### STUDY GUIDE
**UNIT 15 - Electrostatics**

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PURPOSE:
1. To identify and classify different types of electrical charges.
2. To investigate the forces between like charges.
3. To investigate the forces between unlike charges.
4. To investigate how the force between two charged objects depends on the separation distance.
5. To investigate the forces between charged objects and a metallic object.

PROCEDURES:

Hang a strip of cellulose acetate (clear), a strip of vinylite (green or gray), and a strip of aluminum foil by short lengths of masking tape from a cross bar of a ringstand so they can swing freely without twisting. Briskly rub the vinylite strip and the acetate strip with a dry piece of paper. DO NOT touch the rubbed surfaces. Rub another vinylite strip with paper and bring it near each of the suspended strips.

1. Describe your observations.

2. How does the strength of the force depend on separation?

Now rub another strip of acetate with paper and bring it near the hanging strips.

3. Describe your observations.

4. What can you conclude about the charges on the hanging acetate and vinylite strips?
5. How many kinds of charge have you found?

6. Name each charge (you may NOT use positive or negative) and describe its behavior.

   Charge one (found on Vinylite)

   NAME _______________________
   BEHAVIOR

   Charge two (found on Cellulose Acetate)

   NAME _______________________
   BEHAVIOR

7. Bring your hand close to (but not touching) each strip. Describe your observations.

   Based on your observations above and the names that you chose, you are going to try to determine the charge on a number of other substances. The table below indicates the material and what it was rubbed with. Describe the behavior in each case and determine the name of the charge. BE CAREFUL THAT YOU ARE NOT CONFUSING THE EFFECT OF THE MATERIAL AND THAT OF YOUR HAND.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>RUBBED WITH</th>
<th>BEHAVIOR</th>
<th>NAME OF CHARGE</th>
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<td>CLEAR PLASTIC ROD</td>
<td>PAPER</td>
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<td>BLACK ROD</td>
<td>FUR</td>
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<td>GLASS ROD</td>
<td>PLASTIC BAG</td>
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<td></td>
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<tr>
<td>GRAY PIPE</td>
<td>FUR</td>
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8. What general conclusions about the electrification of bodies can you make as a result of your observations in this experiment?

9. What would be the results of changing the names you have given to the charges you observed? Would observed effects change?

10. What happens when you hold a charged strip of vinlylite close to a piece of aluminum foil? What happens when you hold a charged strip of acetate close to a piece of aluminum foil? Try to explain your observations.
1. Electricity at rest is called ____________________

2. Electrostatics involves ____________________________, ____________________________, and ____________________________.

3. Electrical forces arise from particles in ____________.

4. Describe the simple model of an atom as proposed by Rutherford and Bohr:

5. Protons in the nucleus _______ electrons

6. Electrons _______ other electrons

7. List four important facts about atoms:
   a. 
   b. 
   c. 
   d. 

8. The fundamental rule at the base of all electrical phenomena is:

9. Beneath the complexities of electrical phenomena, there lies a fundamental rule from which nearly all other effects stem. What is this fundamental rule?
10. How does the charge of an electron differ from the charge of a proton?

11. Electrons and protons have ________________

12. In a neutral atom, there are ________________ protons as electrons, so there is ____________________

13. A charged atom is called an ________________

14. A ________________ has a net positive charge: it has _______ one or more electrons

15. A ________________ has a net negative charge: it has _______ one or more extra electron

16. An imbalance of charge comes about by adding or removing ________________

17. Inner electron in an atom are bound ________________

18. Outer electrons in an atom are bound ________________

19. Electrons are held more firmly in _______ than in ________

20. When a rubber rod is rubbed by a piece of fur, electrons transfer from the _______ to the _______

21. If you rub a plastic rod with silk, the rod becomes ___________

22. Explain conservation of charge:

23. Electrons _________ be divided into fractions of electrons.

24. If you scuff electrons onto your feet while walking across a rug, are you negatively or positively charges? What is the charge on the rug?
Purpose:
An electroscope is an instrument used by scientists to measure the relative strength of an electric charge. In this activity we will build a simplified version of an electroscope to study and explore static electric charges.

