

**Unit I: Electrostatics****22 Periods****Chapter-1: Electric Charges and Fields**

Electric Charges; Conservation of charge, Coulomb's law-force between two point charges, forces between multiple charges; superposition principle and continuous charge distribution.

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

Electric flux, statement of Gauss's 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).

**Chapter-2: Electrostatic Potential and Capacitance**

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. Dielectrics and electric polarisation, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor.

## PHYSICS CLASS-XII -ELECTROSTATICS

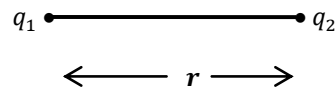
101. State Coulomb's law in electrostatics.

CBSE(F)-2003,(AIC)-2001

[ Ans. **Coulomb's law** : The electrostatic force of attraction or repulsion between any two stationary point charges is directly proportional to the product of magnitude of charges and is inversely proportional to the square of the distance between them.

$$\text{i.e., } F \propto \frac{q_1 q_2}{r^2}$$

$$\Rightarrow F = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r^2}$$



102. Write Coulomb's law in vector form. What is the importance of expressing it in vector form ? CBSE (AIC)-2011

[ Ans. **Coulomb's law in vector form** :

$$\vec{F} = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r^2} \hat{r} = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r^2} \frac{\vec{r}}{|\vec{r}|} = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r^3} \vec{r}$$

**Importance** : (i) As  $\hat{r}_{21} = -\hat{r}_{12} \Rightarrow \vec{F}_{21} = -\vec{F}_{12}$

Which shows that coulomb's force obey Newton's third law of motion

(ii) As the Coulomb's force acts along  $\vec{F}_{21}$  or  $-\vec{F}_{12}$ , i.e., along the line joining the centres of two charges, so they are central forces

103. Write any two limitations of Coulomb's law.

CBSE (AIC)-2001

[ Ans. (i) charges must be stationary point charges  
(ii) distance between the point charges  $r > 10^{-15} \text{ m}$

104. (a) Name any two basic properties of electric charge.

(b) What does  $q_1 + q_2 = 0$  signify in electrostatics ?

CBSE(F)-2003,(AIC)-2001

[ Ans. (a) (i) Quantization of charge (ii) Conservation of charge

(b) It signifies that charges are algebraically additive and here  $q_1$  &  $q_2$  are equal and opposite105. Is the force acting between two point electric charges  $q_1$  and  $q_2$  kept at some distance apart in air, attractive or repulsive when (a)  $q_1 q_2 > 0$  (b)  $q_1 q_2 < 0$  ?

CBSE (F)-2007,2003

[ Ans. (a) when  $q_1 q_2 > 0$ , force is repulsive(b) when  $q_1 q_2 < 0$ , force is attractive106. Two insulated charged copper spheres A and B of identical size have charges  $q_A$  and  $-3q_A$  respectively.

When they are brought in contact with each other and then separated, what are the new charges on them ?

CBSE (F)-2011

[ Ans. Charge on each sphere  $= \frac{q_1 + q_2}{2} = \frac{q_A - 3q_A}{2} = -q_A$ 

107. Define dielectric constant of a medium in terms of force between electric charges. What is its S.I. unit ? CBSE (AI)-2015

[Ans. **Dielectric constant** : It is defined as the ratio of the force ( $F_{\text{vacuum}}$ ) between any two point charges placed at certain distance apart in vacuum to the force ( $F_{\text{medium}}$ ) between them when placed at equal distance in that medium

$$\text{i.e., } K = \frac{F_{\text{vacuum}}}{F_{\text{medium}}} \quad \text{It has no unit}$$

108. How does the Coulomb force between two point charges depend upon the dielectric constant of the intervening medium ?

$$\text{[Ans. } F = \frac{1}{4\pi \epsilon_0 K} \frac{q_1 q_2}{r^2} \Rightarrow F \propto \frac{1}{K}$$

CBSE (AI)-2005

Coulomb's force varies inversely with the dielectric constant of medium

109. Two same balls having equal positive charge ' $q$ ' Coulombs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two ? CBSE (AI)-2014

[Ans.  $F = \frac{1}{4\pi \epsilon_0 K} \frac{q_1 q_2}{r^2} \Rightarrow F \propto \frac{1}{K}$  But for plastic  $K > 1$  hence the force between the two balls will decrease

110. Force between two point electric charges kept at a distance  $d$  apart in air is  $F$ . If the charges are kept at the same distance in water, how does the force between them change ?

CBSE (AI)-2011

$$\text{[Ans. } F_{\text{water}} = \frac{F_{\text{air}}}{K} = \frac{F}{80}$$

111. Two point charges having equal charges separated by  $1 \text{ m}$  distance experience a force of  $8 \text{ N}$ . What will be the force experienced by them, if they are held in water, at the same distance ? (Given :  $K_{\text{water}} = 80$ )

CBSE (AIC)-2011

$$\text{[Ans. } F_{\text{water}} = \frac{F_{\text{air}}}{K} = \frac{8}{80} = 0.1 \text{ N}$$

## PHYSICS CLASS-XII -ELECTROSTATICS

112. Does the charge given to a metallic sphere depend on whether it is hollow or solid ? Give reason for your answer.

[Ans. No, Because the charge resides only at the surface of conductor

CBSE (D)-2017

113. 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 ?

NCERT-2017

[ Ans. When a comb is run through dry hair, it gets charged due to friction. Molecules in the paper gets polarized by the charged comb resulting in a net force of attraction. If the hair is wet or it is a rainy day, friction reduces, comb does not get charged and thus it will not attract small bits of paper

114. Define electric field intensity. Write its S.I. unit. Is it a scalar or vector quantity ?

CBSE (D)-2007

[ Ans. **Electric field intensity** : Electric field intensity at any point is defined as the electrostatic force acting on vanishingly small unit positive test charge placed at that point

$$\text{i.e., } \vec{E} = \lim_{q_0 \rightarrow 0} \frac{\vec{F}}{q_0} \quad \text{Its S.I. unit is } N/C. \text{ It is a vector quantity.}$$

115. The electric field intensity at any point is defined as  $\lim_{q_0 \rightarrow 0} \frac{F}{q_0}$ . What is the physical significance of the term  $\lim_{q_0 \rightarrow 0}$  in this expression ?

CBSE (D)-2007

[Ans. The term  $\lim_{q_0 \rightarrow 0}$  indicates that the test charge  $q_0$  is small enough so that its presence does not affect the distribution of source charge and hence does not change the value of electric field

116. (i) What is the physical significance of electric field ?

(ii) Write an expression for force acting on a test charge  $q_0$  placed in a uniform electric field.

CBSE (D)-2007

[Ans. (i) It gives the magnitude & direction of electric force ( $\vec{F}$ ) experienced by any charge placed at any point.

$$(ii) \vec{F} = q_0 \vec{E}$$

117. A proton is placed in a uniform electric field directed along the positive x-axis. In which direction will it tend to move ?

[Ans. + x-axis, i.e., along the direction of electric field

CBSE (DC)-2011

118. Why must electrostatic field at the surface of a charged conductor be normal to the surface at every point ?

Give reason.

CBSE (AI)-2015,2002,(F)-2014,(AIC)-2002

[Ans.  $\vec{E} \cdot d\vec{r} = dV$  but at the surface of a conductor  $V = \text{constant}$

$$\Rightarrow \vec{E} \cdot d\vec{r} = 0 \Rightarrow E dr \cos \theta = 0 \Rightarrow \theta = 90^\circ$$

Hence electric field at the surface of a charged conductor is always normal to the surface at every point

119. Define electric potential at a point. Write its S.I. unit. Is potential a scalar or vector ?

CBSE (AI)-2015

[Ans. **Electric Potential** ( $V$ ) : Electric potential at any point in an electric field may be defined as the work done by an external force in bringing a unit positive charge from infinity to that point

$$\text{i.e., } V_A = \frac{W_{\infty A}}{q_0} \quad \text{It's S.I. unit is } J/C \text{ or Volts (V). It is a scalar quantity.}$$

120. Name the physical quantity whose S.I. unit is  $JC^{-1}$ . Is it a scalar or vector quantity ?

CBSE (AI)-2010

[Ans. Potential, it is a scalar quantity

121. Why is the potential inside a hollow spherical charged conductor constant and has the same value as on its surface ?

$$[Ans. |E| = \frac{dV}{dr} \Rightarrow dV = |E| dr$$

CBSE (F)-2012,(D)-2012

As inside the hollow spherical conductor  $E = 0$

$$\Rightarrow dV = 0 \Rightarrow V = \text{constant}$$

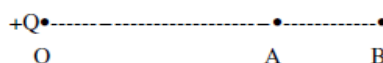
122. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 5 V. What is the potential at the centre of the sphere ?

