11 Electrostatics

Electric Charge

- Like mass, the electric charge is also fundamental and intrinsic property of matter.
- Electric Charge is scalar quantity. It has two types

  (i) Positive Charge (ii) Negative charge
- If electron is removed from the body, it becomes positively charged and its mass is slightly decreased.
- When the body gain the electron, it becomes negatively charged and mass is slightly increased.
- The change in mass of the body = $nm_e = \frac{Q}{e} m_e$.

$$\text{Where } m_e = 9.1 \times 10^{-31} \text{ kg.}$$

Units of Electric Charge and Relation Between Them

SI Unit $\rightarrow$ Coulomb (C)

CGS Unit $\rightarrow$ 1 Stat C or 1 esu of charge

CGS Unit $\rightarrow$ 1 ab C or 1 emu of charge

Relation : 1 C = 3 × 10^9 Stat C = $\frac{1}{10}$ *ab* C

- Practical units of charge

  (i) amp × hr = 3600 C

  (ii) 1 faraday = 96,500 C
- The smallest unit of electric charge $\rightarrow$ Stat Coulomb
- The biggest unit of electric charge $\rightarrow$ Faraday
- The dimensional formula of electric charge $\rightarrow$ T^1A^1 or Q^1
- The minimum magnitude of electric charge on any body is $e = 1.60217733 \times 10^{-19}$ C. It is known as basic or fundamental charge.
- The number of electrons in 1 C negative charge is $n = 6.25 \times 10^{18}$
- The presence of electric charge can be detected by electroscope

Quantization of electric Charge

Magnitude of all charges found in nature are in integral multiple of a fundamental charge.

$Q = ne$ Where $n =$ integer and $e = 1.6 \times 10^{-19}$ C

- Protons and neutrons consists of fundamental particle known as Quarks.

  It has two types : (i) Up quark $(u) \rightarrow +\frac{2}{3}e$ (ii) Down quark $(d) \rightarrow -\frac{1}{3}e$

- Composition of proton : *uud*

  Composition of neutron : *udd*

- If any body consists n_1 number of proton and n_2 number of electron then total charge on it is $Q = (n_2 \sim n_1)e$

Conservation of Electric Charge

- The algebraic sum of electric charges in an electrically isolated system always remains constant irrespective of any process taking place.
- In every chemical or nuclear reaction, the total charge before and after the reaction remains constant.

  e.g. Pair Production : 2γ rays $\longrightarrow {}_{-1}e^0 + {}_{+1}e^0$

  Nuclear reaction : ${}_{92}\text{U}^{238} \rightarrow {}_{90}\text{Th}^{234} + {}_{2}\text{He}^4$

  ${}_0n^1 \rightarrow {}_1P^1 + {}_{-1}e^0$

Electrostatic Induction :

Body can be charged by the following methods :

(1) By Friction :

When two bodies are rubbed together, equal and opposite charges are produced on both the bodies.

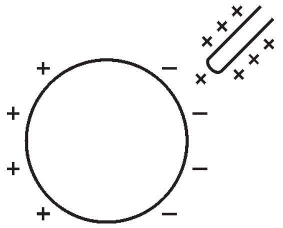
- In the method of Friction, when an electron is transfer from one body to another body, the body which loss the electron becomes positively charged and its mass is reduced. While the body which gain the electron becomes negatively charged and its mass is increased.
- The pair of charged body :

  FGW *PASER*
  (+) (−)

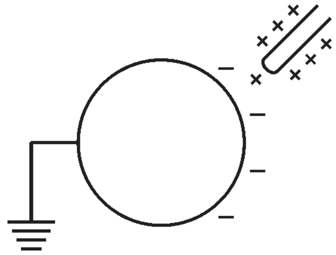
- *F* = Fur, *G* = Glass, *W* = Wool
- *P* = Plastic, *A* = Amber, *S* = Silk, *E* = Ebonite,
  R = Rubber

(2) By Induction :

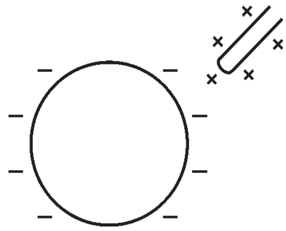
If a charged body is brought near a neutral body, opposite charge is induced at the near end and similar charge at the farther end on neutral body.



Charging substance brought near to uncharged substance



Charged substance connected to the Earth (Earthing)



Disconnecting charged substance from the earth

- Maximum induced charge $Q' = \pm Q\left[1-\frac{1}{K}\right]$ Where $K =$ di-electric constant of chargeless substance.

(3) By Conduction :

When two identical bodies, one of them is charged and the other is neutral, brought in contact, the charge is distributed half-half on them. Hence the neutral body is charged.

- If the two sphere of radius R_1 and R_2 and total charge Q, brought in contact and then separate the charge on them is :

$$q_1 = \frac{QR_1}{R_1+R_2} \text{ and } q_2 = \frac{QR_2}{R_1+R_2}$$

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(1) A copper sphere of mass 2.0 g contains about 2×10^{22} atoms. The charge on the nucleus of each atom is 29e. If the charge on sphere is $+2\mu C$ then fraction of electrons removed is ______.

(A) 5.8×10^{23} (B) 1.25×10^{13} (C) 6.28×10^{23} (D) 2.16×10^{-11}

(2) A substance of mass 1 g consists of 5×10^{21} molecules. If from 0.01 % molecules of the substance 1 electron is removed, then total electric charge on the substance is ______ C.

(A) + 0.08 (B) + 0.8 (C) – 0.08 (D) – 0.8

(3) Total charge on 75 kg electrons is ______ C.

(Mass of electron, $m_e = 9 \times 10^{-31}$ kg)

(A) -1.25×10^{13} (B) -6.25×10^{18} (C) -1.33×10^{13} (D) -1.6×10^{19}

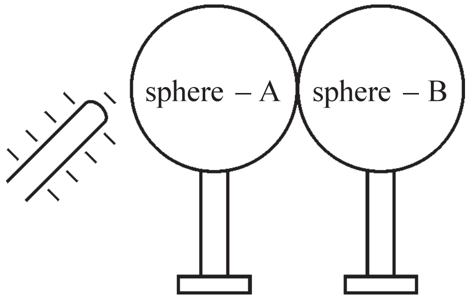
(4) Calculate negative charge in 100 *g* of water.

(A) 1.33×10^{13} C (B) 5.34×10^{6} C (C) 6.25×10^{18} C (D) 2.55×10^{8} C

(5) If 10^{10} electrons are incident on a substance per second, then what time would be taken by it to get total 1 C electric charge ?

(A) 20 Days (B) 20 Years (C) 2 Hours (D) 2 Days

(6) Two chargeless sphere A and B are in contact with each other. As shown in figure, a negatively charged rod is brought near without contact to sphere. Now, if sphere A and B are slightly separated and the rod is removed, the charge on sphere A and sphere B is ________ .



(A) positive and positive
(B) A Positive and B Negative
(C) Negative and Negative
(D) A Negative and B Positive

(7) Sphere having radius 2 cm has $40\mu C$ charge and other sphere having radius 3 cm has $20\mu C$ charge. If they are connected with a conducting wire, the charge move from sphere of radius 2 cm to sphere of radius 3 cm is ________.

(A) $24\mu C$
(B) $72\mu C$
(C) $16\mu C$
(D) $32\mu C$

Ans. : 1 (D), 2 (A), 3 (C), 4 (B), 5 (B), 6 (B), 7 (C)

Coulomb's Law :

In 1785 a scientist Charles Augustin Coulomb gavea the law to find out the electric force between two point charges.

'The electric force between two stationary point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.'

$$F \propto \frac{q_1 q_2}{r^2} \Rightarrow \boxed{F = k\frac{q_1 q_2}{r^2}}$$

Where k is proportionality constant it is known as Coulomb's constant. Its value depends upon two factors :

(i) Unit system (ii) Medium in which the charge is placed.

- **SI System :** $k = \frac{1}{4\pi \in_0} = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$

  CGS System : $k = 1$

  Where $\in_0$ = permitivity of free space = $8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

- **Another unit of is** $\in_0$ **:** farad / metre

- **Relative Permittivity $(\in_r)$ Or Dielectric Constant (K) :**

Dielectric constant of medium K = $\dfrac{\text{Permittivity of medium } (\in)}{\text{Permittivity of vaccum } (\in_0)}$

$$K = \in_r = \frac{\in}{\in_0}$$

- **Coulomb's Law In Terms of dielectric constant (K) :**

  When two charges are put in a medium, the electric force between them

$$F_m = \frac{1}{4\pi\in}\frac{q_1q_2}{r^2}$$

But $\dfrac{\in}{\in_0} = K \Rightarrow \in = K\in_0$

$$F_m = \frac{1}{4\pi\in_0 K}\frac{q_1q_2}{r^2}$$

Therefore $F_m = \dfrac{F}{K}$

- For Insulator (dielectric substances) $K > 1$ thus, $F_m < F$
- In vacuum $K = 1$, For air $K = 1.0006 = 1$
- For Conductor $K = \infty$

Vector form of Coulomb's law :

- The electric force on q_1 due to q_2 is $\vec{F}_{12} = \dfrac{kq_1q_2}{|\vec{r}_1 - \vec{r}_2|^3}\left(\vec{r}_1 - \vec{r}_2\right)$

- The electric force on q_2 due to q_1 is $\vec{F}_{21} = \dfrac{kq_2q_1}{|\vec{r}_2 - \vec{r}_1|^3}\left(\vec{r}_2 - \vec{r}_1\right)$

Important points of Coulomb's law

- The coulombian force acting between two charges is mutually interactive. The force acting between two charges is equal in magnitude and opposite in direction. The ratio of electric force between charges q_1 and q_2 is 1:1.

- Coulomb's law agrees with Newton's Third law. $\vec{F}_{12} = -\vec{F}_{21}$

- Coulomb's law is applicable for the distance more than 10^{-15} m (nuctear distance) and it can be applied for the point charges only.

- If $q_1q_2 > 0$ then two charges repel each other and if $q_1q_2 < 0$ then they attract each other.
- Charge Q is divided in charges q_1 and q_2 and if the force acting between them is maximum then $q_1 = q_2 = \frac{Q}{2}$.
- When a material medium of dielectric constant K is placed between the charges, the force between them becomes $\frac{1}{K}$ of the force between them in vacuum. $F_m = \frac{F}{K}$
- If a dielectric medium of dielectric constant K and thickness t is partially filled between the charges q_1 and q_2 which are at a distance r then the electric force between them is. $F = \frac{kq_1q_2}{\left(r-t+t\sqrt{K}\right)^2}$
- The coulombian force acting between two charges is not influenced by the presence of a third charge. Hence, the coulombian force is called a two body force.
- If two point charge q_1 and q_2 are separated with medium of thickness $t_1, t_2, ...t_n$ and dielectric constant $K_1, K_2, ...K_n$ respectively then the electric force between them is.

  $$F = \frac{kq_1q_2}{\left[\sum_{i=1}^{n} \sqrt{K_i}\ t_i\right]^2}$$

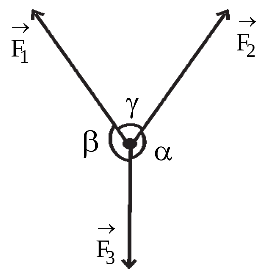
  In above case, if the distance between two charge is taken t then equivalent dielectric constant.

  $$K = \left[\frac{\sum_{i=1}^{n} \sqrt{K_i}\ t_i}{\sum_{i=1}^{n} t_i}\right]^2$$

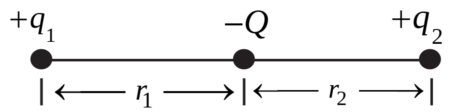
- If the force between two charges at distance r_1 is F_1 and at distance r_2 is F_2 then $F_1r_1^2 = F_2r_2^2$.
- If the force in medium of dielectric constant K_1 is F_1 and in dielectric constant K_2 is F_2 than $F_1K_1 = F_2K_2$.
- If two identical sphere carry charge q_1 and q_2 and force acting between them is F. They are brought in contact and then separated then the force acting between them is $F' = \frac{(q_1+q_2)^2}{4q_1q_2}F$.
- A sphere of mass m, atomic number Z and atomic mass A has electric charge $q = \frac{(\%Ze)\ N_A m}{A}$ where N_A = Avogadro's number

Principle of equilibrium of electric forces :

- To solve some questions of electrostatic, Lami's theorem is very useful. According to this theorem, if three forces are in equilibrium, as shown in figure, it means that $\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$ then,



$$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$$

- 

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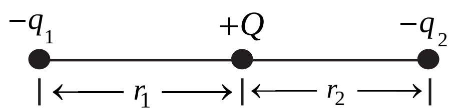


As shown in figure, charges are placed on one line. q_1 and q_2 are like charges while Q is unlike charge then,

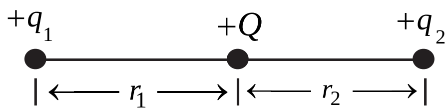
  - When the force on q_1 is zero then $\frac{q_2}{Q} = \frac{(r_1 + r_2)^2}{r_1^2}$

  - When the force on q_2 is zero then $\frac{q_1}{Q} = \frac{(r_1 + r_2)^2}{r_2^2}$

  - When the force on Q is zero then $\frac{q_2}{q_1} = \frac{r_2^2}{r_1^2}$

- If all three charges are like charges then condition for equilibrium of Q is,

$$\boxed{\frac{q_1}{q_2} = \frac{r_1^2}{r_2^2}}$$



- **The magnitude of distance for the same magnitude of force in vacuum and medium**

$$F_{vacuum} = F_{medium}$$

$$\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_0 K}\frac{q_1 q_2}{r'^2}$$

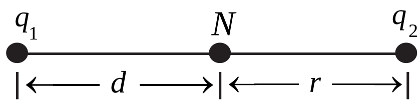
$$\boxed{\Rightarrow r' = \frac{r}{\sqrt{K}}}$$

- **Null points or neutral points due to charge q_1 and q_2 at distance r :**
  - If the neutral point is at the distance d from the charge q_1 then,

$$\boxed{d = \frac{r}{\sqrt{\frac{q_2}{q_1}} \pm 1}} \quad (\text{If } q_2 > q_1)$$

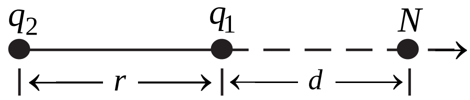
  - If both the charges are identical then,

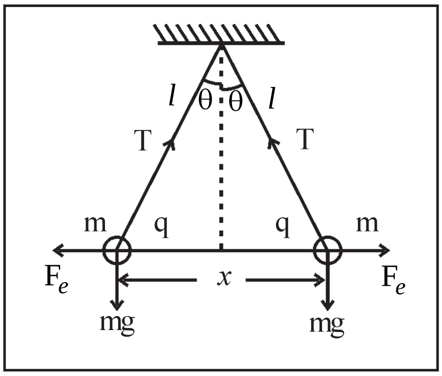
$$d = \frac{r}{\sqrt{\frac{q_2}{q_1}} + 1}$$



  - If both the charges are unidentical then,

$$d = \frac{r}{\sqrt{\frac{q_2}{q_1}} - 1}$$





As shown in figure if the spheres of mass m are charged with charge q then

$$\frac{F_e}{mg} = \tan\theta = \frac{x}{2l}$$

$$\boxed{\therefore\ x = 2l\left(\frac{F_e}{mg}\right) \quad \text{or} \quad x = \left(\frac{2q^2 l}{4\pi \in_0 mg}\right)^{\frac{1}{3}}}$$

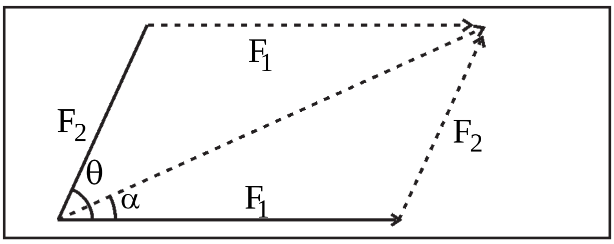
  - If both the spheres are immersed in liquid of density ρ_0 and if the distance between them remains same then the density of the spheres is

$$\rho = \frac{K\rho_0}{K-1}$$

  - If the dielectric constant of liquid is K then,

$$K = \frac{\rho}{\rho - \rho_0}$$

- According to law of parallelogram, the resultant force on a charge due to two electric charges is,



$$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$

where θ = angle between $\vec{F}_1$ and $\vec{F}_2$.

Also $\tan\alpha = \frac{F_2 \sin\theta}{F_1 + F_2\cos\theta}$.

- If $F_1 = F_2 = F'$ then for different angle of θ, magnitude of force is :

Angle θ	**Force F**
0°	$2F'$
30°	$\left(2+\sqrt{3}\right)^{\frac{1}{2}} F'$
45°	$\left(2+\sqrt{2}\right)^{\frac{1}{2}} F'$
60°	$\sqrt{3}\,F'$
90°	$\sqrt{2}\,F'$
120°	F'
150°	$\left(2-\sqrt{3}\right)^{\frac{1}{2}} F'$
180°	0

Principle of Superposition

The electric force on electric charge due to system of n charges is,

$$\vec{F}_i = kq_i \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{q_j}{|\vec{r}_i - \vec{r}_j|^3} \cdot \left(\vec{r}_i - \vec{r}_j\right)$$

Specific charge :

The ratio of electric charge and mass $\left(\frac{e}{m}\right)$ is known as specific charge.

- Its SI unit is $C\,kg^{-1}$ and dimensional formula is : $M^{-1}T^{1}A^{1}$ or $M^{-1}Q^{1}$

(i) As the velocity of a particle increases, its charge remains same, but mass of the particle increases. $m = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{C^2}}}$.

So, as velocity increases, the specific charge of the particle decreases.

(ii) Specific charge of electron $\rightarrow -1.76 \times 10^{11}\ C\,kg^{-1}$

Specific charge of proton $\rightarrow 9.580 \times 10^{7}\ C\,kg^{-1}$

Charge densities :

Charge distributed per unit dimension (length, area or volume) is called charge density.

- There are three types of charge densities.

(i) **Linear charge density :** Charge distribution per unit length is known as linear charge density.

$$\lambda_1 = \frac{Q}{l}$$

SI unit $\rightarrow$ Cm^{-1}; Dimensional formula $\rightarrow$ $L^{-1}T^1A^1$

(ii) **Surface charge density :** Charge Distribusion per unit area is known as surface charge density.

$$\sigma_s = \frac{Q}{A}$$

SI unit $\rightarrow$ Cm^{-2}; dimentional formula $\rightarrow$ $L^{-2}T^1A^1$

(iii) **Volume charge density :** Charge distribution per unit volume is known as Volume charge density.

$$\rho_v = \frac{Q}{V}$$

SI unit $\rightarrow$ Cm^{-3}; Dimensional formula $\rightarrow$ $L^{-3}T^1A^1$

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(8) The distance between two ions of same positive charge is $5\mathring{A}$ and electric force acting on them is 3.7×10^{-9} N, then electron loss by each ion is ______________.

(A) 2 (B) 3 (C) 1 (D) 4

(9) The earth and moon has same type of and equal magnitude of charges. To balance the gravitational force between earth and moon, the required magnitude of charge is ______________.

$[M_e = 6 \times 10^{24}$ kg, $M_m = 7.36 \times 10^{22}$ kg $]$

(A) $1/5.7 \times 10^{-13}$ C (B) 5.7×10^{13} AbC

(C) 5.7×10^{13} C (D) 5.7×10^{13} Stat C

(10) $+q$ and $-q$ charges are put on diametric end points of circle of diameter d, then the force on third charge $+q$ which is on the center of circle is ______________.

(A) $\frac{8Kq^2}{d^2}$ (B) $\frac{2Kq^2}{d^2}$ (C) $\frac{4Kq^2}{d}$ (D) 0

(11) If two unlike charge of same magnitude are placed at certain distance the force between them is F. If 25 % electric charge is moved from one charge to another charge then the force between them is ______________.

(A) F (B) $\frac{4}{5}$F (C) $\frac{15F}{16}$ (D) $\frac{9}{16}$F

(12) Two point charges placed at distance of 20 cm in air attracts each other with certain force. When a dielectric slab of thickness 8 cm and dielectric constant K is introduced between these two charges force of interaction becomes half of its previous value. Then the magnitude of K is ______.

(A) 1 (B) 4 (C) $\sqrt{2}$ (D) 2

(13) Two particles of mass 5 g and charge 10^{-7} C are placed on horizontal table at distance 10 cm. When both the particle are in equilibrium position, the co-efficient of static friction μ_s = ______.

(A) 0.15 (B) 0.19 (C) 0.18 (D) 0.2

(14) Two point charges q and $2q$ are placed in air at distance d. If third electric charge Q is kept on the line joining two charges such that the resultant force on q and $2q$ becomes zero, then the distance of charge Q from charge q is ______.

(A) $\dfrac{d}{\sqrt{2}-1}$ (B) $\left(\sqrt{2}-1\right)d$ (C) $\dfrac{d}{\sqrt{3}+1}$ (D) $\left(\sqrt{3}+1\right)d$

(15) Two point charges q_1 and q_2 are kept at distance $3\ \text{m}$. If sum of these charges is $20\ \mu\text{C}$ and repulsive force between them is $0.075\ \text{N}$, the magnitude of each charge is ______.

(A) $12\ \mu\text{C},\ 8\ \mu\text{C}$ (B) $14\ \mu\text{C},\ 6\ \mu\text{C}$ (C) $16\ \mu\text{C},\ 4\ \mu\text{C}$ (D) $15\ \mu\text{C},\ 5\ \mu\text{C}$

(16) Positive charge on two conducting spheres is q_1 and q_2. These two spheres are brought close to each other such that after touching each other, they return back to their original positious. How much will be the force between then in new situation ?

(A) Force remains same as before the spheres were in contact.

(B) Force becomes more than before the spheres were in contact.

(C) Force becomes less than before the spheres were in contact.

(D) Becomes zero.

(17) The similar spheres of mass 10^{-3} kg are suspended by silk strings of length 0.5 m. When both the spheres are equally charged, they repel each other at 0.2 m distance, then the electric charge on the each sphere is ______.