Materials:
1. Clear Plastic Cup
2. Paper Clip
3. Aluminum Foil
4. Tape
5. Balloon
6. Scissors
7. Push Pin

Procedure:
1. Using the push-pin, create a small hole in the bottom of the plastic cup through which the paper clip will later be inserted.
2. Cut two strips of aluminum foil that measure roughly ¼ inch by 1 ½ inch. Use the end of a paper clip or your push pin to punch small holes in the one end of each foil strip.
3. Unfold a paperclip so that it looks like a long J, and hang the foil strips, called leaves, on the curved end of the J. Smooth out the leaves so that they hang straight and next to each other, but do not try to press them into one other.
4. Holding the cup upside-down, insert the straight part of the J paper clip through the hole in the cup, so the leaves hang inside the upside down cup without touching the table or desk top. Secure the paperclip in place using plastic tape.
5. Roll some aluminum foil into a ball and place the ball on the top of the paperclip that is sticking out from the cup. The electroscope is complete and ready for use.
**Analysis:**

1. **PREDICT:**
   
   What will happen if you move a negatively charged object near the foil ball on the tip of your electroscope?

2. **OBSERVE:**
   
   Blow up your balloon and tie off the end so that air does not escape. Charge the balloon by rubbing it vigorously against your hair. Next, move the charged balloon close to (but not touching) the foil ball. What do you see?

3. **DISCUSS:**
   
   What made the leaves move? Can you explain this using the concepts of charge and electrons?
   
   HINT: What do you know about the way that similarly charged objects behave?

4. **CHARGING BY INDUCTION:**
   
   a) Now charge the balloon again, and hold it near the ball. What will the charge on the ball be?

   b) If you now “ground” the system by touching your finger to it, what do you think will happen?

   c) Now move your finger away, and then the balloon. What happens to the leaves? Can you explain your observations? This is called charging by induction, as you have induced a charge onto the electroscope.

   d) How does charging by induction differ from the way that you first charged the balloon?
Read pages 500-504 again and fill in the appropriate information.

**Electrostatics**

Define:

This section of electricity deals with the following:
1.  
2.  
3.  

**Electric Charges**

There are two types of charges:
-  
-  

To understand why these two different types of charge matter we must look at the basic building block of matter; the ________________.

Below draw and label the Helium Atom (figure 32.2).

What is the charge of each particle?
Neutrons ____________ Protons_____________Electrons_____________

Because of the positively charged nucleus, and the negatively charged electrons there is an attraction that holds the atom together.

Important Notes:
• All electrons are identical; this means that …

• A proton has ________ the mass of an electron, and have a __________charge.
• A neutron has _____________________mass than a proton but has _______charge
• Atoms usually have a net charge of zero. So the number of protons usually __________ the number of electrons

Nobody knows exactly why electrons repel other electrons and why electrons attract protons, but we will accept this as nature and all it fundamental or label it a basic law.

What is the fundamental rule?

___________________________________________________

Question:
How is the charge on an electron different from the charge on a proton?
Conservation of Charge
We have just finished studying Conservation of Momentum and the Conservation of Energy. There is also a rule of conservation that applies to electric charges. This is called, yes you guessed it, the Law of Conservation of Charge.

Explain the Law of Conservation of Charge:

Questions:
1. What happens when electrons are rubbed off of an object?

2. What happens when electrons are rubbed onto an object?

Ions
• What is an ion?

• What happens to make a neutral atom become a positive ion?

• What happens to make a neutral atom become a negative ion?
Examples from class:
When a rubber rod is rubbed with a piece of fur, the rubber rod holds onto its electrons with a stronger force than the fur does so the fur will give up its electrons easier. Therefore the fur has a positive charge and the atoms on its surface become positive ions. The rubber rod gains electrons and now has a negative charge and the atoms on its surface become negative ions.

Question:
1. What is the charge on the fur if 1,000,000 electrons are transferred from it?

2. What is the charge on the rubber rod if 1,000,000 electrons are transferred to it?

3. What is the net charge on the rubber and fur system?

4. Do you think that it is possible for ½ of an electron to be transferred? Why or why not?
1. What is the equation for Newton’s law of gravitation?

