Electrostatics

- Electrostatics is the **branch of physics** that deals with **electric charges at rest**. It involves studying the **forces**, **fields**, and **potentials** produced by stationary charges and their **interactions**.
- When charges move, we enter **current electricity**, but in electrostatics, **charges are static**, i.e., they do not flow.
- **Applications:**
  - Photocopiers and laser printers
  - Electrostatic air filters
  - Painting and coating processes
  - Capacitors in electrical circuits

◈ Electric Charge

- **Definition:**
  Electric charge is a **fundamental property of matter** due to which materials experience an **electric force** when placed in an electric field.
- **Types of Charges:**
  1. **Positive charge (+):** Deficiency of electrons.
  2. **Negative charge (–):** Excess of electrons.
- **Unit:**
  - **SI unit:** Coulomb (C)
  - **1 Coulomb = charge of 6.25 × 10^{18} electrons**
- **Properties of Charge:**
  1. **Quantization:**
     Charge exists in discrete packets called *elementary charges (e)*.
     $$q = ne, e = 1.6 \times 10^{-19}\ C$$
  2. **Conservation:**
     The total charge of an isolated system remains constant.
  3. **Additivity:**
     Net charge is the algebraic sum of individual charges.
  4. **Relative Nature:**
     A body appears charged only with respect to another body.

◈ Coulomb's Law

- **Statement:**
- The electrostatic force between two-point charges is **directly proportional to the product of the charges** and **inversely proportional to the square of the distance** between them.

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

- **Where:**
  - F: Electrostatic force (N)
  - q_1, q_2: Magnitudes of the charges (C)
  - r: Distance between them (m)
  - $\varepsilon_0 = 8.854 \times 10^{-12}\ C^2/N \cdot m^2$: Permittivity of free space
- **Nature:**
  - **Attractive** if charges are opposite.
  - **Repulsive** if charges are like.
- **Vector Form:**

$$\overrightarrow{F_{21}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$$

- where $\hat{r}$is a unit vector along the line joining the charges.

◈ Electric Field (E)

- **Definition:**
  The **electric field** at a point is the **force experienced by a unit positive test charge** placed at that point.

$$\vec{E} = \frac{\vec{F}}{q}$$

- **Unit:**
  - Newton per Coulomb (N/C) or Volt per meter (V/m)
- **For a Point Charge:**

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

- **Properties:**
  - Direction: Away from +ve charge, toward –ve charge.
  - It is a **vector quantity**.
  - The **superposition principle** applies:
    Total field = Vector sum of fields due to individual charges.

◈ Electric Field Lines

- **Concept:**
  Electric field lines are **imaginary lines** that show the **direction of electric force** on a positive test charge.
- **Properties:**
  1. Begin on positive and end on negative charges.
  2. Do not intersect.
  3. Density of lines $\propto$ Field strength.
  4. Perpendicular to the surface of a conductor.
  5. Lines never form closed loops.

◈ Electric Dipole

- **Definition:**
  An **electric dipole** consists of **two equal and opposite charges** separated by a small distance $2a$.
- **Dipole Moment:**

$$\vec{p} = q \times 2a$$

  - Direction: From negative to positive charge.
  - Unit: Coulomb–meter (C·m)
- **Electric Field due to Dipole:**
  1. **On Axial Line:**

$$E_{axial} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

  2. **On Equatorial Line:**

$$E_{equatorial} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

- (Direction opposite to dipole moment)
- **Torque on Dipole in Uniform Field:**

$$\tau = pE\sin\theta$$

- **Potential Energy:**

$$U = -pE\cos\theta$$

◈ **Electric Flux (Φ)**

- **Definition:**
  Electric flux is the **total number of electric field lines** passing through a surface.
- $\Phi = \vec{E} \cdot \vec{A} = EA\cos\theta$
  - Unit: N·m²/C
  - Scalar quantity.
  - Maximum when θ = 0°, Minimum when θ = 90°.

◈ **Gauss's Law**

- **Statement:**
  The total **electric flux** through a closed surface equals **$1/\varepsilon_0$** times the total charge enclosed by the surface.

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\varepsilon_0}$$

- **Applications:**
  (a) Electric Field due to a Point Charge:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

  (b) Infinite Line of Charge:

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

- where λ = linear charge density (C/m)

(c) Infinite Plane Sheet of Charge:

$$E = \frac{\sigma}{2\varepsilon_0}$$

- where σ = surface charge density (C/m²)

◈ Electric Potential (V)

- **Definition:**
  Electric potential at a point is the **work done per unit charge** in bringing a positive test charge from infinity to that point.

$$V = \frac{W}{q}$$

- For a point charge:

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

- **Relation Between Field and Potential:**

$$E = -\frac{dV}{dr}$$

- The **negative sign** indicates that potential decreases in the direction of the electric field.

◈ Equipotential Surfaces

- **Definition:**
  A surface on which the potential is **same at every point**.
- **Properties:**
  1. No work is done in moving a charge on an equipotential surface.
  2. Electric field is always **perpendicular** to it.
  3. Closer surfaces = Stronger electric field.
  4. For a point charge, equipotential surfaces are **spherical**.

◈ Potential Energy of a System of Charges

- For two point charges q_1 and q_2 separated by distance r:

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

- For multiple charges:

$$U = \sum_{i<j} \frac{1}{4\pi\varepsilon_0}\frac{q_i q_j}{r_{ij}}$$

◈ Conductors and Insulators

- **Conductors:**
  Materials that allow charge to move freely.
  Examples: Metals, graphite.
- **Properties:**
  - Electric field inside conductor = 0
  - Surface is equipotential
  - Excess charge resides on the surface
  - Electric field is normal to surface
- **Insulators (Dielectrics):**
  Materials that do not allow free movement of charges.
  Examples: Glass, rubber, wood.

◈ Capacitance and Capacitors

- **Definition:**
  The **capacitance (C)** of a conductor is the **ratio of charge (Q)** stored to the **potential (V)** developed.

$$C = \frac{Q}{V}$$

- **Unit:** Farad (F)
- **For Parallel Plate Capacitor:**

$$C = \frac{\varepsilon_0 A}{d}$$

- where A= plate area, d= distance between plates.
- **With Dielectric Medium:**

$$C = \frac{K\varepsilon_0 A}{d}$$

- where K= dielectric constant.
- **Combination of Capacitors:**
  1. **Series:** $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
  2. **Parallel:** $C_{eq} = C_1 + C_2 + \ldots$

◈ Energy Stored in a Capacitor

$$U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{Q^2}{2C}$$

- It is the work done in charging the capacitor.

◈ Applications of Electrostatics

- Capacitors in filters and tuning circuits
- Electrostatic painting and spraying
- Photocopiers and laser printers
- Electrostatic precipitators for pollution control
- Van de Graaff generator (high voltage source)

⚡ Quick Summary Table:

Concept	**Symbol**	**Formula**	**Unit**
Electric Force	F	$\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$	N
Electric Field	E	F/q	N/C
Potential	V	$\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$	Volt

Concept	**Symbol**	**Formula**	**Unit**
Dipole Moment	p	$q \times 2a$	$C \cdot m$
Capacitance	C	Q/V	Farad
Flux	Φ	$E \cdot A \cdot \cos\theta$	$N \cdot m^2/C$