PHYSICS

BOOKS - VIKRAM PUBLICATION (ANDHRA PUBLICATION)

ELECTROSTATIC POTENTIAL AND CAPACITANCE

Problems

1. An elementary particle of mass 'm' and charge $+e$ initially at a very large distance is projected with velocity 'v' at a much more massive particle of charge $+Ze$ at rest. The closest possible distance of approach of the incident particle is .

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2. In a hydrogen atom the electron and proton are at a distance of 0.5Å. The dipole moment

of the system is .

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3. There is a uniform electric field in the XOY plane represented by $\left(40\hat{j}+30\hat{j}\right)Vm^{-1}$. If the electric potential at the origin is 200 V, the electric potential at the point with coordinates (2m,1m) is

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4. An equilateral triangle has a side length L. A charge $+q$ is kept at the centroid of the triangle . P is a point on the perimeter of the triangle. The ratio of the minimum and maximum possible electric potentials for the point P is

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5. ABC is an equilateral triangle of side 2m. There is a uniform electric field of intensity

100V/m in the plane of the triangle and parallel to BC as shown. If the electric potential at A is 200V, then the electric potentials at B and C.

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6. An electric dipole of moment p is placed in a uniform electric field E, with P parallel to E. it is then rotated by an angle q. The work done is

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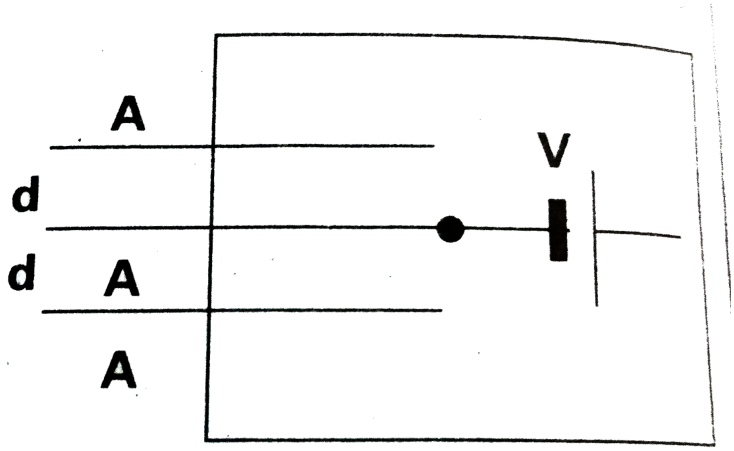
7. Three identical metal plates each of area 'A' are arranged parallel to each other. 'd' is the distance between the plates as shown. A battery of 'V' volts is connected as shown. The charge stored in the system of plates is



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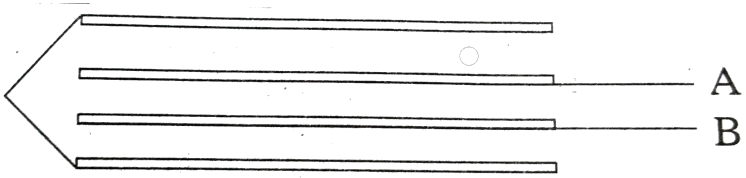
8. Four identical metal plates each of area A are separated mutually by a distance d and are connected as shown. Find the capacity of the system between the terminals A and B.



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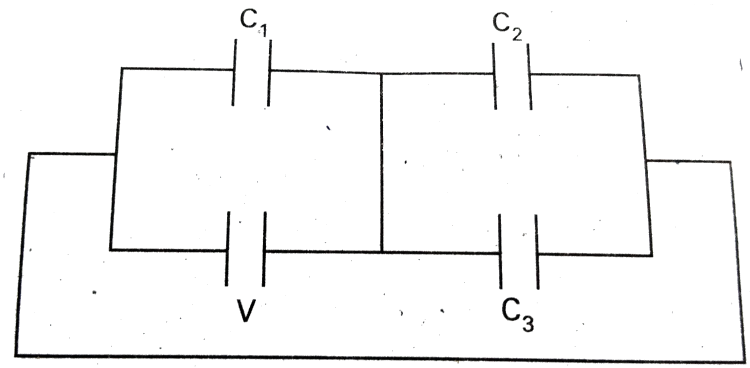
9. In the circuit shown the battery of 'V' volts has no internal resistance . All three condensers are equal in capacity. Find the

condenser that carries more charge ?



