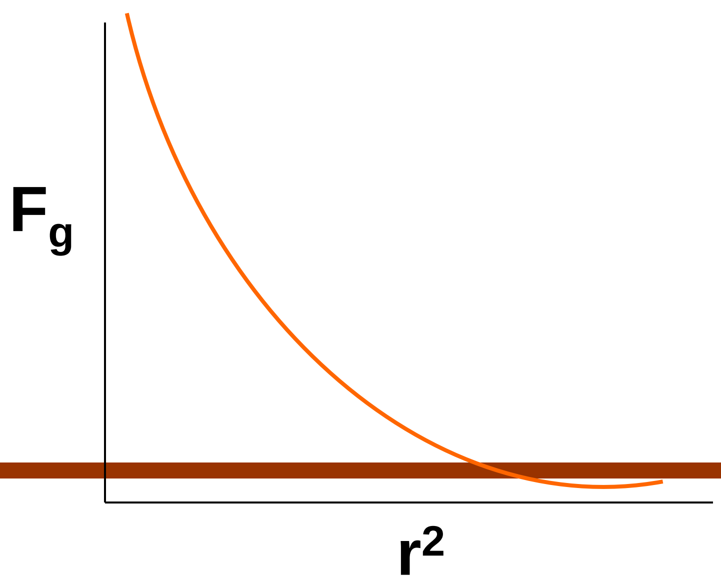
$$F_e = \frac{kq_1q_2}{r^2}$$

Just like G was a constant so is k.
k is the electrostatic constant
and = 8.99 x 10^9 N•m^2/C^2

Remember this…the relationship between the gravitational force and the distance from the object…this is the inverse square law



$$F_g = \frac{GmM}{r^2}$$



Example 1:

Calculate the magnitude of electric force between an electron and proton in a hydrogen atom, if separated by a distance of 0.010 nm.

$$F_e = k\frac{Q_1 Q_2}{d^2}$$

$$= (9.0x10^9)\frac{(1.602x10^{-19})(1.602x10^{-19})}{(0.010x10^{-9})^2}$$

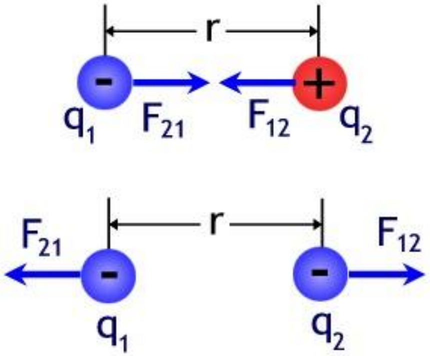
$$= 2.3\mu N$$

Direction:

"-" value for force is a sign of an attractive force

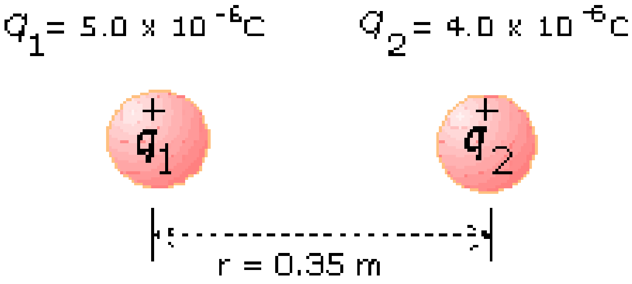
and

"+" value for force signifies a repulsive force.



Example 2:

Two point charges, q_1 = 5.0 μ C and q_2 = 4.0 μ C are 35 cm apart. What is the electrostatic force between them?



Given:

$q_1 = 5.0\ \mu C = 5.0 \times 10^{-6}$ C

$q_2 = 4.0\ \mu C = 4.0 \times 10^{-6}$ C

r = 35 cm = 0.35 m

$k = 9.0 \times 10^9\ Nm^2/C^2$

F = ?

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

$$F = \frac{9.0 x 10^{9}\,Nm^{2}/C^{2}\,(5.0 x 10^{-6}\,C \;\; x \;\; 4.0 x 10^{-6}\,C)}{(0.35\,m)^{2}}$$

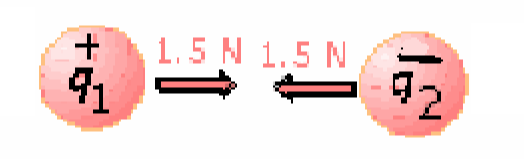
$$F = 1.47\,N$$

The electrostatic force is 1.5 N. Note that this is a positive number because both q_1 and q_2 are positive. In other words, a positive force is a repelling one.

Example 3:

Two point charges, q_1 = 5.0 μ C and q_2 = -4.0 μ C are 35 cm apart. What is the electrostatic force between them?

The solution is exactly the same as that of exercise 1, except that a positive multiplied by a negative gives a negative answer. This means that F will be -1.5 N and not +1.5 N. We conclude that when Coulomb's law results in a negative force, the force is one of attraction (opposite charges attract but result in a negative value for the force].



Example 4:

How far apart must the charges of $q_1 = 5.0\ \mu C$ and $q_2 = -4.0\ \mu C$ be in order that the charges attract each other with a force of 2.2 N?

Givens:

$q_1 = +5.0\ \mu C = +5.0 \times 10^{-6}$ C

$q_2 = -4.0\ \mu C = -4.0 \times 10^{-6}$ C

$F = -2.2$ N

$k = 9.0 \times 10^{9}\ Nm^2/C^2$

$r = ?$

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

$$-2.2\text{N} = \frac{9.0 \times 10^{9}\ \frac{\text{Nm}^2}{\text{C}^2}\ (5.0 \times 10^{-6}\ \text{C} \times -4.0 \times 10^{-6}\ \text{C})}{r^2}$$

$$-2.2\cancel{\text{N}}\ r^2 = -0.18\left[\frac{\cancel{\text{N}}\text{m}^2}{\cancel{\text{C}}^2} \times \cancel{\text{C}}^2\right]$$

$$r^2 = \frac{-0.18\text{m}^2}{-2.2}$$

$$r = \sqrt{0.082\text{m}^2}$$

$$r = 0.29\text{m}$$

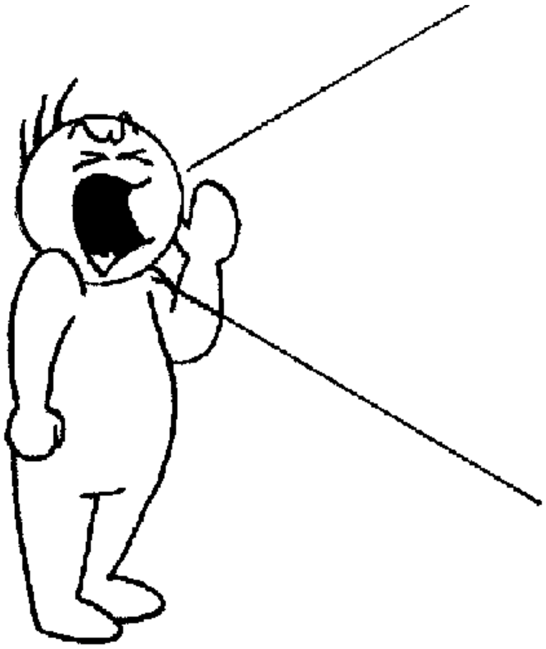
Activity

- Read Text: Sec 13.4

  Pages 535-545

- In your textbook:

  on p. 545--do #1, #2
- on p. 585--#48, #51-#53



Section 1 Topic 3

- **Coulomb's Law-Numerical Exercises in one Dimension**

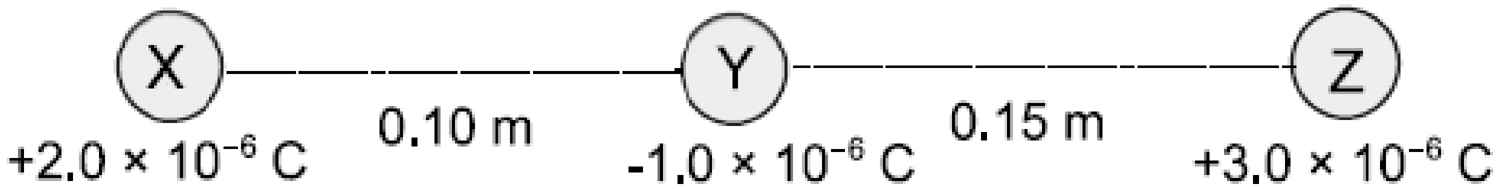
Text: 13.1 – 13.2

SUPERPOSITION PRINCIPLE

- When two or more electrical charges exert forces simultaneously on a given charge.
- The total force experienced by that charge is found to be the vector sum of the forces that the various charges would exert individually.

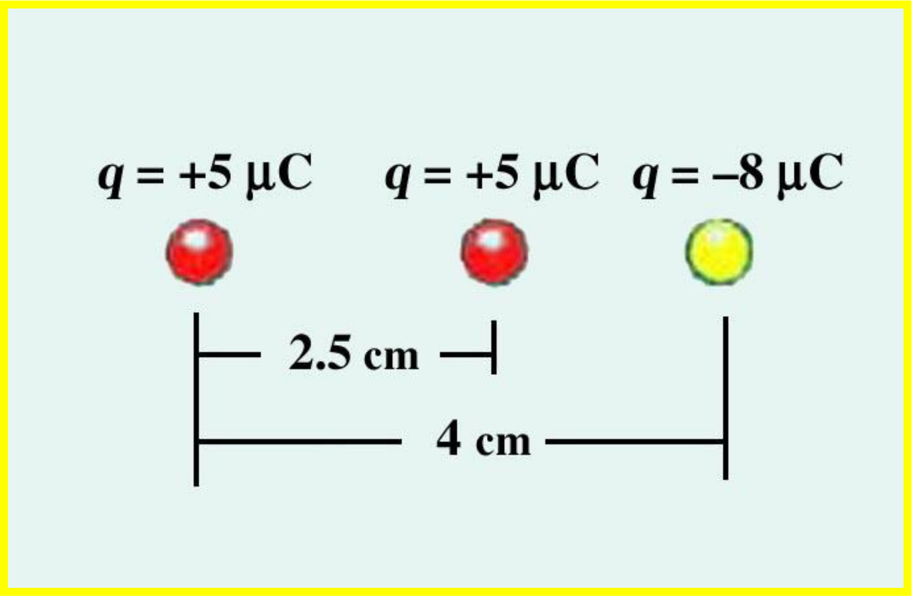
Example 1

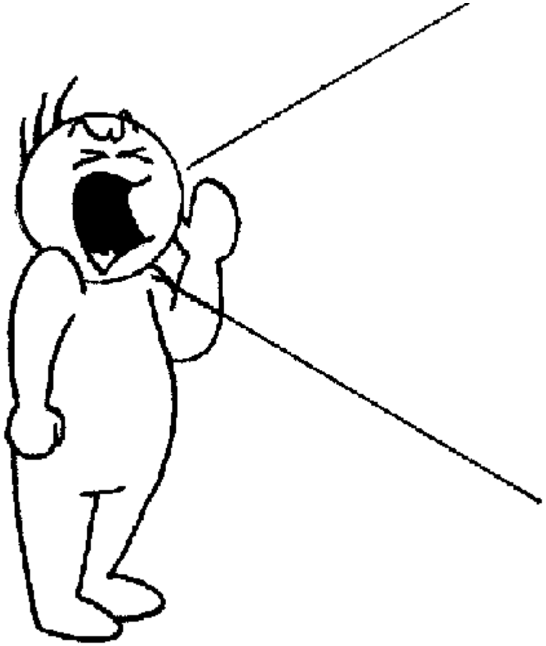
Three charged objects are arranged as shown. Calculate the net force on Y due to the presence of X and Z.



Example 2

Find the net force on the left charge





Section 1 Topic 3

- **Coulomb's Law-Numerical Exercises in Two Dimension**

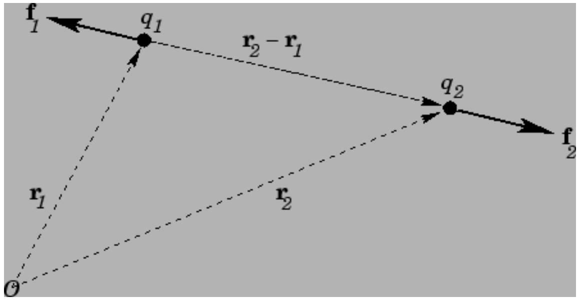
Text: 13.1 – 13.2

COULOMB'S LAW-NUMERICAL EXERCISES IN TWO DIMENSION

Coulomb's Law

Coulomb's law finds the force between two objects only.

- To find the net electric force on an object due to two or more others, find the vector sum of the forces from each other object as if each acts alone.



The only difference between this lesson and the last is that the charges will not be in a single straight line. This means angles and vectors will be involved.