CBSE (AI)-2011

[Ans. 5 V, because potential of a metallic sphere remains unchanged inside the sphere

123. A point charge  $+Q$  is placed at a point  $O$  as shown in the figure. Is the potential difference  $V_A - V_B$  positive, negative or zero ?

$$[Ans. \text{Positive as } V = \frac{1}{4\pi\epsilon_0} \frac{q}{r} \Rightarrow V \propto \frac{1}{r}] \quad \text{CBSE (D)-2016}$$



124. Define electric line of force/electric field line.

CBSE (D)-2005,2003

[Ans. An electric field line may be defined as the imaginary straight or curved path, along which a unit positive, isolated charge would tend to move if free to do so.

## PHYSICS CLASS-XII -ELECTROSTATICS

125. State any two properties of electric field lines.

**CBSE (D)-2005**

- [Ans. (i) Electric field lines do not form closed loops. They start from positive charge and end at negative charge  
(ii) Tangent to any point on the electric field line gives the direction of electric field at that point  
(iii) No two electric field lines can intersect each other  
(iv) They are always normal to the surface of a conductor

126. What is the importance of electric field lines ?

**CBSE (AIC)-2002**

- [Ans. **Importance** : (i) Tangent to any point on the electric field line gives the direction of electric field at that point  
(ii) Relative closeness of electric field lines indicates the strength of electric field

127. Why do the electrostatic field lines not form closed loops ?

**CBSE (AI)-2015,2014**

- [Ans. Due to conservative nature of electric field/ These lines start from positive charges and terminate at the negative charges

128. Why do the electric field lines never cross each other ?

**CBSE (AI)-2014,2005,(D)-2003**

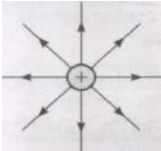
- [Ans. Because if they do so, at the point of intersection two tangents can be drawn, which would represent two directions of electric field at that point, which is not possible

129. Why do the electrostatic field lines are always normal to the surface of a conductor **CBSE (AI)-2009,(F)-2009**

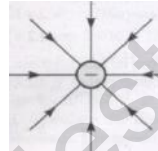
- [Ans. If the field lines are not normal, then electric field  $\vec{E}$  would have a tangential component which will make electrons move along the surface creating surface currents and the conductor will not be in equilibrium

130. Draw the electric field lines of an isolated point charge  $Q$  when (i)  $Q > 0$  and (ii)  $Q < 0$ . **CBSE (D)-2007,2003**

- [Ans. (i)  $Q > 0$



- (ii)  $Q < 0$

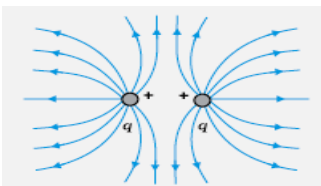


131. (i) Depict electric field lines due to two positive charges kept at a certain distance apart. **CBSE (AI)-2015,(D)-2003**

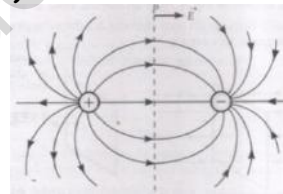
**CBSE (AI)-2015,(D)-2003**

(ii) Depict electric field lines due to an electric dipole or due to two opposite charges kept at a certain distance apart.

- [Ans. (i)



- (ii)

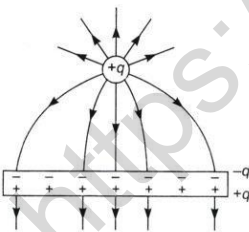


132. (i) A point charge  $+Q$  is placed in the vicinity of a conducting surface. Trace the field lines between the charge and the conducting surface. **CBSE (AIC)-2017,(AI)-2015,2009**

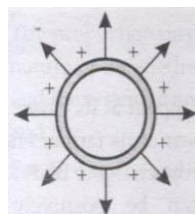
**CBSE (AIC)-2017,(AI)-2015,2009**

(ii) Draw the electric field lines due to uniformly charged thin spherical shell when charge on the shell is (a) positive, (b) negative

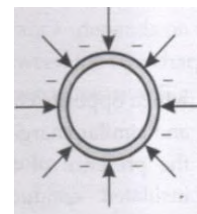
- [Ans. (i)



- (ii) (a)



- (ii) (b)



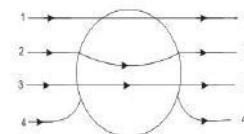
**CBSE (D)-2008**

133. A metallic sphere is placed in a uniform electric field as shown in the figure. Which path is followed by the electric field lines and why ? **CBSE (AI)-2010**

**CBSE (AI)-2010**

- [Ans. Path 4

**Reason** : Electric field lines are normal at each point of the surface and there are no electric field lines within the metallic sphere



## PHYSICS CLASS-XII -ELECTROSTATICS

134. Define dipole moment. Write its S.I. unit. Is it a scalar or vector quantity ? **CBSE (AI)-2013,2011, (D)-2012**

[Ans. **Dipole moment** : The product of magnitude of either charge of the electric dipole and the length of dipole is known as the dipole moment.

$$\text{i.e., } |\vec{p}| = q \times |2\vec{a}|$$

It's S.I. unit is Coulomb X metre (C m). It is a vector quantity

135. What is the charge of an electric dipole ?

**CBSE (DC)-2010**

[ Ans. Zero

136. An electric dipole is placed in a uniform electric field, what is the net force acting on it ?

**CBSE (DC)-2001**

[ Ans. Zero

137. An electric dipole of dipole moment  $\vec{p}$  is placed in a uniform electric field  $\vec{E}$ . Write the value of the angle between  $\vec{p}$  and  $\vec{E}$  for which the torque experienced by the dipole is minimum.

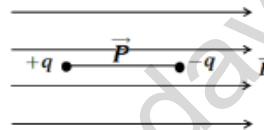
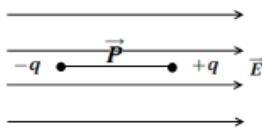
**CBSE (DC)-2009**

[ Ans. Zero because  $\tau = pE \sin \theta = 0$

138. Depict the orientation of the dipole in (i) stable, (ii) unstable equilibrium in a uniform electric field. **CBSE (D)-2017,2010**

[ Ans. (i) **Stable equilibrium**  $\theta = 0$

(ii) **Unstable equilibrium**  $\theta = 180$



139. Find the work done in rotating the dipole from stable to unstable equilibrium in a uniform electric field.

[ Ans. For stable equilibrium,  $\theta = 0$  and for unstable equilibrium  $\theta = 180$  **CBSE (AI)-2016,2015,2012**

$$\Rightarrow W = pE (\cos \theta_1 - \cos \theta_2) = pE (\cos 0 - \cos 180) = pE [1 - (-1)] = 2pE$$

140. Find the work done in rotating the dipole from unstable to stable equilibrium in a uniform electric field.

[ Ans. For unstable equilibrium  $\theta = 180$  and for stable equilibrium,  $\theta = 0$

**CBSE (AI)-2016**

$$\Rightarrow W = pE (\cos \theta_1 - \cos \theta_2) = pE (\cos 180 - \cos 0) = pE [-1 - 1] = -2pE$$

141. Define electric flux. Write its S.I. unit. **CBSE (AIC)-2017,(AI)-2015,2012,2008,(F)-2006,(D)-2007,2006**

[ Ans. **Electric flux** : It is defined as the total number of electric lines of force passing normally through a given surface

$$\phi_E = \oint \vec{E} \cdot d\vec{s}$$

It's S.I. unit is  $Nm^2/C$

142. State Gauss's law in electrostatics.

**CBSE (AI)-2015,2012,2007,2004,(F)-2012,(D)-2008,2006,2004**

[ Ans. **Gauss's Law** : " Electric flux passing through any closed surface is  $\frac{1}{\epsilon_0}$  times the total charge enclosed by that surface".

$$\text{i.e., } \phi_E = \oint \vec{E} \cdot d\vec{s} = \frac{q}{\epsilon_0}$$

143. A charge  $q$  is enclosed by a spherical surface  $R$ . If the radius is doubled/ reduced to half, how would the electric flux through the surface change ?

**CBSE (AI)-2009, (AIC)-2008,(DC)-2007**

[ Ans. No change as flux does not depend on radius/ shape /size of enclosing surface

144. A charge  $q$  is placed at the centre of a cube, what is the electric flux passing through one of its faces ?

[ Ans.  $\phi = \frac{1}{6} \left( \frac{q}{\epsilon_0} \right)$

**CBSE (AI)-2012, (F)-2010**

145. Consider two hollow concentric spheres,  $S_1$  &  $S_2$ , enclosing charges  $2Q$  &  $4Q$  respectively as shown.

**CBSE (AI)-2014,2002**

(i) Find out the ratio of the electric flux through them.

