UNIT I

ELECTROSTATICS

Weightage – 8 Marks

TOPICS TO BE COVERED

Electric charges, Conversation of charges, Coulomb's Law; Force between two points charges, forces between multiple charges, Superposition Principle.

Continuous charge distribution.

Electric field, electric field due to a point charge electric field lines, electric dipole, electric field due to dipole; torque on a dipole in uniform electric field.

Electric flux, statement of Gauss Theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside)

Electric Potential, Potential difference, electric potential due to a point charge, a dipole and system of charges, equipotential surfaces, electrical potential energy of a system of two point charges and of electric dipole in an electrostatic field.

Conductors and Insulators, free charges and bound charges inside a conductor, Dielectric and electric polarization, Capacitors and Capacitance, combination of capacitances in series and parallel.

Capacitance of a parallel plate capacitor with or without dielectirc medium between the plates energy stored in a capacitor, Van de Graff Generator.

KEY POINTS

Physical Quantity	Formulae Used	SI Unit
Quantization of charge	$q = \pm ne$	C
Coulomb's force	$F = \frac{Kq_1q_2}{r^2}$	N
In vector from	$F_{12} = \frac{Kq_1q_2}{r^2_{21}} \hat{r}_{21} = \frac{Kq_1q_2}{r^3_{21}} \vec{r}_{21}$	
Dielectric constant (or relative permitivity)	$K_D = \epsilon_r = \frac{F_0}{F_m} = \frac{\epsilon_m}{\epsilon_0} = \frac{C_m}{C_0} = \frac{\phi_0}{\phi_m} = \frac{E_0}{E_m}$	Dimension less
Hence $F_0 \geq F_m$ as free space has minimum permittivity		
Linear charge density	$\lambda = \frac{q}{L}$	Cm^{-1}
Surface charge density	$\sigma = \frac{q}{A}$	Cm^{-2}
Electric field due to a point charge	$\vec{E} = \underset{q_0 \to 0}{Lt} \frac{\vec{F}}{q_0}$ (theoretical) $\left(\text{In numerical, we use } E = \frac{kq}{r^2}\right)$	NC^{-1}
The components of electric field,	$E_x = \frac{1}{4\pi \epsilon_0} \frac{qx}{r^3}, E_y = \frac{1}{4\pi \epsilon_0} \frac{qy}{r^3}, E_z = \frac{1}{4\pi \epsilon_0} \frac{qz}{r^3}$	NC^{-1}
Torque on a dipole in a uniform electric field	$\vec{\tau} = \vec{p} \times \vec{E} \, (\text{or } \tau = pE \sin\theta)$	Nm

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Electric dipole moment	$\vec{P} = q \cdot (\overrightarrow{2a})$ or $\lvert\vec{p}\rvert = q(2a)$	Cm
Potential energy of a dipole in a unifor electric field	$U = -\vec{p} \cdot \vec{E}$ (or $U = -pE\cos\theta$)	J
Electric field on axial line of an electric dipole	$E_{axial} = \frac{1}{4\pi \epsilon_0} \frac{2pr}{(r^2 - a^2)^2}$ When $2a << r, E_{axial} = \frac{1}{4\pi \epsilon_0} \frac{2p}{r^3}$	NC^{-1}
Electric field on equatorial line of an electric dipole	$E_{equatorial} = \frac{1}{4\pi \epsilon_0} \frac{p}{(r^2 + a^2)^{\frac{3}{2}}}$ When $2a << r, E_{equatorial} = \frac{1}{4\pi \epsilon_0} \frac{p}{r^3}$	
Electric field as a gradient of potential	$E = -\frac{dV}{dr}$	
Electrical potential differences between points A & B	$V_B - V_A = \frac{W_{AB}}{q_0}$	Volts (or JC^{-1})
Electric potential at a point	$V_A = \frac{1}{4\pi \epsilon_0} \frac{q}{r_A} = \frac{W}{q}$	
Electric potential due to a system of charges	$V = \frac{1}{4\pi \epsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_i}$	
Electric potential at any point due to an electric dipole	$V = \frac{1}{4\pi \epsilon_0} \frac{P\cos\theta}{(r^2 - a^2\cos^2\theta)}$ When, $\theta = 0°$ or $\theta = 180°, V = \frac{\pm 1}{4\pi \epsilon_0} \frac{p}{(r^2 - a^2)}$	

	If $r >> a, V = \frac{1}{4\pi \epsilon_0} \frac{p}{r^2}$	
	When, $\theta = 90°, V_{equi} = 0$	
Total electric flux through a closed surface S	$\phi = \oint \vec{E}.d\vec{S} = \frac{q}{\epsilon_0}$	$Nm^2 C^{-1}$
	$= E \times \text{Effective Area} = \frac{q}{\epsilon_0}$	
Electric field due to line charge	$E = \frac{1}{2\pi \epsilon_0} \frac{\lambda}{r}$	NC^{-1}(or V/m)
Electric field due to an infinite plane sheet of charge	$E = \frac{\sigma}{2 \epsilon_0}$	
Electric field due to two infinitely charged plane parallel sheets	$E = \frac{\sigma}{\epsilon_0}$	
Electric field due to a uniformly charged spherical shell	$E = \frac{\sigma}{\epsilon_0} \frac{R^2}{r^2}$	
	When $r = R$, $E_0 = \frac{\sigma}{\epsilon_0}$	
	When $r < R$, $E \times 4\pi r^2 = 0$	
Electrical capacitance	$C = \frac{q}{V}$	F(SI Unit) µF (Practical Unit)
Capacitance of an isolated sphere	$C = 4\pi \epsilon_0 r$	

