

Loyola

EC PHYSICS

12

VOLUME - I & II

This special guide is prepared on the basis of New Syllabus and Govt. Key

LESS STRAIN... SCORE MORE... LOYOLA PUBLICATION, TIRUNELVELI.

Loyola Publications

Vivek Illam, No. 19, Raj Nagar, N.G.O. 'A' Colony,
Palayamkottai, Tirunelveli - 627 007.
Ph: 0462 - 2553186
Cell : 94433 81701, 94422 69810, 90474 74696
81110 94696, 89400 02320, 89400 02321

₹.345/-

Less Strain Score More

Published by

Authors:

Mrs.V.Arul Flora
Mr. R. Inbaraj
Mr. J.Yesudas
Mr.Vijayan
Dr. S.Anbarasu
Mrs.A.S.Antony Samy
Mrs.A. Licy Nivethitha

Revised By :

Mr. C. Sathish Kumar

Loyola Publications

PREFACE

Student with average IQ always struggle to cope up studies. They always seek for the best, sources to learn and score high marks.

The pattern of the question being asked in the exams has changed dramatically and the difficulty level has also increased considerably. To succeed in board exams and to actualise your dream, you are required to prepare strategically and study in a focussed manner.

LOYOLA serves the above cited purpose in perfect manner.

Specially designed for coaching students of different levels. (Slow learners, average and above average students)

- Simplified text matter.
- Focussed on coverage of text book
- MCQ's are framed based on new pattern.
- NEET, IIT questions are given for top learners
- Comprehensive questions are designed for average and above average students based on key points
- **Included GMQ, PTA and Govt. question paper with their keys.**

Best wishes

LOYOLA PUBLICATION

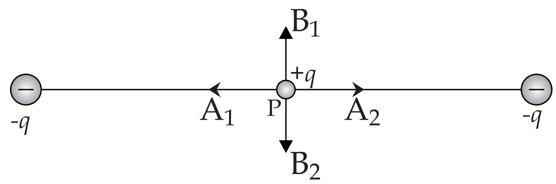
CONTENTS

UNIT 1 ELECTROSTATICS

PART I - TEXT BOOK EVALUATION

I. Multiple Choice Questions

1. Two identical point charges of magnitude -q are fixed as shown in the figure below. A third charge +q is placed midway between the two charges at the point P. Suppose this charge +q is displaced a small distance from the point P in the directions indicated by the arrows, in which direction(s) will +q be stable with respect to the displacement?



a) A_1 and A_2 b) B_1 and B_2
c) both directions d) No stable

Ans : b) B_1 and B_2

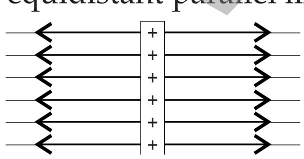
Sol : The potential due to an electric dipole along the equatorial line is zero.

2. Which charge configuration produces a uniform electric field? **HY-2019** **Aug - 2021**

a) point charge
b) uniformly charged infinite line
c) uniformly charged infinite plane
d) uniformly charged spherical shell

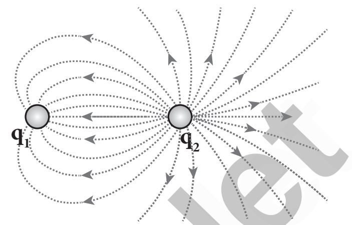
Ans: c) uniformly charged infinite plane

Sol : Uniform field lines are represented by equidistant parallel lines.



3. What is the ratio of the charges $\left|\frac{q_1}{q_2}\right|$ for the following electric field line pattern?

a) $\frac{1}{5}$ b) $\frac{25}{11}$ c) 5 d) $\frac{11}{25}$



Ans: d) $\frac{11}{25}$

Sol : Here q_1 is a negative charge and q_2 is a positive charge $\frac{q_1}{q_2} = \frac{11}{25}$ **Hint:-** Count the number of lines on each charge

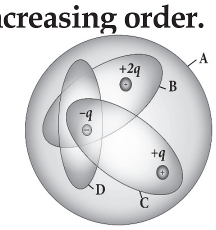
4. An electric dipole is placed at an alignment angle of 30° with an electric field of 2×10^5 N C^{-1}. It experiences a torque equal to 8 Nm. The charge on the dipole if the dipole length is 1 cm is **PTA-6** **QY-2019** **Aug - 2022**

a) 4 mC b) 8 mC c) 5 mC d) 7 mC

Ans : b) 8 mC

Sol :
$$\tau = PE\sin\theta$$
$$\tau = (q \times d)E\sin 30°$$
$$8 = (q \times 10^{-2}) \times 2 \times 10^5 \times \frac{1}{2}$$
$$\boxed{q = 8 \times 10^{-3} C} = 8mC$$

5. Four Gaussian surfaces are given below with charges inside each Gaussian surface. Rank the electric flux through each Gaussian suface in increasing order.



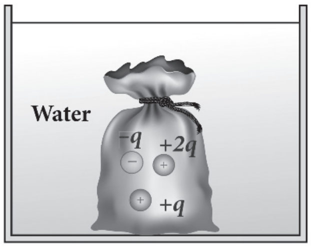
a) D < C < B < A b) A < B = C < D
c) C < A = B < D d) D > C > B > A

Ans : a) D < C < B < A

6. The total electric flux for the following closed surface which is kept inside water.

a) $\frac{80q}{\epsilon_o}$ b) $\frac{q}{40\epsilon_o}$ c) $\frac{q}{80\epsilon_o}$ d) $\frac{q}{160\epsilon_o}$

Ans: b) $\frac{q}{40\epsilon_o}$



Sol : $\phi = \frac{q}{\epsilon} = \frac{q}{\epsilon_r \epsilon_o}$

$= \frac{2q}{80\epsilon_o} \quad \because \epsilon_r = 80$

$\phi = \frac{q}{40\epsilon_o}$

7. Two identical conducting balls having positive charges q_1 and q_2 are separated by a centre to centre distance r. If they are made to touch each other and then separated to the same distance, the force between them will be **NSEP-04-05** **SEP-2020**

a) less than before b) same as before
c) more than before d) zero

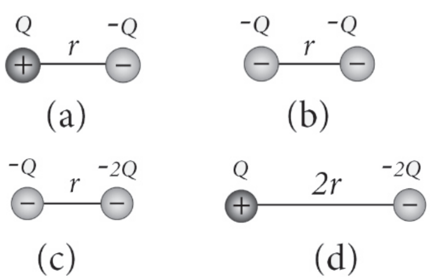
Ans : c) more than before

Sol : $F = \frac{Kq_1q_2}{r^2}$

$F' = \frac{K\left(\frac{q_1+q_2}{2}\right)\left(\frac{q_1+q_2}{2}\right)}{r^2}$

$F' > F$

8. Rank the electrostatic potential energies for the given system of charges in increasing order. **PTA-4**



a) 1 = 4 < 2 < 3 b) 2 = 4 < 3 < 1
c) 2 = 3 < 1 < 4 d) 3 < 1 < 2 < 4

Ans : a) 1 = 4 < 2 < 3

Sol : $U = K\frac{q_1q_2}{r}$

$(i) U = \frac{-KQ^2}{r}$ $(ii) U = \frac{KQ^2}{r}$

$(iii) U = \frac{K2Q^2}{r}$

$(iv) U = \frac{-K2Q^2}{2r} = -\frac{KQ^2}{r}$

9. An electric field $\vec{E} = 10x\hat{i}$ exists in a certain region of space. Then the potential difference $V = V_o - V_A$ where V_o is the potential at the origin and V_A is the potential at $x = 2$m is:

a) 10 V b) -20 V c) +20 V d) -10 V

Ans : c) +20 V

Sol : $E = \frac{-dv}{dx}$

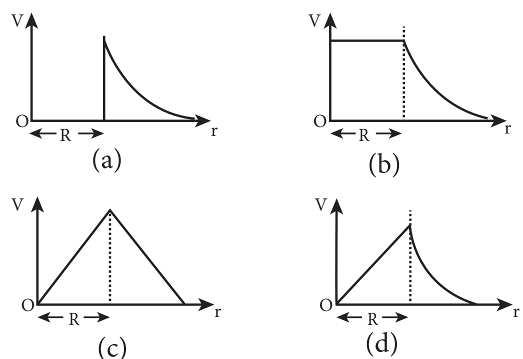
$dv = -E.dx$

$= -10x$

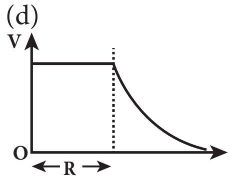
$= -10 \times (-2)$

$dv = +20V$

10. A thin conducting spherical shell of radius R has a charge Q which is uniformly distributed on its surface. The correct plot for electrostatic potential due to this spherical shell is **PTA-1**



Ans :



(b)

Sol : In a spherical shell, electric field inside is zero.but electric potential is constant.

$V = \frac{q}{4\pi\epsilon_o r}$ as distance increase its potential decreases non-linearly.

11. Two points A and B are maintained at a potential of 7 V and - 4V respectively. The work done in moving 50 electrons from A to B is

a) 8.80×10^{-17} J b) -8.80×10^{-17} J

c) 4.40×10^{-17} J d) 5.80×10^{-17} J

Ans : a) 8.80×10^{-17} J

Sol : $W_{A \to B} = (V_A - V_B)q$

$= (7+4)ne$

$= 11 \times 50 \times 1.6 \times 10^{-19}$

$= 8.8 \times 10^{-17}$ J

12. If voltage applied on a capacitor is increased from V to 2V, choose the correct conclusion.

a) Q remains the same, C is doubled **GMQ-2019**

b) Q is doubled, C doubled **MAR-2020, 23**

c) C remains same, Q doubled

d) Both Q and C remain same

Ans : c) C remains same, Q doubled

Sol : $\frac{Q_2}{Q_1} = \frac{\not{C}(2\not{V})}{\not{C}\not{V}}$

$Q_2 = 2Q_1$

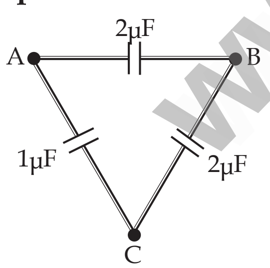
13. A parallel plate capacitor stores a charge Q at a voltage V. Suppose the area of the parallel plate capacitor and the distance between the plates are each doubled then which is the quantity that will change ? **QY-2019** **SEP-2020**

a) Capacitance b) Charge

c) Voltage d) Energy density

Ans : d) Energy density

14. Three capacitors are connected in triangle as shown in the figure. The equivalent capacitance between the points A and C is

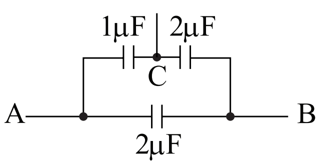


a) 1 μF b) 2μF

c) 3 μF d) 1/4μF

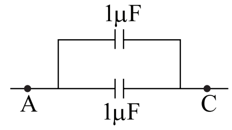
Ans : b) 2μF

Sol :



All three are parallel to each other

$C_P = \frac{C}{n} = \frac{2}{2} = 1\mu F$



$C_P = C_1 + C_2$

$= (1+1)\mu F = 2\mu F$

15. Two metallic spheres of radii 1 cm and 3 cm are given charges of -1×10^{-2} C and 5×10^{-2} C respectively. If these are connected by a conducting wire, the final charge on the bigger sphere is (AIIPMT - 2012) **May-2022**

a) 3×10^{-2} C b) 4×10^{-2} C

c) 1×10^{-2} C d) 2×10^{-2} C

Ans : a) 3×10^{-2} C

Sol : Total charge $Q = q_1 + q_2$

$= 4 \times 10^{-2}$ C

charge on bigger sphere $q_2 = Q\left(\frac{r_2}{r_1 + r_2}\right)$

$= 4 \times 10^{-2} \times \frac{3}{4}$

$q_2 = 3 \times 10^{-2}$ C

II. Short Answer Questions.

1. What is meant by quantisation of charges?

The charge q on any object is equal to an integral multiple of fundamental unit of charge 'e'.

$$q = ne$$

'n' is any integer

$(0, \pm 1, \pm 2, \pm 3, ...)$

2. Write down Coulomb's law in vector form and mention what each term represents.

Vector form :

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

$\vec{F}_{21}$ – force on the charge q_2 exerted by q_1

r – distance between two point charge

$\hat{r}_{12}$ – unit vector from q_1 to q_2

ε_0 – Permitivity of free space.

3. What are the differences between Coulomb force and gravitational force? QY-HY-2019 Mar -2023

	Coulomb force		Gravitational force
1)	It can be attractive or repulsive depends on nature of charge.	1)	It is always attractive
2)	The constant $K = 9 \times 10^9\ Nm^2\ C^{-2}$	2)	The constant $G = 6.626 \times 10^{-11}\ Nm^2\ Kg^{-2}$
3)	It depends on the medium which it exist.	3)	It is independent of medium.

4. Write a short note on superposition principle.

i) The total force acting on a given charge is equal to the vector sum of forces exerted on it by all the other charges.

ii) Consider a system of n charges $q_1, q_2, q_3 \ldots\ldots q_n$.

iii) The force on q_1 exerted by q_2 is $\vec{F}_{12} = K\dfrac{q_1q_2}{r_{21}^2}\hat{r}_{21}$

iv) The force on q_1 exerted by q_3 is $\vec{F}_{13} = K\dfrac{q_1q_3}{r_{31}^2}\hat{r}_{31}$

v) $$\vec{F}_{tot} = K\left\{\frac{q_1q_2}{r_{21}^2}\hat{r}_{21} + \frac{q_1q_3}{r_{31}^2}\hat{r}_{31} + \ldots\ldots \frac{q_1q_n}{r_{n_i}^2}\hat{r}_{n1}\right\}$$

5. Define 'electric field'. Mar -2023

➢ It is defined as the force experience by a unit positive charge, kept at that point

➢ Unit: NC^{-1} $\vec{E} = \dfrac{\vec{F}}{q_o}$

6. What is meant by 'electric field lines' ?

Electric lines of force is an imaginary straight or curved path in which unit positive charge tends to move in the presence of an electric field.

7. The electric field lines never intersect. Justify. PTA-4

➢ If two lines cross at a point, then there will be two different electric field vectors at the same point.

