# SEMESTER II

## physics Core paper. 3

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# Electric Field & Electric Potential

(Short answer type questions)

**Que:-** What do you mean by electric Field intensity?

**Ans:** The region, surrounding any charge or group of charges, in which the effect of the presence of these charges is felt, is known as Electric field.

Let us suppose an additional small charge (or a test charge) $q_0$ is brought into the Electric field and at a certain point in it, it experiences an Electrostatic force $F$. The electric field intensity designated by $E$ at this point is a vector, defined by equation.

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

The direction of the electric intensity is the direction of force $F$, it is the direction in which a test positive charge placed at this point would tend to move. The unit of electric field intensity $E$ is Newton/coulomb

**Que:** What do you mean by Electric Displacement vector $\vec{D}$?

**Ans:** When a material medium is placed in electric field, the no. of lines of force in medium is different than that in free space. The electric Displacement vector $\vec{D}$ is formed of (i) electric lines of force in free space (ii) induced electric lines of force in medium. Thus electric displacement vector $\vec{D}$ at any point is defined as the total no. of electric lines of force in material medium passing per unit area around that point.

Mathematically $\vec{D} = \epsilon \vec{E}$ --- (1)

Where $\epsilon$ is the permittivity of the medium. If $K$ is the dielectric constant (or relative permittivity) and $\epsilon_0$ is the permittivity of free space, then

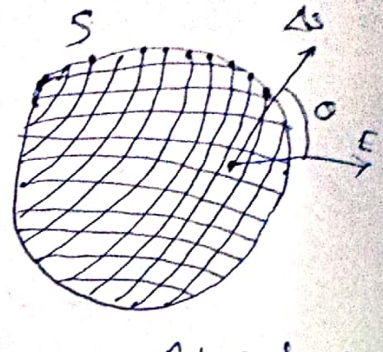
$$\epsilon = K\epsilon_0$$

So from equation (1) $\vec{D} = K\epsilon_0\vec{E}$

The unit of electric Displacement vector $\vec{D}$ is Coulomb/metre²

Que 3: What is Electric Flux?

Ans: The electric flux through an elementary area $\Delta s$ is defined as the product of the area $\Delta s$ and electric field vector E along the normal to this area i.e.




Electric flux $\delta\phi = E\cos\theta . \Delta s$

$= E . \Delta s$

i.e. Electric flux $\delta\phi$ of the electric field E through elementary area $\Delta s$ is the scalar product of electric field vector $\vec{E}$ and the area $\Delta s$.

The electric flux through whole of the surface S is obtained by adding up the scalar quantity $E.\Delta s$ for all elements of area into which the surface has been divided

Total flux $\phi = \sum E . \Delta s = \int_s E . ds$

Que 4: What is Gauss's Theorem?

Ans: The net outward electric flux through any closed surface of any shape drawn in an electric field is equal to $\frac{1}{\epsilon_0}$ times the total charge contained within that surface

$$\oint_s E . ds = \frac{1}{\epsilon_0} \sum q$$

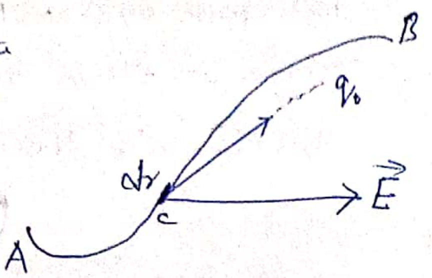
where $\oint_s$ indicates the surface integral over whole of the closed surface and $\sum q$ is the algebraic sum of all the charges enclosed by the surface S in Coulombs.

Que: 5. <u>What do you mean by Electrostatic potential</u>

Ans: The electrostatic potential at any point in an electric field is defined as the work done per unit positive charge required to move the test charge from infinity to the point of question. Thus, if W is the work done in bringing the test charge (positive & infinitesimal) $q_0$ from infinity to given point, then the electric potential at that point $\phi = \lim_{q_0 \to 0} \frac{W}{q_0}$. It is a vector quantity

Que 6: Establish relation between electric potential & electric field vector E.

Ans. Consider an Electric field E due to the stationary distribution of charges and let A and B are two points anywhere in this field.




Thus the line integral of electric field between two points A and B along the path ACB is represented by

$$= \int_A^B E \cdot dr$$

where E is the electric field Intensity or field strength on small segment dr chosen at C.