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10. Two capacitors A and B of capacities C and 2C are connected in parallel and the combination is connected to a battery of V volts. After the charging is over , the battery is removed. Now a dielectric slab of $K = 2$ is

inserted between the plates of A so as fill the completely. The energy lost by the system during the sharing of charges is

(i) With battery of parallel combination :

11. Two capacitors A and B of capacities C and 2C are connected in parallel and the combination is connected to a battery of V volts. After the charging is over , the battery is removed. Now a dielectric slab of $K = 2$ is

inserted between the plates of A so as fill the completely. The energy lost by the system during the sharing of charges is

(ii) Without battery of parallel combination :

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12. A condenser of certain capacity is charged to a potential V and stores some energy. A second condenser of twice the capacity is to store half the energy of the first , find to what potential one must be charged ?

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13. Calculate the potential at a point P due to a charge of $4 \times 10^{-7} C$ located 9 cm away.

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14. There exists a potential at a point P due to a charge of 4 × 10 − 7 C located 9 cm away. Hence obtain the work done in bringing a charge of $2 \times 10^{-9} C$ from infinity to the

point P . Does the answer depend on the path which the charge is brought ?

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15. Two charges $3 \times 10^{-8} C$ and $-2 \times 10^{-8} C$ are located 15 cm apart. At what point on the line joining the two to be charges is the electric potential zero ? Take the potential at infinity to be zero.

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16. A slab of material of dielectric constant K has the same area as the plates of a parallel plate capacitor but has a thickness (3/4)d, where is the separa - tion of the plates. How is the capacitance when the slab is inserted between the plates ?

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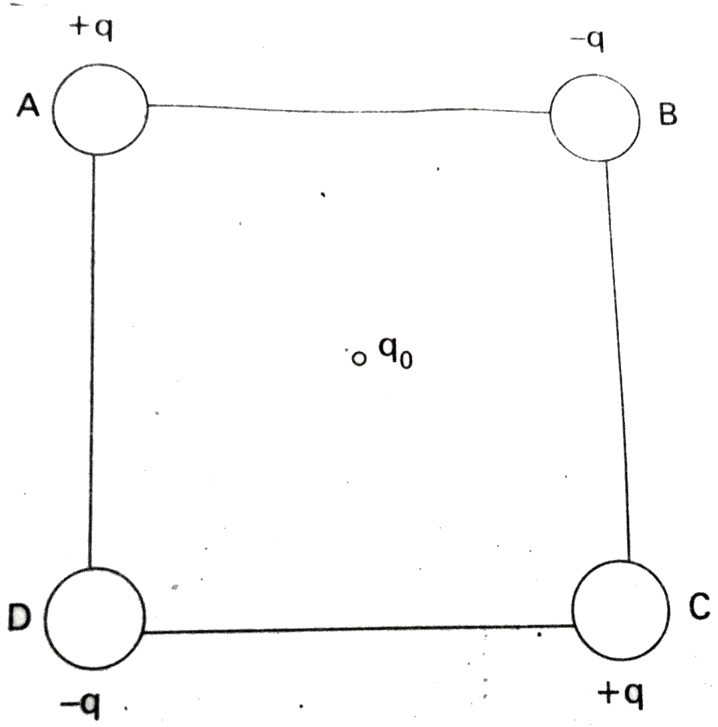
17. Four charges are arranged at the corners of a square ABCD of side d. as shown in fig. Find the work required to put together this

arrangement. (b) A charge q_0 is brought to the centre of the square, the four being held fixed at its corners. How much extra work is needed to do this ?