(A) 1.53×10^{-3} C (B) 2.15×10^{-6} C (C) 9.43×10^{-8} C (D) 2.36×10^{-6} C

(18) Two balls of same mass and radius are suspended by string of length 1 m. The mass and electric charge on each ball is 15 g and $126\ \mu\text{C}$ respectively. When both the spheres are in equilibrium, the distance between them is 8 cm. Now if the charge on any one ball is reduced up to half then the new distance between them is ______ cm.

(A) 5.3 (B) 6.4 (C) 4.2 (D) 2.5

(19) Two spheres having same charge of $10\ \mu C$ are suspended from a rigid support by a string of length 1 m. In equilibrium, the angle between them is 60^{o} then the tension produced in string is ______________ N.

(A) 18 (B) 0.18 (C) zero (D) 1.8

(20) Charge Q is placed at each of the opposite vertices of a square. Charge q is placed at each of the other two vertices. It the net electric force on Q is zero, then $\frac{Q}{q}$ = ______________.

(A) -1 (B) 1 (C) $-2\sqrt{2}$ (D) $-\frac{1}{\sqrt{2}}$

(21) The distance between two equal charge Q is r. A third charge q is placed on line joining these two charges such that all three charges remains in equilibrium. Then what is the position and magnitude of q ?

(A) $2r, Q$ (B) $\frac{r}{2}, -\frac{Q}{4}$ (C) $\frac{r}{2}, -\frac{Q}{2}$ (D) $2r, 2Q$

(22) In right angled triangle PQR, $\angle PQR = \frac{\pi}{2}$. Also $PQ = 5$ cm and $QR = 10$ cm. 10 nC and 20 nC charges are placed respectively on point P and Q. If, due to this charges, the force acting on $1\ \mu C$ charge placed at point Q is $18\sqrt{x}\ mN$, then x = ______________.

(A) 3 (B) 2 (C) 11 (D) 5

(23) The position vector of two $1\ nC$ charges are $(1, 1, -1)$m and $(2, 3, 1)$m respectively. Then the magnitude of coulombian force between this two charges is ______________.

(A) 10^{-6} N (B) 10^{-3} N (C) 10^{-12} N (D) 10^{-9} N

(24) The specific charge of a steady electron is $1.76 \times 10^{11}\ Ckg^{-1}$. If it move with velocity $v = \frac{c}{2}$ (where c = velocity of light) then its specific charge is ______________ $C\ kg^{-1}$.

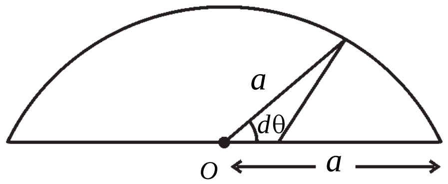
(A) 2.0×10^{11} (B) 1.53×10^{11} (C) Zero (D) 2.6×10^{-15}

(25) The linear charge density on the circumference of a circle of radius a varies as $\lambda = \lambda_0 \cos^2\theta$.

The total charge on it is ______________. $\left[\text{Hint :- } \int_0^{2\pi} \cos^2\theta\ d\theta = \pi\right]$

(A) Infinite (B) Zero (C) $2\pi a$ (D) $\pi a \lambda_0$

(26) As shown in figure the linear charge density on the rim of the semi-circular wire is $\lambda = \alpha\theta$ where $\alpha =$ constant. Then the total charge on a semi-circular wire is ______________.



(A) $\frac{a\alpha\pi}{2}$ (B) $\frac{a\alpha\pi^2}{2}$

(C) $a\alpha\pi$ (D) $\frac{2a\alpha}{\pi^2}$

(27) The charge density on a sphere of radius R is given by equation $\rho(r) = \beta r^2$, then the total charge on the sphere is ______________.

(A) $\frac{2\pi R^3\beta}{3}$ (B) $\frac{4\pi R^3\beta}{3}$ (C) $\frac{4\pi R^5\beta}{5}$ (D) Zero

(28) A square having length a has electric charge distribution of surface charge density $\sigma = \sigma_0 xy$, then total electric charge on the square with respect to the Cartesian Co-ordinate system placed at the centre of the square is ______________.

(A) $\frac{\sigma_0 a^4}{4}$ (B) $4\pi\sigma_0 a^2$ (C) $2\sigma_0 a^2$ (D) Zero

Ans. : 8 (A), 9 (C), 10 (A), 11 (D), 12 (B), 13 (C), 14 (B), 15 (D), 16 (B), 17 (C), 18 (B), 19 (D), 20 (C), 21 (B), 22 (D), 23 (D), 24 (A), 25 (D), 26 (B), 27 (C), 28 (D)

Electric field :

The region of space around a system of electric charge, in which its effect can be experienced, is known as Electric field.

- There are four types of electric field :
  - (i) Uniform electric field : The electric field, at every point of which a unit positive test charge experiences the same electric force, is known as Uniform electric field. In uniform electric field, the lines of force are parallel and equidistant. e.g. Electric field between the plates of a parallel plate condenser.
  - (ii) Non - uniform electric field : The electric field, at different points of which a unit positive test charge experiences different forces, is known as Non-uniform electric field.
  - (iii) Variable electric field : The electric field which changes with respect to time is known as Variable electric field. $E = f(t)$
  - (iv) Constant electric field : The electric field which does not depend on time is known as a Constant electric field. $E \neq f(t)$
- The line integral of electric field along any closed path is zero. i.e. the electric field is a conservative force field. $\oint \vec{E} \cdot \vec{dl} = 0$.

Electric field intensity $(\vec{E})$:

The force acting on a unit positive charge at a given point in an electric field of a point charge of a system at charges is called Electric field or intensity of electric field $(\vec{E})$ at that point.

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0}$$

- Force experienced by a charge q in an electric field of intensity $\vec{F} = q\vec{E}$.
- According to Newton's second law $F = ma$.

  $\therefore\ ma = qE$

  $\therefore\ a = \frac{qE}{m}$

- If charge is in motion in electric field then,
  - Velocity after 't' seconds is $v = v_0 + \left(\frac{qE}{m}\right)t$.
  - Distance travelled in 't' seconds $d = v_0 t + \frac{1}{2}\left(\frac{qE}{m}\right)t^2$
  - Time taken to fall through a height 'h' is $t = \sqrt{\frac{2hm}{qE}}$

Electric field due to a point charge :

By Coulomb's law, $F = \frac{kQq}{r^2}$

$$\therefore\ \frac{F}{q} = \frac{kQ}{r^2}$$

$\therefore$ The electric field due to point charge $\boxed{E = \frac{kQ}{r^2}}$

In vector form, $\boxed{\vec{E} = \frac{kQ}{r^3}\vec{r}}$

- The value of E depends on the magnitude of source charges and distance from that charge.
- The number of electric lines of force passing through unit area imagined around any point in an electric field is defined as Intensity of electric field at that point.

- The electric fiux passing perpendicularly through unit normal area is known as Intensity of electric field. $\vec{E} = \frac{\phi}{\vec{A}}$
- The direction of force acting on unit positive charge at a given point is the direction of electric field at that point.
- SI unit of electric field : (i) NC^{-1} (ii) Vm^{-1}
- Dimensional formula of electric field : $[\vec{E}] = M^1L^1T^{-3}A^{-1}$ or $M^1L^1T^{-2}Q^{-1}$
- A positive charge like alpha-particle, proton and deuteron, experience a force in the direction of electric field and a negative charge like electron experiences a force in a direction opposite to the electric field.
- A charge q_0 is kept in an electric field of strength E and experiences a force F then,

(i) $E < \frac{F}{q_0}$ if field is diverging

(ii) $E = \frac{F}{q_0}$ if field is uniform

(iii) $E > \frac{F}{q_0}$ if field is converging

Electric lines of force :

Scientist Michael Faraday introduced the concept of electric field lines.

- An electric field line is a curve drawn in an electric field in such a way that the tangent to the curve at any point is in the direction of net electric field at that point.

Characteristic of electric field lines :

(1) Electric field lines start from positive charge and end at negative charge.

(2) The tangent drawn at any point on the electric field lines shows the direction of electric field at that point.

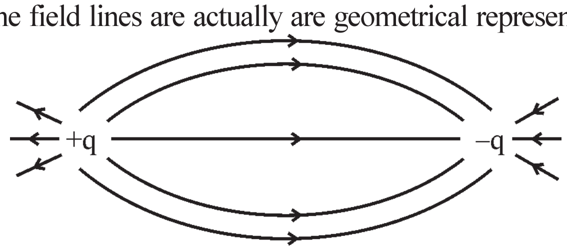
(3) Two field lines never cross each other. If two lines intersect at a point, two tangents can be drawn at that point indicating two directions of electric field at that point which is not possible.

(4) Electric field lines of stationary electric charge distribution do not form closed loops.

(5) The separation of neighbouring field lines in a region at electric field lines indicates the strength of electric field in that region.

(6) Field lines of uniform electric field are mutually parallel and equidistant.

- The electric field lines are geometrical representation of electric field and are not real. But electric field is a reality. The field lines are actually are geometrical representation of electric field.



(29) A coin of mass 1.6 g is placed in an electric field of intensity 10^9 NC^{-1} in vertical direction. For equilibrium of coin, the number of electrons to be removed from the coin is ______________.

(A) 9.8×10^7 (B) 6.25×10^9 (C) 1.6×10^{-19} (D) 4.25×10^{10}

(30) Mass of a bob of simple pendulum is 80 *m*g and the charge on it is $20\ nC$. It is suspended by a string in a horizontal electric field of intensity 2×10^4 NC^{-1}. In equilibrium, the angle made with vertical direction and tension force arising in string is ______________.

(A) $30^\circ,\ 2.4 \times 10^{-2}$ N (B) $45^\circ,\ 1.57 \times 10^{-3}$ N

(C) $27^\circ,\ 8.8 \times 10^{-4}$ N (D) $35^\circ,\ 4.5 \times 10^{-4}$ N

(31) If a particle of mass 1 g and charge $5\ \mu C$ is moved with velocity 20 ms^{-1} in direction opposite of electric field of internsity 2×10^5 NC^{-1} then how much distance is travelled by the particle before coming to rest ?

(A) 1 m (B) 0.4 m (C) 10 cm (D) 0.2 m

(32) Two parallel conducting plates lie at a distance 20 *mm*. Potential of upper plate is +2400 V wrt lower plate. If an electron is released at lower plate then how much time does it take to reach upper plate ?

$$\frac{e}{m} = 1.8 \times 10^{11}\ Ckg^{-1}$$

(A) 2 μs (B) 1.4 ns (C) 1.7 ms (D) 2.7 μs

(33) In Millikan experiment, a drop of charge Q remains stationary between the two plates having 2400 V potential difference. If the radius of drop becomes half and potential difference 600 V then for equilibrium, the charge on drop is ______________.

(A) $\frac{Q}{4}$ (B) $\frac{Q}{2}$ (C) Q (D) $\frac{3Q}{2}$

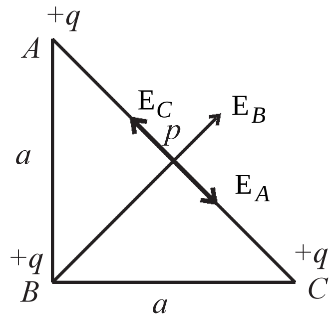
(34) 10^{-8} C and -10^{-8} C charges are placed on any two vertices of equilateral triangle, then the intensity of electric field at third vertix is ______________ NC^{-1}. (length of sides of equilateral triangle is 0.1 m).

(A) 3.6×10^4 (B) 7.2×10^4 (C) 9×10^3 (D) 3×10^9

(35) The length of each side of square PQRS is 5 m. If +50 C, –50 C and +50 C charges are placed at vertices P, R and S respectively then the magnitude and direction of resultant electric field at point Q is ______________. (k = Coulombs, constant)

(A) 3 k, 30° (B) 2 k, 45° (C) 3 k, 25.5° (D) 2 k, 38.5°

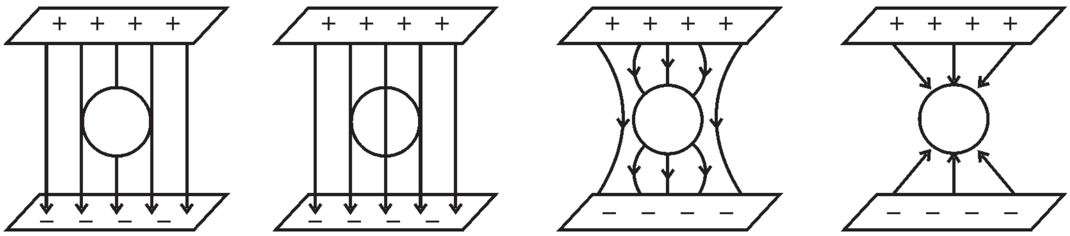
(36) The magnitude of electric field at point P shown in figure is ____________.



(A) $\frac{2kq}{a^2}$ (B) $\frac{kq}{a^2}$

(C) $\frac{3kq}{a^2}$ (D) Zero

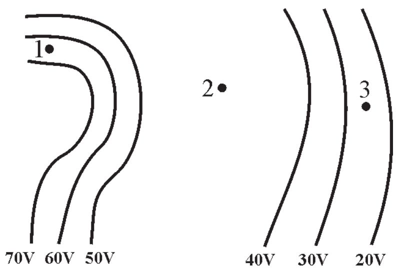
(37) An uncharged sphere of metal is placed in between two charged plates as shown in figure. The lines of force look like.



(a) (b) (c) (d)

(A) *a* (B) *b* (C) *c* (D) *d*

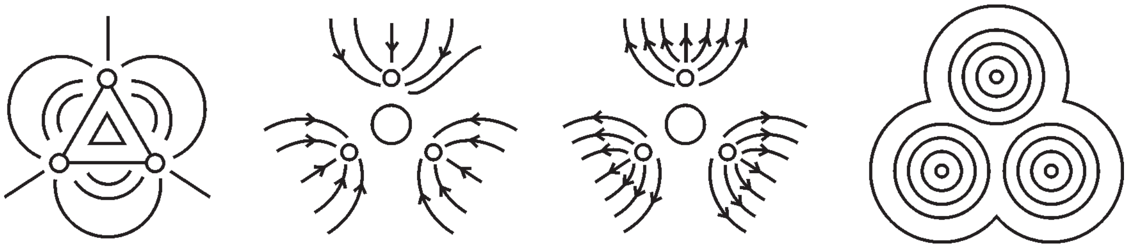
(38) Some equipotential lines are as shown in figure. E_1, E_2 and E_3 are the electric field at point 1, 2 and 3. Then ____________.



(A) $E_1 = E_2 = E_3$ (B) $E_1 > E_2 > E_3$

(C) $E_1 > E_2$, $E_2 < E_3$ (D) $E_1 < E_2 < E_3$

(39) Three positive charges of equal value q are placed at the vertices of an equilateral triangle. Which of the following will be resultant electric field lines ?

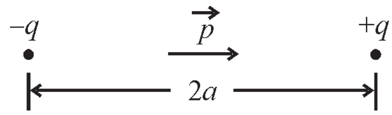


(a) (b) (c) (d)

Ans. : **29 (A), 30 (C), 31 (D), 32 (B), 33 (B), 34 (C), 35 (C), 36 (A), 37 (C), 38 (C), 39 (C)**

Electric Dipole :

A system of two equal and opposite charges, separated by a finite distance is called Electric dipole.



- Electric dipole moment $(\vec{p})$ of the system can be defined as follows :

  $$\vec{p} = q\,2\,\vec{a}$$

- SI unit of electric dipole moment = Cm (coulomb-meter)
- Dimensional formula of dipole moment $[\vec{p}] = \mathrm{L}^1\mathrm{T}^1\mathrm{A}^1$ or $\mathrm{L}^1\mathrm{Q}^1$.
- Electric dipole moment is a vector quantity and its direction is from the negative charge to positive charge.
- The net electric charge on an electric dipole is zero $(-q+q=0)$ but its electric field is not zero, since the position of the two charges is different.
- If lim $q \to \infty$ and 2a $\to$ 0 in $\vec{p} = q\,2\,\vec{a}$, then the electric dipole is called a point dipole.

Electric field of a dipole :

To find out the electric field due to an electric dipole, placed at the co-ordinate system such that its Z-axis coincides with the dipole and origin of the system coincides with the centre of the dipole.

- Electric field at the point on the axis of a dipole is,

  $$\vec{\mathrm{E}}(z) = \frac{2\mathrm{k}pz}{\left(z^2 - a^2\right)^2}\,\hat{p}$$

  If $z >> a$ then a^2 is not considered in denominator,

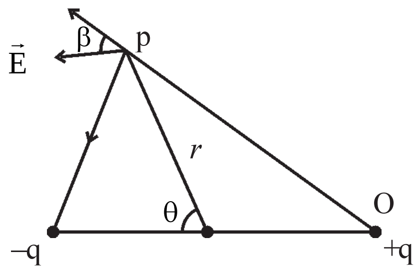
  $$\boxed{\vec{\mathrm{E}}(z) = \frac{2\mathrm{k}p}{z^3}\,\hat{p}}$$

- Electric field at a point on the equator of a dipole is,

  $$\vec{\mathrm{E}}(y) = \frac{-\mathrm{k}p}{\left(y^2 + a^2\right)^{\frac{3}{2}}}\,\hat{p}$$

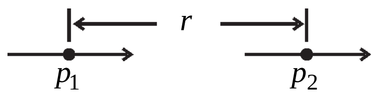
  If $y >> a$ then, $\boxed{\vec{\mathrm{E}}(y) = \frac{-\mathrm{k}p}{y^3}\,\hat{p}}$

- If the point P lies on a line making an angle θ with the axis of the dipole, then the intensity at a point P lying at a distance r from the centre of the dipole is $\mathrm{E} = \frac{\mathrm{k}p}{r^3}\sqrt{3\cos^2\theta + 1}$.

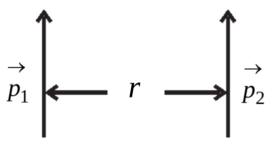


If the direction of $\vec{E}$ is such a way that its makes angle β with OP then $\tan\beta = \frac{1}{2}\tan\theta$.

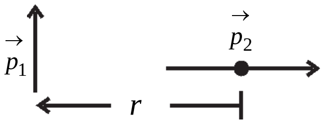
- For short (small) dipole $\frac{E_{axis}}{E_{equater}} = 2$.



- As shown in figure, if $\vec{p_1}$ and $\vec{p_2}$ are placed at distance r then the force between two dipole is $F = \frac{6kp_1p_2}{r^4}$.

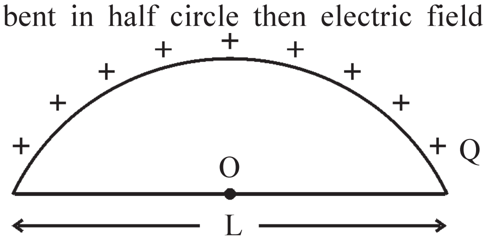


If $\vec{p_1}$ and $\vec{p_2}$ are parallel to each other then electric force $F = \frac{3kp_1p_2}{r^4}$.



If $\vec{p_1}$ and $\vec{p_2}$ are perpendicular to each other then electric force $F = \pm\frac{2kp_1p_2}{r^4}$.

- If a rod of length L and charge Q is bent in half circle then electric field at centre is $E = \frac{Q}{2\epsilon_0 L^2}$.



Torque acting on an electric dipole in a uniform electric field :

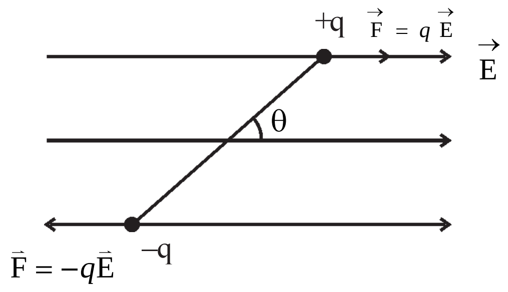
$\vec{\tau} = \vec{p} \times \vec{E}$

$|\vec{\tau}| = pE\sin\theta$

When $\theta = 0^\circ$ or 180° then $\tau = 0$

$\theta = 90^\circ$ then $\tau_{max} = +pE$

$\theta = 270^\circ$ then $\tau_{min} = -pE$



- In uniform electric field, the resultant force is zero. Only torque is experienced.
- In non-uniform electric field, it experience force and torque. When dipole is parallel to electric field, torque is zero. Only force is experienced.

Work required for displacement of dipole in uniform electric field :

- The work done for displacement $d\theta$ of a dipole in uniform electric field is

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

$$\therefore \text{ Total work } W = \int_{\theta_1}^{\theta_2} pE\sin\theta\, d\theta$$

$$\therefore W = pE\left[-\cos\theta\right]_{\theta_1}^{\theta_2}$$

$$\therefore W = -pE\left[\cos\theta_2 - \cos\theta_1\right]$$

$$\therefore \boxed{W = pE\left(\cos\theta_1 - \cos\theta_2\right)}$$

---

(40) Electric field intensity at the centre of electric dipole is ______________.

(A) $\frac{-K\vec{p}}{a^3}$ (B) Infinite (C) Zero (D) $\frac{-2K\vec{p}}{a^3}$

(41) Two electric dipole of same dipole moment 6.2×10^{-3} Ccm are placed on a line in such a way that their axes are is same direction. If the distance between the centre of both dipole is 10^{-8} m, then electric force between them is ______________ N.

(A) 21×10^{39} (B) 2.1×10^{34} (C) 21×10^{-37} (D) 2.1×10^{-17}

(42) A unit positive charge is placed on an axis of electric dipole and its distance from the centre is 0.1 m. It experiences 0.025 N force, when it is placed at 0.2 m distance, the force experienced by it is 0.002 N then the length of dipole is ______________.

(A) 0.05 m (B) 0.2 m (C) 0.1 m (D) 0.4 m

(43) The charge q, q and $-2q$ are placed on a vertices of equilateral triangle ABC. If the length of each side is l then resultant dipole moment of this system is ______________.

(A) $2l$ (B) $2ql$ (C) $\sqrt{3}\,ql$ (D) $4ql$

(44) An electric dipole coincides with X-axis and its midpoint is placed at the origin O. A point P is 20 cm away from the origin and OP makes an angle $\frac{\pi}{3}$ with the x-axis. If the electric field near the point P makes an angle θ with axis, then the magnitude of θ is ______________.