Since electric field strength at any point is the force experienced per unit charge at that point, so, E·dr is the work done per unit charge by the electric field through displacement dr, So the line integral of electric field $\int_A^B E \cdot dr$, is the total work done per unit charge by the electric field point A to point B along the path ABC.

Hence $-\int_A^B E \cdot dr$ is the work done per unit positive charge q by external force against the electric field to move the test charge $q_0$ from point A to B.

Therefore, electric potential difference between two points A & B, by definition

$$\phi_B - \phi_A = \frac{W_{AB}}{q_0} = -\int_A^B E \cdot dr$$

If point A is chosen at infinite distance from all charges, then $\phi_A = 0$

So, electric potential at B

$$\phi_B = -\int_\infty^B E \cdot dr.$$

Thus the electric potential at any point is defined as the negative line integral of the electric field vector E from a point infinitely away from all charges (giving rise to E) to that point

Q7: Establish Gauss's Theorem in Differential Form.

Ans: Let us apply Gauss's divergence theorem to an electric field E. Let there exist volume V enclosed by a surface S in the region of electric field of varying charge density $\rho$, then by Gauss's theorem in electrostatics

$$\int_S E \cdot ds = \frac{1}{\epsilon_0} \times \text{charge enclosed within surface } S$$

$$= \frac{1}{\epsilon_0} \int_V \rho \cdot dV \quad \text{—(1)}$$

According to Gauss's divergence theorem

$$\int_S E \cdot ds = \int_V \text{div} E \cdot dV \quad \text{—(2)}$$

Comparing (1) & (2), we get:

$$\int_V \text{div} E \cdot dV = \frac{1}{\epsilon_0} \int_V \rho \cdot dV$$

$$\int_V \left( \text{div} E - \frac{\rho}{\epsilon_0} \right) dV = 0$$

As the volume, over which integration takes place is arbitrary, we must have

$$\text{div} E - \frac{\rho}{\epsilon_0} = 0$$

$$\boxed{\therefore \text{div} E = \frac{\rho}{\epsilon_0}}$$

This is differential form of Gauss's theorem in free space.

Que: State Laplace's & Poisson's equations.

Ans: If E and $\phi$ are the electric field strength & electric potential at any point respectively, then we know that

$$E = -\text{grad}\,\phi = -\left[\hat{i}\frac{\partial \phi}{\partial x} + \hat{j}\frac{\partial \phi}{\partial y} + \hat{k}\frac{\partial \phi}{\partial z}\right]$$

Poisson's equation: In the region where there exist a distribution of charges of volume charge density (charge/unit volume) is $\rho$, then from Gauss's law

$$\text{div} E = -\frac{\rho}{\epsilon_0}$$ , where $\epsilon_0$ is absolute permittivity of free space

$$\text{div}(-\text{grad}\,\phi) = -\frac{\rho}{\epsilon_0}, \quad \text{div grad}\,\phi = -\frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \nabla \phi = -\frac{\rho}{\epsilon_0}, \quad \boxed{\nabla^2 \phi = -\frac{\rho}{\epsilon_0}}$$ This is Poisson's equation. $\nabla^2$ is called Laplacian operator

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

In charge free region $\rho = 0$

$$\therefore \boxed{\nabla^2 \phi = 0}$$

which is called Laplace's equation

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# Dielectric properties of Matter

(Short answer type questions)

**Que1:** What do you mean by a 'dielectrics'?

**Ans:** A dielectric is a material which contains no free electrons, so that no electric current can flow through it. As a result the electrical conductivity of a dielectric is poor and for an ideal dielectric, it is zero.

**Que2:** What do you mean by 'Dielectric Constant'.

**Ans:** The ratio of capacitance of a capacitor immersed in dielectric to that of capacitance of same capacitor in vacuum is called dielectric constant.

If $C$ is the capacitance of a capacitor in a dielectric and $C_0$ is the capacitance of same capacitor in vacuum, then dielectric constant of that medium $K = \frac{C}{C_0}$,

Alternatively, the ratio of permittivity of the medium to that of vacuum is called dielectric constant $K = \frac{\epsilon}{\epsilon_0}$

It is independent of shape & size of the capacitor and it is different for different material. Its value is 1 for vacuum, 1.0006 for air and nearly 6 for glass.

