APPLIED PHYSICS 2

2nd Semester | Polytechnic Diploma

UNIT – 3 : ELECTROSTATICS

Topics Covered:

Coulomb's Law • Electric Field • Electric Flux
Electric Potential • Gauss Law • Capacitors
Capacitance • Parallel Plate Cap. • Combinations
Dielectric • Dielectric Breakdown

Handwritten-Style Notes • Exam Oriented • With Diagrams

✦ 1. COULOMB'S LAW

→ Statement:

The force between two POINT CHARGES is:

- → Directly proportional to the PRODUCT of their charges ($q_1 \times q_2$)
- → Inversely proportional to the SQUARE of distance (r^2) between them
- → Acts along the LINE joining the two charges

[COULOMB'S LAW]

$F = k \cdot q_1 \cdot q_2 / r^2$

$k = 9 \times 10^9 \ N \cdot m^2/C^2 = 1 / (4\pi\varepsilon_0)$

$\varepsilon_0 = 8.85 \times 10^{-12} \ C^2/N \cdot m^2$ (permittivity of free space)

Unit of Charge → COULOMB (C)

Fig 1: Coulomb's Law – Force Between Two Charges

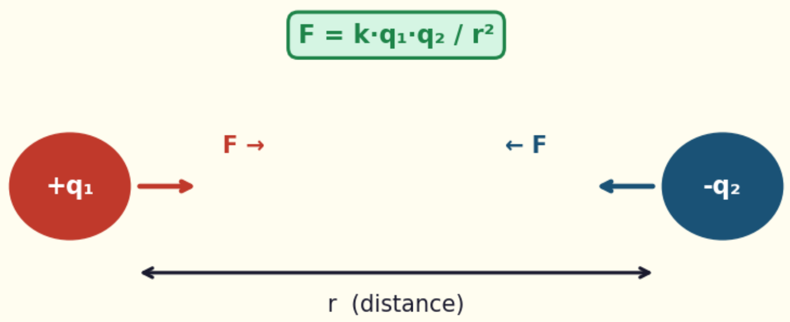

Fig 1: Force between two charges (Coulomb's Law)

- → F is REPULSIVE for same charges, ATTRACTIVE for opposite charges
- → Coulomb's Law valid only for POINT charges in free space / vacuum

✦ 2. ELECTRIC FIELD (E)

→ Definition:

Region around a charge where another +ve test charge FEELS a force.

[ELECTRIC FIELD]

$E = F / q$ → Unit: N/C or V/m

$E = k \cdot Q / r^2$ (field due to point charge Q)

