

St. JOSEPH'S COLLEGE OF ENGINEERING, CHENNAI – 119.
St. JOSEPH'S INSTITUTE OF TECHNOLOGY, CHENNAI – 119.
ASSIGNMENT – II

UNIT – III MAGNETIC MATERIALS

PART – A

1. Define magnetic susceptibility and magnetic permeability.

Magnetic susceptibility : It is defined as the ratio between intensity of magnetization (I) and magnetic field intensity (H) $\chi_m = I / H$

Magnetic Permeability : It is defined as the ratio between the magnetic flux density (B) and magnetic field intensity (H) $\mu = B / H$

2. Define energy product of a magnetic material. Give its importance in the case of permanent magnets.

The product of retentivity and coercivity is known as energy product. It gives the maximum energy stored in the magnets which helps in distinguishing a weak and strong magnet.

3. A paramagnetic material has a magnetic field intensity of 10^4 ampere/m. If the susceptibility of the material at room temperature is 3.7×10^{-3} , calculate the magnetization of the material.

$$\chi = I / H \rightarrow I = \chi H = 3.7 \times 10^{-3} \times 10^4 = 37 \text{ Am}^{-1}$$

4. Define retentivity and coercivity.

Remenance is the property of the magnetic material by which it retains some magnetisation when the magnetising field is reduced to zero. It is expressed in terms of weber / m².

Coercivity is the property of the magnetic material by which it requires a demagnetising force to destroy the residual magnetism in it. It is expressed in terms of ampere turn /m.

5. Define Bohr Magneton

The orbital magnetic moment and the spin magnetic moment of an electron in an atom can be expressed in terms of atomic unit of magnetic moment called Bohr magneton.

$$1 \text{ Bohr magneton} = 9.2 \times 10^{-24} \text{ Am}^2.$$

6. Give any two applications of ferrites.

- Ferrites are used in audio and video transformers
- Used in computer and data processing circuits.

7. What is meant by Meissner effect?

When a material is cooled below its transition temperature the material becomes a perfect diamagnet. The magnetic flux originally present in the material gets ejected out of a superconductor.

8. Define transition temperature with example.

The temperature at which a normal material changes into a superconductor is called transition temperature.

9. Prove that superconductor is a diamagnet.

$B = \mu_0 (I+H)$: When $B = 0$, we get $0 = \mu_0 (I+H)$: Since $\mu_0 \neq 0$, we can write $I + H = 0$; or $I = -H$ or $I/H = -1 = \chi$.

10. Calculate the critical current which can flow through a long thin superconducting wire of aluminium of diameter 10^{-3} m. The critical magnetic field for aluminium is 7.9×10^3 A/m.

$$I_c = 2\pi r H_c = 2 \times 3.14 \times 10^{-3} / 2 \times 7.9 \times 10^3 = 24.81 \text{ Amp}$$

PART – B

1. i) What is ferromagnetism?

Ferromagnetic materials possess permanent dipole moment and undergoes saturation magnetization.

ii) Discuss the domain structure in ferro magnetic material.

Domain Theory of ferromagnetism:

The group of atomic dipoles organized into to bounded regions in the ferromagnetic materials are called Domains.

Domain Walls: The boundaries separating the domain are called domain walls.

Process: (i) In an unmagnetised specimen, the domains are randomly oriented and the net magnetisation is zero.

