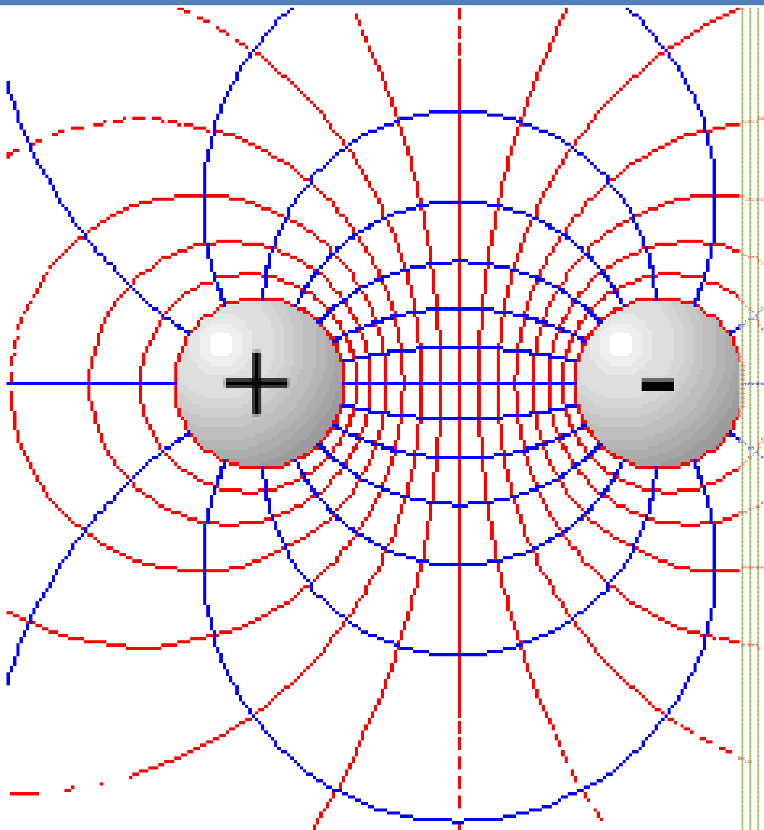
2013

Questions & Answers on Electrostatics



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POWER QUESTIONS

Q. A capacitor of 4 μF is connected to 400V supply. It is then disconnected and connected to an uncharged capacitor of 2 μF . Calculate the common potential after the capacitors are connected together.

$C_1 = 4\mu F = 4\times10^{-6} F$; $V_1 = 400V$ and $C_2 = 2\mu F = 2\times10^{-6} F$

So, charge on capacitor C_1 is given by

Ans. Here, $q_1 = C_1V_1 = 4\times10^{-6}\times400 = 1.6\times10^{-3}C$

Charge on capacitor C_2, $q_2 = 0$

If C be the capacitance of the combination, when C_1 being charged is connected to C_2 in parallel.

$\therefore C = C_1 + C_2 = 4\times10^{-6} + 2\times10^{-6} = 6\times10^{-6}C$

Total charge of combination, $q = q_1 + q_2$

$1.6\times10^{-3} + 0 = 1.6\times10^{-3}C$

If V is the common potential, then,

$$V = \frac{q}{C} = \frac{1.6\times10^{-3}}{6\times10^{-6}} = 266.67V$$

Q. An electrical technician requires a capacitance of 2 μF in a circuit across a potential difference of 1KV. A large number of capacitors are available to him, each of which can withstand a potential difference of not more than 400V. Suggest a possible arrangement that requires a minimum number of capacitors.

Ans. If N capacitors are connected in m rows, each row having n capacitors, then $N=mn$.
Each capacitor=1 μF . Required capacitance of the combination, C=2 μF .
Voltage rating of each capacitor = 400V and required voltage rating of combination =1000V
Since the capacitors are in series, potential difference gets added.
So, n number of capacitors connected in a row will stand a voltage equal to $400\times nV$

Therefore, no. of capacitors to be connected in a row is given by
400n=1000

$$\Rightarrow n = \frac{1000}{400} = 2.5 \; or \; n = 3$$

Total capacitance of the capacitors in row is given by

$$\frac{1}{C'} = \frac{1}{1} + \frac{1}{1} + \frac{1}{1} = 3$$

$$\Rightarrow C' = \frac{1}{3}\mu F$$

Total capacitance of m rows is given by

$$C = mC' \quad \Rightarrow m = \frac{C}{C'} = \frac{2}{1/3} = 6$$

Therefore, he should make three rows of such capacitors, each row containing six capacitors.

Q.A parallel plate capacitor of capacitance C is charged to a potential difference V and then the battery is disconnected. Now a dielectric slab of the dimensions equal to the spacing between the plates is inserted between the plates. What are the changes, if any, in the capacitance, charge, potential difference, electric field and the energy stored ?

Ans. Let K be dielectric constant of the slab and q, E and U be charge on the plates of the capacitor, electric field between the plates and energy stored in the capacitor before inserting the slab.