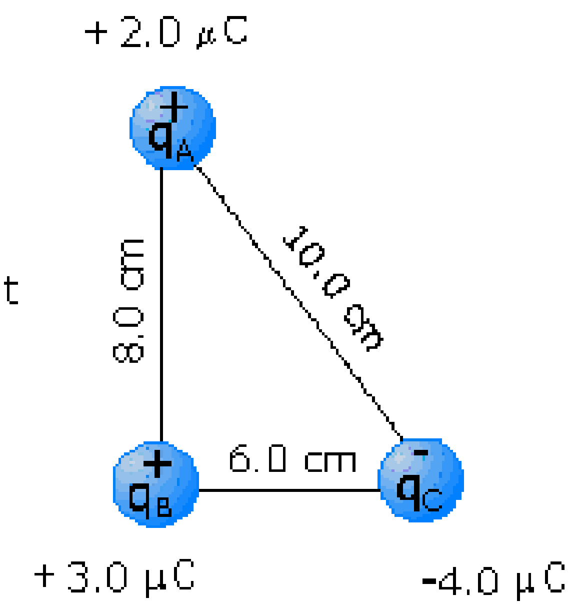
Example 1:

Charges of +2.0 μ C, +3.0 μ C, and -4.0 μ C are situated on the vertices of a right-angled triangle as shown. What is the net force on the +3.0 μ C charge due to the other two forces?

Givens:

q_1 = +2.0 μ C
q_2 = +3.0 μ C
q_3 = -4.0 μ C
r_{12} = 8.0 cm = 0.08 m
r_{32} = 6.0 cm = 0.06 m
k = 9.0 x 109 Nm^2/C^2

Fnet on B = ?



$$F_{AB} = \frac{k\, q_A\, q_B}{r^2}$$

$$= \frac{9 \times 10^9\ \text{Nm}^2/\text{C}^2 \times {}^{+}2.0 \times 10^{-6}\ \text{C} \times {}^{+}3.0 \times 10^{-6}\ \text{C}}{(0.08\ \text{m})^2}$$

$$= 8.4\text{N}$$

Next find F_{CB} :

$$F_{CB} = \frac{k\, q_C\, q_B}{r_{CB}{}^2}$$

$$= \frac{9 \times 10^9\ \text{Nm}^2/\text{C}^2 \times {}^{-}4.0 \times 10^{-6}\ \text{C} \times {}^{+}3.0 \times 10^{-6}\ \text{C}}{(0.06\ \text{m})^2}$$

$$= {}^{-}30\ \text{N}$$

F_{12} is a positive force, therefore is a repelling force straight down the screen.

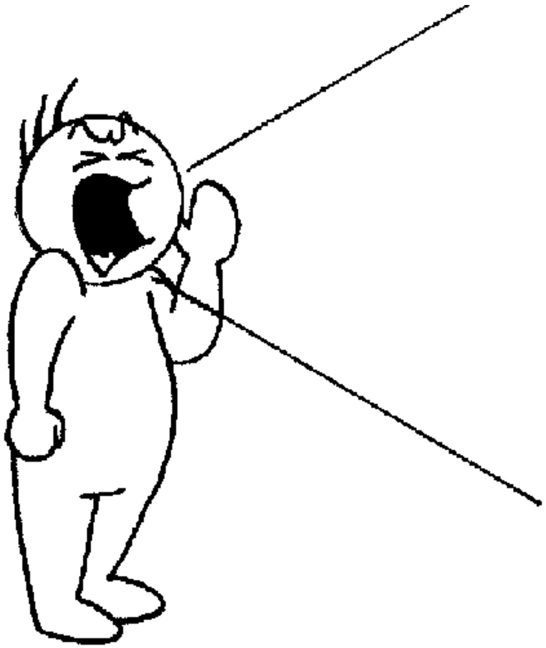
F_{32} is a negative force, therefore it is a force of attraction to the right. (See picture below).

Because the vectors form a right-angled triangle,

$$F_{net\ on\ B} = \sqrt{(30N)^2 + (8.4N)^2}$$
$$= 31.2N$$

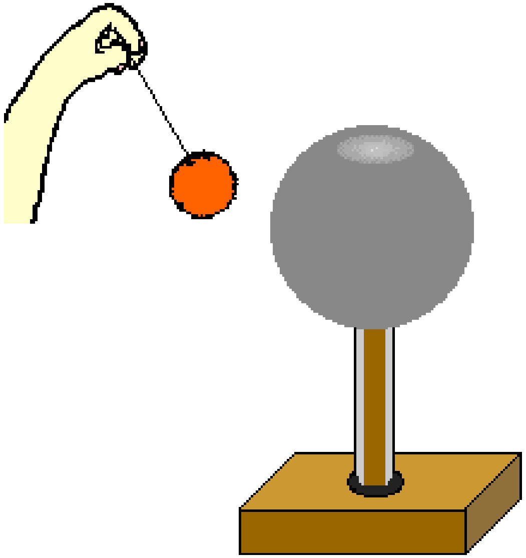
$$\theta = \tan^{-1}\left(\frac{8.4}{30}\right) = 15.6^o$$

To two significant digits, the net electrostatic force exerted on B by A and C is 31 N 16o south of east.



Section 1 Topic 5

- MAPPING ELECTRIC FIELDS



The large quantity of charge on a Van de Graaff generator alters the surrounding space. Other charged objects entering that space experience an electric influence.

Text: 13.1 – 13.2

Gravitational and Electric Fields

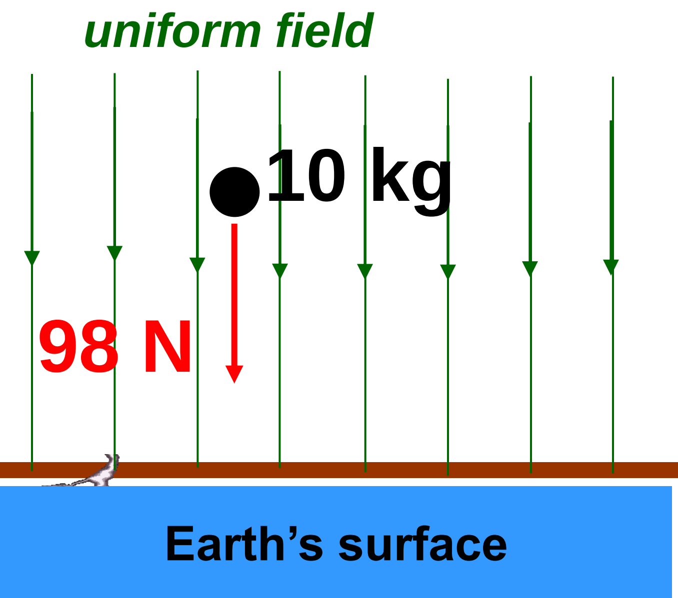
A field *is a region in space where a given effect takes place. The field concept is used to explain non-contact forces that "act at a distance."*

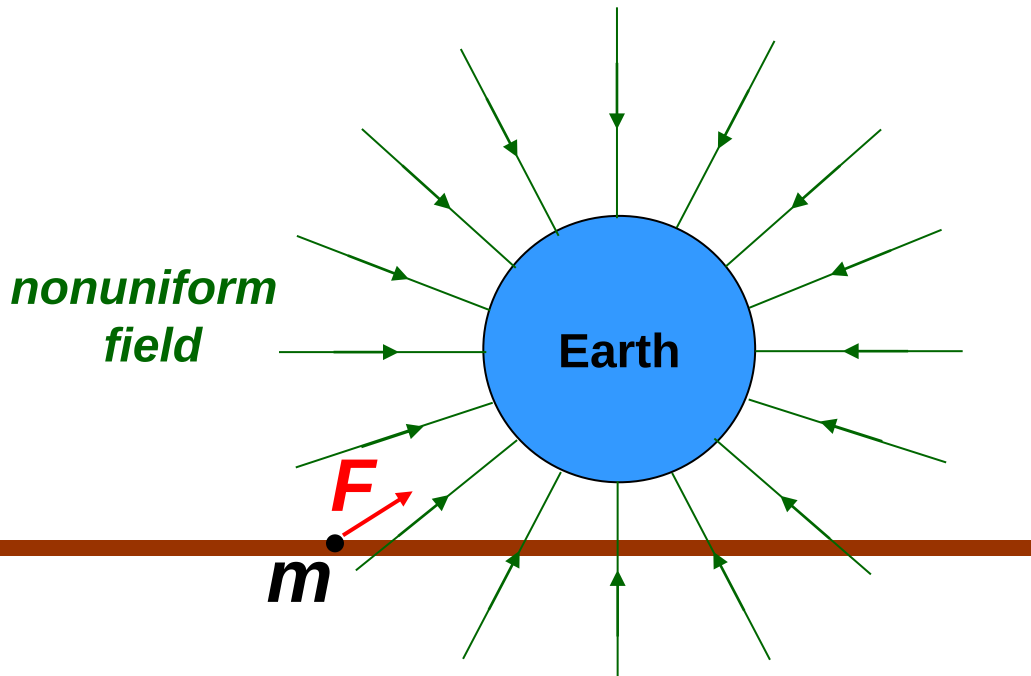
Gravitational Fields

A gravitational field is a region in space that affects mass, and causes the gravitational force. The shape of the gravitational field can be mapped using field lines, which show the direction of force on a "test" mass placed inside the gravitational field

Gravitational Fields: Review

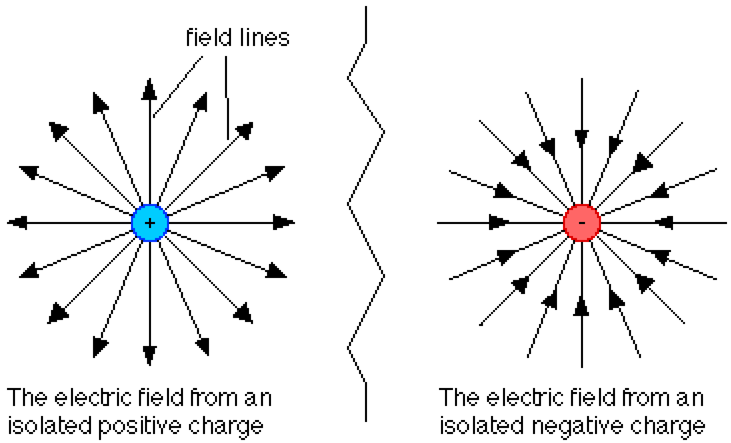
In physics 2204, defined the field strength as the gravitational force per unit mass on any "test mass" placed in the field: $g = F / m$. g is a vector that points in the direction of the net gravitational force; its units are N / kg. F is the vector force on the test mass, and m is the test mass, a scalar. Some Fields are uniform (parallel, equally spaced fields lines). Nonuniform fields are stronger where the field lines are closer together.



