Class 12 Physics · Chapter 2: Electrostatic Potential and Capacitance

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. The equipotential surfaces of an isolated point charge are [1]

(a) parallel planes perpendicular to a line through the charge
(b) coaxial cylinders with the charge on their axis
(c) planes containing the charge
(d) concentric spheres centred at the charge

Answer: (d) $V = q/(4\pi\varepsilon_0 r)$ depends only on r, so V is constant wherever r is constant: on spheres centred at the charge. The radial field lines cross them normally.

2. Capacitors of 6 μF and 3 μF are connected in series. The capacitance of the combination is [1]

(a) 9 μF
(b) 4.5 μF
(c) 18 μF
(d) 2 μF

Answer: (d) $1/C = 1/6 + 1/3 = 1/2$, so C = 2 μF. 9 μF is the parallel value; in series the combination is smaller than the smallest capacitor.

3. The dimensional formula of capacitance is [1]

(a) $[M\,L^2\,T^{-3}\,A^{-1}]$
(b) $[M^{-1}\,L^{-2}\,T^2\,A]$
(c) $[M\,L^2\,T^{-4}\,A^{-2}]$
(d) $[M^{-1}\,L^{-2}\,T^4\,A^2]$

Answer: (d) C = Q/V: charge is [A T] and potential is $[M\,L^2\,T^{-3}\,A^{-1}]$, so $C = [A\,T]/[M\,L^2\,T^{-3}\,A^{-1}] = [M^{-1}\,L^{-2}\,T^4\,A^2]$. $[M\,L^2\,T^{-3}\,A^{-1}]$ is the dimension of potential itself.

4. A capacitor holds a charge of 4.0 mC when the potential difference across it is 200 V. The energy stored in it is [1]

(a) 0.20 J
(b) 0.40 J
(c) 0.80 J
(d) 4.0 mJ

Answer: (b) $U = \tfrac{1}{2}QV = \tfrac{1}{2} \times 4.0 \times 10^{-3} \times 200 = 0.40$ J. QV alone gives 0.80 J; halving twice gives 0.20 J.

5. The plates of an air-filled parallel plate capacitor each have an area of 4.0×10^{-2} m² and are 0.885 mm apart. Take $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2\,N^{-1}\,m^{-2}$. Its capacitance is [1]

(a) 400 pF
(b) 40 pF
(c) 4000 pF
(d) 0.40 pF

Answer: (a) $C = \varepsilon_0 A/d = 8.85 \times 10^{-12} \times 4.0 \times 10^{-2} / (0.885 \times 10^{-3}) = 4.0 \times 10^{-10}$ F = 400 pF.

6. Distinguish between polar and non-polar molecules, giving one example of each, and state how each kind develops a dipole moment in an external electric field. [2]

In a non-polar molecule (O_2, H_2) the centres of positive and negative charge coincide, so it has no permanent dipole moment; a field displaces the charges in opposite directions and induces a dipole moment. In a polar molecule (H_2O, HCl) the centres are separated even without a field, giving a permanent dipole moment; a field tends to align these randomly oriented dipoles, against thermal agitation.

- definitions with one example of each (1)
- induced dipole for non-polar; alignment of permanent dipoles for polar (1)

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7. Capacitors of capacitance C and 2C are connected in series across a battery of emf V. Find the charge on each capacitor and the potential difference across each. [2]

Series: $1/C_s = 1/C + 1/2C = 3/2C$, so $C_s = 2C/3$, and each carries the same charge $Q = 2CV/3$. Then $V_1 = Q/C = 2V/3$ across C and $V_2 = Q/2C = V/3$ across 2C; they add to V. The smaller capacitor takes the larger share of the voltage.