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18. Determine the electrostatic potential energy of a system consisting of two charges $7\mu C$ and $-2\mu C$ (and with no external field) placed at $(-9cm, 0, 0)$ and $(9cm, 0, 0)$ respectively.

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19. How much work is required to separate the two charges infinitely away from each other ?

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20. There is a uniform electric field in the XOY plane represented by $\left(40\hat{j}+30\hat{j}\right)Vm^{-1}$. If the electric potential at the origin is 200 V, the electric potential at the point with coordinates (2m,1m) is

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triangle. The ratio of the minimum and maximum possible electric potentials for the point P is

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22. A condenser of certain capacity is charged to a potential V and stores some energy. A second condenser of twice the capacity is to store half the energy of the first , find to what potential one must be charged ?

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23. Three capacitors each of capaitance 9pF are connected in series.

(a) What is the total capacitance of the combination ?

(b) What is the potential difference across each capacitor if the combination is connected to a 120 V supply ?

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24. Three capacitors each of capaitance 9 p F are connected in series.

(b) What is the potential difference across each capacitor if the combination is connected to a 120 V supply ?

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25. Three capacitors of capacitances 2p F , 3 p F and 4 p F are connected in parallel.

(a) What is the total capacitance of the combination ?

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26. Three capacitors of capacitances 2p F , 3 p F and 4 p F are connected in parallel.

(b) Determine the charge on each capacitor if the combination is connected to a 100 V supply.

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Very Short Answer Questions

1. Can there be electric potential at a point with zero electric intensity ? Give an example.

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2. Can there be electric intensity at a point with zero electric potential ? Give an example.

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3. What are meant by equipotential surfaces ?

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4. Why is the electric field always at right angles to the equipotential surface ? Explain.

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5. Three capacitors of capacitances 1muF,2muF and 3muF`are connected in parallel

(a) What is the ratio of charges ?

(b) What is the ratio of potential differences ?

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6. Three capacitors of capacitances , $1\mu F, 2\mu F$ and $3\mu F$, are connected in parallel

(b) What is the ratio of potential differences ?

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7. Three capacitors of capacitances $1\mu F, 2\mu F$ and $3\mu F$ are connected in series What is the ratio of charges ? What is the ratio of potential differences ?

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8. Three capacitors of capacitances $1\mu F, 2\mu F$ and $3\mu F$ are connected in series

(b) What is the ratio of potential differences ?

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9. What happens to the capacitance of a parallel plate capacitor if the area of its plates is doubled ?

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10. The dielectric strength of air is $3 \times 10^6 Vm^{-1}$. At certain

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Short Answer Questions

1. Derive an expression for the electric potential due to a point charge.

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2. Derive an expression for the electrostatic potential energy of a system of two point charges and find its relation with electric potential of a charge.

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3. Derive an expression for the potential energy of an electric dipole placed in a uniform electric field.

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4. Derive an expression for the capacitance of a parallel plate capacitor.

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5. Explain the behaviour of dielectrics in an external field.

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Long Answer Questions

1. Define electric potential. Derive and expression for the electric potential due to an electric dipole and hence the electric potential

at a point (a) the axial line of electric dipole (b) on the equatorial line of electric dipole.

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2. Explain series and parallel combination of capacitors. Derive the formula for equivalent capacitance in each combination.

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3. What is the energy stored when the space between the plates is filled with dielectric.

(a) With charging battery disconnected ?

(b) With charging battery connected in the circuit ?

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Textual Exercises

1. Two charges $5 \times 10^{-8} C$ and $-3 \times 10^{-8} C$ are located 16 cm apart. At what point(s) on the line joining the two charges is the electric potential zero? Take the potential at infinity to be zero.

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2. A regular hexagon of side 10 cm has a charge $5 \mu C$ each of its vertices, Calaculate the potential at the centre of the hexagon.

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3. Two charges $2\mu C$ and $-2\mu C$ are placed at points A and B 6 cm apart.

(a) Identify an equipotenital surface of the system.