Direction → Away from +ve, Towards -ve charge

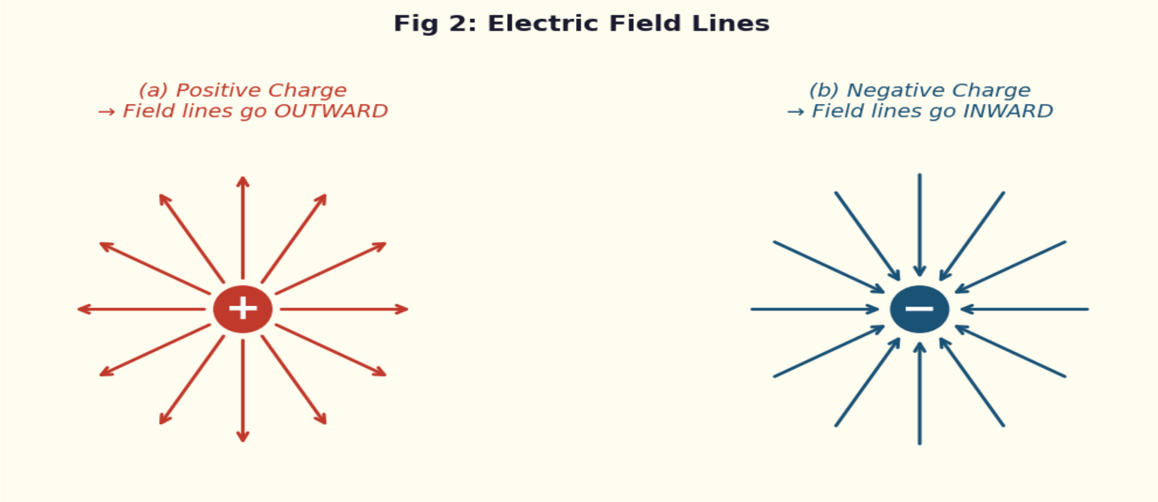

Fig 2: Electric Field Lines – Positive & Negative Charges

→ Properties of Electric Lines of Force:

- → Start from +ve charge → end at -ve charge
- → NEVER cross each other
- → Tangent at any point = direction of E at that point
- → Closer lines = STRONGER field, Farther lines = weaker field
- → They are always perpendicular to the surface of conductor
- → Number of lines $\propto$ magnitude of charge

✦ 3. ELECTRIC FLUX (ϕ)

→ Definition:

Total number of Electric Field lines passing PERPENDICULARLY through a given surface area.

[ELECTRIC FLUX]

$\varphi = E \cdot A \cdot \cos\theta$

θ = angle between E and normal ($\hat{n}$) to surface

Unit: $N \cdot m^2 / C$ or $V \cdot m$

Max flux → $\theta = 0°$ ($E \perp$ surface)

Zero flux → $\theta = 90°$ ($E \parallel$ surface)

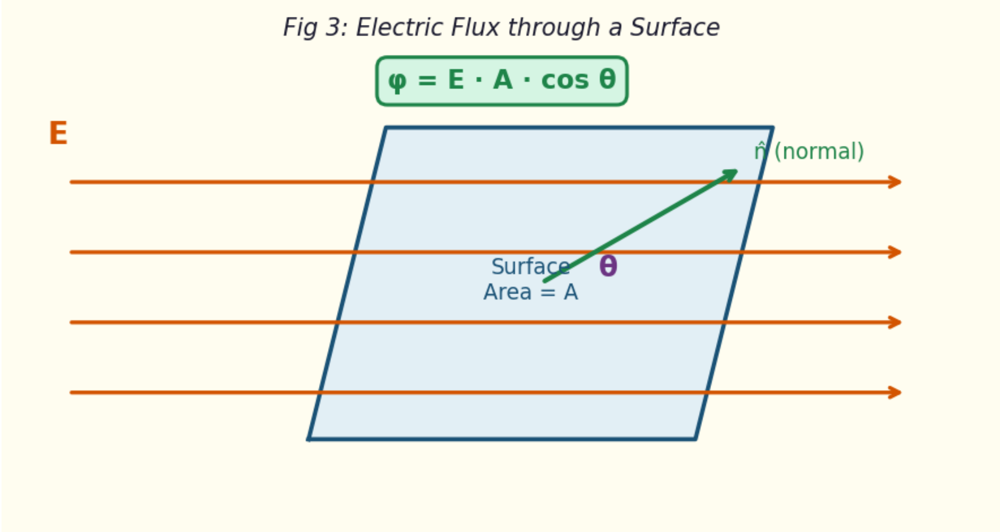

Fig 3: Electric Flux through a surface

✦ 4. ELECTRIC POTENTIAL & POTENTIAL DIFFERENCE

→ **Electric Potential (V):**

Work done in bringing a unit +ve charge from INFINITY to a point in the electric field.

```
[ ELECTRIC POTENTIAL ]
V  =  W / q               Unit:  VOLT (V)  =  J/C
V  =  k · Q / r           (potential due to point charge)
```

→ **Potential Difference (V_AB):**

Difference in electric potential between two points A and B.

```
[ POTENTIAL DIFFERENCE ]
V_AB  =  V_A  –  V_B  =  W_AB / q
Unit:  VOLT (V)
```

→ **Relation Between E and V:**

```
[ E & V RELATION ]
E  =  – dV / dr
E is the NEGATIVE gradient of Potential
→  Stronger E  means  larger change in V per unit
distance
```

✦ 5. GAUSS LAW

→ **Statement:**

Total electric flux (ϕ) through any closed surface equals total charge ENCLOSED divided by ε_0.