On inserting dielectric slab :

$C' = KC (increases)$

Since battery has been disconnected, the charge on capacitor will remain same.

$$\text{pot. difference between the plates, } V' = \frac{q}{C'} = \frac{q}{KC} = \frac{V}{K} (decreases)$$

$$\text{Electric field between the plates, } E' = \frac{V'}{d} = \frac{V}{Kd} = \frac{E}{K} (decreases)$$

$$\text{The energy stored in capacitor, } U' = \frac{1}{2}C'V'^2 = \frac{1}{2}KC\left(\frac{V}{K}\right)^2$$

$$= \frac{1}{K}\left(\frac{1}{2}CV^2\right) = \frac{U}{K} (decreases)$$

Q. Why should circuits containing capacitor be handled cautiously, even when there is no current ?

Ans. A capacitor does not discharge itself. In case, the capacitor is connected in a circuit containing a source of high voltage, the capacitor charges itself to a very high potential. If some person handles such a capacitor without discharging it first, he may get a severe shock.

Q. A man fixes outside his house one evening a two metre high insulating slab carrying on its top a large aluminium sheet of area 1 m . Will he get an electric shock, if he touches the metal sheet next morning ?

Ans. The aluminium sheet and the ground form a capacitor with insulating slab as dielectric. The discharging current in the atmosphere will charge the capacitor steadily and raise its voltage. Next morning, if the man touches the metal sheet, he will receive shock to the extent depending upon the capacitance of the capacitor formed.

Q. If a parallel capacitor of capacitance C is kept connected to a supply voltage V to just fill the space and then a dielectric slab is inserted between the plates then what will be the change in the capacitance, potential difference, the charge, electric field and the energy stored ?

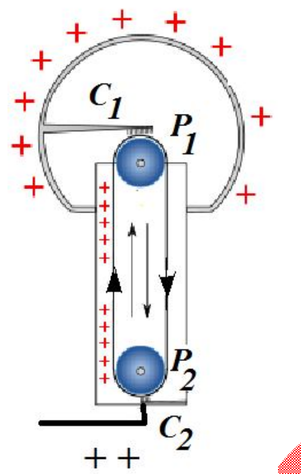
Ans. Let K be dielectric constant of the dielectric slab and *q*, E and U be charge on capacitor, electric field between plates and energy stored in the capacitor before inserting the slab.
On inserting dielectric slab :
The capacitance of the capacitor will become, C'=KC (increases)
Since the capacitor is kept connected to the supply voltage, potential difference will remain unchanged *i.e.* V.
The charge on capacitor will become, $q' = C'V = KCV = Kq$ *(increases)*
It may be pointed out that as battery remains connected to the capacitor, it can draw more charge from the battery.
Since, potential difference between plates does not change, electric field will also remain unchanged.
The energy stored in the capacitor will become, $U' = \frac{1}{2}C'V^2 = \frac{1}{2}KCV^2 = KU$ (increases)

2.6. VAN DE GRAFF GENERATOR

Principle of Van de Graff generator:

(i) The discharging action of pointed ends set up an electric wind
(ii) A charge given to a hollow conductor is transferred to the outer surface and spreads uniformly over it.

Construction and working: Van de Graff generator consists of large hollow metallic sphere S mounted on two insulating columns as shown in the Fig.
A belt runs on two pulleys P_1 and P_2. The spray comb C_2 is held near the lower belt which is maintained at high positive potential of E.H.T. source.
The collector comb C_2 collects the charges through its pointed ends and transfer to the metallic sphere.
As the belt goes on revolving, the accumulation of positive charges on the sphere also goes on increasing. Thus it can generate a very high potential of the order of 5×10^6 V .
The leakage of charge is minimised by enclosing the generator completely inside an earth - connected steel tank. The leakage is due to the high potential on the sphere causing ionization.



VAN DE GRAAFF GENERATOR

SELECTED QUESTIONS

Q1. Is it possible that like charges attract?
Ans. Yes. If one of the two charges is having large magnitude of charge than the other.

Q2. a bird perches on a bare high power line and nothing happens. A man standing on the ground touches the same line and gets a fatal shock. Why?
Ans. For the bird, the circuit does not get completed between the bird and the earth and nothing happens. As for the man the circuit gets completed and he get a fatal shock.

Q3.Is it possible to use the electricity generated during lightning for domestic purposes?
Ans. If we could store the electricity, we can use it. However there is no device to hold the huge electricity generated during lightning.

Q4. What is quantization of charge? Explain why a body cannot have a charge of $1.1\times10^{-19}C$?
Ans. However, the charge is not in accordance with this law and hence it is to be considered to be invalid.

Q6. What is the smallest amount of charge that can exist on a body?
Ans. charge on an electron $(= e = 1.6\times10^{-19}C)$

Q7. Calculate the Coulombs force between two alpha particles ($\alpha - particles$) separated by a distance $3.2\times10^{-15}m$.

Ans.

$$Here,\ r = 3.2\times10^{-15}m,\ q_1 = q_2 = 2e = 2\times1.6\times10^{-19}C$$
$$(as\ charge\ on\ alpha\ partice = 2e)$$
$$\therefore F = \frac{1}{4\pi\in_0}\cdot\frac{q_1q_2}{r^2} = 9\times10^9\times\frac{(2\times1.6\times10^{-19})^2}{\left(3.2\times10^{-15}\right)^2} = 90N$$

Q8. Write down the value of absolute permittivity of free space.
Ans. $\in_0 = 8.854\times10^{-12}C^2N^{-1}m^{-2}$

Q9. How are permittivity and dielectric constant (or relative permittivity) related?
Ans. $\in = \in_0 K\ \ or\ \ \in = \in_0\in_r\ \ (\in_r = K = dielctric\ constant)$

Q10. What is meant by saying that dielectric constant for water is 80?
Ans. It means that the electrostatic force between the chages reduces to *1/80 th* times when placed in water medium.