Capacitance of a parallel plate	$C=\dfrac{A\epsilon_0}{d}$	
Capacitors in series	$\dfrac{1}{C}=\dfrac{1}{C_1}+\dfrac{1}{C_2}+\dfrac{1}{C_3}$	
Capacitors in parallel	$C = C_1 + C_2 + C_3$	
Capacitance of a parallel plate capacitor with dielectric slab between plates	$C=\dfrac{\epsilon_0 A}{d-t\left(1-\dfrac{1}{K}\right)}$	
Capacitance of a parallel plate capacitor with conducting slab between plates	$C=\dfrac{C_0}{\left(1-\dfrac{t}{d}\right)}$	
Energy stored in a charged capacitor	$U=\dfrac{q^2}{2C}=\dfrac{1}{2}CV^2=\dfrac{1}{2}qV$	
Resultant electric field in a polarised dielectric slab	$\vec{E} = \vec{E}_0 - \vec{E}_p$, where	
$\bar{E}_0$ = Applied electric field and		
$\bar{E}_p$ = Electric field due to polarization		
Potential difference between inner and outer shell in Van de Graaff generator	$V_{r_0}-V_R=\dfrac{q}{4\pi\epsilon_0}\left(\dfrac{1}{r_0}-\dfrac{1}{R}\right)$	Volts (or JC^{-1})

QUESTIONS

VERY SHORT ANSWER QUESTIONS (I Mark)

1. Draw schematically an equipotential surface of a uniform electrostatic field along x-axis.

2. Sketch field lines due to (i) two equal positive charges near each other (ii) a dipole.

3. Name the physical quantity whose SI unit is volt/meter. Is it a scalar or a vector quantity?

4. Two point charges repel each other with a force F when placed in water of dielectric constant 81. What will the force between them when placed the same distance apart in air? **Ans. :** (81F)

5. Electric dipole moment of $CuSO_4$ molecule is 3.2×10^{-32} Cm. Find the separation between copper and sulphate ions. **Ans. :** (10^{-3}m)

6. Net capacitance of three identical capacitors connected in parallel is 12 microfarad. What will be the net capacitance when two of them are connected in (i) parallel (ii) series? **Ans. :** C_p = 8μf Cs = 2μf

7. A charge q is placed at the centre of an imaginary spherical surface. What will be the electric flux due to this charge through any half of the sphere. **Ans :** $q/2\epsilon_0$

8. Draw the electric field vs distance (from the centre) graph for (i) a long charged rod having linear charge density $\lambda < 0$ (ii) spherical shell of radius R and charge Q > 0.

9. Diagrammatically represent the position of a dipole in (i) stable (ii) unstable equilibrium when placed in a uniform electric field.

10. A charge Q is distributed over a metal sphere of radius R. What is the electric field and electric potential at the centre? **Ans. :** E = 0, V = kQ/R

11. If a body contains n_1 electrons and n_2 protons then what is the total charge on the body? **Ans. :** $(n_2 - n_1)e$

12. What is the total positive or negative charge present in 1 molecule of water. **Ans. :** 10e.

13. How does the energy of dipole change when it in rotated from unstable equilibrium to stable equilibrium in a uniform electric field.

    Ans. : decreases

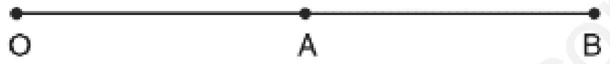
14. Write the ratio of electric field intensity due to a dipole at apoint on the equatorial line to the field at a point at a point on the axial line, when the points are at the same distance from the centre of dipole.

15. Draw equipotential surface for a dipole.

16. An uncharged conductor A placed on an insulating stand is brought near a charged insulated conductor B. What happens to the charge and potential of B? **Ans :** charge same, p.d. decrease

17. A point charge Q is placed at point O shown in Fig. Is the potential difference $V_A - V_B$ positive, negative or zero, if Q is (i) positive (ii) negative charge. **Ans :** When Q is + ive. $V_A - V_B > 0$

When Q is – ive, $V_A - V_B < 0$

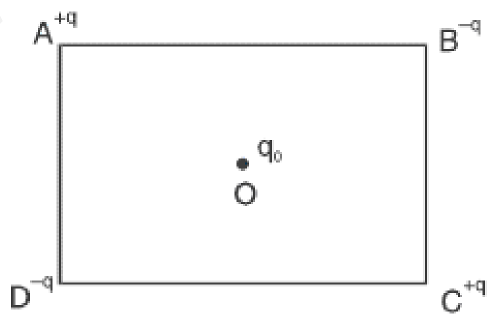


18. An electron and proton are released from rest in a uniform electrostatic field. Which of them will have larger acceleration? **Ans :** $a_e > a_p$

19. In an uniform electric field of strength E, a charged particle Q moves point A to point B in the direction of the field and back from B to A. Calculate the ratio of the work done by the electric field in taking the charge particle from A to B and from B to A. **Ans :** 1 : 1

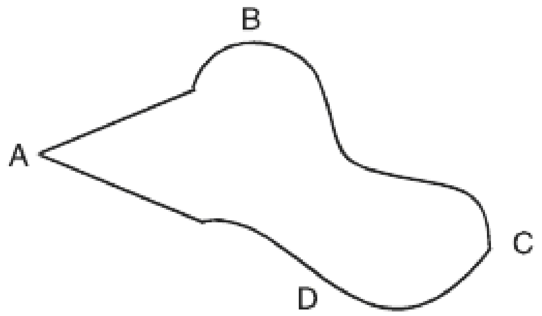
20. If a dipole of charge 2μC is placed inside a sphere of radius 2m, what is the net flux linked with the sphere. **Ans :** Zero

21. Four charges + q, –q, +q, –q are placed as shown in the figure. What is the work done in bringing a test charge from ∞ to point 0.