(b) What is the direction of the electric field at every point on this surface ?

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4. A spherical conductor of radius 12 cm has a charge of $1.6 \times 10^{-7} C$ distributed uniformly on its surface. What is the electric field.

(a) inside the sphere

(b) just outside the sphere

(c) At a point 18 cm from the centre of the sphere ?

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5. A parallel plate capacitor with air between the plates has a cpacitance of $8pF\left(1pF = 10^{-12}F\right)$. What will be the capacitance if the distance between the plates is reduced by half, and the space between them is filled with a substances of dielectric constant 6 ?

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6. Three capacitors each of capaitance 9pF are connected in series.

(a) What is the total capacitance of the combination ?

(b) What is the potential difference across each capacitor if the combination is connected to a 120 V supply ?

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7. Three capacitors or capacitances 2pF, 3pF and 4pF are connected in parallel.

(a) What is the total capacitance of the combination ?

(b) Determine the charge on each capacitor if the combination is connected to a 100 V supply.

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8. In a paralllel plate capacitor with air between the plates , each plate has an area of $6 \times 10^{-3} m^2$ and the distance between the plates is 3 m m. Calculate the capacitance of the capacitor. If this capacitor is connected to a 100 V supply , what is the charge on each plate of the capacitor ?

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9. Explain what would happen if in the capacitor given in Exercise 8,a 3mm thick mica sheet (of dielectric constant =6) were inserted between the plates.

(a) While the voltage supply remained connected.

(b) after the supply was disconnected.

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10. A 12pF capacitor is connected to a 50V battery. How much electrostatic energy is stored in the capacitor ?

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11. A 600pF capacitor is charged by a 200V supply. It is then disconnected form the supply and is connected to another uncharged 600pF capacitor. How much electrostatic energy is lost in the process?

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Additional Excercise

1. A charge of 8mC is located at the origin. Calculate the workdone in taking a small charge of $-2 \times 10^{-9} C$ from a point P(0,03cm) to a point $Q(0, 4cm, 0)$ Via a point $R(0, 6cm, 9cm)$.

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2. A cube of side b has a charge q at each of its vertices , Determine the potential and electric field due to this charge array at the centre of the cube.

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3. Two tiny spheres carrying charges $1.5\mu C$ and $2.5\mu C$ are located 30 cm apart. Find the potential and electric field :

(a) at the mid-point of the line joining the two

charges and

(b) at a point 10 cm from this midpoint in a plane normal to the line and passing through the mid-point.

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4. A spherical conducting sheel of inner redius s_1 and outer radius r_2 has a charge Q. (a) A charge q is placed at the centre of the shell. What is the surface charge density on the inner and outer surfaces of the shell ?

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5. Is the electric field inside a cavity (with no charge) , zero, even if the shell is not spherical, but has any irregular shape ? Explain.

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6. Show that the normal component of electrostatic field has a discontinuity from one side of a charged surface to another given by $(E_2 - E_1).\hat{n} = \frac{\sigma}{\varepsilon_0}$

Where $\hat{n}$ is a nuit vector normal to the surface at a point and σ is the surface charge density at that point . (The direction of $\hat{n}$ is from side 1 to side 2.) Hence show that just out side a conductor , the electric field is $\sigma\hat{n}/\varepsilon_0$.

(b) Show that the tangential component of electrostatic field is continuous from one side of a charge surface of another. use the fact that work done by electrostatic field on a closed loop is zero.)

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7. A long charged cylinder of linear charged density λ is surrounded by a hollow co-axial conducting cylinder. What is the electric field in the space between the two cylinders ?

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8. In a hydrogen atom , the electron and proton are bound at a distance of about 0.53Å.

(a) Estimate the potential energy of the system in e V, taking the zero of the potential

energy at infiniate separation of the electron from proton.

(b) What is the minimum work required to free the electron, given that is kinetic energy in the orbit is half the magnitude of potenital energy obtained in (a) ?

