EF01 ELECTRIC CHARGE & FORCES

SPH4U

CH 7 – KEY IDEAS

- define and describe concepts and units related to electric and gravitational fields
- state Coulomb's law and Newton's law of universal gravitation, and analyze, compare, and apply them in specific contexts
- compare the properties of electric and gravitational fields by describing and illustrating the source and direction of the field in each case
- apply quantitatively the concept of electric potential energy and compare it to gravitational potential energy
- analyze quantitatively, and with diagrams, electric fields and electric forces in a variety of situations
- describe and explain the electric field inside and on the surface of a charged conductor and how the properties of electric fields can be used to control the electric field around a conductor
- perform experiments or simulations involving charged objects
- explain how the concept of a field developed into a general scientific model, and describe how it affected scientific thinking

EQUATIONS

- Coulomb's Law

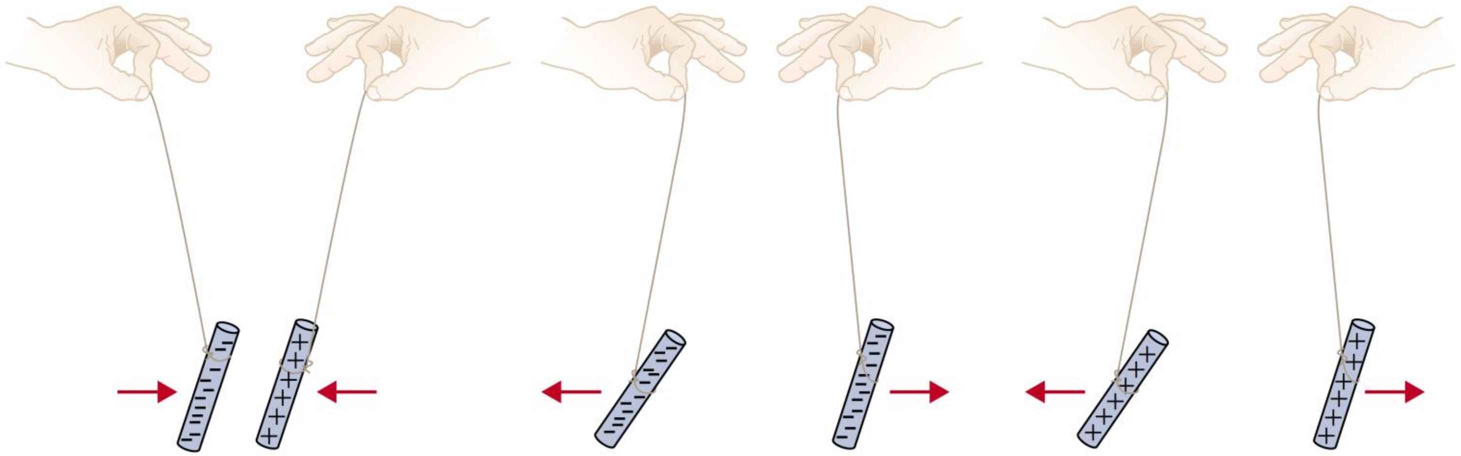
$$F_E = \frac{kq_1q_2}{r^2}$$

- Coulomb's Constant

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

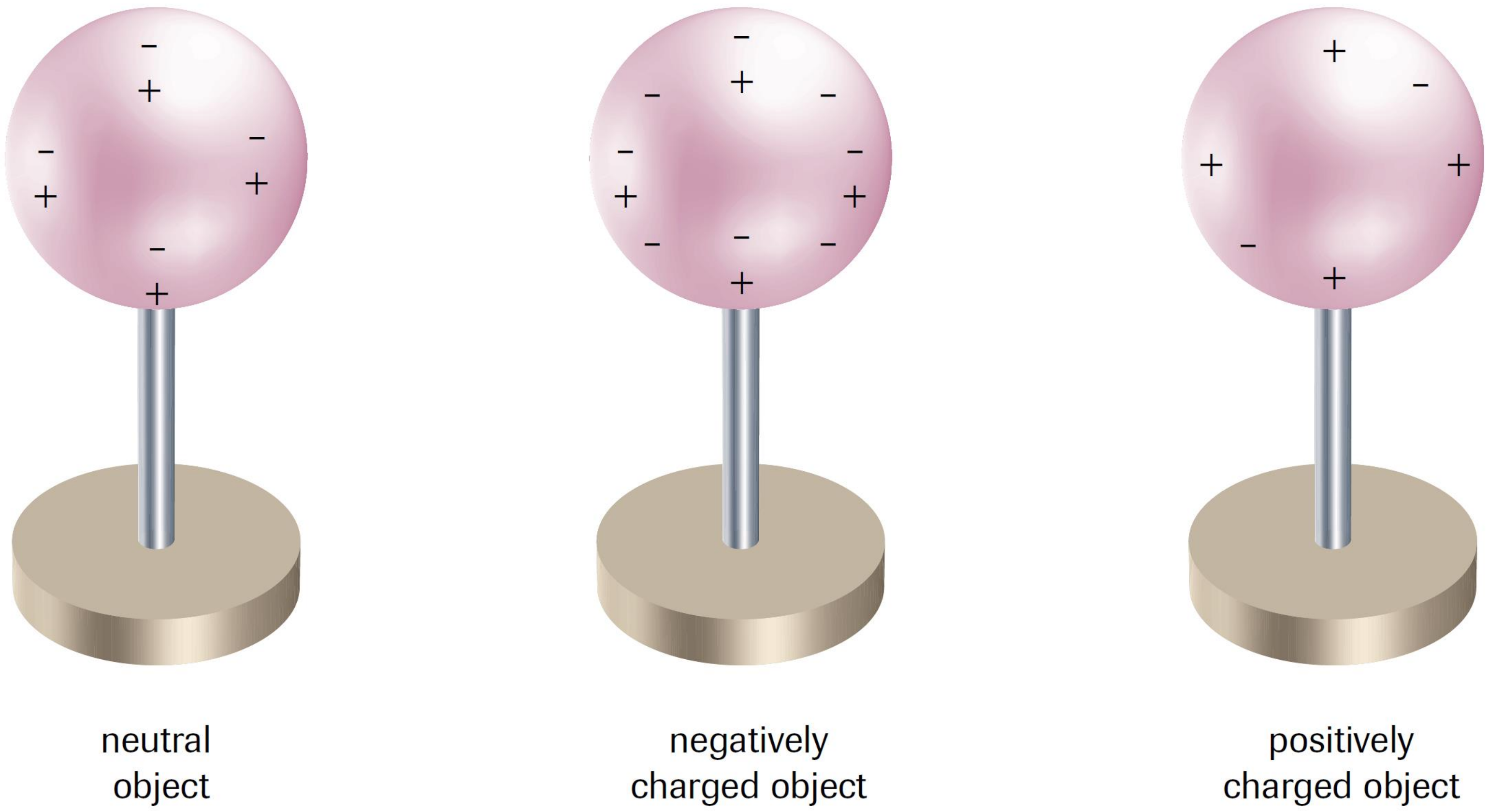
THE LAWS OF ELECTRIC CHARGES

- Opposite electric charges attract each other.
- Similar electric charges repel each other.
- Charged objects attract some neutral objects.



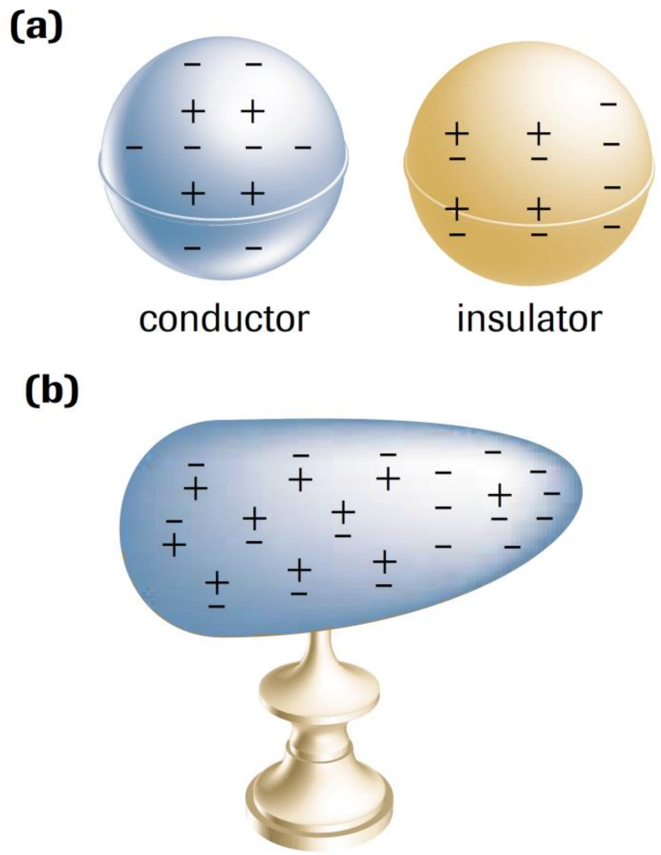
DRAWING CHARGED OBJECTS

- Recall:



DISTRIBUTING CHARGES

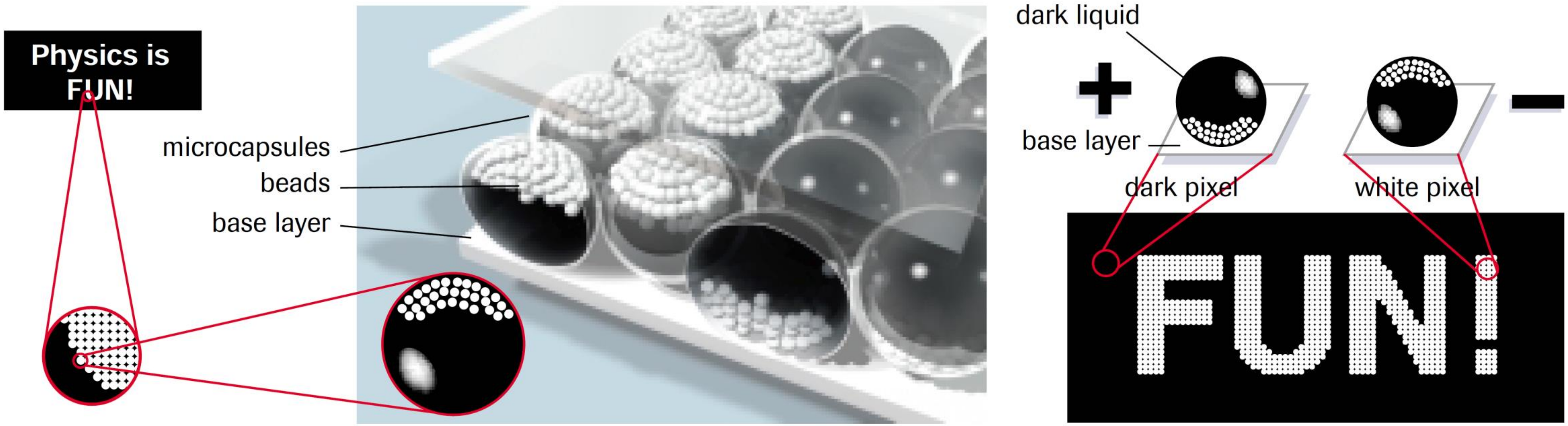
- **Insulators:** charges remain where they are introduced
- **Conductors:** charges disperse and spread out evenly
  - Non-spherical conductors: charges collect toward the more pointed surfaces
- **Liquid conductors:** need charge carriers (ions) as a part of the solution
- **Gas conductors:** X-rays or other radiation can form ions in air; humid air also contains mineral ions