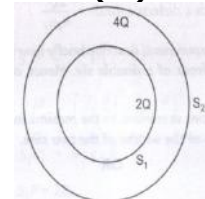
(ii) how will the electric flux through the sphere  $S_1$  change, if a medium of dielectric constant  $\epsilon_r$  is introduced in the space inside  $S_1$  in place of air ?

Deduce the necessary expression.

[ Ans. (i)  $\phi_1 = \frac{2Q}{\epsilon_0}$  &  $\phi_2 = \frac{2Q+4Q}{\epsilon_0} = \frac{6Q}{\epsilon_0}$

$$\Rightarrow \frac{\phi_1}{\phi_2} = \frac{\frac{2Q}{\epsilon_0}}{\frac{6Q}{\epsilon_0}} = \frac{1}{3}$$

$$\text{(ii) } \phi_1 = \frac{2Q}{\epsilon_r \epsilon_0} = \frac{2Q}{\epsilon_r K}$$



## PHYSICS CLASS-XII -ELECTROSTATICS

146. (i) Define electric potential energy of a system of charges.

CBSE (AI)-2015

(ii) Write an expression of electric potential energy of a system of two charges.

[ Ans. (i) **Electric potential energy of a system of charges** : It is defined as the total amount of work done in placing the charges to their respective positions to constitute the system, by bringing them from infinity

$$(ii) U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

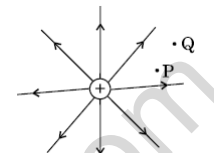
147. The figure shows field lines of a positive point charge. What will be the sign of the potential energy difference of a small negative charge between the points Q and P. Justify your answer.

CBSE (AI)-2015, (F)-2014

[Ans. **Positive** i.e.,  $(U)_Q - (U)_P > 0$

$$\text{Reason : } U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

P.E. of a positive charge & a negative charge is negative hence P.E. of a negative charge is more negative at P, i.e.,  $(U)_Q > (U)_P$



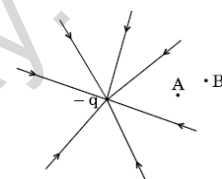
148. Figure shows the field lines of a negative point charge. Give the sign of the potential energy difference of a small negative charge between the points A and B.

CBSE (F)-2014

[Ans. **Positive** i.e.,  $(U)_A - (U)_B > 0$

$$\text{Reason : } U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

P.E. of two negative charges is positive hence P.E. of a negative charge is more positive at A, i.e.,  $(U)_A > (U)_B$



140. The figure shows field lines of a positive point charge. Is the work done by the field in moving a small positive charge from Q to P is positive or negative? Justify your answer.

CBSE (F)-2014

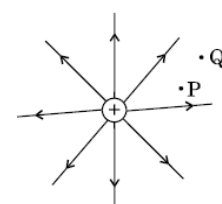
[Ans. **Negative**,

$$\text{Reason : } V_P > V_Q \Rightarrow V_P - V_Q > 0$$

$$\text{But } V_P - V_Q = \frac{W_{QP}}{q_0} \Rightarrow W_{QP} > 0$$

$\Rightarrow$  Work done by external agency is positive

$\Rightarrow$  Work done by electric field is negative

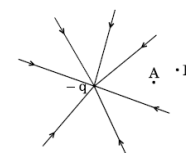


150. The field lines of a negative point charge are as shown in the figure. Does the kinetic energy of a small negative charge increase or decrease in going from B to A?

CBSE (AI)-2015

[Ans. **K.E. decreases**

**Reason :** As the negative charge moves from B to A, it experiences more repulsion, its velocity decreases and so, its K.E. decreases



151. (i) Define an equipotential surface?

CBSE (AI)-2016,2015,2002,(D)-2003

(ii) Write any two properties of an equipotential surface.

[ Ans. (i) **Equipotential surface** : A surface drawn in an electric field at which every point has the same potential, is known as equipotential surface

(ii) **Properties :**

(a) No work is done in moving a test charge from one point to another over an equipotential surface

(b) Electric field is always normal to the equipotential surface at every point

(c) No two equipotential surfaces can intersect each other

(d) Equipotential surfaces are closer in regions of strong field and farther in regions of weak field

152. "For any charge configuration, equipotential surface through a point is normal to the electric field."

Justify this statement.

CBSE (AI)-2016,(D)-2014

[Ans. At an equipotential surface  $V_1 = V_2$

$$\text{Hence work done, } W = q_0(V_1 - V_2) = 0$$

$$\cos\theta \Rightarrow F S = 0, \Rightarrow \theta = 90^\circ$$

## PHYSICS CLASS-XII -ELECTROSTATICS

153. No work done in moving a charge from one point to another on an equipotential surface. Why ? **CBSE (AIC)-2002**

[Ans. We know for any two points on an equipotential surface  $V_1 = V_2$

Hence work done,  $W = q_0 (V_1 - V_2) = 0$

154. Can electric field exist tangential to an equipotential surface ? Give reason. **CBSE (AI)-2016**

[Ans. No, It would mean some work will be done in moving charge from one point to another on equipotential surface which is not possible

155. Why do the equipotential surfaces due to uniform electric field not intersect each other ? **CBSE (F)-2013,(D)-2009**

[Ans. Because if they do so then at the point of intersection there will be two values of the electric potential, which is not Possible

156. Why the equipotential surfaces about a single charge are not equidistant ? **CBSE (AI)-2016,2015,(DC)-2011**

OR

Why does the separation between successive equipotential surfaces get wider as the distance from the charges increases ?

[Ans.  $|E| = \frac{dV}{dr} \Rightarrow dr = \frac{dV}{|E|}$  -----(1)

**CBSE (AI)-2016**

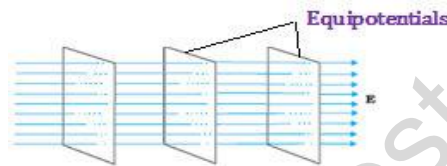
As the distance increases, electric field  $E \left( = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \right)$  decreases therefore from (1),  $dr$  will be large hence

large hence equipotential surfaces get wider. That's why equipotential surfaces are not equidistant

157. Draw an equipotential surface in a uniform electric field.

**CBSE (F)-2008,2006,(D)-2001**

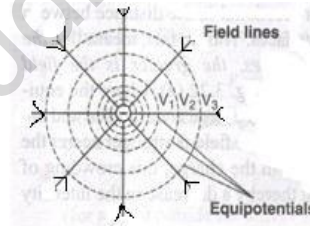
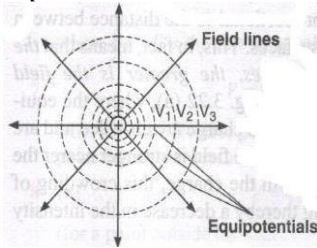
[Ans.



158. Draw an equipotential surface and corresponding electric field lines for a single point charge (i)  $+q$  ( $q > 0$ ) (ii)  $-q$  ( $q < 0$ ). **CBSE (AI)-2016,(F)-2006,(D)-2001**

[Ans. (i)  $q > 0$

(ii)  $q < 0$



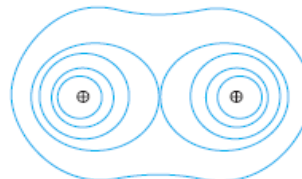
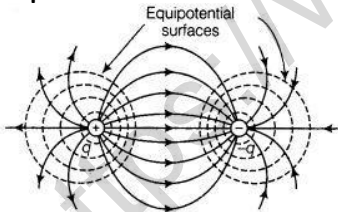
159. (i) Draw the equipotential surfaces for an electric dipole. **CBSE (AI)-2015**

(ii) Draw the equipotential surfaces due to two equal positive point charges placed at a certain distance.