(A) $\frac{\pi}{3}$ (B) $\frac{3\pi}{2}$

(C) $\tan^{-1}\frac{\sqrt{3}}{2}$ (D) $\frac{\pi}{3} + \tan^{-1}\frac{\sqrt{3}}{2}$

(45) An electric dipole having dipole moment $\vec{p} = 10^{-7}\left(5\hat{i} + \hat{j} - 2\hat{k}\right)$ Cm placed in a uniform electric field $\vec{E} = 10^{7}\left(\hat{i} + \hat{j} + \hat{k}\right)$ Vm^{-1} then magnitude of torque is ______________ Nm.

(A) 8.6 (B) 5 (C) 7.6 (D) Zero

(46) An electric dipole placed in a uniform electric field of intensity 4×10^{5} NC^{-1} at angle 60° with the electric field, experiences torque $8\sqrt{3}$ Nm. If length of dipole is 4 cm then magnitude of charge will be ______________.

(A) 3μC (B) 1 mC (C) 2μC (D) 2 mC

(47) Dipole moment of an electric dipole is 2×10^{-8} Cm. The electric field intensity at a point of distance 1 m and make an angle 60° with the centre of dipole is ______________ NC^{-1}.

(A) 300 (B) 238.1 (C) 429.5 (D) 255.2

(48) An electric dipole consists of two opposite charges 1 μC, each separated by a distance 2 cm is placed in an electric field of 10^{5} Vm^{-1}. The work done for rotation of this dipole from equilibrium to 180° is ______________ J.

(A) 4×10^{-3} (B) 2×10^{-3} (C) 10^{-3} (D) 5×10^{-3}

(49) Three point charges $+q$, $-2q$ and $+q$ are situated at points $(0, a, 0)$, $(0, 0, 0)$, $(a, 0, 0)$ respectively. The magnitude and direction of the dipole moment consisting this charges is ______________.

(A) $\sqrt{2}qa$, in $+y$ direction

(B) $\sqrt{2}qa$, In direction of line joining points $(0, 0, 0)$ and $(a, a, 0)$

(C) qa, In the direction of line joining points $(0, 0, 0)$ and $(a, 0, a)$

(D) $\sqrt{2}qa$, in $+x$ direction

(50) An electric dipole consists of charges ±10 μC, each separated by a distance 5 *mm*. The electric field intensity at the points 15 cm distance on axis and 15 cm distance on equator is ______________ NC^{-1}.

(A) 2.66×10^{5}, 1.33×10^{5} (B) 4.4×10^{5}, 2.2×10^{5}

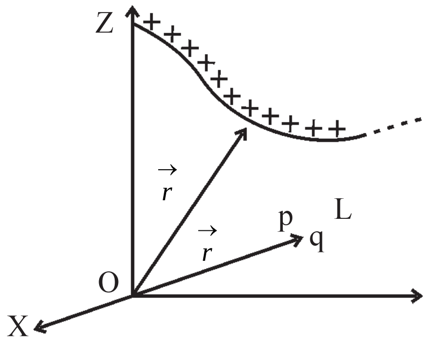
(C) 2.44×10^{5}, 1.22×10^{5} (D) 4.6×10^{5}, 2.3×10^{5}

Ans. : 40 (A), 41 (B), 42 (C), 43 (C), 44 (D), 45 (A), 46 (B), 47 (B), 48 (A), 49 (B), 50 (A)

Continuous distribution of charges :

- The continuous distribution of electric charge can be of three types :

(1) **Linear charge distribution :**

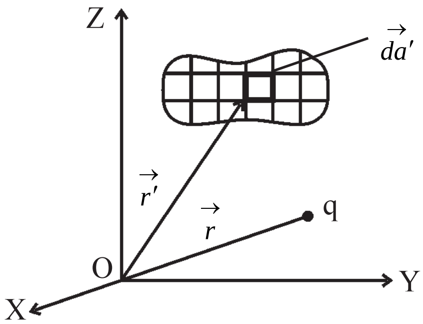


The force acting on a charge due to linear charge distribution is,

$$\vec{F} = kq \int_{l} \frac{\lambda(\vec{r'})\,|\vec{dl'}|}{|\vec{r} - \vec{r'}|^3} \left(\vec{r} - \vec{r'}\right)$$

$$\therefore \text{ Electric field } \vec{E} = k \int_{l} \frac{\lambda(\vec{r'})\,|\vec{dl'}|}{|\vec{r} - \vec{r'}|^3} \left(\vec{r} - \vec{r'}\right)$$

(2) **Surface charge distribution :**

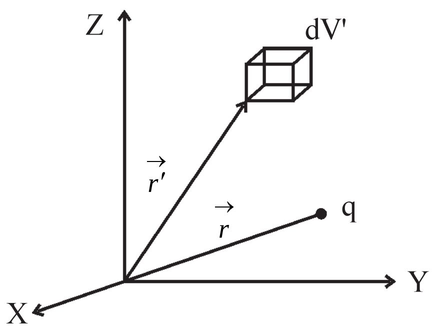


The force acting on a charge due to surface charge distribution is,

$$\vec{F} = kq \int_{s} \frac{\sigma(\vec{r'})\,|\vec{da'}|}{|\vec{r} - \vec{r'}|^3} \left(\vec{r} - \vec{r'}\right)$$

$$\therefore \text{ Electric field } \vec{E} = k \int_{s} \frac{\sigma(\vec{r'})\,|\vec{da'}|}{|\vec{r} - \vec{r'}|^3} \left(\vec{r} - \vec{r'}\right)$$

(3) Volume charge distribution :



The force acting on a charge due to volume charge distribution is,

$$\vec{F} = kq \int_{v} \frac{\rho(\vec{r'})\,dv'}{|\vec{r} - \vec{r'}|^3} \left(\vec{r} - \vec{r'}\right)$$

$$\therefore \text{ Electric field } \vec{E} = k \int_{v} \frac{\rho(\vec{r'})\,dv'}{|\vec{r} - \vec{r'}|^3} \left(\vec{r} - \vec{r'}\right)$$

- A conducting wire of length L carries total charge q which is uniformly distributed on it, then the electric field at a point located on the axis of the wire at a distance a from the nearer end is

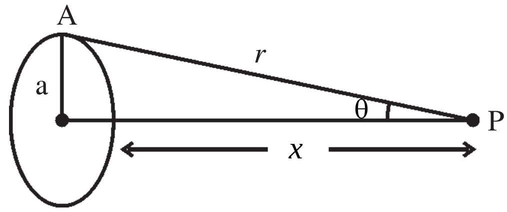
$$E = \frac{1}{4\pi\epsilon_0}\left[\frac{q}{a(L+a)}\right]$$

- An arc of radius r subtends an angle θ at the centre. A charge is distributed over the arc such that the linear charge density is λ . The electric field at the centre is,

$$\vec{E} = \frac{k\lambda}{r}\left[-\sin\theta\,\hat{i} + (\cos\theta - 1)\,\hat{j}\right]$$

- A charge Q is uniformly distributed on the circumference of a circular ring of radius *a*. The electric field at a distance *x* from the centre is,

$$E = \frac{kQx}{\left(a^2 + x^2\right)^{\frac{3}{2}}}$$



- If point P is at very large distance $(x >> a)$ then electric field, $E = \frac{kQx}{\left(0 + x^2\right)^{\frac{3}{2}}} = \frac{kQ}{x^2}$

  Which is a equation of point charge. It shows that at very large distance, the charge on the ring behaves like a point charge.

---

(51) Surface charge density on the surface of charged sphere is 0.7 Cm^{-2}. When the charge increases by 0.44 C the surface charge density is increased by 0.14 Cm^{-2}. The initial charge and radius of the sphere is ______________.

(A) 2 C, 1 m (B) 2.2 C, 0.5 m (C) 1.5 C, 1 m (D) 2.5 C, 0.5 m

(52) 64 small drops of radius 0.02 m and charge $5\,\mu C$ are combined to form one big drop. If the charge is not leak then the ratio of initial and final charge density on the drop is ______________.

(A) 2 : 4 (B) 1 : 2 (C) 1 : 4 (D) 1 : 1

(53) A charged wire is bent in half circle arc of radius *a*. If the linear charge density is λ, then the electric field at the center of arc is ______________.

(A) $\frac{\lambda}{2\pi\epsilon_0 a}$ (B) $\frac{\lambda}{2\pi\epsilon_0 a^2}$ (C) $\frac{\lambda}{4\pi^2\epsilon_0 a}$ (D) Zero

(54) Let there be a spherically symmetric charge distribution with charge density varying as $\rho(r) = \rho_0\left(\frac{5}{4} - \frac{r}{R}\right)$ up to $r = R$ and $\rho(r) = 0$ For $r > R$, where *r* is the distance from the origin. The electric field at a distance r $(r < R)$ from the origin is given by ______________

(A) $\frac{4\rho_0 r}{3\epsilon_0}\left[\frac{5}{4} - \frac{r}{R}\right]$ (B) $\frac{\rho_0 r}{3\epsilon_0}\left[\frac{5}{4} - \frac{r}{R}\right]$ (C) $\frac{4\pi\rho_0 r}{3\epsilon_0}\left[\frac{5}{3} - \frac{r}{R}\right]$ (D) $\frac{\rho_0 r}{4\epsilon_0}\left[\frac{5}{3} - \frac{r}{R}\right]$

(55) The linear charge density on a thin circular ring of radius *r* is $q = q_0\cos\theta$. Here q_0 is constant and θ is angle made in anti clock wise direction by maximum electric charge density from diameter. The electric field at the centre of ring is ______________.

(A) $\frac{q_0}{\epsilon_0 r}$ (B) $\frac{q_0}{4\epsilon_0 r}$ (C) $\frac{q_0}{2\epsilon_0 r}$ (D) $\frac{q_0}{3\epsilon_0 r}$

(56) The radius of thin semi-circular ring is $20\ \text{cm}$. It is uniformly charged with charge $0.7\ \text{nC}$. Then the electric field at the centre of ring is ______________ NC^{-1}.

(A) 10 (B) 75 (C) 50 (D) 125

(57) Charge Q is uniformly distributed on a circumference of ring having radius a. If an electron placed on a centre of ring is displaced very small then it executes simple harmonic motion with frequency f = ______________.

(A) $\frac{1}{2\pi}\sqrt{\frac{Q}{4\pi \epsilon_0 ema^2}}$ (B) $\frac{1}{2\pi}\sqrt{\frac{eQ}{4\pi \epsilon_0 ma^3}}$

(C) $\sqrt{\frac{eQ}{4\pi \epsilon_0 ma}}$ (D) $\sqrt{\frac{Q}{4\pi \epsilon_0 ema^3}}$

(58) A charged wire is bent in the form of a semi circular arc of length 'l'. If the charge on wire is Q then electric field intensity at the centre is ______________ .

(A) $\frac{Q}{2\epsilon_0 l^2}$ (B) $\frac{\pi Q}{4\epsilon_0 l^2}$ (C) $\frac{Q}{4\pi\epsilon_0 l^2}$ (D) $\frac{Q}{4\pi\epsilon_0 l}$

Ans. : 51 (B), 52 (C), 53 (A), 54 (D), 55 (B), 56 (A), 57 (B), 58 (A)

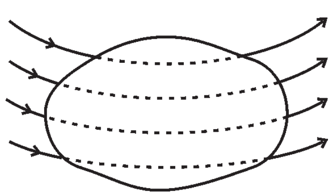
- **Electric flux :**

The concepts of electric flux relates the electric field with its source.

"The flux linked with any surface is the surface integration of the electric field over the given surface."

$$\boxed{\phi = \int_{\text{Surface}} \vec{E} \cdot d\vec{a}}$$

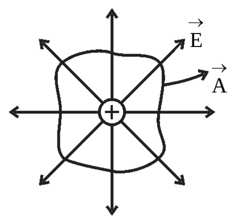
SI unit : (1) Nm^2C^{-1} (2) Vm



$\phi = 0$

Electric field lines (flux) enters in to closed surface is negative and electric field lines (flux) come outer is positive.

$\therefore$ resultant flux $\phi = 0$

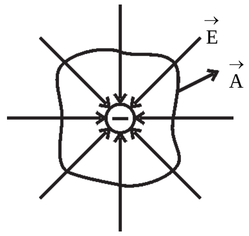


The flux of positive charge

$\phi = EA\cos 0^\circ$

$\phi = EA$

$\phi > 0$ positive flux.

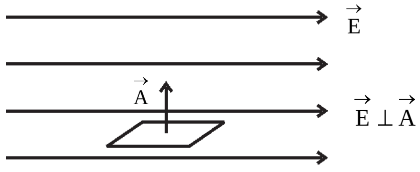


The flux of negative charge

$$\phi = EA\cos 180^\circ$$

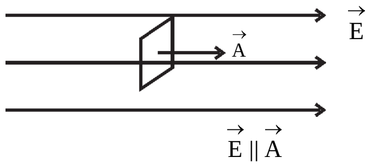
$$\phi = -EA$$

$$\phi < 0 \text{ negative flux.}$$



Flux $\phi = EA\cos 90^\circ$

$$\phi = 0$$

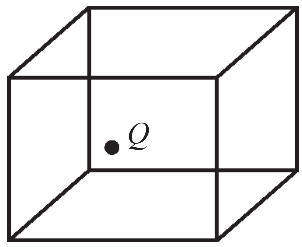


Flux $\phi = EA\cos 0$

$$\phi = EA$$

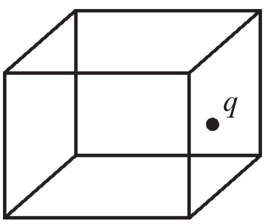
Calculation of flux in different cases :

(1) The charge ***Q*** on center of a cube :



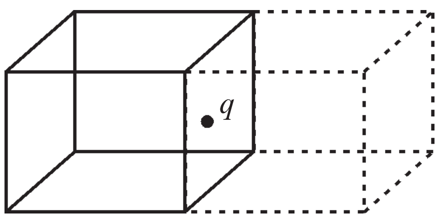
- Total flux $\phi = \dfrac{Q}{\epsilon_0}$
- The flux passing from any one surface $\phi = \dfrac{Q}{6\epsilon_0}$
- The flux passing from any one point of vertices. $\phi = \dfrac{Q}{8\epsilon_0}$
- The flux passing from any one edge $\phi = \dfrac{Q}{12\epsilon_0}$

(2) The charge on centre of any one side of cube :



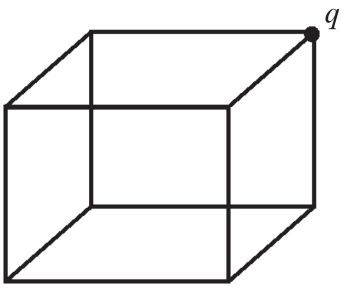
- The flux passing through the system of two cube

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



- The flux passing throgh any one cube $\phi = \dfrac{q}{2\epsilon_0}$
- The flux passing through any one side of cube $\phi = \dfrac{q}{10\epsilon_0}$

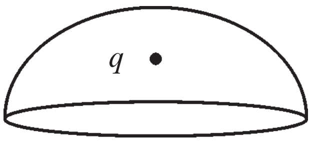
(3) The charge placed on any vertices of cube :



- To consider the charge q on center of cube another seven cube is required.
- Thus the flux passing through the system of eigth cube $\phi = \frac{q}{\epsilon_0}$

$\therefore$ The flux passing through given cube $\phi = \frac{q}{8\epsilon_0}$

- The flux passing through any one side of cube $\phi = \frac{q}{24\epsilon_0}$



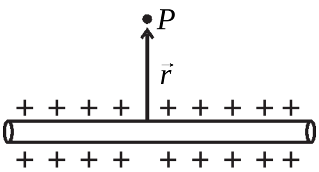
(4) The flux related with the surface of semi-sphere $\phi = \pi r^2 E$

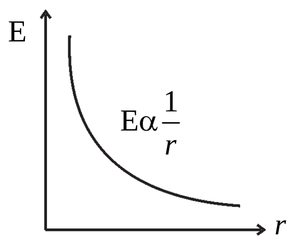
Gauss's Law :

- Gauss's law is one of the fundamental laws of nature.
  "The total electric flux associated with any closed surface is equal to the ratio of the net electric charge enclosed by the surface to ϵ_0"
- Flux associated with any closed surface $\phi = \int \vec{E} \cdot \vec{da} = \frac{\Sigma q}{\epsilon_0}$.
- Gauss's law implies that the total electric flux through a closed surface is zero if no charge is enclosed by the surface.
- Gauss's law is true for any closed surface, no matter what its shape or size.
- The surface that we choose for the application of Gauss's Law is called Gaussian surface.
- Gauss's law is useful towarde a much easier calculation of electric field when system has some symmetry.

Application of Gauss's Law :

(1) Electric field due to linear charge distribution :





- Electric field at distance r due to an infinitely long straight uniformly charged wire,

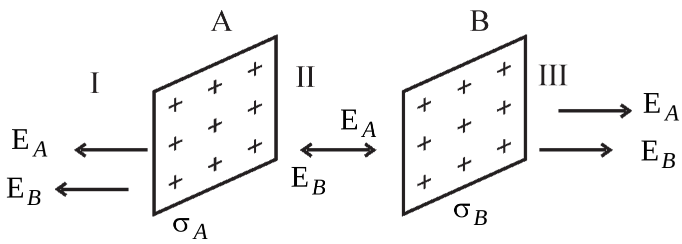
$$\vec{E} = \frac{\lambda}{2\pi\epsilon_0 r}\hat{r} \quad \text{or} \quad \vec{E} = \frac{2k\lambda}{r}\hat{r}$$

Where $\lambda =$ linear charge distribution

(2) Electric field due to a uniformly charged infinite plane sheet :

- Electric field due to a uniformly charged infinite plane sheet is $E = \dfrac{\sigma}{2\in_0}$.
- This electric field is independent of the distance of the point from the plane. It depends only on σ.

(3) Electric fied due to two parallel plane sheet :



For region - I $\quad E = -E_A - E_B = -\dfrac{1}{2\in_0}(\sigma_A + \sigma_B)$

For region - II $\quad E = \dfrac{1}{2\in_0}(\sigma_A - \sigma_B)$

For region - III $\quad E = \dfrac{1}{2\in_0}(\sigma_A + \sigma_B)$

If $\sigma_A = \sigma$ and $\sigma_B = -\sigma$ then,

For region - I $\quad E = 0$

For region - II $\quad E = \dfrac{\sigma}{\in_0}$

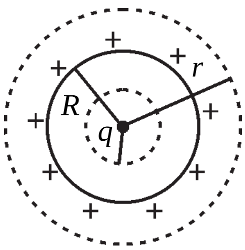
For region - III $\quad E = 0$

Note : I case of conducting metal plate of definite thickness the total charge enclosed $\sum q = 2\sigma A$.

$\therefore$ Electric field $E \cdot 2A = \dfrac{2\sigma A}{\in_0}$

$\therefore \boxed{E = \dfrac{\sigma}{\in_0}}$

(4) Electric Field Due to a unifrom charged Thin Spherical Shell :



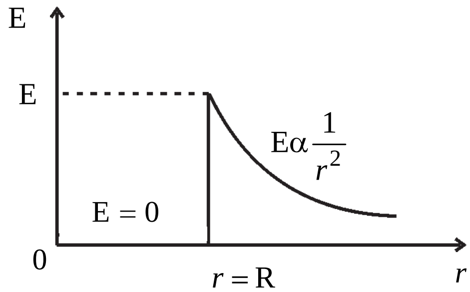
(i) For a point lying Inside a shell

$$\oint \vec{E} \cdot \vec{da} = \frac{\sum q}{\in_0} = 0$$

$$\therefore \vec{E} = 0$$

Thus, electric field inside the charged spherical shell is zero.

(ii) For a point Lying outside the shell :



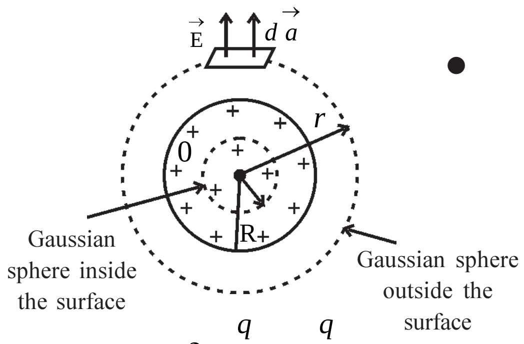
$$E = \frac{1}{4\pi \epsilon_0} \frac{q}{R^2}$$

Put, $q = \sigma A = \sigma 4\pi R^2$

$$E = \frac{1}{4\pi \epsilon_0} \frac{\left(4\pi R^2 . \sigma\right)}{r^2}$$

$$E = \frac{\sigma}{\epsilon_0} \frac{R^2}{r^2}$$

(5) Electric field intensity due to uniformly charged sphere :



$$\rho = \frac{q}{v} = \frac{q}{\frac{4}{3}\pi R^3}$$

- **For point lying inside the sphere :**

Imagine spherical Gaussian surface of radius r' $(r' < R)$ to determine the electric field at a point p' at a distance r'.

$$q' = \frac{4}{3}\pi r'^3 \cdot \rho$$

$$q' = \frac{4}{3}\pi r'^3 \cdot \frac{q}{\frac{4}{3}\pi R^3}$$

$$q' = q \cdot \frac{r'^3}{R^3}$$

The flux linked with the Gaussian surface

$$\int \vec{E} \cdot d\vec{a} = \frac{q'}{\epsilon_0}$$

$$\therefore \ E \cdot 4\pi r'^2 = \frac{r'^3}{R^3 \epsilon_0} q$$

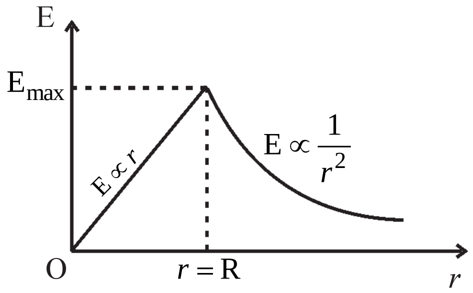
$$\therefore \boxed{E = \frac{q}{4\pi \epsilon_0} \cdot \frac{r'}{R^3}}$$

Putting the value of q,

$$\boxed{E = \frac{\rho r'}{3\epsilon_0}} \quad \text{Thus, } E \propto r'.$$

- **For point lying outside the sphere :**

  Consider a Gaussian surface of radius r $(r > R)$,



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

$$\therefore \ E \cdot 4\pi r^2 = \frac{q}{\epsilon_0}$$

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

---

(59) A hollow cylinder of radius 1 cm is placed in a uniform electric field of magnitude $\vec{E} = 2\times10^4\ NC^{-1}$ in such a way that its axis is parallel to electric field, then flux linked with cylinder is ______________.