ELECTRONIC INK

- An application of charged particles is electronic ink (eReader)
- Millions of microcapsules contain dozens of negatively charged white beads suspended in a dark liquid
- These microcapsules are sandwiched between insulating base and top layers
- Charging different locations of the base layer as positive or negative will control whether the beads sink or float, showing dark or light pixels

ELECTRONIC INK – CONT.



CHARGING BY FRICTION

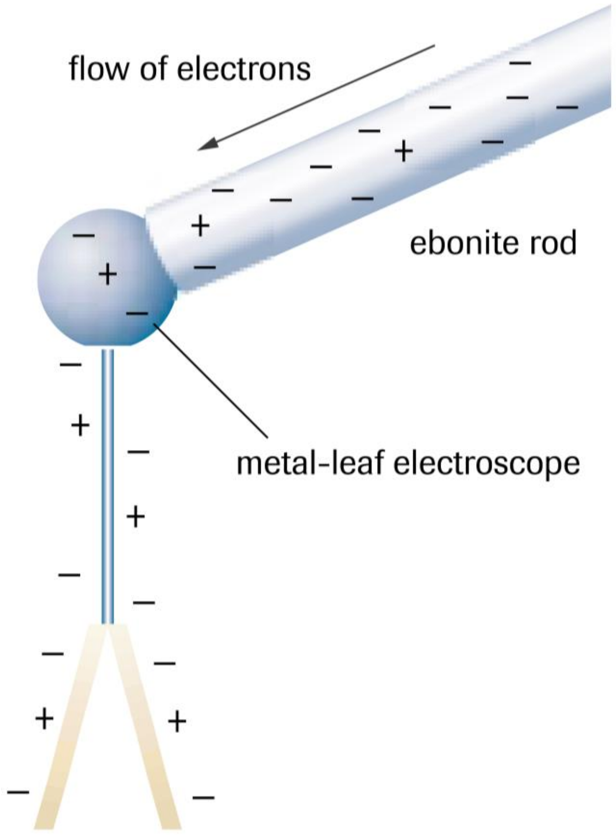
- When two substances have a great enough difference in their attraction to electrons, the electrons are transferred when they are rubbed together
- EX: ebonite rod and fur
  - the ebonite has a stronger attraction to the e^- than the fur
  - the electrons move from the fur to the ebonite
  - Ebonite is now negatively charged; the fur is positively charged
- Position on the Electrostatic Series determines the attraction to e^- and the resulting charges

ELECTROSTATIC SERIES

acetate	weak hold on electrons	
glass	↓	
wool		
cat fur, human hair		
calcium, magnesium, lead		increasing tendency
silk		to gain electrons
aluminum, zinc		
cotton		
paraffin wax		
ebonite		
polyethylene (plastic)		
carbon, copper, nickel		
rubber		
sulphur		
platinum, gold	strong hold on electrons	

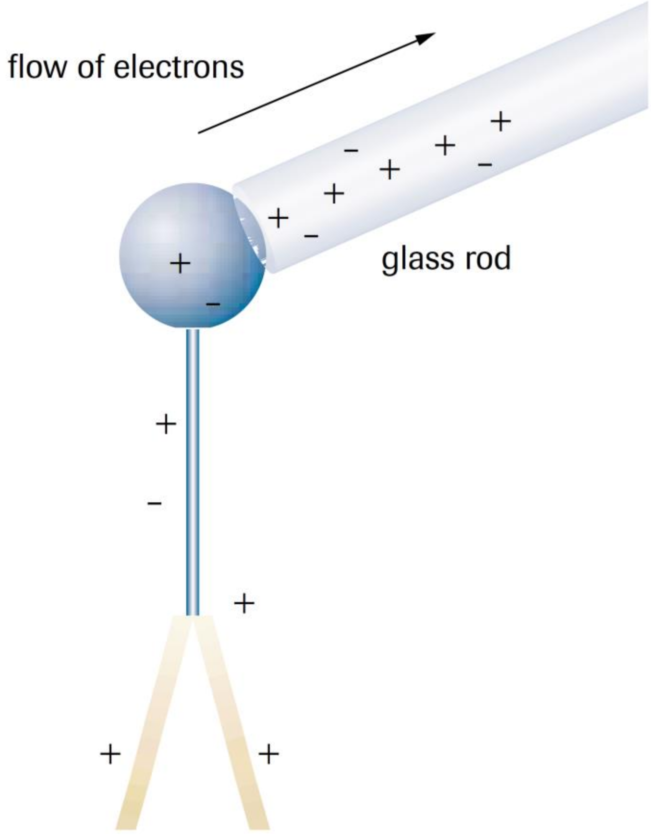
CHARGING BY CONTACT

- **Negative Charging:** excess e^- travel from negatively charged object onto the neutral object until equilibrium is reached
- NOTE: the metal leaves repel as they are both negatively charged



CHARGING BY CONTACT – CONT.