[Ans. (i) dipole

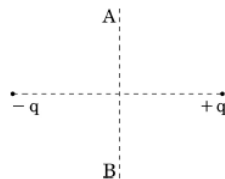
(ii) equal positive charges

**CBSE (AI)-2015,(D)-2010**



160. A charge ' $q$ ' is being moved from a point A above a dipole of dipole moment ' $p$ ' to a point B below the dipole in equatorial plane without acceleration. Find the work done in the process. **CBSE (AI)-2016**

[Ans. Zero, as AB is an equipotential surface]



## PHYSICS CLASS-XII -ELECTROSTATICS

161. What is the amount of work done in moving a point charge  $Q$  around a circular arc of radius ' $r$ ' at the centre of which another point charge ' $q$ ' is located ? **CBSE (AI)-2016**

[Ans. zero]

162. Define the capacitance of a conductor. Write its S.I. unit. **CBSE (AIC)-2003**

[Ans. It is defined as the charge required to raise the potential of conductor by unit amount.

$$\text{i.e., } C = \frac{q}{V}$$

Its S.I. unit is Farad (F)

163. Define the capacitance of a capacitor. On what factors does it depends ? **CBSE (F)-2017,(DC)-2001**

[Ans. **Capacitance** : Capacitance of a capacitor may be defined as the ratio of magnitude of charge on its either plate to the potential difference between them.

$$\text{i.e., } C = \frac{q}{V}$$

**Factors** : (i) geometrical configuration (shape, size, separation) of the system of two conductors and  
(ii) nature of the medium separating the two conductors

164. Define dielectric constant of a medium in terms of capacitance. **CBSE (D)-2006**

[Ans. The dielectric constant of a medium may be defined as the ratio of capacitance of capacitor completely filled with that dielectric medium to the capacitance of the same capacitor with vacuum between its plates.

$$\text{i.e., } K = \frac{C}{C_0}$$

165. A metal plate is introduced between the plates of a charged parallel plate capacitor. What is the effect on the capacitance of the capacitor ? **CBSE (F)-2009**

[Ans. Capacitance increase as the effective separation between the plates is decreased

166. (i) Define the term polarization of a dielectric. **CBSE (AI)-2016,2015,(D)-2015**

(ii) Write a relation for polarization  $\vec{P}$  of a dielectric material in the presence of an external electric field  $\vec{E}$ .

[Ans. (i) **Polarization of a dielectric** : Induced dipole moment per unit volume, is called polarization  $P$

$$\text{(ii) Relation : } \vec{P} = \chi_e \vec{E}$$

where  $\chi_e$  is the electric susceptibility of the dielectric medium

167. How is the electric field due to a charged parallel plate capacitor affected when a dielectric slab is inserted between the plates fully occupying the intervening region ? **CBSE (F)-2010**

[Ans. Electric field decreases due to dielectric polarization and becomes

$$E = E_0 - E_{in} = \frac{E_0}{K}$$

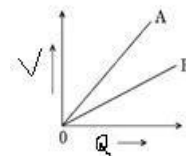
168. The graph shows the variation of voltage  $V$  across the plates of two capacitors A and B versus increase of charge  $Q$  stored on them. Which of the capacitors has higher capacitance ? Give reason for your answer. **CBSE (D)-2004**

[Ans. B has higher capacitance

$$\text{Reason : } C = \frac{q}{V}$$

If  $V = \text{constant}$  then  $C \propto q$

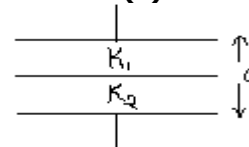
$$\text{As } q_B > q_A \Rightarrow C_B > C_A$$



169. A parallel plate capacitor of plate area  $A$  and separation  $d$  is filled with dielectrics of dielectric constants  $K_1$  and  $K_2$  shown in the figure. Find the net capacitance of the capacitor. **CBSE (F)-2011**

$$[\text{Ans. } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{\frac{K_1 \epsilon_0 A}{d/2}} + \frac{1}{\frac{K_2 \epsilon_0 A}{d/2}} = \frac{d/2}{K_1 \epsilon_0 A} + \frac{d/2}{K_2 \epsilon_0 A}$$

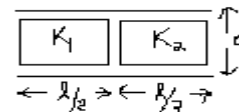
$$\Rightarrow \frac{1}{C} = \frac{d}{2\epsilon_0 A} \left( \frac{1}{K_1} + \frac{1}{K_2} \right) = \frac{d}{2\epsilon_0 A} \left( \frac{K_1 + K_2}{K_1 K_2} \right) \Rightarrow C = \left( \frac{2K_1 K_2}{K_1 + K_2} \right) C_0$$



170. Two dielectric slabs of dielectric constants  $K_1$  and  $K_2$  are filled in between the two plates, each of area  $A$ , of the parallel plate capacitor as shown. Find net capacitance of the capacitor. **CBSE (AI)-2005,(F)-2011**

$$[\text{Ans. } C = C_1 + C_2 = \frac{K_1 \epsilon_0 A/2}{d} + \frac{K_2 \epsilon_0 A/2}{d}$$

$$\Rightarrow C = \frac{\epsilon_0 A}{2d} (K_1 + K_2) = \frac{\epsilon_0 A}{d} \left( \frac{K_1 + K_2}{2} \right) = \left( \frac{K_1 + K_2}{2} \right) C_0$$



## PHYSICS CLASS-XII -ELECTROSTATICS

171. How will the (i) energy stored and (ii) the electric field inside the air capacitor be affected when it is completely filled with a dielectric material of dielectric constant  $K$  ?

CBSE (AI)-2012

[ Ans. (i)  $U_0 = \frac{q^2}{2C_0}$  &  $U = \frac{q^2}{2C} = \frac{q^2}{2KC_0} \Rightarrow U = \frac{U_0}{K}$  (ii)  $E_0 = \frac{\sigma}{\epsilon_0}$  &  $E = \frac{\sigma}{K\epsilon_0} \Rightarrow E = \frac{E_0}{K}$

172. A charge is distributed uniformly over a ring of radius ' $a$ '. Obtain an expression for the electric field intensity  $E$  at a point on the axis of the ring. Hence show that for points at large distances from the ring, it behaves like a point charge.

CBSE (D)-2016

[Ans. linear charge density,  $\lambda = \frac{q}{2\pi a}$   
charge on the small element  $dl$

$$dq = \lambda dl = \frac{q}{2\pi a} dl$$

Electric field intensity due to small element  $dl$  at P

$$dE = \frac{1}{4\pi\epsilon_0} \frac{dq}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{\lambda dl}{r^2}$$

On resolving  $dE$  in to horizontal and vertical components the resultant electric field intensity at P is given by

$$E = \int dE \cos \theta = \int \frac{1}{4\pi\epsilon_0} \frac{\lambda dl}{r^2} \times \frac{x}{r} \quad [\because \cos \theta = \frac{x}{r}]$$

$$\Rightarrow E = \frac{\lambda x}{4\pi\epsilon_0 r^3} \int dl = \frac{x}{4\pi\epsilon_0 r^3} \left( \frac{q}{2\pi a} \right) (2\pi a) = \frac{1}{4\pi\epsilon_0} \frac{qx}{r^3}$$

$$\Rightarrow E = \frac{1}{4\pi\epsilon_0} \frac{qx}{(x^2 + a^2)^{3/2}}$$

At the centre of the ring  $x = 0 \Rightarrow E = 0$

for large distances  $x \gg a$

$$\Rightarrow E = \frac{1}{4\pi\epsilon_0} \frac{q}{x^2}$$

This is the electric field intensity due a point charge at distance  $x$

173. (i) An electric dipole is held in a uniform electric field. Using suitable diagram show that it does not undergo any translatory motion. Derive the expression for the torque acting on it.

(ii) What would happen if the field is non-uniform ?

(iii) What would happen if the external electric field  $E$  is increasing

(a) parallel to  $\vec{p}$  and (b) anti-parallel to  $\vec{p}$  ?

CBSE (AI)-2016,2014,2008,(F)-2016,(DC)-2015

[ Ans. (i) Let an electric dipole of dipole moment  $\vec{p}$  is placed in a uniform electric field  $\vec{E}$  as shown in figure.

**Force** : Force on  $+q$ ,  $F_1 = qE$

Force on  $-q$ ,  $F_2 = -qE$

Hence net force on the dipole

$$F = qE - qE = 0$$

**Torque** : Two equal and opposite forces  $-qE$  and  $+qE$  forms a couple which tries to rotate the dipole. Torque due to this couple

$$\tau = \text{either force} \times \perp \text{ distance} = qE \times 2a \sin \theta$$

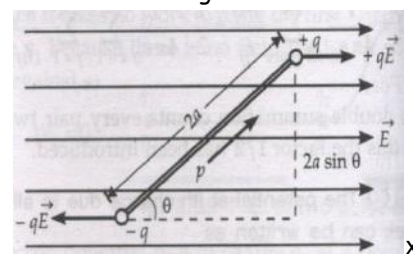
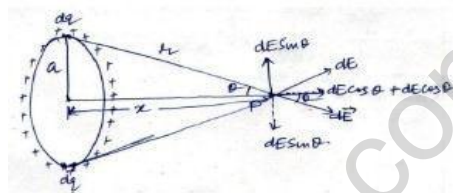
$$= qE \times 2a \sin \theta$$

$$\Rightarrow \tau = pE \sin \theta = \vec{p} \times \vec{E}$$

(ii) If the electric field is non-uniform, the net force on the dipole will not be zero hence there will be the translator motion of the dipole.

(iii) (a) Net force will be in the direction of increasing electric field.

(b) Net force will be in the direction opposite to the increasing field



## PHYSICS CLASS-XII -ELECTROSTATICS

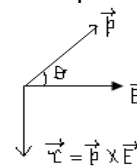
174. An electric dipole is held in a uniform electric field. Write the expression for the torque acting on it. Express it in vector form and specify its direction. Identify two pairs of perpendicular vectors in the expression.