Q11. Why one ignore the quantization of charge when dealing with macroscopic (large charges) charges?
Ans. In practice, the charges on bodies are large whereas the charge on electrons are smaller. If electron (of charge e) is added or removed from a charged body, there is not much change on the charge of the body. Hence while dealing with large amount of charges, quantization of charge is ignored.

Q13. Define capacitance. Derive an expression for the capacitance of a parallel plate capacitor.

Q14. Derive an expression for the energy stored in a capacitor.

Q15. Explain how does the capacitance of a capacitor gets modified, when a dielectric slab is introduced between the plates.

Q16. Briefly discuss the principle, construction and working of a Van de Graff Generator.

Q17. What meaning would you give to the capacitance of a single conductor?
Ans. A single capacitor also possesses capacitance. It is a capacitor whose one plate is at infinity.

Q18. Is there an electric field inside a conductor?
Ans. No. The electric field inside a conductor is zero.

Q19. Two copper spheres of same radii, one hollow and the other solid are charged to same potential. Which, if any, of the two sphere will have more charge?

Ans: Same.

Q21. Why is the Van de Graff Generator enclosed inside a steel tank filled with air pressure?
Ans. To prevent leakage of charge due to ionization.

Q22. What is Gaussian surface? What is its use?
Ans. Any closed surface around the charge so that Gauss's law can be applied successfully to find the electric field intensity is known as Gaussian surface.
It is used to find surface integral of electric field .

Q23. If Coulomb's law involved $\frac{1}{r^3}$ dependence, would Gauss's law be valid?

Ans. No. Gauss's law is valid for inverse square laws only. ($\frac{1}{r^3}$)

Q24. What is difference between a sheet of charge and a plane conductor having charge?
Ans. On a sheet of charge, the same charge is found on both the surfaces while in a plane conductor, charge on each side is different.

Q25. A man inside an insulated metallic cage does not receive any electric shock when the cage is highly charged, why?
Ans. Since the electric potential is the same everywhere inside a metallic cage, no potential difference is created inside and the man does not get any shock.
Q26. State Gauss's theorem. Find an expression for the electric field due to an infinitely long line charge.

Q27.State Gauss's theorem in electrostatics. Apply this theorem to calculate the electric field due to an infinite plane sheet of charge.

Q28. Applying Gauss's theorem show that for a spherical shell, the electric field inside a shell vanishes, whereas outside it, the electric field is as if all the charge has been concentrated at the centre.

Q29. How does a dielectric differ from an insulator ?
Ans. Both the dielectrics and insulators cannot conduct electricity. However, in case of a dielectric, when an external field is applied ; induced charges appear on the faces of the dielectric. In other words, dielectrics have the property of transmitting electric effects without conducting.

Q30. Explain why presence of a dielectric increases capacitance of the capacitor ?
Ans. When a dielectric slab is introduced between the two plates of a capacitor, the electric field between the plates gets reduced due to polarization of the dielectric. The reduced value of electric field is equivalent to a decreased value of potential difference between the plates. In order to make the potential difference again same, more charge has to be given to the capacitor. *i.e.* the capacitance of the capacitor increases.

Q31. Is, there any kind of material that when inserted between the plates of a capacitor reduces its capacitance ? f instead of a dielectric slab, we put a slab of metal between the plates of a capacitor keeping it insulated from them, what effect does it have on capacitance ?

Ans. The dielectric constant K of a material is always greater than 1 and is defined as the ratio of the capacitance (C) of the capacitor with dielectric between its plates to its capacitance (C') without the dielectric between the plates, Thus, $K = \frac{C'}{C}$ As $K > 1,\ C' > C$

. ie. capacitance of a capacitor on placing the dielectric between the plates is always greater than the capacitance without dielectric.

Q32.What limits the maximum potential to which the hollow sphere in a Van de Graaff generator can be raised ?
Ans. When the rate of loss of charge because of leakage due to ionization of surrounding air becomes equal to the rate at which the charge is transferred to the sphere, the maximum potential of the sphere is reached.

Q33. If instead of a dielectric slab, we put a slab of metal between the plates of a capacitor keeping it insulated from them, what effect does it have on capacitance ?

Ans. When a slab of metal is put between the plates of a capacitor, its capacitance increases, provided the slab does not touch the plates of the capacitor. In case, the slab of metal touches the two plates, both plates become at the same potential and as a result, the capacitance of the capacitor becomes zero.

Q34. Is it correct to write the unit of electric dipole moment as mC?
Ans. Wrong. *mC* stands for milli coulomb.

Q35. What is the net force experienced by an electric dipole in an uniform electric field? What about if the electric field is non uniform?
Ans. If the electric field is uniform, the net force is equal to zero. If the field is non uniform, the net force is not equal to zero.