Ans : Zero

23. If the metallic conductor shown in the figure is continuously charged from which of the points A,B,C or D does the charge leak first. Justify.



Ans : 'A'

24. What is dielectric strength? Write the value of dielectric strength of air. **Ans :** 3×10^{6} Vm^{-1}

25. Two charge –q and +q are located at points A (0, 0, –a) and B(0, 0, +a). How much work is done in moving a test charge from point (b, 0, 0) to Q (–b, 0, 0)? **Ans :** Zero

26. If an electron is accelerated by a Potential difference of 1 Volt, Calculate the gain in energy in Joul and electron volt. **Ans.** 1.6×10^{-19} J, 1eV

27. Draw schematically the equipotential surface corresponding to a field that uniformly increases in magnitude but remains in a constant (say z) direction.

28. What is the work done in rotating a dipole from its unstable equilibrium to stable equilibrium? Does the energy of the dipole increase or decrease?

SHORT ANSWER QUESTIONS (2 Marks)

1. An oil drop of mass m carrying charge –Q is to be held stationary in the gravitational field of the earth. What is the magnitude and direction of the electrostatic field required for this purpose? **Ans :** E = mg/Q, downward

2. Find the number of field lines originating from a point charge of q = 8.854 μC.

   Ans : $\phi = 10^{12}$ NC^{-1} m^2

3. If q is the positive charge on each molecule of water, what is the total positive charge in (360g) a Mug of water.

   Ans : $q\left(\frac{360}{18} \times 6.02 \times 10^{23}\right)C$

4. Derive an expression for the work done in rotating an electric dipole from its equilibrium position to an angle θ with the uniform electrostatic field.

5. Show that there is always a loss of energy when two capacitors charged to different potentials share charge (connected with each other).

6. A thin long conductor has linear charge density of 20 μC/m. Calculate the electric field intensity at a point 5 cm from it. Draw a graph to show variation of electric field intensity with distance from the conductor. **Ans. :** 72×10^5 N/C

7. What is the ratio of electric field intensity at a point on the equatorial line to the field at a point on axial line when the points are at the same distance from the centre of the dipole? **Ans :** 1:2

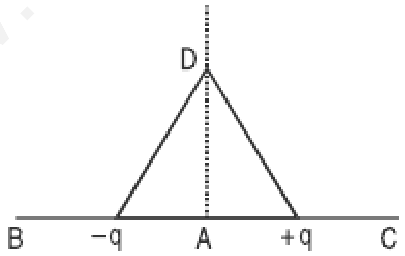
8. Show that the electric field intensity at a point can be given as negative of potential gradient.

9. A charged metallic sphere A having charge q_A is brought in contact with an uncharged metallic sphere of same radius and then separated by a distance d. What is the electrostatic force between them.

Ans : $\dfrac{1}{16\pi \epsilon_0} \dfrac{q_A^2}{d^2}$

10. An electron and a proton fall through a distance in an uniform electric field E. Compare the time of fall.

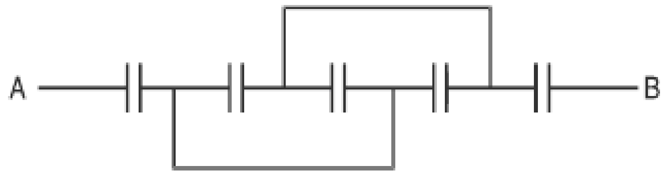
11. Two point charges –q and +q are placed 2l metre apart, as shown in fig. Give the direction of electric field at points A,B,C and D.



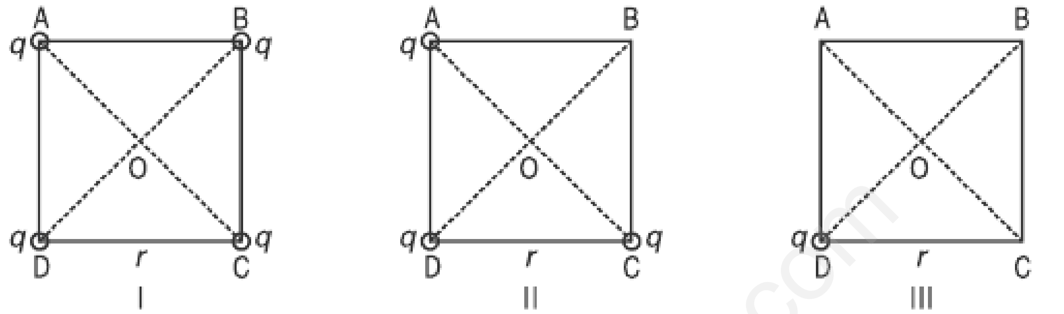
12. The electric potential V at any point in space is given $V = 20x^3$ volt, where x is in meter. Calculate the electric intensity at point P (1, 0, 2). **Ans :** $60 NC^{-1}$

13. Justify why two equipotential surfaces cannot intersect.

14. Find equivalent capacitance between A and B in the combination given below : each capacitor is of 2 μF. **Ans. :** 6/7 μF



15. What is the electric field at O in Figures (i), (ii) and (iii). ABCD is a square of side *r*.



Ans : (i) Zero, (ii) $\frac{q}{4\pi \epsilon_0} \frac{1}{r^2}$ **(iii)** $\frac{2q}{4\pi \epsilon_0}$

16. What should be the charge on a sphere of radius 4 cm, so that when it is brought in contact with another sphere of radius 2cm carrying charge of 10 μC, there is no transfer of charge from one sphere to other?