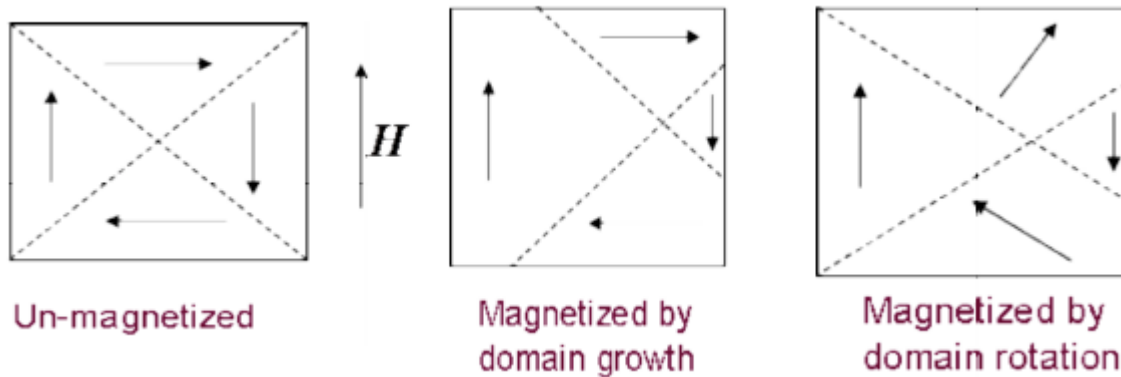
(ii) When the external field is applied, domains align with the direction of field resulting in large net magnetization.

By the movement of domain wall:

- Initially, domains are randomly oriented and $B=0$.
- Application of an external field (H) grows any domains with a similar orientation as H , shrinking the others.
- Eventually, only a single domain remains.
- Ultimately, something near the saturation magnetization is reached (M_s or B_s).

1.Domain growth:

Volume of domains oriented favourably w. r. t to the field at the expense of less favourably oriented domains.



2. Domain rotation:

Rotation of the directions of magnetization towards the direction of the field.

iii) Explain the different types of energy involved in the formation of domain.

Energies involved in the process of Domain growth:

If Exchange energy, then why not all spins of the piece of material become parallel and form only one single domain

Origin of Domains:

According to Neel, origin of domains in the ferromagnetic materials may be understood in terms of thermodynamic principle that

In equilibrium the total energy of the system is minimum.

Total energy:

1. Exchange energy,
2. Magnetic energy,
3. Anisotropy energy and
4. Domain wall or Bloch wall energy.

1. Exchange Energy

It is lowered when spins are parallel. Thus, it favours an infinitely large domain or a single domain in the specimen.

2. Magnetic Energy

This arises because the magnetized specimen has free poles at the ends and thus produce external field H.

3. Anisotropy energy

For bcc Fe

[100] easy direction

[110] medium direction

[111] hard direction

For Ni

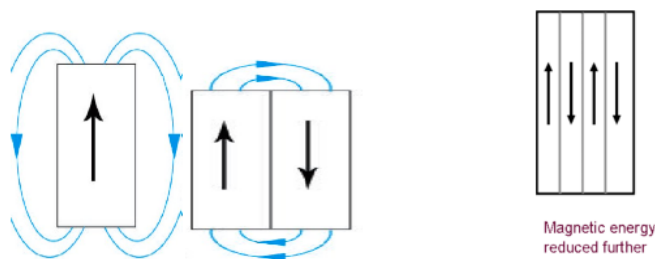
[111] easy direction

[110] medium direction

[100] hard direction

4. Domain wall or Bloch wall energy

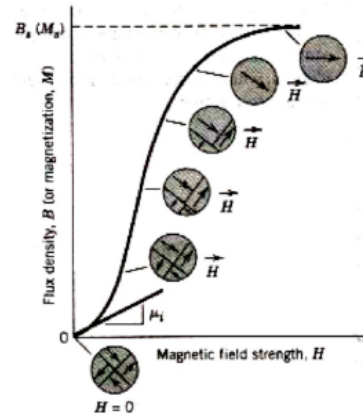
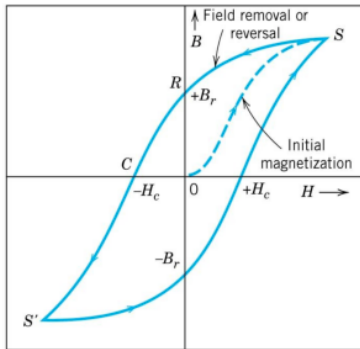
Domain wall creation involves energy which is known as domain wall energy or Bloch energy.



2. Explain the phenomenon of hysteresis on the basis of domain theory in ferromagnetism.

Hysteresis: Lagging behind – Ferromagnetic material is taken through a cycle of magnetization, the variation of B with respect to H is represented by a closed loop is called hysteresis loop.