**Que3:** What do you mean by polar & Non-polar molecules.

**Ans:** A molecule in which the centre of positive and negative charges coincide, and thus for which the inherent dipole moment is zero is called a Non-polar molecules. $H_2$, $O_2$, $CO_2$, $CH_4$ etc are the examples of non polar molecules

A molecule the centre of positive and negative charges are separated by a distance forming an electric dipole is called a polar molecule. $H_2O$, $CHCl_3$, $C_2H_5OH$ etc are the examples of polar molecules.

**Que4:** What is electric polarisation?

**Ans:** When a dielectric with polar molecules is placed in an electric field, the positive & negative charge centres are relatively displaced. The molecules thus acquire induced dipole moments and are said to be polarised.

If the dielectric has polar molecules, the permanent dipoles are oriented along the direction of electric field and have their dipole moments increased. This is also called polarisation.

Thus the phenomenon in which a dielectric acquires an overall dipole moment is called Electric polarisation

Que5: Explain the term electronic, atomic & orientational polarisation.

Ans.: When a dielectric is placed in an electric field, there is a displacement of electronic cloud relative to positively charged nucleus in the atoms forming the molecules. This causes an induced dipole moment in molecules. This phenomenon is called electric polarisation.

When a dielectric made of nucleus having separate positive & negative atoms (i.e. ions), is placed in an external electric field, the separation between positive & negative charges is altered. This causes an induced dipole moment in the molecules. This phenomenon is called atomic polarisation.

When a dielectric made of molecules having randomly oriented permanent dipole moment, is placed in an external electric field, the molecules as a whole may rotate about its axes of symmetry so that the dipoles align along the field direction. This phenomenon is called orientational polarisation.

Que6: Define the term Molecular polarisability and electrical susceptibility.

Ans: When a nonpolar molecule is placed in an electric field, the centre of negative charges is displaced relative to the centre of positive charges. The molecules The molecule thus acquires induced dipole moment. For most molecules the induced dipole moment P is directly proportional to the applied field E i.e

$$P \propto E$$

$$P = \alpha E.$$

Where constant $\alpha$ is called molecular polarisability. This relation is strictly true for small E.

If there are n molecules per unit volume of dielectric, then the total induced dipole moment per unit volume or total polarisation vector $\vec{P} = n\alpha \vec{E}$

Electric Susceptibility

When a dielectric material is placed in an electric field. For the most materials the polarisation is proportional to Electric field E

$$P \propto E$$

$$P = \epsilon_0 \chi_e E$$

where $\chi_e$ is a constant, characteristic of material, called electrical susceptibility, $\epsilon_0$ is introduced to make $\chi_e$ dimensionless

$$\chi_e = \frac{P}{\epsilon_0 E}$$

So, electrical susceptibility is defined as the ratio of polarisation to the $\epsilon_0$ times the electric field strength. It is dimensionless & has no unit.

The susceptibility $\chi_e$ depends on temperature for polar molecules, but it is independent of temperature for non-polar molecules

Ques 7: Establish relation between dielectric constant (K) & susceptibility.

Ans: We know the relation between three electric vector Electric field strength $\vec{E}$, Displacement vector $\vec{D}$ & Polarisation $\vec{P}$ is

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P}$$

Also, $\vec{D} = \epsilon \vec{E}$ and $\vec{P} = \epsilon_0 \chi_e \vec{E}$

Substituting the value of $\vec{D}$ & $\vec{P}$, we have

$$\epsilon \vec{E} = \epsilon_0 E + \epsilon_0 \chi_e E$$

$$\frac{\epsilon}{\epsilon_0} = 1 + \chi_e$$

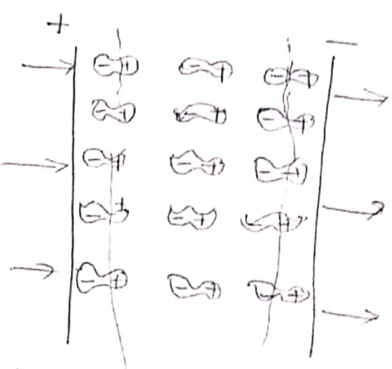
$\frac{\epsilon}{\epsilon_0} = K$ dielectric Constant

So, $\boxed{K = 1 + \chi_e}$

This is the required relation, clearly the value of K is greater than 1 for all dielectrics, for empty space $\chi_e = 0$ & $\boxed{K = 1}$

Ques: Establish a relation between three electric vectors $\vec{E}$, $\vec{P}$ & $\vec{D}$.