(A) $2\times10^4\pi$ Vm (B) $2\times10^2\pi$ Vm (C) $0.02\times10^3\ NC^{-1}$ (D) zero

(60) The electric field in a region is given by the following equation :

$$\vec{E} = \left[\frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}\right] \times 2\times10^3\ NC^{-1}$$

The flux passing through a rectangular of 0.2 m^2 area placed in *yz* plane inside the electric field is ______________ Nm^2C^{-1}.

(A) 240 (B) 120 (C) 2.4×10^2 (D) 3×10^3

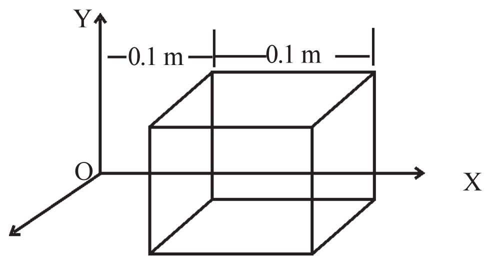
(61) A copper wire having linear charge density λ is passed through a cube of length a, then the maximum flux linked with the cube is ______________.

(A) $\frac{\lambda a}{\epsilon_0}$ (B) $\frac{\sqrt{2}\lambda a}{\epsilon_0}$ (C) $\frac{6\lambda a^2}{\epsilon_0}$ (D) $\frac{\sqrt{3}\lambda a}{\epsilon_0}$

(62) The inward and outward electric flux for a elosed surface are respectively 5×10^5 and 4×10^5 MKS unit. Then how much charge is inside the surface ?

(A) -8.85×10^{-7} C (B) 8.85×10^{7} C (C) 8.85×10^{-7} C (D) 6.85×10^{-7} C

(63) As shown in figure the component of electric field produced due to a charge inside a cube is $E_x = 600\ x^{\frac{1}{2}}$, $E_y = 0$ and $E_z = 0$ then the charge inside the cube a ______________.



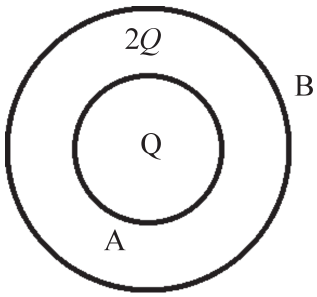
(A) 600 μC (B) 60 μC

(C) 7 $\mu\mu$C (D) 6 $\mu\mu$C

(64) The charge Q and $2Q$ are enclosed by two concentric spheres A and B respectively.

(i) The ratio of electric flux linked with both sphere is ______________.

(ii) If sphere A is fill with substance of dielectric constant $K = 2$, how much flux linked with it ?



(A) (i) 1:3, (ii) $\frac{Q}{5\in_0}$ (B) (i) 1:4, (ii) $\frac{Q}{4\in_0}$

(C) (i) 1:3, (ii) $\frac{Q}{2\in_0}$ (D) (i) 2:1, (ii) $\frac{Q}{\in_0}$

(65) A disk of radius $\frac{a}{4}$ having a uniformly distributed charge of $6\,C$ is placed in the x-y plane with its centre at $\left(\frac{-a}{2}, 0, 0\right)$. A rod of length a carrying a uniformly distributed charge $8\,C$ is placed on the x-axis from $x = \frac{a}{4}$ to $x = \frac{5a}{4}x$. Two point charges $-7\,C$ and $3\,C$ are placed at $\left(\frac{a}{4}, \frac{-a}{4}, 0\right)$ and $\left(\frac{-3a}{4}, \frac{3a}{4}, 0\right)$, respectively. Consider a cubical surface formed by six surfaces $x = \pm\frac{a}{2}$, $y = \pm\frac{a}{2}$, $z = \pm\frac{a}{2}$. The electric flux through this cubical surface is ______________.

(A) $\frac{-2C}{\in_0}$ (B) $\frac{2C}{\in_0}$ (C) $\frac{10C}{\in_0}$ (D) $\frac{12C}{\in_0}$

(66) $8q$ charge is placed on any one vertex of a cube. The flux linked with this cube is ______________ .

(A) $\frac{q}{8\in_0}$ (B) $\frac{q}{4\pi\in_0}$ (C) $\frac{q}{6\in_0}$ (D) $\frac{q}{\in_0}$

(67) An infinitely long wire of linear charge distribution λ is passing through any side of cube of length “a”, then the total flux passing through cube is ______________.

(A) $\frac{\lambda a}{\in_0}$ (B) $\frac{\lambda a}{2\in_0}$ (C) $\frac{\lambda a}{4\in_0}$ (D) $\frac{\lambda a}{6\in_0}$

(68) The electric charge density on two parallel very long straight wire is $2 \times 10^{-4}\ \mathrm{Cm^{-1}}$ respectively. If the distance between these two wire is 0.2 m, then due to charge of first wire the force on unit length of second wire is ______________ N.

(A) 72×10^{2} (B) 8.4×10^{9} (C) 9×10^{9} (D) Zero

(69) The linear charge density on infinitely long straight wire is $\lambda\ \mathrm{Cm^{-1}}$. If an electron moving round in perpendicular plane to the wire and its centre is on the wire then the kinetic energy of electron is ______________.

(A) $\frac{\lambda}{2\pi \in_0}$ (B) $\frac{e\lambda}{2\pi \in_0}$ (C) $\frac{e\lambda}{\in_0}$ (D) $\frac{e\lambda}{8\pi \in_0}$

(70) Two wires of linear charge density λ passing through a sphere of radius R and a cube of sides R so that the flux linked with them is maximum. Then the ratio of flux of sphere to the cube is ______________.

(A) $\sqrt{2}$ (B) $\frac{1}{\sqrt{2}}$ (C) $\frac{2}{\sqrt{3}}$ (D) $\frac{\sqrt{3}}{2}$

(71) Electric charge is uniformly distributed on a long straight wire of radius 1 *m*m. The charge per 1 cm length of wire is Q C. Another cylindrical surface of radius 50 cm and length 1 m symmetrically encloses the wire. The total electric flux passing through the cylindrical surface is ______________.

(A) $\frac{Q}{\in_0}$ (B) $\frac{100Q}{\in_0}$ (C) $\frac{10\,Q}{\pi \in_0}$ (D) $\frac{100\,Q}{\pi \in_0}$

(72) The linear charge density on a infinitely long wire is $\frac{1}{3}\ \mathrm{cm^{-1}}$. Then the electric field intensity at a point $18\ \mathrm{cm}$ perpendicular to the wire is ______________ $\mathrm{N\,C^{-1}}$.

(A) 0.66×10^{11} (B) 3×10^{11} (C) 0.33×10^{11} (D) 1.32×10^{11}

(73) Separation between two long conducting parallel plates is $2\ \mathrm{cm}$. electron starts from rest and moves from one plate to another plate in $2\ \mu\mathrm{s}$ then electric charge density on the plate is ______________ $\mathrm{Cm^{-2}}$.

(A) 2×10^{-13} (B) 2.52×10^{-13} (C) 1.52×10^{-13} (D) 3.2×10^{-13}

(74) An electric dipole is prepared by taking two electric charges of $\pm 5\mathrm{nC}$ separated by distance $2\ mm$. This dipole is kept near a line charge distribution having density $4.5 \times 10^{-4}\ \mathrm{Cm^{-1}}$ in such a way that the negative electric charge of the dipole is at a distance $2.5\ \mathrm{cm}$ perpendicular to the wire. The force acting on the dipole ______________ N.

(A) 0.12 (B) 0.5 (C) 1.5 (D) 0.25

(75) The radius of gold nucleus (Z = 79) is 7×10^{-15} m. If the volume charge density on nucleus is ρ and electric field on the surface of nucleus is E then electric field at the centre of nucleus radius is ______________.

(A) E (B) $2E$ (C) $\frac{E}{3}$ (D) $\frac{E}{2}$

(76) A ball of mass $1\ mg$ and charge $20\ nC$ is suspended by a string. When a uniformly charged large plate is brought near the ball, string makes angle 30° with plane of plate. Then surface charge density on plate is ______________ .

(A) 2.5×10^{-9} (B) 1.22×10^{-9} (C) 1.5×10^{-8} (D) 3.5×10^{-12}

(77) A large sheet carries uniform surface charge density σ. A rod of length $2\,l$ has a linear charge density λ on one half and $-\lambda$ on the other half. The rod is hanged at midpoint O and makes angle θ with the normal to the sheet. The torque experienced by the rod is ______________.

(A) $\frac{\sigma\lambda l}{\in_0} \cos^2\theta$ (B) $\frac{\sigma\lambda l^2}{2 \in_0} \cos\theta$ (C) $\frac{\sigma\lambda l^2}{2 \in_0} \sin\theta$ (D) $\frac{\sigma\lambda l}{\in_0} \sin^2\theta$

(78) An electron placed at distance *d* from a uniformly charged long plate is projected parallel to plate with initial velocity *u*. If electron collide with plate after travelling distance *l* in horinzontal direction then the surface charge density on the plate is ______________.

(A) $\frac{d \in_0 mu}{el}$ (B) $\frac{2d \in_0 mu}{el}$ (C) $\frac{d \in_0 mu^2}{el}$ (D) $\frac{4d \in_0 mu^2}{el^2}$

(79) A rectangular frame of sides $25\ \text{cm} \times 15\ \text{cm}$ is placed perpendicular to uniform electric field of $2 \times 10^4\ \text{NC}^{-1}$. If this frame is bent into circular frame then flux linked with it is ______________ Nm^2C^{-1}.

(A) 750 (B) 1019.1 (C) 800 (D) 2015.5

(80) A particle of mass 9×10^{-5} g is held at some distance from very large uniformly charged plane.The surface charge density on the plane is $5 \times 10^{-5}\ \text{Cm}^{-2}$. What should be the charge on the particle so that the particle remains stationary even after releasing it ?

(A) 1.6×10^{-19}C (B) 1.56×10^{-13}C (C) 6.25×10^{18}C (D) 2.52×10^{-12}C

Ans. : 59 (D), 60 (A), 61 (D), 62 (A), 63 (C), 64 (A), 65 (A), 66 (D), 67 (C), 68 (A), 69 (B), 70 (C), 71 (B), 72 (C), 73 (B), 74 (A), 75 (D), 76 (A), 77 (C), 78 (D), 79 (B), 80 (B)

Assertion - Reason type Question :

Instruction : Read assertion and reason carefully, select proper option from given below.

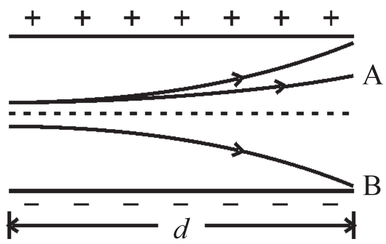
(a) Both assertion and reason are true and reason explains the assertion.

(b) Both assertion and reason are true but reason does not explain the assertion.

(c) Assertion is true but reason is false.

(d) Assertion is false and reason is true.

(81) **Assertion :** Two charged particle A and B move in uniform electric field as shown in figure. The ratio of charge and mass of particle B is greater than that of particle A. Neglect the gravitational effect.



Reason : The vertical acceleration of particle A is greater than that of particle B.

(A) (a) (B) (b)

(C) (c) (D) (d)

(82) **Assertion :** If dielectric substance having dielectric constant K is put between two electric charge then electric field is reduced.

Reason : According to equation $E_m = \frac{Ea}{K}$ electric field becomes $\frac{1}{K}$.

(A) (a) (B) (b) (C) (c) (D) (d)

(83) **Assertion :** Electric field lines cross each other.

Reason : In uniform electric field, electric field lines are parallel to each other.

(A) (a) (B) (b) (C) (c) (D) (d)

(84) **Assertion :** If proton and electron are placed in uniform electric field, their accelerations are different.

Reason : The electric force on unit positive charge is independent of mass.

(A) (a) (B) (b) (C) (c) (D) (d)

(85) **Assertion :** Electric flux coming out and going inside from closed surface are 3 KVm and 8 KVm respectively. Electric charge enclosed by close surface is $0.53\,\mu C$.

Reason : From Gauss's theorem $\phi = \frac{Q}{\epsilon_0}$, equation $Q = \phi \epsilon_0$ can be used to verify this statement.

(A) (a) (B) (b) (C) (c) (D) (d)

(86) **Assertion :** Two spherical shells have radii r_1 amd r_2 respectively. Their surface charge densities are equal. Thus, electric field intensities near their surface is also same.

Reason : Surface charge density = $\frac{\text{Electric charge}}{\text{Surface area}}$

(A) (a) (B) (b) (C) (c) (D) (d)

(87) **Assertion :** When a high energy X-Ray beam is made incident on a small metal ball suspended in uniform electric field, the ball experiences some deflection.

Reason : X-Ray produces photo electron, so metal ball becomes negatively charged.

(A) (a) (B) (b) (C) (c) (D) (d)

(88) **Assertion :** A charge is put at midpoint of line joining two identical charges. For equilibrium of this system, the magnitude of this charge must be $\left(\frac{Q}{4}\right)$.

Reason : For equilibrium of any charge, the forces applied on it must be equal in magnitude and opposite in direction.

(A) (a) (B) (b) (C) (c) (D) (d)

(89) **Assertion :** When a substance is negatively charged, its mass is slightly decreased.

Reason : Due to displacement of electron, the mass of substance is changed.

(A) (a) (B) (b) (C) (c) (D) (d)

(90) **Assertion :** When two substance attract each other, then maybe they are not charged.

Reason : Due to induction, charged substance attract neutral substance.

(A) (a) (B) (b) (C) (c) (D) (d)

Ans. : 81 (A), 82 (A), 83 (D), 84 (B), 85 (A), 86 (B), 87 (C), 88 (B), 89 (D), 90 (A)

Comprehension Type Questions :

Passage (I) :

The distance between two horizontal parallel plates is 1.5 cm and electric field between them is 10^5 Vm^{-1} in downward direction. A oil drop of mass 4.9×10^{-15} kg and radius 5×10^{-5} m is placed stationery between these two plate. Density of air is negligible compare to oil. Co-efficient of viscosity is 1.8×10^{-5} Nsm^{-2}.

(91) Number of excess electron on the oil drop ______________.

(A) 2 (B) 3 (C) 4 (D) 5

(92) If the direction of electric field is inverted then initial acceleration of oil drop is ______________.

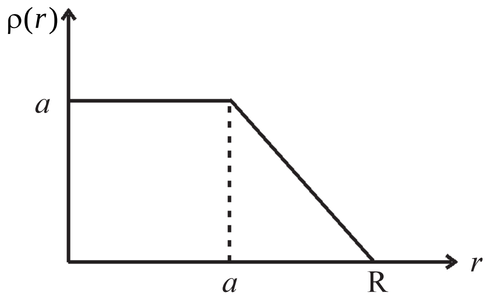
(A) 4.9 ms^{-2} (B) 9.8 ms^{-2} (C) 19.6 ms^{-2} (D) Zero

(93) Terminal velocity of drop is nearly ______________ ms^{-1}.

(A) 2.7×10^{-5} (B) 3.7×10^{-5} (C) 4.7×10^{-5} (D) 5.7×10^{-5}

Passage (II) :

The nuclear charge 'Ze' is non uniformly distributed within a nucles of a radius R. The charge density $\rho(r)$ (charge per unit volum) depend only on the radial distance r from the center of the nucleus as shown in figure. The electric field is along radial direction.



(94) At r = R electric field is ______________.

(A) independent of a (B) directly proportional to a

(C) directly proportional to a^2 (D) inverselay proportional to a

(95) For a = 0, the magnitude of d (the maximum magnitude of ρ) ______________.

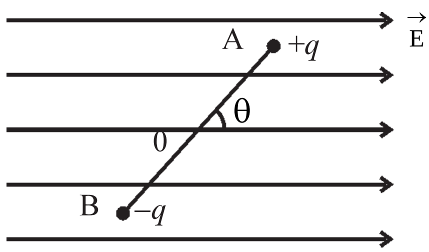
(A) $\frac{3Ze^2}{4\pi R^2}$ (B) $\frac{3Ze}{\pi R^3}$ (C) $\frac{4Ze}{3\pi R^2}$ (D) $\frac{Ze}{3\pi R^2}$

(96) Inside the nucleus, normally electric field depends linearly on r. For this, ______________.

(A) $a = 0$ (B) $a = \frac{R}{2}$ (C) $a = R$ (D) $a = \frac{2R}{3}$

Passage - III

Two point particle of mass m are connected at the end of light rod of length l. These two particles have charge $+q$ and $-q$ respectively. This arrangement is put into uniform electric field at small angle θ.



(97) Magnitude of torque applied on rod is ______________.

(A) $qEl\cos\theta$ (B) $qEl\sin\theta$ (C) qEl (D) Zero

(98) When rod becomes free, it rotates with ______________ angular frequency.

(A) $\left(\frac{qE}{ml}\right)^{\frac{1}{2}}$ (B) $\left(\frac{2qE}{ml}\right)^{\frac{1}{2}}$ (C) $\left(\frac{qE}{2ml}\right)^{\frac{1}{2}}$ (D) $\frac{1}{2}\left(\frac{qE}{2ml}\right)^{\frac{1}{2}}$

(99) When rod becomes free, the minimum time required for becoming parallel to electric field is ______________.

(A) $\frac{\pi}{2}\left(\frac{ml}{2qE}\right)^{\frac{1}{2}}$ (B) $2\pi\left(\frac{ml}{qE}\right)^{\frac{1}{2}}$ (C) $2\pi\left(\frac{2ml}{qE}\right)^{\frac{1}{2}}$ (D) $2\pi\left(\frac{ml}{2qE}\right)^{\frac{1}{2}}$

Ans. : 91 (B), 92 (C), 93 (D), 94 (A), 95 (B), 96 (C), 97 (B), 98 (B), 99 (A)

Match the columns :

Match appropriately the column-1 with column-2 :

(100)

Column-1		Column-2	
(a)	Electric field of a point charge is proportional to _ at any point.	(p)	$\frac{1}{r}$
(b)	Electric field of a short electric dipole is proportional to _ at any point.	(q)	$\frac{1}{r^2}$
(c)	Electric field of linear charge distribution is proportional to _ at any point.	(r)	$\frac{1}{r^3}$

(A) a – q, b – r, c – p
(B) a – r, b – q, c – p
(C) a – p, b – q, c – r
(D) a – r, b – p, c – q

(101)

Column-1		Column-2	
(a)	If $Q_1 = 0$ and $Q_2 \neq 0$ then	(p)	$E \neq 0$ and $\phi \neq 0$
(b)	If $Q_1 \neq 0$ and $Q_2 = 0$ then	(q)	E will change but ϕ will not
(c)	If Q_1 changes	(r)	$E \neq 0$ but $\phi \neq 0$
(d)	If Q_2 changes	(s)	Both E and ϕ will change

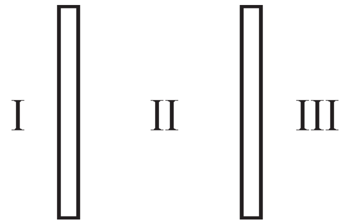
(A) a – s, b – p, c – q, d – r
(B) a – r, b – p, c – q, d – s
(C) a – q, b – s, c – p, d – r
(D) a – r, b – q, c – s, d – p

(102)

Column-1		Column-2	
(a)	Electric field due to a uniformly charged infinite plane sheet of thickness *d*	(p)	Zero
(b)	Electric field of a point lying inside the sphere	(q)	$\frac{\sigma}{\epsilon_0}$
(c)	Electric field of a point lying inside a shell	(r)	$\frac{\rho r}{3\epsilon_0}$

(A) a – r, b – p, c – q
(B) a – p, b – r, c – q
(C) a – q, b – r, c – p
(D) a – p, b – q, c – r

(103) Two plates of surface charge density σ_1 and σ_2 are placed parallel to each other.



Column-1		Column-2	
(a)	$\sigma_1 = \sigma_2 = -\sigma$	(p)	In area I and II, $E = 0$
(b)	$\sigma_1 = \sigma_2 = +\sigma$	(q)	In area II, $E = 0$
(c)	$\sigma_1 = -\sigma$ and $\sigma_2 = +\sigma$	(r)	In area I, II and III, $E = 0$

(A) a – p, b – q, c – r (B) a – p, b – p, c – r

(C) a – q, b – q, c – p (D) a – q, b – q, c – r

Ans. : 100 (A), 101 (B), 102 (C), 103 (C)

Matrix matching questions

Note : The question below have some statement/option. shown in Column-I and Column - II. Match this statement/option correctly. Show the answer by filling the circle of matrix as given.

(104) By introducing a di-electric substance of constant K between two charges, its......

Column-1		Column-2	
(a)	Electric Charge	(p)	Becomes $\frac{1}{K}$ times
(b)	Electric Field	(q)	Becomes $\frac{1}{K^2}$ times

	p	q	r
a	○	○	○
b	○	○	○
c	○	○	○

Ans. :

	p	q	r
a	○	○	●
b	●	○	○
c	●	○	○

Difference between Electric field and Electric potential

- Electric field around an electrical device can be expressed in two ways :

  (1) Electric field $\vec{E}$ (2) Electric Potential (V)

- Electric field is a vector quantity, while electric potential is a scalar quantity.
- Both the quantities can be defined near any point in electric field and both are interlinked (related) to each other.

Electric Potential : The work required to be done in bringing a unit charge q from infinite distance to a given finite point in the electric field is called Electric Potential (V).