- The magnetic induction B increases along the curve **OA** with the magnetic field.
- Beyond A, if the magnetic field is increased, the magnetic induction does not increase and it remains constant. Specimen is saturated.
- The value of magnetic field is decreased, but the induction does not decrease at the same rate. When **H = 0** but **B ≠ 0**, induction has a definite value **OB** known as **Retentivity**.
- The applied field H is reversed and increased gradually till the point C is reached. The induction B becomes zero at the point C and it is known as **Coercivity**.
- It is clear that the induction B will not come to zero, when the field strength H is zero. It shows that the magnetic induction lags behind the applied magnetic field strength is called magnetic hysteresis.



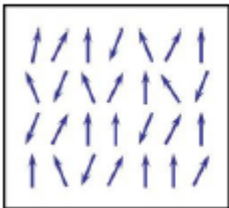
3. Classify the magnetic materials on the basis of their spin.

Diamagnetism:

1. The atoms in the diamagnetic materials do not possess permanent magnetic moment.
2. Because there is no unpaired electrons in these materials.
3. The direction of the induced dipole moment is opposite to that of externally applied magnetic field.
4. Due to this effect the material gets very weakly repelled, in the magnetic field. This phenomenon is known as diamagnetism.
5. The induced dipoles and magnetization vanish as soon as the applied field is removed.
6. The susceptibility of the dia. Magnetic materials is negative, and it independent of temperature.
7. Magnetic permeability is small.

Ex: Gold, Germanium, silicon.

Paramagnetism:



1. The magnetic moments are randomly oriented in the absence of an external magnetic field.

2. When an external magnetic field is applied, the magnetic dipoles tend to align themselves in the direction of the magnetic field and the material becomes magnetized. This effect is known as paramagnetism.

3. The paramagnetic susceptibility varies inversely with temperature. $\chi = C/T$

4. These materials attract the magnetic lines of force.

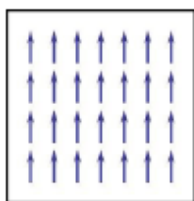
5. They possess permanent dipole moment.

6. The susceptibility is positive and depends on temperature.

7. Permeability is large.

Ex: Manganous sulphate, ferric oxide, ferrous sulphate.

Ferromagnetism:



1. All the dipoles are aligned parallel to each other due to the magnetic interaction between any two dipoles.

2. They have permanent dipole moment. They are strongly attracted by the magnetic field.

3. They exhibit magnetization even in the absence of magnetic field - **Spontaneous magnetization.**

4. They exhibit hysteresis curve.

5. On heating, they lose their magnetization slowly.

6. The susceptibility is very high and depends on temperature.

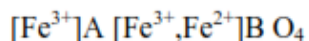
7. Permeability is large.

Ex: Iron, Cobalt, Nickel.

4. Briefly explain the structure and applications of ferrites.

In ionic compounds, such as oxides, more complex forms of magnetic ordering can occur as a result of the crystal structure. One type of magnetic ordering is called ferrimagnetism.

The magnetic structure is composed of two magnetic sublattices (called A and B) separated by oxygens. The exchange interactions are mediated by the oxygen anions. When this happens, the interactions are called indirect or superexchange interactions. The strongest superexchange interactions result in an antiparallel alignment of spins between the A and B sublattice.

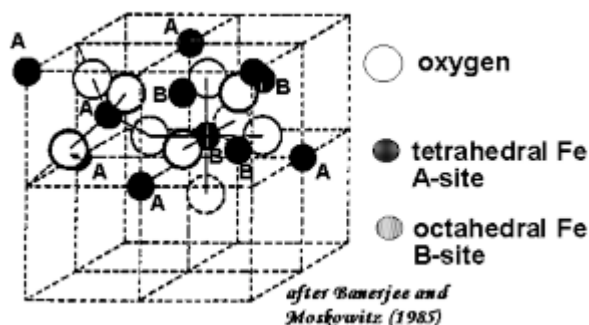


This particular arrangement of cations on the A and B sublattice is called an inverse spinel structure. With negative AB exchange interactions, the net magnetic moment of magnetite is due to the B-site Fe^{2+} .

