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

• Explain and demonstrate the first law of electrostatics 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. 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.

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.
When a glass rod is rubbed against silk, electrons are removed from the glass and deposited on the silk. The glass is said to be positively charged because of a deficiency of electrons. The silk is said to be negatively charged because of an 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.
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

- Uncharged Spheres
- Separation of Charge
- Isolation of Spheres
- Charged by Induction

Conducting the process of charging spheres by induction, we observe the movement of electrons and their repulsion.
Induction for a Single Sphere

Uncharged Sphere

Separation of Charge

Electrons move to ground.

Charged by Induction
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: \(1 \text{ C} = 6.25 \times 10^{18} \text{ electrons}\)

Which means that the charge on a single electron is:

1 electron: \(e^- = -1.6 \times 10^{-19} \text{ C}\)
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.

\[
1 \, \mu\text{C} = 1 \times 10^{-6} \, \text{C} \\
1 \, \text{nC} = 1 \times 10^{-9} \, \text{C} \\
1 \, \text{pC} = 1 \times 10^{-12} \, \text{C}
\]
**Example 1.** If 16 million electrons are removed from a neutral sphere, what is the charge on the sphere in coulombs?

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

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

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

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

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

$$k = \frac{Fr^2}{qq'} = 9 \times 10^9 \frac{N \cdot m^2}{C^2}$$
Example 2. A $-5 \, \mu\text{C}$ charge is placed 2 mm from a $+3 \, \mu\text{C}$ charge. Find the force between the two charges.

Draw and label givens on figure:

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

$$F = 3.38 \times 10^4 \, \text{N}; \quad \text{Attraction}$$

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 $-6 \mu C$ charge is placed 4 cm from a $+9 \mu C$ charge. What is the resultant force on a $-5 \mu C$ charge located midway between the first charges? \( 1 \text{nC} = 1 \times 10^{-9} \text{C} \)

1. Draw and label.

2. Draw forces.

3. Find resultant; right is positive.

\[
F_1 = \frac{kq_1q_3}{r_1^2} = \frac{(9 \times 10^9)(6 \times 10^{-6})(5 \times 10^{-6})}{(0.02 \text{ m})^2}; \quad F_1 = 675 \text{ N}
\]

\[
F_2 = \frac{kq_2q_3}{r_1^2} = \frac{(9 \times 10^9)(9 \times 10^{-6})(5 \times 10^{-6})}{(0.02 \text{ m})^2}; \quad F_2 = 1013 \text{ N}
\]
**Example 3.** (Cont.) Note that direction (sign) of forces are found from attraction-repulsion, not from $+$ or $-$ of charge.

\[ F_1 = 675 \text{ N} \]
\[ F_2 = 1013 \text{ N} \]

The resultant force is sum of each independent force:

\[ F_R = F_1 + F_2 = 675 \text{ N} + 1013 \text{ N}; \]
\[ F_R = +1690 \text{ N} \]
**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.

Next we find the forces $F_1$ and $F_2$ from Coulomb’s law. Take data from the figure and use SI units.

\[
F_1 = \frac{k q_1 q_3}{r_1^2}, \quad F_2 = \frac{k q_2 q_3}{r_2^2}
\]

\[
F_1 = \frac{(9 \times 10^9)(8 \times 10^{-6})(4 \times 10^{-6})}{(0.05 \text{ m})^2}
\]

\[
F_2 = \frac{(9 \times 10^9)(6 \times 10^{-6})(4 \times 10^{-6})}{(0.03 \text{ m})^2}
\]

Thus, we need to find resultant of two forces:

\[
F_1 = 115 \text{ N, 53.1}^\circ \text{ S of W}
\]

\[
F_2 = 240 \text{ N, West}
\]
Example 4 (Cont.) We find components of each force $F_1$ and $F_2$ (review vectors).

$F_{1x} = -(115 \text{ N}) \cos 53.1^\circ$
$= -69.2 \text{ N}$

$F_{1y} = -(115 \text{ N}) \sin 53.1^\circ$
$= -92.1 \text{ N}$

Now look at force $F_2$:

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

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

$R_x = -69.2 \text{ N} - 240 \text{ N} = -309 \text{ N}$

$R_y = -69.2 \text{ N} - 0 = -69.2 \text{ N}$
Example 4 (Cont.) Next find resultant $R$ from components $F_x$ and $F_y$. (review vectors).

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

We now find resultant $R, \theta$:

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

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

Thus, the magnitude of the electric force is:

$R = 317 \text{ N}$
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: \( \phi = 77.4^\circ \text{S of W} \)

Or, the polar angle \( \theta \) is: \( \theta = 180^\circ + 77.4^\circ = 257.4^\circ \)

Resultant Force: \( R = 317 \text{ N}, \theta = 257.4^\circ \)
Summary of Formulas:

Like Charges Repel; Unlike Charges Attract.

\[ F = \frac{kqq'}{r^2} \]

\[ k = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \]

1 μC = 1 x 10^{-6} C

1 nC = 1 x 10^{-9} C

1 pC = 1 x 10^{-12} C

1 electron: \( e^- = -1.6 \times 10^{-19} \) C
CONCLUSION: Chapter 23
Electric Force