Unit-2. Electrostatics - Short Solutions

Part A: Definitions (1-2 marks)

Electric Field (E)

Force per unit positive charge at a point.

```
E = F/q₀ = kQ/r²
Unit: N/C or V/m
```

Electric Potential (V)

Work done to bring unit positive charge from infinity to a point.

```
V = W/q = kQ/r
Unit: Volt (V) or J/C
```

Electric Potential Difference (ΔV)

Work done to move unit charge from one point to another.

```
ΔV = W/q = V₂ - V₁
Unit: Volt (V)
```

Electric Flux (Φ)

Number of electric field lines passing through a surface.

```
Φ = E·A = EA cos θ
Unit: N·m²/C or V·m
```

Capacitor

Device that stores electric charge and energy. Two conducting plates separated by dielectric.

Capacitance (C)

Ability to store charge. Ratio of charge to potential difference.

```
C = Q/V
C (parallel plate) = ε₀εᵣA/d
Unit: Farad (F)
```

Part B: Detailed Answers (2-3 marks)

(1) Coulomb's Law

Electric force between two stationary point charges is directly proportional to product of charges and inversely proportional to square of distance.

$$F = kq_1q_2/r^2$$
$$k = 9\times10^9\ N\cdot m^2/C^2$$

Nature:

- Like charges: Repulsive
- Unlike charges: Attractive

(2) Characteristics of Electric Field Lines

1. **Start/End:** Start from +ve, end at -ve charges
2. **Direction:** Tangent shows field direction
3. **No intersection:** Lines never cross
4. **Density:** Close lines = strong field, far lines = weak field
5. **Uniform field:** Parallel and equidistant
6. **Imaginary:** Lines are imaginary, field is real
7. **Perpendicular:** Always perpendicular to conductor surface
8. **Open curves:** Never form closed loops

(3) Parallel Plate Capacitor

Construction: Two parallel conducting plates of area A separated by distance d with dielectric between.

Capacitance:

$$C = \varepsilon_0\varepsilon_r A/d = \varepsilon_0 KA/d$$

Factors affecting C:

- $C \propto A$ (area)
- $C \propto 1/d$ (distance)
- $C \propto K$ (dielectric constant)

Applications: Energy storage, filtering, timing circuits, coupling/decoupling

(4) Series Connection of Capacitors

Characteristics:

- Same charge: $Q_1 = Q_2 = Q_3 = Q$

- Different voltages: $V = V_1 + V_2 + V_3$

Formula:

```
1/Cₛ = 1/C₁ + 1/C₂ + 1/C₃

For 2 capacitors: Cₛ = C₁C₂/(C₁+C₂)
For n equal: Cₛ = C/n
```

Result: C_s < smallest capacitance

(5) Parallel Connection of Capacitors

Characteristics:

- Same voltage: $V_1 = V_2 = V_3 = V$
- Different charges: $Q = Q_1 + Q_2 + Q_3$

Formula:

```
Cₚ = C₁ + C₂ + C₃

For n equal: Cₚ = nC
```

Result: C_p > largest capacitance

(6) Effect of Dielectric on Capacitance

When dielectric (K) inserted between plates:

Capacitance increases:

```
C = KC₀
```

Why it increases:

- Dielectric molecules polarize
- Reduces electric field: $E = E_0/K$
- Reduces voltage: $V = V_0/K$
- Same charge, lower voltage → higher capacitance

Other effects:

- Increases breakdown voltage
- Provides mechanical support
- Makes capacitor compact

Part C: Numericals (3 marks)

(1) Coulomb force

Given: $q_1 = 20\ \mu C$, $q_2 = 10\ \mu C$, $r = 0.02$ m, $k = 9\times10^9$

$$F = kq_1q_2/r^2$$
$$F = (9\times10^9)(20\times10^{-6})(10\times10^{-6})/(0.02)^2$$
$$F = 1800\times10^{-3}/4\times10^{-4} = 4500\ N$$

Answer: 4500 N (repulsive)

(2) Potential difference

Given: $W = 1600$ J, $q = 25$ C

$$V = W/q = 1600/25 = 64\ V$$

Answer: 64 V

(3) Capacitance

Given: $Q = 60\ \mu C$, $V = 12$ V

$$C = Q/V = 60\times10^{-6}/12 = 5\times10^{-6}\ F = 5\ \mu F$$

Answer: 5 μF

(4) Series and Parallel (3 × 10μF)

Series:

$$C_s = C/n = 10/3 = 3.33\ \mu F$$

Parallel:

$$C_p = nC = 3\times10 = 30\ \mu F$$

Answer: Series = 3.33 μF, Parallel = 30 μF

(5) Capacitance of small capacitor

Given: $A = 10\ mm^2 = 10^{-5}\ m^2$, $d = 1\ mm = 10^{-3}$ m

$$C = \varepsilon_0 A/d = (8.85\times10^{-12})(10^{-5})/(10^{-3})$$
$$C = 8.85\times10^{-14}\ F = 0.0885\ pF$$

Answer: 8.85×10^{-14} F

(6) Area for 1F capacitor

Given: C = 1 F, d = 1 mm = 10^{-3} m

```
A = Cd/ε₀ = (1)(10⁻³)/(8.85×10⁻¹²)
A = 1.13×10⁸ m² = 113 km²
```

Answer: 1.13×10^8 m² (113 km²) - Shows 1F is huge!

(7) Mixed Circuit

Example: (C_1 ∥ C_2) in series with C_3
Given: C_1 = 10 μF, C_2 = 20 μF, C_3 = 30 μF

Step 1: Parallel

```
C₁₂ = C₁ + C₂ = 10 + 20 = 30 μF
```

Step 2: Series with C_3

```
1/Cₜ = 1/30 + 1/30 = 2/30
Cₜ = 15 μF
```

Answer: 15 μF

Quick Reference

Formulas

```
Coulomb's Law: F = kq₁q₂/r², k = 9×10⁹
Electric Field: E = F/q = kQ/r²
Potential: V = W/q = kQ/r
Flux: Φ = EA cos θ
Capacitance: C = Q/V = ε₀εᵣA/d
Series: 1/Cₛ = 1/C₁ + 1/C₂ + 1/C₃
Parallel: Cₚ = C₁ + C₂ + C₃
With dielectric: C = KC₀
Energy: U = ½QV = ½CV² = Q²/(2C)
```

Constants

```
k = 9×10⁹ N·m²/C²
ε₀ = 8.85×10⁻¹² F/m
e = 1.6×10⁻¹⁹ C
1 μF = 10⁻⁶ F
1 nF = 10⁻⁹ F
1 pF = 10⁻¹² F
```

Short Solutions - Unit 2