➢ Consequently, if some charge is placed in the intersection point, then it has to move in two different directions at the same time, which is physically impossible.

➢ Hence, electric field lines do not intersect.

8. Define 'electric dipole'. Give the expression for the magnitude of its electric dipole moment and the direction. PTA-5

<u>Electric dipole:</u>

➢ Two equal and opposite charges separated by a small distance constitute an electric dipole.

➢ The magnitude of the electric dipole moment is equal to the product of the magnitude of one of the charges and the distance between them.

➢ $|\vec{P}| = 2qa$

➢ It is acting from – q to + q.

9. Write the general definition of electric dipole moment for a collection of point charge.

➢ The electric dipole moment for a collection of 'n' point charges is given by

➢ $\vec{p} = \sum_{i=1}^{n} q_i\vec{r}_i$;

➢ $\vec{r}_i$ is the position vector of q_i from origin.

10. Define 'electrostatic potential'. **Aug -2021**

The electric potential at a point is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point in the region of the external electric field $\vec{E}$.

11. What is an equipotential surface ?

An equipotential surface is a surface on which all the points are at same electric potential.

12. What are the properties of an equipotential surface ?

- The work done to move a charge q between any two points A and B in equi-potential surface is zero.
  i.e. $W = q(V_B - V_A) = 0$, since $V_A = V_B$ in equi-potential surface.
- The electric field is always normal to an equi-potential surface.

13. Give the relation between electric field and electric potential.

$E = -\frac{dv}{dx}$ The electric field is the negative gradient of the electric potential.

14. Define 'electrostatic potential energy'.

It is defined as the amount of work done in assembling the charges at their locations by bringing them in from infinity.

15. Define 'electric flux'.

The number of electric field lines crossing a given area kept normal to the electric field lines is called electric flux.

Unit:- $Nm^2 C^{-1}$ $\varphi = \frac{q}{\epsilon_o}$

16. What is meant by electrostatic energy density ?

The Electrostatic potential energy stored per unit volume of space.

$$u = \frac{U}{V}$$

17. Write a short note on 'electrostatic shielding'.

- The process of isolating certain region of space from the external field. It is based on the fact that electric field inside a conductor is zero.
- A sensitive electrical instrument which is to be protected from external electrical disturbance is kept inside the cavity.

18. What is Polarisation ?

- Polarisation is defined as the total dipole moment per unit volume of the dielectric.
  $\vec{P} = \chi_e \vec{E}_{ext}$
  χ_e = electric susceptibility

19. What is dielectric strength?

The maximum electric field the dielectric can with stand before it breakdowns is called dielectric strength.

20. Define 'capacitance'. Give its unit.

The ratio of the magnitude of charge on either of the conductor plates to the potential difference between the conductors.

Unit:- farad (or) $C = \frac{q}{v}$

21. What is corona discharge ? **MAR-2020** **May-2022**

The reduction of total charges of the conductor near the sharp edge due to ionisation of air.

III. Long Answer Questions.

1. Discuss the basic properties of electric charges.

- The electric charge is an inherent property of particles. Its unit is coulomb.

Conservation of electric charge :

- Total electric charge in the universe is constant.
- Charge can be neither created nor destroyed.
- In any physical process, the net change in charge will always be zero.

- The charge 'q' of any object is equal to an integral multiple of the fundamental unit of charge 'e'.

  $\boxed{q = ne}$
- n is any integer
- e is charge of an electron $= 1.6 \times 10^{-19}$ C

2. Explain in detail Coulomb's law and its various aspects. **PTA-3**

i) Coulombs law states that "force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to square of distance between them.

$$\vec{F}_{21} = k\frac{q_1q_2}{r^2}\hat{r}_{12}$$

ii) The force on the charge q_2 exerted by the charge q_1 always lies along the line joining the two charges.

$\hat{r}_{12}$ is a unit vector pointing from q_1 to q_2

iii) $K = \frac{1}{4\pi\epsilon_o} = 9 \times 10^9$ Nm^{2}C^{-2}

where $\epsilon_o = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}

iv) The magnitude of the electrostatic force between two charges each of one coulomb and separated by a distance of 1m is $= 9 \times 10^9$N

v) Coulombs law in vacuum,

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_o}\frac{q_1q_2}{r^2}\hat{r}_{12}$$

In a medium of permittyvity E $\left.\right\}$ $\vec{F}_{21} = \frac{1}{4\pi\epsilon}\frac{q_1q_2}{r^2}\hat{r}_{12}$

$\epsilon > \epsilon_o$, $F_m < F$.

vi) Relative permitivity $\epsilon_r = \frac{\epsilon}{\epsilon_o}$

for vacuum and air, $\epsilon_r = 1$

for other media, $\epsilon_r > 1$

3. Define 'electric field' and discuss its various aspects.

- The electric field is defined as the force experienced by unit positive charge kept at that point.

$$\vec{E} = \frac{\vec{F}}{q_o}$$

Important aspects of the Electric field :

i) If the charge q is positive then the electric field points away from the source charge and if q is negative, the electric field points towards the source charge q.

ii) If the electric field at a point P is $\vec{E}$, then the force experienced by the test charge q_o placed at the point P is

$\vec{F} = q_o\vec{E}$

iii) Electric field is independent of the test charge q_o and depends only on the source charge q.

iv) It is a vector quantity, this field has unique direction.

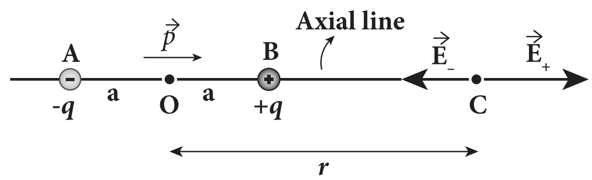
v) The test charge is made sufficiently small such that it will not modify the electric field of the source charge.

vi) For continuous and finite size charge distributions, integration techniques must be used.

4. Calculate the electric field due to a dipole on its axial line and equatorial plane.

Case (i) Electric field due to an electric dipole at points on the axial line. **Aug-21**

i) Consider an electric dipole placed on the x-axis. A point C is located at a distance of r from the midpoint of the dipole along the axial line.



The electric field at a point C due to + q is

$$\vec{E}_+ = \frac{1}{4\pi\epsilon_o}\frac{q}{(r-a)^2} \text{ (along BC)}$$

Since the electric dipole moment $\vec{p}$ along BC,

$$\vec{E}_+ = \frac{1}{4\pi\epsilon_o}\frac{q}{(r-a)^2}\hat{p} \quad ....(1)$$

The electric field at a point C due to –q is

$$\vec{E}_- = -\frac{1}{4\pi\epsilon_o}\frac{q}{(r+a)^2}\hat{p} \quad ....(2)$$

Total Electric field according to super position principle.

$$\vec{E}_{tot} = \vec{E}_{+} + \vec{E}_{-}$$

$$= \frac{1}{4\pi\epsilon_o}\frac{q}{(r-a)^2}\hat{p} - \frac{1}{4\pi\epsilon_o}\frac{q}{(r+a)^2}\hat{p}$$

- $$\vec{E}_{tot} = \frac{q}{4\pi\epsilon_o}\left(\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right)\hat{p} \quad \text{........(3)}$$
- $$\vec{E}_{tot} = \frac{1}{4\pi\epsilon_o}q\left(\frac{4ra}{(r^2-a^2)^2}\right)\hat{p} \quad \text{............(4)}$$

r >> a, so 'a' can be neglected

hence $(r^2 - a^2)^2 \simeq r^4$

Substitute is eqn (4)

$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0}\left(\frac{4aq}{r^3}\right)\hat{p}$$

$$\left(\therefore 2aq\hat{p} = \vec{p}\right)$$

$$E_{tot} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3} \quad \text{........(5)}$$

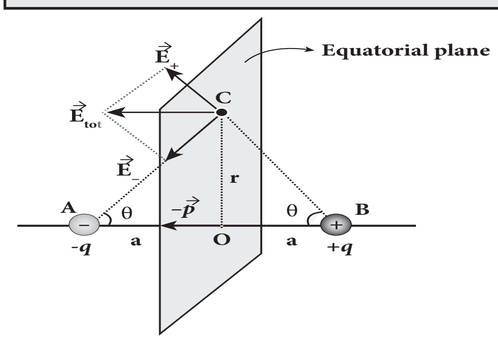
Case (ii) Electric field due to an electric dipole at a point on the equatorial plane **PTA-5**

- Consider a point C at a distance r from the midpoint O of the dipole on the equatorial plane.

  The direction of $\vec{E}_{+}$ is along BC and the direction of $\vec{E}_{-}$ is along CA.

  $\vec{E}_{+}$ and $\vec{E}_{-}$ are resolved into two components; one component parallel to the dipole axis and the other perpendicular to it.
- The perpendicular components $|\vec{E}_{+}|\sin\theta$ and $|\vec{E}_{-}|\sin\theta$ are oppositely directed and cancel each other.

$$E_{tot} = -|\vec{E}_{+}|\cos\theta\hat{p} - |\vec{E}_{-}|\cos\theta\hat{p} \quad \text{....... (1)}$$



$$|\vec{E}_{+}| = |\vec{E}_{-}| = \frac{1}{4\pi\epsilon_o}\frac{q}{(r^2+a^2)} \quad \text{.... (2)}$$

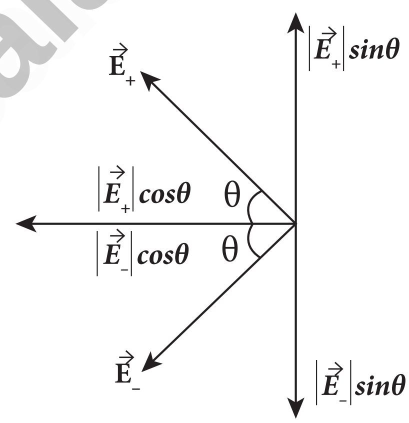
Substituting Equation (2) in (1)

$$\vec{E}_{tot} = \frac{-1}{4\pi\epsilon_0}\frac{2q\cos\theta}{(r^2+a^2)}\hat{p}$$

$$= -\frac{1}{4\pi\epsilon_o}\frac{2qa}{(r^2+a^2)^{\frac{3}{2}}}\hat{p} \quad \left(\because \cos\theta = \frac{a}{\sqrt{r^2+a^2}}\right)$$

$$\vec{E}_{tot} = -\frac{1}{4\pi\epsilon_o}\frac{\vec{p}}{(r^2+a^2)^{\frac{3}{2}}} \quad \left(\because \vec{P} = 2qa\hat{p}\right)$$

..... (3)



- At very large distances (r>>a),

$$\vec{E}_{tot} = -\frac{1}{4\pi\epsilon_o}\frac{\vec{p}}{r^3} \quad \text{....... (4)}$$

5. Derive an expression for the torque experienced by a dipole due to a uniform electric field. **PTA-3**

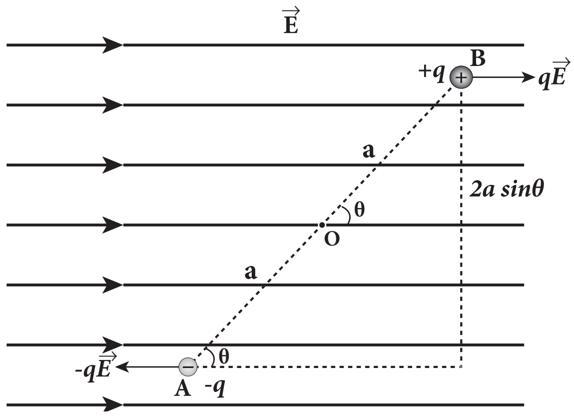
- Consider an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. The charge +q will experience a force $q\vec{E}$ in the direction of the field and charge -q will experience a force $-q\vec{E}$ in a direction opposite to the field. The total force acting on the dipole is zero.

- These two forces acting at different points will constitute a couple and the dipole experience a torque. This torque tends to rotete the dipole.

$$\vec{\tau} = \overline{OA} \times \left(-q\vec{E}\right) + \overline{OB} \times q\vec{E}$$

The magnitude of the total torque

$$\vec{\tau} = \left|\overrightarrow{OA}\right|\left|\left(-q\vec{E}\right)\right|\sin\theta + \left|\overrightarrow{OB}\right|\left|q\vec{E}\right|\sin\theta$$



Torque on dipole

$$\tau = qE.2a\sin\theta$$

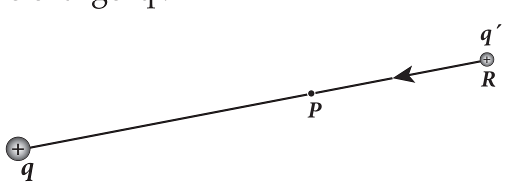
$$\vec{\tau} = \vec{p} \times \vec{E} \quad (\quad p \quad 2aq)$$

$\tau = PE\sin\theta$

- Torque (τ) is maximum when $\theta = 90^o$.
- Torque (τ) is zero when $\theta = 0^o$.
- If the electricfield is not uniform, then there will be net force acting on the dipole in addition to the torque.

6. Derive an expression for electrostatic potential due to a point charge. **Mar -2023**

- Consider a positive charge 'q' kept fixed at the origin. Let P be a point at distance r from the charge 'q'.