Q36. What is the ratio of the strength of electric field at a point on the axial line at a point at the same distance on the equitorial line of an electric dipole of very small length?
Ans. As we know that

$$E_{axial} = \frac{1}{4\pi \in_0}.\frac{2p}{r^3} \ and \ E_{equatorial} = \frac{1}{4\pi \in_0}.\frac{p}{r^3}$$

$$\therefore \frac{E_{axial}}{E_{equatorial}} = \frac{\frac{1}{4\pi \in_0}.\frac{2p}{r^3}}{\frac{1}{4\pi \in_0}.\frac{p}{r^3}} = 2$$

ADDITIONAL POWER QUESTIONS

Q1. Obtain an expression for electric field due to a point charge.
Q2. Find the expression for the electric field intensity at a point on the (i) axial line and (ii) equatorial line of an electric dipole.
Q3. What is electric potential energy due to a system of two charges? Find the expression for it.
Ans. The electrostatic potential energy of two point charges can be defined as the work done required to bring the charges constituting the system to their respective positions from infinity.
Mathematically, $U = \frac{1}{4\pi \in_0}.\frac{q_1 q_2}{r_{12}}$

Q4. An electrostatic field line cannot have sudden breaks. Why?
Ans. If the electrostatic field line have sudden breaks, it will indicate absence of electric field at that point in the electric field which is not possible. Hence, the line cannot have sudden break.

ADDITIONAL EXAMINATION QUESTIONS

Q1.Define relative permittivity of a medium.

Ans. Relative permittivity (dielectric constant) $k\ (\in_r) = \dfrac{\in}{\in_0}$

where $\in$ = permittivity and $\in_0$ = absolute permittivity of free space

Q2. What is meant by quantization of charge and conservation of charge ?

Ans. Quantization of charge: The charge on a body is an integral multiple of $\pm e$.

ie. $q = \pm ne$ where e = charge on an electron = 1.6×10^{-19}C

.

Conservation of charge The total charge on an isolated body is always conserved ie. total number of charge before and after a chemical reaction are the same.

Q3. What does $q_1 + q_2 = 0$ signify ?

Ans. $q_1 + q_2 = 0$ means that $q_1 = -q_2$ Such a system is an electric dipole where the two charges are equal and opposite.

Q4. What is the nature of symmetry of the dipole field ?

Ans. The dipole field has a cylindrical symmetry. The axis of the cylinder passes through the dipole axis.

Q5. When is an electric dipole in unstable equilibrium in an electric field?

Ans. When $\vec{p}$ is antiparallel to $\vec{E}$ ie. $\theta = 180^0$

Q6. Is torque on an electric dipole a vector?

Ans. Torque is a vector quantity.

Q7. Give the SI unit of electric dipole moment.

Ans. It is C-m (coulomb- metre)

Q8. At what points, dipole field intensity is parallel to the line joining charges?

Ans. At any point on axial line or equatorial line of the dipole.

Q9. Two point charges of +3μC each are 100 cm apart. At what point on the line joining charges will the electric intensity be zero?

Ans. The electric intensity will be zero at the centre of the point charges.

Q10. Derive an expression for electric field intensity at a point due to a point charge.

Ans. Assume that a unit positive test charge is kept at P. Force on $+q_0$ at pointP is $F = \dfrac{1}{4\pi\in_o}\dfrac{q\,q_o}{r^2}$.

$F = \dfrac{1}{4\pi\in_o}\dfrac{q\,q_o}{r^2}$ Now, $E = \dfrac{F}{q_o}$ $\left[\because \text{Electric field is the force per charge}\right]$

$$\therefore E = \frac{1}{4\pi\in_o}\frac{q\,q_o}{r^2}\frac{1}{q_o} = \frac{1}{4\pi\in_o}\frac{q}{r^2}$$

Q11. If a point charge be rotated in a circle of radius r around a charge q, what will be the work done ?

Ans. The circle of radius ***r*** will act as an equipotential surface and hence no work is done in moving the charge.

Q12. What is the amount of work done in moving a 220C charge between two points 5cm apart on an equipotential surface.

A. On an equipotential surface, work done in moving the charge is zero.

Q13. Do electrons tend to go regions of high potential or low potential ?

A. Since electrons are negatively charged, they have tendency to go to regions of higher potential.

Q14. If V equals a constant throughout a given region of space, what can you say about E in that region?

Ans. If V = constant, then $E = -\dfrac{dV}{dr} = -\dfrac{d}{dr}(\text{constant}) = 0 \Rightarrow E = 0$. It means that when electric potential is constant, electric field in that region is zero.

Q15. How many electrons volt make one joule ?

Ans. Here, $1eV = 1.6 \times 10^{-19} J \quad \therefore \quad 1J = \frac{1}{1.6 \times 10^{-19}} eV = 0.625 \times 10^{19} eV$

Q16. An electric dipole of dipole moment 20 X 10^{-6} Cm is enclosed by a closed surface. What is the net flux coming out of the surface ?

Ans. Since net charge on the electric dipole is zero, net flux coming out of the surface will be zero.

Q17. A technician has only two capacitors. By using them singly, in series or in parallel, he is able to obtain the capacitance of 4, 5, 20, and 25 μ F. What are the capacitance of the two capacitors ?

Ans. Maximum capacitance is obtained for parallel combination. Therefore $C_p = 25 \ \mu F$. The minimum capacitance is obtained for series combination ie. $C_s = 4 \ \mu F$. The remaining values 5 μ F and 20 μ F will represent individual values of the two capacitors.

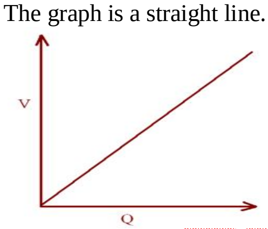
Q18. If two isolated conductors having definite capacity are separated by a fine wire. Calculate the capacitance. Are they in series or parallel combination ?

A. On connecting, both the spheres acquire a common potential V. The total charge will be given by

$q_1 + q_2 = CV \quad (\text{since } q = CV) \quad \therefore \ C = \frac{q_1}{V} + \frac{q_2}{V} = C_1 + C_2$ Hence, they act as parallel combination.