2. The electrical force between any two objects obeys the same ________________

3. State Coulomb’s Law:

4. The SI unit for charge is the ________________

5. A charge of 1 C is the charge on ________________ electrons

6. What is the value for the proportionality constant k in Coulomb’s Law (in scientific notation)  k = ________________

7. Write and label the comparison of Newton’s law of gravitation and Coulomb’s law (figure 32.5)

8. The greatest difference between gravitation and electrical forces is:

9. Because most objects have almost exactly equal numbers of protons and electrons, electrical forces usually ________________ ________________

10. Material in which electrons can roam around freely are called ________________

11. Materials in which electrons are not free to wander are called ________________
**COULOMB’S LAW**

**ELECTROSTATIC FORCE**

_Vocabulary_ **Electrostatics:** The study of electric charges, forces, and fields.

The symbol for electric charge is the letter "q" and the SI unit for charge is the **Coulomb** (C). The coulomb is a very large unit.

\[ 1 \text{ C} = 6.25 \times 10^{18} \text{ electrons} \]

or

\[ 1 \text{ electron has a charge of } 1.60 \times 10^{-19} \text{ C}. \]

Electrons surrounding the nucleus of an atom carry a negative charge. Protons, found inside the nucleus of the atom, carry a positive charge of \( 1.60 \times 10^{-19} \text{ C} \), while neutrons (which also reside in the nucleus) are neutral. It is important to remember that only electrons are free to move in a substance. Protons and neutrons usually do not move.

When two objects with like charges, positive or negative, are brought near each other, they experience forces that cause them to repel. When objects with opposite charges, one negative and one positive, are brought side by side, they experience forces of attraction. These forces can be described with Coulomb's law.

_Vocabulary_ **Coulomb's Law:** Two charged objects attract each other with a force that is proportional to the charge on the objects and inversely proportional to the square of the distance between them.

\[ F_{\text{electrical}} \propto \frac{q_1 q_2}{d^2} \]

This equation looks very similar to Newton's law of universal gravitation. As before, the sign \( \propto \) means "proportional to." To make an equation out of this proportionality, insert a quantity called the electrostatic constant, \( k \).

\[ k = 9.0 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \]

The magnitude of Coulomb's law can now be written as an equation.

\[ F_e = k \frac{q_1 q_2}{d^2} \]

Like all other forces, the electrostatic force between two charged objects is measured in newtons.
Given the mathematical representation of Coulomb’s Law:

\[ F_e = k \frac{q_1 q_2}{d^2} \]

Where \( k = 9.0 \times 10^9 \ \frac{Nm^2}{C^2} \)

Describe in words the relationship among electric force, charge and distance
Solved Examples

Example 1: Anthea rubs two latex balloons against her hair, causing the balloons to become charged negatively with $2.0 \times 10^{-6} \text{ C}$. She holds them a distance of 0.70 m apart. a) What is the electric force between the two balloons? b) Is it one of attraction or repulsion?

Solution: It is not necessary to carry the sign of the charge throughout the entire exercise. However, when determining the direction of your final answer, it is important to remember the charge on each object.

\[
\begin{align*}
q_1 &= 2.0 \times 10^{-6} \text{ C} \\
q_2 &= 2.0 \times 10^{-6} \text{ C} \\
d &= 0.70 \text{ m} \\
\varepsilon_0 &= 9.0 \times 10^{-12} \frac{\text{N m}^2}{\text{C}^2} \\
F_{\text{electric}} &= \frac{k |q_1 q_2|}{d^2}
\end{align*}
\]

\[
F_{\text{electric}} = \frac{\left(9.0 \times 10^{-12} \frac{\text{N m}^2}{\text{C}^2}\right) (2.0 \times 10^{-6} \text{ C})^2}{(0.70 \text{ m})^2} = 0.073 \text{ N}
\]

Example 2: Two pieces of puffed rice become equally charged as they are poured out of the box and into Kirk's cereal bowl. If the force between the puffed rice is $4 \times 10^{-23} \text{ N}$ when the pieces are 0.03 m apart, what is the charge on each of the pieces?