- equivalent 2C/3 and the same charge 2CV/3 on each (1)
- 2V/3 across C and V/3 across 2C (1)

8. An electron and a proton, each starting from rest, are accelerated through a potential difference of 2.0 kV. (a) Find the kinetic energy each gains, in eV and in joule ($e = 1.6 \times 10^{-19}$ C). (b) Taking the proton's mass as 1836 times the electron's, find the ratio of the electron's speed to the proton's. [2]

(a) Each has charge of magnitude e and falls through 2.0 kV, so each gains $eΔV = 2.0$ keV $= 2.0 \times 10^3 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-16}$ J. (b) Equal kinetic energies: $½m_e v_e^2 = ½m_p v_p^2$, so $v_e/v_p = √(m_p/m_e) = √1836 ≈ 43$.

- 2.0 keV $= 3.2 \times 10^{-16}$ J for each (1)
- $v_e/v_p = √1836 ≈ 43$ (1)

9. A 10 μF parallel plate capacitor is charged to 100 V and kept connected to the 100 V battery. A slab of dielectric constant 3 is slid in to fill the gap completely. Find (a) the extra charge that flows from the battery, (b) the increase in the energy stored in the capacitor, and (c) the work done by the battery in sending this charge round, and compare it with (b). [3]

(a) $Q_0 = CV = 10 \times 10^{-6} \times 100 = 1.0 \times 10^{-3}$ C. With the battery connected V is fixed and C becomes 30 μF, so $Q = 3.0 \times 10^{-3}$ C: an extra 2.0×10^{-3} C flows. (b) $U_0 = ½ \times 10 \times 10^{-6} \times 100^2 = 0.050$ J; $U = ½ \times 30 \times 10^{-6} \times 100^2 = 0.15$ J; increase 0.10 J. (c) The battery moves 2.0×10^{-3} C through a potential difference of 100 V: $W = qV = 0.20$ J, twice the increase in stored energy; the other 0.10 J does not stay in the capacitor's field.

- extra charge 2.0×10^{-3} C (1)
- stored energy rises from 0.050 J to 0.15 J, by 0.10 J (1)
- battery work 0.20 J, twice the increase (1)

10. An air-filled parallel plate capacitor has plates of area 2.0×10^{-2} m², 2.0 mm apart. Air breaks down in a field of about 3×10^6 V m^{-1}. Take $ε_0 = 8.85 \times 10^{-12}$ C² N^{-1} m^{-2}. Find (a) its capacitance, (b) the largest potential difference it can safely take, and (c) the largest charge it can then hold. [3]

(a) $C = ε_0A/d = 8.85 \times 10^{-12} \times 2.0 \times 10^{-2}/2.0 \times 10^{-3} = 8.85 \times 10^{-11}$ F ≈ 89 pF. (b) $V_{max} = E_{max}\, d = 3 \times 10^6 \times 2.0 \times 10^{-3} = 6.0 \times 10^3$ V. (c) $Q_{max} = CV_{max} = 8.85 \times 10^{-11} \times 6.0 \times 10^3 ≈ 5.3 \times 10^{-7}$ C. Beyond this the air ionises and the charge leaks away.

- $C ≈ 8.9 \times 10^{-11}$ F (1)
- $V_{max} = 6.0 \times 10^3$ V (1)
- $Q_{max} ≈ 5.3 \times 10^{-7}$ C (1)

11. The gap d between the plates of a parallel plate capacitor (air capacitance C_0) is filled with two dielectric layers, each of thickness d/2 and parallel to the plates, of dielectric constants 2 and 4. Show that the capacitance becomes $(8/3)C_0$. [3]

Each layer acts as a capacitor of plate area A and separation d/2, and the two are in series (the same charge sits on each). $C_1 = 2ε_0A/(d/2) = 4C_0$ and $C_2 = 4ε_0A/(d/2) = 8C_0$. Then $1/C = 1/4C_0 + 1/8C_0 = 3/8C_0$, so $C = (8/3)C_0$.

- layers treated as two capacitors in series (1)
- $C_1 = 4C_0$ and $C_2 = 8C_0$ (1)
- $1/C = 3/8C_0$, so $C = 8C_0/3$ (1)