- Electric Potential at a point at a distance r in the given electric field i.e. integration of electric field from infinite distance to distance r against the field is given by.

$$V = -\int_{\infty}^{r} \vec{E} \cdot d\vec{r}$$

- Electric Potential at infinite point is zero.
- Electric Potential $V = \frac{\text{Work done(W)}}{\text{Charge}(q)}$ $\therefore \boxed{V = \frac{W}{q}} \Rightarrow \boxed{W = qV}$
- SI unit = JC^{-1} or Volt (V)
- CGS unit = Statvolt or abvolt

$$1 \text{ ab Volt (1 emu)} = 10^{-8} \text{ Volt}$$
$$1 \text{ State Volt (1 esu)} = 299.8 = 300 \text{ Volt}$$

- Dimension $[V] = M^1L^2T^{-3}A^{-1}$ or $M^1L^2T^{-2}Q^{-1}$
- Potential is a (comparative) relative quantity. It can be $-Ve$, $+Ve$ or zero on a good conductor.
- The absolute electric potential of earth is negative, because earth having $1\,nC\,m^{-2}$ negative charge. But by taking this potential as a reference its magnitude is considered zero.

Factors affecting potential :

- Following factors affect the potential of any conducting substance :

  (1) Magnitude of charge : Electric potential is directly proportional to magnitude of electric charge.

(2) Area of a conductor : If magnitude of charge is variable then, potential of conductor is $V \propto \frac{1}{A}$.

(3) Presence of a conductor in vicinity of charged conductor :

When a conductor is brought near charged conductor, then Potential of charged conductor decreases.

(4) Medium around conductor : Medium around conductor affects potential as $V' = \frac{V}{K}$;

Where $K =$ dielectric constant.

Potential difference :

Potential at point P in electric field, $V_P = -\int_{\infty}^{P} \vec{E} \cdot d\vec{r}$

Potential at Point Q, $V_Q = -\int_{\infty}^{Q} \vec{E} \cdot d\vec{r}$

Potential difference between points P and Q : $\boxed{V_Q - V_P = -\int_{P}^{Q} \vec{E} \cdot d\vec{r}}$

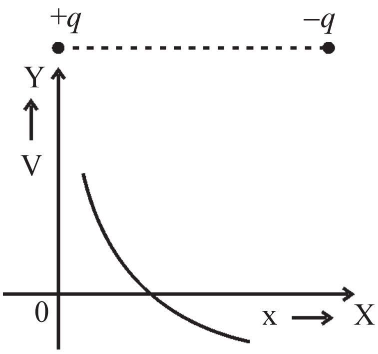
Two types of Electric Potential :

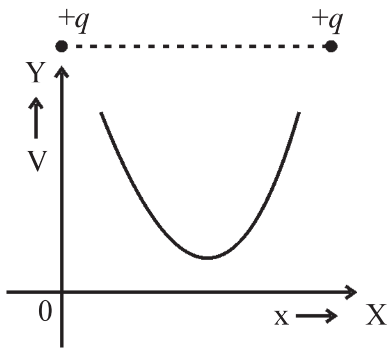
(1) Positive potential : The work done against electric field in bringing unit positive charge from infinity to a point in electric field, then potential of that point is called Positive potential.

- If the material has resultant positive charge, then also potential is taken positive.
- If a positively charged particle is connected to earth, then electrons from earth flow into that particle. In such situation also, potential is considered positive.

- **Negative potential :** The work done in direction of electric field in bringing a unit positive charge from infinity to a point in electric field, then potential at that point is called Negative Potential.
    - If the resultant charge of particle is negative, then potential is considered negative.
    - If a negatively charged particle is brought in contact with earth, then electrons from particle will flow in to earth. In such situation also, potential is considered negative.
- The direction of positive potential is from higher charge to a lower charge while that of negative potential is from lower charge to higher charge.
    - Generally in practice, potential of positive charge is considered positive while potential of negative charge is considered negative.

- **Graph showing variation of potential :**

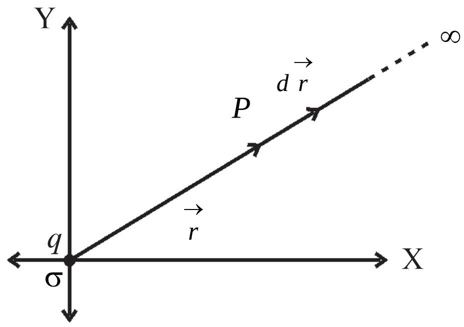




- If position vector of source charge q is $\vec{r}$, then potential difference is given as,

$$V_Q - V_P = kq\left(\frac{1}{\left|\vec{r}_Q - \vec{r}\right|} - \frac{1}{\left|\vec{r}_P - \vec{r}\right|}\right)$$

Potential for a point charge :



Potential at point P,

$$V_P = -\int_{\infty}^{P} \vec{E} \cdot d\vec{r}$$

$$\therefore\ V_P = \int_{P}^{\infty} \vec{E} \cdot d\vec{r}$$

but, electric field due to point charge, $\vec{E} = \dfrac{kq}{r^2}\hat{r}$

$$\therefore\ V_P = \int_{P}^{\infty} \frac{kq}{r^2}\, dr$$

$$\therefore\ V_P = kq \int_{r}^{\infty} \frac{1}{r^2}\, dr$$

$$\therefore\ V_P = kq\left[-\frac{1}{r}\right]_r^{\infty}$$

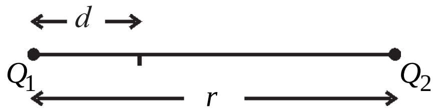
$$\boxed{V_P = \frac{kq}{r}} \quad \text{or} \quad \boxed{V_P = \frac{1}{4\pi \in_0}\frac{q}{r}}$$

Thus, potential due to a point charge is $V \propto \dfrac{1}{r}$.

Zero potential due to system of charges

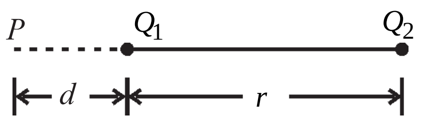
- If the charges are like, then zero potential is not acheived at finite distance.
- If two charges are unlike and having diffrent magnitude then zero potential can be obtained at the points on a closed curve.
- Two points having zero potential are obtained on the line of joining of two charges, one among them is lies between two charges and another is outside. Both points are nearer to lower charge.
  Both near the lower charge.
- $|Q_1| < |Q_2|$ for,

  For point on the line joining two charges,



$$\boxed{d = \frac{r}{\frac{Q_2}{Q_1} + 1}}$$

For point outside the line joining two charges,



$$\boxed{d = \frac{r}{\frac{Q_2}{Q_1} - 1}}$$

Work done in electric field :

The work done to move a charge q from point P having potential V_1 to point Q having potential V_2 is,

$$W = q \, \Delta V$$
$$\therefore W = q(V_2 - V_1)$$

- Now, kinetic energy of charge q due to potential difference.

$$K = qV$$
$$\therefore \frac{1}{2} mv^2 = qV$$
$$\therefore v = \sqrt{\frac{2qV}{m}}$$

$\therefore$ Momentum of electrically charged particle is $p = \sqrt{2qVm}$.

- Electric Potential gradiant : $\left(\frac{dV}{dr}\right)$ The potential difference per unit length is known as Electric potential gradiant.

  Its SI unit is Vm^{-1}.

(105) If work done to take 4C charge located near a point having –10 V potential, to a point having potential V is 100 J then V = ______________ V.

(A) 10 (B) 15 (C) 20 (D) 5

(106) How much should be a sphere of radius 14 cm charged so that its surface charge density is $1\,\mu C\,m^{-2}$?

(A) 12,420 V (B) 15,200 V (C) 15,820 V (D) 20,000 V

(107) $200\,\mu C$ charge is uniformly spread on a conducting wire. The wire is then wound in a circle of radius 10 cm, then potential at the centre of circle is ______________ V.

(A) 18×10^6 (B) 12×10^6 (C) 9×10^9 (D) 15×10^{10}

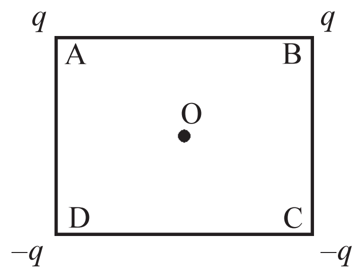
(108) Two charges $30\,nC$ and $-20\,nC$ are seperated by 15 cm. At which points on the line joining two charges, the potential will be zero ?

(A) 45 cm, 200 cm (B) 40 cm, 100 cm (C) 80 cm, 150 cm (D) 9 cm, 45 cm

(109) In an electric field, the potential about points P and Q are 10 V and –4 V respectively, then what is the work done to take 100 electrons from P to Q ?

(A) 2.24×10^{-16} J (B) -19×10^{-17} J (C) 9.6×10^{-17} J (D) -2.24×10^{-16} J

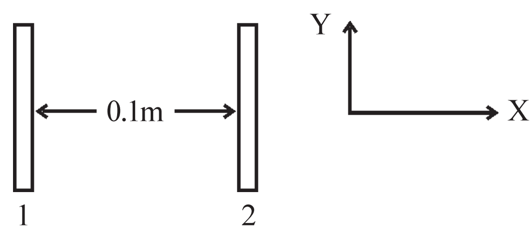
(110) As shown in figure, charges across the vertices of the square A and D and B and C are exchanged, the electric field $\vec{E}$ and electric potential V about centre O will,



(A) $\vec{E}$ remains constant, V changes (B) Both $\vec{E}$ and $\vec{V}$ changes

(C) Both $\vec{E}$ and V remains constant (D) $\vec{E}$ changes, V remains constant

(111) Two infinite long plates 1 and 2 are kept at a distance 0.1 m from each other having potential difference $V_2 - V_1 = 20$ V . What will be the velocity of an electron located on inside surface of plate 1 from steady state when accelerated towards plate 2 ?



(A) 32×10^{-19} m/s (B) 2.66×10^6 m/s (C) 7.02×10^{12} m/s (D) 1.87×10^6 m/s

(112) What is the potential difference between two points $A\left(\sqrt{2}, \sqrt{2}\right)$ m and $B(2, 0)$ m situated in the electric field generated due to a point charge $10^{-3}\,\mu C$ located at the origin ?

(A) 4.5 V (B) 9 V (C) 2 V (D) Zero

(113) Electric field in a region is $\vec{E} = 30x^2\hat{i}$, then potential difference $V_A - V_0 =$ ______ Where

V_0 = Potential at origin point.

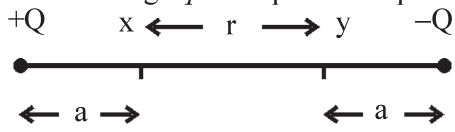
V_A = Potential at point A located at $x = 2$m

(A) 80 V (B) –80 V (C) 120 V (D) –120 V

(114) The work done to move a charge 5 C from point A to point B against electric field is 20 J. If the electric potential at point A is 10 V, then what is the potential at point B ?

(A) Zero (B) 6 V (C) 14 V (D) 2.5 V

(115) Find the work done to move charge q from point x to point y as shown in figure.



(A) $\frac{2kqQr}{a(a+r)}$ (B) $\frac{kQq}{r+2a}$ (C) $\frac{Qq}{r}$ (D) $\frac{2kQqa}{r(r+a)}$

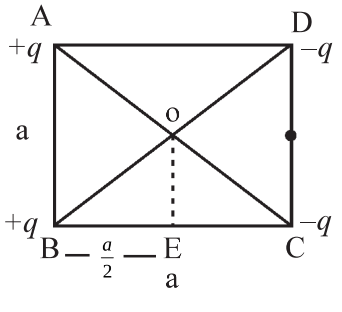
(116) The potential on "n" point drops having equal magnitude is V volt. They join together and form a bigger drop, then find the potential on it.

(A) $\frac{V}{n}$ (B) Vn (C) $Vn^{\frac{1}{2}}$ (D) $Vn^{\frac{2}{3}}$

(117) The potential and electric field intensity of point P situated at some distance from electric charge Q C is 600 V and 150 NC^{-1}, then distance of point P from Q is ______ m.

(A) 4 (B) 2 (C) 3.2 (D) 6.5

(118) As shown in figure, a square having side a has charges $+q$, $+q$, $-q$ and $-q$ on vertices of square ABCD. It E is the midpoint of side BC, then what is the amount of work to be done to move a charge e from centre of square O to point E ? ______.



(A) $\frac{qe}{4\pi \epsilon_0}\left(\sqrt{2}-1\right)$ (B) Zero

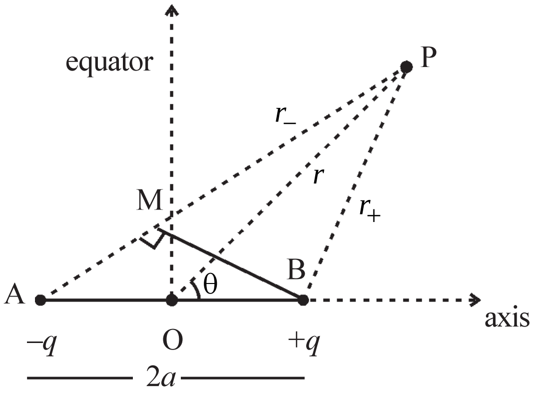
(C) $\frac{qe}{4\pi \epsilon_0}\left(4\sqrt{2}-1\right)$ (D) $\frac{qe}{\pi \epsilon_0 a}\left(\frac{1}{\sqrt{5}}-1\right)$

(119) The sides PQ and QR of a right angle triangle PQR is 25 cm and 60 cm. A sphere of radius 2 cm and potential 9×10^5 V is placed at point Q. The work done to take 1 C charge from R to P is W = ______.

(A) 2 kJ (B) 25 kJ (C) 42.12 kJ (D) 38.9 kJ

Ans. : 105 (B), 106 (C), 107 (A), 108 (D), 109 (A), 110 (D), 111 (B), 112 (D), 113 (B), 114 (C), 115 (A), 116 (D), 117 (A), 118 (B), 119 (C)

Electric Potential due to electric dipole



- Electric Potential about point P

$$V_P = \frac{1}{4\pi \in_0}\frac{q}{r_+} - \frac{1}{4\pi \in_0}\frac{q}{r_-}$$

$$= \frac{q}{4\pi \in_0}\left[\frac{1}{r_+} - \frac{1}{r_-}\right]$$

$$= \frac{q}{4\pi \in_0}\left[\frac{r_- - r_+}{r_+ r_-}\right]$$

- Point P is at larger distance $r >> 2a$, So we can take $AB \parallel OP \parallel BP$.

  $\therefore\ r_- = r_+ = r$

  and $r_- - r_+ = AM = 2a\cos\theta$

  $$\therefore\ V(r) = \frac{q}{4\pi \in_0}\left(\frac{2a\cos\theta}{r^2}\right)$$

  $$\therefore\ V(r) = \frac{1}{4\pi \in_0}\frac{p\cos\theta}{r^2}$$

- writing $\overrightarrow{OP}$ as unit vector $\hat{r}$ i.e. $\vec{p}\cdot\hat{r} = p\cos\theta$.

  $$\therefore\ \vec{V}(r) = \frac{1}{4\pi \in_0}\frac{\vec{p}\cdot\hat{r}}{r^2}$$

- Potential on axis of dipole : Here $\theta = 0$ or $\theta = \pi$

$$\therefore\ \boxed{V = \pm\frac{1}{4\pi \in_0}\frac{p}{r^2}}$$

  - If charge near given point is $+q$, then potential will be V and if charge is $-q$, then potential will be $-V$.

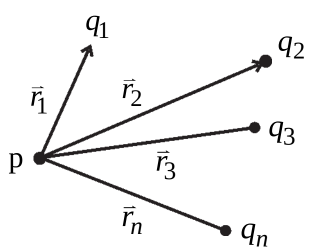
- **Electric Potential at equator :** At a point on equator, $\theta = \frac{\pi}{2}$. $\therefore\ V = 0$

  - At any point, potential depends upon the angle between $\vec{r}$ and $\vec{p}$.

  - The potential produced due dipole decreases with distance as $\frac{1}{r^2}$.

Electric Potential generated due to system of charges.

(i)



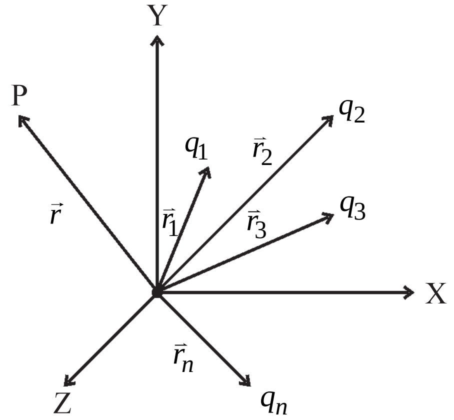
As shown in figure $q_1, q_2, \dots q_n$ charges are at distance $r_1, r_2, \dots r_n$ from any point, then electric potential at point P is ....

$$V = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} + ... + \frac{kq_n}{r_n}$$

$$\therefore \quad V = K\left[\frac{q_1}{r_1} + \frac{q_2}{r_2} + ... + \frac{q_n}{r_n}\right]$$

$$\text{or } V = \frac{1}{4\pi \in_0} \sum_{j=1}^{n} \frac{q_j}{r_j}$$

(ii)



As shown in figure if the position vectors of charge $q_1, q_2, ... q_n$ are $\vec{r}_1, \vec{r}_2, ... \vec{r}_n$ respectively and the position vector of point P is $\vec{r}$ then the total electric potential at point P is,

$$V = \frac{kq_1}{\left|\vec{r} - \vec{r}_1\right|} + \frac{kq_2}{\left|\vec{r} - \vec{r}_2\right|} + ... + \frac{kq_n}{\left|\vec{r} - \vec{r}_n\right|}$$

$$\therefore \quad V = k \sum_{j=1}^{n} \frac{q_j}{\left|\vec{r} - \vec{r}_j\right|}$$

Potential due to continuous charge distribution :

(i) Potential due to an infinite line charge distribution having density λ and length l at distance $\vec{r}$ from point P,

$$V = \frac{1}{4\pi \in_0} \int_l \frac{\lambda dl}{\left|\vec{r} - \vec{r}'\right|}$$

(ii) Potential due to a charged plane sheet having surface charge density σ and area A at distance $\vec{r}$ from point P.

$$V = \frac{1}{4\pi \in_0} \int_A \frac{\sigma dA}{\left|\vec{r} - \vec{r}'\right|}$$

(iii) Potential due to a charged object having volume charge density ρ and volume V at distance $\vec{r}$ from point P,

$$V = \frac{1}{4\pi \in_0} \int_V \frac{\rho dV}{\left|\vec{r} - \vec{r}'\right|}$$

Potential due to a shell having equal charge distribution :

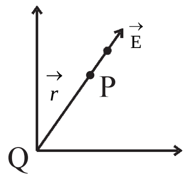
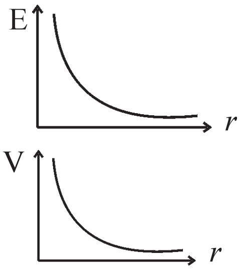
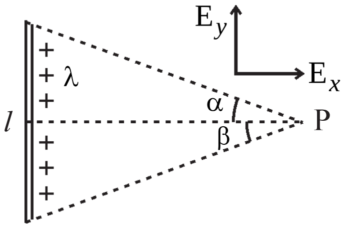
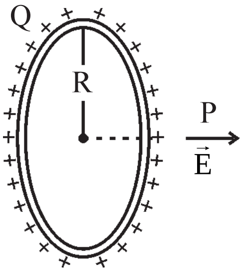
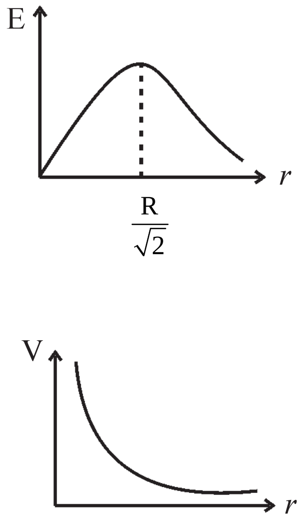
(i) Potential at distance $\vec{r}$ from a shell having radius R and total charge on sphere is q,

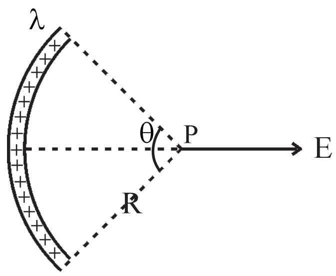
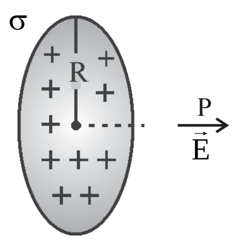
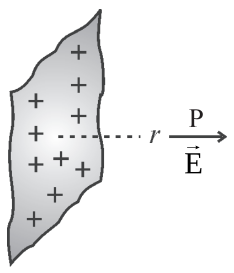
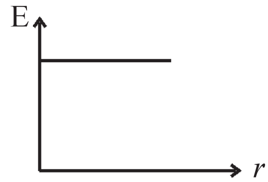
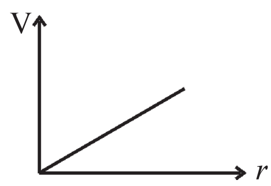
$$V = \frac{1}{4\pi \in_0} \frac{q}{r} \text{ Where } r > R.$$

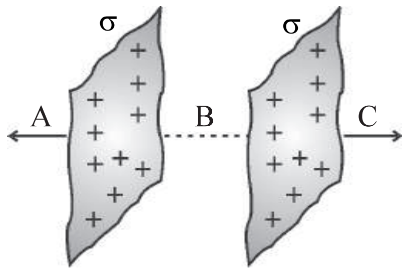
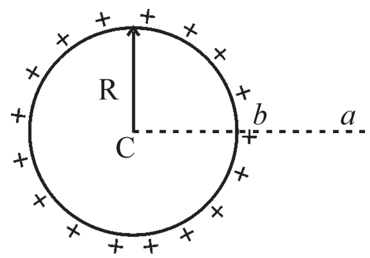
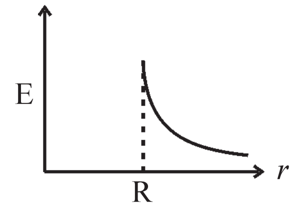
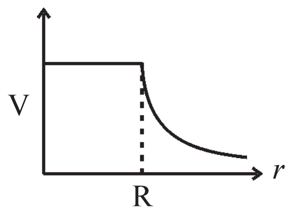
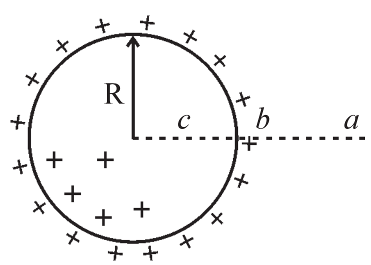
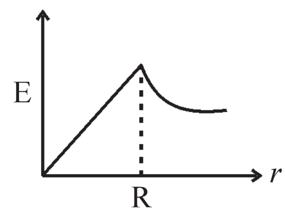
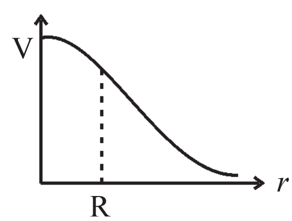
(ii) On the surface of shell $V = \frac{1}{4\pi \epsilon_0} \frac{q}{R}$ Where $r = R$.