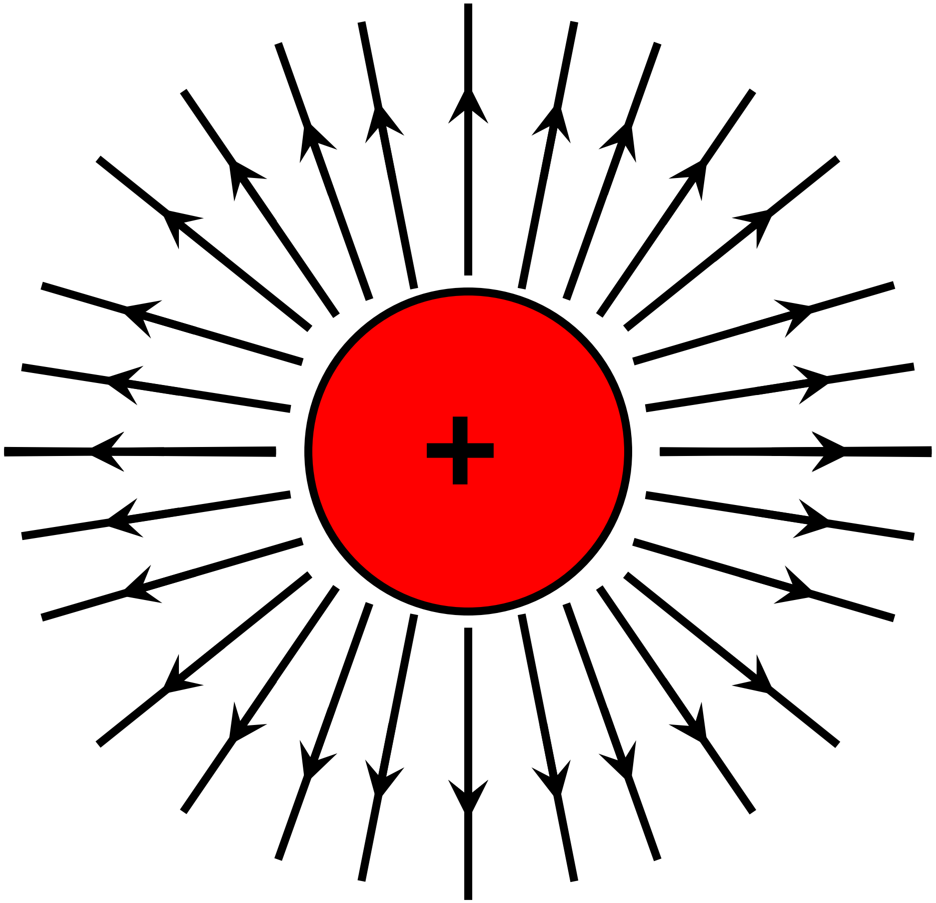


Electric Fields

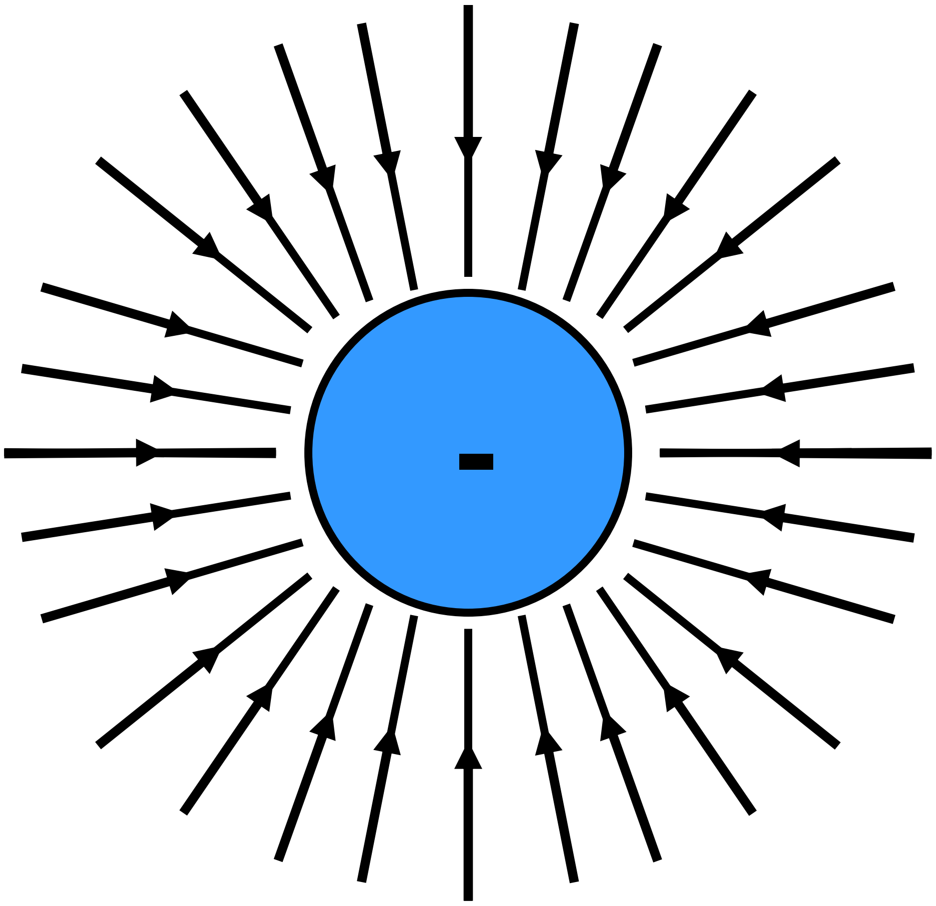
- An electric field is a region in space that affects charge, and causes the electric force on a test charge placed inside the electric field. Electric field are graphically represented by lines of force



Single Positive Field Charge

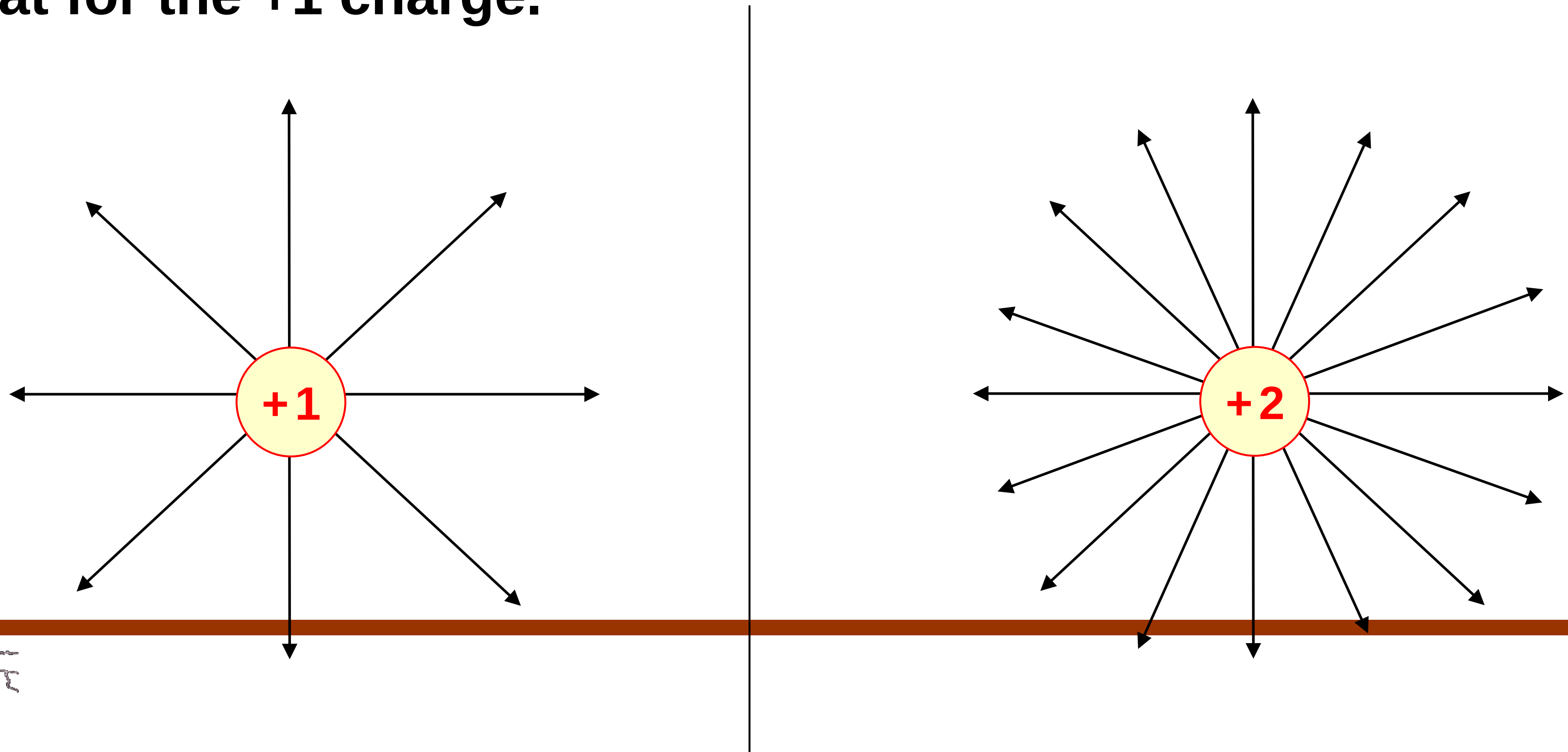


Single Negative Field Charge

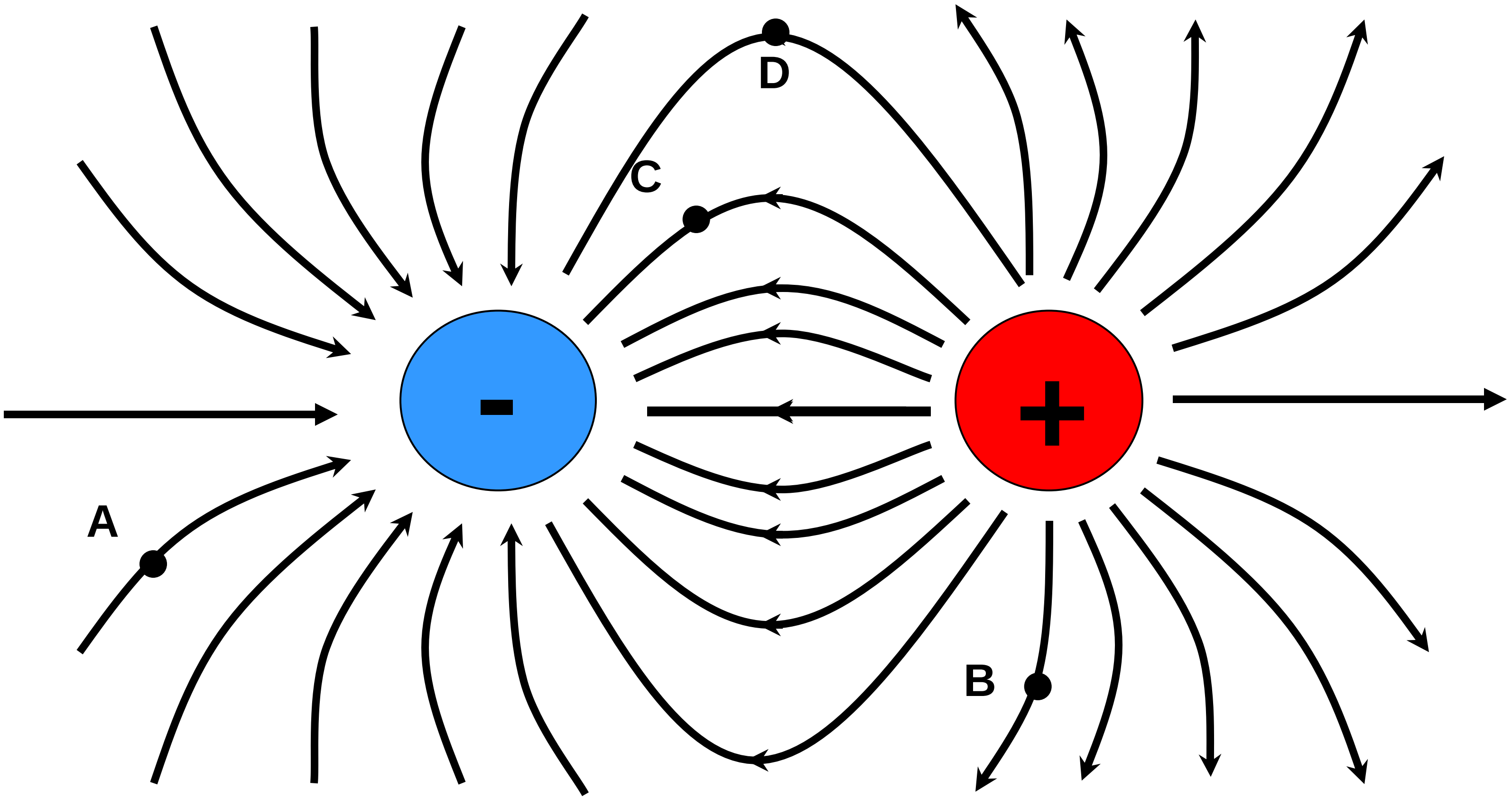


Point Charges of Different Magnitudes

Let's compare the fields on two separate isolated point charges, one with a charge of +1 unit, the other with a charge of +2 units. It doesn't matter how many field lines we draw emanating from the +1 charge so long as we draw twice as many line coming from the +2 charge. This means, at a given distance, the strength of the E field for the +2 charge is twice that for the +1 charge.