[GAUSS LAW]

$$\varphi = Q\_enclosed / \varepsilon_0$$

$$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N\cdot m^2$$

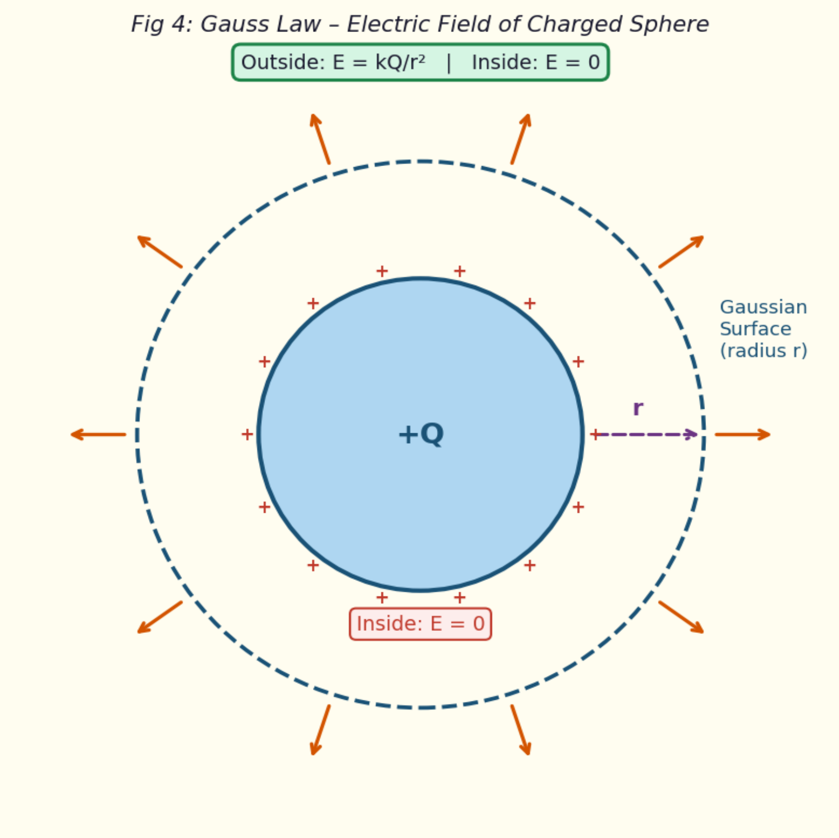

Fig 4: Electric field of a uniformly charged sphere (Gauss Law)

→ **Application – Electric Field Due to Charged Sphere:**

- → Outside sphere (r > R) → $E = kQ / r^2$ (same as point charge)
- → On surface (r = R) → $E = kQ / R^2$
- → Inside sphere (r < R) → $E = 0$ ← IMPORTANT!

Remember:
KEY POINT: Electric field INSIDE a hollow charged sphere = ZERO
All charge resides on the OUTER surface of conductor

✦ 6. CAPACITORS

→ **Definition:**

A device that STORES electrical energy in the form of electric field between two conducting plates / surfaces separated by an insulator.

→ **Working:**

- → Two conducting plates are connected to a battery
- → +Q accumulates on one plate, −Q on the other
- → Electric field builds up between the plates

→ Energy stored → $U = \frac{1}{2}CV^2$

→ **Types of Capacitors:**

→ 1. Parallel Plate Capacitor → two flat plates
→ 2. Cylindrical Capacitor → coaxial cylinders
→ 3. Spherical Capacitor → two concentric spheres
→ 4. Electrolytic Capacitor → used in circuits (polarised, large C)

✦ 7. CAPACITANCE (C)

→ **Definition:**

Ability of a capacitor to STORE charge per unit applied voltage.