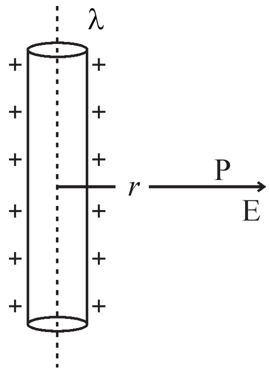
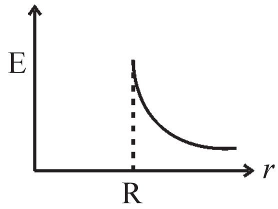
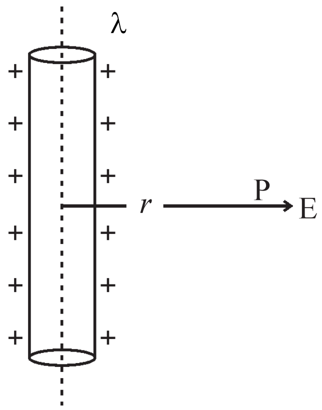
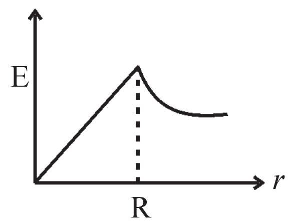
(iii) Inside the shell, charge is zero. So work done to move that charge inside the shell is zero. Thus, all points are equipotential. So potential is,

$$V = \frac{1}{4\pi \epsilon_0} \frac{q}{R} \quad \text{Where } r < R.$$

Distribution of electric Charge	**Electric field and Electric potential**	**Graph**
1. Point charge Q 	$E = k\frac{Q}{r^2}$ $V = k\frac{Q}{r}$	
2. Line charge 	$E_x = \frac{k\lambda}{r}(\sin\alpha + \sin\beta)$ $E_y = \frac{k\lambda}{r}(\cos\beta + \sin\alpha)$ $V = 2k\lambda \log\left[\frac{\sqrt{r^2 + l^2} - 1}{\sqrt{r^2 + l^2} + 1}\right]$	
	$E = \frac{kQr}{(r^2 + R^2)^{\frac{3}{2}}}$ On the centre of plane $r = 0$ then $E_{centre} = 0$	
3. Circular charged ring 	$r = \pm\frac{R}{\sqrt{2}}$ $E_{max} = \frac{2kQ}{3\sqrt{3}R^2}$ $r >> R$ $E = \frac{kQ}{r^2}$ $V = \frac{kQ}{(r^2 + R^2)^{\frac{1}{2}}}$ $r >> R$ $V = \frac{kQ}{r}$	

Distribution of electric Charge	Electric field and Electric potential	Graph
4. Arc shaped charged rod  	$E_{centre}=\frac{2k\lambda}{R}\sin\theta$ Special cases (i) when $\theta=45^\circ$ (quarter ring) $E_{centre}=\frac{\sqrt{2}k\lambda}{R}$ (ii) when $\theta=90^\circ$ (half ring) $E_{centre}=\frac{2k\lambda}{R}$ (iii) when $\theta=135^\circ$ ($\frac{3}{4}$ th ring) $E_{centre}=\frac{\sqrt{2}k\lambda}{R}$ $V_{centre}=2k\lambda\theta$ (θ in *radian*)	
5. Continuosly charged ring  	$E=\frac{\sigma}{2\varepsilon_0}\left[1-\frac{r}{\sqrt{r^2+R^2}}\right]$ $r\to 0$, near $E=\frac{\sigma}{2\varepsilon_0}$, It will behave as charged shell for points near the ring $V=\frac{\sigma}{2\varepsilon_0}\left[1-\sqrt{r^2+R^2}-r\right]$	
6. Infinite charged plane sheet  	At any point $E=\frac{\sigma}{2\varepsilon_0}$ $V=\frac{\sigma r}{2\varepsilon_0}+C$	 

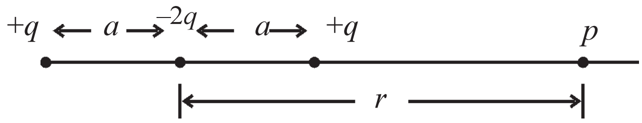
Distribution of electric Charges	Electric field and Electric potential	Graph
7. Two infinite charged plane sheet  	$E_A = -\frac{\sigma}{\varepsilon_0}$ $E_B = 0$ $E_C = \frac{\sigma}{\varepsilon_0}$	
8. Charged conducting sphere  	$E_a = \frac{kQ}{r^2} \quad (r > R)$ $E_b = \frac{kQ}{R^2} \quad (r = R)$ $E_c = 0 \quad (r < R)$ $V_a = \frac{kQ}{r} \quad (r > R)$ $V_b = \frac{kQ}{R} \quad (r = R)$ $V_c = \frac{kQ}{R} \quad (r < R)$	 
9. Contiuosly charged conducting sphere  	$E_a = \frac{kQ}{r^2} \quad (r > R)$ $E_b = \frac{kQ}{R^2} \quad (r = R)$ $E_c = \frac{kQr}{R^3} \quad (r < R)$ $V_a = \frac{kQ}{r} \quad (r > R)$ $V_b = \frac{kQ}{R} \quad (r = R)$ $V_c = \frac{kQ(3R^2 - r^2)}{2R^3} \quad (r = R)$ $V_{centre} = \frac{3}{2} V_b$	 

<table>
<tr><th>Distribution of electric Charges</th><th>Electric field and Electric potential</th><th>Graph</th></tr>
<tr><td>10. Infinite long charged conducting hollow cylinder

R is radius of cylinder</td><td>$E_{out\ side} = \frac{2k\lambda}{r}$ $(r > R)$
$E_{in\ side} = 0$ $(r < R)$
$E_{surface} = \frac{2k\lambda}{R}$ $(r = R)$
$V_{out\ side} = 2k\lambda \log r$ $(r > R)$
$V_{in\ side} = 2k\lambda \log R$ $(r < R)$
$V_{out\ side} = 2k\lambda \log R$ $(r = R)$</td><td></td></tr>
<tr><td>11. Infinitely long continuosly charged conducting solid cylinder

R radius of cylinder</td><td>$E_{out\ side} = \frac{2k\lambda}{r}$ $(r > R)$
$E_{in\ side} = \frac{2k\lambda r}{R^2}$ $(r < R)$
$E_{surface} = \frac{2k\lambda}{R}$ $(r = R)$
$V_{out\ side} = 2k\lambda \log r$ $(r > R)$
$V_{in\ side} = 2k\lambda\left(1 - \frac{r^2}{R^2}\right)$ $(r < R)$
$V_{out\ side} = 2k\lambda \log R$ $(r = R)$</td><td></td></tr>
</table>

(120) Q charge is uniformly distributed on a thin ring of radius R. If, initially, electron is steady at point A which is quite far from centre and axis of ring, then find the velocity when electron passes through the centre of ring.

(A) $\sqrt{\frac{2kQe}{mR}}$ (B) $\sqrt{\frac{kQe}{m}}$ (C) $\sqrt{\frac{kme}{QR}}$ (D) $\sqrt{\frac{kQe}{mR}}$

(121) A quadruple is shown in figure. What is the potential at a point which is at distance r from the axis of quadruple ?



(A) $\dfrac{2qa^2}{4\pi \in_0 r\left(r^2+a^2\right)}$ (B) $\dfrac{2qa^2}{4\pi \in_0 r\left(r^2-a^2\right)}$ (C) $\dfrac{2qa^2}{4\pi \in_0 r^3}$ (D) $\dfrac{qa^2}{4\pi \in_0 r^3}$

(122) A solid sphere of radius R is uniformly charged. At what distance from the surface, the electric potential is half of the potential at centre of sphere ?

(A) $\dfrac{R}{2}$ (B) R (C) $\dfrac{R}{3}$ (D) $\dfrac{4R}{3}$

(123) The charge per unit length of an arc ring having radius R is λ. What is the electric potential at its centre ?

(A) $\dfrac{k\lambda}{2\pi R}$ (B) $\dfrac{k\lambda}{R}$ (C) $\dfrac{k\pi\lambda}{R}$ (D) $k\pi\lambda$

(124) Two dipoles of dipole moment 5×10^{-12} Cm are placed in such a way that their axis are parallel to co-ordinate axis and intersect at the origin, Then potential at point 20 cm away and making an angle 30° with axis is ______________ V.

(A) 1.536 (B) 1.12 (C) 1.25 (D) 2.12

(125) The potential at a point on the bisector of a thin rod of length 2 l and at a distance "a" from the centre of thin rod is ______________. (Linear charge density = λ)

(A) $\dfrac{\lambda}{\pi \in_0} \ln \dfrac{l^2+a^2}{l^2-a^2}$ (B) $\dfrac{\lambda}{4\pi \in_0} \ln \dfrac{\sqrt{l^2+a^2}+l}{\sqrt{l^2+a^2}-l}$

(C) $\dfrac{\lambda}{\pi \in_0} \ln \dfrac{\sqrt{l^2+a^2}}{\sqrt{l^2-a^2}}$ (D) Zero

(126) The electric potential for half sphere having radius R and surface charge density σ is ______________.

(A) $\dfrac{\sigma R}{4 \in_0}$ (B) $\dfrac{\sigma R}{\in_0}$ (C) $\dfrac{R}{4\sigma \in_0}$ (D) $\dfrac{\sigma R}{2 \in_0}$

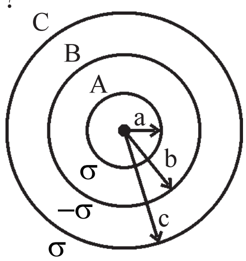
(127) Two identical plane S_1 and S_2 having surface charge density σ_1 and σ_2 $\left(\sigma_1 > \sigma_2\right)$ are placed at distance d on a line normal to both plane. A line of length a ($a < d$) make an angle 45° has charge q. The work done by field for motion of the charge perpendicular to field. W = ______________.

(A) $\dfrac{(\sigma_1-\sigma_2)\in_0}{2qa}$ (B) $\dfrac{q(\sigma_1+\sigma_2)\,a}{\sqrt{2}\in_0}$ (C) $\dfrac{(\sigma_1-\sigma_2)\,a}{2\in_0 q}$ (D) $\dfrac{q(\sigma_1-\sigma_2)\,a}{\sqrt{2}\in_0}$

(128) The total charge on an insulator ring of radius $0.5\,\text{m}$ is $1.11 \times 10^{-10}\,\text{C}$, which is distributed unequally on circumference. Then magnitude of electric field surrounding this $\int_{l=\infty}^{l=0} -\vec{E} \cdot \vec{dr}$ = ______________ V. ($l = 0$ is the centre of ring.)

(A) –1 (B) +2 (C) –2 (D) Zero

(129) As shown in figure A, B and C are concentric shells of radius *a, b* and *c* respectively. ($a < b < c$). Their surface charge densities are $\sigma, -\sigma$ and σ respectively. What is the electric potential on the surface of shell A ?



(A) $\frac{-\sigma}{\epsilon_0}(a+b+c)$ (B) $\frac{\sigma}{\epsilon_0}(a+b+c)$ (C) $\frac{\sigma}{\epsilon_0}(b-a-c)$ (D) $\frac{\sigma}{\epsilon_0}(a-b+c)$

(130) The radius of two concentric metal shells are R_1 and R_2 respectively and electric charge on them are Q_1 and Q_2. The surface charge density σ of both the shell is equal. Find the electric potential at the centre.

(A) $\frac{\sigma}{\epsilon_0}\left(\frac{R_1}{R_2}\right)$ (B) $\frac{\sigma}{\epsilon_0}(R_1 - R_2)$ (C) $\frac{\sigma}{\epsilon_0}(R_1 + R_2)$ (D) $\frac{\sigma}{\epsilon_0}\left(\frac{R_2}{R_1}\right)$

(131) The radius of a conducting hollow sphere is "*a*". If the potential defference between two points, one at distance "*a*" from centre and other at distance "3 *a*" from centre is V, then electric field at distance 3 *a* from centre is ______________.

(A) $\frac{V}{6a}$ (B) $\frac{V}{3a}$ (C) $\frac{V}{4a}$ (D) $\frac{V}{2a}$

(132) The distance between two points A and B is 2 *L*. $+q$ and $-q$ charges are placed at points A and B respectively. The midpoint of distance AB is C. What is the work done for $+Q$ charge to move in semicircle arc CRD ?

(A) $\frac{qQ}{2\pi \epsilon_0 L}$ (B) $\frac{qQ}{6\pi \epsilon_0 L}$ (C) $\frac{-qQ}{6\pi \epsilon_0 L}$ (D) $\frac{qQ}{4\pi \epsilon_0 L}$

(133) The distance between two thin rings of radius R is *d*. The charge on these rings are $+Q$ and $-Q$ respectively. The potential difference between centre of these two rings is ______________.

(A) Zero

(B) $\frac{Q}{4\pi \epsilon_0}\left[\frac{1}{R} - \frac{1}{\sqrt{R^2 + d^2}}\right]$

(C) $\frac{QR}{2\pi \epsilon_0 d^2}$

(D) $\frac{Q}{2\pi \epsilon_0}\left[\frac{1}{R} - \frac{1}{\sqrt{R^2 + d^2}}\right]$

Ans. : 120 (A), 121 (B), 122 (C), 123 (D), 124 (A), 125 (B), 126 (D), 127 (D), 128 (B), 129 (D), 130 (C), 131 (A), 132 (C), 133 (D)

Equipotential surface : The surface on which all the points have same potential is called equipotential surface.

- The potential difference between any two points on equipotential surface is zero.
- The work done to move a charge on equipotential surface is always zero.
- Equipotential surfaces never intersect each other.
- Electric field on the equipotential surface is always normal to it.
- The surface of any charged conductor can be considered as equipotential surface as charge is equally distributed on it's surface.
- For point charge q, equipotential surfaces are spherical surfaces drawn with q as its centre.
- It is not necessary that equipotential surfaces are spherical because equipolential surfuce due to linear charge distribution is cylindrical.

Relation between Electric field and Electric potential

- Non-uniform electric field, $E = -\frac{dV}{dr}$
- For uniform electric field, $E = \frac{V}{d} \Rightarrow V = Ed$
- Relation between electric field and electric potential at a point in space $E = -\frac{dV}{dr}$
- Ingeneral (In cartesian co-ordinate system) $\vec{E} = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$

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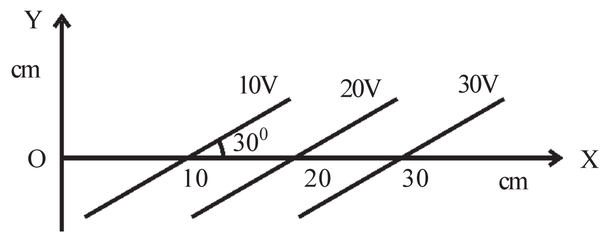
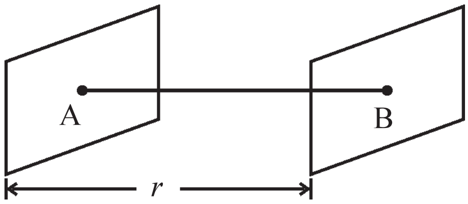
(134) Equipotential surface are shown in figure, then electric field intensity ______________.



(A) $200\ Vm^{-1}$, at 120° angle with x-axis (B) $100\ Vm^{-1}$, at 50° angle with x-axis

(C) $50\ Vm^{-1}$, In x-direction (D) $100\ Vm^{-1}$, In y-direction

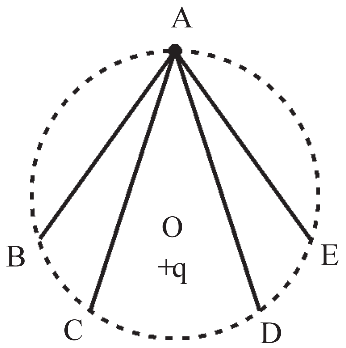
(135) Two equipotential surfaces are placed parallel near to each other at distance as shown in figure. The work done to bring a point charge q from surface A to surface B is ______________.



(A) $\frac{1}{4\pi \epsilon_0} \frac{q}{r}$ (B) $\frac{1}{4\pi \epsilon_0} \frac{q}{r^2}$

(C) $-\frac{1}{4\pi \epsilon_0} \frac{q}{r}$ (D) Zero

(136) In the electric field of a point charge q, a certain charge is carried from point A to B, C, D and E. Then the work done ______________.



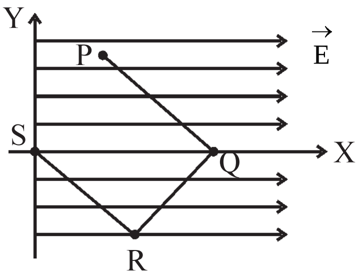
(A) is least along the path AB

(B) is least along the path AD

(C) is zero along any one of the path AB, AC, AD and AE

(D) is least along the path AE

(137) Point charge 'q' moves from point P to point S along the path PQRS in a uniform electric field E pointing co-parallel to the positive direction of the x-axis. The co-ordinates of the points P, Q, R and S are $(a, b, 0)$, $(2a, 0, 0)$, $(a, -b, 0)$ and $(0, 0, 0)$ respectively. The work done by the field in the above process is ______________.



(A) $q\text{E}a$ (B) $-q\text{E}a$

(C) $q\text{E}a\sqrt{2}$ (D) $q\text{E}\sqrt{(2a)^2+b^2}$

(138) An electric field is represented by $\vec{E} = \frac{A}{x^3}\hat{i}$ in a region. Then magnitude of electric potential in this region is ______________ Assume the electric potential zero at infinite distance.

(A) $\frac{2A}{x^2}$ (B) $\frac{A}{2x^2}$ (C) Zero (D) $\frac{-A}{x^3}$

(139) What is the electric potential of electric field $\vec{E} = y\hat{i} + x\hat{j}$?

(A) $V = -xy + C$ (B) $V = -(x+y) + C$ (C) $V = -(x^2+y^2) + C$ (D) $V = C$

(140) The electric potential at point (x, y, z) is $V = -x^2y - xz^3 + 4$. Electric field intensity at this point is______________.

(A) $\vec{E} = 2xy\hat{i} + (x^2+y^2)\hat{j} + (3xz - y^2)\hat{k}$ (B) $\vec{E} = z^3\hat{i} + xyz\hat{j} + z^2\hat{k}$

(C) $\vec{E} = (2xy - z^3)\hat{i} + xy^2\hat{j} + 3z^2x\hat{k}$ (D) $\vec{E} = (2xy + z^3)\hat{i} + x^2\hat{j} + 3xz^2\hat{k}$

(141) The electric potential at point (x, y, z) is $V = 4x^2$ V, then electric field at point (1, 0, 2) is ______ Vm^{-1}.

(A) 16, in +X direction (B) 8, in +X direction

(C) 8, in –X direction (D) 16, in –X direction

(142) The potential at a point X due to some charges situated on the X-axis is given by

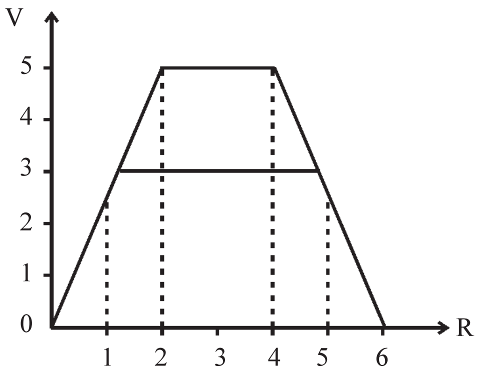
$$V(x) = \frac{20}{x^2 - 4} \text{ volt.}$$

The electric field E at $x = 4\ \mu m$ is given by ______.

(A) $\frac{10}{9}\ V\mu m^{-1}$, in $+X$ direction (B) $\frac{5}{3}\ V\mu m^{-1}$, in $-X$ direction

(C) $\frac{5}{3}\ V\mu m^{-1}$, in $+X$ direction (D) $\frac{10}{9}\ V\mu m^{-1}$, in $-X$ direction

(143) The graph of electric potential $\rightarrow$ distance R is shown in figure. At $R = 5$ m distance the electric field is ______.



(A) $2.5\ Vm^{-1}$ (B) $-2.5\ Vm^{-1}$

(C) $\frac{2}{5}\ Vm^{-1}$ (D) $\frac{-2}{5}\ Vm^{-1}$

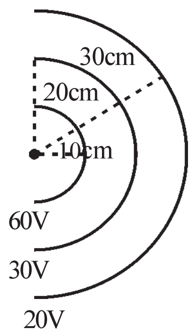
(144) The electric potential at point (x, z) in xz plane is given by $V = -Kxz$, then at distance r from origin the electric field intensity $E \propto$ ______.

(A) r^2 (B) $\frac{1}{r}$ (C) r (D) $\frac{1}{r^3}$

(145) The relation between electric potential V and distance y is $V = 5 + 4y^2$, then the force on the electric charge $-2\ \mu C$ at distance $y = 0.5$ m is ______ N.

(A) 4×10^{-6} (B) 2×10^{-6} (C) 6×10^{-6} (D) 8×10^{-6}

(146) Some equipotential surface are shown in figure. The electric field intensity at each surface is ______ Vm^{-1}.



(A) $\frac{3}{r^2}$ (B) $\frac{6}{r^2}$

(C) $\frac{9}{r^2}$ (D) Zero

(147) The linear charge density λ is given on a arc of radius r. If the angle made by the arc at origin is $\frac{\pi}{3}$, then electric potential at centre is ______________.