(c) What are the answers to (a) and (b) above if the zero of potential energy is taken at 1.06Å separation ?

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9. If one of the two electrons of a H_2 molecule id removed , we get a hydrogen molecules ion H_2^+. In the ground state of an H_2^+. The two protons are separated by roughly 1.5Å. And the electron is at 1Å roughly from the nucleus. Find potential energy of the system. Specigy your choice of the zero of potential energy.

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10. Two charged conducting spheres of radii a and b are connected to each other by a wire. What is the ratio of electric fields at the surfaces of the two spheres ? Use the reuslt obtained to explain why charge density on the sharp and pointed ends of a conductor is higher than on its flatter portions.

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11. Two charges -q and +q are located at points (0,0-a) and (0,0-a), respectively.

(a) What is the electrostatic potential at the points (0,0,z) and (x,y,0) ?

(b) Obtain the dependence of potential on the distance r of a point from the origin when $r/a > > 1$.

(c) How much work is done in moving a small test charge from the point (5,0,0) to (-7,0,0) along the x-axis? Does the answer change if the path of the test charge between the same points is not along the x-axis ?

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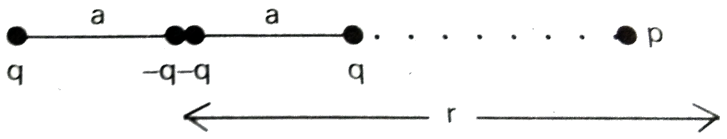
12. Figure shows a charge array known as an electric qudarupole. For a point on the axis of the quadrupole , obtain the dependence of potential on r for $r/a > > 1$. And contrast your results with that due to an electric dipole, and an electric monopole (i.e., a single charge).



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13. An electrical technician requires a capacitance of $2\mu F$ in a circuit across a potential difference of $1kV$. A large number of $1\mu F$capacitors are available to him each of which can withstand a potential difference of not more than 400V. Suggest a possible arrangement that requires the minimum number of capacitors.

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14. What is the area of the plates of a 2 F parallel plate capacitor , given that the separation between the plates is 0.5cm ? [You will realise from your answer why ordinary capacitors are in the range of μF or less. However , electrolytic capacitors do have a much larger capacitance $(0.1F)$ because of very minute separation between the conductors.]

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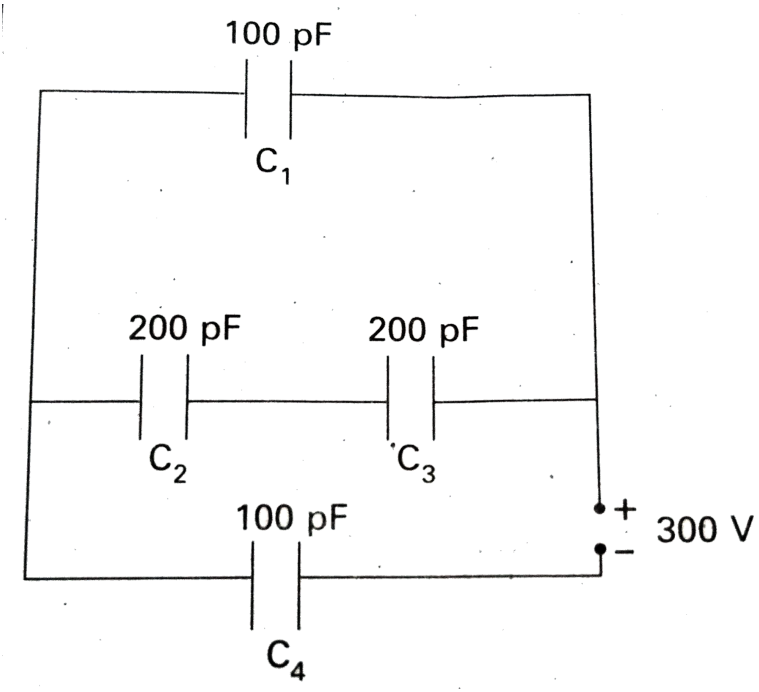
15. Obtain the equivalent capacitance of the network in Fig. For a 300 V supply. Determin the change and voltage across each capacitor.