[ Ans. Torque :  $\tau = pE \sin \theta$

Vector form :  $\vec{\tau} = \vec{p} \times \vec{E}$

Direction of  $\vec{\tau}$ : Direction of torque is  $\perp$  to the plane containing

$\vec{p}$  and  $\vec{E}$  given by right hand screw rule



Two pairs of  $\perp$  vectors : (i)  $\vec{\tau}$  and  $\vec{p}$  (ii)  $\vec{\tau}$  and  $\vec{E}$

175. (a) Derive an expression for the electric field  $E$  due to a dipole of length ' $2a$ ' at a point distant  $r$  from the centre of the dipole on the axial line.

CBSE (AI)-2017,2013,(D)-2015

(b) Draw a graph of  $E$  versus  $r$  for  $r \gg a$ .

[ Ans. Let  $\vec{E}_1$  and  $\vec{E}_2$  be the electric field at  $P$  due to  $-q$  and  $+q$  charges respectively then

$$|\vec{E}_1| = \frac{q}{4\pi\epsilon_0(r+a)^2} \quad \text{along PA}$$

$$\& \quad |\vec{E}_2| = \frac{q}{4\pi\epsilon_0(r-a)^2} \quad \text{along BP}$$

Obviously the resultant electric field intensity at  $P$

$$|\vec{E}| = |\vec{E}_2| - |\vec{E}_1| = \frac{q}{4\pi\epsilon_0(r-a)^2} - \frac{q}{4\pi\epsilon_0(r+a)^2} = \frac{q}{4\pi\epsilon_0} \left[ \frac{1}{(r-a)^2} - \frac{1}{(r+a)^2} \right] = \frac{q}{4\pi\epsilon_0} \left[ \frac{(r+a)^2 - (r-a)^2}{(r^2 - a^2)^2} \right]$$

$$\Rightarrow |\vec{E}| = \frac{q}{4\pi\epsilon_0} \frac{4ar}{(r^2 - a^2)^2}$$

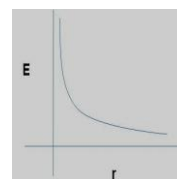
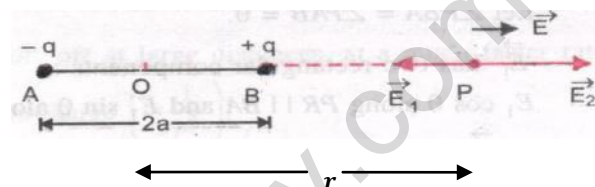
$$\Rightarrow |\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{2pr}{(r^2 - a^2)^2} \quad [\because p = 2qa]$$

Obviously, if  $r \gg a$ , then

$$E = \frac{1}{4\pi\epsilon_0} \frac{2pr}{(r^2)^2}$$

$\Rightarrow$

$$E = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^3}$$



direction of  $\vec{E}$  is along the direction of dipole moment  $\vec{p}$

176. Derive an expression for the electric field intensity at a point on the equatorial line of an electric dipole of dipole moment  $\vec{p}$  and length  $2a$ . What is the direction of this field?

CBSE (D)-2017,(AI)-2016,2013,(F)-2015,2009

[ Ans. Let,  $\vec{E}_1$  and  $\vec{E}_2$  be the electric field intensity at  $P$  due to  $-q$  &  $+q$  charges respectively, then

$$|\vec{E}_1| = |\vec{E}_2| = \frac{1}{4\pi\epsilon_0} \frac{q}{(\sqrt{r^2 + a^2})^2}$$

$$\Rightarrow |\vec{E}_1| = |\vec{E}_2| = \frac{1}{4\pi\epsilon_0} \frac{q}{(r^2 + a^2)} \quad \text{-----(1)}$$

On resolving  $\vec{E}_1$  and  $\vec{E}_2$  in horizontal and vertical components, resultant electric field intensity

$$|\vec{E}| = E_1 \cos \theta + E_2 \cos \theta = 2 E_1 \cos \theta$$

$$\Rightarrow |\vec{E}| = 2 \frac{1}{4\pi\epsilon_0} \frac{q}{(r^2 + a^2)} \frac{a}{\sqrt{r^2 + a^2}} \quad [\because \cos \theta = \frac{a}{\sqrt{r^2 + a^2}}]$$

$$\Rightarrow |\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{2qa}{(r^2 + a^2)^{3/2}}$$

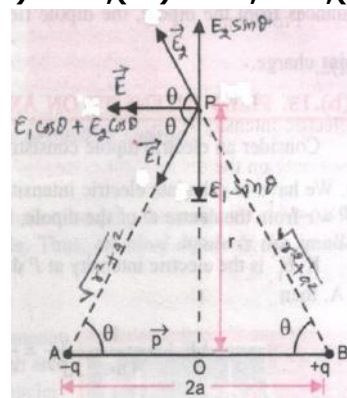
$$\Rightarrow |\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2 + a^2)^{3/2}}$$

$[\because p = 2qa]$

Obviously, if  $r \gg a$ , then

$$|\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3}$$

direction of  $\vec{E}$  is opposite to that of dipole moment  $\vec{p}$



## PHYSICS CLASS-XII -ELECTROSTATICS

177. Derive an expression for the potential at a point along the axial line of a short dipole. For this dipole draw a plot showing the variation of potential  $V$  versus  $r$ , where  $r$  ( $r \gg 2a$ ), is the distance from the point charge  $-q$  along the line joining the two charges.

CBSE (AI)-2015, (D)-2008,2007

[ Ans. Let  $V_1$  and  $V_2$  be the electric potential at P due to  $-q$  and  $+q$  charges respectively then

$$V_1 = \frac{-q}{4\pi\epsilon_0(r+a)}$$

$$\& \quad V_2 = \frac{q}{4\pi\epsilon_0(r-a)}$$

Resultant electric potential at P

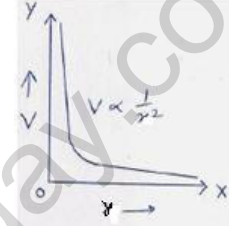
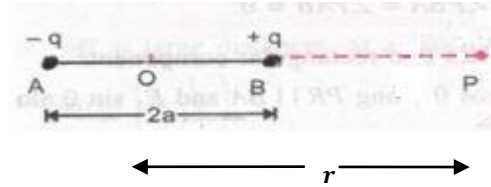
$$V = V_1 + V_2 = \frac{-q}{4\pi\epsilon_0(r+a)} + \frac{q}{4\pi\epsilon_0(r-a)} = \frac{q}{4\pi\epsilon_0} \left[ \frac{1}{(r-a)} - \frac{1}{(r+a)} \right] = \frac{q}{4\pi\epsilon_0} \left[ \frac{r+a-(r-a)}{(r^2-a^2)} \right]$$

$$\Rightarrow V = \frac{1}{4\pi\epsilon_0} \frac{2qa}{(r^2-a^2)}$$

$$\Rightarrow V = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2-a^2)} \quad [\because p = 2qa]$$

Obviously, if  $r \gg a$ , then

$$V = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$$



- 178 (i) Derive the expression for the potential energy of an electric dipole of dipole moment  $\vec{p}$  placed in a uniform electric field  $\vec{E}$ .  
(ii) Find out the orientation of the dipole when it is in (a) stable equilibrium (b) unstable equilibrium.

CBSE (AI)-2016,2015,2012

[ Ans. (i) Two equal and opposite forces  $-qE$  and  $+qE$  forms a couple which tries to rotate the dipole. Torque due to this couple

$$\tau = \text{either force} \times \perp \text{ distance} = qE \times 2a \sin \theta$$

$$\tau = pE \sin \theta$$

Work done in rotating the dipole through an angle  $d\theta$

$$dW = \tau d\theta = pE \sin \theta d\theta$$

$$\Rightarrow W = \int_{\theta_1}^{\theta_2} pE \sin \theta d\theta = pE \int_{\theta_1}^{\theta_2} \sin \theta d\theta = pE [-\cos \theta]_{\theta_1}^{\theta_2}$$

$$\Rightarrow W = pE (\cos \theta_1 - \cos \theta_2) \quad \text{-----(1)}$$

When  $\theta_1 = 90^\circ$  and  $\theta_2 = \theta$ , then  $W = U$

$$\Rightarrow U = pE (\cos 90^\circ - \cos \theta) = pE (0 - \cos \theta) = -pE \cos \theta$$

$$\Rightarrow u(\theta) = -\vec{p} \cdot \vec{E}$$

(ii) (a) When  $\theta = 0^\circ$ ,  $U = -pE \cos 0 = -pE$

In this case P.E. is minimum hence it is the orientation of stable equilibrium.