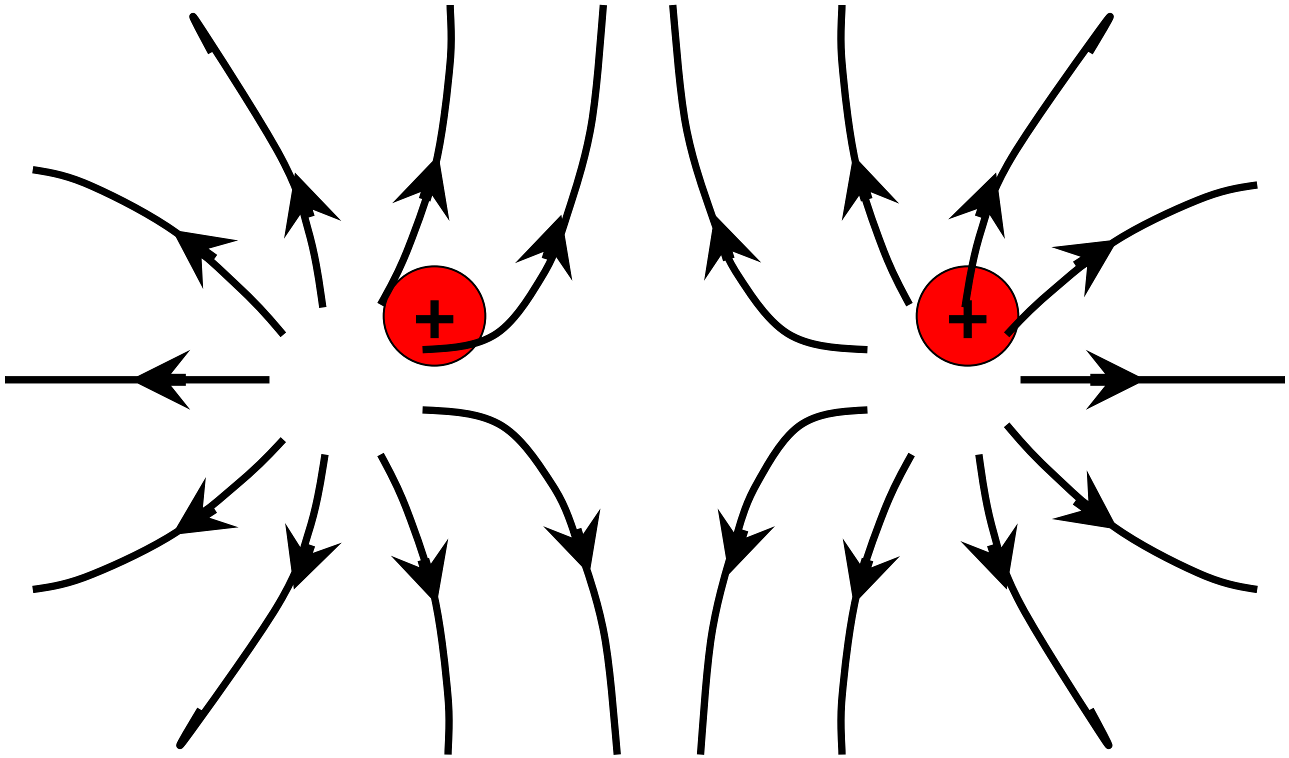


Equal but Opposite Field Charges

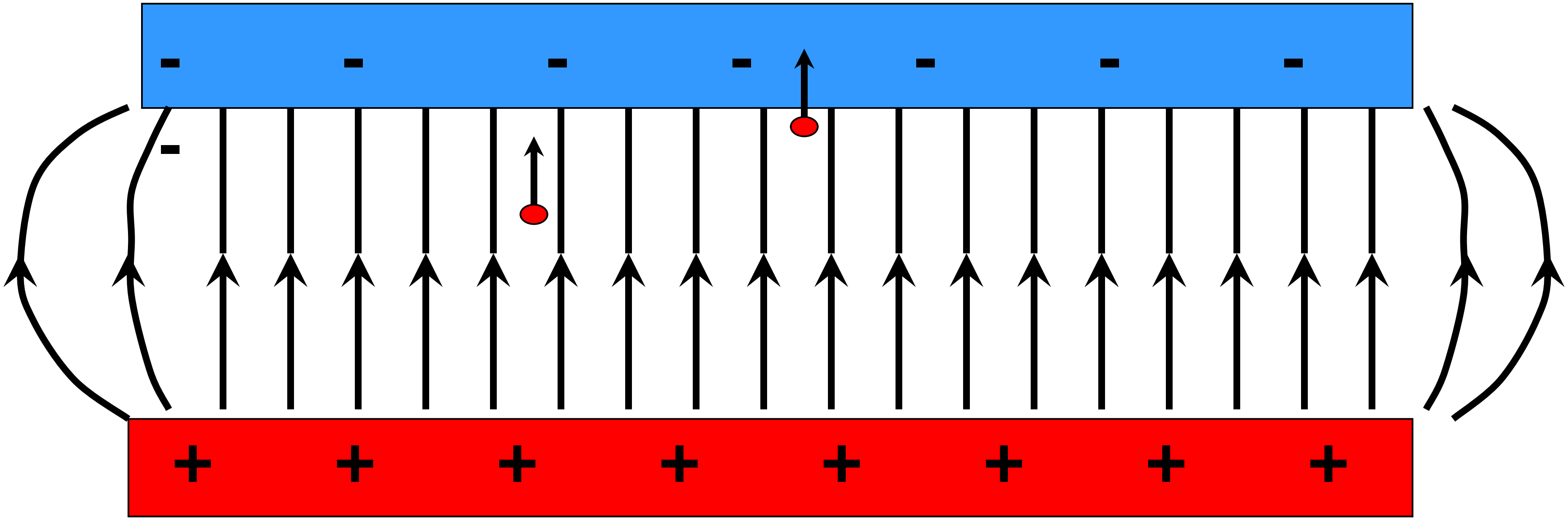


Here is another view of the field. Since the net force on a charge can only be in one direction, field lines never intersect.

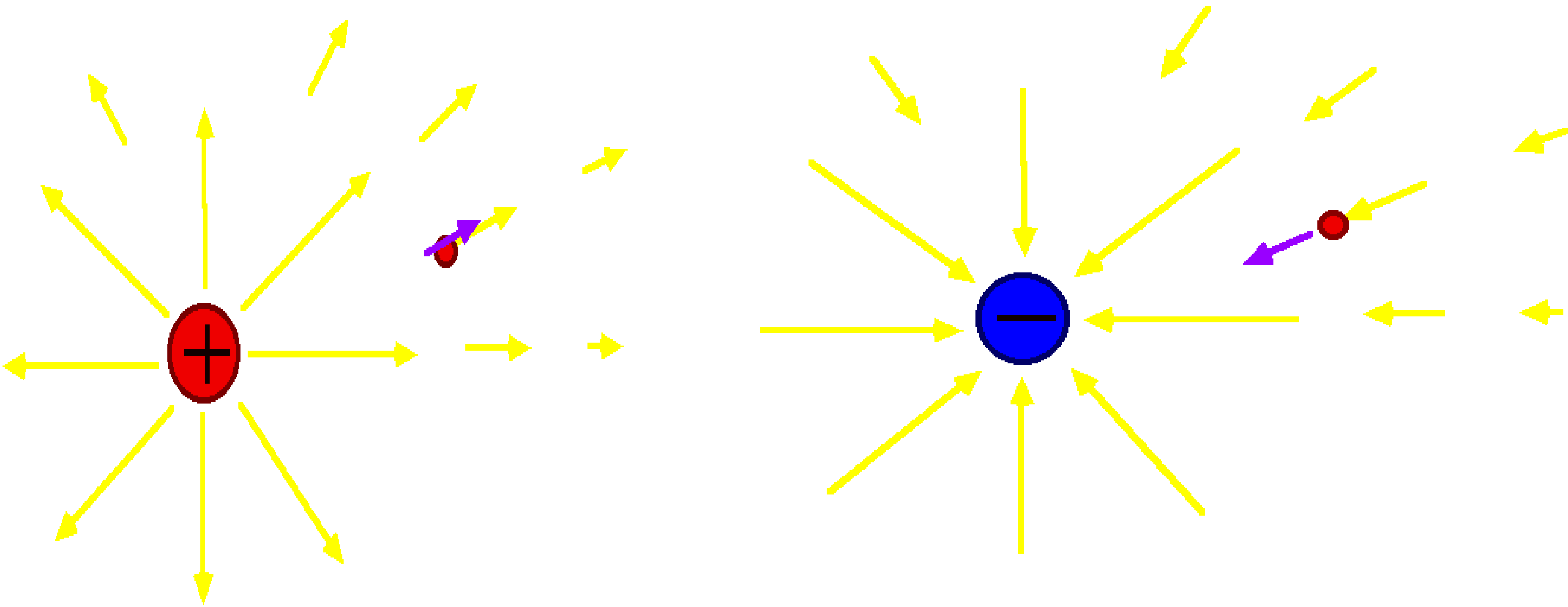
Two Identical Charges



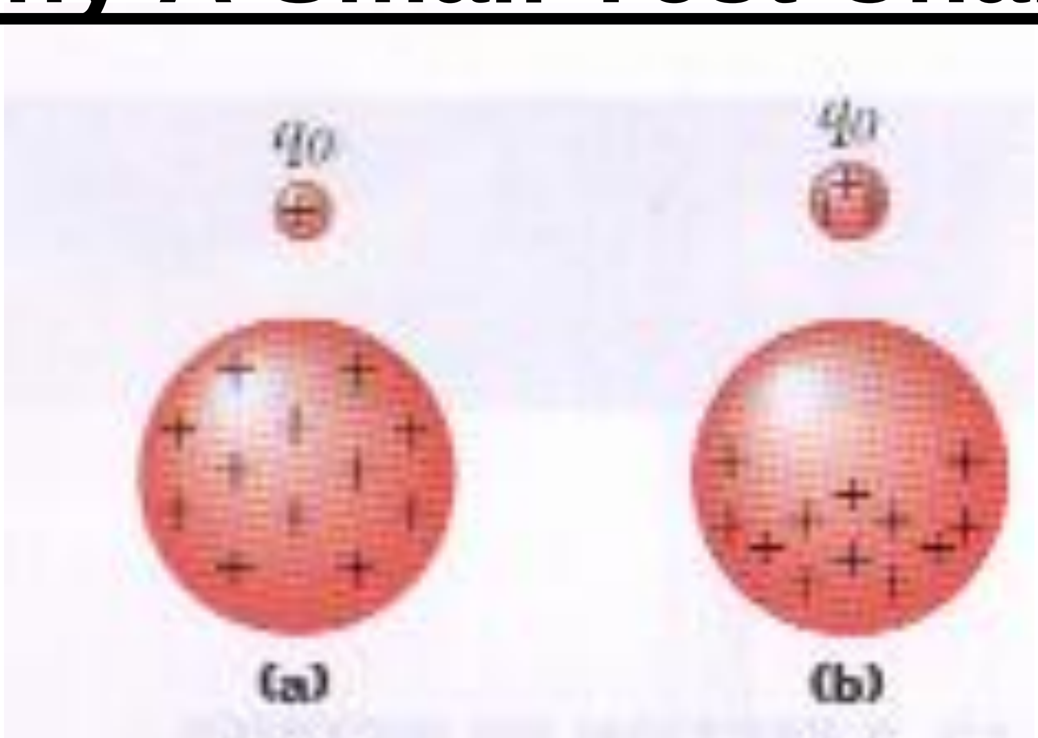
Uniform Field



In the diagrams below we see the effect of field lines on a small positive test charge q_t



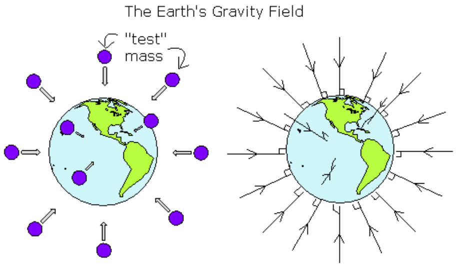
Why A Small Test Charge



We must assume a small test charge, as in (a), because a larger test charge, as in (b), can cause a redistribution of the charge on the sphere, which changes the electric field strength

Properties of Field Lines:

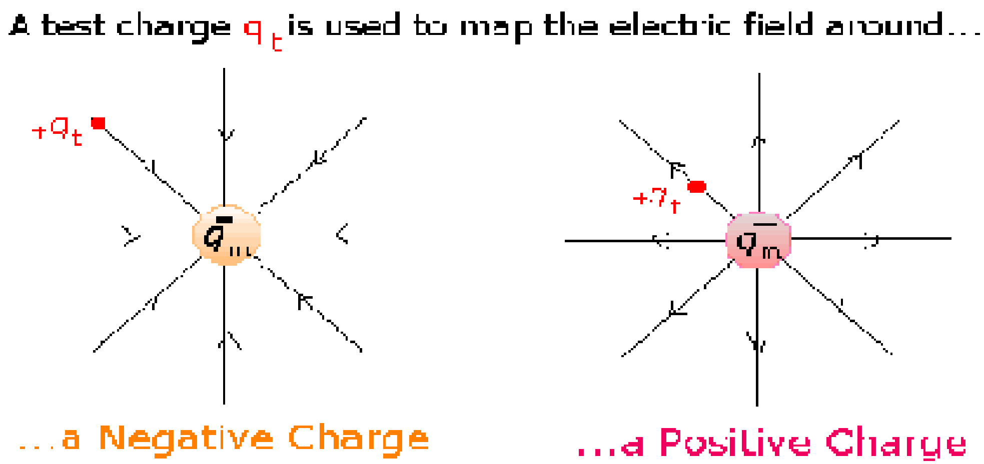
Let's consider the gravity field of our planet as shown below:



- **the lines are not in a flat plane. It is a 3-D field.**
- **the lines meet the surface of the earth at right angles.**
- **the lines never cross.**
- **where the field is strongest (near the earth) the lines are closest together.**
- **the direction of the field is always towards the source (the earth).**

The earth's mass is the source of the gravity field. The source of an electric field is charge. We will call it the source charge or main charge, q_m.

Electric fields are tested with a test charge (q_t). We will allow the main charge to be either positive or negative, but normally **fields are tested and mapped out by always using a positive charge (never negative). It is called a positive test charge.** The two pictures below show the behaviour of a positive test charge when brought near a main charge that is negative (on the left) and a main charge that is positive (on the right.)



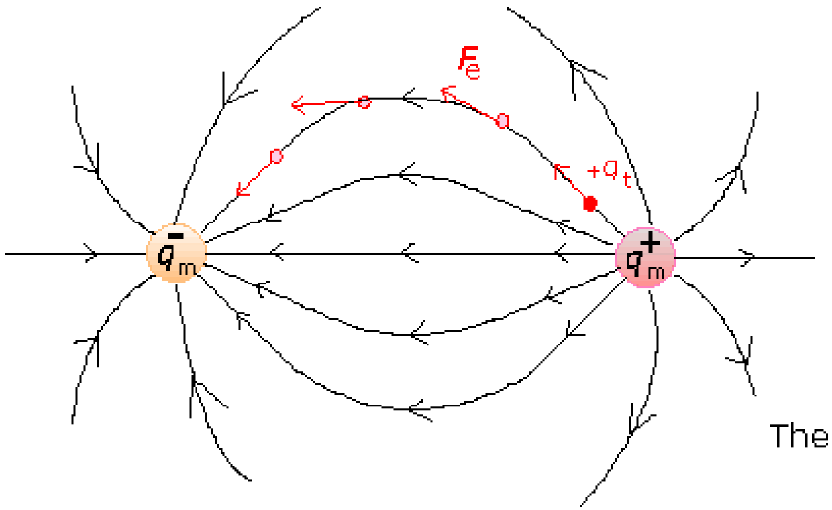
The gravity field is always directed towards the source mass, but the electric field is directed away from the source charge when the main charge is positive . This is because the main charge and the test charge have the same sign (positive).

