Chapter 23. Electric Force

A PowerPoint Presentation by

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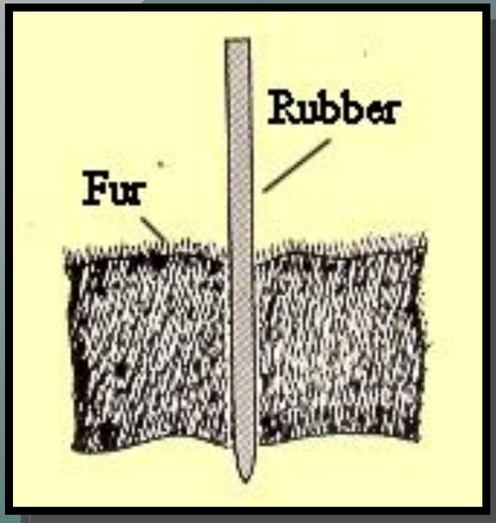
Objectives: After finishing this unit, you should be able to:

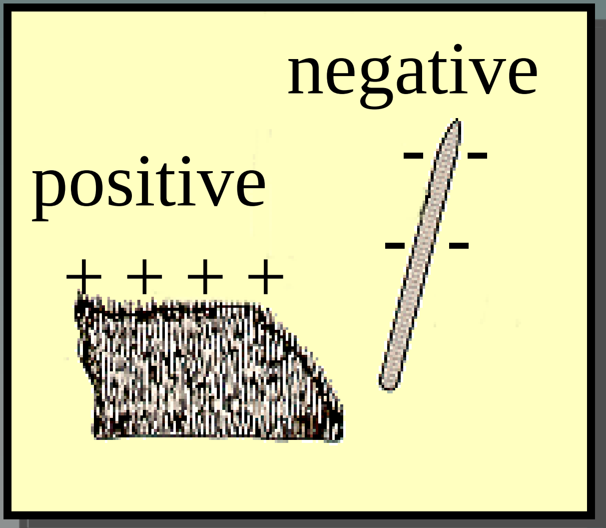
- Explain and demonstrate the first law of electro-statics and discuss charging by contact and by induction.
- Write and apply Coulomb's Law and apply it to problems involving electric forces.
- Define the electron, the coulomb, and the microcoulomb as units of electric charge.

Electric Charge

When a rubber rod is rubbed against fur, electrons are removed from the fur and deposited on the rod.



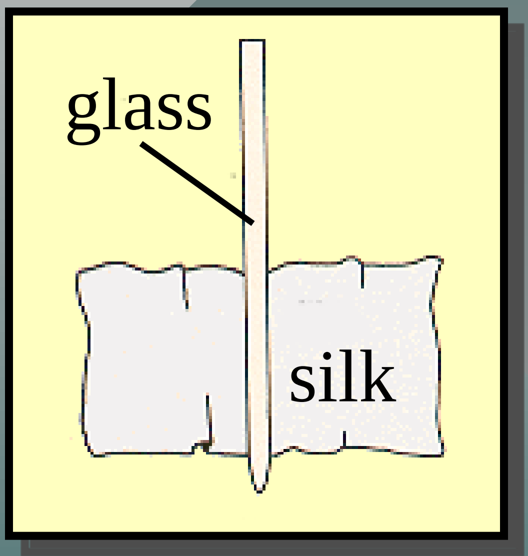
Electrons move from fur to the rubber rod.



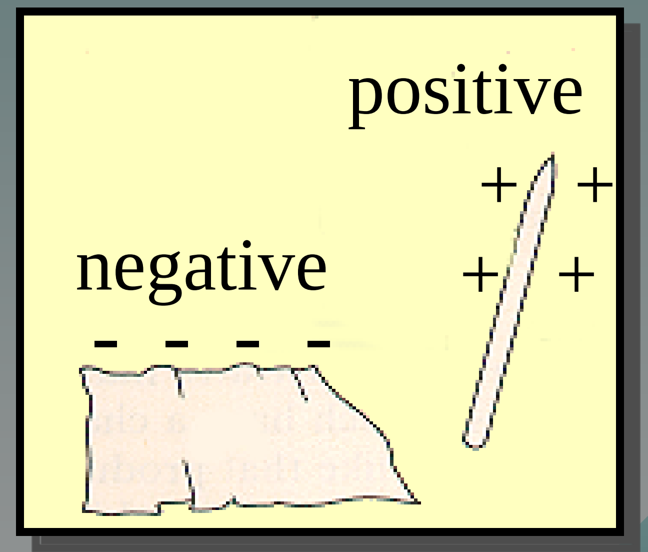
The rod is said to be negatively charged because of an excess of electrons. The fur is said to be positively charged because of a deficiency of electrons.

Glass and Silk

When a glass rod is rubbed against silk, electrons are removed from the glass and deposited on the silk.



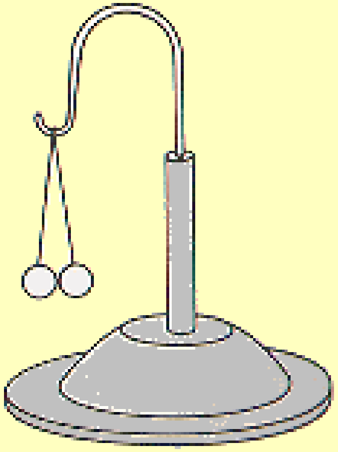
Electrons move from glass to the silk cloth.



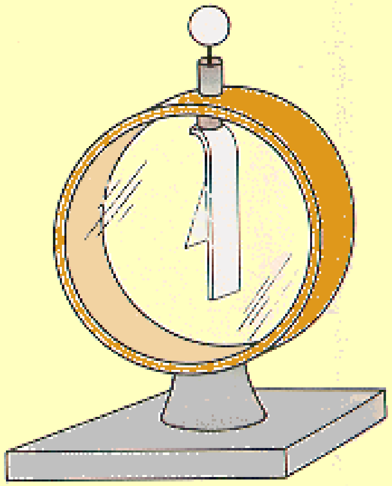
The glass is said to be positively charged because of a deficiency of electrons. The silk is said to be negatively charged because of a excess of electrons.