\[
\begin{align*}
F_{\text{electric}} &= 4 \times 10^{-23} \text{ N} \\
d &= 0.03 \text{ m} \\
\varepsilon_0 &= 9.0 \times 10^{-12} \frac{\text{N m}^2}{\text{C}^2} \\
q_1 &= x \\
q_2 &= x \\
\frac{q_1 q_2}{\varepsilon_0 d^2} &= \frac{F_{\text{electric}}}{k} \\
x^2 &= \left(0.03 \text{ m}\right)^2 \left(4 \times 10^{-23} \text{ N}\right) \\
\frac{9.0 \times 10^{-12} \frac{\text{N m}^2}{\text{C}^2}}{4 \times 10^{-23} \text{ N}} \\
x^2 &= 4 \times 10^{-3} \text{ C} \\
x &= 2 \times 10^{-15} \text{ C}
\end{align*}
\]
12. Write the equation for Coulomb’s Law:

\[ F_{\text{electric}} = \frac{k q_1 q_2}{d^2} \]

13. Identify each variable in the equation for Coulomb’s Law:

- \( q \): charge (C)
- \( d \): distance (m)

\( k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \)

14. When sugar is poured from the box into the sugar bowl, the rubbing of sugar grains creates a static electric charge that repels the grains, and causes sugar to go flying out in all directions. If two sugar grains each acquire a charge of \( 3.0 \times 10^{-11} \text{ C} \) at a separation of \( 8.0 \times 10^{-5} \text{ m} \), with what force will they repel each other?

\[ q_1 = 3.0 \times 10^{-11} \text{ C} \]
\[ q_2 = 3.0 \times 10^{-11} \text{ C} \]
\[ d = 8.0 \times 10^{-5} \text{ m} \]
\[ k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \]

\[ F_e = \frac{k q_1 q_2}{d^2} = \frac{(9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(3.0 \times 10^{-11} \text{ C})^2}{(8.0 \times 10^{-5} \text{ m})^2} = 0.0013 \text{ N} \]

15. Boppo, the clown, carries two mylar balloons that rub against a circus elephant, causing the balloons to separate. Each balloon acquires \( 2.0 \times 10^{-7} \text{ C} \) of charge. How large is the electric force between them when a distance of 0.50 m separates them?

\[ q_1 = 2.0 \times 10^{-7} \text{ C} \]
\[ q_2 = 2.0 \times 10^{-7} \text{ C} \]
\[ d = 0.50 \text{ m} \]
\[ k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \]

\[ F_e = \frac{k q_1 q_2}{d^2} = \frac{(9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(2.0 \times 10^{-7} \text{ C})^2}{(0.50 \text{ m})^2} \]
\[ F_e = 0.0064 \text{ N} \]
16. Liz uses hairspray on her hair each morning before going to school. The spray spreads out before reaching her hair partly because of the electrostatic charge on the hairspray droplets. If two drops of hairspray repel each other with a force of $9.0 \times 10^{-9} \text{ N}$ at a distance of 0.070 cm, what is the charge on each of the equally-charged drops of hairspray?

\[ E = k \frac{q_1 q_2}{d^2} \]
\[ F_e = \frac{k q_1 q_2}{d^2} \]
\[ d = 0.070 \text{ cm} = 0.00070 \text{ m} \]
\[ k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \]
\[ 9.0 \times 10^{-9} \text{ N} = \frac{9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}}{d^2} \]
\[ d^2 = 9.0 \times 10^{-25} \text{ m}^2 \]
\[ d = 7.0 \times 10^{-13} \text{ m} \]

17. Bonnie is dusting the house and raises a cloud of dust particles as she wipes across a table. If two $4.0 \times 10^{-14} \text{ C}$ pieces of dust exert an electrostatic force of $2.0 \times 10^{-12} \text{ N}$ on each other, how far apart are the dust particles at that time?

\[ F_e = \frac{k q_1 q_2}{d^2} \]
\[ d = \sqrt{\frac{k q_1 q_2}{F_e}} \]
\[ k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \]
\[ 2.0 \times 10^{-12} \text{ N} = \frac{9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}}{d^2} \times (4.0 \times 10^{-14} \text{ C})^2 \]
\[ d = 0.0027 \text{ m} \]
1. Suppose that two point charges, each with a charge of +1 Coulomb are separated by a distance of 1 meter.
   (a) Will they attract or repel? ______________ Why?
   (b) Determine the magnitude of the electrical force between them.