All the other statements apply:

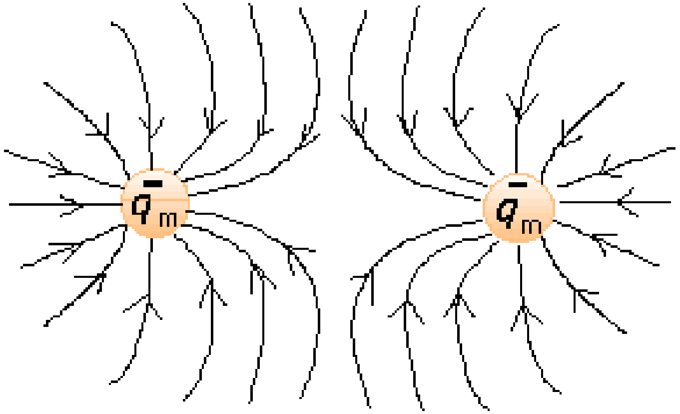
- **the lines are not in a flat plane. It is a 3-D field.**
- **the lines meet the surface of the main charge at right angles.**
- **the lines never cross.**
- **where the field is strongest (near the main charge) the lines are closest together.**
- **the direction of the field is always towards the main charge when that charge is negative but away from the main charge when that charge is positive. A better way to say this is electric field lines are in the direction that a positive test charge moves when brought near--the lines therefore originate on a positive source charge and end on a negative source charge.**

for some parallel expressions between the electric field and earth's gravitational field look at the top of p. 557 in your text.

The electric field in the vicinity of two opposite charges



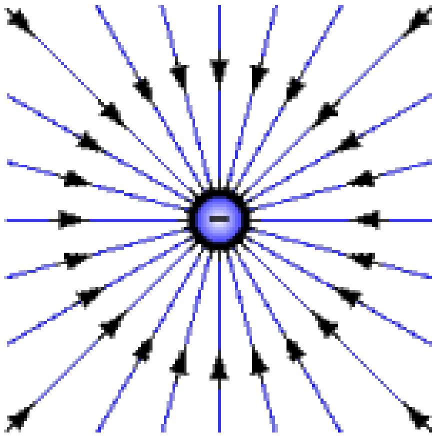
The electric field in the vicinity of two negative charges



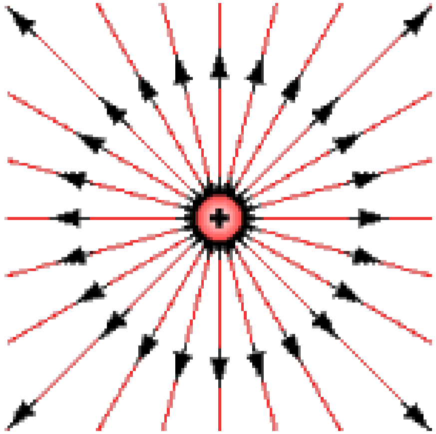
Some Common Electric Field Configurations

Note that the electric force (Fe) is always tangent to the field line.

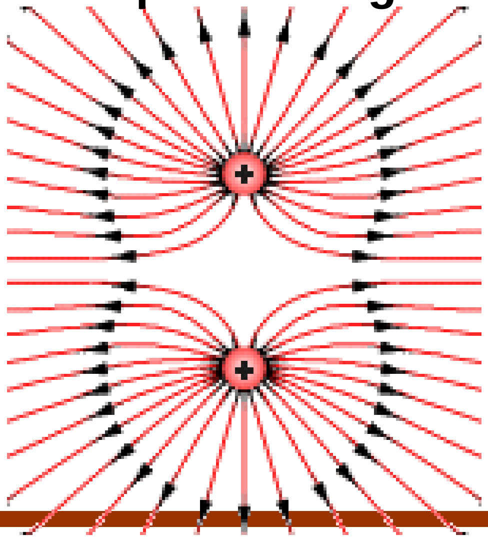
Negative point charge



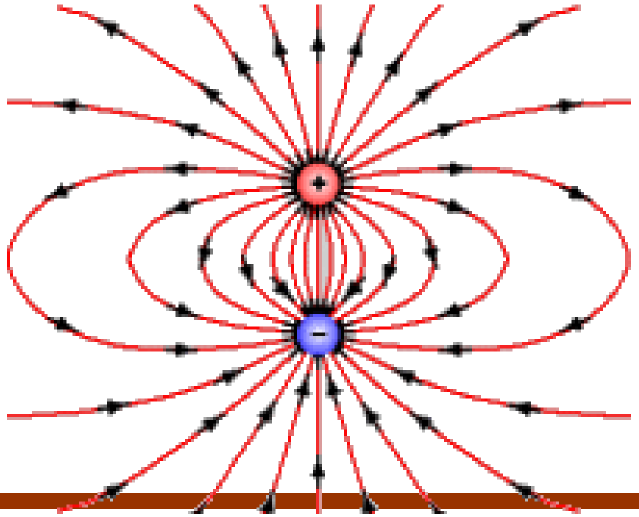
Positive point charge



Like point charges

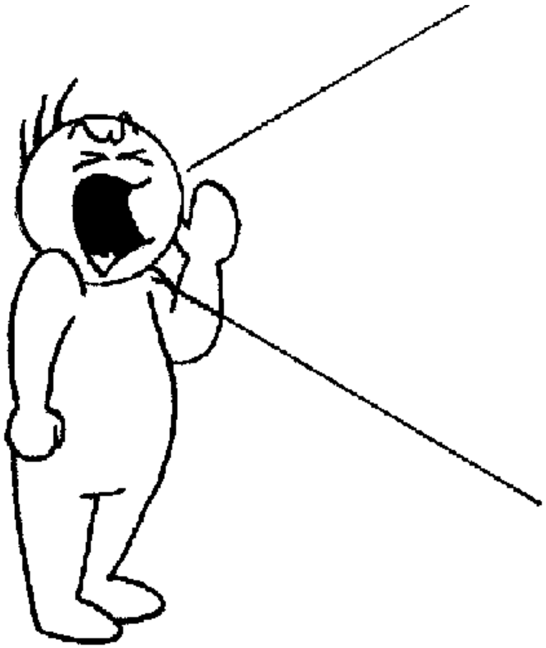


Unlike point charges



Activity

- In your textbook:
- p. 551--do #1 & #2.
- p. 579 - 580--do #8 - #16, #18, #20, #22, #30
- p. 583-584--#56-#58.



Section 1 Topic 6

- **ELECTRIC FIELD STRENGHT**

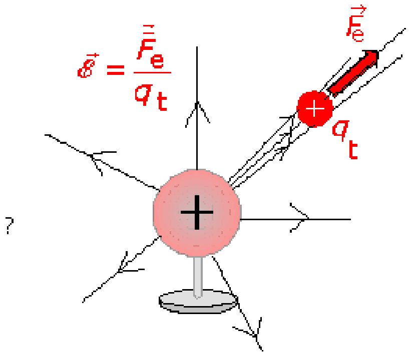
Text: 13.1 – 13.2

ELECTRIC FIELD STRENGTH

- Since an electric field exerts a force on a charge that is in the field, the field must also have strength.

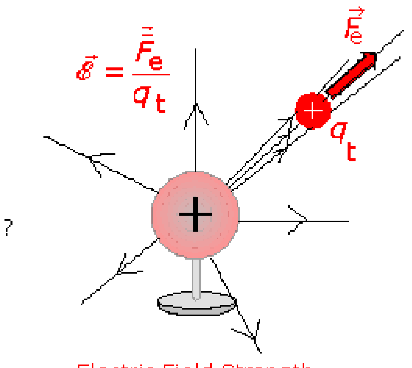
For Example:

A test charge in the picture is being repelled with an electric force of 10 N. Further, assume that the test charge q_t is 2.0 C.



Electric Field Strength

What is the force per coulomb on the test charge?



Answer

10 N on 2.0 C means 5 N per C, or 5 N/C.

5 N/C (or 10 N ÷ 2 C) is the Electric Field Strength represented by the symbol in the picture. Therefore, electric field strength at a particular point in the field is the force per unit charge at that point, or in mathematical terms:

$$\varepsilon = \frac{F_e}{q} \text{ (Vector quantity)}$$

The units of electric field strength are N/C. This is a vector quantity there for you will need magnitude and direction for the electric field strength. The term electric field strength is shortened to electric field

Example 1:

A test charge of 2.5 μC is brought into a field caused by a main charge and experiences a force of 7.5 x 10^{-2} N. What is the field strength in the vicinity of the test charge?

$$E = Fe / qt = (7.5 \times 10^{-2}\ N) / (2.5 \times 10^{-6}\ C)$$

$$= 3.0 \times 10^{4}\ N/C$$

Example 2

If a test charge of 2.5 µC of exercise 1 is removed, and a 5.0 µC test charge put in the exact same spot, what electric force will it experience?

The new test charge takes the exact spot of the original test charge, the field strength (E) at that point is 3.0×10^4 N/C (calculated in exercise 1) . The electric field strength is 3.0×10^4 N/C whether there is a test charge there or not.

Because $E = Fe / q_t$,

$$F_e = E \times q_t = 3.0 \times 10^4 \text{ N/C} \times 5.0 \times 10^{-6} \text{ C}$$

$$F_e = 1.5 \times 10^{-1} \text{ N.}$$

Example 3: (STUDENTS TRY)

The electric field in a certain neon sign is 5000 N/C.

A) What force does this field exert on the neon ion of mass 3.3×10^{-26} kg and a charge of a +e?

B) What is the acceleration of this ion?

Electric Field (ε)- PART 2 1/2

- In last two practice exercises there where no restrictions placed on the main charge (q_m) that causes the electric field. If we to restrict q_m to a point source, then we can derive another expression for E.

- Remember Coulomb's Law?

$$F_e = \frac{kq_1 q_2}{r^2}$$

If the source charge qm is a point charge, then for qm and qt Coulomb's Law becomes

$$F_e = \frac{k q_m q_t}{r^2}$$

Substitute this expression for F_e into $\mathcal{E} = \frac{F_e}{q_t}$ and simplify to get

$$\mathcal{E} = \frac{\frac{k q_m q_t}{r^2}}{q_t}$$

$$\mathcal{E} = \frac{k q_m \not{q_t}}{r^2} \times \frac{1}{\not{q}_t}$$

$$\mathcal{E} = \frac{k q_m}{r^2}$$

This gives two expressions for electric field strength. Use

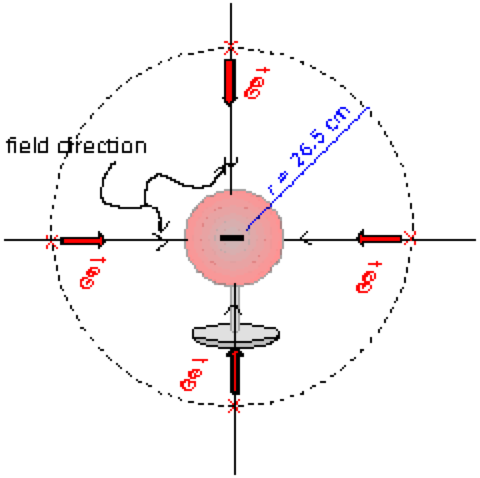
$\mathcal{E} = \dfrac{F_e}{q_t}$ when the main charge is unknown or not a point source.

Use $\mathcal{E} = \dfrac{kq_m}{r^2}$ when there is no test charge, and when both the main charge and the distance from the main charge are known. This expression reinforces the idea that the electric field has strength even if there are no test charges around. (You have strength even if you are not lifting anything).

Example 1

Calculate the field strength 26.5 cm from a charge of -9.7 μC.

Given:



$q_m = -9.7\ \mu C = -9.7 \times 10^{-6}\ C$

$r = 26.5\ cm = 0.265\ m$

$k = 9.0 \times 10^9\ Nm^2/C^2$

Here we are given the charge that is causing the field, as well as the distance r from this main charge, we must assume that q_m is a point charge

$$\mathcal{E} = \frac{kq_m}{r^2}$$

$$= \frac{9 \times 10^9\ \mathrm{Nm^2/C^2} \times {}^{-}9.7 \times 10^{-6}\ \mathrm{C}}{(0.265\ \mathrm{m})^2}$$

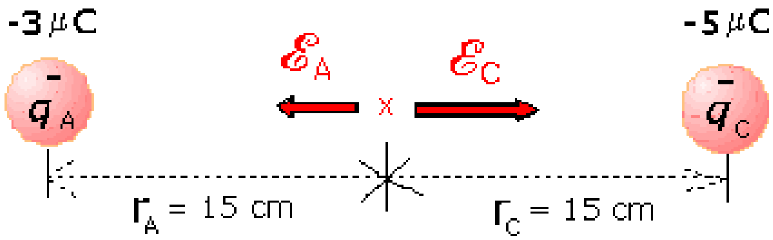
$$= {}^{-}1.2 \times 10^6\ \mathrm{N/C}$$

The negative sign indicates that the direction of the field strength is towards the main charge. Note that the field strength is in the same direction as the field lines, which is the direction that a positive test would move if place at point x in the field.