The Electroscope

Laboratory devices used to study the existence of two kinds of electric charge.



Pith-ball Electroscope

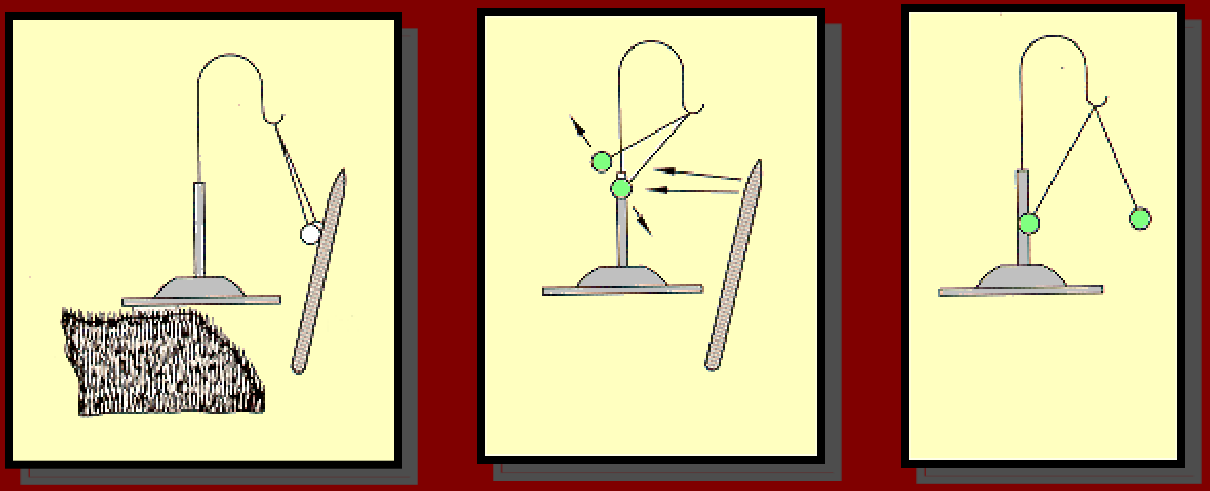


Gold-leaf Electroscope

Two Negative Charges Repel

1. Charge the rubber rod by rubbing against fur.

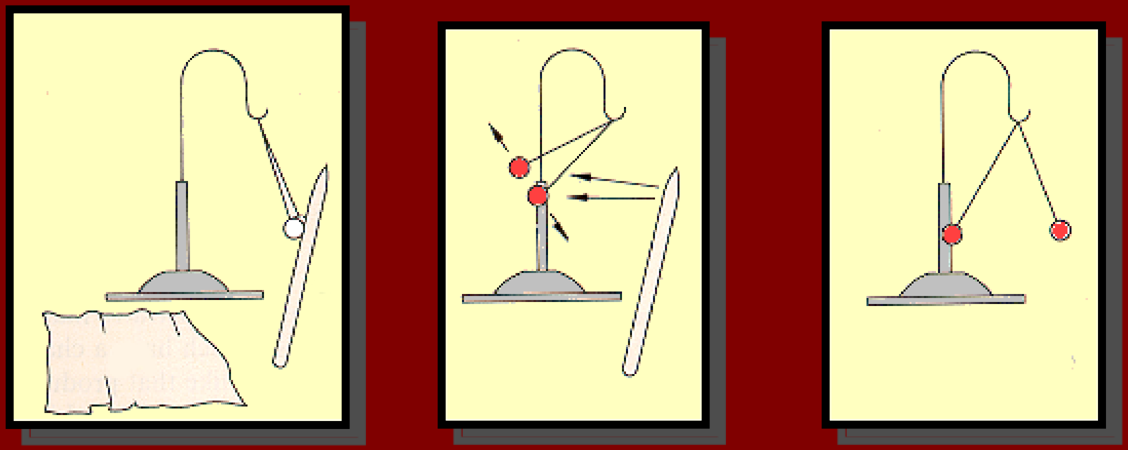
2. Transfer electrons from rod to each pith ball.



The two negative charges repel each other.

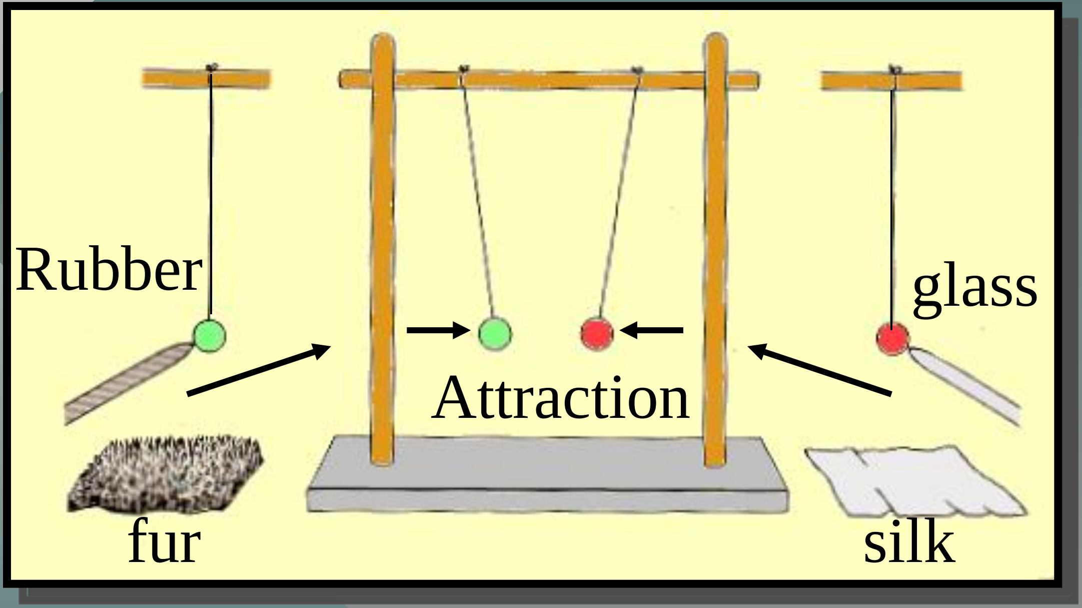
Two Positive Charges Repel

1. Charge the glass rod by rubbing against silk.
2. Touch balls with rod. Free electrons on the balls move to fill vacancies on the cloth, leaving each of the balls with a deficiency. (Positively charged.)



