


# Electric Charge

Ali Alzahrani

# Electric Charge

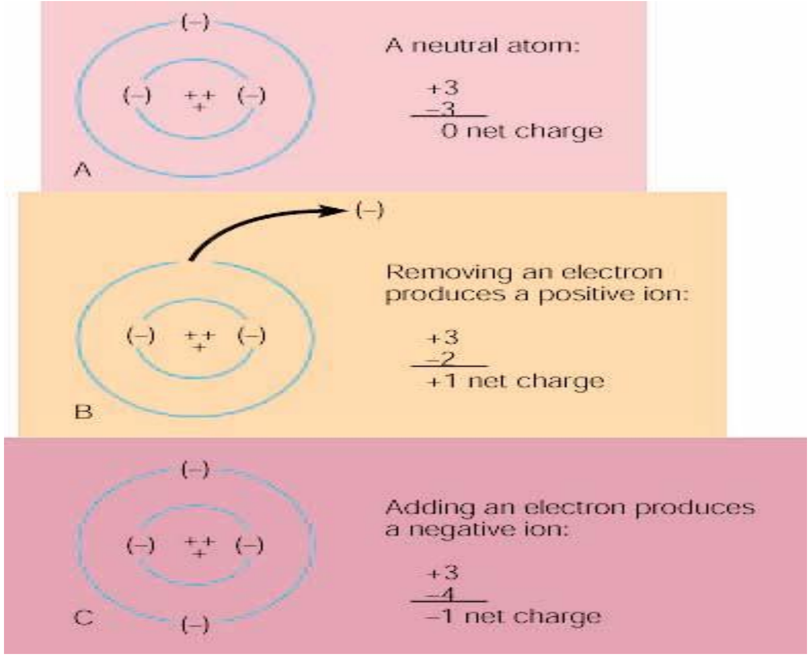
- **Electric charge** is an **intrinsic property** of particles, such as electrons and protons.
- There are two types of charges: **positive** and **negatives**.
- **Electrons** have a **negative** charge.
- **Protons** have a **positive** charge.
- Charged particles can interact to create an **electrical force**.
- **Similar charges** produce a **repulsive force**, where each one repels the other.
- **Dissimilar charges** produce an **attractive force**, where each one attracts the other.

# NEUTRAL AND CHARGED ATOMS

(A) Equality of the numbers of electrons and protons produces a zero net charge; the atom is called neutral atom, such as Ar.

(B) Removing an electron from an atom produces a net positive charge; the charged atom is called a positive ion (cation), such as Na.

(C) Adding an electron to an atom produces a net negative charge and a negative ion (anion)., such as Cl.



# Electrostatic Charge

- The charge on an ion is called an **electrostatic charge**.
- There are different ways to electrostatically charge a non charged particle:
  - **Friction** which transfers electrons between two objects,
  - **Contact** with a charged body which results in the transfer of electrons, and
  - **Induction** which produces a charge redistribution of electrons in a material.

# Conductors and Insulators

- Materials are classified into **four** categories in terms of their capability of conducting electricity.
- **Insulators**: materials that a significant amount of electrons are **not free** to move.
- **Conductors**: materials that a significant amount of electrons are **free** to move.
- **Semiconductors**: materials that sometimes behave like insulators and sometimes behave like conductors, intermediate between conductors and insulators.
- **Superconductors**: materials that almost all electrons are free to move, perfect conductors.

# Quantization of Charge

- The fundamental charge is the electron charge ($e$) which is $1.6\times 10^{-19}$ Coulomb (C), where the Coulomb (C) is the SI unit of charge.
- Any electric charge ($q$) is quantized, that means it depends on the number of electrons ($n$), according to

$$q = n\,e$$

- The electric current is the rate of change of the electric charge

$$i = \frac{dq}{dt}$$

Therefore , 1 Coulomb (C) = 1 Ampere (A). 1 second (s).