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16. The plates of parallel plate capacitor have an area of $90cm^2$ each and area separated by 2.5mm. The capacitor is charged by connecting it to a 400V supply.

(a) How much electrostatic energy is stored by the capacitor ?

(b) View this energy as stored in the electrostatic field between the plates , and obtain the energy per unit volume n, Hence arrive at a relation between u and the magnitude of electric field E between the plates.

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17. A $4\mu F$ capacitor is charged by a 200 V supply. It is then disconnected from the supply . And is connected to another uncharged $2\mu F$ capacitor. How much electrostatic energy of the first capacitor is lost in the form of heat and electromagnetic radiation ?

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18. Show that the force on each plate of a parallel plate capacitor has a magnitude equal to $(1/2)$ QE, where Q is the charge on the capacitor , and E is the magnitude of electric field between the plates . Explain the origin of the factor $1/2$.

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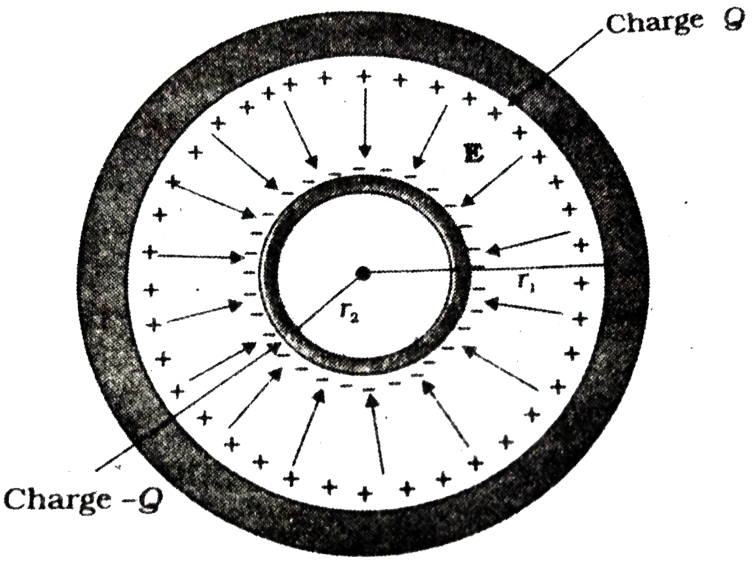
19. A spherical capacitor consists of two concentric spherical conductors, held in

position by suitable insulating supports (Fig).

Show that the capacitance of a spherical capacitor is given by $C = \dfrac{4\pi\varepsilon_0 r_1 r_2}{r_1 - r_2}$



where r_1 and r_2 are the radii of outer and inner spheres , respectively.

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20. A spherical capacitor has an inner sphere of radius 12 cm and an outer sphere of radius 13 cm. The outer sphere is earthed and the inner sphere is given a charge of $2.5\mu C$. The space between the concentric spheres is fillled with a liquid of dielectric constant 32.

(a) Determine the capacitance of the capacitor.

(b) What is the potential of the inner sphere ?

(c) Compare the capacitance of this capacitor with that of an isolated sphere of radius 12 cm. Explain why the latter is much smaller.

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21. Two large conducting sphers carrying charges Q_1 and Q_2 are brought close to each other. Is the magnitude of electrostatic force between them exactly given by $Q_1Q_2/4\pi\varepsilon_0 r^2$. Where r is the distance between their centres ?

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22. If Coulomb's law involved $1/r^3$ dependence (instead of $1/r^2$), would Gauss's

law be still true ?

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23. A small test charge is released at rest at a point in an electrostatic field configuaration. Will it travel along the field line passing through that point ?

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24. What is the work done by the field of a nucleus in a complete circular orbit of the electron ? What if the orbit is elliptical ?

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25. We know that electric field is discontinuous across the surface of a charged conductor . Is electric potential also discontinuous there ?