The two positive charges repel each other.

The Two Types of Charge

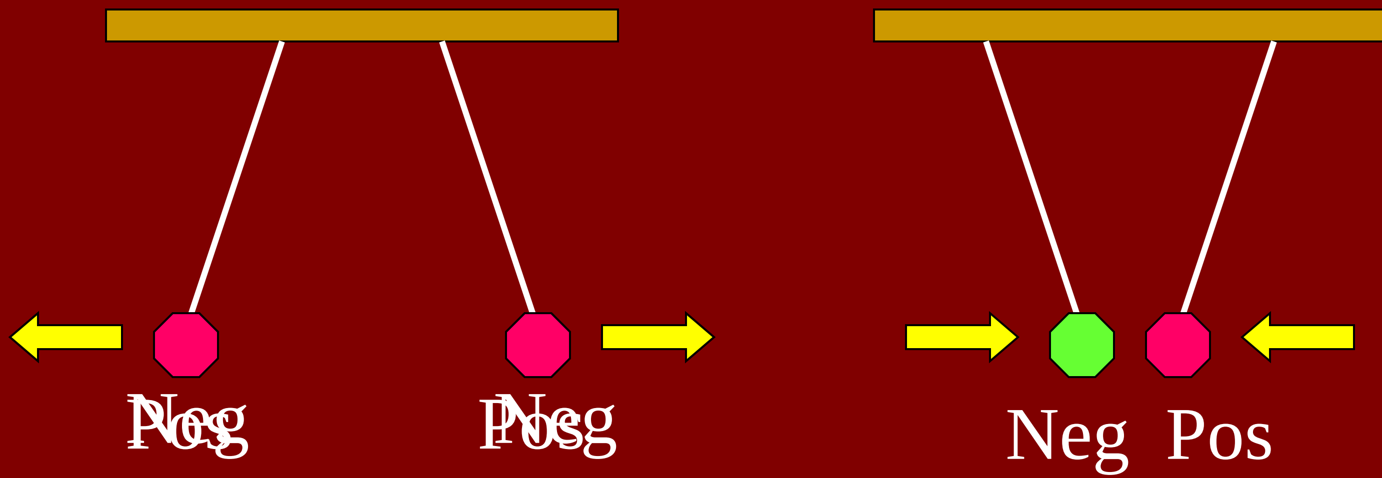


Note that the negatively charged (green) ball is attracted to the positively charged (red) ball.

Opposite Charges Attract!

The First Law of Electrostatics

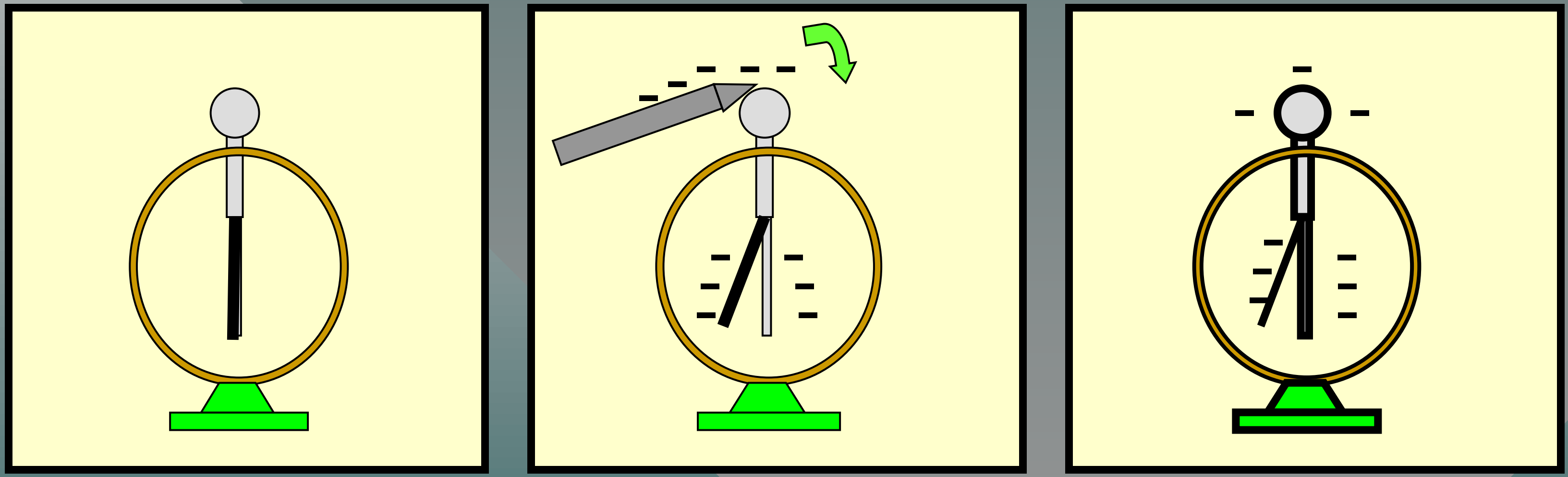
Like charges repel; unlike charges attract.