# Electrostatic Force – Coulomb's Law

- The magnitude of the electrostatic force (attractive or repulsive) between two charged particles $q_1$ and $q_2$ separated by a distance $r$ is determined by

$$F = \frac{k|\,q_1||\,q_2|}{r^2}$$

where $k$ is a constant equals to $9.0 \times 10^9$ N. m$^2$ / C$^2$, which is also defined as

$$k = \frac{1}{4\pi\varepsilon_0}$$

where $\varepsilon_0$ is known as the permittivity and equals to $8.85 \times 10^{-12}$ C$^2$ /(N. m$^2$).

- The electric force is a vector quantity, therefore the resultant force on an object is the superposition vector of all forces acting on it due to others.

# Worked Exercises

**1. How many electrons would be removed from a metal to have a charge of 4.8 μC?**

**Solution**

We know that the electric charge is quantized and defined by the equation

$$q = n\, e$$

$$n = \frac{q}{e} = \frac{4.8 \times 10^{-6}}{1.6 \times 10^{-19}} = 3.0 \times 10^{13} \text{ electrons}$$

# Worked Exercises

**2. $5\times 10^{20}$ electrons pass between two points in 4 s, calculate the current.**

**Solution**

We know that the current is the rate of change of charge, therefore

$$i = \frac{dq}{dt} = \frac{q}{t}$$

But the charge is

$$q = n\,e$$

$$i = \frac{ne}{t} = \frac{5\times10^{20}\times1.6\times10^{-19}}{4} = 20\text{ A}$$

# Worked Exercises

**3. Two charges 4 μC and - 3 μC are separated by 2 cm. Calculate the force between them ?**

**Solution**

Since the signs of the charges are different, they produce an attractive force. The magnitude of this force is

$$F = \frac{k|\,q_1||\,q_2|}{r^2}$$

$$F = \frac{9 \times 10^9 \times 4 \times 10^{-6} \times 3 \times 10^{-6}}{0.02^2} = 270\ \text{N}$$

# Worked Exercises

**4. Calculate the distance between two point charges 2.4 μC and – 1.8 μC for the electrostatic force to be of magnitude 10.8 N?**

**Solution**

The magnitude of the electrostatic force is given by

$$F = \frac{k|\,q_1||\,q_2|}{r^2} \qquad \rightarrow \qquad r = \sqrt{\frac{k|\,q_1||\,q_2|}{F}}$$

$$r = \sqrt{\frac{k|\,q_1||\,q_2|}{F}} = \sqrt{\frac{9\times10^9\times2.4\times10^{-6}\times1.8\times10^{-6}}{10.8}} = 0.06\ m = 6\ cm$$

# Worked Exercises

**5. A point charge 2.0 μC is placed at a distance 4 cm form another point charge q. If the attractive force between them is 56.25 N, find q.**

**Solution**

The magnitude of the electrostatic force is given by

$$F = \frac{k|\,q_1||\,q_2|}{r^2} \quad \rightarrow \quad q_2 = \frac{F\,r^2}{k\,q_1}$$

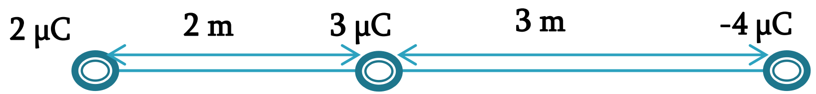
$$q_2 = \frac{56.25 \times 0.04^2}{9\times10^9\times2.0\times10^{-6}} = 5.0 \times 10^{-6}\text{C} = 5\mu C$$

Since the force is ATTRACTIVE, the signs of the charges are DIFFERENT. Therefore the unknown charge is negative **-5.0 μC** .