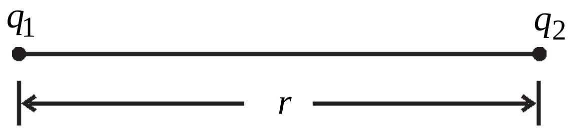
(A) $\frac{\lambda}{4 \in_0}$ (B) $\frac{\lambda}{8 \in_0}$ (C) $\frac{\lambda}{12 \in_0}$ (D) $\frac{\lambda}{16 \in_0}$

Ans. : 134 (A), 135 (D), 136 (C), 137 (B), 138 (B), 139 (A), 140 (D), 141 (C), 142 (A), 143 (A), 144 (C), 145 (D), 146 (B), 147 (C)

Electric Potential due to a system of charges

- Potential energy of point charge q is $U_p = qV_p$ (at any point p in electric field)

- **Potential energy of system of two point charges :**



$$U = \frac{kq_1q_2}{r}$$

$$U = \frac{1}{4\pi \in_0} \frac{q_1q_2}{r} \quad \text{(In vaccum)}$$

$$U = \frac{1}{4\pi \in_0 K} \frac{q_1q_2}{r} \quad \text{(In dielectric medium)}$$

- **Potential energy of system of three point charges :**

$$U = \frac{k\,q_1q_2}{r_{12}} + \frac{k\,q_2q_3}{r_{23}} + \frac{k\,q_1q_3}{r_{13}}$$

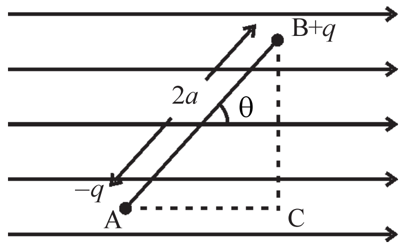
- **Potential Energy of system of '*n*' point charges :**

$$U_n = \frac{1}{4\pi \in_0} \left[\frac{q_1q_n}{|\vec{r}_n - \vec{r}_1|} + \frac{q_2q_n}{|\vec{r}_n - \vec{r}_2|} + \frac{q_{n-1}q_n}{|\vec{r}_n - \vec{r}_{n-1}|} \right]$$

- Total pairs of electric charge due to 'N' electric charges is $\frac{N(N-1)}{2}$.

- Relation between work and potential energy : If any electric charge performs motion from one point to another in an electric field, the work $W = U_f - U_i$.

Potential energy of an electric dipole in an external electric field



As the electric field is only in X-direction,

$$E = -\frac{\Delta V}{\Delta x} = -\frac{(V_B - V_A)}{AC}$$

$$E = \frac{-V_B}{2a\cos\theta} \quad [\because V_A = 0]$$

$$\therefore \quad V_B = -E\,2a\cos\theta.$$

$\therefore$ Potential energy of $+q$ at B, is

$$U = qV_B$$

$$U = -Eq\,2a\cos\theta$$

$$U = -\vec{E}\cdot\vec{p}$$

- If the axis of the dipole is normal to the electric field, then $\theta = \frac{\pi}{2}$ and

  $\therefore \quad U = Ep\cos\frac{\pi}{2} = 0$

- If the axis of the dipole is parallel to the field then $\theta = 0$

  $\therefore \quad U_{min} = -pE$

Effect in the case of a metallic conductor placed in an external electric field.

(i) A steady electric charge distribution is induced on the surface of the conductor.

(ii) The net electric field inside the conductor is zero.

(iii) The net electric charge inside the conductor is zero.

(iv) On the outer surface of the conductor, the electric field at every point is locally normal to the surface.

(v) Since $\vec{E} = 0$ at every point inside the conductor, $E = -\frac{dV}{dr}$ thus $\frac{dV}{dr} = 0$ $\therefore$ V = constant.

(vi) If there is a cavity inside the conductor then even when the conductor is placed in an external electric field $(\vec{E})$, the net electric field inside the conductor is zero and also inside the cavity is zero. This fact is called electrostatic sheilding.

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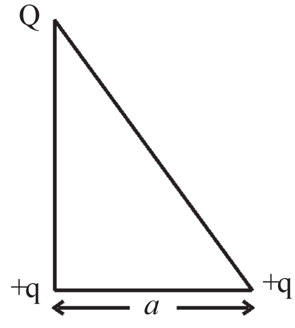
(148) on the vertices of an isosceles right angled triangle Q, $+q$ and $+q$ charges are placed as in figure. If the total electrostatic energy of the whole system is zero, $Q =$ ______________.



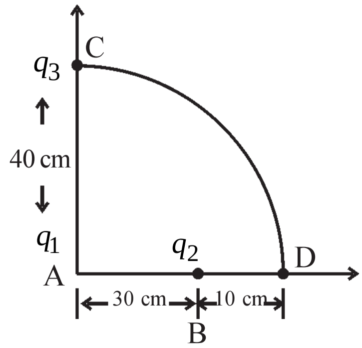
(A) $\frac{-q}{1+\sqrt{2}}$ (B) $\frac{-2q}{2+\sqrt{2}}$

(C) $-2q$ (D) $+q$

(149) On the vertices of a cube of sides b, $-q$ charges are placed. The electric potential energy of $+q$ charge placed at the centre of cube is ______________.

(A) $\frac{-4\sqrt{2}q^2}{\pi \in_0 b}$ (B) $\frac{8\sqrt{2}q^2}{4\pi \in_0 b}$ (C) $\frac{-8\sqrt{2}q^2}{\pi \in_0 b}$ (D) $\frac{-4q^2}{\sqrt{3}\pi \in_0 b}$

(150) Two charges q_1 and q_2 are placed 30 cm apart, as shown in figure. A third charge q_3 is moved along the arc of a circle of radius 40 cm from C to D. The change in the potential energy of the system is $\frac{kq_3}{4\pi \in_0}$ then K is = ______________.



(A) $6q_2$ (B) $8q_1$

(C) $8q_2$ (D) $6q_1$

(151) Three charges $-q$, Q and $-q$ are placed on a stright line at same distance. If the total potential energy of the system is zero, then $\frac{q}{Q}$ = ______________.

(A) 4:1 (B) 1:4 (C) 2:1 (D) 1:2

(152) Three charges $+q, +2q$ and Q are placed on the vertices of equilatral triangle. If total potential energy of system is zero, then Q = ______________.

(A) $\frac{q}{3}$ (B) $\frac{-2q}{3}$ (C) $\frac{-q}{3}$ (D) $\frac{+2q}{3}$

(153) Three point charges q, $2q$ and $8q$ are placed on a line of length 9 cm. If the potential energy of system is minimum then the distance between charges is ______________.

(A) 0.03 m, 0.06 m (B) 2 cm, 7 cm (C) 0.05 m, 0.04 m (D) 0.07 m, 0.02 m

(154) Four charges $+q$, $-q$, $+q$ and $-q$ are placed at vertices ABCD of a square of side r. The potential energy of the system is ______________.

(A) Zero (B) $\frac{kq^2\left(\sqrt{2}-4\right)}{r}$ (C) $\frac{kq^2\sqrt{2}}{r}$ (D) $\frac{kq\left(\sqrt{3}+2\right)}{r}$

(155) Two charges $5\ \text{nC}$ and $-2\ \text{nC}$ are placed at $(2, 0, 0)\ \text{cm}$ and $(x, 0, 0)\ \text{cm}$. If the electric potential energy of the system is $-0.5\ \mu\text{J}$ then x = ______________ cm.

(A) 10 (B) 30 (C) 20 (D) 50

(156) The length of electric dipole is 4 cm. If it is placed at angle 60^{o} in unifrom electric field then potential energy U = ____________ J. magnitude of charge $\pm 8\,nC$ and electric field $E = 2.5 \times 10^{10}\ NC^{-1}$.

(A) –4 (B) 2 (C) –8 (D) 6

(157) An electric dipole consists of two opposite charge $1\,\mu C$ separated by a distance 2 cm. The dipole is placed in an electric field of $10^5\ NC^{-1}$. The work done for displacement of dipole from equilibrium to 180° is W = ____________.

(A) 2×10^{-3} J (B) 5×10^{-2} J (C) 7×10^{-6} J (D) 4×10^{-3} J

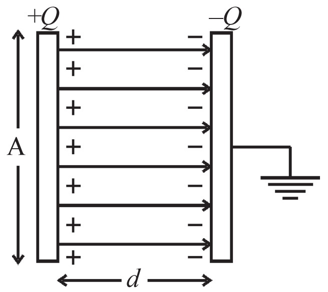
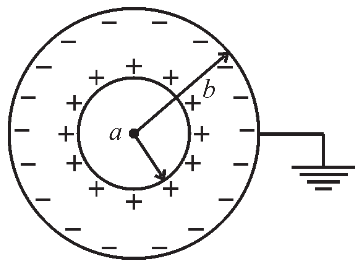
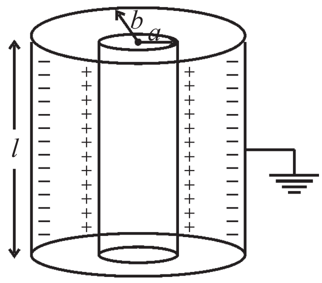
(158) Two equal point charges placed on x-axis at distance $x = -a$ and $x = +a$. A point charge Q is at origin. When the charge Q travel a distance x on x-axis the electric potential energy difference is propotional to ____________.

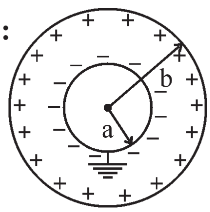
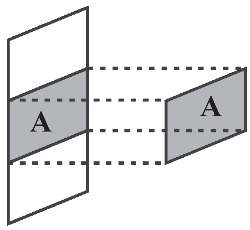
(A) x^3 (B) x^2 (C) $\frac{1}{3}$ (D) x

(159) An insulated solid sphere of radius R have positive charge density ρ. The potential energy difference to bring a charge q from centre to the surface of sphere is ____________.

(A) $\frac{\rho R q}{6 \epsilon_0}$ (B) $\frac{q\rho}{3 \epsilon_0}$ (C) Zero (D) $\frac{\rho \epsilon_0}{3q}$

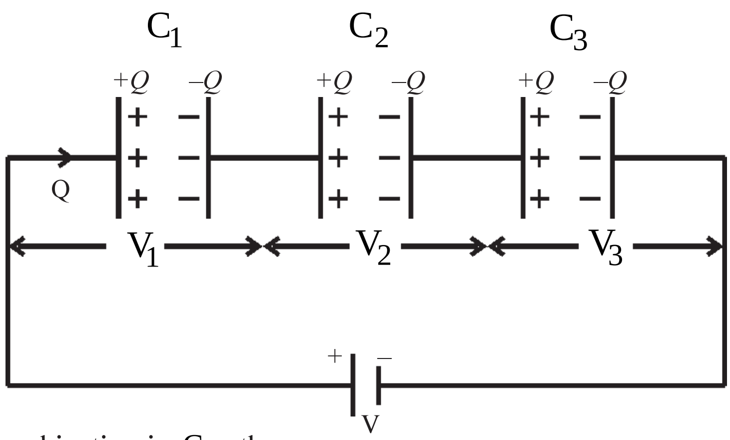
Ans. : 148 (B), 149 (D), 150 (C), 151 (A), 152 (B), 153 (A), 154 (B), 155 (C), 156 (A), 157 (D), 158 (B), 159 (A)

Parallel plate capacitor	**Spherical capacitor**	**Cylindrical capacitor**
		
● Surface charge density $\sigma = \frac{Q}{A}$	● Capacitance :	● Capacitance $C = \frac{2\pi\varepsilon_0 l}{\log_e\left(\frac{b}{a}\right)}$
● The electric field between the two paltes	$C = 4\pi\varepsilon_0\left(\frac{ab}{b-a}\right)$	In Presence of dielectric material of dielectric constant K is
$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} = \frac{V}{d}$	in *C.G.S.* $C = \frac{ab}{b-a}$	
● electric potential $V = Ed$	● electric potential $V = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{a} - \frac{1}{b}\right)$	$C' = \frac{2\pi\varepsilon_0 K l}{\log_e\left(\frac{b}{a}\right)}$

Parallel plate capacitor	Spherical capacitor	Cylindrical capacitor
● Energy stored $U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$ ● The force on one plate due to other plate is $F = \frac{Q^2}{2\varepsilon_0 A} = \frac{1}{2}\frac{CV^2}{d} = \frac{QE}{2}$ ● electric energy density $\rho_\varepsilon = \frac{1}{2}\varepsilon_0 E^2$ ● Capacitance $C = \frac{\varepsilon_0 A}{d}$ In *C.G.S.* $C = \frac{A}{4\pi d}$ ● When the dielectric substance of dielectric constant K is fill between two plates, Electric field $E' = \frac{E}{K}$ and Capacitance $C' = KC$ $C = \frac{K\varepsilon_0 A}{d}$	● If dielectric substance of dielectric constant K fill between the area of two Concentric sphere, then Capacitance : $C' = 4\pi\varepsilon_0 K\left(\frac{ab}{b-a}\right)$ ● electric potential $V = \frac{Q}{4\pi\varepsilon_0 K}\left(\frac{1}{a} - \frac{1}{b}\right)$ **Spacial Case :**  ● The induced Charge inside the sphere is $Q' = -\frac{a}{b}Q$ and capacitance $C' = 4\pi\varepsilon_0\left(\frac{b^2}{b-a}\right)$	**Special Note :** When two plates of different cross section area is given and they consist a capacitor then only effective cross section area is consider. 

Combinations of capacitors

Series Combination of Capacitors :



- The charge on every capacitor has the same value and equal to the charge of battery.
- The potential difference between the two plates of different capacitors is.

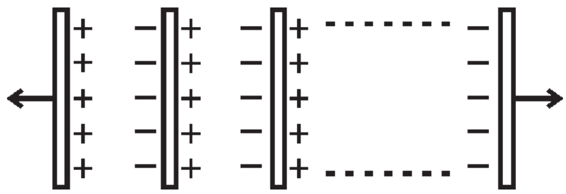
  $\therefore\ V = V_1 + V_2 + V_3$

- If the effective capacitance of this combination is C_S, then

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\therefore\ C_S = \frac{C_1C_2C_3}{C_1C_2 + C_2C_3 + C_3C_1}$$

- Electric potential $V \propto \frac{1}{C}$ and energy stored $U \propto \frac{1}{C}$.
- If two capacitors are connected in series, then the effective capacitance between them is $C_S = \frac{C_1C_2}{C_1+C_2} = \frac{\text{Multiplication}}{\text{Addition}}$.
- Electric potential $V_1 = \left(\frac{C_2}{C_1+C_2}\right)V$ and $V_2 = \left(\frac{C_1}{C_1+C_2}\right)V$.
- If n Capacitors of equal capacitance 'C' are connected in series, then equivalent capacitance is $C_S = \frac{C}{n}$ and potential difference between two ends of the each capacitor is $V' = \frac{V}{n}$.

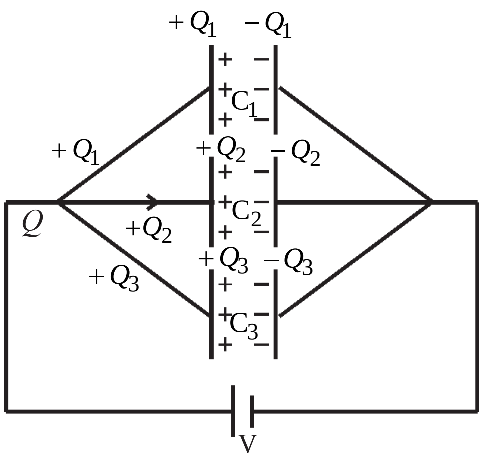


As shown in figure, if at equal distance *'d'*, *'n'* plates are placed, then it is considered as $(n-1)$ Capacitor connected in series.

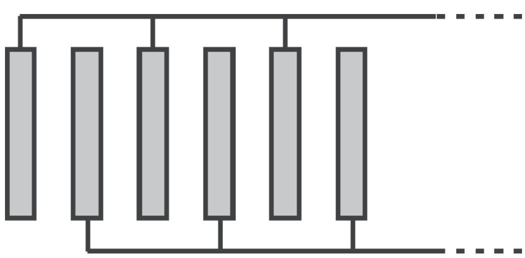
$\therefore$ Equivalent Capacitance $C' = \frac{A\varepsilon_0}{(n-1)d} = \frac{C}{(n-1)}$.

Parallel combination of Capacitors :

- In such a combination the potential difference (V) between the plates of every capacitor is the same and is equal to the potential difference.
- Electric charge Q on every capacitor is different, Therefore total charge $Q = Q_1 + Q_2 + Q_3$
- If effective capacitance is C_P then $C_P = C_1+C_2+C_3$
- Electric charge on capacitor $Q \propto C$ and energy stored $U \propto C$.
- If two capacitors are connected in parallel combination then equivalent capacitance is $C_P = C_1+C_2$.



- Electric charge $Q_1 = \left(\frac{C_1}{C_1+C_2}\right)Q$ and $Q_2 = \left(\frac{C_2}{C_1+C_2}\right)Q$.
- If n capacitors of equal capacitance 'C' are connected in parallel the equivalent capacitance is $C_P = nC$ and electric charge on each capacitor is $Q' = \frac{Q}{n}$.

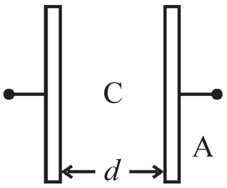


As shown in figure, if at equal distance *'d'*, *'n'* plates are placed, then it is considered as $(n-1)$ capacitor connected in parallel.

$\therefore$ Equivalent capacitance $C' = (n-1)\frac{\varepsilon_0 A}{d} = (n-1)\,C$.

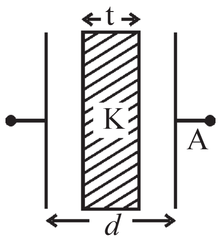
Parallel plate capacitor

Air medium between to plates



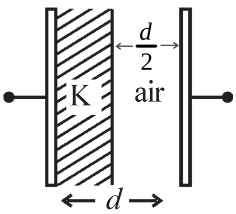
$$C = \frac{\varepsilon_0 A}{d}$$

Partially filled dielectric medium between two plates



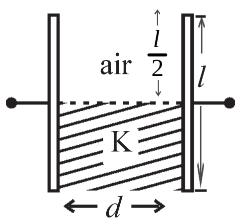
$$C = \frac{\varepsilon_0 A}{d - t\left[1 - \frac{1}{K}\right]}$$

Separation of distance



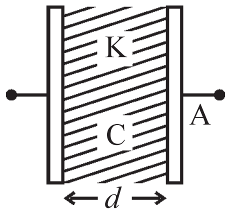
$$C' = \left[\frac{2K}{K+1}\right]C$$

Separation of area.



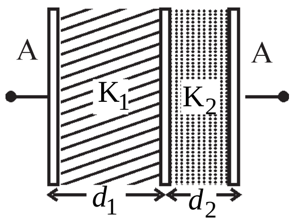
$$C' = \left[\frac{K+1}{2}\right]C$$

dielectric medium between two plates

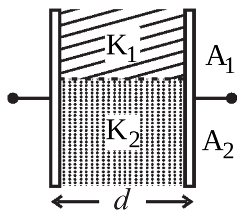


$$C' = \frac{K\varepsilon_0 A}{d} = CK$$

Separation of distance

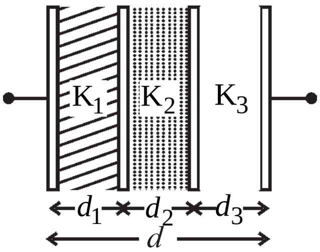


Separation of area.



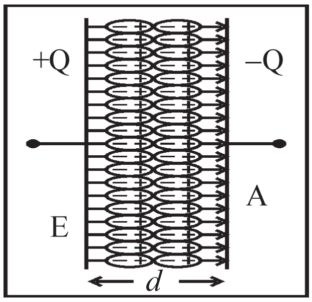
	Separation of distance	Separation of area
Behaviour :	Series connection	Parallel connection
equivalent capacitance	$C' = \varepsilon_0 A\left[\frac{K_1K_2}{K_1d_2 + K_2d_1}\right]$	$C' = \frac{\varepsilon_0}{d}(K_1A_1 + K_2A_2)$
Special case :	If $d_1 = d_2 = \frac{d}{2}$ then	If $A_1 = A_2 = \frac{A}{2}$ then
	$C' = \frac{\varepsilon_0 A}{d}\left[\frac{2K_1K_2}{K_1+K_2}\right] = \left[\frac{2K_1+K_2}{K_1K_2}\right]C$	$C' = \frac{\varepsilon_0 A}{d}\left[\frac{K_1+K_2}{2}\right] = \left[\frac{K_1+K_2}{2}\right]C$

- **Mediums of different dielectric constant between the plates :**

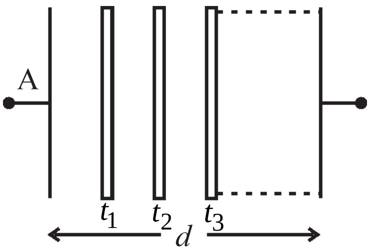


Resultant capacitor

$$C = \frac{\varepsilon_0 A}{\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}}$$

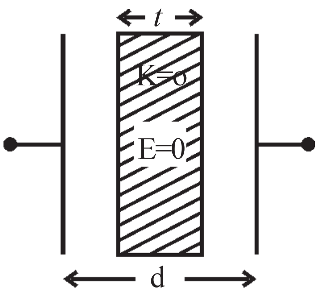


- In dielectric slab of different dielectric constant and different thickness insert between two plates of Capacitor then.



equivalent Capacitance $$C' = \frac{\varepsilon_0 A}{d - (t_1 + t_2 + t_3 + ...) + \left(\frac{t_1}{K_1} + \frac{t_2}{K_2} + \frac{t_3}{K_3} + ...\right)}$$

- **Conducting slab of thickness *t* between two plates :**



equivalent Capacitance

$$C' = \frac{\varepsilon_0 A}{(d - t)}$$

Note : If thickness of conducting plate is negligible then $t \simeq 0$.

$$C' = \frac{\varepsilon_0 A}{d} = C$$

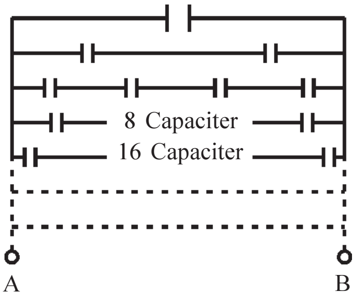
- n capacitors of equal capacitance connected in parallel the equivalent capacitance $C_{max} = nC$ and when connected in series equivalent capacitance is $C_{min} = \frac{C}{n}$

$$\therefore \frac{C_{max}}{C_{min}} = n^2 = \frac{C_P}{C_S}$$

- **Between two plates of parallel plate Capacitors a medium of dielectric constant K is insert and battery**

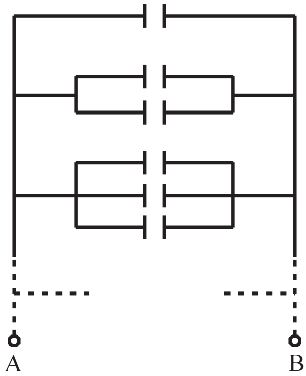
Physical quantity in air medium	**removed**	**Connected**
electric charge Q	$Q' = Q$	$Q' = KQ$
Electric field E	$E' = \frac{E}{K}$	$E' = E$
Capacitance C	$C' = KC$	$C' = KC$
electric potential	$V' = \frac{V}{K}$	$V' = V$
Energy stored	$U' = \frac{U}{K}$	$U' = KU$

- **Special Case :** As shown in figure if capacitance of each capacitor is 'C' then.