Charging by Contact

1. Take an uncharged electroscope as shown below.

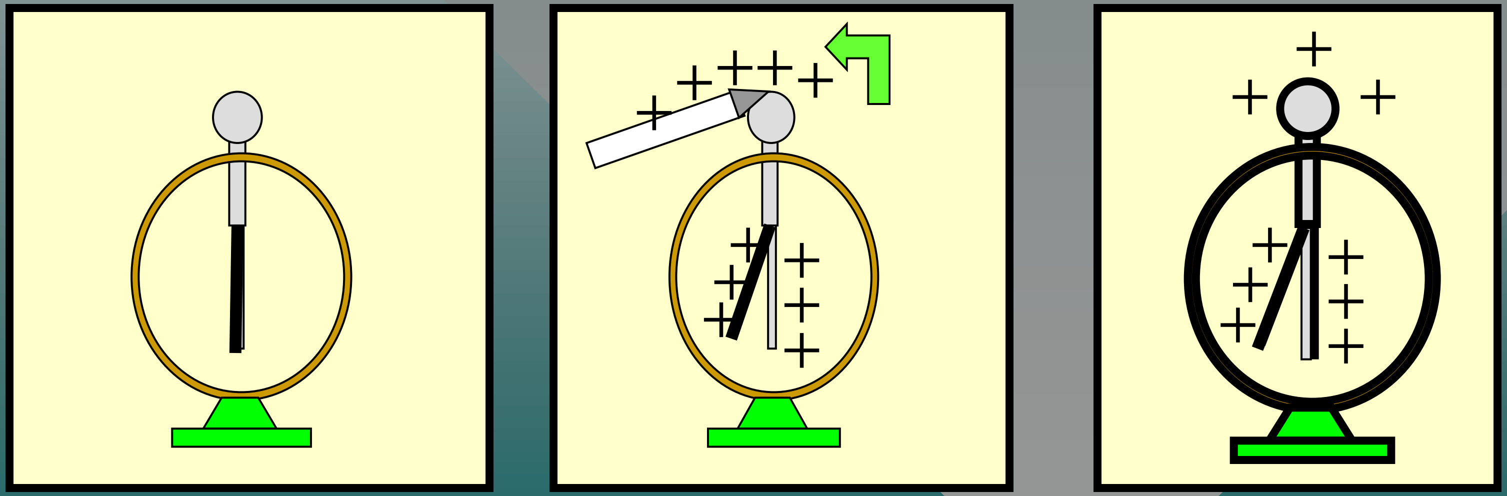
2. Bring a negatively charged rod into contact with knob.



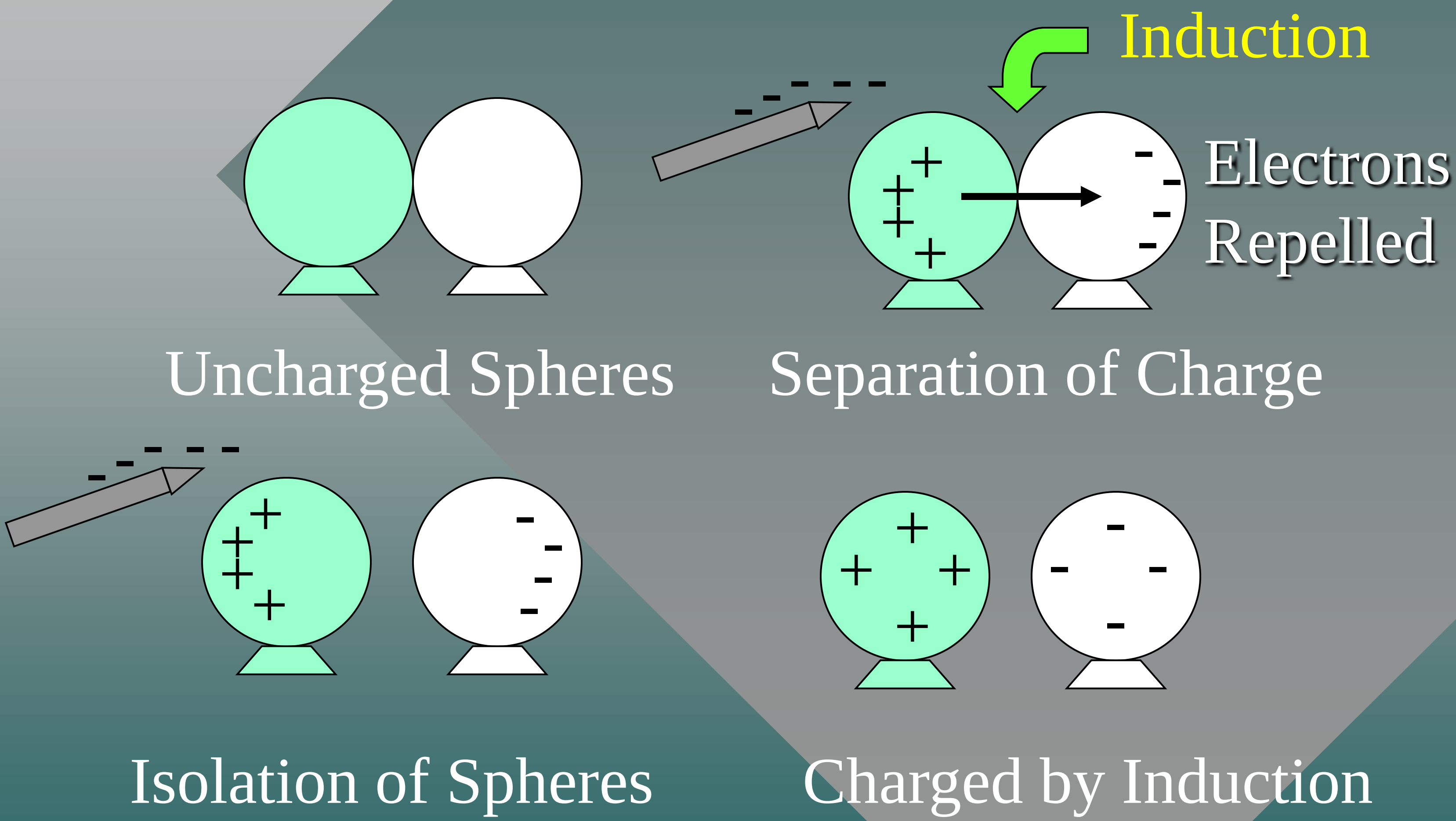
3. Electrons move down on leaf and shaft, causing them to separate. When the rod is removed, the scope remains negatively charged.