Ans : Va = Vb, Q = 20μC

17. For an isolated parallel plate capacitor of capacitance C and potential difference V, what will happen to (i) charge on the plates (ii) potential difference across the plates (iii) field between the plates (iv) energy stored in the capacitor, when the distance between the plates is increased?

Ans : (i) No change (ii) increases (iii) No change (iv) increases.

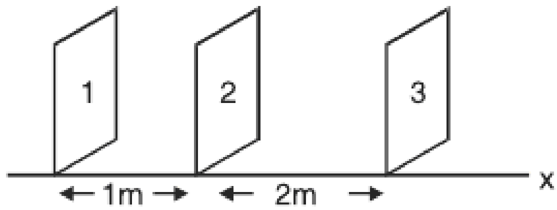
18. Does the maximum charge given to a metallic sphere of radius R depend on whether it is hollow or solid? Give reason for your answer. **Ans :** No charge resides on the surface of conductor.

19. Two charges Q_1 and Q_2 are separated by distance r. Under what conditions will the electric field be zero on the line joining them (i) between the charges (ii) outside the charge?

Ans : (i) Charge are alike (ii) Unlike charges of unequal magnitude.

20. Obtain an expression for the field due to electric dipole at any point on the equatorial line.

21. The electric field component in the figure are $\vec{E}_x = 2x\hat{i}, \vec{E}_y = E_z = 0,$. Calculate the flux through, (1,2,3) the square surfaces of side 5m.



22. Calculate the work required to separate two charges 4μc and –2μc placed at (–3cm, 0, 0) and (+3cm, 0, 0) infinitely away from each other.

23. What is electric field between the plates with the separation of 2cm and (i) with air (ii) dielectric medium of dielectric constant K. Electric potential of each plate is marked in Fig.

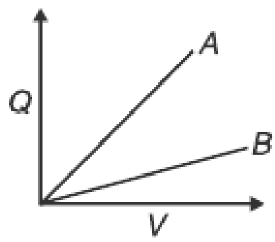
____________150 V

(i) ____________–50 V

Ans. : $E_0 = 10^4 NC^{-1}$, $E = \frac{10^4}{k} NC^{-1}$

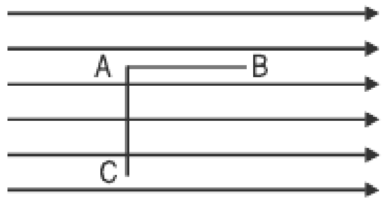
24. A storage capacitor on a RAM (Random Access Memory) chip has a capacity of 55pF. If the capacitor is charged to 5.3V, how may excess electrons are on its negative plate? **Ans. :** 1.8×10^9

25. The figure shows the Q (charge) versus V (potential) graph for a combination of two capacitors. Identify the graph representing the parallel combination.



Ans : A represents parallel combination

26. Calculate the work done in taking a charge of 1 μC in a uniform electric field of 10 N/C from B to C given AB = 5 cm along the field and AC = 10 cm perpendicular to electric field.



Ans : $W_{AB} = W_{BC} = 50 \times 10^{-8}$ J, $W_{AC} = 0$J

27. Can two equi potential surfaces intersect each other? Give reasons. Two charges –q and +q are located at points A (0, 0, –a) and B (0, 0, +a) respectively. How much work is done in moving a test charge from point P(7, 0, 0) to Q(–3, 0, 0)? (zero)

28. The potential at a point A is –500V and that at another point B is +500V. What is the work done by external agent to take 2 units (S.I.) of negative charge from B to A.

29. How does the Potential energy of (i) mutual interaction (ii) net electrostatic P.E. of two charges change when they are placed in an external electric field.

30. With the help of an example, show that Farad is a very large unit of capacitance.

31. What is meant by dielectric polarisation? Why does the electric field inside a dielectric decrease when it in placed in an external field?

SHORT ANSWER QUESTIONS (3 Marks)

1. Define electrostatic potential and its unit. Obtain expression for electrostatic potential at a point P in the field due to a point charge.

2. Calculate the electrostatic potential energy for a system of three point charges placed at the corners of an equilateral triangle of side 'a'.

3. What is polarization of charge? With the help of a diagram show why the electric field between the plates of capacitor reduces on introducing a dielectric slab. Define dielectric constant on the basis of these fields.

4. Using Gauss's theorem in electrostatics, deduce an expression for electric field intensity due to a charged spherical shell at a point (i) inside (ii) on its surface (iii) outside it. Graphically show the variation of electric field intensity with distance from the centre of shell.

5. Three capacitors are connected first in series and then in parallel. Find the equivalent capacitance for each type of combination.