Magnetite, Fe_3O_4 crystallizes with the spinel structure. The large oxygen ions are close packed in a cubic arrangement and the smaller Fe ions fill in the gaps. The gaps come in two flavors:

Tetrahedral site: Fe ion is surrounded by four oxygens

Octahedral site: Fe ion is surrounded by six oxygens



Applications of Ferrites:

1. Manufacture of permanent magnet
2. Production of cores
3. Magnetic films
4. Magnetic discs and tapes
5. Production of Ultrasonic waves
6. Radio receiver
7. Gyrator, circulator and isolator

5. i) Distinguish between hard and soft magnetic materials.

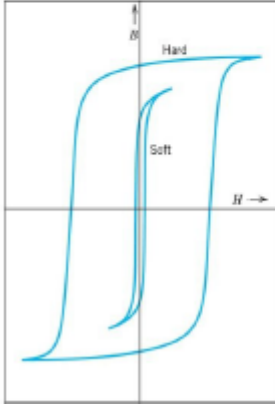
Soft magnetic materials:

- i. They can be magnetized and demagnetized easily.
- ii. They have high permeability
- iii. They have low residual magnetism
- iv. They have low coercive force.

- v. They have low hysteresis losses.
- vi. The magnetic energy stored low.

Ex: ferrites, carbon steel, permalloy.

Applications: Cores of transformer, dynamos, armatures of motors.



Hard magnetic materials:

- i. They cannot be magnetized and demagnetized easily.
- ii. They have low permeability.
- iii. They have high retentivity and coercivity.
- iv. They have large hysteresis loop
- v. They require high magnetizing force to attain magnetic saturation.
- vi. They possess high value of B-H product.

Ex: Tungsten steel, Cobalt steel, Alini.

Applications: Permanent magnets, fans, heavy duty instruments.

ii) In a magnetic material, the field strength is found to be 10^6 A/m. If the magnetic susceptibility is 0.5×10^{-5} , calculate the intensity of magnetization and flux density in the material.

$$\chi = I / H \rightarrow I = \chi H = 0.5 \times 10^{-5} \times 10^6 = 50 \text{ Am}^{-1}$$

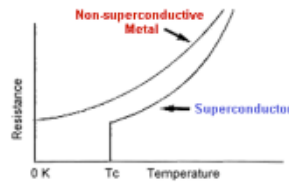
$$B = \mu_0 (H + I) = 4\pi \times 10^{-7} (10^6 + 50) = 1.256 \text{ Wb/m}^2$$

6. Explain the superconducting phenomena with its properties.

The phenomenon of sudden disappearance of electrical resistance in a material, when it is cooled below a certain temperature is known as superconductivity

Below certain temperature:

Resistanceless supercurrent



The Meissner Effect

When a material makes the transition from the normal to superconducting state, it actively excludes magnetic fields from its interior; this is called the Meissner effect. The specimen acts as an ideal diamagnet. This effect is reversible, i.e. when the temperature is raised from T_c, the flux lines suddenly start penetrating and the specimen returns back to the normal state. This constraint to zero magnetic field inside a superconductor is distinct from the perfect diamagnet which would arise from its zero electrical resistance.

Effect of current:

In a normal conductor, an electrical current may be visualized as a fluid of electrons moving across a heavy ionic lattice. The electrons are constantly colliding with the ions in the lattice, and during each collision some of the energy carried by the current is absorbed by the lattice and converted into heat, which is essentially the vibrational kinetic energy of the lattice ions. As a result, the energy carried by the current is constantly being dissipated. This is the phenomenon of electrical resistance.