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26. What meaning would you give to the capacitance of a single conductor ?

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27. Guess a possible reason why water has a much greater dielectric constant (=80) than say, mica(=6).

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28. A cylinderical capacitor has two co-axial cylinders of length 15 cm and radii 1.5cm and 1.4 cm . The outer cylinder is earthed and the inner cylinder is given a charge of $3.5\mu C$. Determine the capacitance of the system and the potential of the inner cylinder. Neglect end effets (i.e., bending of filed lines at the ends).

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29. A parallel plate capacitor is to be desigined with a voltage rating 1kV, using a material of dielectric constant 3 and dielectric strength about $10^7 Vm^{-1}$ (Dielectric strength is the maximum electric field a material can tolerate without breakdown, i.e., without starting to conduct electricity through partical ionisation.) For safety, we should like the field never to exceed, say $10\,\%$ of the dielectric strength. What minimum area of the plates is required to have a capacitance of 50 pF?

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30. Describe schematically the equipotential surfaces corresponding to

(a) a constant electric field in the z-direaction .

(b) a field that uniformaly increases in magnitude but reamins in a constant (say,z) direction.

(c) a single positive charge at the origin, and

(d) a uniform grid consisting of long equally spaced parallel charged wires in a plane.

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31. In a Van de Graff type generator a spherical metal shell is to be a $15 \times 10^6 V$ electrode. The dielectric strength of the gas surrounding the electrode is $5 \times 10^7 V m^{-1}$. What is the minimum radius of the spherical shell required ? (You will learn from this excerise why one cannot build and electrostatic generator using a very small shell which requires a small charge to acquire a high potential.)

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32. A small sphere of radius r_1 and charge q_1 is enclosed by a spherical shell of radium r_2 and charge q_2. Show that if q_1 is positive , charge will neecessarily flow from the sphere to the shell (when the two are connected by a wire) no matter what the charge q_2 on the shell is .

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33. The top of the atmosphere is at about 400kV with respect to the surface of the earth , corresponding to an electric field that

decreases with altitude. Near the surface of the earth, the field is about $100 V m^{-1}$. Why then do we not our house into the open? (Assume the house to be a steel cage so there is no field inside)

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34. A man fixes outside his house on evening on its top a large aluminium sheet of area $l m^2$. Will he get an electric shock if he touches the metal sheet next morning ?

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35. The discharging current in the atmosphere due to the small conductivity of air is known to be 1800 A on an average over the globe . Why then does the atmosphere not discharge it self completely in due course and becomed electrically neutral ? In other words, what keeps the atmosphere charged?

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36. What are the forms of energy into which the electrical energy of the atmosphere is dissipated during a lighting ?

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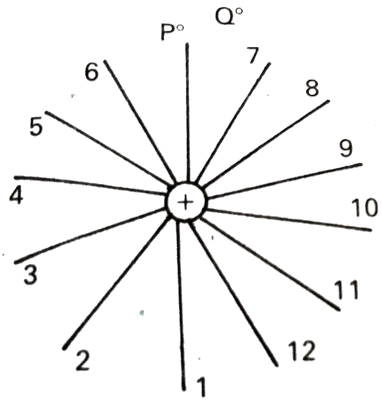
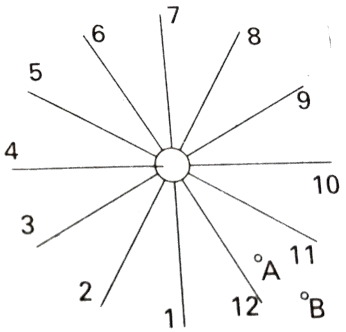
Textual Examples

1. Figure (a) and (b) shows the field lines of a positive and negative point charge respectively.



(a)



(b)

Give the signs of the potential difference $V_p - V_Q, V_B - V_A$.

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2. Give the sign of the potentiaol energy difference of a small negative charge between the points Q and P,A and B.