Charging Electroscope Positively by Contact with a Glass Rod:

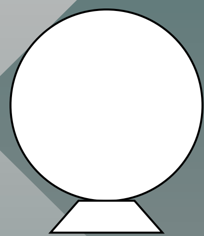
Repeat procedures by using a positively charged glass rod. Electrons move from the ball to fill deficiency on glass, leaving the scope with a net positive charge when glass is removed.



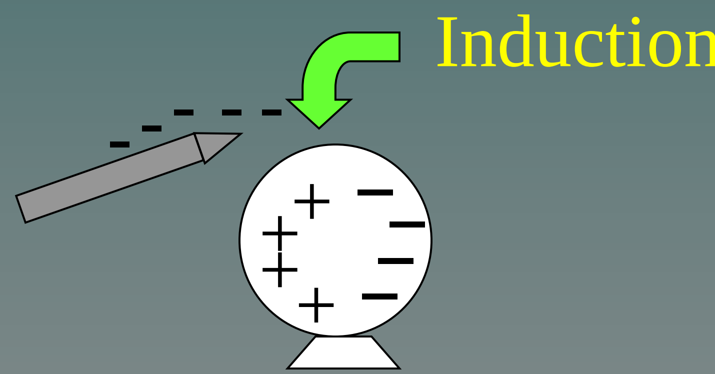
Charging Spheres by Induction



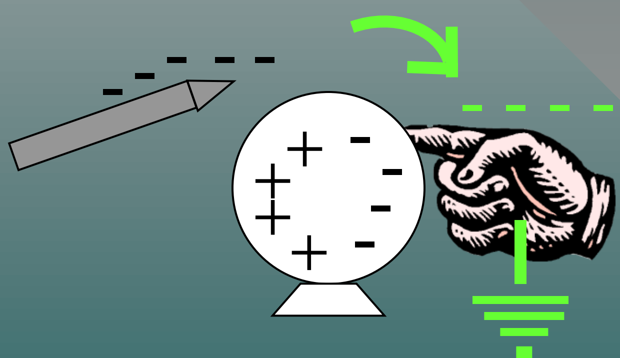
Induction for a Single Sphere



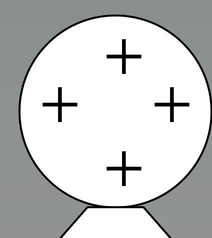
Uncharged Sphere



Separation of Charge



Electrons move
to ground.



Charged by Induction

The Quantity of Charge

The quantity of charge (q) can be defined in terms of the number of electrons, but the Coulomb (C) is a better unit for later work. A temporary definition might be as given below:

The Coulomb: $1\ C = 6.25 \times 10^{18}$ electrons

Which means that the charge on a single electron is:

1 electron: $e^- = -1.6 \times 10^{-19}\ C$

Units of Charge

The coulomb (selected for use with electric currents) is actually a very large unit for static electricity. Thus, we often encounter a need to use the metric prefixes.

$1\ \mu C = 1 \times 10^{-6}\ C$

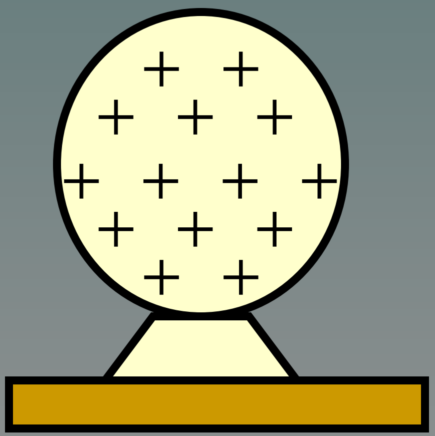
$1\ nC = 1 \times 10^{-9}\ C$

$1\ pC = 1 \times 10^{-12}\ C$

Example 1. If 16 million electrons are removed from a neutral sphere, what is the charge on the sphere in coulombs?

1 electron: $e^- = -1.6 \times 10^{-19}$ C

$$q = (16 \times 10^6 e^-)\left(\frac{-1.6 \times 10^{-19} \mathrm{C}}{1\ e^-}\right)$$



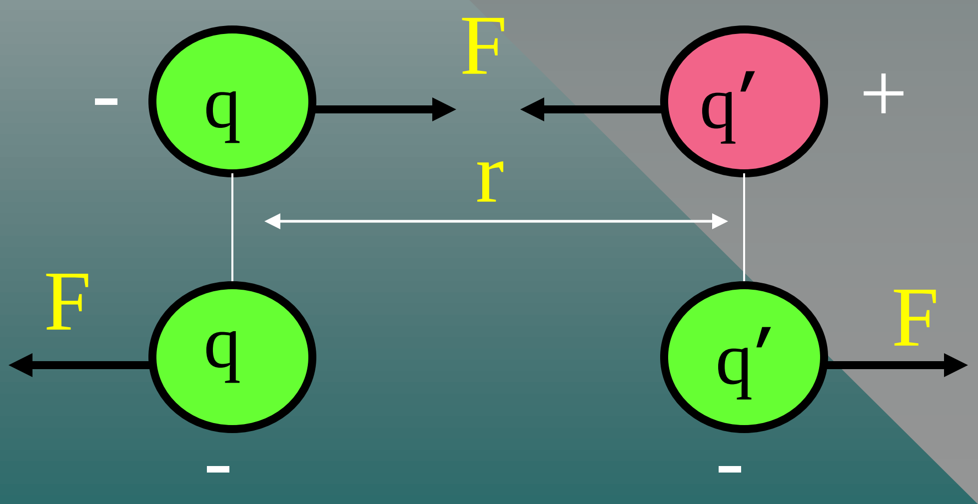
$q = -2.56 \times 10^{-12}$ C

Since electrons are removed, the charge remaining on the sphere will be positive.