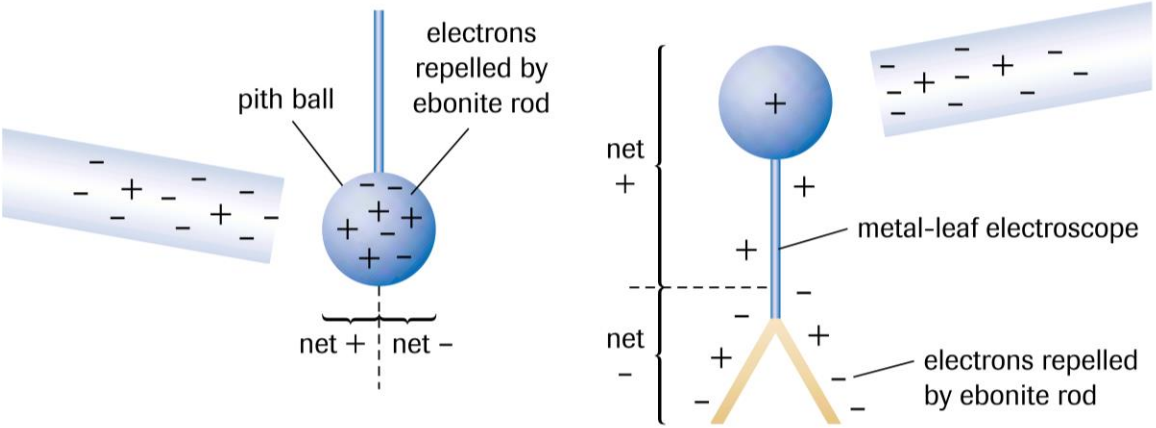
- **Positive Charging:** e^- travel from the neutral object onto the positively charged object until equilibrium is reached
- NOTE: the metal leaves repel as they are both positively charged



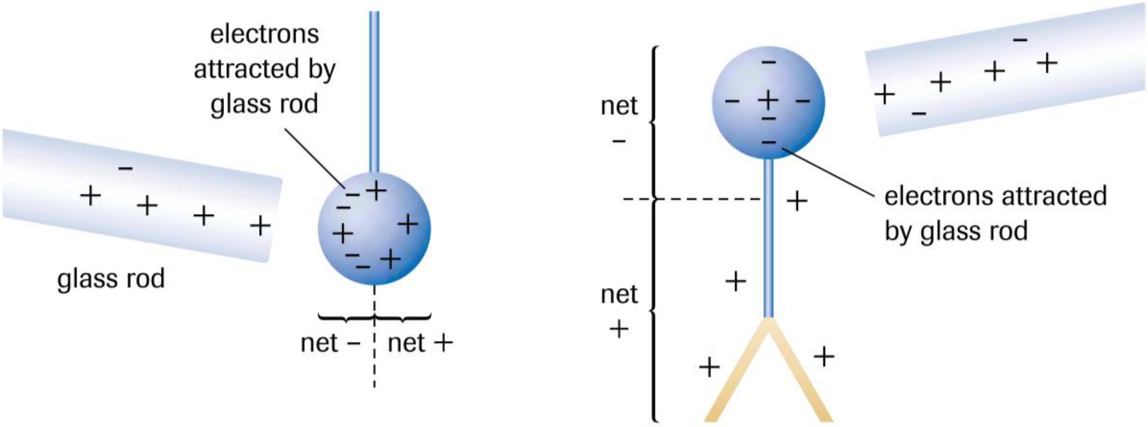
INDUCED CHARGE SEPARATION

- **Induced Charge Separation:** distribution of charge that results from a change in the distribution of electrons in or on an object