- The electric potential at P is

$$V = \int_{\infty}^{r} (-\vec{E}).\,d\vec{r} = -\int_{\infty}^{r} \vec{E}.d\vec{r}$$

- Electric field due to positive point charge is

$$\vec{E} = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2}\hat{r}$$

$$V = \frac{-1}{4\pi\epsilon_o}\int_{\infty}^{r}\frac{q}{r^2}\hat{r}.d\vec{r}$$

- The infinitesimal displacement vector, $d\vec{r} = dr\hat{r}$ and using $\hat{r}\,.\,\hat{r} = 1$, we have

$$V = \frac{-1}{4\pi\epsilon_o}\int_{\infty}^{r}\frac{q}{r^2}\hat{r}.dr\hat{r} = -\frac{1}{4\pi\epsilon_o}\int_{\infty}^{r}\frac{q}{r^2}dr$$

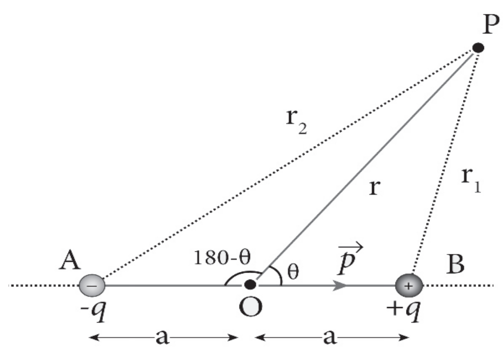
$$V = -\frac{1}{4\pi\epsilon_o}q\left\{-\frac{1}{r}\right\}_{\infty}^{r} = \frac{1}{4\pi\epsilon_o}\frac{q}{r}$$

Hence,

$$V = \frac{1}{4\pi\epsilon_o}\frac{q}{r}$$

7. Derive an expression for electrostatic potential due to an electric dipole. **PTA-4** **QY-HY-2019** **May-2022**

- Consider two equal and opposite charges separated by a small distance 2a. The point P is located at a distance r from the midpoint of the dipole. θ is angle between OP and AB.



- Let r_1 and r_2 be the distance of 'P' from + q and – q.

Potential at P due to charge +q = $\frac{-1}{4\pi\epsilon_o}\frac{q}{r_1}$

Potential at P due to charge -q = $\frac{-1}{4\pi\epsilon_o}\frac{q}{r_2}$

Hence, the total potential

$$V = \frac{q}{4\pi\epsilon_o}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad \text{.......... (1)}$$

- By the cosine law for triangle BOP,

$r_1^2 = r^2 + a^2 - 2ra\cos\theta$

$$r_1^2 = r^2\left(1 + \frac{a^2}{r^2} - \frac{2a}{r}\cos\theta\right)$$

Since r >> a

$\frac{a^2}{r^2}$ is very small, and can be neglected.

$$r_1^2 = r^2\left(1 - 2a\frac{\cos\theta}{r}\right) \quad \text{(or)}$$

$$r_1 = r\left(1 - \frac{2a}{r}\cos\theta\right)^{\frac{1}{2}}$$

$$\frac{1}{r_1} = \frac{1}{r}\left(1 - \frac{2a}{r}\cos\theta\right)^{\frac{-1}{2}}$$

using Binomial theorem.

$$\frac{1}{r_1} = \frac{1}{r}\left(1 + \frac{a}{r}\cos\theta\right) \quad \text{........... (2)}$$

Similarly applying the cosine law for triangle AOP,

$r_2^2 = r^2 + a^2 - 2ra\cos(180 - \theta)$

Since $\cos(180 - \theta) = -\cos\theta$

$r_2^2 = r^2 + a^2 + 2ra\cos\theta$

Neglecting $\frac{a^2}{r^2}$ $\quad r_2^2 = r^2\left(1 + \frac{2a\cos\theta}{r}\right)$

$$r_2 = r\left(1 + \frac{2a\cos\theta}{r}\right)^{\frac{1}{2}}$$

Using Binomial theorem,

$$\frac{1}{r_2} = \frac{1}{r}\left(1 - a\frac{\cos\theta}{r}\right) \quad \text{........... (3)}$$

- Sub (2) & (3) in eqn (1),

$$V = \frac{q}{4\pi\epsilon_o}\left(\frac{1}{r}\left(1 + a\frac{\cos\theta}{r}\right) - \frac{1}{r}\left(1 - a\frac{\cos\theta}{r}\right)\right)$$

$$V = \frac{q}{4\pi\epsilon_o}\left(\frac{1}{r}\left(1 + a\frac{\cos\theta}{r} - 1 + a\frac{\cos\theta}{r}\right)\right)$$

$$V = \frac{1}{4\pi\epsilon_o}\frac{2aq}{r^2}\cos\theta \quad (\because p = 2qa)$$

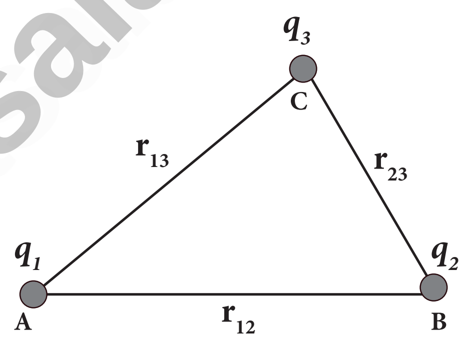
$$V = \frac{1}{4\pi\epsilon_o}\left(\frac{p\cos\theta}{r^2}\right) \left(\because p\cos\theta = \vec{p}\cdot\hat{r}\right)$$

$$V = \frac{1}{4\pi\epsilon_o}\frac{\vec{p}.\hat{r}}{r^2} \quad \text{............(4)}$$

Special cases

If the point lies near	θ	V
+q	0^0	$\frac{p}{4\pi\epsilon_0 r^2}$
-q	180^0	$-\frac{p}{4\pi\epsilon_0 r^2}$
equitorial point	90^0	0

8. Obtain an expression for potential energy due to a collection of three point charges which are separated by finite distances.



- Work done to assemble the charges is called electrostatic potential energy.

i) Bringing a charge q_1 from infinity to the point A requires no work, because there are no other charges already present.

ii) To bring the second charge q_2 to the point B, work must be done against the electric field at B created by the charge q_1. So the work done is $W = q_2 V_{1B}$. V_{1B} is electrostatic potential.

$$U = \frac{1}{4\pi\epsilon_o}\frac{q_1 q_2}{r_{12}} \quad \text{.......(1)}$$

iii) Similarly to bring the charge q_3 to the point C, work has to be done against the total electric field due to both the charges q_1 and q_2. So the work done is $W = q_3(V_{1C} + V_{2C})$.

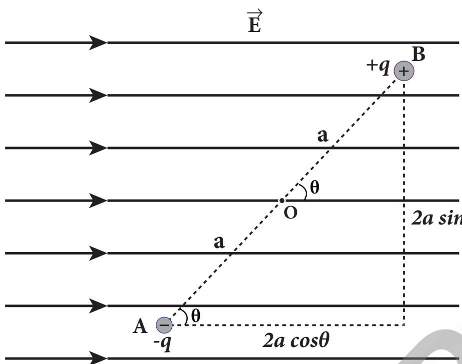
$$U = \frac{1}{4\pi\epsilon_o}\left(\frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right) \quad ....(2)$$

iv) Adding equations (2) and (3),

$$U = \frac{1}{4\pi\epsilon_o}\left(\frac{q_1q_2}{r_{12}} + \frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right) \quad ....(3)$$

9. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field. **PTA-2**

- A dipole placed in the uniform electric field $\vec{E}$. A dipole experiences a torque. This torque rotates the dipole to align it with the direction of the $\vec{E}$.
- To rotate the dipole an equal and opposite external torque must be applied on the dipole.



- The work done by the external torque to rotate the dipole from angle θ' to θ at constant angular velocity is

$$W = \int_{\theta'}^{\theta} \tau_{ext}\, d\theta \quad ....(1)$$

Since $\vec{\tau}_{ext} = \vec{\tau}_E$

$\vec{\tau}_E = \vec{p} \times \vec{E}$, we have

$$|\vec{\tau}_{ext}| = |\vec{\tau}_E| = |\vec{p} \times \vec{E}| \quad ....(2)$$

Substituting equation (2) in (1),

$$W = \int_{\theta'}^{\theta} pE\sin\theta d\theta$$

$$W = pE(\cos\theta' - \cos\theta)$$

$U(\theta) - U(\theta') = \Delta U = -PE\cos\theta + pE\cos\theta'$

- If θ' = 90º, then U(θ')= 0.
- The potential energy stored in the dipole

$$U = -pE\cos\theta = -\vec{p}.\vec{E} \quad ....(3)$$

If θ = 0º, U(θ) = – PE (minimum)

- If θ = 180º, U(θ) = PE (maximum)

10. Obtain Gauss law from Coulomb's law. **MAR-SEP 2020**

- Consider a positive point charge Q is surrounded by an imaginary sphere of radius r.
- The total electric flux for the closed surface

$$\Phi_E = \oint E.d\vec{A} = \oint EdA\cos\theta \quad ....(1)$$

The electric field of the point charge is directed radially outward at all points on the surface of the sphere. Therefore the direction of the area element $d\vec{A}$ is along the electric field $\vec{E}$ and θ=0º

$$\phi_E = \oint E.dA \text{ (since } \cos 0° = 1) \quad ....(2)$$

E is a uniform on the surface of the sphere.

$$\phi_E = E\oint dA \quad ....(3)$$

Substituting for $\oint dA = 4\pi r^2$ and

$$E = \frac{1}{4\pi\epsilon_o}\frac{Q}{r^2}, \text{ we get}$$

$$\phi_E = \frac{1}{4\pi\epsilon_o}\frac{Q}{r^2} x 4\pi r^2 = 4\pi\frac{1}{4\pi\epsilon_o}Q$$

$$\phi_E = \frac{Q}{\epsilon_o} \quad ....(4)$$

- This equation is Gauss Law.

11. Obtain the expression for electric field due to an infinitely long charged wire. **PTA-1** **MAR-2020**

- Consider an infinitely long straight wire having uniform linear charge density λ.
- Let P be point located at a perpendicular distance *r* for the wire.
- The charged wire possesses a cylindrical symmetry.

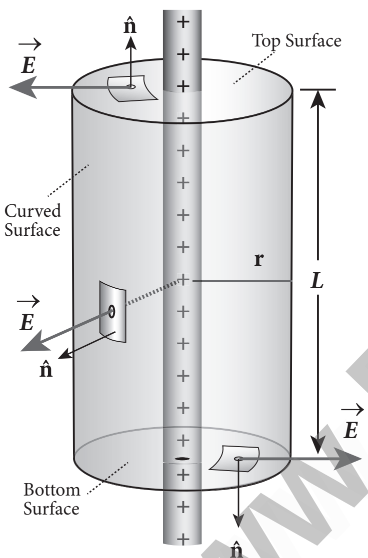
- Let us choose a cylindrical Gaussian surface of radius r and length L.
- The total electric flux in this closed surface is

$$\Phi_E = \oint \vec{E}.d\vec{A}$$

$$= \int_{\text{Curved surface}} \vec{E}.d\vec{A} + \int_{\text{top surface}} \vec{E}.d\vec{A} + \int_{\text{bottom surface}} \vec{E}.d\vec{A} \quad \text{..... (1)}$$

- For the curved surface. $\vec{E}$ is parallel to $\vec{A}$, $\vec{E}.dA = EdA$.
For the top and bottom surfaces, $\vec{E}$ is perpendicular to A, $\vec{E}.d\vec{A} = 0$

$$\Phi_E = \int_{\text{Curved surface}} EdA = \frac{Q_{encl}}{\epsilon_o} \quad \text{........ (2)}$$



Cylindrical Gaussian Surface

$Q_{encl} = \lambda L.$

$$\Phi_E = E\int_{\text{Curved surface}} dA = \frac{\lambda L}{\epsilon_o} \quad \text{........ (3)}$$

Here

$$\Phi_E = \int_{\text{Curved surface}} dA = \text{total area of the curved surface} = 2\pi rL$$

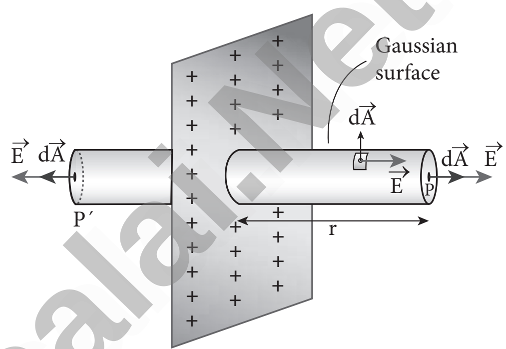
$$E.2\pi rL = \frac{\lambda L}{\epsilon_o}$$

$$E = \frac{1}{2\pi\epsilon_o}\frac{\lambda}{r} \quad \text{........ (4)}$$

In vector form $\vec{E} = \frac{1}{2\pi\epsilon_o}\frac{\lambda}{r}\hat{r}$ .... (5)

12. Obtain the expression for electric field due to an charged infinite plane sheet.

- Consider an infinite plane sheet of charges with uniform surface charge density σ.
- Let P be a point at a distance of r from the sheet.



Electric field due to changed infinite Plane sheet

- A cylindrical shaped Gaussian surface of length 2r and area A of the flat surfaces is chosen such that the infinite plane sheet passes perpendicularly through the middle part of the Gaussian surface.
- Applying Gauss law

$$\Phi_E = \oint \vec{E}.d\vec{A}$$

$$= \int_{\text{Curved surface}} \vec{E}.d\vec{A} + \int_{P} \vec{E}.d\vec{A} + \int_{P'} \vec{E}.d\vec{A} = \frac{Q_{encl}}{\epsilon_o} \quad \text{........ (1)}$$

Then,

$$\Phi_E = \oint_P EdA + \oint_{P'} EdA = \frac{Q_{encl}}{\epsilon_o} \quad \text{........ (2)}$$

$$Q_{encl} = \sigma A, \text{ we get } 2E\int_P dA = \frac{\sigma A}{\epsilon_o}$$

The total area of surface either at P or P'

$$\int_P dA = A$$

Hence $2EA = \frac{\sigma A}{\epsilon_o}$ or $E = \frac{\sigma}{2\epsilon_o}$ .... (3)

In vector form, $\vec{E} = \frac{\sigma}{2\epsilon_o}\hat{n}$ .... (4)

13. Obtain the expression for electric field due to an uniformly charged spherical shell. **GMQ-2019**

- Consider a uniformly charged spherical shell of radius R and total charge Q.