Isotope Effect:

Any physical property that depends directly or indirectly on the mass of the ions building up the lattice of a superconductor may display an **isotope effect**: Most conventional superconductors display a rather well-understood variation of T_c upon

isotopic substitution of one element. The variation of the transition temperature with the average isotopic mass M of their constituents is found to follow the general form

$$T_c \propto M^{-\alpha}$$

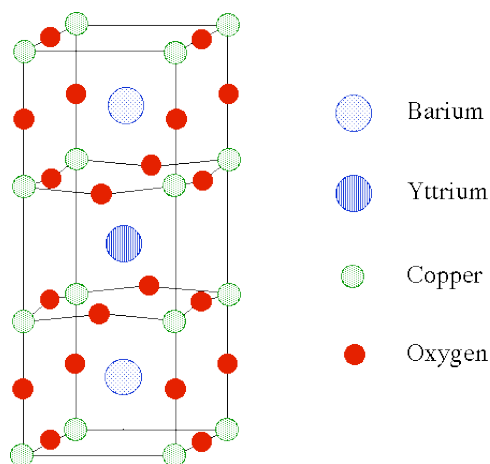
$$\text{Or } M^{\alpha} T_c = \text{Constant}$$

7. i) What are high temperature superconductors? Give examples.

High-temperature superconductors (abbreviated **high- T_c** or **HTS**) are materials that behave as superconductors at unusually high temperatures. HTS have been observed with transition temperatures as high as 138 K

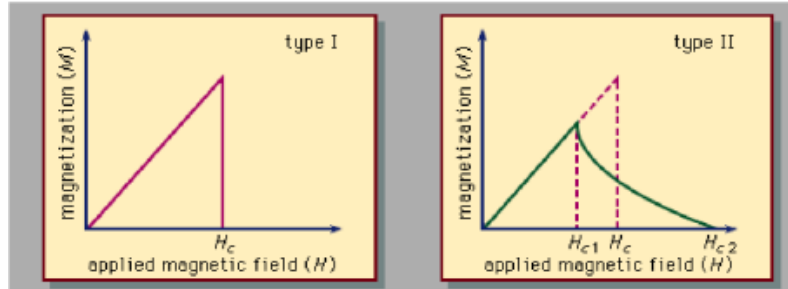
ii) Explain its structure and give the importance of oxygen content in $\text{YBa}_2\text{Cu}_3\text{O}_7$

The first superconductor found with $T_c > 77 \text{ K}$ is yttrium barium copper oxide ($\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$); the proportions of the 3 different metals in the $\text{YBa}_2\text{Cu}_3\text{O}_7$ superconductor are in the mole ratio of 1 to 2 to 3 for yttrium to barium to copper, respectively. Thus, this particular superconductor is often referred to as the 123 superconductor. The unit cell of $\text{YBa}_2\text{Cu}_3\text{O}_7$ consists of three pseudocubic elementary perovskite unit cells. Each perovskite unit cell contains a Y or Ba atom at the center:



8. i) Discuss type I and type II superconductors.

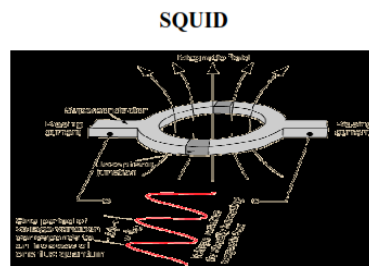
S.No	Type – I	Type – II
1	The material loses magnetisation suddenly	The material loses magnetisation gradually
2	There is only one critical magnetic field	There are two critical magnetic fields, lower and upper.
3	No mixed state exists.	Mixed state is present.



ii) Explain the BCS theory of superconductors

BCS theory is the first microscopic theory of superconductivity since its discovery in 1911. The theory describes superconductivity as a microscopic effect caused by a condensation of Cooper pairs into a boson-like state. The theory is also used in nuclear physics to describe the pairing interaction between nucleons in an atomic nucleus. It was proposed by John Bardeen, Leon Neil Cooper, and John Robert Schrieffer ("BCS") in 1957; they received the Nobel prize in physics for this theory in 1972. BCS derived several important theoretical predictions that are independent of the details of the interaction, since the quantitative predictions mentioned below hold for any sufficiently weak attraction between the electrons and this last condition is fulfilled for many low temperature superconductors - the so-called weak-coupling case. These have been confirmed in numerous experiments. The electrons are bound into Cooper pairs, and these pairs are correlated due to the Pauli exclusion principle for the electrons, from which they are constructed. Therefore, in order to break a pair, one has to change energies of all other pairs. This means there is an energy gap for single-particle excitation, unlike in the normal metal (where the state of an electron can be changed by adding an arbitrarily small amount of energy). This energy gap is highest at low temperatures but vanishes at the transition temperature when superconductivity ceases to exist. The BCS theory gives an expression that shows how the gap grows with the strength of the attractive interaction and the (normal phase) single particle density of states at the Fermi level. Furthermore, it describes how the density of states is changed on entering the superconducting state, where there are no electronic states any more at the Fermi level. The energy gap is most directly observed in tunneling experiments and in reflection of microwaves from superconductors.