Negative

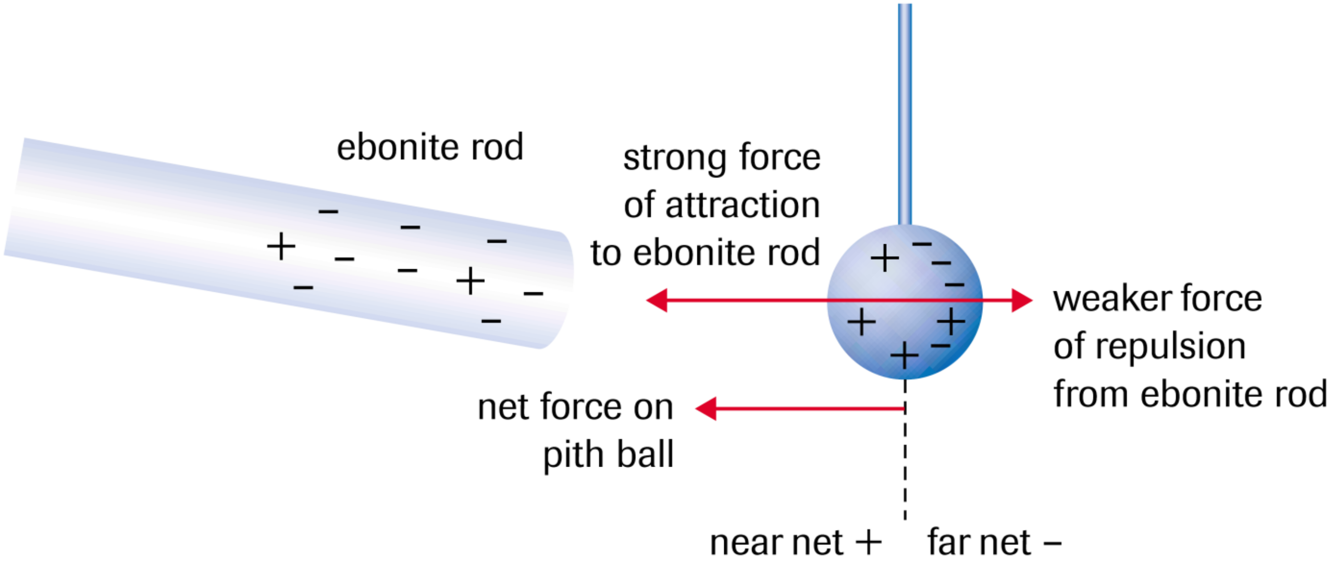


Positive



ATTRACTING NEUTRAL OBJECTS

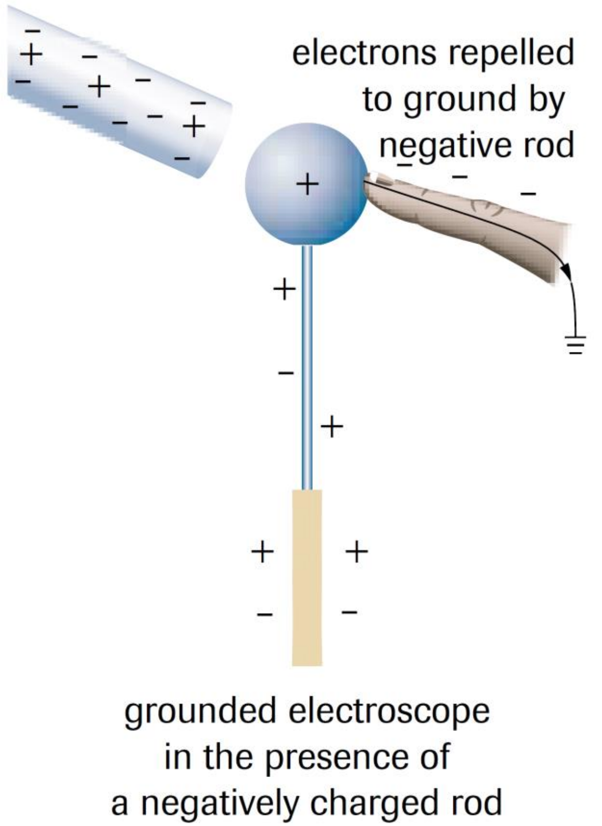
- In both cases, a strong attraction force causes the pith ball to attract to the charged rod

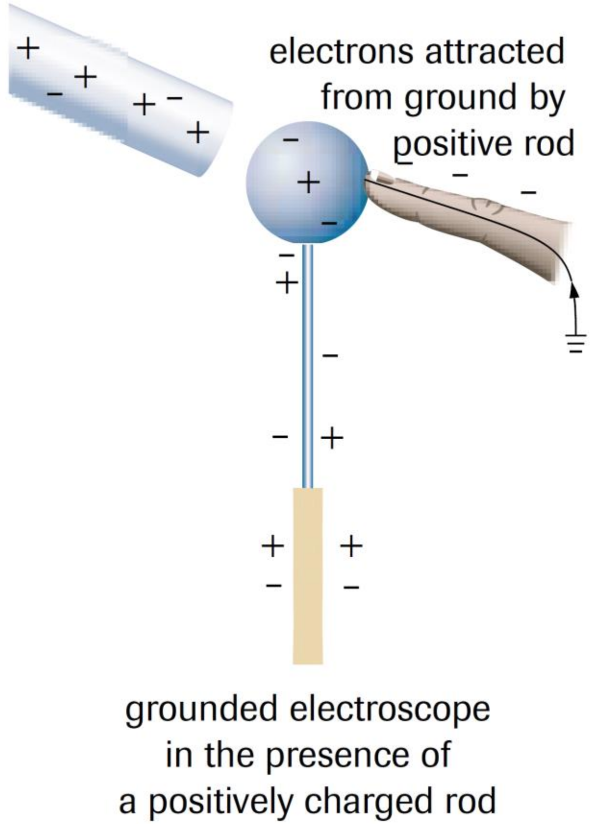


CHARGING BY INDUCTION

- **Law of Conservation of Charge:** The total charge (the difference between the amounts of positive and negative charge) within an isolated system is conserved.
- When you ground an object with an induced charge, it allows e^- to move freely
  - Positively charged: e- flow through the ground to the object
  - Negatively charged: e- flow through the ground from the object
- When the ground is removed, the object is now charged, even after the induced charge is removed