Example 2

Charges A, and C are in a straight line a distance 30.0 cm apart. Find the net electric field strength at the point midway between the charges. The charges are as follows:

A....................-3.0μC
C....................-5.0 μ C



givens and the unknown

q_A = -3.0μ C = -3.0×10^{-6} C

q_c = -5.0 μ C = -5.0×10^{-6} C

k = 9.0×10^{9} Nm^2/C^2
r_A = 15.0 cm = 0.15 m
r_C = 15.0 cm = 0.15 m
$E_{net} = E_A + E_C$ = ?

Calculate E_A and E_C

$$\mathcal{E}_A = \frac{kq_A}{(r_A)^2}$$

$$= \frac{9 \times 10^9\ Nm^2/C^2 \ \times \ {}^{-}3.0 \times 10^{-6}\ C}{(0.15\ m)^2}$$

$$= {}^{-}1.2 \times 10^6\ N/C$$

$$\text{and } \mathcal{E}_C = \frac{kq_B}{(r_C)^2}$$

$$= \frac{9 \times 10^9\ Nm^2/C^2 \ \times \ {}^{-}5.0 \times 10^{-6}\ C}{(0.15\ m)^2}$$

$$= {}^{-}2.0 \times 10^6\ N/C$$

The negative signs are just telling us that if a test charge were inserted between the main charges, it would be attracted to each of them. To find E_{net} assign a negative sign to E_A because it is to the left, and a positives sign to E_C because it is to the right.

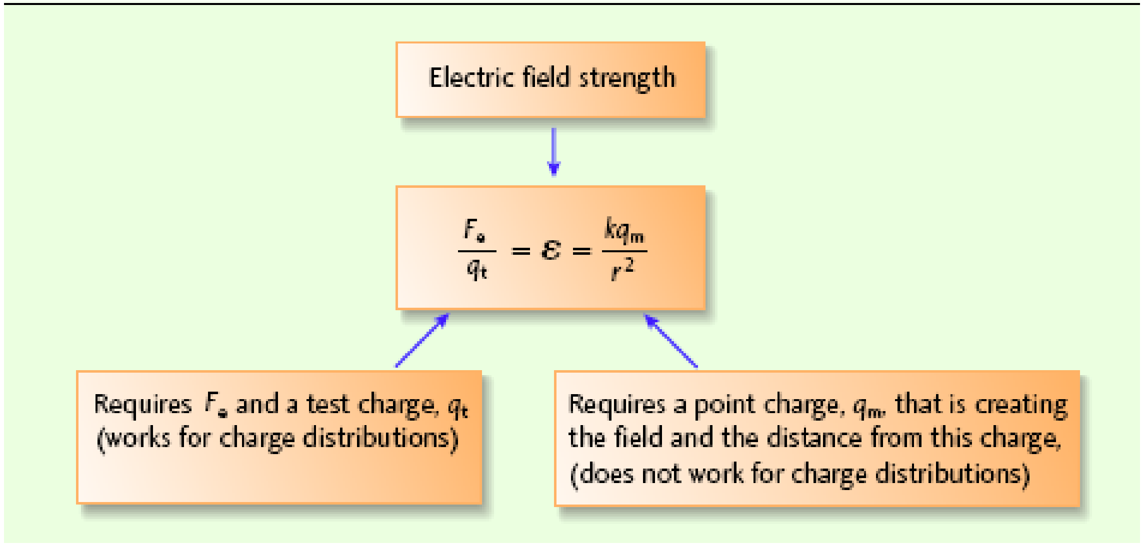
$$E_{net} = E_A + E_C = -1.2 \times 10^6\ N/C + +2.0 \times 10^6\ N/C$$

$$E_{net} = 0.8 \times 10^6\ N/C = 8.0 \times 10^5\ N/C.$$

Summary For Electric Fields

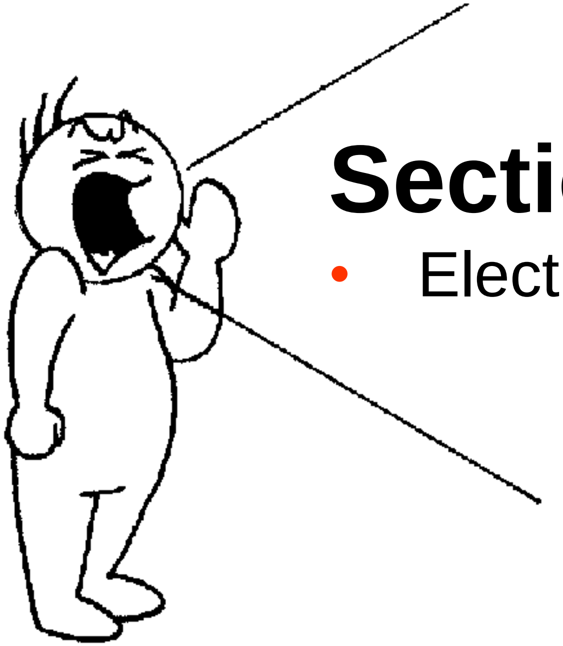
- **Electric Field or Electric Field Strength (E)**

- **Electric field or electric field strength at a particular point in the field is defined as the electric force per unit charge at that point. There were two formulas used:**



Activity

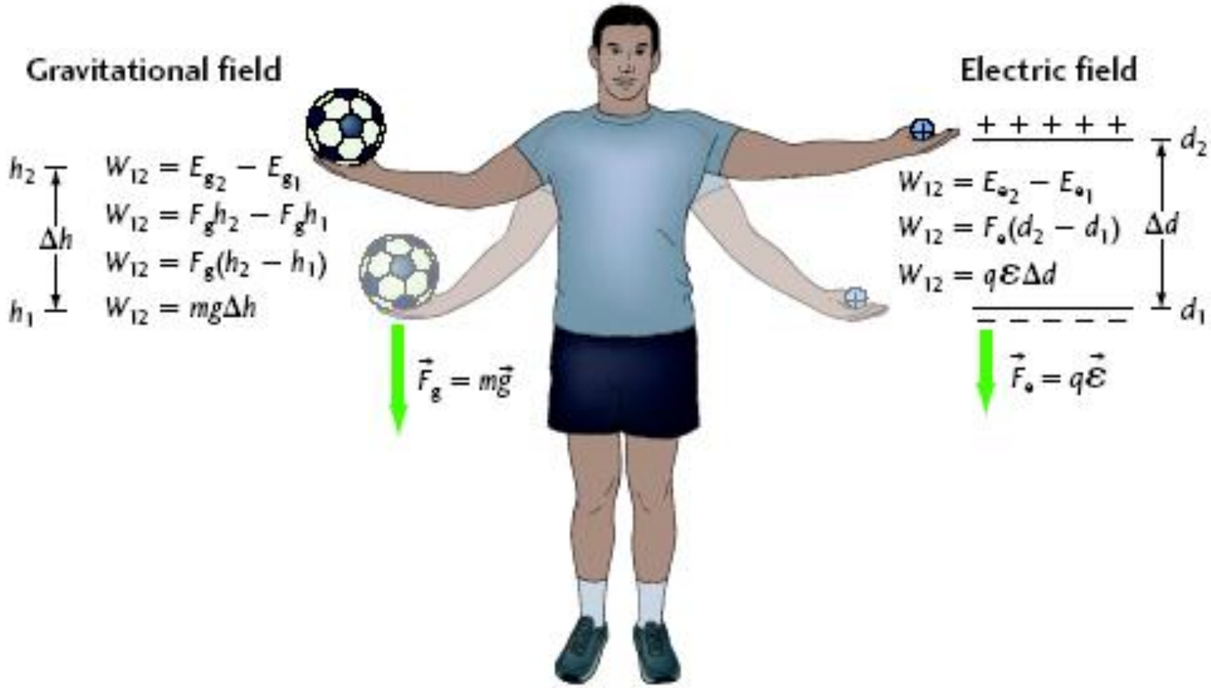
- on p. 557--do #1 - #4.
- on pp. 579 - 580--do #7, #17, #19



Section 1 Topic 7

- Electric Potential Energy,
  Electric Potential ,
  and
  Electric Potential difference

Text: 13.7 – 13.8

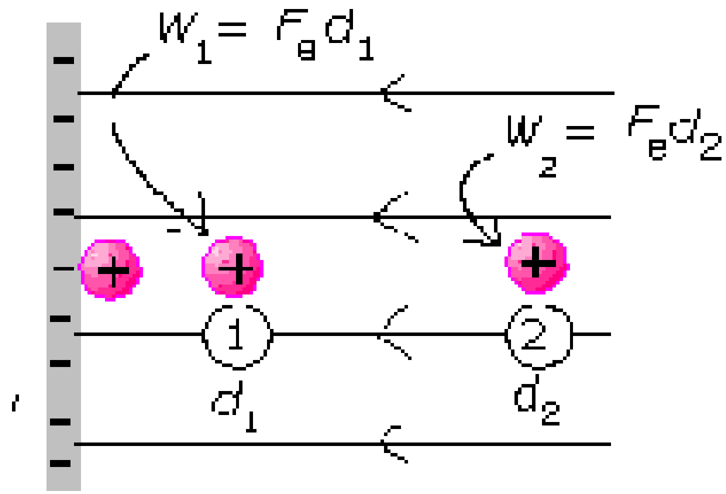


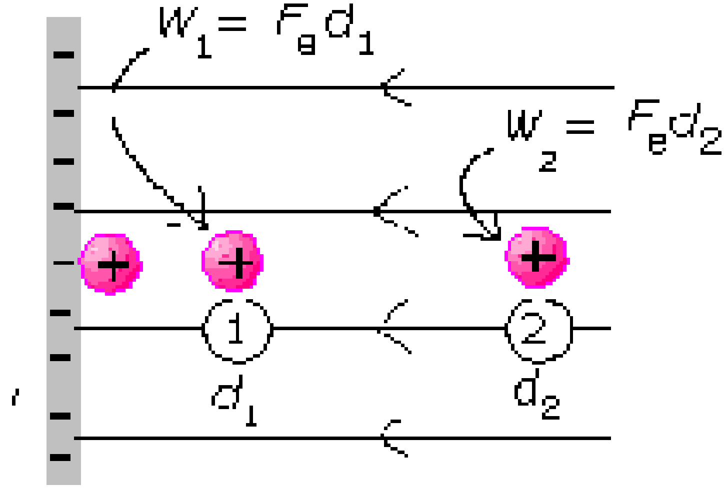
An electric force that displaces a charged particle from point A to point B does work on the particle. As a result, the charged particle has an increased *ability to do work*, or increased **electric potential energy, *E*e**. The work done in pushing the charge against the electric field is equal to the difference in the electric potential energy between point A and point B.

ELECTRIC POTENTIAL ENERGY (E_e) IN A UNIFORM FIELD

For a uniform field

- the lines of force are parallel which means that electric field strength ε is constant.
- ε is smiliar to g, the gravitational field strength in a uniform gravity field.





In the electrical situation above the positive charge would just love to stay on the negative plate. So, to get the charge to level 1 and then to level 2, work has to be done.

This time the force to overcome is not the force due to gravity, but is the electrical force, F_e.The change in potential energy is not a change in gravitational potential energy (E_g), but is called a change in electrical potential energy, E_e.

The work done in pushing the charge against the electric field is equal to the difference in the electric potential energy between point A and point B.

$$W_{12} = E_e = E_{e2} - E_{e1}$$

$$W_{12} = E_e = (F_e \times d_2) - (F_e \times d_1)$$

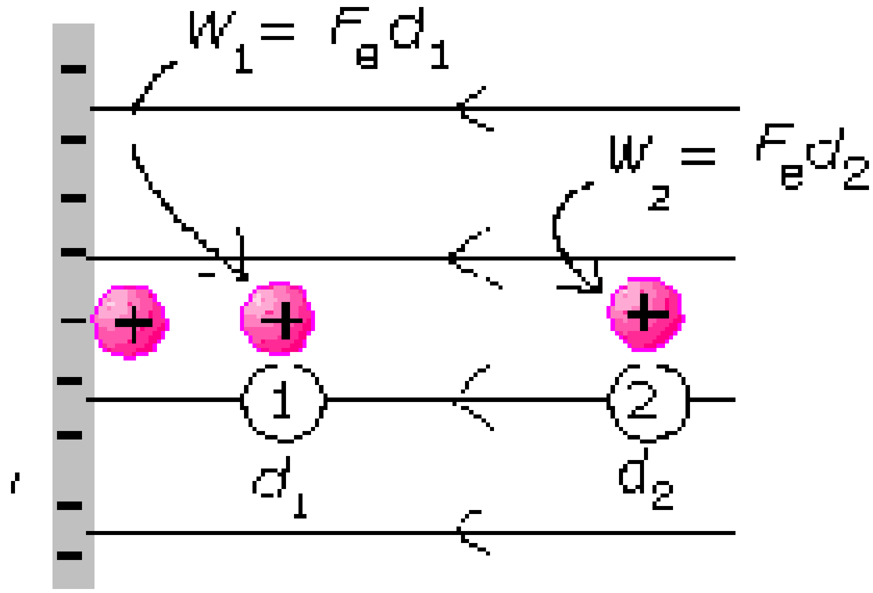
$$W_{12} = E_e = F_e (d_2 - d_1)$$

from the definition of electric field strength ($E = F_e/q_t$), we get

$Fe = q_t E$. Making this substitution for F_e gives

$$W_{12} = E_e = q_t E (d_2 - d_1).$$

This gives the change in electric potential energy when a charge moves from position 1 to position 2 in a uniform electric field



Note:

If the charge moves in the opposite direction, from position 2 to position 1, work is still done on the charge. This time it is the electric field that is doing the work and the charge loses potential energy. In the first case (from 1 to 2) work was done against the electric field and the charge gained potential energy.