Final charge on sphere: $\boxed{q = +2.56 \text{ pC}}$

Coulomb's Law

The force of attraction or repulsion between two point charges is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them.



$$F \propto \frac{qq'}{r^2}$$

Calculating Electric Force

The proportionality constant k for Coulomb's law depends on the choice of units for charge.

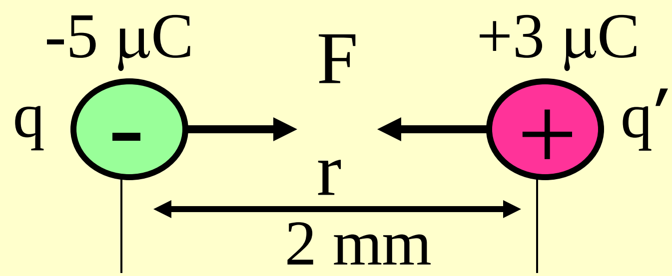
$$F = \frac{kqq'}{r^2} \quad \text{where} \quad k = \frac{Fr^2}{qq'}$$

When the charge q is in coulombs, the distance r is in meters and the force F is in newtons, we have:

$$k = \frac{Fr^2}{qq'} = 9 \text{ x } 10^9 \ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$$

Example 2. A –5 μC charge is placed 2 mm from a +3 μC charge. Find the force between the two charges.

Draw and label givens on figure:



$$F = \frac{kqq'}{r^2} = \frac{(9 \text{ x } 10^9 \frac{\text{Nm}^2}{\text{C}^2})(-5 \text{ x } 10^{-6}\text{C})(3 \text{ x } 10^{-6}\text{C})}{(2 \text{ x } 10^{-3}\text{m})^2}$$

$F = 3.38 \text{ x } 10^4$ N; Attraction

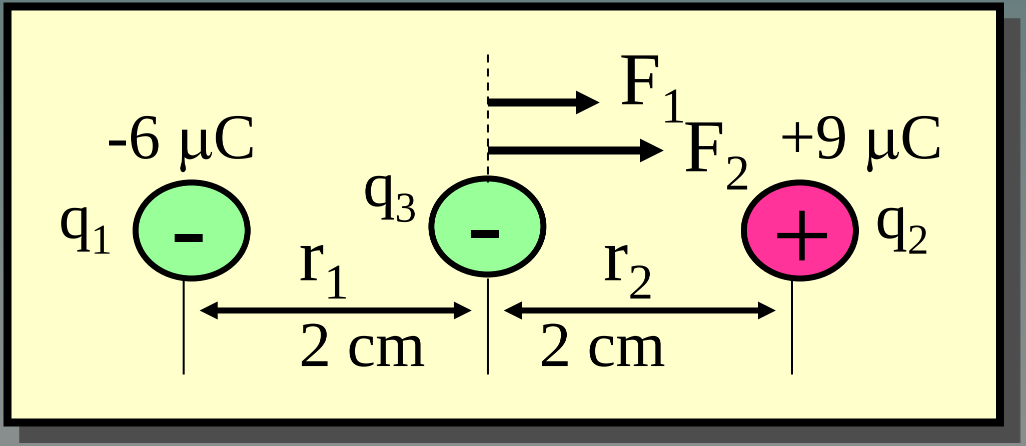
Note: Signs are used ONLY to determine force direction.

Problem-Solving Strategies

1. Read, draw, and label a sketch showing all given information in appropriate SI units.
2. Do not confuse sign of charge with sign of forces. Attraction/Repulsion determines the direction (or sign) of the force.
3. Resultant force is found by considering force due to each charge independently. Review module on *vectors*, if necessary.
4. For forces in equilibrium: $\Sigma F_x = 0 = \Sigma F_y = 0$.

Example 3. A –6 μC charge is placed 4 cm from a +9 μC charge. What is the resultant force on a –5 μC charge located midway between the first charges? 1 nC = 1 x 10^{-9} C

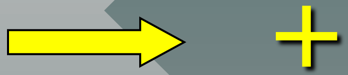
1. Draw and label.
2. Draw forces.
3. Find resultant; right is positive.



$$F_1 = \frac{kq_1q_3}{r_1^2} = \frac{(9 \text{ x } 10^9)(6 \text{ x } 10^{-6})(5 \text{ x } 10^{-6})}{(0.02 \text{ m})^2}; \qquad F_1 = 675 \text{ N}$$

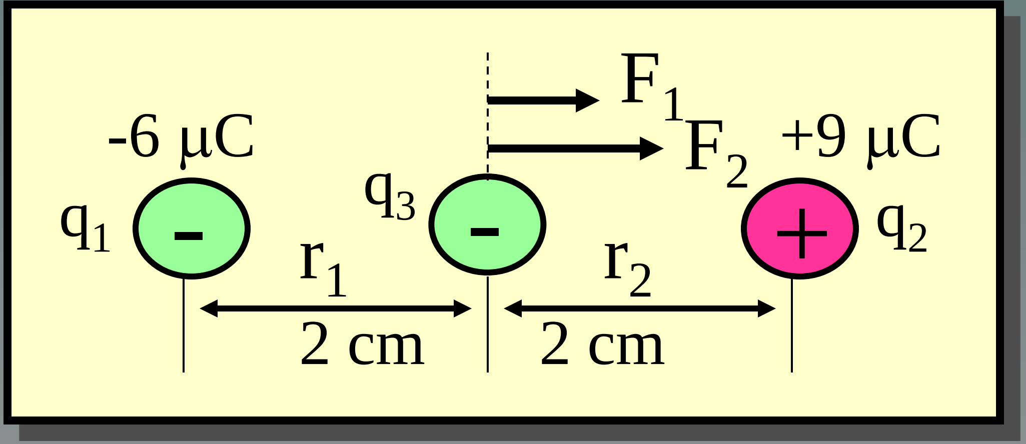
$$F_2 = \frac{kq_2q_3}{r_1^2} = \frac{(9 \text{ x } 10^9)(9 \text{ x } 10^{-6})(5 \text{ x } 10^{-6})}{(0.02 \text{ m})^2}; \qquad F_2 = 1013 \text{ N}$$

Example 3. (Cont.) Note that direction (sign) of forces are found from attraction-repulsion, not from + or – of charge.