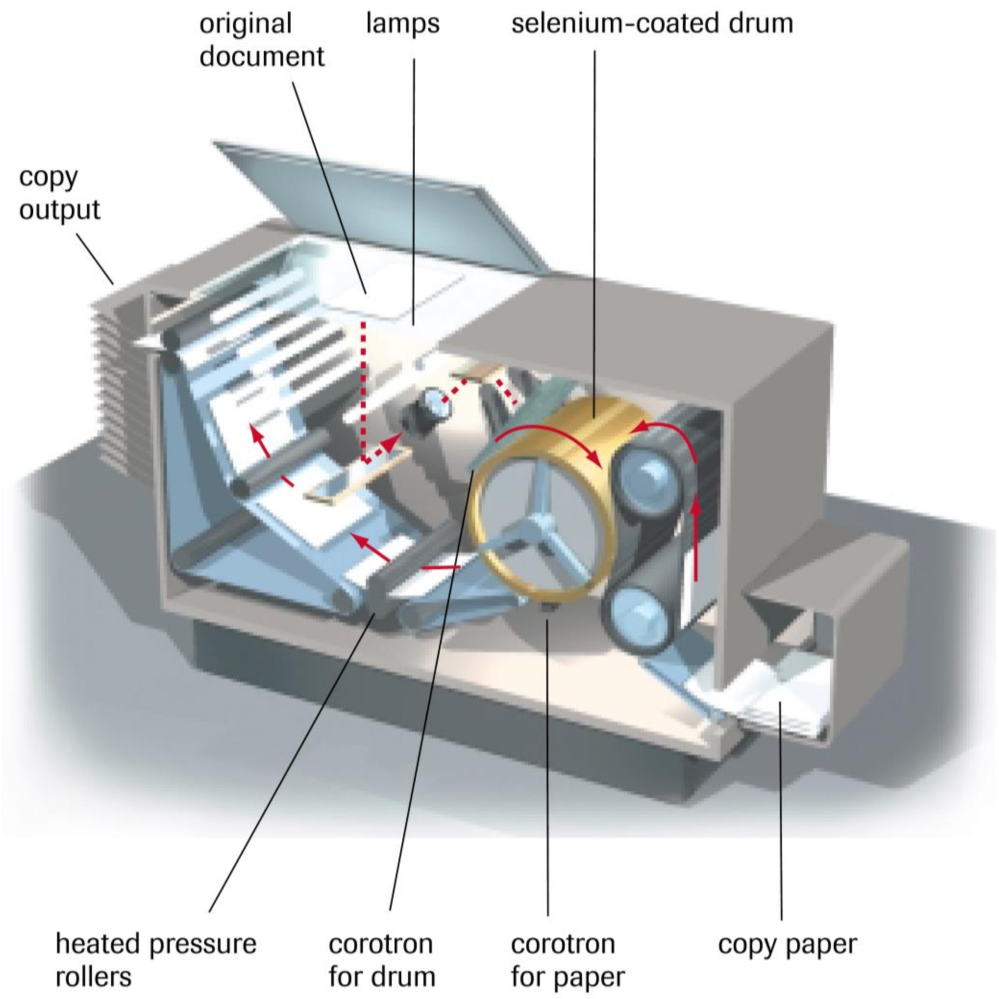
CHARGING BY INDUCTION – CONT.





THE PHOTOCOPIER

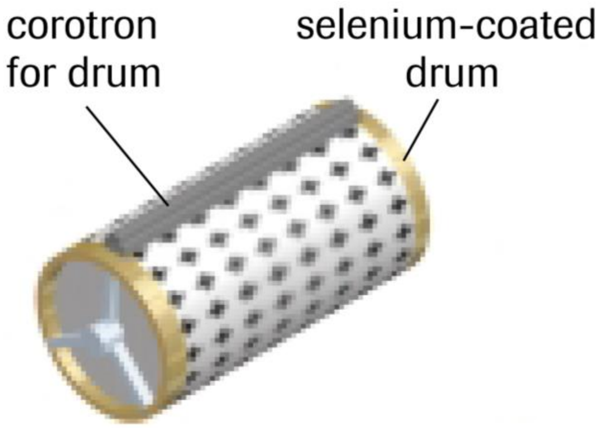
- Electrostatic Photocopying
  - Xerography – *xeros*, “dry”, *graphein*, “to write”
- Uses **photoconductors**
  - Insulator in the dark
  - Conductor in the light



THE PHOTOCOPIER – CONT.

1. Electrode (corotron) deposits positive charge to selenium in the dark (insulator).

- Selenium retains the charge unless exposed to light

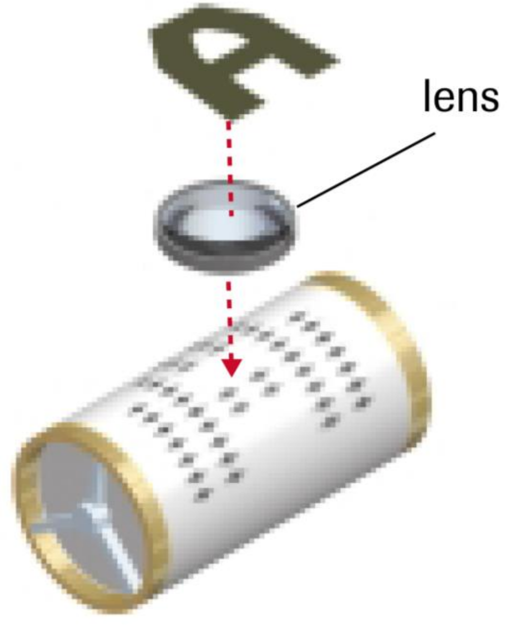


1. Charging the drum

THE PHOTOCOPIER – CONT.

2. Light reflects off the image through a series of mirrors and lenses.

- Where the image is white, light shines on the selenium and e^- flow from the aluminum and dispel the positive charge
- Where the image is dark, the light is blocked and the selenium retains the positive charge

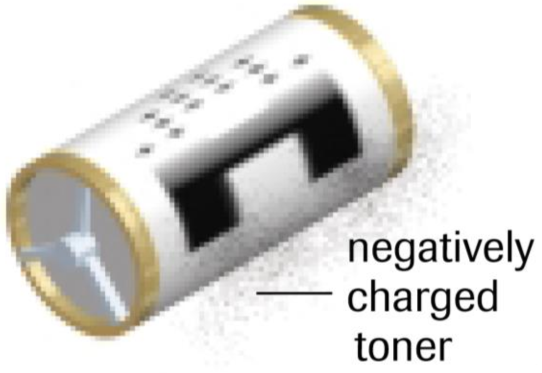


2. Imaging the document on the drum

THE PHOTOCOPIER – CONT.