[CAPACITANCE]

$C = Q / V$

Unit: FARAD (F) → 1 F = 1 C / 1 V

Practical units: microfarad (μF) = 10^{-6} F
picofarad (pF) = 10^{-12} F

→ Larger C → more charge stored at same voltage
→ Farad is a very LARGE unit → μF and pF are used in practice

✦ 8. PARALLEL PLATE CAPACITOR

[PARALLEL PLATE CAPACITOR]

$C = \varepsilon_0 \cdot A / d$ (without dielectric)

$C = \varepsilon_0 \cdot \varepsilon_r \cdot A / d$ (with dielectric)

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

A = area of plates (m^2)

d = distance between plates (m)

ε_r = relative permittivity (dielectric constant)

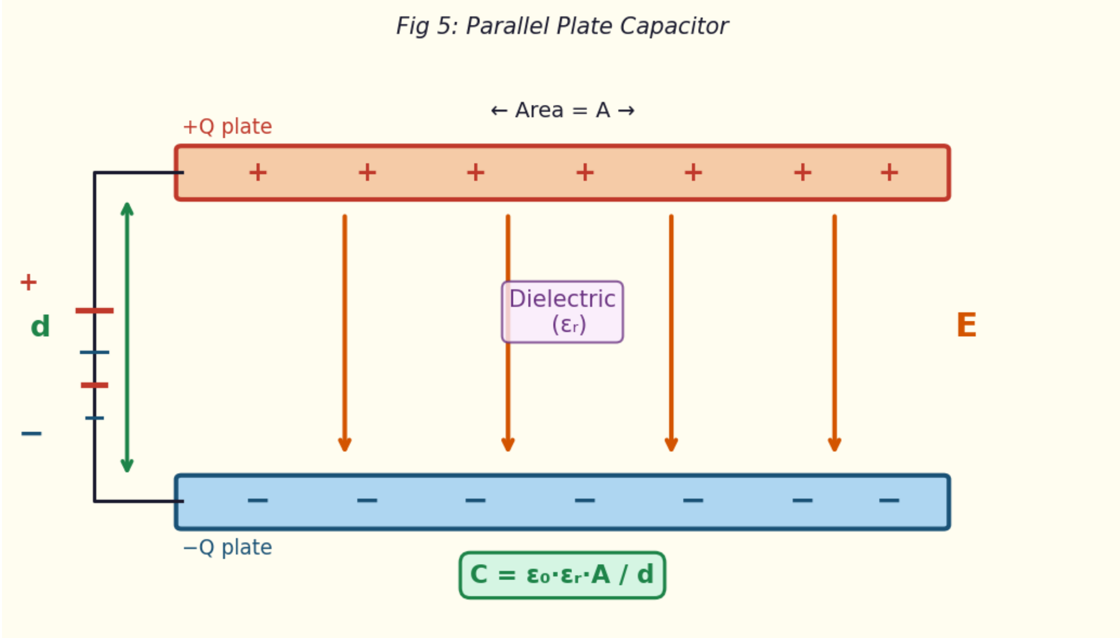

Fig 5: Parallel Plate Capacitor with Dielectric

- → C INCREASES if: A increases OR d decreases OR dielectric is added
- → C DECREASES if: d increases OR A decreases

✦ 9. COMBINATION OF CAPACITORS

→ Series Combination:

- → Capacitors connected END to END
- → SAME charge Q on each capacitor
- → Voltage DIVIDES across capacitors