Case (a) At a point outside the shell (r>R)

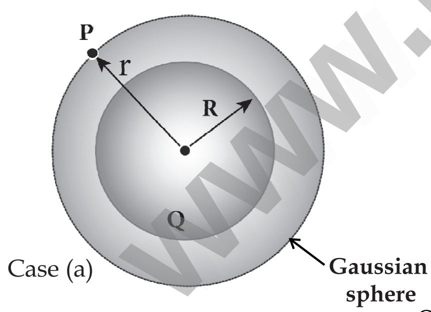
- Let us choose a point P outside the shell at a distance r from the center.
- The charge is uniformly distributed on the surface of the sphere.
  If Q > 0; Electric field radially outward.
  If Q < 0; Electric field radially inward.
- A spherical Gaussian surface of radius r is chosen and the total charge enclosed by this Gaussian surface is Q.
- By Gauss law.

$$\oint_{\text{Gaussian surface}} \vec{E}.d\vec{A} = \frac{Q}{\epsilon_o} \quad ....(1)$$

Hence $$E \oint_{\text{Gaussian surface}} dA = \frac{Q}{\epsilon_o} \quad ....(2)$$

The total area of the Gaussian surface $\int dA = 4\pi r^2$

$$E.4\pi r^2 = \frac{Q}{\epsilon_o}$$



Case (a)

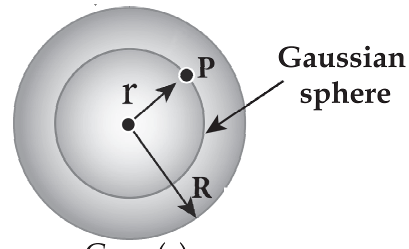
$$E.4\pi r^2 = \frac{Q}{\epsilon_o} \quad \text{or} \quad E = \frac{Q}{4\pi\epsilon_o r^2}$$

In vector form $$\vec{E} = \frac{Q}{4\pi\epsilon_o r^2}\hat{r} \quad ....(3)$$

Case (b) : At point on the surface of the spherical shell (r=R)

$$\vec{E} = \frac{Q}{4\pi\epsilon_o R^2}\hat{r} \quad ....(4)$$

Case (c) : At point inside the spherical shell (r<R)



Case (c)

- Consider a point P inside the shell at a distance r from the center.
- A Gaussian sphere of radius r is constructed.

$$\oint_{\text{Gaussian surface}} \vec{E}.d\vec{A} = \frac{Q}{\epsilon_o}$$

$$E.4\pi r^2 = \frac{Q}{\epsilon_o} \quad ....(5)$$

- Since Gaussian surface encloses no charge, Q=0.

$E = 0$ .... (6)

- The electric field due to the uniformly charged spherical shell is zero at all points inside the shell.

14. Discuss the various properties of conductors in electrostatic equilibrium.

i) The electric field is zero everywhere, inside the conductor. This is true regardless of whether the conductor is solid or hollow.

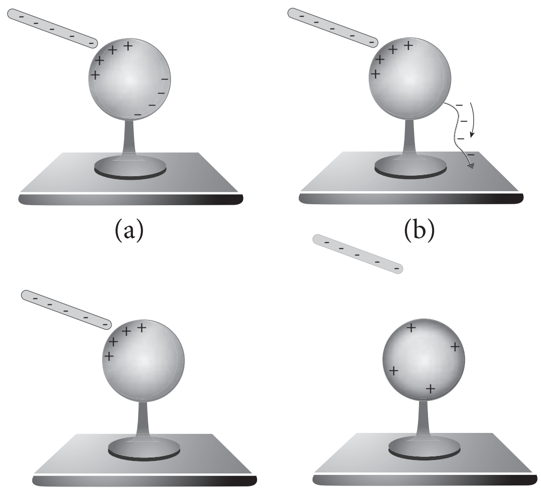
ii) There is no net charge inside the conductors. The charges must reside only on the surface of the conductors.

iii) The electric field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of σ / ε_0 Where σ is the surface charge density at that point.

iv) The electrostatic potential has the same value on the surface and inside of the conductor.

15. Explain the process of electrostatic induction.

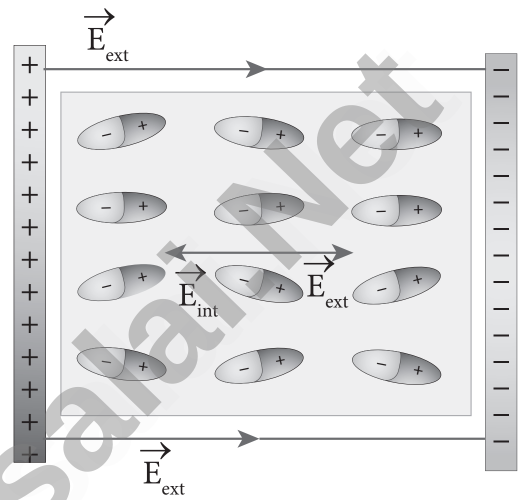
Charging without actual contact is called electrostatic induction.



- Consider an uncharged conducting sphere at rest on an insulating stand. A negatively charged rod is brought near the conductor without touching. (Fig. a)
- As a result, positive charges are induced near the region of the charged rod while negative charges repels on the farther side.
- Before introducing the charged rod, the total charge is zero. Now the distribution of particles becomes non-uniform although the total charge remains zero.
- Now the conducting sphere is connected to the ground through a conducting wire, This is called grounding. Since the ground can always receive any amount of electrons. (Fig. b)
- When the grounding wire is removed from the conductor, the positive charges remain near the charged rod. (Fig. c)
- Now the charged rod is taken away from the conductor. As soon as the charged rod is removed, the positive charge gets distributed uniformly on the surface of the conductor. By this process, the neutral conducting sphere becomes positively charged. (Fig. d)

16. Explain dielectrics in detail and how an electric field is induced inside a dielectric.

- A dielectric, has no free electrons, the external electric field only realigns the charges so that an internal electric field is produced.
- The magnitude of the internal electric field is smaller than that of external electric field.
- Therefore the net electric field inside the dielectric is not zero but is parallel to an external electric field with magnitude less than that of the external electric field.
- For example, let us consider a rectangular dielectric slab placed between two oppositely charged plates (capacitor).



- The uniform electric field between the plates acts as an external electric field $\vec{E}_{ext}$ which polarizes the dielectric placed between plates.
- The positive charges are induced on one side surface and negative charges are induced on the other side of surface.
- But inside the dielectric, the net charge is zero even in a small volume.
- So the dielectric in the external field is equivalent to two oppositely charged sheets with the surface charge densities $+\sigma_b$ and $-\sigma_b$.
- These charges are called bound charges. They are not free to move like free electrons in conductors.

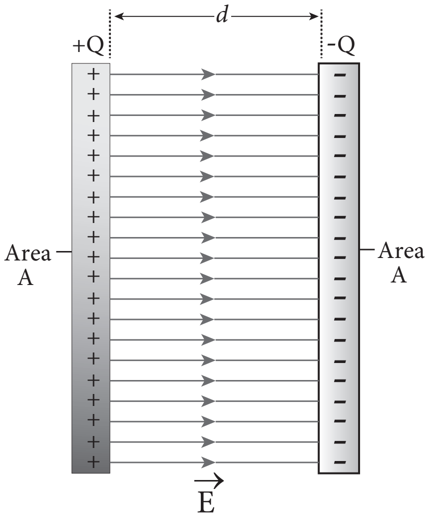
17. Obtain the expression for capacitance for a parallel plate capacitor. PTA-2

- Consider a capacitor with two parallel plates each of cross-sectional area A and separated by a distance 'd'.

  The electric field between two infinite parallel plates is uniform.

  $$E = \frac{\sigma}{\epsilon_o}$$

$\sigma = \frac{Q}{A}$ (σ = surface charge density on the plates)



Hence,

$$E = \frac{Q}{A\epsilon_o}$$

Electric potential between the plates

$$V = Ed = \frac{Qd}{A\epsilon_o}$$

∴ the capacitance of the capacitor

$$C = \frac{Q}{V} = \frac{Q}{\left(\frac{Qd}{A\epsilon_o}\right)} = \frac{\epsilon_o A}{d}$$

$$C \propto A;\ C \propto \frac{1}{d}$$

18. Obtain the expression for energy stored in the parallel plate capacitor. **GMQ- 2019, Aug- 2021** **Aug- 2022**

- Capacitor not only stores the charge but also it stores energy.
- When a battery is connected to the capacitor, electrons of total charge - Q are transferred from one plate to the other plate.
- To transfer the charge, work is done by the battery. This work done is stored as electrostatic potential energy in the capacitor.
- To transfer an infinitesimal charge dQ for a potential difference V, the work done is given by

$$dW = V\,dQ \quad \text{........... (1)}$$

where $V = \frac{Q}{C}$

- The total work done to charge a capacitor is

$$W = \int_0^Q \frac{Q}{C}\,dQ = \frac{Q^2}{2C} \quad \text{............. (2)}$$

- This work done is stored as electrostatic potential energy (U_E) in the capacitor.

$$U_E = \frac{Q^2}{2C} = \frac{1}{2}CV^2 \quad \text{............. (3)}$$

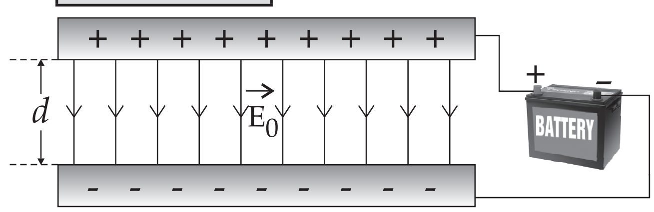
where Q = CV is used.

$U_E \propto C;\ Q \propto V^2$

19. Explain in detail the effect of a dielectric placed in a parallel plate capacitor. **PTA-6** **SEP-2020**

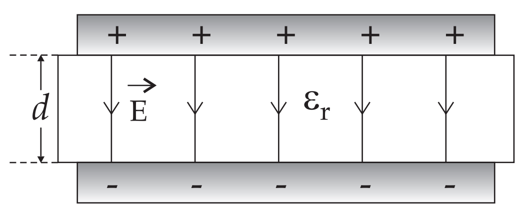
- Consider a capacitor with two parallel plates each of cross-sectional area A and are separated by distance d.
- The capacitor is charged by a battery of voltage V_0 and the charge stored is Q_0.
- The capacitance of the capacitor without the dielectric is

$$C_0 = \frac{Q_0}{V_0}$$



(a)

o



(b)

The modified electric field is

$$E = \frac{E_o}{\epsilon_r} \quad \text{.............................. (1)}$$

- Here E_o is the electric field without dielectric and ϵ_r is the dielectric constant. Since $\epsilon_r>1$, $E<E_o$.
- As a result, the electrostatic potential difference between the plates (V=Ed) is also reduced. But at the same time, the charge Q_o will remain constant once the battery is disconnected.
- Hence the new potential difference is

$$V = Ed = \frac{E_o}{\epsilon_r} d = \frac{V_o}{\epsilon_r} \quad \text{............ (2)}$$

- Thus new capacitance in the presence of a dielectric is

$$C = \frac{Q_o}{V} \epsilon_r = \frac{Q_o}{V_o} = \epsilon_r C_o \text{............ (3)}$$

Since $\epsilon_r > 1$, $C > C_o$. Thus insertion of the dielectric ϵ_r increases the capacitance.

$$C = \frac{\epsilon_r \epsilon_o A}{d} = \frac{\epsilon A}{d} \text{................ (4)}$$

where $\epsilon = \epsilon_r \epsilon_o$ is the permititivity of the dielectric medium.

- The energy stored in the capacitor before the insertion of a dielectric is given by

$$U = \frac{1}{2}\frac{Q_0^2}{C_0} \quad \text{............. (5)}$$

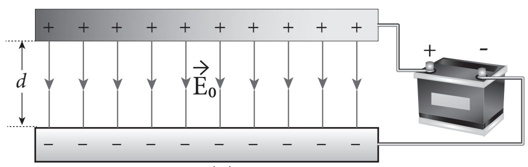
- After the dielectric is inserted, Q_0 remains constant but the capacitance is increased. The stored energy is decreased.

$$U = \frac{1}{2}\frac{Q_0^2}{C} = \frac{1}{2}\frac{Q_0^2}{\epsilon_r C_0} = \frac{U_o}{\epsilon_r} \quad \text{...........(6)}$$

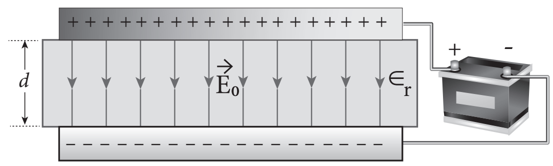
$\epsilon_r > 1$, $U < U_o$.

ii) When the battery remains connected to the capacitor.

- When dielectric is inserted, the charge stored in the capacitor is increased by ϵ_r.
- V_0 is constant



(a)



(b)

$$Q = \epsilon_r Q_o \text{.................................... (7)}$$

$$C = \frac{Q}{V_o} = \epsilon_r \frac{Q_o}{V_o} = \epsilon_r C_o \text{............................ (8)}$$

$$\text{Now, } C_o = \frac{\epsilon_o A}{d} \quad \text{and} \quad C = \frac{\epsilon A}{d} \text{...... (9)}$$

- The energy stored in the capacitor before the insertion of a dielectric is given by

$$U_o = \frac{1}{2} C_o V_o^2 \quad \text{....................... (10)}$$

- After the dielectric is inserted, the capacitance is increased and the stored energy is also increased.

$$U = \frac{1}{2} CV_o^2 = \frac{1}{2} \epsilon_r C_o V_o^2 = \epsilon_r U_o \text{ ... (11)}$$

$\epsilon_r > 1$, $U > U_o$.