3. Toner sticks to the drum in the shape of the image.

- Plastic toner particles are given a negative charge
- Toner is spread over the entire drum
- Particles attract to the positively charged selenium sections, forming the image
- Remain toner falls off to be used another time

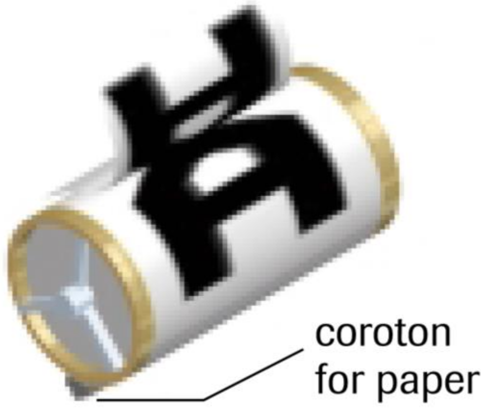


3. Fixing the toner to the drum

THE PHOTOCOPIER

4. Another corotron deposits positive charge onto the paper.

- Paper given a greater positive charge than the selenium
- Paper attracts the toner particles as it moves over selenium drum

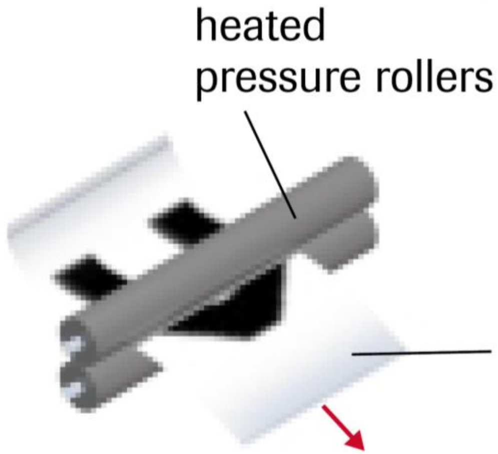


4. Transferring the toner to the paper

THE PHOTOCOPIER

5. Toner particles are melted onto the paper.

- Toner is dry, and so is the paper
- In order for the image to last, the paper and toner need to be heated to melt the plastic to the paper



5. Melting the toner into the paper

DERIVING COULOMB’S LAW

- Coulomb built an apparatus to measure the force required to bring to similarly charged spheres close together
- He determined that the force is inversely proportional to the distance between the centres of the spheres

$$F_E \propto \frac{1}{r^2}$$

DERIVING COULOMB'S LAW – CONT.

- Coulomb was also able to control the charges of the spheres
- He noticed, for example, that halving the charge on one sphere halved the force of electric repulsion, but halving the charges of both spheres decreased it by a factor of 4

$$F_E \propto q_1 q_2$$

- Combining these two observations, we notice

$$F_E \propto \frac{q_1 q_2}{r^2}$$

COULOMB'S LAW

- Coulomb's Law: The force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the product of the charges.

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

  - F_E – electric force (repel if same, attract if opposite) [N]
  - k – Coulomb's constant [N m^2/C^2]
  - q_1, q_2 – magnitudes of charges of two spheres [C]
  - r – distance between the centres of the spheres [m]

COULOMB'S CONSTANT

- Coulomb (C): the SI unit of electric charge
- To find the value of Coulomb's constant, k, we can measure the other components of Coulomb's Law, which give

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

- Through great care and detailed measurements, the accepted value for k is

$$k = 9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2}$$

PROBLEM 1

The magnitude of the electrostatic force between two small, essentially pointlike, charged objects is 5.0×10^{-5} N. Calculate the force for each of the following situations:

(a) The distance between the charges is doubled, while the size of the charges stays the same.

(b) The charge on one object is tripled, while the charge on the other is halved.

(c) Both of the changes in (a) and (b) occur simultaneously.

PROBLEM 1 – SOLUTIONS

$F_1 = 5.0 \times 10^{-5}$ N

$F_2 = ?$

(a) Since $F_E \propto \frac{1}{r^2}$,

$$\frac{F_2}{F_1} = \left(\frac{r_1}{r_2}\right)^2$$

$$F_2 = F_1\left(\frac{r_1}{r_2}\right)^2$$

$$= (5.0 \times 10^{-5}\ \text{N})\left(\frac{1}{2}\right)^2$$

$$F_2 = 1.2 \times 10^{-5}\ \text{N}$$

When the distance between the charges is doubled, the magnitude of the force decreases to 1.2×10^{-5} N.

PROBLEM 1 – SOLUTIONS CONT.

(b) Since $F_E \propto q_A q_B$,

$$\frac{F_2}{F_1} = \frac{q_{A_2} q_{B_2}}{}$$

$$F_2 = F_1\left(\frac{q_{A_2}}{q_{A_1}}\right)\left(\frac{q_{B_2}}{q_{B_1}}\right)$$

$$= (5.0 \times 10^{-5}\ \text{N})\left(\frac{1}{2}\right)\left(\frac{3}{1}\right)$$

$$F_2 = 7.5 \times 10^{-5}\ \text{N}$$

When the charge on one object is tripled, and the charge on the other object is halved, the magnitude of the force increases to 7.5×10^{-5} N.

PROBLEM 1 – SOLUTIONS CONT.

(c) Since $F_E \propto \frac{q_A q_B}{r^2}$,

$$\frac{F_2}{F_1} = \left(\frac{q_{A_2} q_{B_2}}{}\right)\left(\frac{r_1}{r_2}\right)^2$$

$$F_2 = F_1\left(\frac{q_{A_2}}{q_{A_1}}\right)\left(\frac{q_{B_2}}{q_{B_1}}\right)\left(\frac{r_1}{r_2}\right)^2$$

$$= (5.0 \times 10^{-5}\ \text{N})\left(\frac{1}{2}\right)\left(\frac{3}{1}\right)\left(\frac{1}{2}\right)^2$$

$$F_2 = 1.9 \times 10^{-5}\ \text{N}$$

When the charges and the separation from (a) and (b) change simultaneously, the magnitude of the force decreases to 1.9×10^{-5} N.