Ans: When a thin slab of dielectric is placed in a electric field, the slab becomes polarised. If the field is from left to right, the negative charges of the induced dipoles are on the left and positive charges on the right. The interior charges cancel out and surface charges, equal in magnitude but opposite in sign appear at the two ends. These are called polarisation charges and are 'bound charges'.

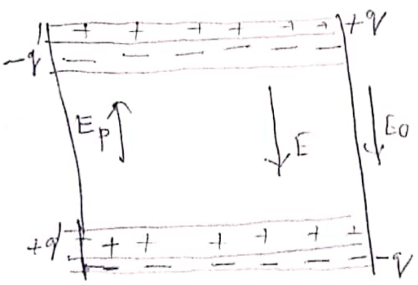



Displacement vector $\vec{D}$

The displacement vector is an auxiliary vector associated with every electric field and whose flux across any closed surface is equal to the free charges enclosed by the surface

$$\therefore \oint \vec{D} \cdot \vec{ds} = q_{free}$$

Relation




Let us consider a parallel plate capacitor with plate area A. Charges on the plates are $+q$ and $-q$, which are free charges. The electric field $E_0$ due to free charges will be

$$E_0 = \frac{\sigma}{\epsilon_0}, \text{ where } \sigma = \frac{q}{A}$$

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A dielectric slab of dielectric constant 'k' is introduced between the plates. Induced charges of magnitude q' appear at the end faces of the slab. The electric field due to polarisation charges q' will be

$$E_p = -\frac{\sigma_p}{\epsilon_0} \quad , \text{where } \sigma_p = \frac{q'}{A}$$

Resultant field due to free and polarisation charges will be

$$\vec{E} = \vec{E_0} + \vec{E_p}$$

$$= \frac{1}{\epsilon_0}(\sigma - \sigma_p)$$

The polarisation charge density is equal to polarisation P, i.e $\sigma_p = P$

$$\therefore \vec{E} = \frac{1}{\epsilon_0}(\sigma - \vec{P})$$

$$\epsilon_0 \vec{E} + \vec{P} = \sigma$$

The quantity on the left side is called Electric displacement and denoted by $\vec{D}$.

$$\boxed{\therefore \vec{D} = \epsilon_0 \vec{E} + \vec{P}}$$

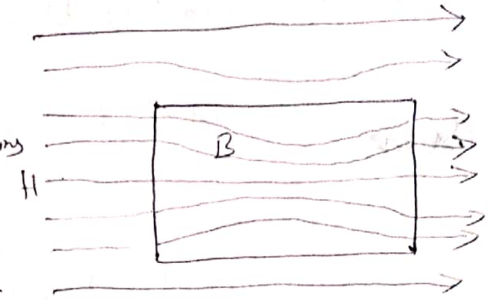
This is the required relation.

# Magnetic properties of Matter

Que 1: What do you mean by Magnetic Induction B and Magnetic field H ?

Ans: The no. of magnetic lines of force passing per unit area normally in free space ( before magnetisation) is a measure of magnetic field H while the net no. of magnetic lines of force within the material medium when it is placed in an external magnetic field field is called magnetic induction or flux density within the sample, The magnetising field is denoted by 'H' and also called magnetic field intensity while the flux density within the medium is denoted by 'B' and is called magnetic Induction,

When a specimen of soft iron is placed in vacuum within its length parallel to the magnetising field H. The bar or specimen is magnetised and the no. of lines of force within the specimen (B) is greater than the no. of lines in free space (H), B > H in iron.




Que 2: What do you mean by 'Intensity of magnetisation I' ?

Ans: When a specimen of magnetic material is placed in an external magnetic field, the magnetisation is induced in the sample. The physical quantity measuring magnetisation is Magnetic moment 'M'.

Intensity of magnetisation (I):

When a magnetic material is placed in an uniform magnetic field the elementary current loops in the material become align parallel to the field. The material is said to be magnetised and thus acquires a magnetic moment.

The acquired magnetic moment per unit volume is called Intensity of magnetisation and denoted by I,

$$I = \frac{M}{V}$$

Que 3: What do you mean by Relative permeability $\mu_r$?

Ans ; The ratio of magnetic Induction within the Sample to the magnetising field, when expressed in same units is called relative permeablity $\mu_r$.