Q19. Sketch a graph to show how charge Q given to a capacitor of capacity C varies with the potential difference V.

A. The graph is a straight line.



Q20. Can you place a parallel plate capacitor of one farad capacity in your house ?

A. No.

The capacitor will become too large.

Since $C = \frac{A\epsilon_0}{d} \Rightarrow A\epsilon_0 = Cd \Rightarrow A = \frac{Cd}{\epsilon_0}$.

If we take $d = 1mm = 10^{-3} m$

$$\therefore \ A = \frac{1 \times 10^{-3}}{8.854 \times 10^{-12}} \approx 10^8 m^2$$

This is a very big size to accommodate in a room!

Q21. Can there be a potential difference between two conductors of same volume carrying equal positive charges?

A. Yes, because two conductors of same volume may have different shapes and hence different capacitances.

Q22. A parallel capacitor has a capacity of 6 μ C in air and 60 μ C when dielctric medium is introduced. What is the dielectric constant of the medium ?

A. Di-electric constant $K = \frac{C_m}{C_0} = \frac{\text{capacitance in medium}}{\text{capacitance in air}} = \frac{60}{6} = 10$

Q23. Where does the energy of a capacitor reside ?

A. The energy resides in the di-electric medium separating the two plates.

Q24. Why does the electric field inside a dielectric decrease when it is placed in an external electric field ?

A. It is because the dielectric gets polarised.

Q25. How much work must be done to charge a 24 F capacitor, when the potential difference between the plates is 500 V?

Ans of QNo.25.

Here, $C = 24\ \mu F = 24 \times 10^{-6}\ F$ and $V = 500$ Volts.

$$\therefore \text{ Work done} = \frac{1}{2}CV^2 = \frac{1}{2}(24 \times 10^{-6})\ 500^2 = 3 \text{ joules}$$

Q26. By what factor does the capacity of a metal sphere increase if its volume is tripled ?

A. $\dfrac{C_2}{C_1} = \dfrac{R_2}{R_1} = \left(\dfrac{V_2}{V_1}\right)^{\frac{1}{3}} \Rightarrow C_2 = C_1\left(\dfrac{V_2}{V_1}\right)^{\frac{1}{3}} = C_1\,(3)^{\frac{1}{3}} = 1.44\ C_1$

Q27. What are dielectric substances ?

A. Dielectric substances are basically insulators on which electrical effects can be passed through them without actual conduction(charges will develop on the dielectric when electric field is applied).

Q28. An uncharged insulated conductor A is brought near a charged insulated conductor B. What happen to charge and potential ?

A. Charge on B remains same, but the potential of B gets lowered because it induces charge of opposite sign on conductor A.(when a body induces charge on other body, its potential will be lowered)

Q29. State Coulombs law of forces between two charges at rest. What is the force of repulsion between two charges of 1C kept 1m apart in vacuum?

Ans.

According to Coulomb's law, force between two charges

q_1 and q_2 is given by

$F \propto q_1 q_2$ and $F \propto \dfrac{1}{r^2}$

where r = distance between the charges.

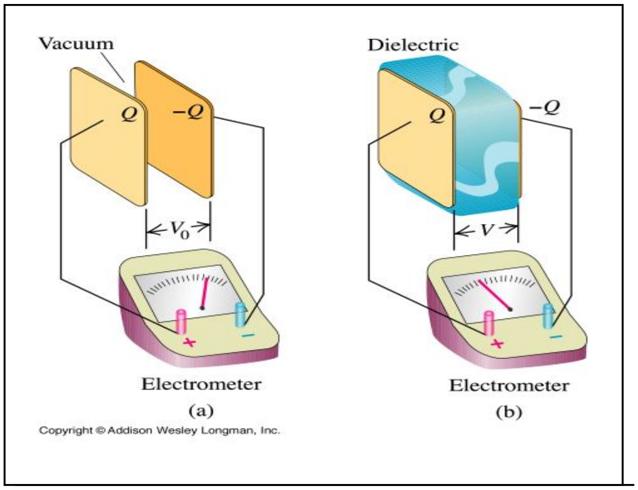
$$\therefore F \propto \frac{q_1 q_2}{r^2} \Rightarrow F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

where $\dfrac{1}{4\pi\varepsilon_0}$ = constant = $9\times10^9\ Nm^2C^{-2}$

If $q_1 = q_2 = 1C$; $r = 1m$

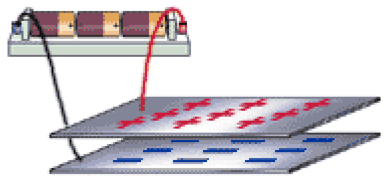
$$F = 9\times10^9 \times \frac{1\times1}{1^2}$$

$$\Rightarrow F = 9\times10^9\ N$$



Observe the above following figure.

- On introduction of the dielectric, capacitance increases and hence the potential V decreases.



a simple parallel plate capacitor connected to a battery

39. Can you place a parallel plate capacitor of one farad capacity in your house ?
A. No.
This is a very big size to accomodate in a room!

Q 30. Two insulated charged spheres of radii 10 cm and 20 cm having same charge are connected by a conductor and then they are separated. Which of the two spheres will carry more charge ?
A. Bigger sphere will carry more charge as its capacity is larger, (q = CV). The potential V becomes same on connecting them with a wire.