$F_1 = 675$ N

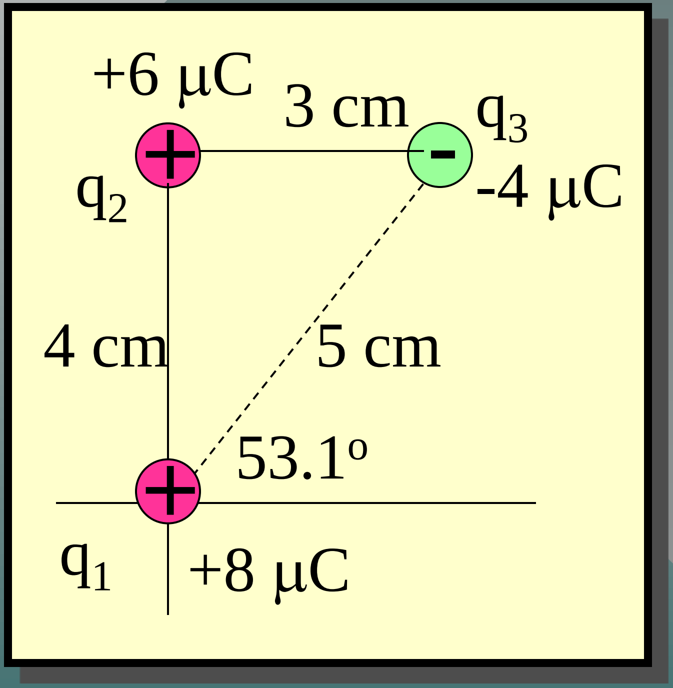
$F_2 = 1013$ N



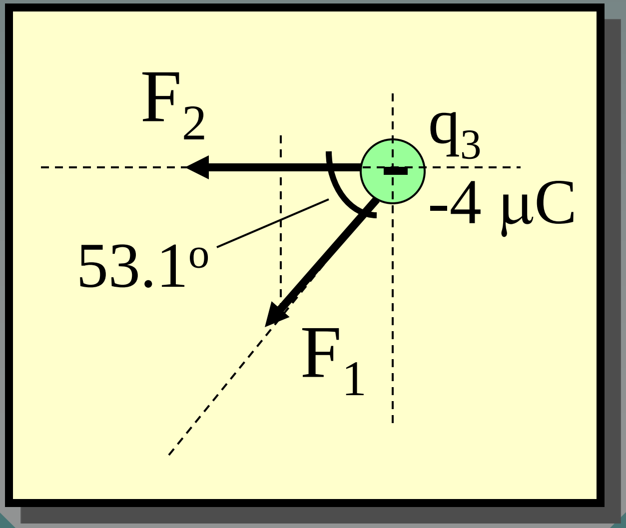
The resultant force is sum of each independent force:

$F_R = F_1 + F_2 = 675\text{ N} + 1013\text{ N};$ $\boxed{F_R = +1690\text{ N}}$

Example 4. Three charges, $q_1 = +8\ \mu C$, $q_2 = +6\ \mu C$ and $q_3 = -4\ \mu C$ are arranged as shown below. Find the resultant force on the $-4\ \mu C$ charge due to the others.



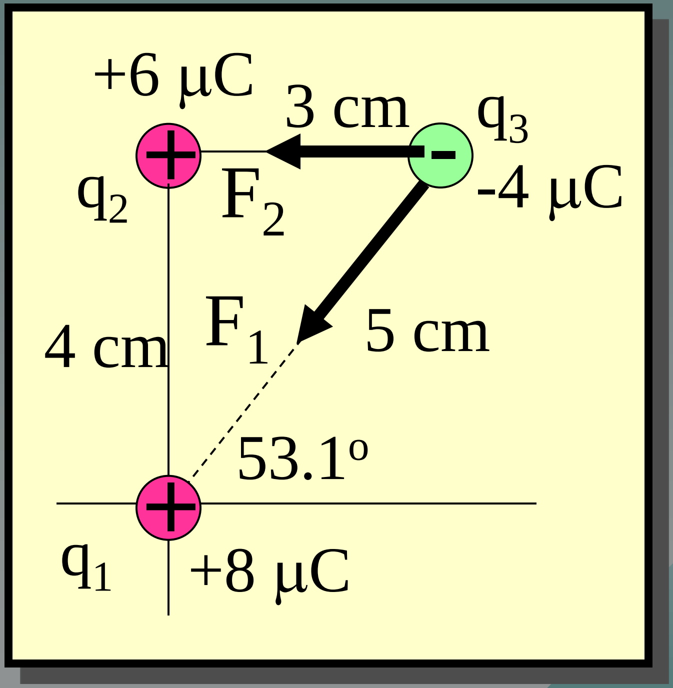
Draw free-body diagram.



Note the directions of forces F_1 and F_2 on q_3 based on attraction/repulsion from q_1 and q_2.