[SERIES COMBINATION]

$$1/C_t = 1/C_1 + 1/C_2 + 1/C_3$$

$$C_t < \text{smallest individual capacitor}$$

$$V = V_1 + V_2 + V_3$$

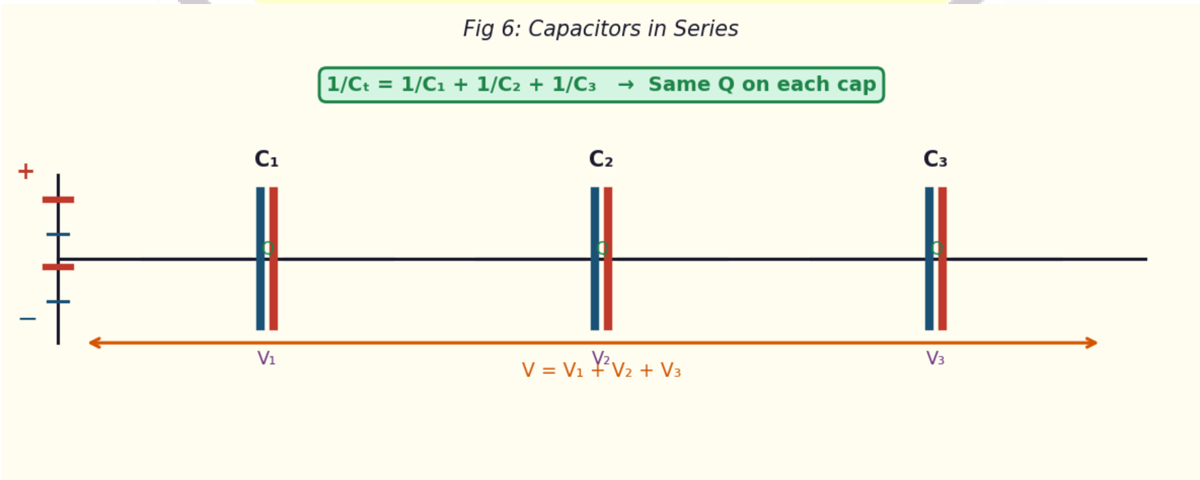

Fig 6: Capacitors in Series

→ **Parallel Combination:**

- → All capacitors connected between SAME two nodes
- → SAME voltage V across each capacitor
- → Total charge ADDS up → $Q = Q_1 + Q_2 + Q_3$

[PARALLEL COMBINATION]