Q 31. Can there be a potential difference between two conductors of same volume carrying equal positive charges ?
Ans. Yes. because two conductors of same volume may have different shapes and hence different capacitances.

Q 32. What is the net charge on a charged capacitor ?
Ans. Zero, because one plate has positive charge and the other carries an equal negative charge.

Q 33. If the plates of a charged capacitor be suddenly connected to each other by a wire, what will happen ?
Ans. The capacitor will be discharged immediately.

Q 34. On which factors does the capacitance of a capacitor depend ?
Ans. It depends on geometry of the plates, distance between them and nature of dielectric medium separating the plates.

Q 35. What is the basic use of a capacitor ?
Ans. To store charge and energy.

Q 36 . What meaning would you give to capacity of a single conductor ?
Ans. A single conductor can be visualized as a capacitor whose second plate is far away at infinity.

Q37. Why does the electric field inside a dielectric decrease when it is placed in an external electric field?
Ans. It is because the dielectric gets polarized.

***Q 38.* Where does the energy of a capacitor reside ?**
Ans. The energy resides in the dielectric medium separating the two plates.

FACT FILE FOR MAXIMUM SCORE IN EXAMINATIONS

Coulombs Law

- The charges developed on the bodies during the process of rubbing are due to the transfer of electrons only from one body to the other.
- Coulomb's law in electrostatics holds only for stationary charges and the charges, points in size.
- When the same two charges located in air are placed in a dielectric medium without altering the distance between them, electrostatic force always decreases.
- A system of charge is said to be in equilibrium, if the net force experienced by each charge of the system is zero.
- Electrostatic force between two charges is not affected by the presence of a third charge in their vicinity.

Electric Field

- The test charge used to measure electric field at a point has to be vanishingly small. If the test charge is not vanishingly small, then the test charge may bring about a change in electric field at the observation point.

For this, one is advised to understand the difference between the statement *'the force experienced by a unit positive test charge'* and *'the force experienced per unit positive test charge.'* The former statement is incorrect, as a unit positive charge used as test charge will cause a change in the value of electric field at the observation point.

- The unit of electric dipole moment is C m and not m C. It is because, m C is used as mill coulomb.
- The direction of electric field at a point on the axial line of an electric dipole is same as that of *p(dipole moment).*
- The direction of electric field at a point on equatorial line of an electric dipole is opposite to that *of p.*
- For very large distance of observation point from the charged circular loop *(x > > a)*, the circular loop **behaves** as a point charge.
- No torque acts on a dipole, when it is aligned along the direction of electric field.
- The electrostatic potential energy of the dipole is maximum, when it is aligned anti parallel to the direction of the electric field.

- The electric lines of force do not exist but what they represent is a reality.
  It gives the path along which positive test charge would move, when free to do so.
- In a uniform electric field, the lines of force are parallel lines. The electric line of force crowd near each other in regions of strong electric field.
- The relative closeness of the lines of force at different points in the electric field gives an estimate of the strength of the electric field at these points.

Electric Potential

- The work done in moving a test charge between two points in an electric field is independent of the path followed between the two points.

- The work done in moving a test charge over a closed path in an electric field is always zero.
  The above two results hold for the reason that electrostatic force between two charges obeys inverse law i.e. electrostatic field is inverse square field.

> > The work done per unit positive test charge from a point A to point B is equal to $V_B - V_A$
i.e. potential difference between the points B and A (and not between points A and B).

- Electric potential at any point inside a charged spherical conductor is always equal to that at a point on its surface *i.e.* it is same (constant) every where.

As a result of it, the electric field inside a charged spherical conductor is zero.

- For a point outside the charged spherical conductor, the whole charge appears to be **concentrated at its centre.**

- The electrostatic potential increases steadily as one moves against the direction of electric **field and it** decreases in the direction of electric field.

The above result is a consequence of negative sign in the relation $E = -\frac{dV}{dr}$

- The electric field is always at right angle to the equipotential surface.

- No work is done in moving a test charge between two points on an equipotential surface,

- .If work has to be done in moving one of the charges of a system from one point to some other, then electrostatic potential energy of the system increases by an amount equal to the work done in moving the charge.

2.7. Gauss's Theorem

>> The electric flux through a small portion of the closed surface is affected by the charges present outside the surface.

- The total electrical flux through a closed surface is not affected by the charge present outside the surface. It depends only upon the charges enclosed by the close surface.
- The electric flux through a small portion of the closed surface may change, if the charges inside the closed surface are moved to the new positions.
- The total electric flux through a closed surface is not affected, if the charges inside the closed surface are moved to new positions.
- For both the spherical shell and the sphere, electric field at a point outside is same as if the charge is . concentrated at their centre.
- Inside a spherical shell, electric potential is zero. It is zero inside a sphere also, provided sphere is conducting.
- A sphere of charge is not a conducting sphere.

2.8. Capacitors

- The capacitors are connected in parallel to increase the capacitance.
- The capacitors are connected in series to decrease the capacitance
- When a dielectric slab of dielectric constant K is introduced between the plates of a charged

air-capacitor (battery disconnected after charging), then
(a) capacitance increases by a factor K,
(b) potential difference decreases by a factor K.
(c) charge of the capacitor remains unaffected.
(d) electrostatic potential energy stored in the capacitor decreases by a factor K.

> When a dielectric slab of dielectric constant K is introduced between the plates of an air capacitor (battery remains connected across the capacitor), then
(a) capacitance increases by a factor K
(b) potential difference across capacitor remains unaffected.
(c) charge on the capacitor increases by a factor K.
(d) electrostatic potential energy stored increased by a factor K.