6. A charge Q is distributed over two concentric hollow sphere of radii r and R (R>r), such that their surface density of charges are equal. Find Potential at the common centre.

7. Derive an expression for the energy density of a parallel plate capacitor.

8. You are given an air filled parallel plate capacitor. Two slabs of dielectric constants K_1 and K_2 having been filled in between the two plates of the capacitor as shown in Fig. What will be the capacitance of the capacitor of initial area was A distance between plates d?

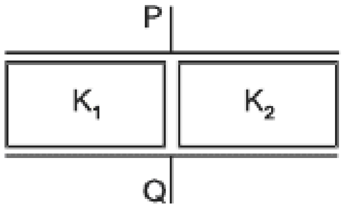


Fig. 1

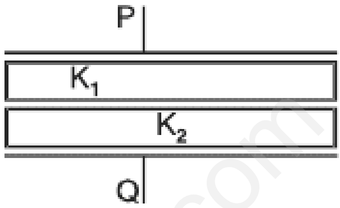
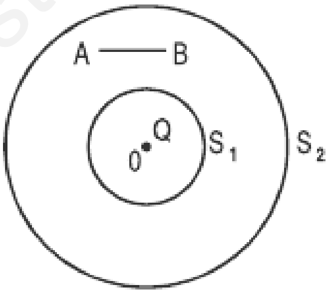


Fig. 2

$$C_1 = (K_1 + K_2)C_0$$

$$C_2 = \frac{K_1 K_2 C_0}{(K_1 + K_2)}$$

9. In the figure shown, calculate the total flux of the electrostatic field through the sphere S_1 and S_2. The wire AB shown of length l has a liner charge density λ given λ = kx where x is the distance measured along the wire from end A.



Ans. Total charge on wire AB = Q = $\int_0^l \lambda dx = \int_0^l kx dx = \frac{1}{2}Kl^2$

By Gauss's theorem.

$$\text{Total flux through } S_1 = \frac{Q}{\epsilon_0}$$

$$\text{Total flun through } S_2 = \frac{Q + \frac{1}{2}kl^2}{\epsilon_0}$$

10. Explain why charge given to a hollow conductor is transferred immediately to outer surface of the conductor.
(*See* Page 83. NCERT Vol I)

11. Derive an expression for total work done in rotating an electric dipole through an angle θ in an uniform electric field. Hence calculate the potential energy of the dipole.

12. Define electric flux. Write its SI unit. An electric flux of ϕ units passes normally through a spherical Gaussian surface of radius r, due to point charge placed at the centre.

    (1) What is the charge enclosed by Gaussian surface?

    (2) If radius of Gaussian surface is doubled, how much flux will pass through it?

13. A conducting slab of thickness 't' is introduced between the plates of a parallel plate capacitor, separated by a distance d (t<d). Derive an expression for the capacitance of the capacitor. What will be its capacitance when t = d?

14. If a dielectric slab is introduced between the plates of a parallel plate capacitor after the battery is disconnected, then how do the following quantities change.

    (i) Charge

    (ii) Potential

    (iii) Capacitance

    (iv) Energy.

15. What is an equipotential surface? Write its three properties Sketch equipotential surfaces of

    (i) Isolated point charge

(ii) Uniform electric field

(iii) Dipole

LONG ANSWER QUESTIONS (5 MARKS)

1. State the principle of Van de Graaff generator. Explain its working with the help of a neat labelled diagram.

2. Derive an expression for the strength of electric field intensity at a point on the axis of a uniformly charged circular coil of radius R carrying charge Q.

3. Derive an expression for potential at any point distant *r* from the centre O of dipole making an angle θ with the dipole.

4. Suppose that three points are set at equal distance r = 90 cm from the centre of a dipole, point A and B are on either side of the dipole on the axis (A closer to +ve charge and B closer to B) point C which is on the perpendicular bisector through the line joining the charges. What would be the electric potential due to the dipole of dipole moment 3.6×10^{-19} Cm at points A, B and C?

5. Derive an expression for capacitance of parallel plate capacitor with dielectric slab of thickness t(t<d) between the plates separated by distance d. How would the following (i) energy (ii) charge, (iii) potential be affected if dielectric slab is introduced with battery disconnected, (b) dielectric slab is introduced after the battery is connected.

6. Derive an expression for torque experienced by dipole placed in uniform electric field. Hence define electric dipole moment.

7. State Gauss's theorem. Derive an expression for the electric field due to a charged plane sheet. Find the potential difference between the plates of a parallel plate capacitor having surface density of charge 5×10^{-8} Cm^{-2} with the separation between plates being 4 mm.

8. Derive an expression for capacitance of parallel plate capacitor with dielectric slab of thickness t (t<d) between the plates separated by distance d. If the dielectric slab is introduced with the battery connected, then how do the following quantities change (i) charge (ii) potential (iii) capacitance (iv) energy.

9. Using Gauss's theorem obtain an expression for electric field intensity due to a plane sheet of charge. Hence obtain expression for electric field intensity in a parallel plate capacitor.