$$C_t = C_1 + C_2 + C_3$$

C_t > largest individual capacitor

$$Q\_total = Q_1 + Q_2 + Q_3$$

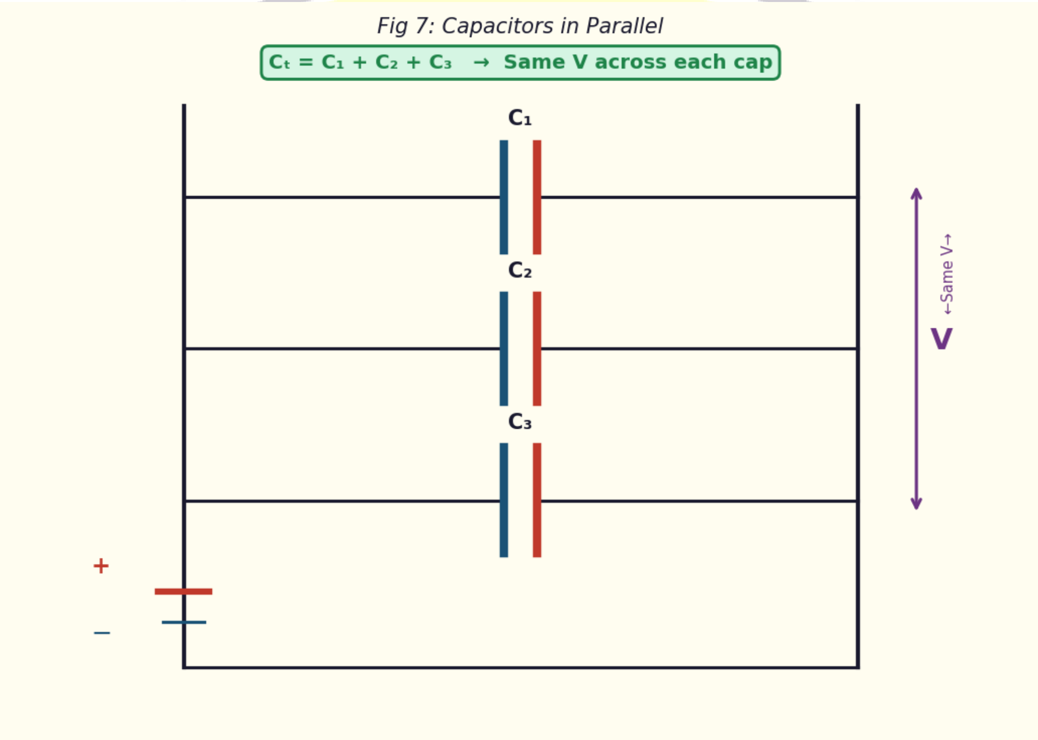

Fig 7: Capacitors in Parallel

✦ SOLVED NUMERICALS

NUMERICAL 1

Find capacitance if Q = 50 μC and V = 10 V.

Given: $Q = 50\ \mu C = 50 \times 10^{-6}$ C $V = 10$ V

Formula: $C = Q / V$

Sol: $C = (50 \times 10^{-6}) / 10 = 5 \times 10^{-6}$ F

$\Longrightarrow C = 5\ \mu F$ ✓

NUMERICAL 2

$C_1 = 2\ \mu F$, $C_2 = 3\ \mu F$, $C_3 = 6\ \mu F$ → SERIES. Find C_t.

Formula: $1/C_t = 1/C_1 + 1/C_2 + 1/C_3$

$1/C_t = 1/2 + 1/3 + 1/6 = 3/6 + 2/6 + 1/6 = 6/6 = 1$

$\Longrightarrow C_t \ = \ 1\ \mu F$ ✓

NUMERICAL 3

$C_1 = 4\ \mu F$, $C_2 = 6\ \mu F$, $C_3 = 2\ \mu F$ → PARALLEL. Find C_t.

Formula: $C_t = C_1 + C_2 + C_3$

$C_t = 4 + 6 + 2 \ = \ 12\ \mu F$

$\Longrightarrow C_t \ = \ 12\ \mu F$ ✓

✦ 10. DIELECTRIC

→ **Definition:**

An INSULATING material placed between capacitor plates that INCREASES the capacitance without conducting electricity.

- → Examples: Glass, Mica, Paper, Air, Rubber, Plastic
- → Dielectric Constant (ε_r or K) = measure of increase in C
- → ε_r for air = 1, glass ≈ 7, mica ≈ 6, water ≈ 80

→ **Effect on Capacitance:**

[DIELECTRIC EFFECT]

```
C (with dielectric)  =  εᵣ  ×  C (without dielectric)
εᵣ  ≥  1   always
Higher εᵣ  →  higher capacitance  →  more charge stored
```