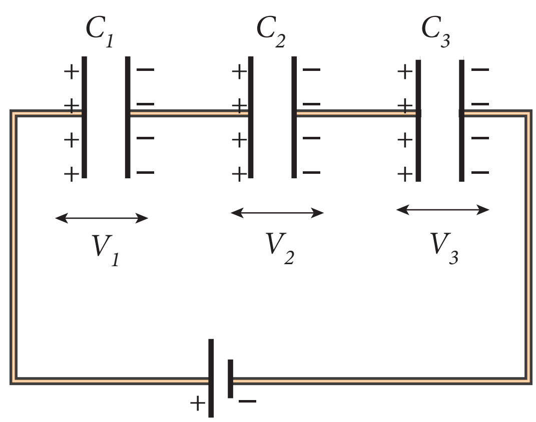
- V_o and E are constant
- The energy density is given by

$$U = \frac{1}{2} \epsilon E_o^2$$

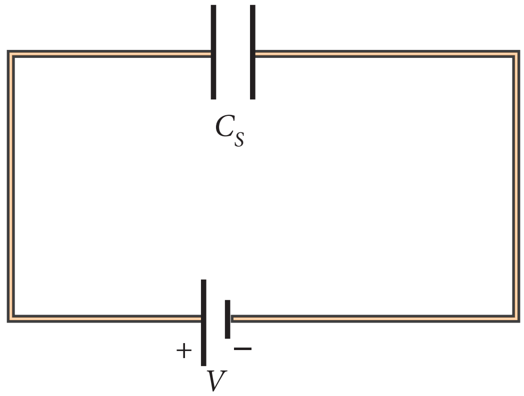
20. Derive the expression for resultant capacitance, when capacitors are connected in series and in parallel.

i) Capacitor in series **May-2022**

- Consider three capacitors of capacitance C_1, C_2 and C_3 connected in series with a battery of voltage V.



a) Capacitor connected series



b) Equivalent Capacitor

- By these processes, each capacitor stores the same amount of charge Q. But the voltage across each capacitor is different and are denoted as V_1, V_2 and V_3 respectively.

$V = V_1 + V_2 + V_3$ .... (1)

$Q = CV, V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$

$$V = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right] \quad .... (2)$$

C_S is an equivalent capacitance

$$V = \frac{Q}{C_S} \quad .... (3)$$

Substituting eqn (2) in (3)

$$\frac{Q}{C_S} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

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

- The inverse of the equivalent capacitance C_S of three capacitors connected in series is equal to the sum of the inverse of each capacitance.

ii) **Capacitance in parallel** **MAR-2020**

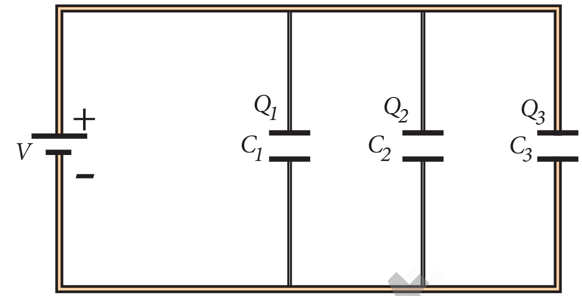
- Consider three capacitors of capacitance C_1, C_2 and C_3 connected in parallel with a battery of voltage V.
- Potential difference across each capacitor is same.

Total charge $Q = Q_1 + Q_2 + Q_3$.

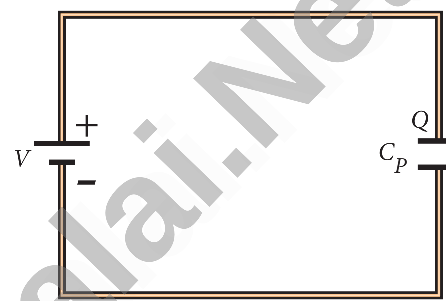
Q_1, Q_2, Q_3 - Charge stored in C_1, C_2, C_3.

Now, since Q = CV, we have

$$Q = C_1V + C_2V + C_3V$$



Capacitors in parallel



Equivalent capacitance with the same total charge

C_p is Equivalent capacitance $Q = C_pV$.

$C_pV = C_1V + C_2V + C_3V$

$C_p = C_1 + C_2 + C_3$

- The equivalent capacitance of capacitors connected in parallel is equal to the sum of the individual capacitances.

21. Explain in detail how charges are distributed in a conductor, and the principle behind the lightning conductor.

- Consider two conducting spheres A and B of radii r_1 and r_2 respectively connected to each other by a thin conducting wire.
- If a charge Q is introduced into any one of the spheres, this charge Q is redistributed into both the spheres such that the electrostatic potential is same in both the spheres.
- They are now uniformly charged and attain electrostatic equilibrium.
- Let q_1 be the charge residing on the surface of sphere A and q_2 is the charge residing on the surface of sphere B such that $Q = q_1 + q_2$.
- The charges are distributed only on the surface and there is no net charge inside the conductor.

- The electrostatic potential at the surface of the sphere A is given by

$$V_A = \frac{1}{4\pi\epsilon_o}\frac{q_1}{r_1} \quad \text{........... (1)}$$

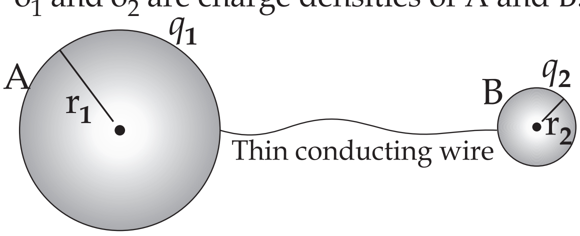
- The electrostatic potential at the surface of the sphere B is given by

$$V_B = \frac{1}{4\pi\epsilon_o}\frac{q_2}{r_2} \quad \text{........... (2)}$$

$V_A = V_B$

or $\frac{q_1}{r_1} = \frac{q_2}{r_2}$ .... (3)

σ_1 and σ_2 are charge densities of A and B.



$q_1 = 4\pi r_1^2\sigma_1$
$q_2 = 4\pi r_2^2\sigma_2$.

$\sigma_1 r_1 = \sigma_2 r_2$ .... (4)

σr = constant .... (5)

$\sigma \propto \frac{1}{r}$

Lightning conductor

- **Uses :-** To protect tall buildings from lightning strikes.
- **Principle :** action at points or corona discharge.

Construction :

- This device consists of a long thick copper rod passing from top of the building to the ground .
- The upper end of the rod has a sharp spike or sharp needles.
- The lower end of the rod is connected to the copper plate which is buried deep into the ground.

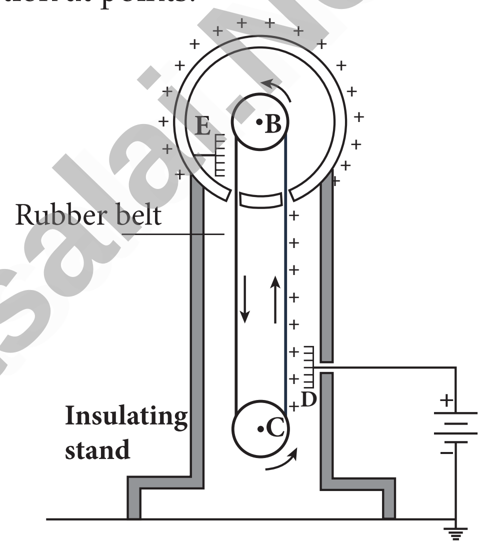
Working :

- When a negatively charged cloud is passing above the building, it induces a positive charge on the spike.
- Since the induced charge density on thin sharp spike is large, it results in a corona discharge.
- This positive charge ionizes the surrounding air which in turn neutralizes the negative charge in the cloud.
- The negative charge pushed to the spikes passes through the copper rod and is safely diverted to the earth.
- The lightning arrester does not stop the lightning; rather it diverts the lightning to the ground safely.

22. Explain in detail the construction and working of a VandeGraaff generator.

QY-2019 Aug-2022

PRINCIPLE : Electrostatic induction and action at points.



Van de Graaff

CONSTRUCTION:

- Hollow metallic sphere A is mounted on a insulating pillar.
- Pulley B is mounted at the centre of the sphere.
- Pulley C is mounted near the bottom.
- A silk belt moves over the pulleys.
- Pulley C is driven continuously by an electric motor.
- D and E are the comb shaped conductors mounted near the pulleys.

WORKING :

- 10^4V is given to the comb D.
- Near the comb D air gets ionized due to action of points.
- Negative charges move towards the needle and

- Positive charges stick to the belt, moves up and reaches the comb E. Due to the electrostatic induction.
- Comb E gets negative charge and sphere gets positive charge.
- Comb E ionize the air.
- Hence descending belt will be left uncharged.
- The machine transfers the positive charge to the sphere.
- Leakage of charges can be reduced by enclosing it in a gas filled steel chamber at very high pressure.
- It produces large potential 10^7 V.

USES :

- To accelerate positive ions (protons, deuteron) for the purpose of nuclear disintegration.

IV. EXERCISES

1. When two objects are rubbed with each other, approximately a charge of 50 nC can be produced in each object. Calculate the number of electrons that must be transferred to produce this charge. PTA-6

Sol :

$$n = \frac{q}{e} = \frac{50x10^{-9}}{1.6x10^{-19}}$$

$$= \frac{50}{1.6}x10^{10}$$

$$= \frac{50}{16}x10^{11} = 3.125x10^{11}$$

(or) $31.25x10^{10}$ electrons.

2. The total number of electrons in the human body is typically in the order of 10^{28}. Suppose, due to some reason, you and your friend lost 1% of this number of electrons. Calculate the electrostatic force between you and your friend separated at a distance of 1m. Compare this with your weight. Assume mass of each person is 60kg and use point charge approximation.

Given:

m = 60 Kg
r = 1m

n = 28
n' = 1 % of 10^{28}

$$= \frac{1}{100} \times 10^{28} = 10^{26}$$

q = n' e

$$= 10^{26} \times 1.6 \times 10^{-19}$$

$$= 1.6 \times 10^{7}\text{ C}$$

Sol :

(i) $$F_e = \frac{Kq^2}{r^2}$$

$$= \frac{9 \times 10^9 \times (1.6 \times 10^7)^2}{1^2}$$

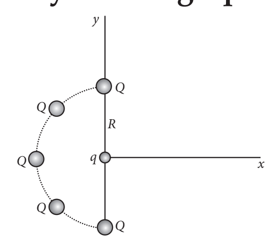
$$= 23 \times 10^{23}\text{ N}$$

(ii) $W = mg = 60 \times 9.8$

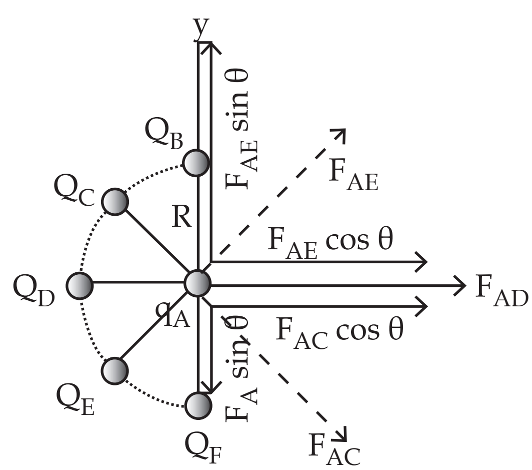
$= 588$ N

$$\frac{F_e}{W} = \frac{23 \times 10^{23}}{588} = 3.9 \times 10^{21}$$

3. Five identical charges Q are placed equidistant on a semicircle as shown in the figure. Another point charge q is kept at the center of the circle of radius R. Calculate the electrostatic force experienced by the charge q.



Sol :



$F_{AE} \sin\theta$ and $F_{AC} \sin\theta$ cancel to each other similarly Q_B and Q_F.
Total Force on q_A

$$\vec{F}_{Tot} = \vec{F}_{AD} + \vec{F}_{AE} \cos\theta\,\hat{i} + \vec{F}_{15} \cos\theta\,\hat{i}$$

$$\theta = 45^o$$

$$\cos 45^o = \frac{1}{\sqrt{2}}$$

$$\vec{F}_{Tot} = \frac{KQ_D q_A}{r^2}\hat{i} + \frac{KQ_C q_A}{r^2}\cos 45^o\,\hat{i} + \frac{KQ_E q_A}{r^2}\cos 45^o\,\hat{i}$$

$$= \frac{KQq_A}{r^2}\hat{i}\left[1 + \frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right] \quad [\because\ Q_C = Q_D = Q_E = Q]$$

$$= \frac{1}{4\pi\epsilon_0}\frac{q_A Q}{r^2}\left[1+\sqrt{2}\right]\hat{i}\ N$$

4. Suppose a charge +q on Earth's surface and another +q charge is placed on the surface of the Moon. (a) Calculate the value of q required to balance the gravitational attraction between Earth and Moon (b) Suppose the distance between the Moon and Earth is halved, would the charge q change?
(Take $m_E = 5.9 \times 10^{24}$kg, $m_M = 7.9 \times 10^{22}$kg)

Sol : $F_e = F_G$

$$K\frac{q^2}{\cancel{R^2}} = \frac{Gm_e m_m}{\cancel{R^2}}$$

$$q^2 = \frac{Gm_e\ m_m}{K}$$

$$q^2 = \frac{6.67\times10^{-11}\times5.9\times10^{24}\times7.9\times10^{22}}{9\times10^9}$$

$$= \frac{310.88}{9}\times10^{26}$$

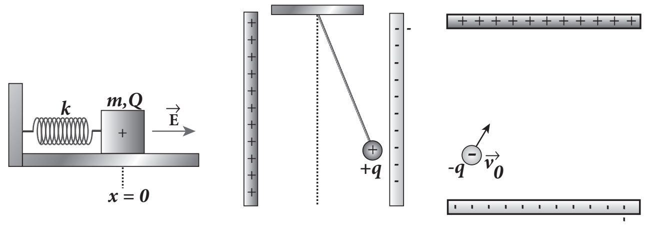
$$= 34.54 \times 10^{26}$$

$$= \sqrt{34.54\times10^{26}}$$

$$= 5.87 \times 10^{13}\ C$$

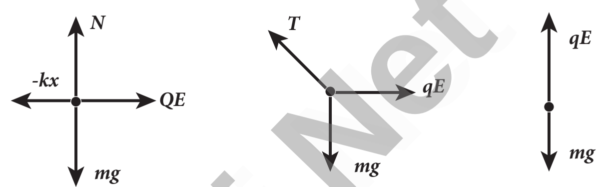
b) distance is independent hence 'q' value does not change.

5. Draw the free body diagram for the following charges as shown in the figure (a), (b) and (c).



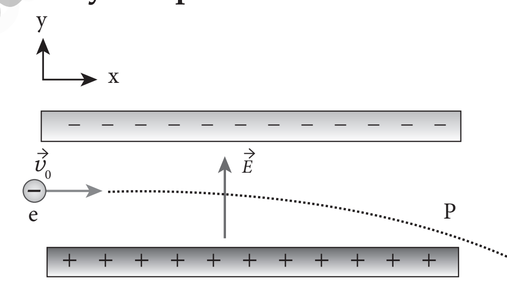
(a) (b) (c)

Ans :



(a) (b) (c)

6. Consider an electron travelling with a speed v_o and entering into a uniform electric field $\vec{E}$ which is perpendicular to $\vec{v}_o$, as shown in the Figure. Ignoring gravity, obtain the electron's acceleration, velocity and position as functions of time.