(b) When  $\theta = 180^\circ$ ,  $U = -pE \cos 180 = +pE$

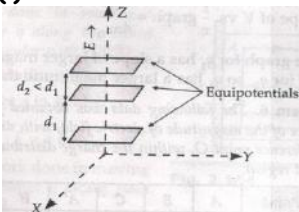
In this case P.E. is maximum hence it is the orientation of unstable equilibrium.

- 179 (i) Draw 3 equipotential surfaces corresponding to a field that uniformly increases in magnitude but remains constant along z-direction.

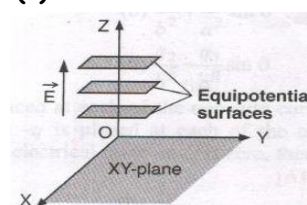
CBSE (AI)-2016,2009,(F)-2008

(ii) How are these surfaces different from that of a constant electric field along z- direction ?

[Ans. (i)



(ii)

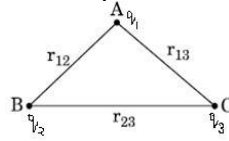


**Difference :** In the first case, as the magnitude of field increases, equipotential surfaces get closer  
In the second case, equipotential surfaces are equidistant planes parallel to XY planes

## PHYSICS CLASS-XII -ELECTROSTATICS

180. (i) Derive an expression for electric potential energy of a system of two point charges.

(ii) Three point charges  $q_1$ ,  $q_2$  and  $q_3$  are kept respectively at points A, B and C as shown in the figure. Derive the expression for the electric potential energy of the system. **CBSE (AI)-2015**



[ Ans. Electric potential energy of a system of two point charges :

$$W_1 = 0$$

$$W_2 = V_1 \times q_2 = \left( \frac{1}{4\pi\epsilon_0} \frac{q_1}{r} \right) \times q_2 = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$\Rightarrow U = W_1 + W_2 = 0 + \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

(ii) Electric potential energy of a system of three point charges :

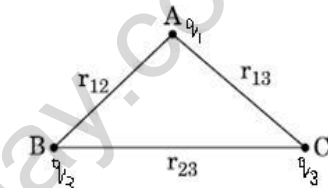
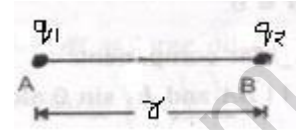
$$W_1 = 0$$

$$W_2 = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}}$$

$$W_3 = \frac{1}{4\pi\epsilon_0} \frac{q_2 q_3}{r_{23}} + \frac{1}{4\pi\epsilon_0} \frac{q_3 q_1}{r_{31}}$$

$$\Rightarrow U = W_1 + W_2 + W_3 = 0 + \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}} + \frac{1}{4\pi\epsilon_0} \frac{q_2 q_3}{r_{23}} + \frac{1}{4\pi\epsilon_0} \frac{q_3 q_1}{r_{31}}$$

$$\Rightarrow U = \frac{1}{4\pi\epsilon_0} \left[ \frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}} \right]$$



181. (i) What is a dielectric ? Give one example.

**CBSE (AI)-2016,(D)-2015,(F)-2006**

(ii) Distinguish with the help of a suitable diagram, the difference in the behaviour of a conductor and a dielectric placed in an external electric field. How does polarized dielectric modify the original external field ?

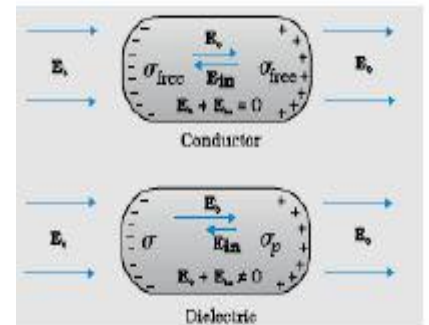
[ Ans. (i) **Dielectric** : Dielectrics are non-conducting substances which allows electric induction to take place through them but do not allow the flow of charge through them.

for example : Air, glass, mica

(ii) **In a conductor**, in the presence of external electric field the free charge carriers move and charge distribution in the conductor adjusts itself in such a way that the net electric field within the conductor becomes zero. i.e.,  $E = 0$

**In a dielectric**, external electric field induces net dipole moment by stretching or re-orienting molecules. The electric field due to this induced dipole moment opposes the external field but does not exactly cancel it. As a result net electric field is reduced.

$$E = E_0 - E_{in} = \frac{E_0}{K}$$



182. Define the term 'dielectric strength'. What does this term signify ? What is its value for (a) air (b) vacuum ? **CBSE (AIC)-2015**

[ Ans. (i) **Dielectric strength** : The maximum electric field that a dielectric medium can withstand without break-down (of its insulating property) is called its dielectric strength.

**Significance** : This signifies the maximum value of electric field, up to which the dielectric can safely play its role

(ii) (a) for air it is about  $3 \times 10^6 \text{ Vm}^{-1}$  (b) for vacuum it is infinity

183. What is electrostatic shielding ? How is this property used in actual practice ? Is the potential in the cavity of a charged conductor zero ? **CBSE (AI)-2016**

[ Ans. **Electrostatic shielding** : Whatever be the charge and field configuration outside, any cavity in a conductor remains shielded from outside electric influence : the field inside the cavity is always zero. This is known as electrostatic shielding.

**Use** : The effect can be made use of in protecting sensitive instruments from outside electrical influence by enclosing them in a hollow conductor.  $\Rightarrow$  Potential inside the cavity is not zero. It is constant

## PHYSICS CLASS-XII -ELECTROSTATICS

184. Using Gauss's law, derive an expression for the electric field intensity due to an infinitely long, straight wire of linear charge density  $\lambda$  C/m.

CBSE (AIC)-2017,(AI)-2007,2006,2005,(D)-2009,04

[ Ans. Charge enclosed by Gaussian surface,  $q = \lambda l$

At the part I and II of Gaussian surface  $\vec{E}$  and  $\hat{n}$  are  $\perp$ , so flux through surfaces I and II is zero.

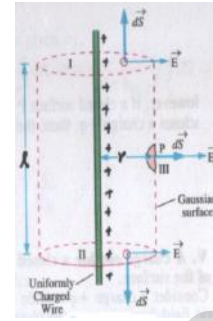
By Gauss's law,  $\oint \vec{E} \cdot \vec{ds} = \frac{q}{\epsilon_0}$

$$\Rightarrow \oint E ds \cos 0 = \frac{q}{\epsilon_0}$$

$$\Rightarrow E \oint ds = \frac{q}{\epsilon_0}$$

$$\Rightarrow E(2\pi r l) = \frac{\lambda l}{\epsilon_0}$$

$$\Rightarrow E = \frac{\lambda}{2\pi\epsilon_0 r}$$



185. Using Gauss's law, obtain the expression for electric field intensity at a point due to an infinitely large, plane sheet of charge of charge density  $\sigma$  C/m<sup>2</sup>. How is the field directed if the sheet is (i) positively charged (ii) negatively charged?

CBSE (AI)-2015,2010,2005,2004,(D)-2012,2009,06,(DC)-2002,01,(F)-2003

[ Ans. Let us consider a Gaussian surface as shown.

At the curved part of Gaussian surface  $\vec{E}$  and  $\hat{n}$  are  $\perp$ , so flux through curved surface is zero.

By Gauss's law,  $\oint \vec{E} \cdot \vec{ds} = \frac{q}{\epsilon_0}$

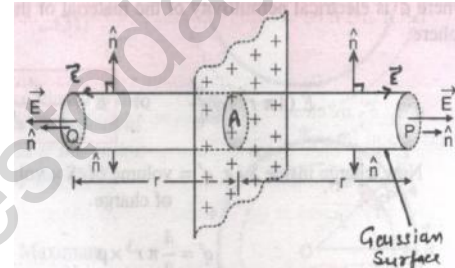
$$\Rightarrow \oint E ds \cos 0 = \frac{q}{\epsilon_0}$$

$$\Rightarrow E \oint ds = \frac{q}{\epsilon_0}$$

$$\Rightarrow E(2A) = \frac{q}{\epsilon_0}$$

$$\Rightarrow E = \frac{q}{2\epsilon_0 A} = \frac{\sigma}{2\epsilon_0}$$

**Direction of field :** (i) If the sheet is positively charged the field is directed away from it  
(ii) If sheet is negatively charged the field is directed towards it



186. Using Gauss's law, deduce the expression for the electric field due to uniformly charged spherical conducting shell of radius  $R$  at a point (i) outside and (ii) inside the shell.

Plot a graph showing variation of electric field as a function of  $r > R$  and  $r < R$ .