Example 4 (Cont.) Next we find the forces F_1 and F_2 from Coulomb's law. Take data from the figure and use SI units.

$$F_1 = \frac{kq_1q_3}{r_1^2}; \qquad F_2 = \frac{kq_2q_3}{r_2^2}$$



$$F_1 = \frac{(9 \text{ x } 10^9)(8 \text{ x } 10^{-6})(4 \text{ x } 10^{-6})}{(0.05 \text{ m})^2}$$

$$F_2 = \frac{(9 \text{ x } 10^9)(6 \text{ x } 10^{-6})(4 \text{ x } 10^{-6})}{(0.03 \text{ m})^2}$$

Thus, we need to find resultant of two forces:

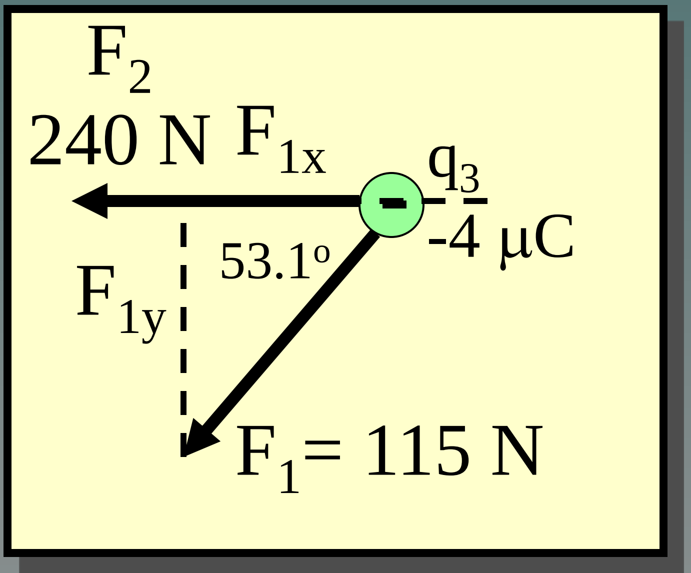
F_1 = 115 N, 53.1° S of W

F_2 = 240 N, West

Example 4 (Cont.) We find components of each force F_1 and F_2 (review vectors).

F_{1x} = -(115 N) Cos 53.1°
= - 69.2 N

F_{1y} = -(115 N) Sin 53.1° =
- 92.1 N



Now look at force F_2:

F_{2x} = -240 N; F_{2y} = 0

$R_x = \Sigma F_x$; $R_y = \Sigma F_y$

R_x = – 69.2 N – 240 N = -309 N

$\boxed{R_x = -92.1\text{ N}}$

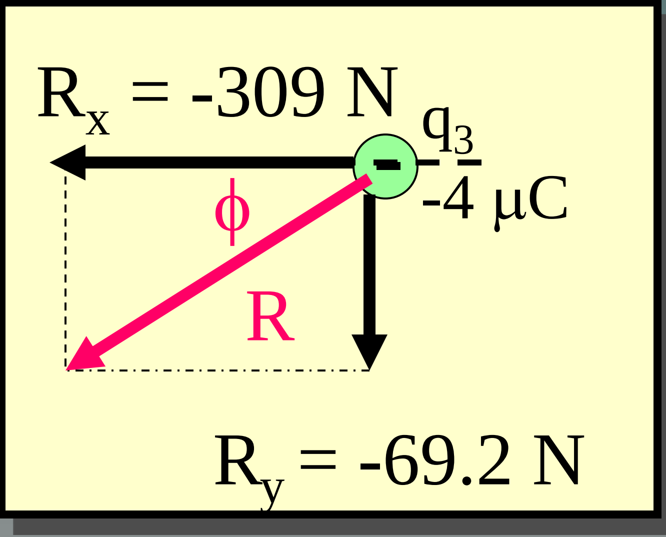
R_y = -69.2 N – 0 = -69.2 N

$\boxed{R_y = -240\text{ N}}$

Example 4 (Cont.) Next find resultant R from components F_x and F_y. (review vectors).

$R_x = -309$ N

$R_y = -69.2$ N



We now find resultant R,θ:

$$R = \sqrt{R_x^2 + R_y^2}; \quad \tan\phi = \frac{R_y}{R_x}$$

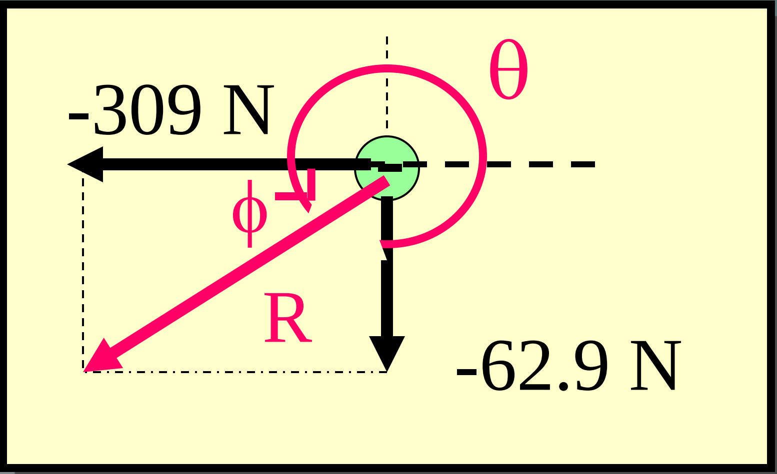
$$R = \sqrt{(309\text{ N})^2 + (69.2\text{ N})^2} = 317\text{ N}$$

Thus, the magnitude of the electric force is:

R = 317 N

Example 4 (Cont.) The resultant force is 317 N. We now need to determine the angle or direction of this force.

$$R = \sqrt{R_x^2 + R_y^2} = 317 \text{ N}$$



$$\tan\phi = \frac{R_y}{R_x} = \frac{-309 \text{ N}}{-69.2 \text{ N}}$$

The reference angle is: $\phi = 77.4^0$S of W

Or, the polar angle θ is: $\theta = 180^0 + 77.4^0 = 257.4^0$

Resultant Force: $R = 317$ N, $\theta = 257.4^0$

Summary of Formulas:

Like Charges Repel; Unlike Charges Attract.

$$F = \frac{kqq'}{r^2}$$

$$k = 9 \text{ x } 10^9 \; \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$$

$1\ \mu\mathrm{C} = 1 \text{ x } 10^{-6}\ \mathrm{C}$

$1\ \mathrm{nC} = 1 \text{ x } 10^{-9}\ \mathrm{C}$

$1\ \mathrm{pC} = 1 \text{ x } 10^{-12}\ \mathrm{C}$

1 electron: $e^- = -1.6 \text{ x } 10^{-19}\ \mathrm{C}$

CONCLUSION: Chapter 23
Electric Force