10. Write five to six important results regarding eloectro statics of conductors. (See Page 68, NCERT Vol I).

NUMERICALS

1. What should be the position of charge $q = 5\mu C$ for it to be in equilibrium on the line joining two charges $q_1 = -4\ \mu C$ and $q_2 = 16\ \mu C$ separated by 9 cm. Will the position change for any other value of charge q? (9 cm from – 4 μC)

2. Two point charges 4e and e each, at a separation r in air, exert force of magnitude F. They are immersed in a medium of dielectric constant 16. What should be the separation between the charges so that the force between them remains unchanged. (1/4 the original separation)

3. Two capacitors of capacitance 10 μF and 20 μF are connected in series with a 6V battery. If E is the energy stored in 20 μF capacitor what will be the total energy supplied by the battery in terms of E. (6E)

4. Two point charges 6 μC and 2 μC are separated by 3 cm in free space. Calculate the work done in separating them to infinity. (3.6 joule)

5. ABC is an equilateral triangle of side 10 cm. D is the mid point of BC, charge 100 μC, – 100 μC and 75 μC are placed at B, C and D respectively. What is the force experienced by a 1 μC positive charge placed at A? ($90\sqrt{2} \times 10^3$ N)

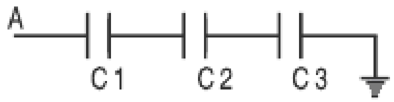
6. A point charge of 2 μC is kept fixed at the origin. Another point charge of 4 μC is brought from a far point to a distance of 50 cm from origin. Calculate the electrostatic potential energy of the two charge system. Another charge of 11 μC is brought to a point 100 cm from each of the two charges. What is the work done? (3.2×10^{-3}J)

7. A 5 MeV α particle is projected towards a stationary nucleus of atomic number 40. Calculate distance of closest approach. (1.1×10^{-4} m)

8. To what potential must a insulated sphere of radius 10 cm be charged so that the surface density of charge is equal to 1 μC/m^2. (1.13×10^4V)

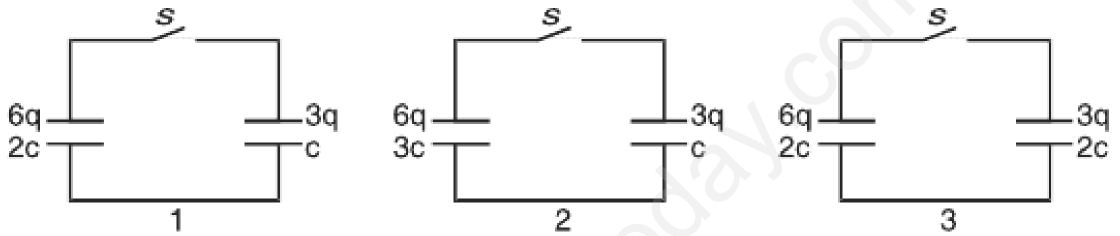
9. In the following fig. calculate the potential difference across capacitor C_2.

Given potential at A is 90 V. C_1 = 20 μF, C_2 = 30 μF, and C_3 = 15 μF.
(20V)



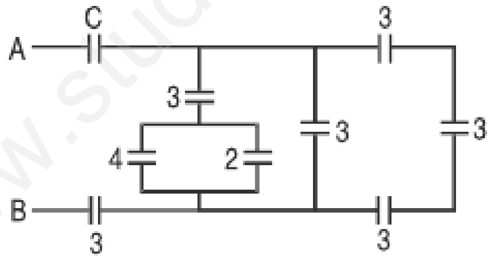
10. A point charge develops an electric field of 40 N/C and a potential difference of 10 J/C at a point. Calculate the magnitude of the charge and the distance from the point charge. (2.9×10^{-10} C, 25 cm)

11. Figure shows three circuits, each consisting of a switch and two capacitors initially charged as indicated. After the switch has been closed, in which circuit (if any) will the charges on the left hand capacitor (i) increase (ii) decrease (iii) remain same?



(1 remains unchanged, 2 increases, 3 decreases).

12. For what value of C does the equivalent capacitance between A and B is 1μF in the given circuit.



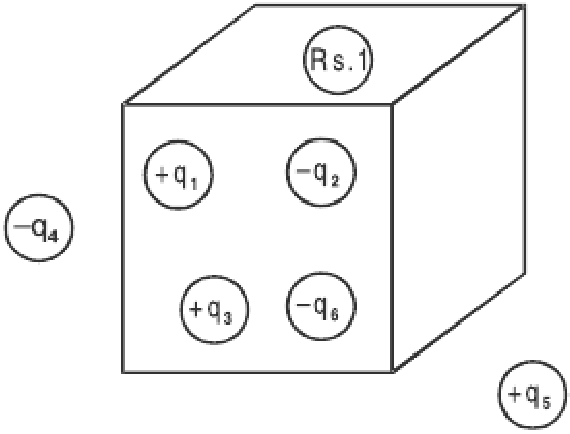
All capacitance given in micro farad

Ans. : 2 μF

HOTS

VERY SHORT ANSWER QUESTIONS (I MARK)

1. Figure shows five charged lumps of plastic and an electrically neutral coin. The cross-section of a Gaussian surface S is indicated. What is the net electric flux through the surface?



2. Without referring to the formula $C = \epsilon_0 A/d$. Explain why the capacitance of a parallel plate capacitor reduce on increasing the separation between the plates?

3. Draw field lines to show the position of null point for two charges $+Q_1$ and $-Q_2$ when magnitude of $Q_1 > Q_2$ and mark the position of null point.

SHORT ANSWER QUESTIONS (2 Marks)

4. In charging a capacitor of capacitance C by a source of emf V, energy supplied by the sources QV and the energy stored in the capacitor is ½QV. Justify the difference.