CBSE (AI)-2015,2013,2007,2004,(D)-2011,2009,2008,2006,2004

[ Ans. (i) Outside the shell ( $r > R$ )

Let us consider the Gaussian surface as shown

by Gauss's law,  $\oint \vec{E} \cdot \vec{ds} = \frac{q}{\epsilon_0}$

$$\Rightarrow \oint E ds \cos 0 = \frac{q}{\epsilon_0}$$

$$\Rightarrow E \oint ds = \frac{q}{\epsilon_0}$$

$$\Rightarrow E(4\pi r^2) = \frac{q}{\epsilon_0}$$

$$\Rightarrow E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

(ii) Inside the shell ( $r < R$ )

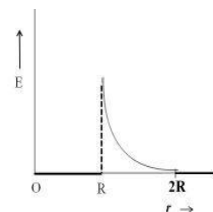
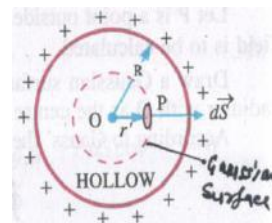
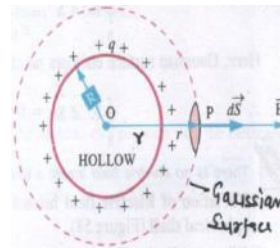
Let us consider the Gaussian surface as shown

By Gauss's law

$$\oint \vec{E} \cdot \vec{ds} = \frac{q}{\epsilon_0}$$

But, charge inside the spherical shell, i.e.,  $q = 0$

$$\Rightarrow \oint E ds \cos 0 = 0 \quad \Rightarrow E = 0$$



## PHYSICS CLASS-XII -ELECTROSTATICS

187. What is a capacitor? Deduce an expression for the capacitance of a parallel plate capacitor with air as the medium between the plates.

CBSE (F)-2017,2006,(AI)-2003,2001,(DC)-2005,2004

[ Ans. **Capacitor** : It is an arrangement required to increase the capacity of a conductor so that a large amount of charge can be stored in it without changing its dimensions

**Capacitance of || plate capacitor** : let us consider a parallel plate capacitor filled with a medium of dielectric constant  $K$  as shown

Electric field between the plates

$$E = \frac{\sigma}{\epsilon_0 K} = \frac{q}{\epsilon_0 KA}$$

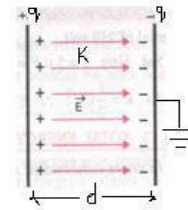
⇒ potential difference between the plates

$$V = E d = \frac{q d}{\epsilon_0 KA}$$

$$\Rightarrow C = \frac{q}{V} = \frac{q}{\frac{q d}{\epsilon_0 KA}} = K \frac{\epsilon_0 A}{d}$$

If air is as the medium between the plates then,  $K = 1$

$$\Rightarrow C_0 = \frac{\epsilon_0 A}{d}$$



188. A dielectric slab of thickness 't' is introduced without touching between the plates of a parallel plate capacitor separated by a distance 'd' ( $t < d$ ). Derive an expression for the capacitance of the capacitor.

[ Ans. Electric field between the plates in air

$$E_0 = \frac{q}{\epsilon_0 A}$$

Electric field in dielectric slab

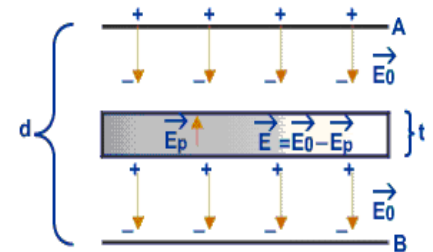
$$E = E_0 - E_p = E_0 - \frac{\sigma_p}{\epsilon_0} = \frac{E_0}{K} = \frac{q}{\epsilon_0 KA}$$

⇒ potential difference between the plates

$$V = E_0 (d - t) + \frac{E_0}{K} t = E_0 \left[ (d - t) + \frac{t}{K} \right] = \frac{q}{\epsilon_0 A} \left[ (d - t) + \frac{t}{K} \right]$$

$$\Rightarrow C = \frac{q}{V} = \frac{q}{\frac{q}{\epsilon_0 A} \left[ (d - t) + \frac{t}{K} \right]}$$

$$\Rightarrow C = \frac{\epsilon_0 A}{(d - t) + \frac{t}{K}}$$



CBSE (AIC)-2005,2001

189. Why does the capacitance of a parallel plate capacitor increase on introduction of a dielectric in between its plates ?

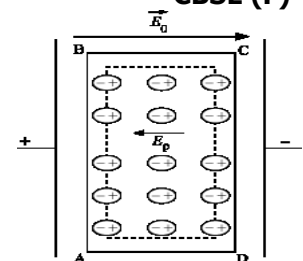
[ Ans. Due to dielectric polarization, an electric field is induced in the dielectric opposite to external electric field. Hence net electric field decreases to

$$E = E_0 - E_{in} = E_0 - \frac{\sigma_p}{\epsilon_0} = \frac{E_0}{K}$$

It reduces potential difference to  $V = E d = \frac{E_0}{K} d = \frac{V_0}{K}$

$$\Rightarrow C = \frac{q_0}{V} = \frac{q_0}{V_0/K} = K \left( \frac{q_0}{V_0} \right) = K C_0$$

Hence capacitance increases K times



CBSE (F)-2006

## PHYSICS CLASS-XII -ELECTROSTATICS

190. A slab of material of dielectric constant  $K$  has the same area as that of the plates of a parallel plate capacitor but has the thickness  $3d/4$ , where  $d$  is the separation between the plates. Find out the expression for its capacitance when the slab is inserted between the plates of the capacitor. **CBSE (F)-2017,2010,(AI)-2013,NCERT-2017**

[ Ans.  $V = E_0 (d - t) + \frac{E_0}{K} t = E_0 \left[ (d - 3d/4) + \frac{3d/4}{K} \right] = \frac{E_0 d}{4} \left( 1 + \frac{3}{K} \right) = \frac{V_0}{4} \left( \frac{K+3}{K} \right)$

$$C = \frac{q_0}{V} = \frac{q_0}{\frac{V_0}{4} \left( \frac{K+3}{K} \right)} = \frac{4K}{(K+3)} \frac{q_0}{V_0} = \frac{4K}{(K+3)} C_0$$

191. Prove that the total electrostatic energy stored in a parallel plate capacitor is  $\frac{1}{2} C V^2$ . Hence derive an expression for energy density of the capacitor. How does the stored energy change if air is replaced by medium of dielectric constant 'K'? **CBSE (AI)-2015,2012,2008,2002,(F)-2013,2006,(D)-2006,2002**

[ Ans. **Energy stored in a capacitor** : When a capacitor is charged by a battery, work is done by the battery at the expense of its chemical energy. This work done is stored between the plates as electrostatic potential energy

Small work done in giving a charge  $dq$

$$dW = V \times dq = \frac{q}{C} dq$$

⇒ Total work done in giving a charge  $Q$  to the capacitor

$$W = \frac{1}{C} \int_0^Q q dq = \frac{1}{C} \left[ \frac{q^2}{2} \right]_0^Q = \frac{Q^2}{2C}$$

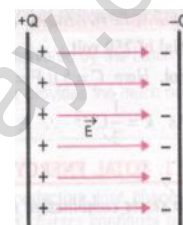
⇒  $U = \frac{Q^2}{2C} = \frac{(CV)^2}{2C} = \frac{1}{2} C V^2$

**Energy density:**  $u = \frac{U}{\text{Volume}} = \frac{\frac{1}{2} C V^2}{A d} = \frac{\frac{1}{2} \left( \frac{\epsilon_0 A}{d} \right) (Ed)^2}{A d} = \frac{1}{2} \epsilon_0 E^2$

⇒  $u = \frac{1}{2} \epsilon_0 E^2$

If air is replaced by a medium of dielectric constant  $K$  then

$$U' = \frac{1}{2} C' (V')^2 = \frac{1}{2} K C \left( \frac{V}{K} \right)^2 = \frac{1}{2} \frac{C V^2}{K} = \frac{U}{K}$$



192. Three capacitors of capacitances  $C_1, C_2$  &  $C_3$  are connected (a) in series (b) in parallel. Show that the energy stored in the series combination is the same as that in the parallel combination. **CBSE (AI)-2003**

[ Ans. (i) In series,  $U_s = \frac{Q^2}{2C_s} = \frac{1}{2} Q^2 \left( \frac{1}{C_s} \right) = \frac{1}{2} Q^2 \left( \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) = \frac{1}{2} \frac{Q^2}{C_1} + \frac{1}{2} \frac{Q^2}{C_2} + \frac{1}{2} \frac{Q^2}{C_3}$

⇒  $U_s = U_1 + U_2 + U_3$

(ii) In parallel,  $U_p = \frac{1}{2} C_p V^2 = \frac{1}{2} (C_1 + C_2 + C_3) V^2 = \frac{1}{2} C_1 V^2 + \frac{1}{2} C_2 V^2 + \frac{1}{2} C_3 V^2$