# Worked Exercises

**6. Three point charges 2.0, 3.0, and -4.0 μC are located as shown in the figure. Find the magnitude of the force acting on the 2 μC charge due to the others .**

**Solution**




Since the signs of charges (2 μC and 3 μC) are similar, the force is repulsive. That means the force will be to left and its magnitude is

$$F_{12} = \frac{9 \times 10^{9} \times 2 \times 10^{-6} \times 3 \times 10^{-6}}{2^{2}} = 0.0135 \text{ N}$$

# Worked Exercises

Since the signs of charges (2 μC and -4 μC) are dissimilar, the force is attractive. That means the force will be to right and its magnitude is

$$F_{13} = \frac{9 \times 10^{9} \times 2 \times 10^{-6} \times 4 \times 10^{-6}}{5^{2}} = 0.00288 \text{ N}$$

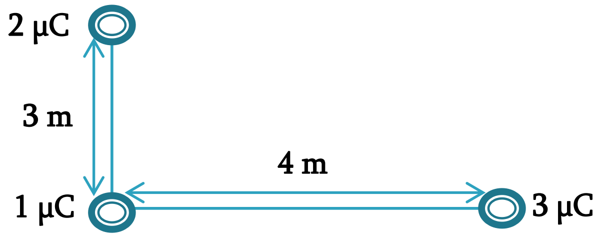
Therefore the magnitude of the force on the 2 μC particle due to the other charged particles is

$$F = |F_{12} - F_{13}| = |0.0135 - 0.00288| = 0.01062 \text{ N}$$

# Worked Exercises

**7. Three point charges 1.0, 2.0, and 3.0 μC are arranged as shown in the figure. Find the magnitude of the force acting on the 2 μC charge due to the others .**

**Solution**




Since the signs of charges (1 μC and 2 μC) are similar, the force will be up along the positive y-direction with magnitude of

$$F_{12} = \frac{9 \times 10^9 \times 1 \times 10^{-6} \times 2 \times 10^{-6}}{3^2} = 0.002 \text{ N}$$

# Worked Exercises

Since the signs of charges (2 μC and 3 μC) are also similar, the force will have two components (one along x and other along y axes)

$$F_{13x} = \frac{9 \times 10^9 \times 2 \times 10^{-6} \times 3 \times 10^{-6}}{5^2} \cdot \frac{4}{5} = 0.00173 \text{ N}$$

$$F_{13y} = \frac{9 \times 10^9 \times 2 \times 10^{-6} \times 3 \times 10^{-6}}{5^2} \cdot \frac{3}{5} = 0.0013 \text{ N}$$

Therefore the magnitude of the force on the 2 μC particle due to the other charged particles is

$$F_x = 0.00173\ N$$

$$F_y = 0.002 + 0.0013 = 0.0033\ N$$

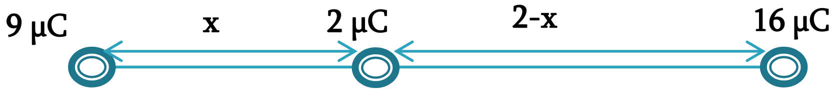
$$F = \sqrt{F_x^2 + F_y^2} = 0.00372\ N$$

# Worked Exercises

**8. Two charges 9.0 and 16.0 μC are separated by a distance of 2 m. Where should a third charge 2 μC be placed for a net force on it zero?**

## Solution

As the charges are of same sign, the third charge must be placed between them and close to the smaller charge in order to have a zero net force.




$$F_{13} = F_{12}$$

$$\frac{9\times10^{9}\times2\times10^{-6}\times9\times10^{-6}}{x^{2}} = \frac{9\times10^{9}\times2\times10^{-6}\times16\times10^{-6}}{(2-x)^{2}}$$

# Worked Exercises

$$\frac{9}{x^2} = \frac{16}{(2-x)^2}$$

Taking the square root of the above, we get

$$\frac{3}{x} = \frac{4}{2-x}$$

This leads to

$$x = \frac{6}{7} = 0.86\ m$$

# Worked Exercises

**9. Four identical charges (2 μC) are located at the vertices of a square of side 5 cm. Calculate the magnitude of the electric force on a 5 μC located at the center of the square.**

Solution

The electric forces on the 5 μC due to the other charges have the same magnitude. Each charge along the diagonal will experience equal and opposite force on the 5 μC charge, therefore, the resultant force is zero.