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3. Give the sign of the work done by the field in moving a small positive charge from Q to P.

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4. Give the sign of the work done by the external agency in moving a small negative charge from B and A.

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5. Does the kinetic energy of a small negative charge increase or decrease in going from B to A ?

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6. Suppose that the same system of charges is now placed in an external electric field $E = A\left(1/r^2\right), A = 9 \times 10^5 Cm^{-2}$. What would the electros -tatic energy of the configuration be ?

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7. A molecule of a substance has a permanent electric dipole moment of magnitude $10^{-29}C$ m. A mole of this substance is polarised (at low temperature)by applying a strong electrostatic field of magnitude $10^{6}Vm^{-1}$. The direction of the field is suddenly changed by an angle of 60°. Estimate the heat released by the substance in aligning its dipoles along the new direcation of the field. For simplicity. assume $100\,\%$ polarisation of the sample .

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8. A comb run through one's dry hair attracts small bits of paper. Why? What happens if the hair is wet or if it is a rainy day? (Remember a paper does not conduct electricity.)

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9. A network of four $10\mu F$ capacitors is connected to a $500V$ Supply , as shown in Fig.

Determine (a) the equivalent capacitance of the network and (b) the charge on each capacitor, (Note , the charge on a capacitor is the charge on the plate with higher potential , equal and opposite to the charge on the plate with lower potential.)

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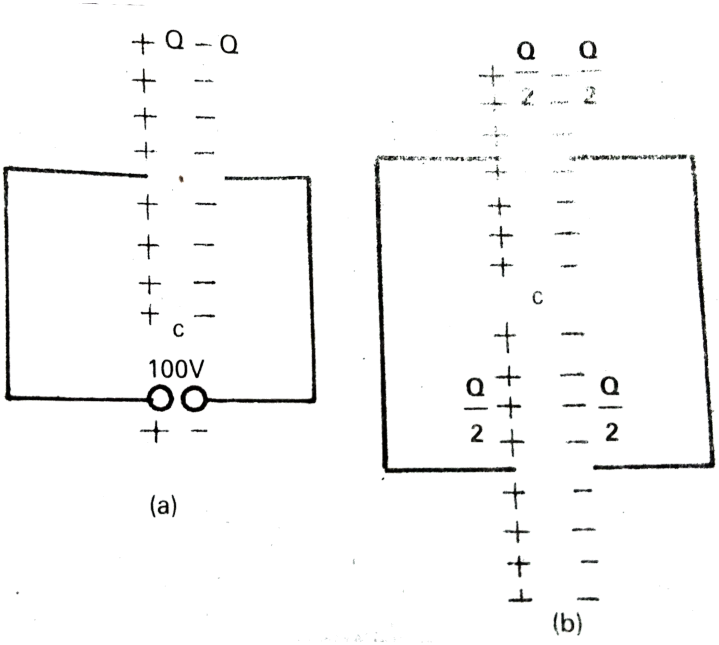
10. A $900pF$ capacitor is charged by 100 V battery. How much electros-tatic energy is stored by the capacitor?

(b) The capacitor is disconnected from the battery and connected to another 900 pF. Capacitor. What is the electrostatic energy stored by the system?



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Important Questions

1. Three capacitors of capacitances 1muF,2muF and 3muF`are connected in parallel

(a) What is the ratio of charges ?

(b) What is the ratio of potential differences ?

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2. Three capacitors of capacitances $1\mu F, 2\mu F$ and $3\mu F$ are connected in series

What is the ratio of charges ? What is the ratio of potential differences ?

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3. Derive an expression for the electric potential due to a point charge.

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Saqs

1. What is series combination of capacitors. Derive the formula for equivalent capacitance in series combination.

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2. What is parallel combination of capacitors. Derive the formula for equivalent capacitance in parallel combination.

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3. Derive an expression for the energy stored in a capacitor.

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4. What is the energy stored when the space between the plates is filled with dielectric.

(a) With charging battery disconnected ?

(b) With charging battery connected in the circuit ?

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