If B is the magnetic Induction within the Sample in Tesla & $B_0$ is the applied external field in free space also in Tesla, Then $\mu_r = \frac{B}{B_0}$

In general the magnetising field is expressed by H and its unit is ampere-turn/meter and magnetic flux density within in Sample is denoted by B whose unit is Tesla, then the ratio B/H is called absolute permeablity $\mu$, $\boxed{\mu = \frac{B}{H}}$

The absolute permeablity in vacuum is $\mu_0$, so

$$\mu_0 = \frac{B_0}{H} = 4\pi \times 10^{-7} \text{ weber/amp-meter}$$

So, The relative permeablity is also defined as the ratio of permeablity of medium to the permeablity in free space.

$\boxed{\mu = \frac{\mu}{\mu_0}}$ It has no unit.

Que 4: What do you mean by Magnetic Susceptiblity '$\chi_m$'?

Ans : In Simple isotropic materials the intensity of Magnetisation I is found to be proportional to magnetising field H and parallel to it, ie.

$$I \propto H$$

$$\therefore I = \chi_m H.$$

Where $\chi_m$ is a dimensionless constant and called magnetic Susceptiblity and it is characteristic of the medium.

So, the magnetic Susceptiblity is defined as the ratio of Intensity of magnetisation to the magnetising field.

$$\boxed{\chi_m = \frac{I}{H}}$$

Ques 5: What do you mean by Dia, para & Ferro magnetic substances.

Ans: Those substances which get weakly magnetised by a strong magnetic field in a direction opposite to that of the applied magnetic field are called diamagnetic substances. Cu, Ag, Au, Bi are the examples of Diamagnetic substances.

Those substances which get weakly magnetised by a strong magnetic field in the same direction as the applied magnetic field, are called paramagnetic substances. Al, Mg, liquid oxygen are the examples of paramagnetic substances.

Those substances which get strongly magnetised by relatively weak magnetic field in the same sense as the applied magnetic field are called Ferromagnetic materials. Fe, Ni, Co are the examples of Ferromagnetic substances.

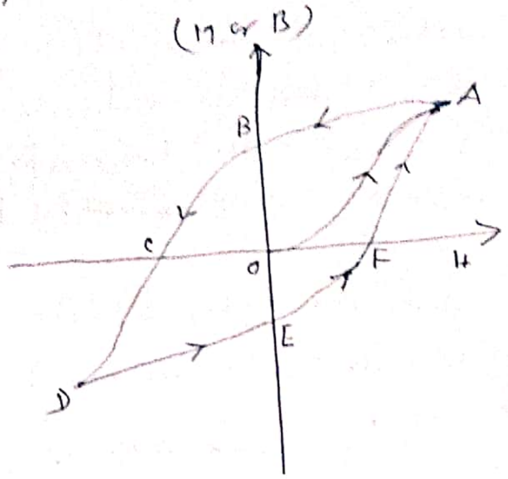
Que 6: Compare between Diamagnetic, Paramagnetic & Ferromagnetic substances.

Ans:

| S.N. | Paramagnetic | Ferromagnetic | Diamagnetic |
|---|---|---|---|
| 1. | Found in solid, liquid & Gaseous form | It is crystalline and found in solid form | Found in solid, liquid & Gaseous form |
| 2. | In comparison to Ferromagnetic there is less attraction | Attraction of the magnetic field is very large | There is slow repulsion. |
| 3. | A rod tries to be parallel to the magnetic field | A rod comes parallel to magnetic field | rod tries to be normal to the magnetic field. |
| 4. | Permeability $\mu$ is a little greater than 1 | $\mu$ has value much larger than 1 | $\mu$ has value less than 1. |
| 5. | Susceptibility is less but positive | Susceptibility K is much greater than 1 and always positive | Susceptibility K is less value & negative. |
| 6. | With increase of Temperature K varies inversely with temperature $K \propto \frac{1}{T}$ (Curie Law) | With increase of temp K decreases regularly | There is no effect of temperature |
| 7. | Hysteresis is not observed | Hysteresis is observed | Hysteresis is not observed |
| 8. | Curie point is not fixed | Curie point is fixed | There is no any Curie point. |

Que:7 : Explain what is hysteresis and hysteresis loop?

Ans : When a specimen of a magnetic material is slowly magnetised, the intensity of magnetisation M increases non-linearly until it reaches a maximum, and the specimen is said to have acquired a state of saturation. This is magnetic saturation The figure shows a qualitative plot of M or magnetic induction B against magnetising field H.