⇒  $U_p = U_1 + U_2 + U_3$

193. A network of four capacitors each of  $10 \mu F$  capacitance is connected to a  $500 V$  supply as shown in the figure. Determine the - **CBSE (AI)-2015**

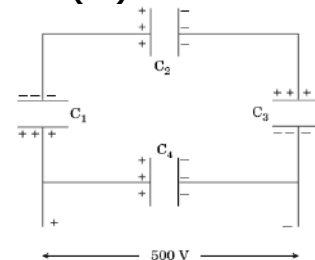
(i) equivalent capacitance of the network and (ii) charge on each capacitor

[ Ans. (i)  $\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{10} + \frac{1}{10} + \frac{1}{10} = \frac{3}{10} \Rightarrow C' = \frac{10}{3} \mu F$

⇒ equivalent capacitance,  $C = C' + C_4 = \frac{10}{3} + 10 = \frac{40}{3} \mu F$

(ii) charge on  $C_4$ ,  $q_4 = C_4 \times V = 10 \times 10^{-6} \times 500 = 5 \times 10^{-3} C$

$q_1 = q_2 = q_3 = C' \times V = \frac{10}{3} \times 10^{-6} \times 500 = \frac{5}{3} \times 10^{-3} C$



## PHYSICS CLASS-XII -ELECTROSTATICS

194. Find the equivalent capacitance of the network shown in the figure, when each capacitor is of  $1 \mu F$ . When the ends X and Y are connected to a  $6 V$  battery, find out (i) the charge and (ii) energy stored in the network.

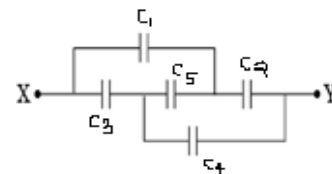
[ Ans.  $\frac{C_1}{C_2} = \frac{C_3}{C_4} \Rightarrow \frac{1}{1} = \frac{1}{1}$

this is the condition of balance so there will be no current in  $C_5$

Now  $C_1$  &  $C_2$  are in series  $\Rightarrow C_{12} = \frac{C_1 C_2}{C_1 + C_2} = \frac{1 \times 1}{1 + 1} = 1/2 \mu F$

$C_3$  &  $C_4$  are in series,  $\Rightarrow C_{34} = \frac{C_3 C_4}{C_3 + C_4} = \frac{1 \times 1}{1 + 1} = 1/2 \mu F$

$\Rightarrow C = C_{12} + C_{34} = \frac{1}{2} + \frac{1}{2} = 1 \mu F$



CBSE (AI)-2015,(AIC)-2003,(D)-2001

$\Rightarrow$  (i)  $q = CV = 1 \times 6 = 6 \mu C$  (ii)  $U = \frac{1}{2} qV = \frac{1}{2} \times 6 \times 10^{-6} \times 6 = 31 \times 10^{-6} J$

195. Given the components of an electric field as  $E_x = \alpha x$ ,  $E_y = 0$  and  $E_z = 0$ , where  $\alpha$  is dimensional constant. Calculate the flux through the cube of side 'a' as shown in the figure and the effective charge inside the cube.

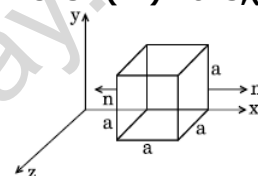
CBSE (AI)-2015,(F)-2012

[ Ans. (i)  $\phi = \phi_L + \phi_R = E_x ds \cos 180 + E_x ds \cos 0$

$\Rightarrow \phi = (\alpha a) a^2 (-1) + [\alpha (a + a)] a^2 (1) = -\alpha a^3 + 2\alpha a^3$

$\Rightarrow \phi = \alpha a^3$

(ii)  $\phi = \frac{q}{\epsilon_0} \Rightarrow q = \epsilon_0 \phi = \epsilon_0 \alpha a^3$



196. Given a uniform electric field  $\mathbf{E} = 6 \times 10^3 \hat{i}$  N/C, Find the flux of this field through a square of  $10 \text{ cm}$  on a side whose plane is parallel to Y-Z plane. What would be the flux through the same square if the plane makes a  $30^\circ$  angle with the x- axis?

CBSE (D)-2014

[ Ans. Given :  $\mathbf{E} = 6 \times 10^3 \hat{i}$  N/C,  $a = 10 \text{ cm} = 10 \times 10^{-2} \text{ m}$ ,  $\phi = ?$

In first case,  $\phi = E ds \cos 0 = 6 \times 10^3 \times (10 \times 10^{-2})^2 = 60 \text{ N m}^2/\text{C}$

In second case,  $\phi = E ds \cos(90 - 30) = E ds \cos 60 = 6 \times 10^3 \times (10 \times 10^{-2})^2 \times \frac{1}{2} = 30 \text{ N m}^2/\text{C}$

197. Two point charges  $4 \mu C$  and  $+1 \mu C$  are separated by a distance of  $2 \text{ m}$  in air. Find the point on the line-joining charges at which the net electric field of the system is zero.

CBSE (AIC)-2017

[Ans.  $\frac{1}{4\pi\epsilon_0} \frac{q_1}{r_1^2} = \frac{1}{4\pi\epsilon_0} \frac{q_2}{r_2^2} \Rightarrow \frac{4}{x^2} = \frac{1}{(2-x)^2} \Rightarrow 2(2-x) = x \Rightarrow x = \frac{4}{3} \text{ m}$

198. Two point charges  $20 \times 10^{-6} \text{ C}$  and  $-4 \times 10^{-6} \text{ C}$  are separated by a distance of  $50 \text{ cm}$  in air. Find-

(i) the point on the line joining the charges, where the electrostatic potential is zero.

(ii) calculate the electrostatic potential energy of the system.

CBSE (AI)-2008

[Ans. (i)  $\frac{1}{4\pi\epsilon_0} \frac{q_1}{r_1} + \frac{1}{4\pi\epsilon_0} \frac{q_2}{r_2} = 0 \Rightarrow \frac{20 \times 10^{-6}}{x} + \frac{-4 \times 10^{-6}}{(50-x)} = 0 \Rightarrow \frac{20}{x} = \frac{4}{(50-x)} \Rightarrow x = \frac{250}{6} = 41 \text{ cm}$

(ii)  $U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} = -9 \times 10^9 \times \frac{20 \times 10^{-6} \times 4 \times 10^{-6}}{50 \times 10^{-2}} = -1.44 \text{ J}$

## PHYSICS CLASS-XII -ELECTROSTATICS

199. Show that if we connect the smaller and the outer sphere by a wire, the charge  $q$  on the former will always flow to the latter, independent of how large  $Q$  is.

CBSE (F)-2015,(AI)-2009

[Ans. Potential at a point on the inner sphere

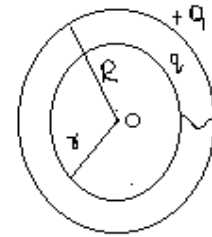
$$V_1 = \frac{1}{4\pi\epsilon_0} \frac{q}{r} + \frac{1}{4\pi\epsilon_0} \frac{Q}{R}$$

Potential at a point on the spherical shell

$$V_2 = \frac{1}{4\pi\epsilon_0} \frac{q}{R} + \frac{1}{4\pi\epsilon_0} \frac{Q}{R}$$

$$\Rightarrow V_1 - V_2 = \frac{1}{4\pi\epsilon_0} \left[ \frac{q}{r} - \frac{Q}{R} \right] = \frac{q}{4\pi\epsilon_0} \left[ \frac{R-r}{rR} \right]$$

$$\Rightarrow V_1 - V_2 > 0 \Rightarrow V_1 > V_2, \text{ hence the charge will flow from inner sphere to outer shell ]}$$



199\*. Calculate the work done to dissociate the system of three charges placed on the vertices of an equilateral triangle of side 10 cm as shown in figure. Here  $q = 1.6 \times 10^{-10} \text{ C}$ .

CBSE (AI)-2016,2013, (D)-2008

[ Ans. Required work done = - potential energy of the system

$$W = -\frac{1}{4\pi\epsilon_0} \left[ \frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}} \right] = -\frac{1}{4\pi\epsilon_0} \left[ \frac{q(-4q)}{a} + \frac{(-4q)(2q)}{a} + \frac{q(2q)}{a} \right]$$

$$\Rightarrow W = -\frac{1}{4\pi\epsilon_0} \left[ -\frac{4q^2}{a} - \frac{8q^2}{a} + \frac{2q^2}{a} \right] = +\frac{1}{4\pi\epsilon_0} \frac{10q^2}{a}$$

$$\Rightarrow W = 9 \times 10^9 \frac{10 \times (1.6 \times 10^{-10})^2}{10 \times 10^{-2}} = 2.304 \times 10^{-8} \text{ J}$$