- The dielectric slab can be removed from the space between the plates of a charged capacitor only by performing work. However, the work done appears as increase in the potential energy of the capacitor.
- When a part of the space between the two plates of a capacitor is filled with the slab of one dielectric slab, then the two parts of the capacitor may be looked upon as the combination of two capacitors.
- The capacitor behaves as a parallel combination of the two sub capacitors, if each slab is of thickness equal to separation *d*. On the other hand, it behaves as a series combination of the two sub capacitors, if the slabs together make thickness equal to *d*.

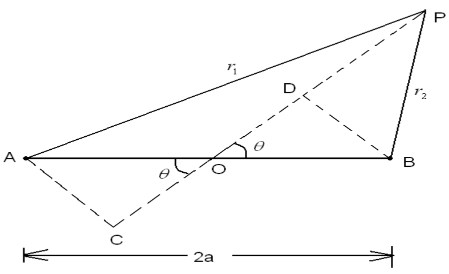
WHAT IF IT COMES IN EXAM????

Q. 1. Define electric potential at a point in an electric field. Derive an expression for the electric potential at a point due to an electric dipole.(1+4=5)

Solution. *Electric potential at a point in the electric field is defined as the work done per unit charge in moving a unit positive test charge from infinity to that point against the electrostatic force independent of the path followed.*

Potential at a point due to electric dipole.

Consider an electric dipole consisting of two charges -q and +q at A and B separated by a small distance distance 2a.



Figure

Suppose $AP = r_1$ *and* $BP = r_2$. *Draw* $BD \perp OP$ *and* $AC \perp PO$ *produced.*

$\therefore OC = OA\cos\theta = a\cos\theta$

and $OD = OB\cos\theta = a\cos\theta$

Potential at P due to dipole is

$$V_p = \frac{q}{4\pi\epsilon_0 r_2} - \frac{q}{4\pi\epsilon_0 r_1} = \frac{q}{4\pi\epsilon_0}\left[\frac{1}{r_2} - \frac{1}{r_1}\right]$$

Now $r_1 = AP \approx CP = OP + OC = r + a\cos\theta$

$r_2 = BP \approx DP = OP - OD = r - a\cos\theta$

$$\therefore V_p = \frac{q}{4\pi\epsilon_0}\left[\frac{1}{(r - a\cos\theta)} - \frac{1}{(r + a\cos\theta)}\right]$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{(r + a\cos\theta) - (r - a\cos\theta)}{r^2 - a^2\cos^2\theta}\right]$$

$$\therefore V_p = \frac{q}{4\pi\epsilon_0}\left[\frac{2a\cos\theta}{r^2 - a^2\cos^2\theta}\right]$$

$$= \frac{p\cos\theta}{4\pi\epsilon_0 (r^2 - a^2\cos^2\theta)} \quad [\because q \times 2a = p]$$

In practice, $OD (= OC = a\cos\theta)$ *is very small as compared to* $OP (= r)$.

Therefore, $a^2\cos^2\theta$ *can be neglected as compared to* r^2.

$$\therefore V_p = \frac{p\cos\theta}{4\pi\epsilon_0 r^2}$$

Special Cases. (i) If point P lies on the axial line of the dipole, then $\theta = 0$

$$\therefore V_p = \frac{p\cos 0^0}{4\pi\epsilon_0 r^2} = \frac{p}{4\pi\epsilon_0 r^2}$$

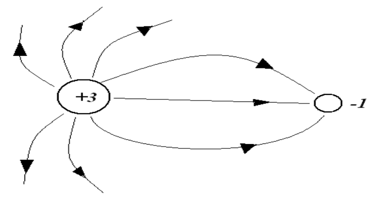
(ii) If point P lies on the equatorial line of the dipole , Then $\theta = 90$.

$$\therefore V_p = \frac{p\cos 90^0}{4\pi\epsilon_0 r^2} = 0$$

Hence potential due to an electric dipole is zero at every point on the equatorial line of the dipole.

2. Plot electric field lines around two charges +3 unit and -1 unit.

Solution.



3. A small metallic ball is suspended through an insulating thread in uniform electric field. If high energy X-ray beam falls on the ball, what will happen to the ball?

Solution. Electrons will be emitted from the ball and acquire +ve charge. Thus ball is deflected by the uniform electric field.

4. Define electric flux. Give its SI unit.

Solution. Electric flux is defined as the surface integral of electric field. Its SI unit is Nm^2C^{-1}

5. What is the total charge on an electric dipole?

If the dipole is enclosed in a closed surface, what will be the electric flux through the surface?

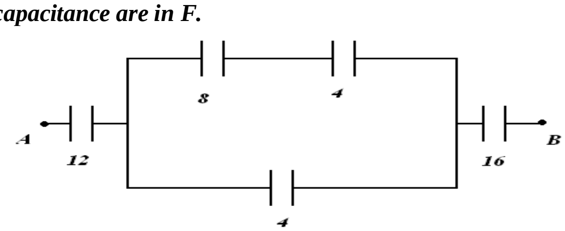
Solution. Total charge +q - q = 0. Since the total charge is equal to zero, the electric flux is also equal to zero as

$$\phi = \frac{q}{\epsilon_0}$$

6. Electric field lines can never appear as closed loops. Why?

Solution. As the electric field starts from positive charge and end at negative charge, they do not appear as closed loops.