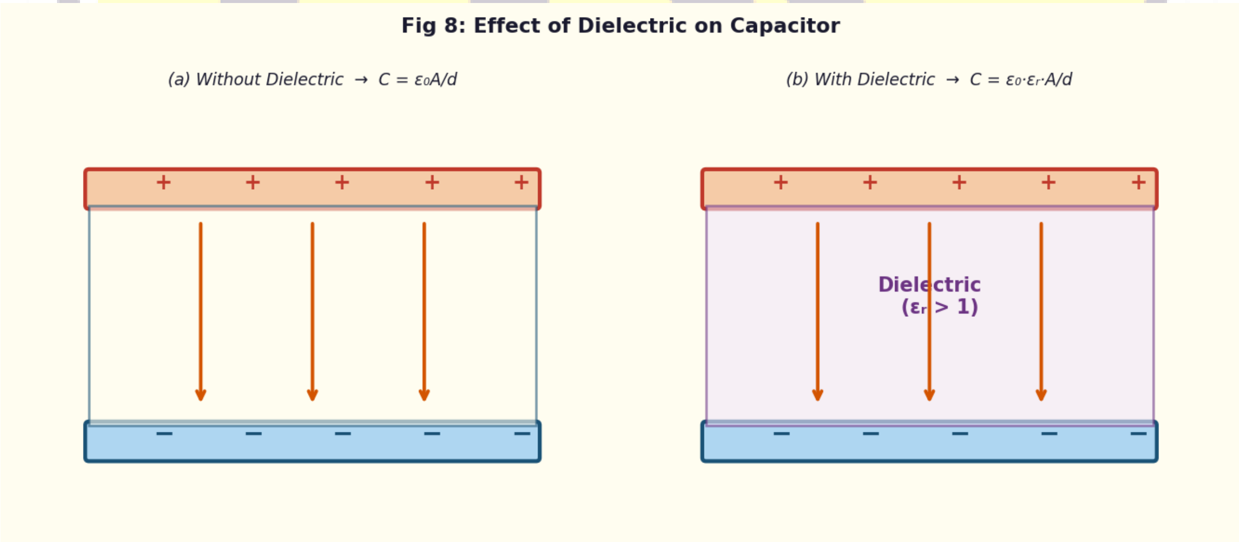

Fig 8: Effect of Dielectric on Parallel Plate Capacitor

✦ 11. DIELECTRIC BREAKDOWN

→ **Definition:**

When voltage across dielectric becomes EXCESSIVELY HIGH, the insulating property is destroyed and it allows electric current to flow through it.

- → The voltage at which breakdown occurs = BREAKDOWN VOLTAGE

→ After breakdown → dielectric is PERMANENTLY damaged (burnt / melted)
→ Real-life example → LIGHTNING = dielectric breakdown of air!
→ To prevent: use thicker dielectric or choose high breakdown-strength material

⚠Key Fact:
Breakdown Strength = max E-field a dielectric can withstand (V/m)
For air ≈ 3×10^6 V/m
For mica ≈ 5×10^7 V/m (much better than air)

★ IMPORTANT FOR EXAM ★

1. State Coulomb's Law and write its formula
2. Define Electric Field with formula ($E = F/q$)
3. Define Electric Flux → $\phi = E \cdot A \cdot \cos\theta$
4. State Gauss Law (statement only)
5. Define Capacitance and its unit (Farad)
6. Formula for Parallel Plate Capacitor → $C = \varepsilon_0 \varepsilon_r A/d$
7. Series and Parallel combination formulas + numericals
8. Define Dielectric and state its effect on capacitance
9. What is Dielectric Breakdown? Give one real-life example
10. Draw diagram of Parallel Plate Capacitor (labeled)

? COMMON VIVA QUESTIONS ?

Q: What is the SI unit of charge?
Ans: Coulomb (C)

Q: What is the unit of Capacitance?
Ans: Farad (F)

Q: What is the value of Coulomb's constant k?
Ans: 9×10^9 $N \cdot m^2/C^2$

Q: What is E inside a hollow charged sphere?
Ans: $E = 0$ (zero) inside

Q: Does C depend on Q or V?
Ans: No. $C = Q/V$ is constant for a given capacitor

Q: What increases when dielectric is inserted?
Ans: Capacitance increases by factor ε_r

Q: In series, what remains same?
Ans: Charge Q is same on all capacitors

Q: In parallel, what remains same?
Ans: Voltage V is same across all capacitors

Q: Give a real-life example of dielectric breakdown?
Ans: Lightning (breakdown of air)

Q: What is electric flux unit?
Ans: $N \cdot m^2/C$ or $V \cdot m$