5. An electric dipole of dipole moment p, is held perpendicular to an electric field; (i) $p = E_0$ **i** (ii) $E = E_0 \times$ **i**. If the dipole is released does it have (a) only rotational motion (b) only translatory motion (c) both translatory and rotatory motion?

6. The net charge of a system is zero. Will the electric field intensity due to this system also be zero.

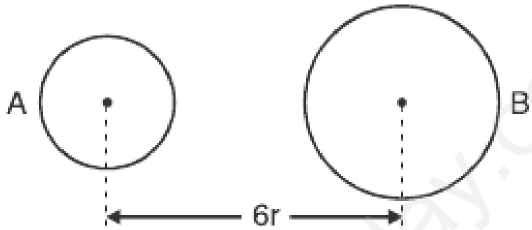
7. A point charge Q is kept at the intersection of (i) face diagonals (ii) diagonals of a cube of side a. What is the electric flux linked with the cube in (i) and (ii)?

8. There are two large parallel metallic plates S1 and S2 carrying surface charge densities σ_1 and σ_2 respectively ($\sigma_1 > \sigma_2$) placed at a distance d apart in vacuum. Find the work done by the electric field in moving a point charge q a distance a (a < d) from S1 and S2 along a line making an angle $\pi/4$ with the normal to the plates.

SHORT ANSWER QUESTIONS (3 Marks)

9. If a charge Q is given to the parallel plates of a capacitor and E is the electric field between the plates of the capacitor the force on each plate is 1/2QE and if charge Q is placed between the plates experiences a force equal to QE. Give reasons to explain the above.

10. Two metal spheres A and B of radius r and 2r whose centres are separated by a distance of 6r are given charge Q, are at potential V_1 and V_2. Find the ratio of V_1/V_2. These spheres are connected to each other with the help of a connecting wire keeping the separation unchanged, what is the amount of charge that will flow through the wire?



NUMERICALS

11. A pendulum bob of mass 80 mg and carrying charge of 3×10^{-8} C is placed in an horizontal electric field. It comes to equilibrium position at an angle of 37° with the vertical. Calculate the intensity of electric field. ($g = 10 m/s^2$) (2×10^4 N/C)

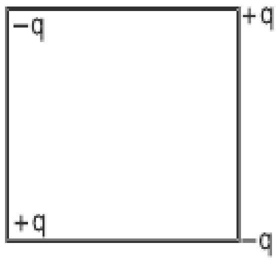
12. Eight charged water droplets each of radius 1 mm and charge 10×10^{-10}C coalesce to form a single drop. Calculate the potential of the bigger drop. (3600 V)

13. What potential difference must be applied to produce an electric field that can accelerate an electron to 1/10 of velocity of light. (2.6×10^3 V)

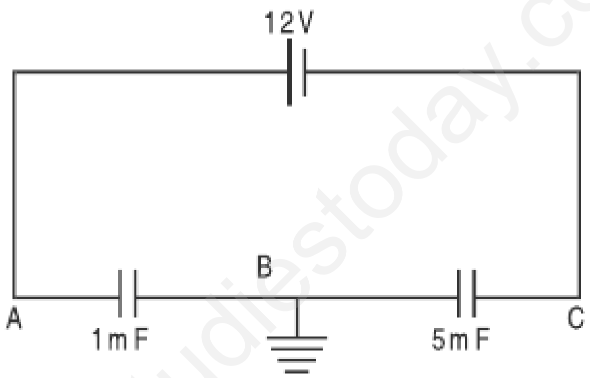
14. A 10 μF capacitor can withstand a maximum voltage of 100 V across it, whereas another 20 μF capacitor can withstand a maximum voltage of only 25 V. What is the maximum voltage that can be put across their series combination? (75V)

15. Three concentric spherical metallic shells A < B < C of radii a, b, c (a < b < c) have surface densities σ, –σ and σ respectively. Find the potential of three shells A, B and (ii). If shells A and C are at the same potential obtain relation between a, b, c.

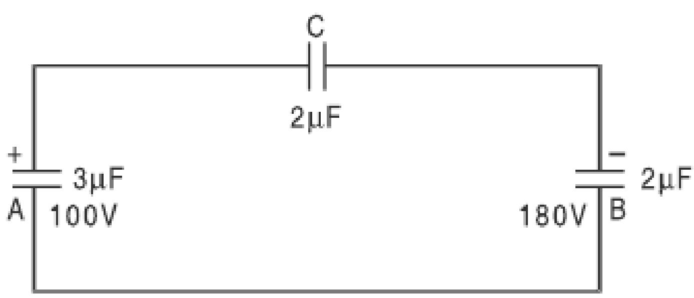
16. Four point charges are placed at the corners of the square of edge a as shown in the figure. Find the work done in disassembling the system of charges. $\left[\frac{kq^2}{a}\left(\sqrt{2}-4\right)\right]$ J



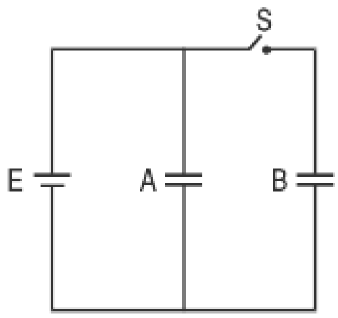
17. Find the potential at A and C in the following circuit :



18. Two capacitors A and B with capacitances 3 μF and 2 μF are charged 100 V and 180 V respectively. The capacitors are connected as shown in the diagram with the uncharged capacitor C. Calculate the (i) final charge on the three capacitors (ii) amount of electrostatic energy stored in the system before and after the completion of the circuit.