Sol : i) $a = \frac{F}{m}$

$= \frac{eE}{m}$ (along negative y-axis)

$$\vec{a} = -\frac{eE}{m}\hat{j}$$

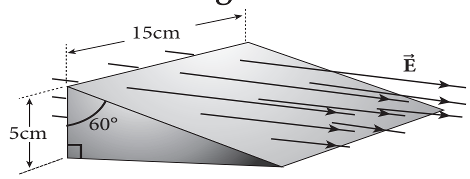
ii) Velocity acts along Positive x-axis

$$\vec{v} = v_o\hat{i} - \frac{eE}{m}t\hat{j}$$

iii) $S = ut + \frac{1}{2}at^2$

$$\vec{r} = v_o t\hat{i} - \frac{1}{2}\frac{eE}{m}t^2\hat{j}$$

7. A closed triangular box is kept in an electric field of magnitude $\vec{E} = 2 \times 10^3\ N C^{-1}$ as shown in the figure.



Calculate the electric flux through the

(a) vertical rectangular surface

(b) slanted surface and

(c) entire surface

Given:

$E = 2 \times 10^3\ NC^{-1}$

$A = 15\ cm \times 5\ cm = 75 \times 10^{-4}\ m^2$

Sol : i) $\phi = EA \cos\theta$

$\theta = 0^o$

$= 2 \times 10^3 \times 75 \times 10^{-4} \cos 0^o$

$= 15\ Nm^2\ C^{-1}$

ii) $A = 15 \times 10^{-2} \times 10 \times 10^{-2}$

$A = 150 \times 10^{-4}\ m^2$

$\phi = EA\cos\theta = 2 \times 10^3 \times 150 \times 10^{-4} \cos 60^o$

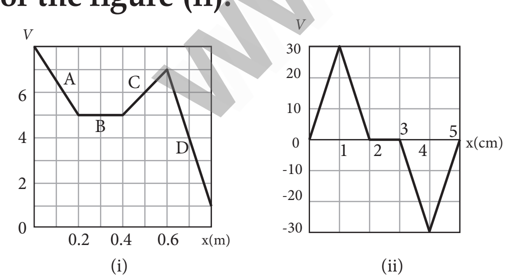
$\phi = 300 \times 10^{-1} \times \frac{1}{2}$

$= 15\ Nm^2\ C^{-1}$

iii) $\phi = EA \cos 90^o$

$\phi = 0$

8. The electrostatic potential is given as a function of *x* in figure (i) and (ii). (a) Calculate the corresponding electric fields in regions A, B, C and D for the figure (i). Plot the electric field as a function of x for the figure (ii).



Fig(a)

Sol : figure (a)

$\vec{E} = -\frac{dv}{dx}\hat{i}$

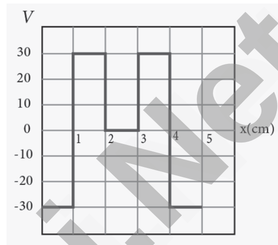
From 0 to 0.2 m,

$E_x = \frac{dv}{dx} = \frac{3}{0.2} = \frac{30}{2} = 15 Vm^{-1}$ (region A)

$E_x = \frac{dv}{dx} = 0$ Since the potential is constant (region B)

$E_x = \frac{dv}{dx} = \frac{-2}{0.2} = \frac{-20}{2} = -10 Vm^{-1}$ (region c)

$E_x = \frac{dv}{dx} = \frac{6}{0.2} = \frac{60}{2} = 30 Vm^{-1}$ (region d)



Fig(b)

$E_x = \frac{dv}{dx} = -30 Vm^{-1}$ (region 0-1 cm)

$E_x = \frac{dv}{dx} = 30 Vm^{-1}$ (region 1-2 cm)

$E_x = \frac{dv}{dx} = 0$ (region 2-3 cm)

$E_x = \frac{dv}{dx} = 30 Vm^{-1}$ (region 3-4 cm)

$E_x = \frac{dv}{dx} = -30 Vm^{-1}$ (region 4-5 cm)

9. A spark plug in a bike or a car is used to ignite the air-fuel mixture in the engine. It consists of two electrodes separated by a gap of around 0.6 mm gap as shown in the figure.

To create the spark, an electric field of magnitude $3 \times 10^6\ Vm^{-1}$ is required.

(a) What potential difference must be applied to produce the spark? (b) If the gap is increased, does the potential difference increase, decrease or remains the same ? (c) find the potential difference if the gap is 1mm.

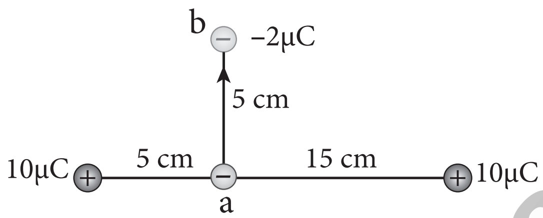
Sol :

a) $V = E \times d = 3 \times 10^6 \times 0.6 \times 10^{-3}$
$= 1800$ V

b) If the distance between the plate increased, then its capacitance will decrease which gives rise to increase in potential.

c) $V = E \times d = 3 \times 10^6 \times 1 \times 10^{-3} = 3000$V

10. A point charge of +10μC is placed at a distance of 20 cm from another identical point charge of +10μC. A point charge of -2μC is moved from point a to b as shown in the figure. Calculate the change in potential energy of the system? Interpret your result.



Sol :

$q_1 = 10 \times 10^{-6}$C, $r_1 = 5 \times 10^{-2}$m
$q_2 = -2 \times 10^{-6}$C, $r_2 = 15 \times 10^{-2}$m
$q_3 = 10 \times 10^{-6}$C

Initial PE is $U_1 = \dfrac{1}{4\pi\epsilon_0}\left(\dfrac{q_1 q_2}{r_1} + \dfrac{q_2 q_3}{r_2}\right)$

$= 9 \times 10^9 \times \dfrac{10^{-12}}{10^{-2}}\left(\dfrac{10(-2)}{5} + \dfrac{(-2)10}{15}\right)$

$= 0.9(-4 - 1.33)$

$= 0.9 \times -5.33 = -4.8$J

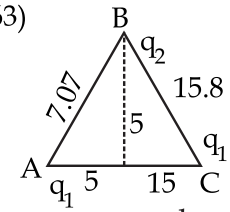
Final PE is U_2 = $AB = \sqrt{5^2 + 5^2} = 7.07$ Cm

$BC = \sqrt{5^2 + 15^2} = 15.8$ Cm

$$U_2 = \frac{1}{4\pi\epsilon_0}\left(\frac{10(-2)}{7.07 \times 10^{-12}} + \frac{(-2)10}{15.8 \times 10^{-2}}\right) \times 10^{-12}$$

$$= -9 \times 10^9 \times 20 \times 10^{-10}\left(\frac{1}{7.07} + \frac{1}{15.8}\right)$$

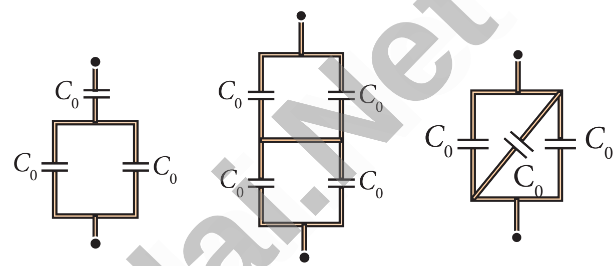
$= -18(0.141+0.063)$
$= -18(0.2043)$
$U_2 = -3.68$J



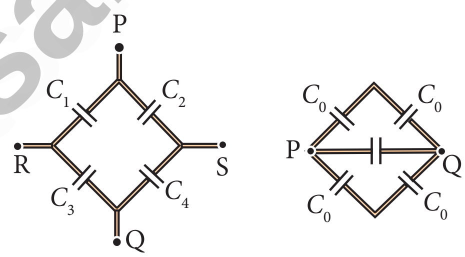
Work done, $\Delta U = U_2 - U_1$
$\Delta U = +1.12$J

Positive sign implies that to move the charge -2μC external work is required.

11. Calculate the resultant capacitances for each of the following combinations of capacitors.

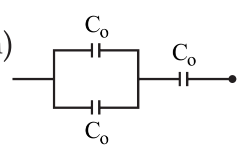


(a) (b) (c)

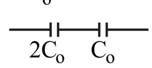


(d) (e)

Sol : a)



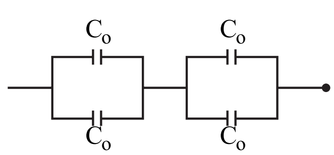
$C_P = C = 2C_o$



$$C_s = \frac{2C_o x C_o}{2C_o + C_o} = \frac{2C_o^{\,2}}{3C_o}$$

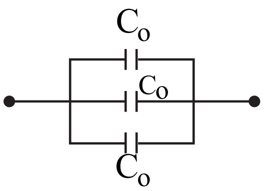
$$\boxed{C_s = \frac{2C_o}{3}}$$

b)



It is a balanced wheats tone Network

$\boxed{C_{net} = C_o}$

c) 

$C_{net} = 3C_o$

d) across RS

$$C_p = \left(\frac{C_1C_2}{C_1+C_2}\right) + \left(\frac{C_3C_4}{C_3+C_4}\right)$$

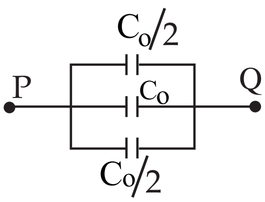
$$C_p = \frac{C_1C_2C_3 + C_1C_2C_4 + C_1C_3C_4 + C_2C_3C_4}{(C_1+C_2)(C_3+C_4)}$$

across PQ

$$C_P = \left(\frac{C_1C_3}{C_1+C_3}\right) + \left(\frac{C_2C_4}{C_2+C_4}\right)$$

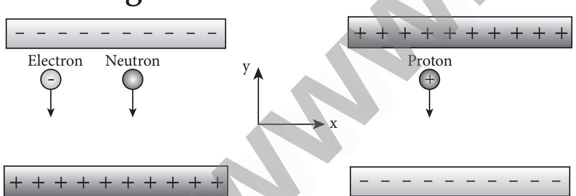
$$C_P = \frac{C_1C_2C_3 + C_1C_3C_4 + C_1C_2C_4 + C_2C_3C_4}{(C_1+C_3)(C_2+C_4)}$$

e) across PQ;



$C_{PQ} = 2C_o$

12. An electron and a proton are allowed to fall through the separation between the plates of a parallel plate capacitor of voltage 5V and separation distance h = 1mm as shown in the figure.



a) Calculate the time of flight for both electron and proton (b) Suppose if a neutron is allowed to fall, what is the time of flight? c) Among the three, which one will reach the bottom first?

(Take m_e =1.6 × 10^{-27} kg, m_e = 9.1×10^{-31} kg and g = 10ms^{-2})

$$E = \frac{V}{d} = \frac{5}{10^{-3}} = 5x10^3\ Vm^{-1}$$

(a) $t_e = \sqrt{\frac{2hm_e}{eE}} = \sqrt{\frac{2x10^{-3}x9.1x10^{-31}}{1.6x10^{-19}x5x10^3}}$

$= \sqrt{\frac{18.2x10^{-34}}{8x10^{-16}}}$

$= \sqrt{2.275x10^{-18}}$

$= 1.5x10^{-9}s$ = 1.5 ns

$t_p = \sqrt{\frac{2hm_p}{eE}} = \sqrt{\frac{2x10^{-3}x1.6x10^{-27}}{1.6x10^{-19}x5x10^3}}$

$= \sqrt{\frac{2}{5}x10^{-14}}$

$= \sqrt{0.4}x10^{-7} = 0.632x10^{-7}$

$= 63.2x10^{-9}s$ $\simeq 63ns$

(b) $t_n = \sqrt{\frac{2h}{g}}$

$= \sqrt{\frac{2x10^{-3}}{10}}$ $g \simeq 10\,ms^{-2}$

$= \sqrt{0.2 \text{ x } 10^{-3}}$

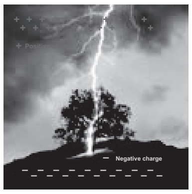
$= \sqrt{2}x10^{-2}$

$= 1.414x10^{-2}$

$= 14.1x10^{-3}$ $= 14.1ms$

(c) hence electron will reach the bottom first

13. During a thunder storm, the movement of water molecules within the clouds creates friction, partially causing the bottom part of the clouds to become negatively charged. This implies that the bottom of the cloud and the ground act as a parallel plate capacitor. If the electric field between the cloud and ground exceeds the dielectric breakdown of the air ($3x10^6$ Vm^{-1}), lightning will occur.



a) If the bottom part of the cloud is 1000 m above the ground, determine the electric potential difference that exists between the cloud and ground.

b) In a typical lightning phenomenon, around 25C of electrons are transferred from cloud to ground. How much electrostatic potential energy is transferred to the ground?

Sol :

a) $V = E \times d$

$= 3 \times 10^6 \times 10^3$

$= 3 \times 10^9$ V

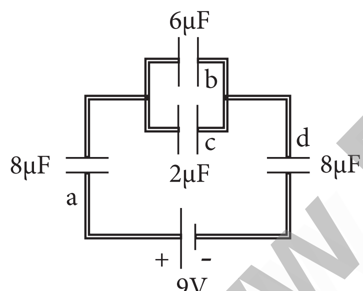
b) $U = V \times q$

$= 3 \times 10^9 \times 25$

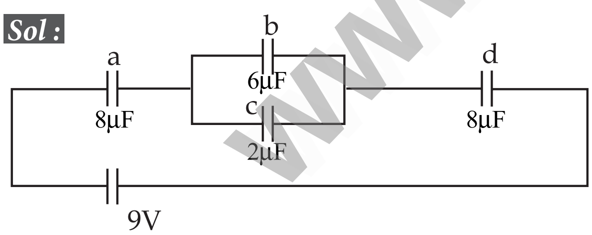
$U = 75 \times 10^9$ J

14. For the given capacitor configuration **QY-2019**

a) Find the charges on each capacitor
b) potential difference across them
c) energy stored in each capacitor.