Electrical Potential Energy for a uniform field is:

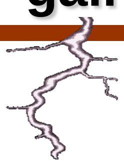
$$E_e = q_t E (d_2 - d_1) \text{ Or } E_e = q_t E (\Delta d)$$

Electrical potential energy is the energy gained (or lost) by a charge when it moves in an electric field. This energy is equal to the work done on the charge. Consequently, the units of measure are Joules (J) or Newtons •Meter (N•m)

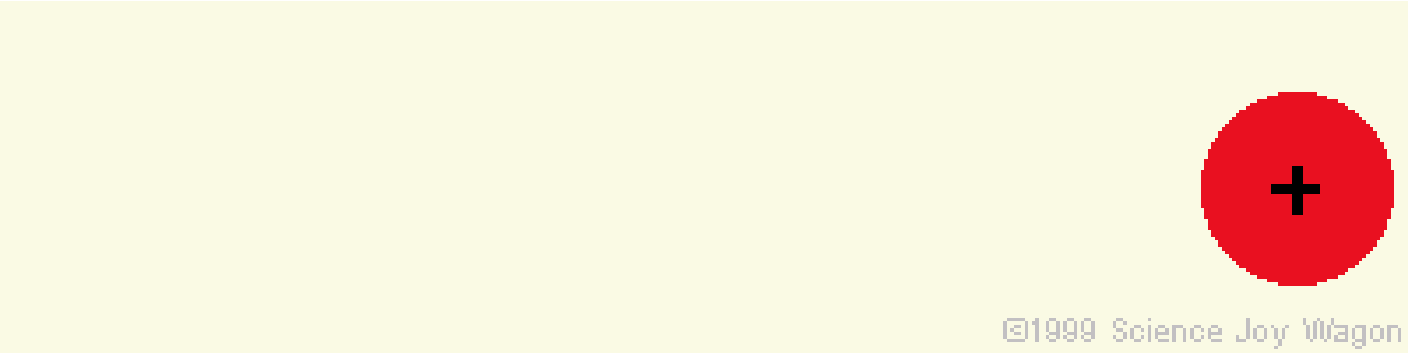
Electric potential energy is dependent upon at least two types of quantities:

1) **Electric charge - a property of the object experiencing the electrical field,**
2) **Distance from source - the location within the electric field**

If the charge moves in the opposite direction, from position 2 to position 1, work is still done on the charge. This time it is the electric field that is doing the work and the charge loses potential energy. In the first case (from 1 to 2) work was done against the electric field and the charge gained potential energy.



In order to bring two like charges near each other work must be done.   In order to separate two opposite charges, work must be done. Remember that whenever work gets done, energy changes form.



As the monkey does work on the positive charge, he increases the energy of that charge. The closer he brings it, the more electrical potential energy it has.   When he releases the charge, work gets done on the charge which changes its energy from electrical potential energy to kinetic energy. Every time he brings the charge back, he does work on the charge. If he brought the charge closer to the other object, it would have more electrical potential energy. Electrical potential energy could be measured in Joules just like any other form of energy.

Example 1:

What is the change in electric potential energy of a 2.0×10^{-6} C charge if the work done on it is 3.0×10^{-5} J?

Answer

$E_e = W_{12} = 3.0 \times 10^{-5}$ J.

Note: that since the work is given, there is no need to use the value of the test charge 2.0×10^{-6} C.

Example 2:

The electric field strength ϵ in a uniform field is 1000 N/C. What will be the change in electric potential energy (E_e) if a 2.15×10^{-6} C charge moves 0.12 m in the field?

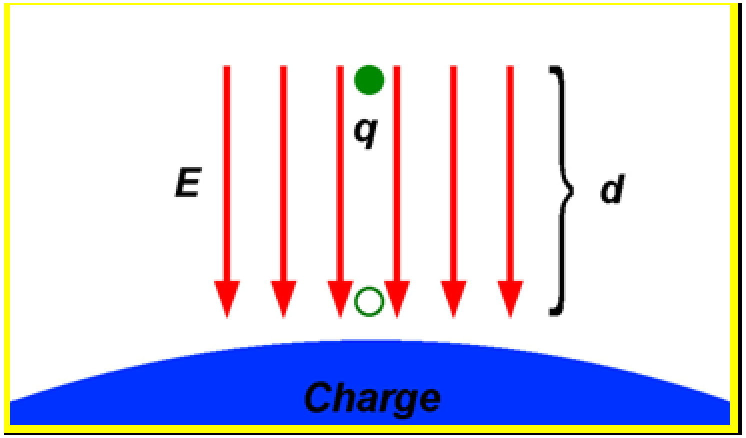
Solution

Givens:
ϵ = 1000 N/C,
q = 2.15×10^{-6} C
d = 0.12 m

$$E_e = q_t \epsilon \Delta d$$
$$= 2.15 \times 10^{-6}\ C \times 1000\ N/C \times 0.12\ m$$
= 2.6 x 10-4 J.

Example 3:

How much potential energy is converted when an electron is accelerated through 0.25 m in a cathode ray tube (TV set) with an electric field strength of 2.0×10^5 N/C?



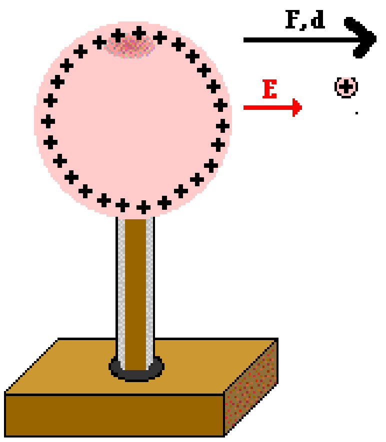
ELECTRIC POTENTIAL ENERGY – POINT CHARGE

You know that the change in electric potential energy = the work done on a charge

$$E_e = W = (F_e\, d)$$

According to Coulomb's Law, we can write the following for point charges:

$$Fe = (kq_m\, q_t)/r^2\ .$$



therefore

$$Ee = (kq_m\, q_t)/r^2\,) \bullet d$$

Remember d=r, therefore

$$Ee = (kq_m\, q_t)/r\,)$$

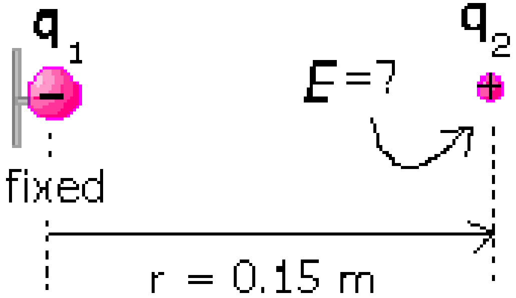
Electric Potential energy (work) is measured in Joules.

Example 1:

How much electrostatic potential energy in a hydrogen atom, which consists of one electron at a distance of 5.3 x 10^{-11} meters from the nucleus (proton).

Example 2:

A positive test charge (q_2) of 1.2×10^{-6} C is placed 15 cm from a fixed point charge of $+6.0 \times 10^{-5}$ C. What will be the change in electric potential energy (E_e) of the test charge if it moved to a position 0.05 m closer to q_1?



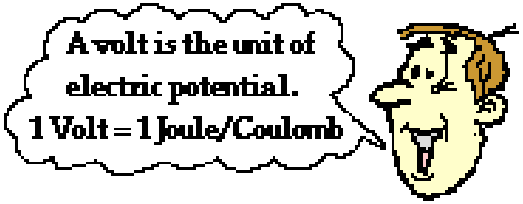
Activity

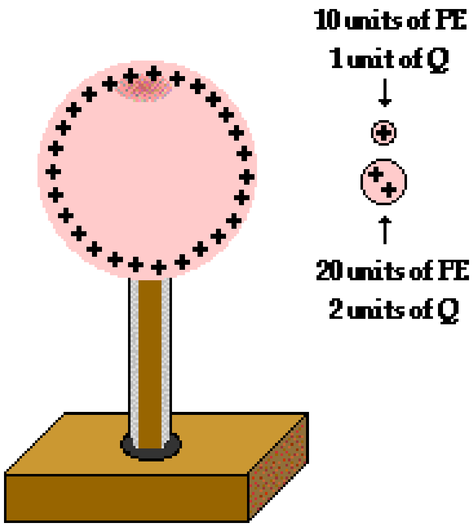
- on p. 561--do #1 & #2
- on p. 580--do #21,

ELECTRIC POTENTIAL (V) IN A UNIFORM FIELD

Electric potential - the potential energy per unit charge required to move charge from a region of zero potential .

$V = W/q_t$ OR $V = Ee/q_t$





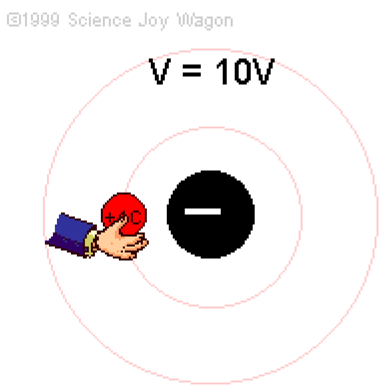
An object with twice the charge will experience twice the potential energy when placed at the same location. Yet the electric potential - the PE / charge is the same for both objects.

- unit is the volt (V) or (J/C)

- an example would be electrons sitting on the surface of a positively charged sphere or on the positive terminal of a battery.

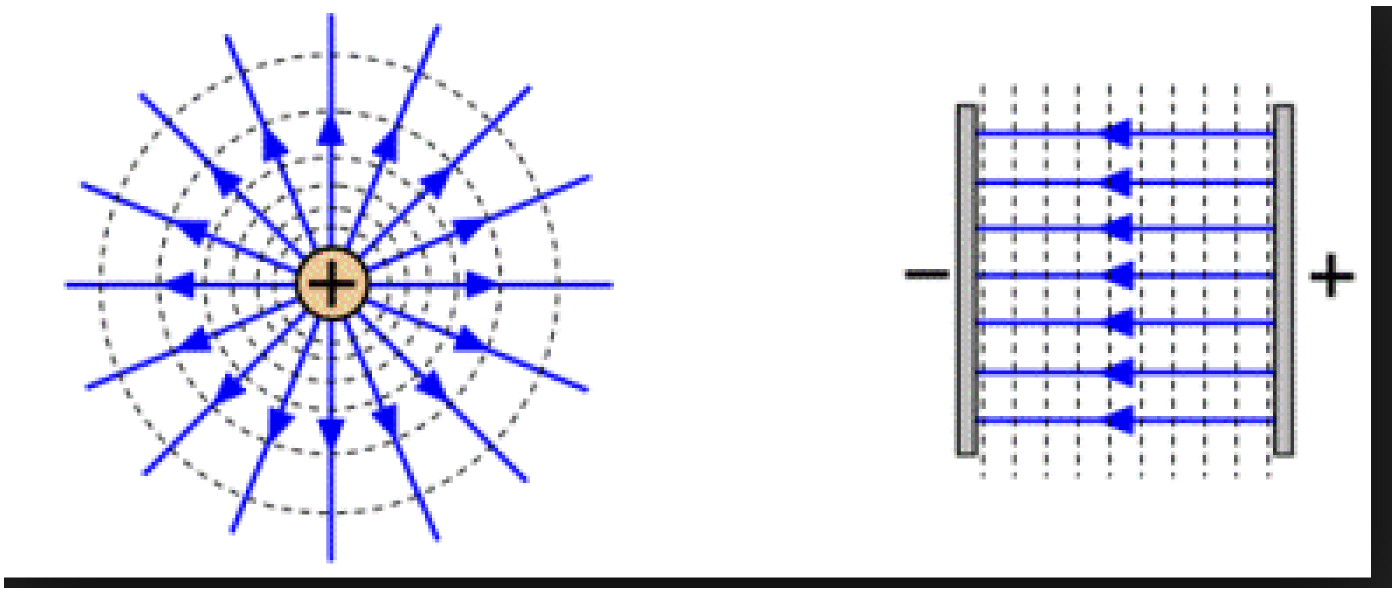
Equipotential Lines

Equipotential lines are lines connecting points of the same potential. They often appear on field line diagrams. Equipotential lines are always perpendicular to field lines, and therefore perpendicular to the force experienced by a charge in the field. **If a charge moves along an equipotential line, no work is done**



The animation to the left shows that no matter where the charge is dragged along that curve, the electric potential is the same. We call that curve an **equipotential line** since no matter where you go on the curve the electric potential is equal.