7. What is the equivalent capacitance between A and B? All capacitance are in F.



Solution.

8 and 4 are in series.

$\therefore \frac{1}{C'} = \frac{1}{8} + \frac{1}{4} = \frac{3}{8}$ *So,* $C' = \frac{8}{3}F$

Now C' and 4F are in parallel.

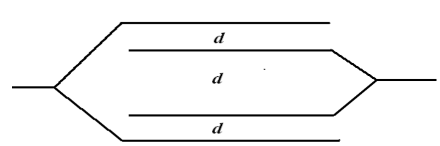
$\therefore C'' = C' + 4 = \frac{8}{3} + 4 = \frac{20}{3}F$

Now 12F, C'' and 16F are in series.

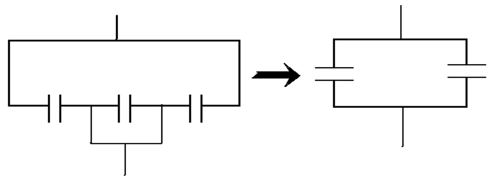
$\therefore \frac{1}{C} = \frac{1}{12} + \frac{3}{20} + \frac{1}{16} = \frac{47}{240}$

$\therefore C = \frac{240}{47}F$

8. What is the equivalent capacity in the given fig.?

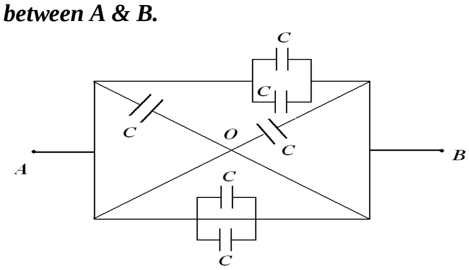


Solution of QNo.8

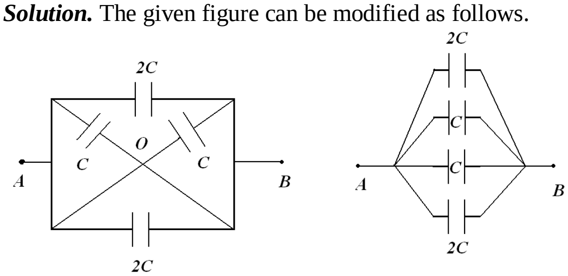


Equivalent capacitance $C' = C_1 + C_2 = \dfrac{2 \in_0 A}{d}$

9. Six capacitors each of capacitance 2 are connected as shown in the given figure. What is the effective capacitance between A & B.



Solution. The given figure can be modified as follows.



$C_p = 2C + C + C + 2C = 6C = 6 \times 2\mu F = 12\mu F$

10. Capacitor 2, 3 and 6 are given. How do you connect them to get the minimum capacitance?
Solution.

$\frac{1}{C} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3+2+1}{6} = 1\mu F$

$\therefore C = 1\mu F$

11. What is the work done in placing a charge of $8 \times 10^{-18} C$ ***on a condenser of capacity 100?***
Solution.

$W = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2}\frac{\left(8 \times 10^{-18}\right)^2}{100 \times 10^{-6}} = 32 \times 10^{-32} J$

12. Where is the electric field due to uniformly charged sphere maximum?
Solution. Since $E \propto r$, the electric field is maximum at the surface.

13. What is the net charge on a current carrying conductor?
Solution. Zero.

14. When dielectric substance is put between two plates of condenser, what is the change is capacity, potential and PE?
Solution.

Capacity increases, potential and PE decreases.

$C = \frac{A \in_0 K}{d}$ and $C = \frac{q}{V}$ and $P.E. = \frac{Q^2}{2C}$

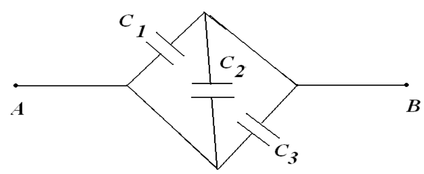
15. What are the units of $\frac{1}{4\pi \in_0}$ ***?***

Solution. Nm^2C^{-2}

15. What is the dielectric constant of a metal?
Solution. Infinity.

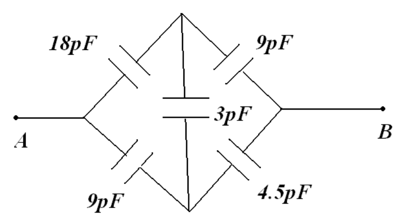
16. Does the electric flux depends on the shape and size of the Gaussian surface?
Solution. No. Gaussian surface is independent of the shape and size of the Gaussian surface. However, the flux depends on the net charge enclosed.

17. Calculate equivalent capacitance between A and B if $C_1 = 1\mu F,\ C_2 = 3\mu F,\ C_3 = 3\mu F$



Solution. All the capacitors are in parallel.
So, $C = C_1 + C_2 + C_3 = 1\mu F + 2\mu F + 3\mu F = 6\mu F$

18. Calculate equivalent capacitance between A & B.



Solution.

Since $\frac{18}{9} = \frac{9}{4.5} = 2pF$, *capacitance of* $3pF$ *is neglected.*
As $18pF$ *and* $9pF$ *are in series giving* $6pF$. *Similarly* $9pf$ & $4.5pF$ *are in series giving* $3pF$. *Since* $6pF$ & $3pF$ *are in parallel,* $C = 6pF + 3pF = 9pF$