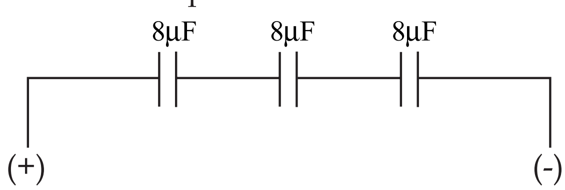
Sol :



$C_p = C_1 + C_2 = 6 + 2$

$= 8\ \mu F$

To find total capacitance.



$$C_S = \frac{C}{n} = \frac{8}{3} = 2.6 \mu F$$

$$\text{Total charge } q = CV = \frac{8}{3} \times 10^{-6} \times 9$$

$$= 24 \times 10^{-6} C$$

$$Q_a = C_a V_a = 8 \times 10^{-6} \times 3 = 24 \times 10^{-6} C$$

$$Q_b = C_b V_b = 6 \times 10^{-6} \times 3 = 18 \times 10^{-6} C$$

$$Q_c = C_c V_c = 2 \times 10^{-6} \times 3 = 6 \times 10^{-6} C$$

$$Q_d = C_d V_d = 8 \times 10^{-6} \times 3 = 24 \times 10^{-6} C$$

$$V_a = \frac{q_a}{C_a} = \frac{24\times10^{-6}}{8\times10^{-6}} = 3V$$

$$V_b = \frac{q_b}{C_b} = \frac{18\times10^{-6}}{6\times10^{-6}} = 3V$$

$$V_c = \frac{q_c}{C_c} = \frac{6\times10^{-6}}{2\times10^{-6}} = 3V$$

$$V_d = \frac{q_d}{C_d} = \frac{24\times10^{-6}}{8\times10^{-6}} = 3V$$

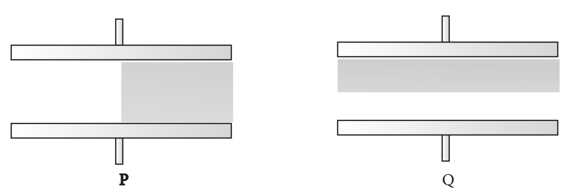
$$U_a = \frac{q^2}{2C} = \frac{24x10^{-6}x24x10^{-6}}{8x10^{-6}x2} = 36x10^{-6} J$$

$$U_b = \frac{q^2}{2C} = \frac{18x10^{-6}x18x10^{-6}}{2x6x10^{-6}} = 27x10^{-6} J$$

$$U_c = \frac{q^2}{2C} = \frac{6x10^{-6}x6x10^{-6}}{2x2x10^{-6}} = 9x10^{-6} J$$

$$U_d = \frac{q^2}{2C} = \frac{24x10^{-6}x24x10^{-6}}{2x8x10^{-6}} = 36x10^{-6} J$$

15. Capacitors P and Q have identical cross sectional areas A and separation d. The space between the capacitors is filled with a dielectric of dielectric constant ϵ_r as shown in the figure. Calculate the capacitance of capacitors P and Q. **PTA-4**



Ans:

$$C_P = \frac{\epsilon_0 A}{2d}(1+\epsilon_r)$$

$$C_Q = \frac{2\epsilon_0 A}{d}\left(\frac{\epsilon_r}{(1+\epsilon_r)}\right)$$

Sol :

i) The arrangement can be supposed to be a parallel combination of two capacitors each with plate area A/2 and separation. d.
Total capacitance $C_p = C_{air} + C_{dielectric}$

$$= \frac{\epsilon_0(A/2)}{d} + \frac{\epsilon_0(A/2)\epsilon_r}{d}$$

$$\boxed{C_p = \frac{\epsilon_0 A}{2d}(1+\epsilon_r)}$$

ii) The arrangement can be suppose to be a series combination of two capacitors, each with plate area A and separation d/2.

Total capacitance $C_Q = \frac{C_1C_2}{C_1 + C_2}$

$$\frac{1}{C_S} = \frac{1}{2\epsilon_0 A/d} + \frac{1}{2\epsilon_0\epsilon_r A/d}$$

$$= \frac{d}{2\epsilon_0 A}\left(\frac{1}{\epsilon_r} + 1\right)$$

$$= \frac{d}{2\epsilon_0 A} \times \left(\frac{1+\epsilon_r}{\epsilon_r}\right)$$

$$C_S = \frac{2\epsilon_0 A}{d}\left(\frac{\epsilon_r}{1+\epsilon_r}\right)$$

PART - II GMQ, PTA & GOVT. EXAM QUESTIONS AND ANSWERS

I. Choose the best Answer

1. When a point charge of 6mC is moved between two points in an electric field, the work done is 1.8 x 10^{-5} J. The potential difference between the two points is **GMQ-2019**

a) 1.08 V b) 1,08 μV
c) 3 V d) 30 V **Ans: c) 3 V**

Sol : $V = \frac{W}{q} = \frac{1.8 \times 10^{-5}}{6 \times 10^{-6}}$
$= 3$ V

2. An air-corecapacitor is charged by a battery. After disconnecting it from the battery, a dielectric slab is fully inserted in between its plates. Now, which of the following quantities remains constant? **PTA-1**

a) Energy b) voltage
c) Electric field d) Charge

Ans: d) Charge

3. The unit of permittivity is **PTA-2**

a) $C^2 N^{-1} m^{-2}$ b) $Nm^2 C^{-2}$
c) $H m^{-1}$ d) $N C^{-2} m^{-2}$

Ans: a) $C^2 N^{-1} m^{-2}$

4. A coil of area of cross-section 0.5 m^2 with 10 turns is in a plane which is parallel to a uniform electric field of 100 N/C. The flux through the plane is? **PTA-2**

a) 100 V.m b) 500 V.m
c) 20 V.m d) zero

Ans : b) 500 V.m

5. Dimension and unit of Electric flux is **PTA-3 Aug - 2021**

a) $ML^2 T^{-3} A^{-2}, Nm^2 C^{-1}$
b) $ML^3 T^{-3} A^{-1}, Nm^2 C^{-1}$
c) $ML^2 T^{-1} A^{-2}, Nm^2 C^{-1}$
d) $ML^{-4} T^{-3} A^{-2}, Nm^2 C^{-1}$

Ans: b) $ML^3 T^{-3} A^{-1}, Nm^2 C^{-1}$

6. At infinity, the electrostatic potential is **PTA-4**

a) Infinity b) maximum
c) minimum d) zero **Ans: d) zero**

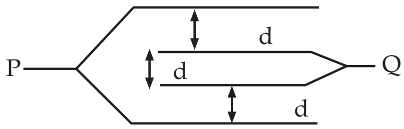
7. Five balls marked 1, 2, 3, 4 and 5 are suspended by separate threads. The pairs (1, 2) (2, 4) and (4, 1) show mutual

attraction and the pairs (2, 3) and (4, 5) show repulsion. The nature of ball marked as 1 is **PTA-5**

a) positive b) negative
c) neutral d) can't determine

Ans: c) neutral

8. The resultant capacitance of four plates,



each is having an area A, arranged as shown above, will be (plate separation is d) PTA-5

a) $\frac{A\epsilon_0}{d}$ b) $\frac{A\epsilon_0}{ed}$ c) $\frac{2A\epsilon_0}{d}$ d) $\frac{3A\epsilon_0}{d}$

Ans: c) $\frac{2A\epsilon_0}{d}$

9. An electric dipole is placed at an angle 30^o with an electric field intensity of 2×10^5 NC^{-1}. It experiences a torque equal to 4 Nm. The charge on the dipole is the dipole length is 2cm is PTA-6

a) 8 mC b) 2 mC
c) 5 mC d) 7 μC

Ans: b) 2 mC

10. Two point charges A and B having charges +Q and -Q respectively, are placed at certain distance, apart and force acting between them is F. If 25% charge of A is transformed to B, then force between the charges becomes QY -2019

a) $\frac{16}{F}$ F b) $\frac{4}{3}$ F c) F d) $\frac{9}{16}$ F

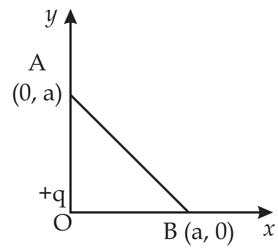
Ans: d) $\frac{9}{16}$ F

11. A cylinder of radius R and length L is placed in a uniform electric field E parallel to the cylinder axis. The total flux for the surface of the cylinder is given by QY - 2019

a) $2\pi R^2 E$ b) $\frac{\pi}{E} R^2$
c) $(\pi R^2 - \pi R)/E$ d) Zero

Ans: d) Zero

12. In the given diagram a point charge +q is placed at the origin O. Work done in taking another point charge -Q from point A to point B is : MAR-2020



a) $\frac{qQ}{4\pi\epsilon_0 a^2}\left(\frac{a}{\sqrt{2}}\right)$

b) Zero

c) $\left[\frac{-qQ}{4\pi\epsilon_0}\frac{1}{a^2}\right]\sqrt{2}a$

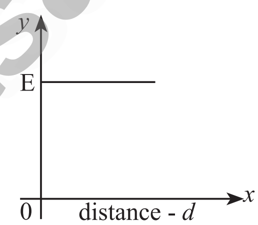
d) $\left[\frac{qQ}{4\pi\epsilon_0}\frac{1}{a^2}\right]\sqrt{2}a$

Ans: b) Zero

II. Short Answers (2 & 3 Marks)

1. Show graphically the variation of electric field E(y-axis) due to a charged infinite plane sheet with distance d(x-axis) from the plate. GMQ - 2019

It is independent of the distance. It is a straight line parallel to x-axis.



2. The electric field outside a conductor is perpendicular to its surface. Justify. PTA-1

- The electric field has components parallel to the surface of the conductor.
- The free electrons in the conductor would experience acceleration.
- The conductor is not in equilibrium. At electrostatic equilibrium, the electric field must be perpendicular to its surface.

3. State the law of converation of electric charges. PTA-2

- Total electric charge in the universe is constant.
- Charge can be neither created nor destroyed. In any physical process the net change incharge will always be zero.

4. Define the physical quantity whose unit is Vm, and state whether it is scalar or vector. **PTA-3**

- Electric flux has the unit Vm.
- The number of electric field lines passing through a given area.
  $\phi = EA \cos\theta$
- It is a scalar quantity.
- The other unit is Nm^2C^{-1}.

5. Can two equipotential surfaces intersect? Give reason. **PTA - 5**

Since the electric field is normal to the equipotential surface and also the potential difference between any two points on the surface is nullified, the intersection is not possible.

6. State Gauss law ? **Aug - 2022**

Gauss law states that the total flux of the electric field E over any closed surface is equal to $1/\epsilon_o$ times of the net charge enclosed by the surface

$$\phi_E = \frac{q}{\epsilon_o}$$

7. State coulomb's law. **Mar - 2023**

Coulomb's law states that the force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

III. Long Answer Questions (5 Marks)

1. Define electric potential. **PTA-6**
Discuss the Relation between electric field and potential

It is defined as the amount of work done in moving a unit positive charge from infinity to that point.

Relation between electric field and Potential:

Consider a positive charge q kept fixed at the origin. To move a unit positive charge by a small distance dx in the electric field E, the workdone is given by dW = - E.dx.

-ve sign indicated the work is done against the electric field.

$dw = dV$

$dV = -E\,dx$

hence $E = -\frac{dV}{dx}$

The electric field is the negative gradient of the electric potential.

2. State the rules followed while drawing electric field lines for the representation of electric field. **QY-2019**

i) The electric field lines start from a positive charge and end at negative charges or at infinity.

ii) The electric field vector at a point in space is tangential to the electric field line at the point.

iii) The electric field lines are denser (more closer) in a region where the electric field has larger magnitude and less dense in a region where the electric field is of smaller magnitude.

iv) No two electric field lines intersect each other. If two lines cross at a point, then there will be two different electric field vectors at the same point.

v) The number of electric field lines that emanate from the positive charge or end at a negative charge is directly proportional to the magnitude of the charges.

IV. Problems

1. Four point charges +q, +q and -q are to be arranged respectively at the four corners of a square PQRS of side r. Find the work needed to assemble this arrangement.