19. Two identical parallel plate capacitors connected to a battery with the switch S closed. The switch is now opened and the free space between the plates of the capacitors is filled with dielectric of dielectric constant 3. Find the ratio of the total electrostatic energy stored in both capacitors before and after the introduction of dielectric.

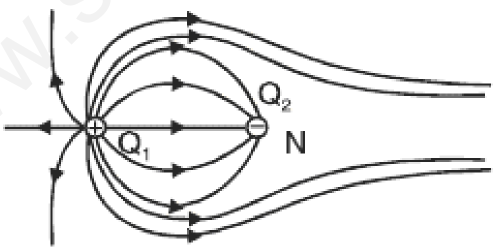


ANSWERS OF HOTS

I MARK QUESTIONS

1. $(q_1 + q_3 - q_2 - q_6)/\epsilon_0$

3. $|Q_1| > |Q_2|$, N → Neutral point



2 MARKS QUESTIONS

4. In the capacitor the voltage increases from O to V, hence energy stored will correspond to average which will be ½ QV. While the source is at constant emf V. So energy supplied will be QV. The difference between the two goes as heat and em radiations.

7. Construct a closed system such that charge is enclosed within it. For the charge on one face, we need to have two cubes place such that charge is on the common face. According to Gauss's theorem total flux through the gaussian surface (both cubes) is equal to $\frac{q}{\varepsilon_0}$. Therefore the flux through one cube will be equal to $\frac{q}{2\varepsilon_0}$.

8. Work done = fd cos θ = qEd cos θ = $\frac{q(\sigma_1 - \sigma_2)}{\varepsilon_0} \frac{a}{\sqrt{2}}$

3 MARKS QUESTIONS

9. If E′ be the electric field due to each plate (of large dimensions) then net electric field between them

$$E = E' + E' \Rightarrow E' = E/2$$

Force on change Q at some point between the plates F = QE

Force on one plate of the capacitor due to another plate F′ = QE′ = QE/2

10.
$$V_1 = \frac{kq}{r} + \frac{kq}{6r} = \frac{7kq}{6r}$$

$$V_2 = \frac{kq}{2r} + \frac{kq}{6r} = \frac{3kq + kq}{6r} = \frac{4kq}{6r}$$

$$\frac{V_1}{V_2} = \frac{7}{4}$$

$$V_{common} = \frac{2q}{4\pi\varepsilon_0 (r + 2r)} = \frac{2q}{12\pi\varepsilon_0 r} = V'$$

Charge transferred equal to

$$q' = C_1V_1 - C_1V' = \frac{r}{k} \cdot \frac{kq}{r} - \frac{r}{k} \cdot \frac{k_2 q}{3r}$$

$$= q - \frac{2q}{3} = \frac{q}{3}.$$

NUMERICALS

15. $$V_A = k\left[\frac{q_1}{a} + \frac{q_2}{b} + \frac{q_3}{c}\right]$$

$$= k\,4\pi a\sigma - k\,4\pi b\sigma + k\,4\pi c\sigma$$

$$= 4\pi a\sigma\,(a - b + c)$$

$$= \frac{\sigma}{\varepsilon_0}(a - b + c)$$

$$V_B = k\left[\frac{q_1}{b} + \frac{q_2}{b} + \frac{q_3}{c}\right] = k\left[\frac{4\pi a^2\sigma}{b} - 4\pi kb\sigma + 4\pi kc\sigma\right]$$

$$= \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{b} - b^2 + c^2\right)$$

$$V_C = \frac{\sigma}{\varepsilon_0 c}\left(a^2 - b^2 + c^2\right)$$

When $V_A = V_C$

$$\frac{\sigma}{\varepsilon_0}(a - b + c) = \frac{\sigma}{\varepsilon_0 C}\left(a^2 - b^2 + c^2\right)$$

$$ac - bc + c^2 = a^2 - b^2 + c^2$$

$$c\,(a - b) = (a - b)\,(a + b)$$

$$c = a + b.$$

17. $$Q = CV$$

Total charge Q = Total capacitance in series × voltage

$$= \left(\frac{5}{6} \times 10^{-3}\right) \times 12 = 10 \times 10^{-3}\,\text{coulomb}$$

$$V_{AB} = \frac{Q}{c_1} = \frac{10 \times 10^{-3}}{1 \times 10^{-3}} = 10V$$

$$V_{BC} = \frac{Q}{c_2} = \frac{10 \times 10^{-3}}{5 \times 10^{-3}} = 2V.$$

When B is earthed $V_B = 0$, $V_A = 10V$ and $V_C = -2V$.

19. Before dielectric is introduced.

$$E_A = \frac{1}{2}CV^2; \qquad E_B = \frac{1}{2}CV^2$$

$$E = E_A + E_B = CV^2$$

After disconnecting the battery and then introducing dielectric

$$E'_A = \frac{1}{2}(3C)\ V^2$$

$$E'_B = \frac{Q^2}{2C} = \frac{(CV)^2}{2 \times 3C} = \frac{1}{3}\left(\frac{1}{2}CV^2\right), \qquad E' = E'_A + E'_B$$

$$\frac{E'}{E} = \frac{5}{3}.$$