\[
\begin{align*}
q_1 &= +1 \text{ C} \\
q_2 &= +1 \text{ C} \\
d &= 1 \text{ m} \\
K &= 9.0 \times 10^9 \text{ N m}^2/\text{C}^2 \\
F_e &= \frac{Kq_1q_2}{d^2} \\
&= \frac{(9.0 \times 10^9 \text{ N m}^2/\text{C}^2)(1 \text{ C})(1 \text{ C})}{(1 \text{ m})^2} \\
&= 9.0 \times 10^9 \text{ N} \\
\end{align*}
\]

2. Two balloons are charged with an identical quantity and type of charge: -0.0025 C.
   They are held apart at a separation distance of 8 m.
   (a) Will they attract or repel? ______________ Why?
   (b) Determine the magnitude of the electrical force of repulsion between them.

\[
\begin{align*}
q_1 &= -0.0025 \text{ C} \\
q_2 &= -0.0025 \text{ C} \\
d &= 8 \text{ m} \\
F_e &= \frac{Kq_1q_2}{d^2} \\
&= \frac{(9.0 \times 10^9 \text{ N m}^2/\text{C}^2)(-0.0025 \text{ C})(-0.0025 \text{ C})}{(8 \text{ m})^2} \\
&= 879 \text{ N} \\
\end{align*}
\]

3. Two charged boxes are 4 meters apart from each other. The blue box has a charge of +0.000337 C and is attracting the red box with a force of 626 Newtons.
   (a) Determine charge of the red box.
   (b) Remember to indicate if it is positive or negative.

\[
\begin{align*}
a &= 4 \text{ m} \\
q_1 &= +0.000337 \text{ C} \\
q_2 &= \chi \\
F_e &= 626 \text{ N} \\
K &= 9.0 \times 10^9 \text{ N m}^2/\text{C}^2 \\
q_2 &= \frac{d^2 F_e}{K q_1} \\
&= \frac{(4 \text{ m})^2 \cdot 626 \text{ N}}{9.0 \times 10^9 \text{ N m}^2/\text{C}^2 \cdot 0.000337 \text{ C}} \\
&= 0.00329 \text{ C}
\end{align*}
\]
4. A piece of Styrofoam has a charge of -0.004 C and is placed 3.0 m from a piece of salt with a charge of -0.003 C.
   (a) Will they attract or repel? ______________ Why?
   (b) How much electrostatic force is produced?

\[ \frac{q_1 q_2}{4 \pi \varepsilon_0 d^2} = \frac{(9.0 \times 10^9 \text{ Nm}^2 / \text{C}^2)(-0.004 \text{ C})(-0.003 \text{ C})}{(3.0 \text{ m})^2} \]
\[ F_e = 12,000 \text{ N} \]

5. Two coins lie 1.5 meters apart on a table. They carry identical electric charges.
   (a) Will they attract or repel? ______________ Why?
   (b) How large is the charge on each coin if each coin experiences a force of 2.0 N?

\[ d^2 F_e = k \frac{q_1 q_2}{d^2} \cdot \frac{dx}{dx} \]
\[ q_1 q_2 = d^2 F_e \]
\[ x^2 = (1.5 \text{ m})^2 \left( \frac{2.0 \text{ N}}{9.0 \times 10^9 \text{ Nm}^2 / \text{C}^2} \right) \]
\[ x^2 = 5 \times 10^{-10} \]
\[ x = 2.2 \times 10^{-5} \text{ C} \]

6. Two hot-air balloons each acquire a charge of $3.0 \times 10^{-5}$ C on their surfaces as they travel through the air.
   (a) Will they attract or repel? ______________ Why?
   (b) How far apart are the balloons if the electrostatic force between them is $8.1 \times 10^2$ N?

\[ d = \frac{k q_1 q_2}{F_e} \]
\[ d = \frac{19.0 \times 10^9 \text{ Nm}^2 / \text{C}^2 \times (3.0 \times 10^{-5})^2}{8.1 \times 10^2 \text{ N}} \]
\[ d = 10 \text{ m} \]