Sol : **PTA-1**

(i) First, the charge +q is brought to the corner P. This requires no work since no charge is already present, $W_P = 0$

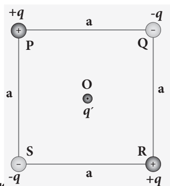
(ii) Work required to bring the charge –q to the corner Q

$$W_Q = -q \times \frac{1}{4\pi\epsilon_0}\frac{q}{a}$$
$$= \frac{1}{4\pi\epsilon_0}\frac{q^2}{a}$$

(iii) Work required to bring the charge +q to the corner R

$$W_R = -q \times \frac{1}{4\pi\epsilon_0}\left(-\frac{q}{a} + \frac{q}{\sqrt{2}a}\right)$$

$$= \frac{1}{4\pi\epsilon_0}\frac{q^2}{a}\left(-1 + \frac{q}{\sqrt{2}}\right)$$



(iv) Work required to bring the fourth charge –q at the position S

$$W_S = -q \times \frac{1}{4\pi\epsilon_0}\left(\frac{q}{a} + \frac{q}{a} + \frac{q}{\sqrt{2}a}\right)$$

$$= \frac{1}{4\pi\epsilon_0}\frac{q}{a}\left(2 - \frac{1}{\sqrt{2}}\right)$$

2. Two capacitors of unknown capacitance are connected in series and parallel. If net capacitances in two combinations are 6μF and 25μF respectively. Find their capacitances. **PTA-2**

Sol : $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_1+C_2}{C_1 C_2}$

$\Rightarrow C_s = \frac{C_1C_2}{C_1+C_2}$ But $C_p = C_1 + C_2$

Hence $C_s = \frac{C_1C_2}{C_p} \Rightarrow 6 = \frac{C_1C_2}{25}$

$\therefore C_1 C_2 = 25 \times 6 = 150$

$\Rightarrow C_2 = \frac{150}{C_1}$; $C_1 + C_2 = 25$

$C_1 = \frac{150}{C_1} = 25 \Rightarrow C_1^2 + 150 = 25\,C_1$

(or)

$C_1^2 - 25\,C_1 + 150 = 0$

$C_1^2 - 10\,C_1 - 15\,C_1 + 150 = 0$

$C_1(C_1 - 10) - 15(C_1 - 10) = 0$

$(C_1 - 10)(C_1 - 15)$ or $C_1 = 10$ or 15

If $C_1 = 10\mu F$; $C_2 = 15\mu F$

$C_1 = 15\mu F$; $C_2 = 10\mu F$

3. Calculate the force between electron and proton in Hydrogen atom. ($e = 1.6 \times 10^{-19}$ and $r_0 = 0.53$Å) **PTA-3**

Sol : $F_e = \frac{ke^2}{r^2}$

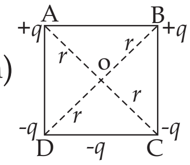
$$= \frac{9\times10^9 \times (1.6 \times 10^{-19})^2}{(0.53 \times 10^{-10})^2} = \frac{9 \times 2.56 \times 10^{-7}}{28.09}$$

$$\boxed{F_e = 8.2 \times 10^{-8}\ N}$$

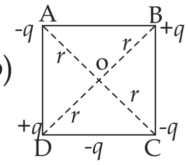
4. Four point charges are placed at the four corners of a square in two ways (a) and (b) as shown in figure. Will the (i) electric potential and (ii) electric field, at the centre of the square be the same or different in the two configurations and why? **PTA-5**

Sol :

(a)



(b)



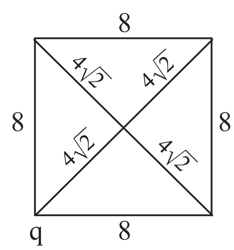
i) Electric field at the centre of fig (b) will be zero because same charges on the diagonally opposite corners of a square give zero electric field at the centre whereas it will be 'non zero' in fig (a)

ii) Electric potential will be the same in case of fig(a) and (b) because there are two positive and two negative charges of same magnitude at equal distance from centres in both the figures.

5. Charges of $+\frac{10}{3} \times 10^{-9}$ C are placed at each of the four corners of a square of side 8cm. Find the potential at the intersection of the diagonals **QY -2019**

Sol : $V = \frac{q}{4\pi\epsilon_0}\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4}\right)$

$\left[q = \frac{10}{3} \times 10^{-9} C\right]$



$$= 9 \times 10^{-9} \times \frac{10}{3} \times 10^{-9}$$

$$\times \left(\frac{1}{4\sqrt{2}\times10^{-2}} + \frac{1}{4\sqrt{2}\times10^{-2}} + \frac{1}{4\sqrt{2}\times10^{-2}} + \frac{1}{4\sqrt{2}\times10^{-2}}\right)$$

$V = 2.1216 \times 10^3$ V.

6. A parallel plate capacitor has square plates of side 5cm and separated by a distance of 1mm, then calculate the capacitance of the capacitor. **QY-2019**

Sol : $C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 25 \times 10^{-4}}{1 \times 10^{-3}}$

$= 221.2 \times 10^{-13}$ F

$C = 22.12 \times 10^{-12}$ F = 22.12 pF

7. A dipole is formed by two charges of 5μC and -5 μC at a distance of 8mm. Find the electric field at **HY-2019**

a) a point 25cm away from centre of dipole along its axial line.

b) a point 20cm away from centre of dipole along its equatorial line.

q = 5 μC, E along axial line at 25 cm = ?

E along equatorial line at 20 cm = ?

Sol : a)

$P = 2qd = 2 \times 5 \times 10^{-6} \times 8 \times 10^{-3} = 80 \times 10^{-9}$ cm

E along axial line at 25 cm

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

$= 9 \times 10^9 \times \frac{2 \times 80 \times 10^{-9}}{(25 \times 10^{-2})^3}$

$= 0.09216 \times 10^6$

$= 9.2 \times 10^4$ NC^{-1}

b) E along equatorial line at 20 cm

$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} = 9 \times 10^9 \times \frac{80 \times 10^{-9}}{(20 \times 10^{-2})^3}$

$= 0.09 \times 10^6 = 9 \times 10^4$ NC^{-1}

8. Dielectric strength of air is 4×10^6 Vm^{-1}. Suppose the radius of a hollow sphere in the Van de Graff generator is R = 0.4 m, calculate the maximum potential difference created by this Van de Graff generator. **AUG - 2021**

Given:

$E_{max} = 4 \times 10^6$ Vm^{-1}

R = 0.4 m

Sol : $V_{max} = E_{max} R$

$= 4 \times 10^6 \times 0.4$

$= 1.6 \times 10^6$

Vmax = 1.6 million Volt.

PART - III ADDITIONAL QUESTIONS

I. Matching type questions

1. Match the Column I and Column II

	Column I		Column II
A	Additivity of charge	1	${}_0n^1 + {}_{92}U^{235} \rightarrow {}_{56}Ba^{144} + {}_{36}Kr^{89} + 3\,{}_0n^1$
B	Conservation of charge	2	-5μC + 15μC = 10μC
C	Quantisation of charge	3	Gold nucleus repels alpha particle
D	Attraction and repulsion	4	q = ne

Ans: (A) → (2), (B) → (1), (C) → (4), (D) → (3)

2. Match the Column I and Column II

	Column I		Column II
A	Linear charge density	1	$\frac{\text{Charge}}{\text{Volume}}$
B	Surface charge density	2	$\frac{\text{Charge}}{\text{Length}}$
C	Volume charge density	3	$\frac{\text{Charge}}{\text{Area}}$
D	Discrete charge distribution	4	System consisting of ultimate individual charges

Ans: (A) → (2), (B) → (3), (C) → (1), (D) → (4)

GOVT. EXAM - MARCH 2023

Time : 3.00 Hours **Maximum Marks : 70**

Instructions: (1) Check the question paper for fairness of printing. If there is any lack of fairness, inform the Hall Supervisor immediately.
(2) Use **Blue** or **Black** ink to write and underline and pencil to draw diagrams.

PART - I

Note : (i) Answer **all** the questions. **15×1=15**
(ii) Choose the most appropriate answer from the given **four** alternatives and write the option code and the corresponding answer.

1. The wavelength λ_c of an electron and λ_p of a photon of same energy E are related by:

a) $\lambda_p \propto \frac{1}{\sqrt{\lambda_c}}$ b) $\lambda_p \propto \lambda_c$ **c) $\lambda_p \propto \lambda_c^2$** d) $\lambda_p \propto \sqrt{\lambda_c}$

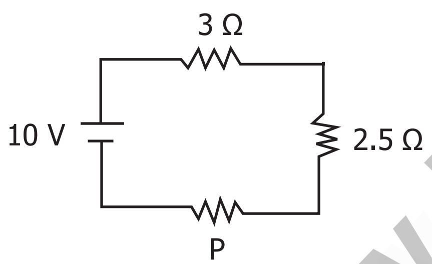
2. Two polaroids are kept with their transmission axes inclined at 30º. Unpolarised light of intensity I falls on the first polaroid. Intensity of light emerging from the second polaroid:

a) $\frac{1}{8}I$ b) $\frac{1}{4}I$ **c) $\frac{3}{8}I$** d) $\frac{3}{4}I$

3. If the magnitude of the magnetic field is 3×10^{-6} T, then the magnitude of electric field for a electromagnetic wave is:

a) 600 Vm^{-1} b) 100 Vm^{-1} **c) 900 Vm^{-1}** d) 300 Vm^{-1}

4. There is a current of 1.0 A in the circuit shown below. What is the resistance of P?



a) 3.5 Ω b) 1.5 Ω
c) 4.5 Ω d) 2.5 Ω

Sol : By Kirchhoff's voltage law,
$10 = (3 \times 1) + (2.5 \times 1) + (P \times 1)$
$10 = 3 + 2.5 + P$
$10 = 5.5 + P$
$P = 10 - 5.5$
$\boxed{P = 4.5\Omega}$

5. A carbon resistor of (47 ± 4.7) kΩ is to be marked with rings of different colours for its identification. The colour code sequence will be:

a) Violet - Yellow - Orange - Silver b) Yellow - Green - Violet - Gold
c) Green - Orange - Violet - Gold **d) Yellow - Violet - Orange - Silver**

6. In an hydrogen atom, the electron revolving in the second orbit, has angular momentum

a) $\frac{4h}{\pi}$ b) h c) $\frac{2h}{\pi}$ **d) $\frac{h}{\pi}$**

Sol :

$L = \frac{nh}{2\pi}$; n = 2

$L = \frac{2h}{2\pi}$ $L = \frac{h}{\pi}$

7. In Young's double slit experiment, the slit separation is doubled. To maintain the same fringe spacing on the screen, the screen-to-slit distance D must be change to:
a) $\sqrt{2D}$ **b) 2D** c) $\frac{D}{\sqrt{2}}$ d) $\frac{D}{2}$

8. A parallel plate capacitor stores a charge Q at a voltage V. Suppose the area of the parallel plate capacitor and distance between the plates are each doubled the which is the quantity that will change?
a) Voltage b) Capacitance **c) Energy density** d) Charge

9. An electromagnetic wave is propagating in a medium with viscocity $\vec{v} = v\hat{i}$. The instantaneous oscillating electric field of this electromagnetic wave is along - Y axis, then the direction of oscillating magnetic field of the electromagnetic wave will be along
a) + Z direction b) Y direction c) – Z direction d) X direction

10. For light incident from air on a slab of refractive index 2, the maximum possible angle of refraction is:
a) 60º **b) 30º** c) 90º d) 45º

11. The Zener diode is primarily used as:
a) Oscillator b) Rectifier **c) Voltage regulator** d) Amplifier

12. The flux linked with a coil at any instant t is given by $\Phi_B = 15t^2 - 50t + 250$.
The reduced emf at t = 3 s is:
a) – 40 V b) – 190 V c) 40 V d) – 10 V

Sol :

$$e-\frac{d\phi}{dt}=-\frac{d}{dt}(15t^2 - 50t + 250)$$
$$e = -30t + 50$$
$$t = 3s, \text{ So}$$
$$e = -40V$$

13. An example of Diamagnetic material is
a) Nickel **b) Water** c) Aluminium d) Iron

14. What is value of Forbidden Energy gap for silicon at room temperature?
a) 0.3 eV b) 0.7 eV c) 0.9 eV **d) 1.1 eV**

15. The alloys used for muscle wires in Robots are:
a) Gold silver alloys **b) Shape memory alloys**
c) Two dimensional alloys d) Gold copper alloys

PART - II

Answer any six questions. Question No. 24 is Compulsory. **6 x 2 = 12**

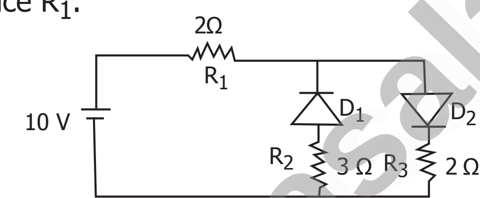
16. Define 'electric field'. **Unit - 1**
17. How will you define Q-factor? **Unit - 4**
18. State Ampere's Circuital Law. **Unit - 3**
19. Explain the reason for the glittering of diamond. **Unit - 6**
20. The ratio of intensities of two waves in an interference pattern is 36 : 1.
What is the ratio of the amplitudes of the two interfering waves? **Unit - 7**

21. Define work function of a metal. Give its unit. **Unit - 8**
22. What is meant by activity or decay rate? Give its unit. **Unit - 9**
23. Draw the circuit diagram of a full wave rectifier. **Unit - 10**
24. If the resistance of coil is 3Ω at 20º C and α = 0.004 / ºC then, determine in resistance at 100º C. **Unit - 2**

PART - III

Answer any six questions. Question No. 33 is Compulsory. **6x3=18**

25. Derive an expression for electrostatic potential due to a point charge. **Unit - 1**
26. State Kirchhoff's First and Second Rules. **Unit - 2**
27. Explain the conversion of galvanometer into an ammeter. **Unit - 3**
28. How will you induce an emf by changing the area enclosed by the coil? **Unit - 4**
29. What are Fraunhofer lines? How are they useful in the identification of elements present in the Sun? **Unit - 5**
30. The given circuit has two ideal diodes connected as shown in figure below. Calculate the current flowing through the resistance R_1. **Unit - 10**



31. What is optical path? Write down the equation for optical path and mention what each term represents. **Unit - 6**
32. Write any three Laws of Photoelectric Effect. **Unit - 8**
33. Calculate the amount of energy released in joules when 1 kg of $^{235}_{92}U$ undergoes fission reaction. **Unit - 9**

PART - IV

Answer all the questions. **5 x 5 = 25**

34. a) i) State Coulomb's Law in electrostatics. **Unit - 1**
    ii) State the differences between Coulomb force and Gravitational force. **Unit - 1**

(OR)

b) Describe the Fizeau's method to determine the speed of light. **Unit - 6**

35. a) Discuss the working of Cyclotron in detail. **Unit - 3**

(OR)

b) Discuss the diffraction at single slit and obtain the condition for n^{th} minimum. **Unit - 7**

36. a) Derive an expression for phase angle between the applied voltage and current in a series RLC circuit. **Unit - 4**

(OR)

b) Describe Davission-Germer experiment which demonstrated the wave nature of the electrons. **Unit - 8**

37. a) Describe the microscopic model of current and obtain microscopic form of Ohm's Law. **Unit - 2**

(OR)

b) Derive an expression for Radius and Velocity of an electron in the n^{th} orbit using Bohr atom model. **Unit - 9**

38. a) i) Write down the properties of electromagnetic waves. **Unit - 5**

ii) The relative magnetic permeability of the medium is 2.5 and the relative electrical permittivity of the medium is 2.25. Compute the refractive index of the medium. **Unit - 5**

(OR)

b) Describe the function of a transistor as an amplifier with the neat circuit diagram. Sketch the input and output waveforms. **Unit - 10**