COULOMB'S LAW VS THE LAW OF UNIVERSAL GRAVITATION

- Coulomb's Law

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

- Universal Law of Gravitation

$$F_G = \frac{Gm_1m_2}{r^2}$$

- These equations are obviously very similar in structure, which leads to the conclusion that there are other parallels between electricity and gravitation
- Key differences:
  - F_E can attract or repel, F_G only attracts
  - G is very small, so F_G can be ignored unless one mass is very large
  - k is very large, so even small charges can result in noticeable forces

PROBLEM 2

Charged spheres A and B are fixed in position (**Figure 6**) and have charges $+4.0 \times 10^{-6}$ C and -2.5×10^{-7} C, respectively. Calculate the net force on sphere C, whose charge is $+6.4 \times 10^{-6}$ C.

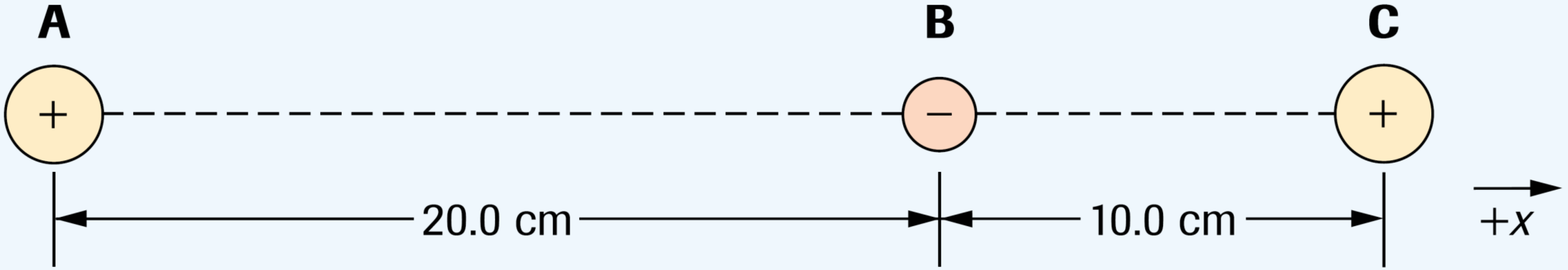


Figure 6

PROBLEM 2 – SOLUTIONS

$q_A = +4.0 \times 10^{-6}$ C $\qquad r_{AB} = 20.0$ cm

$q_B = -2.5 \times 10^{-7}$ C $\qquad r_{BC} = 10.0$ cm

$q_C = +6.4 \times 10^{-6}$ C $\qquad \sum \vec{F}_{net} = ?$

Since all three charges are in a straight line, we can take the vector nature of force into account by assigning forces to the right as positive. Sphere C has forces acting on it from spheres A and B. We first determine the magnitude of the force exerted on C by A:

$$F_{CA} = \frac{kq_A q_C}{{r_{CA}}^2}$$

$$= \frac{(9.0 \times 10^9 \text{ N·m}^2/\text{C}^2)(4.0 \times 10^{-6} \text{ C})(6.4 \times 10^{-6} \text{ C})}{(0.30 \text{ m})^2}$$

$$F_{CA} = 2.6 \text{ N}$$

Therefore, $\vec{F}_{CA} = 2.6$ N [right].

PROBLEM 2 – SOLUTIONS CONT.

Next, we determine the magnitude of the force exerted on C by B:

$$F_{CB} = \frac{kq_B q_C}{{r_{CB}}^2}$$

$$= \frac{(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(2.5 \times 10^{-7}\ \text{C})(6.4 \times 10^{-6}\ \text{C})}{(0.10\ \text{m})^2}$$

$$F_{CB} = 1.4\ \text{N}$$

Our formulation of Coulomb's law gives only the magnitude of the force. But since B and C are dissimilar charges, we know that B attracts C leftward, so the direction of the force exerted on C by B is

$$\vec{F}_{BC} = 1.4\ \text{N [left]}$$

PROBLEM 2 – SOLUTIONS CONT.

The net force acting on sphere C is the sum of $\vec{F}_{CA}$ and $\vec{F}_{CB}$:

$$\sum\vec{F} = \vec{F}_{CA} + \vec{F}_{CB}$$

$$= 2.6\ \text{N [right]} + 1.4\ \text{N [left]}$$

$$\sum\vec{F} = 1.2\ \text{N [right]}$$

The net force acting on sphere C is 1.2 N [right].

SUMMARY – ELECTRICAL CHARGE AND THE ELECTRICAL STRUCTURE OF MATTER

- The laws of electric charges state: opposite electric charges attract each other; similar electric charges repel each other; charged objects attract some neutral objects.
- There are three ways of charging an object: by friction, by contact, and by induction.

SUMMARY – ELECTRIC FORCES: COULOMB'S LAW

- Coulomb's law states that the force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the product of the charges:

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

  - $k = 9.0 \times 10^9\ \text{Nm}^2/\text{C}^2$
- Coulomb's law applies when the charges on the two spheres are very small, and the two spheres are small compared to the distance between them.
- There are similarities and differences between Coulomb's law and Newton's law of universal gravitation:
  - Both are inverse square laws that are also proportional to the product of quantities that characterize the bodies involved;
  - the forces act along the line joining the two centres of the masses or charges; and
  - the magnitude of the force is accurately given by the force that would be measured if all the mass or charge is concentrated at a point at the centre of the sphere. However, the gravitational force can only attract while the electric force can attract or repel. The universal gravitational constant is very small, while Coulomb's constant is very large.

PRACTICE

Readings

- Section 7.1 (pg 318)
- Section 7.2 (pg 327)

Questions

- pg 326 #2-5
- pg 335 #2,4,5,7,9,(10)