Equivalent Capacitance

$C_{AB} = 2C$



Equivalent Capacitance

$C_{AB} = \frac{1}{2}n(n+1)\,C$

Where n is number of capacitors connected in parallel

- If we want to get equivalent capacitance 'C' at voltage 'V', then 'n' capacitors of equal capacitance 'C'' and voltage 'V'' should be connected.

$$\text{Where } n = \frac{CV^2}{C'V'^2}$$

- When air is the medium between two plates of the parallel plate capacitor, then the force acting on them is

$$F = \frac{Q^2}{2\epsilon_0 A} = \frac{1}{2}\frac{CV^2}{d}$$

- Equivalent potential of two charged capacitors :

(i) If same charged plates are connected then,

$$V = \frac{Q_1+Q_2}{C_1+C_2}, \quad V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2} = \frac{Q_1' + Q_2'}{C_1 + C_2}$$

(ii) If different charged plates are connected then,

$$V = \frac{Q_1-Q_2}{C_1+C_2}, \quad V = \frac{C_1V_1 - C_2V_2}{C_1 + C_2} = \frac{Q_1' - Q_2'}{C_1 + C_2}$$

- If capacitors of capacitance C_1 and C_2 are connected in parallel, then there charge distribution is $\frac{Q_1'}{Q_2'} = \frac{C_1}{C_2}$.

- When two capacitors are connected in parallel then total charge on them is conserved. If $V_1 = V_2$, then total energy is conserved , otherwise it decreases.

- Radius of two spherical conductors is r_1 and r_2 and electric charge on them is q_1 and q_2, then in air medium if they connected with a copper wire the eqvivalent capacitance is $C = 4\pi\epsilon_0\left(r_1 + r_2\right)$.

- The loss of energy when two charged capacitors are connected $U_{loss} = \frac{C_1 C_2}{2(C_1+C_2)}(V_1 - V_2)^2$.

- **Simple electric circuits**

  - Two capacitors connected in series $V_1 = V\frac{C_2}{C_1+C_2}$, $V_2 = V\frac{C_1}{C_1+C_2}$.

  - Three capacitors connected in series

$$V_1 = \frac{C_2C_3V}{C_1C_2 + C_2C_3 + C_1C_3}, \quad V_2 = \frac{C_1C_3V}{C_1C_2 + C_2C_3 + C_1C_3}, \quad V_3 = \frac{C_1C_2V}{C_1C_2 + C_2C_3 + C_1C_3}.$$

- **Charging and discharging of *R – C* series connection :**

  Charging :

  - instantaneous electric potential $V = V_0\left(1 - e^{\frac{-t}{CR}}\right)$ $V_0 =$ maximum voltage

  - instantaneous electric potential $Q = Q_0\left(1 - e^{\frac{-t}{CR}}\right)$ $Q_0 =$ maximum charge

  - instantaneous current $I = I_0\left(1 - e^{\frac{-t}{CR}}\right)$

  - $\tau = CR$ is called time constant. Its unit is second.

  Discharging :

  - instantaneous potential $V = V_0\, e^{\frac{-t}{RC}}$

  - instantaneous charge $Q = Q_0\, e^{\frac{-t}{RC}}$

  - instantaneous current $I = -I_0\, e^{\frac{-t}{RC}}$

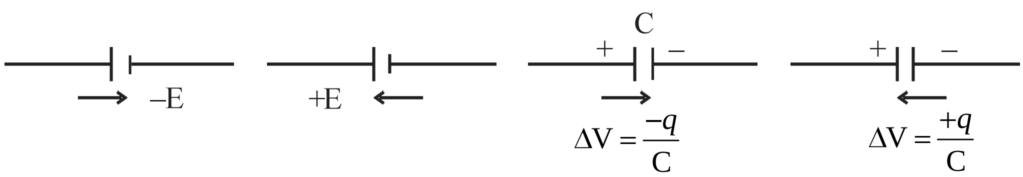
- At charging $1\,\tau$ (one time constant) after capacitor $V' = 63.212\,\%\,V$.

  After $2\,\tau$ $V = 86.466\,\%\,V$, $3\,\lambda$ After $V' = 95.021\,\%\,V$ and after $\infty\,\tau$ it gets $100\,\%\,V$.

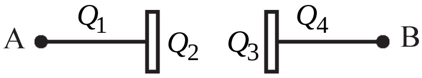
- At discharging after $1\,\lambda$ time the voltage on capacitor is $V' = 36.78\,\%\,V$.
- **Kirchoff's law of circuit with capacitors :**
- At branch point $\sum q = 0$

- For closed circuit, $\sum \frac{q}{C} = \sum E$

- Sign convention :

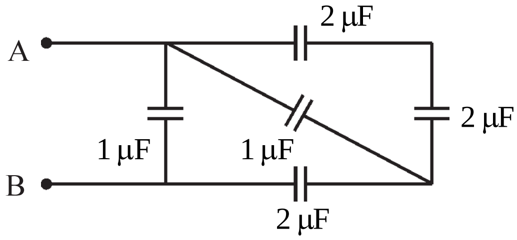


(160) In an isolated parallel plate capacitor the electric charges on the surfaces of the plates are Q_1, Q_2, Q_3 and Q_4 as shown in figure. If the capacitance is C. What is the potential difference between the plates ?



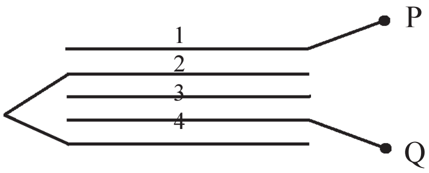
(A) $\frac{Q_1+Q_2+Q_3+Q_4}{2C}$ (B) $\frac{Q_2+Q_3}{2C}$ (C) $\frac{Q_1-Q_2-Q_3-Q_4}{2C}$ (D) $\frac{Q_2-Q_3}{2C}$

(161) In the figure, what is the equivalent capacitance between A and B ?



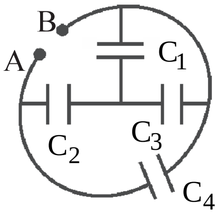
(A) 2 μF (B) 1 μF
(C) 3 μF (D) 4 μF

(162) The area of each plate shown in the figure is A and the distance between consecutive plates is *d,* then the equivalent capacitance between points P and Q is ______________.



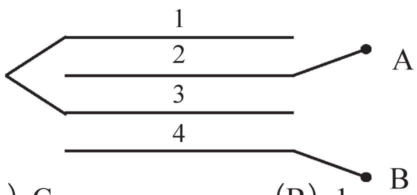
(A) $\frac{3A \in_0}{5d}$ (B) $\frac{4A \in_0}{2d}$
(C) $\frac{5A \in_0}{d}$ (D) $\frac{5A \in_0}{3d}$

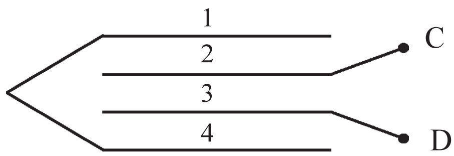
(163) 4 capacitors of $9\ \mu F$ are connected as shown in figure. The equivalent capacitance between points A and B is ______________ μF .



(A) 18 (B) 9
(C) 15 (D) 4.5

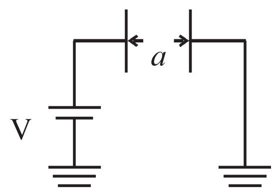
(164) Multiplication of equivalent capacitance of capacitors made by four plates as shown in figure ____________.





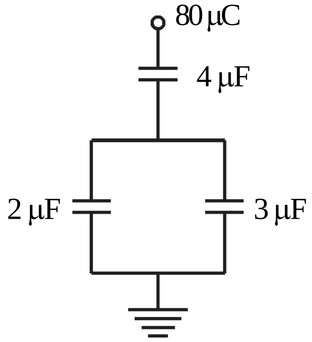
(A) C (B) 1 (C) C^2 (D) $\frac{9}{4}C^2$

(165) The area of each plate of a parallel plate capacitor is A and the separation between the plates is *a*. One plate is connected with battery of V volt and the negative terminal of battery is grounded. If the second plate of capacitor is ground then the charge on plates of capacitor is ______________.



(A) $\frac{\in_0 AV}{a}$ (B) $\frac{3}{2}\frac{\in_0 AV}{a}$ (C) $\frac{2\in_0 AV}{a}$ (D) $\frac{\in_0 AV}{2a}$

(166) $80\,\mu C$ charge is applied on the upper plate of $4\,\mu F$ capacitor as shown in figure. In steady circuit the charge on upper plate of $3\,\mu F$ capacitor is ______________ μC.

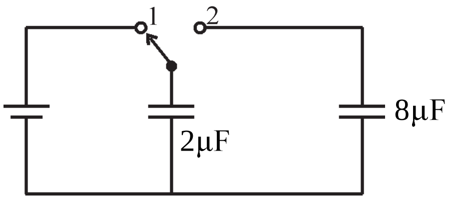


(A) 80 (B) 40
(C) 48 (D) 32

(167) Two parallel plates placed at distance 1 cm are connected to a DC source of potential difference *X*. If a steady proton at a centre of two plates move at angle 45^{o} in presence of field, then $X =$ ______________.

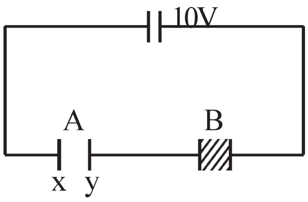
(A) 1×10^{-15} V (B) 1×10^{-10} V (C) 1×10^{-7} V (D) 1×10^{-9} V

(168) As shown in figure $2\,\mu F$ capacitor is charged. When switch S is in position-2 the percentage loss of stored energy of capacitor is ______________.



(A) 0 % (B) 20 %
(C) 75 % (D) 80 %

(169) The dimension of two capacitor A and B are same as shown in figure. A dielectric subtance of dielectric constant $K=3$ is placed between two plate of capacitor-B. The potential difference between plates A and B is ______________ respectively.



(A) 7.5 V, 2.5 V (B) 2.5 V, 7.5 V
(C) 2 V, 8 V (D) 8 V, 2 V

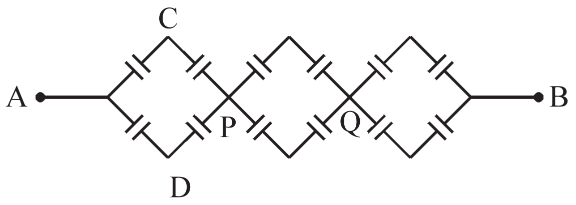
(170) The distance between two plates of parallel plate capacitor is *t*. The capacitance is 100 pF. Now a metallic slab of thickness $\frac{t}{3}$ is placed between two plates then its new capacitance is __________.

(A) 100 pF (B) 150 pF (C) $\frac{200}{3}$ pF (D) $\frac{100}{3}$ pF

(171) The area of each plate of a parallel plate capacitor is A and the separation between the plates is *a*. If a dielectric slab of dielectric constant *K* and thickness *t* $(t < d)$ is insert between the two plates then new capacitance of the capacitor ______________.

(A) $\dfrac{A\in_0}{d+t\left(1-\frac{1}{K}\right)}$ (B) $\dfrac{\in_0 A}{d-t\left(1+\frac{1}{K}\right)}$ (C) $\dfrac{A\in_0}{d+\in\left(1+\frac{1}{K}\right)}$ (D) $\dfrac{A\in_0}{d-t\left(1-\frac{1}{K}\right)}$

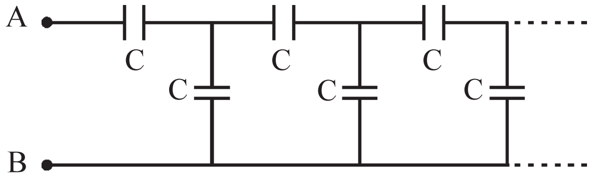
(172) In the figure below the capacitance of every capacitor is $3\ \mu F$. The equivalent capacitance between A and B is ______________.



(A) $9\ \mu F$ (B) $\frac{1}{3}\mu F$

(C) $1\ \mu F$ (D) $12\ \mu F$

(173) For the system given below the equivalent capacitance between A and B is ______________.



(A) $\left(\sqrt{5}-1\right)\frac{C}{2}$ (B) $\left(\sqrt{2}-1\right)\frac{C}{2}$

(C) $\sqrt{3}\ \frac{C}{2}$ (D) $\left(\sqrt{3}-1\right)\frac{C}{2}$

(174) n_1 capacitors of capacitance C_1 are connected in series with a battery of 4 V and are charged. n_2 capacitors of capacitance C_2 are connected in parallel with a battery of 1V volt. If the energy stored in both type connection is same then C_2 = ______________.

(A) $\frac{2C_1}{n_1 n_2}$ (B) $\frac{16 n_2 C_1}{n_1}$ (C) $\frac{2 n_2 C_1}{n_1}$ (D) $\frac{16 C_1}{n_1 n_2}$

(175) n drops of capacitance C are combine to form a big spherical drop. The capacitance of this big drop is ______________.

(A) $n^{\frac{1}{3}}C$ (B) nC (C) $n^{\frac{1}{2}}C$ (D) $n^3 C$

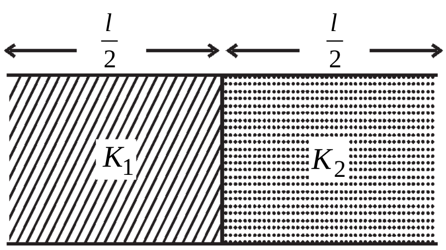
(176) When a dielectric slab of thickness $t = \frac{d}{2}$ placed between two plate of parallel plate capacitor its capacitance becomes $\frac{4}{3}$ times then the initial. Where d = distance between two plates. Then the magnitude of dielectric constant of slab is ______________.

(A) 4 (B) 8 (C) 2 (D) 6

(177) A capacitor of capacity C has charge q and stored energy is W. If the charge is increased to $2q$, the stored energy will be ______________.

(A) 2W (B) 4W (C) $\frac{W}{2}$ (D) $\frac{W}{4}$

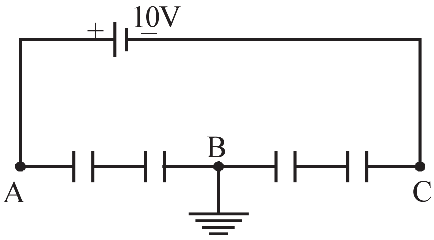
(178) Two different dielectric substance are placed between a parallel plate capacitor as shown in figure. Then the ratio of capacitance of this capacitor and a capacitor without dielectric is ______________.



(A) $\frac{K_1 K_2}{K_1 + K_2}$ (B) $K_1 + K_2$

(C) $\frac{K_1 + K_2}{2}$ (D) $2(K_1 + K_2)$

(179) Four capacitors of equal capacitance are connected with 10 V battery as shown if figure. If point B is ground then potential of point A and C is __________.



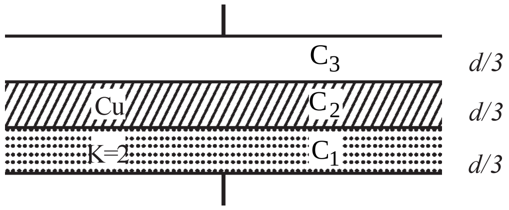
(A) +10 V, −10 V (B) +5 V, −10 V

(C) 0 V, 0 V (D) +5 V, −5 V

(180) In a variable capacitor n plates are placed in such a way that two consecutive plates are sparated by distance d then its capacitance is __________.

(A) $(n-1)$ C (B) nC (C) $\frac{C}{n}$ (D) zero

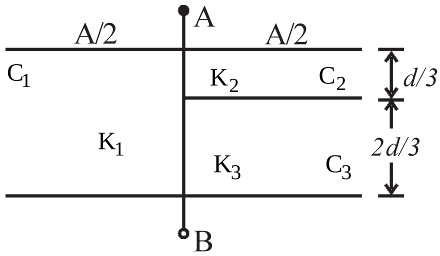
(181) The distance between two parallel plates of area A is d. A copper sheet is placed above a dielectric slab of dielectric constant $K = 2$. The equivalent capacitance of this arrangment is __________.



(A) $\frac{A \in_0}{d}$ (B) $\frac{2A \in_0}{d}$

(C) $\frac{3A \in_0}{d}$ (D) $\frac{5A \in_0}{d}$

(182) A parallel plate capacitor filled with three different dielectric materials having dielectric constants K_1, K_2 and K_3 as shown in figure. The resultant capacitance is __________.



(A) $\frac{AK_2K_3}{2d(K_1+2K_2)}$ (B) $\frac{2 \in_0 K_1K_2 A}{2d(K_2+3K_3)}$

(C) $\frac{3 \in_0 AK_2K_3}{2d(K_3+2K_2)}$ (D) $\frac{A \in_0}{2d}\left[\frac{3K_2K_3 + K_3K_1 + 2K_2K_1}{K_3+2K_2}\right]$

Ans. : 160 (D), 161 (A), 162 (A), 163 (C), 164 (C), 165 (A), 166 (C), 167 (D), 168 (D), 169 (A), 170 (B), 171 (D), 172 (C), 173 (A), 174 (D), 175 (A), 176 (C), 177 (B), 178 (C), 179 (D), 180 (A), 181 (B), 182 (D)

Assertion - Reason type Question :

Instruction : Read assertion and reason carefully, select proper option from given below.

(a) Both assertion and reason are true and reason explains the assertion.

(b) Both assertion and reason are true but reason does not explain the assertion.

(c) Assertion is true but reason is false.

(d) Assertion is false and reason is true.

(183) **Assertion :** An electron in rest position travels from a point having electric potential 10 V to the point having 30 V potential, then its kinetic energy is 3.2×10^{-18} J.

Reason : Kinetic energy $E = q\Delta V = e(V_2 - V_1) = 1.6 \times 10^{-19} (30-10) = 3.2 \times 10^{-18}$ J.

(A) (a) (B) (b) (C) (c) (D) (d)

(184) **Assertion :** The capacitance of parallel plate capacitor is decreases as the plate is increase.

Reason : The capacitance of parallel plate capacitor is $C = \frac{A \in_0}{d}$

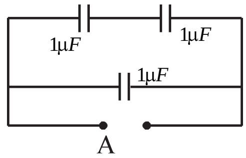
(A) (a) (B) (b) (C) (c) (D) (d)

(185) **Assertion :** Due to uniform linear charge distribution on infinitely long straight wire the electric potential at point r is propotional to log r.

Reason : $E \propto \frac{1}{r}$ and $E = -\frac{dV}{dr}$.

(A) (a) (B) (b) (C) (c) (D) (d)

(186) **Assertion :** As shown in figure the effective capacitance between points A and B is $1.5\ \mu F$.



Reason : Two capacitors in first line are in series and this connection is parallel to third capacitor.

(A) (a) (B) (b) (C) (c) (D) (d)

Ans. :183 (A), 184 (D), 185 (A), 186 (B)

Comprehension Type Questions :

The electric potential due to point charge $\pm q$, at a distance r is $V = \pm\frac{kq}{r}$. Where $K = 9 \times 10^9$ MKS. work done to transfer a electric charge q from point A to B is $W = q(V_B - V_A)$. This work can be observed as kinetic energy/potential energy of charge. Potential energy of charges q_1 and q_2 placed in air at a distance r is $U = \frac{kq_1q_2}{r}$ J. The magnitude may be positive, negative or zero depends upon the sign of charges.

(187) Potential at 1 m due to a electric charge $1 \mu C$ placed in air is ______________ V.

(A) 10^3 (B) 9×10^3 (C) 9×10^6 (D) 3×10^3

(188) Potential at mid point of dipole prepared by taking two electric charges of $\pm 10\ \mu C$ separated by distance 1 cm is ______________.

(A) zero (B) $10\ \mu V$ (C) 10 V (D) 100 V

(189) Work done to bring $10{,}000\ \mu C$ charge from A to B at 250 V potential is 2 J. Then the potential at point A is ______________ V.

(A) 10,000 (B) 10^{-2} (C) 500 (D) 50

(190) Find out the work to travel two electrons from 1 m distance to 2 m distance placed in air. Where e is electric charge and k is constant of electric.

(A) Ke^2 (B) $\frac{Ke^2}{2}$ (C) $\frac{-Ke^2}{2}$ (D) zero

(191) Two protons of charge e and mass m are placed at distance 1 m in air. If K is constant of electric force the velocity gain by proton when it is free ______________.

(A) $e\sqrt{\frac{k}{m}}$ (B) $2e\sqrt{\frac{k}{m}}$ (C) $\frac{e}{2}\sqrt{\frac{k}{m}}$ (D) zero

Ans. : 187 (B), 188 (A), 189 (D), 190 (C), 191 (A)