The blue indicates the electric field and the dotted lines indicate the equipotential lines

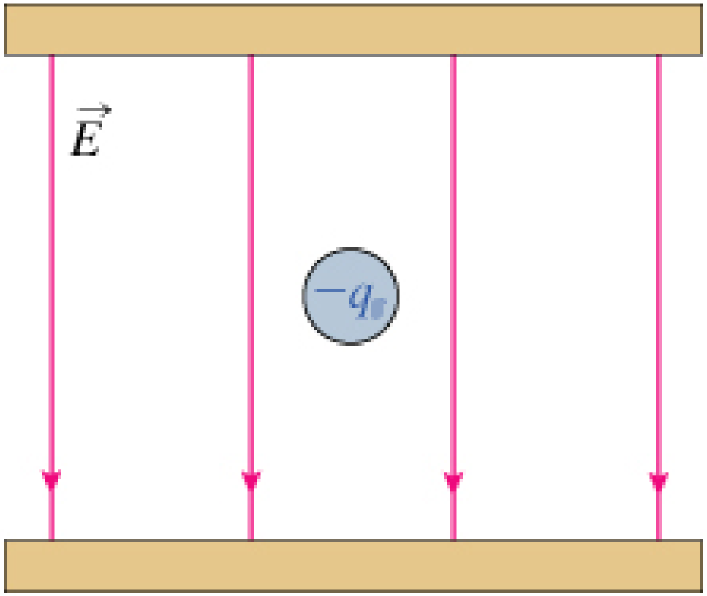


Electric Potential For a Uniform Field

V $= E_e \div q_t$

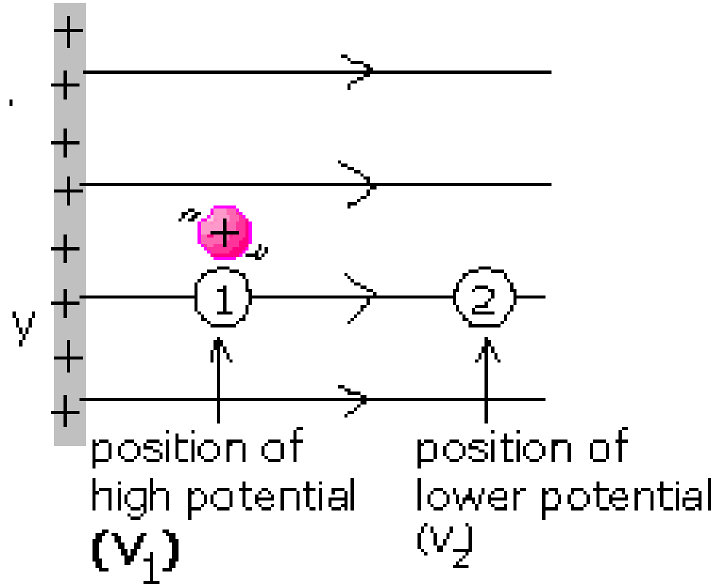
$= q_t \epsilon\ r \div q_t$ which gives

$V = \epsilon\ r$



Example 1:

Look at the charge in the picture. It's itching to move. Which way will it move if released?



Answer

It will move to a position of lower electric potential, say position 2.

For Non-uniform Field (Point Charge)

non-uniform field caused by a point charge, q_m:

$$V = \frac{E_E}{q}$$

Remember for a point charge that $E_e = \dfrac{kq_m q}{r}$

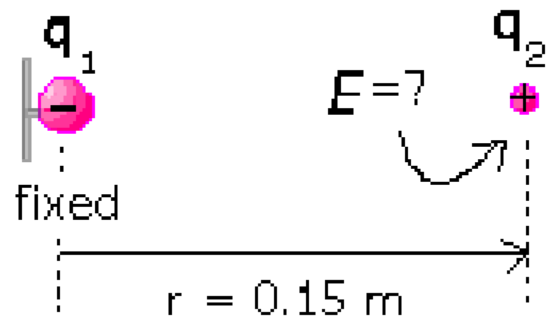
Therefore:

$$V = \frac{\frac{kq_m q}{r}}{q}$$

The test charge (q) cancels to give : $V = \dfrac{kq_m}{r}$

Example 2:

a positive test charge of 1.2 x 10^{-6} C is placed 15 cm from a fixed point charge of 6.0 x 10^{-5} C.   What is the electric potential?

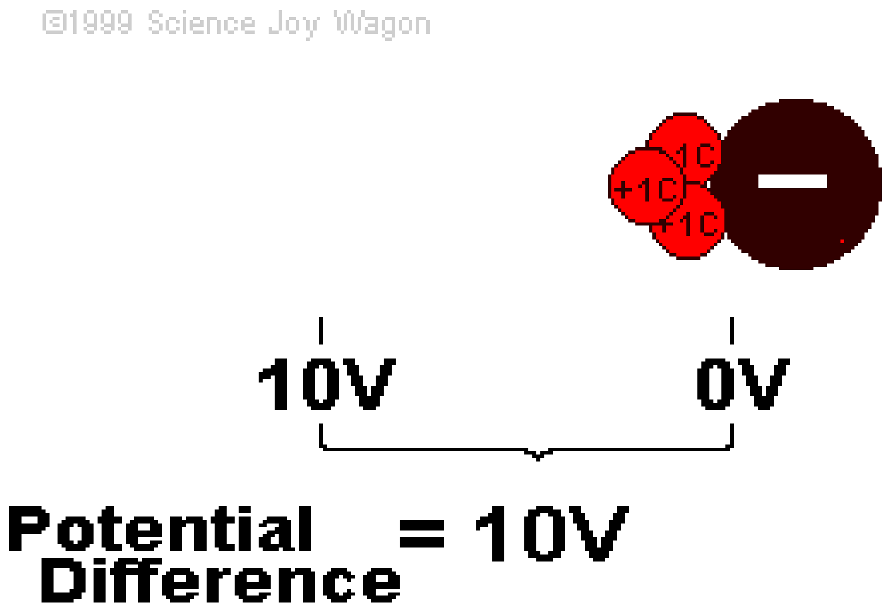


We are dealing with a non-uniform field. Using V = kq/r where it is understood that q is the master or main charge.

$$V = \frac{kq}{r} = \frac{9.0 \times 10^9 \, Nm^2/C^2 \times 6.0 \times 10^{-5} \, C}{(0.15m)^2} = 3.6 \times 10^6$$

ELECTIC POTENTIAL DIFFERENCE (voltage), (ΔV)

Electric potential difference refers to the change in electric potential The unit of electric potential and the change in electric potential or potential difference is J/C or volt.



Example 2:

A positive test charge of 1.2 x 10^{-6} C is placed 15 cm from a fixed point charge of 6.0 x 10^{-5} C. What is the potential difference between this position and a position that is only 5.0 cm from the main (fixed) charge?

Note: The word difference implies that the test charge must be moved from one position to another.

the original position is r_1=15 cm, and the new position is r_2 = 5 cm. You are asked to find V, the potential difference between the two positions.

$$\Delta V = V_2 - V_1 = \frac{kq}{r_2} - \frac{kq}{r_1} = kq\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

$$\Delta V = 9.0 \times 10^{9}\ \mathrm{N\cancel{m}^2/C^2} \times 6.0 \times 10^{-5}\ C\left(\frac{1}{0.05\ \cancel{m}} - \frac{1}{0.15\ \cancel{m}}\right)$$

$$\Delta V = 5.4 \times 10^{5}\ \mathrm{Nm/C}\ (20 - 6.7)$$

$$\Delta V = 7.2 \times 10^{6}\ \mathrm{J/C} = 7.2 \times 10^{6}\ \text{volts}$$

What is an electron-volt (eV)?

Remember that 1Coulomb of charge is a large amount. Also a Joule is a fairly large unit for work. These units don't work well if we are dealing with a small amount of charge. When Dealing with elementary charge (charge on 1 electron or proton), we need a smaller unit to measure energy or work in. The unit of the electron volt (eV) was developed. The electron volt is **not** a smaller unit for volts!!! It is a smaller unit for energy.

An electron volt is the amount of energy it takes to move an electron through a potential difference of 1volt.

remember,

$$V = Ee/q$$

In this special case, q = 1 electron = 1 e, and V = 1 volt.

So, (Ee) = q V = 1 e x 1 V = 1.602 x 10^{-19} C x 1 J/C

giving .... 1eV = 1.602 x 10^{-19} J

This is read as

1 electron-volt is equivalent to 1.602 x 10^{-19} joules.

Summing up the terminology

ϵ = electric field or electric field strength

F_e = electric force

q_t = test charge--sometimes written as q_2 or simply q

q_m = source or master or main charge causing the field--sometimes called q_1 or simply q

W = work done against the electric field or by the electric field

E_e = electric potential energy

V = electric potential or just potential

d = distance--sometimes written a r for distance from a point source

Summing up the formulas

For uniform fields

$$\mathcal{E} = \frac{F_e}{q_t} \quad \text{or} \quad F_e = \mathcal{E} q_t$$

$$W = F_e d, \quad W = \Delta E_e,$$

$$\therefore \Delta E_e = F_e d, \quad \text{or} \quad \Delta E_e = \mathcal{E} q_t d = \mathcal{E} q d$$

$$V = \frac{E_e}{q_t}, \quad \therefore V = \frac{\mathcal{E} q_t d}{q_t} = \mathcal{E} d$$

$$W = \Delta E_e, \quad \therefore W = \Delta V q_t = \Delta V q$$

For fields around a point charge only

$$E_e = F_e d = F_e r = \left(\frac{k q_m q_t}{r^2}\right) r$$

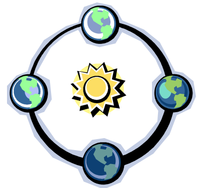
$$\therefore E_e = \frac{k q_m q_t}{r}, \quad \text{or} \quad E_e = \frac{k q_1 q_2}{r}$$

$$V = \frac{E_e}{q_t} = \frac{\frac{k q_m q_t}{r}}{q_t}, \quad \therefore V = \frac{k q_m}{r} \quad \text{or} \quad V = \frac{k q}{r}$$

	Gravitational	Electrical
Force	for fields due to point masses $\vec{F}_g = G\frac{m_1 m_2}{r^2}$ for uniform fields $\vec{F}_g = m\vec{g}$ unit: N	for fields due to point charges $\vec{F}_e = k\frac{q_1 q_2}{r^2}$ for uniform fields $\vec{F}_e = q\vec{E}$ unit: N
Field Strength	for fields due to point masses $\vec{g} = G\frac{m}{r^2}$ for uniform fields $\vec{g} = \frac{\vec{F}}{m}$ unit: $\frac{N}{kg}$	for fields due to point charges $\vec{E} = k\frac{q}{r^2}$ for uniform fields $\vec{E} = \frac{\vec{F}}{q}$ unit: $\frac{N}{C}$
Potential Energy	for fields due to point masses $E_g = G\frac{m_1 m_2}{r}$ for uniform fields $\Delta E_g = mg\Delta h$ unit: J	for fields due to point charges $E_e = k\frac{q_1 q_2}{r}$ for uniform fields $\Delta E_e = q\vec{E}\Delta x$ unit: J
Potential	for fields due to point masses $V_g = -G\frac{m}{r}$ for uniform fields $\Delta V_g = \vec{g} \bullet \Delta\vec{h}$ unit: $\frac{J}{kg}$	for fields due to point charges $V_e = k\frac{q}{r}$ for uniform fields $\Delta V_e = \vec{E} \bullet \Delta\vec{x}$ unit: $\frac{J}{C}$

Another Comparison

Gravitation



Force between two masses

$F_g = GMm/d^2$

$G = 6.67 \times 10^{-11}\ Nm^2/kg^2$

Gravitational Force Field(N/kg)

$g = F/m$

$F_g = mg$

Gravitational Potential Energy(Joules)

$W = F\, \Delta x$

$W = (mg)h$

$GPE = mgh$

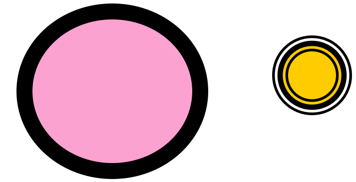
Gravitational Potential(J/kg)

G.P. = G.P.E./m

G.P. = mgh/m

G.P. = gh

Electricity



Force between two charges

$Fe = k\, qQ/d^2$

$K = 9.0 \times 10^9\ Nm^2/q^2$

Electric Force Field (N/C)

$E = F/q$

or

$F_e = Eq$

Electric Potential Energy(Joules)

$W = F\, \Delta x$

$W = (qE)d$

$Pe_e = qEd$

Electric Potential (J/C=volts)

E.P. =PEe/q

E.P. =qEd/q

E.P. =E * d

Potential Difference(v,volts)

P.E. = Δ E.P