The above described process is represented by curve OA and is called 'magnetisation curve'.

If now H is decreased, the field B follows the path AB reaching B at H = 0. The portion OB represents "residual magnetism". in M-H curve, it is called 'retentivity' and in B-H curve it is called residual induction. Reversing the direction of H keeps M decreasing along BC until it becomes zero at C. The portion OC represent "Coercivity" of the magnetic material. Increasing H in reverse direction produces reverse magnetisation which again reaches saturation at 'D'.

Magnitude of H in the reverse direction is now decreased, and M also decreases in magnitude, 'Retentivity' in the reverse direction is represented by DE, with H = 0 at E. Here after H is increased in the original direction and the curve reaches back to the point A. The path ABCDEFA thus formed a closed loop which is called "hysteresis loop".

The hysteresis loop is a characteristic of the material of the specimen and found in ferromagnetic materials. It is observed that the zero value of M always occurs at a later point of the cycle than the zero value of H. This lag of magnetisation behind the magnetising field is called "hysteresis".

## Electric field & Electric potential

### Objective type questions:-

1. The relation between electric field strength E & Electric potential $\phi$ is —
   (a) $E = -\nabla\phi$ (b) $\phi = -\nabla E$ (c) $E = \nabla^2\phi$ (d) $\phi = \nabla^2 E$

2. Electric field strength just outside a charged Conductor is
   (a) $(\epsilon_0 \sigma)$ (b) $\left(\frac{\sigma}{\epsilon_0}\right)$ (c) $(\epsilon_0^2 \sigma)$ (d) $\epsilon_0 \sigma^2$

3. Total outward Electric flux through any closed Surface in an electric field is equal to
   (a) $\epsilon_0$ times the charge Contained
   (b) $\frac{1}{\epsilon_0}$ times the charge Contained
   (c) twice the charge Contained
   (d) half the charge Contained.

4. The electric field Strength E at a distance r from the midpoint of an electric dipole which is situated on its axis is
   (a) $\frac{1}{4\pi\epsilon_0}\frac{p}{r^3}$ (b) $\frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$ (c) $\frac{1}{4\pi\epsilon_0}\frac{2p}{r^2}$ (d) $\frac{1}{4\pi\epsilon_0}\frac{p}{r^2}$
   where P - electric dipole Moment

5. The electric field strength at a distance r from the mid point of an electric dipole which is situated on perpendicular bisector is
   (a) $\frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$ (b) $\frac{1}{4\pi\epsilon_0}\frac{p}{r^3}$ (c) $\frac{1}{4\pi\epsilon_0}\frac{2p}{r^2}$ (d) $\frac{1}{4\pi\epsilon_0}\frac{p}{r^2}$

6. Electric field intensity due to a charged spherical shell of radius R at its inside point whose distance is r will be
   (a) $\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ (b) $\frac{1}{4\pi\epsilon_0}\frac{q^2}{r}$ (c) zero (d) $\frac{qr}{4\pi\epsilon_0}$
   where q is the charge on the shell

7. The unit of Electric displacement vector $\vec{D}$ is
   (a) Coulomb/meter (b) coulomb/meter$^2$ (c) Coulomb meter (d) None of these

8. Electric field Strength due to infinite flat sheet of charge density $\sigma$ near this sheet is
   (a) $\frac{\sigma}{\epsilon_0}$ (b) $\frac{\sigma}{2\epsilon_0}$ (c) $\epsilon_0\sigma$ (d) None of these

(9) Dielectric Constant (K) of all dielectric is

(a) greater than 1 (K>1)
(b) Less than 1 (K<1)
(c) equal to 1
(d) none of these

(10) $H_2$ & $O_2$ have

(a) non-polar molecules
(b) Polar molecules
(c) Some polar & Some non polar molecules
(d) other than above.

(11) Hysteresis is observed in

(a) Diamagnetic Substance
(b) Paramagnetic Substance
(c) Ferromagnetic Subs.
(d) None of these

(12) Permeability of Diamagnetic Substance

(a) Less than 1
(b) Little greater than 1.
(c) much greater than 1
(d) None of these

(13) Found always in Solid form only

(a) Diamagnetic Substances
(b) paramagnetic Substances
(c) Ferromagnetic Substances
(d) Dia & Para Substance.

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