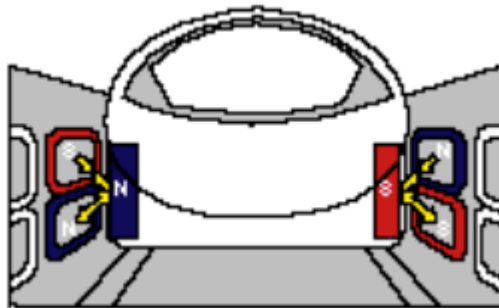
9. Based on the properties of superconductors, describe the various application of superconductors.



- ▶ SQUID is nothing but a two Josephson Junctions mounted on a superconducting ring .
 - ▶ Magnetic field is applied normal to the plane of the ring
 - ▶ It induces a current in the ring. The total current varies with the magnetic flux.
 - ▶ Total magnetic flux through the superconducting ring is quantized and
 - ▶ it is $= nh/2e$ and “ $2e$ ” is the charge of the Cooper Pairs.
 - ▶ Detect change of 100 billion times weaker signal than that moves a compass needle.
 - ▶ It act as the storage device for the magnetic field.
- The electromagnets on the underside of the train pull it up to the ferromagnetic stators on the track and levitate the train.
 - The magnets on the side keep the train from moving from side to side.
 - A computer changes the amount of current to keep the train 1 cm from the track.

Levitation

- The passing of the superconducting magnets by figure eight levitation coils on the side of the track induces a current in the coils and creates a magnetic field. This pushes the train upward so that it can levitate 10 cm above the track.
- The train does not levitate until it reaches 50 mph, so it is equipped with retractable wheels.



10. Distinguish between ferro, ferri and anti ferro magnetic materials. Give examples for each.

Antiferromagnetism:

1. The electron spin of neighbouring atoms are aligned antiparallel.
2. Susceptibility mainly depends on temperature.
3. $\chi = C/T + \theta$
4. Susceptibility initially increases with the temperature and beyond Neel Temperature, it decreases with the temperature.

Ex: MnO, MnS

Ferrimagnetism

In ionic compounds, such as oxides, more complex forms of magnetic ordering can occur as a result of the crystal structure. One type of magnetic ordering is called ferrimagnetism.

The magnetic structure is composed of two magnetic sublattices (called A and B) separated by oxygens. The exchange interactions are mediated by the oxygen anions. When this happens, the interactions are called indirect or superexchange interactions. The strongest superexchange interactions result in an antiparallel alignment of spins between the A and B sublattice.

In ferrimagnets, the magnetic moments of the A and B sublattices are not equal and result in a net magnetic moment. Ferrimagnetism is therefore similar to ferromagnetism. It exhibits all the hallmarks of ferromagnetic behavior- spontaneous magnetization, Curie temperatures, hysteresis, and remanence. However, ferro- and ferrimagnets have very different magnetic ordering.

UNIT – IV DIELECTRIC MATERIALS

PART – A

1. Define dielectric constant

Dielectric constant is the measure of the polarization produced in the material. It is the ratio between the absolute permittivity and the permittivity of free space.

2. Mention any two liquid insulating materials.

- Synthetic oils are used as coolant and in high voltage transformers.
- Mineral oils are used as transformer oils.

3. Calculate the electronic polarisability of argon atom given $\epsilon_r=1.0024$ at NTP and $N=2.7 \times 10^{25}$ atoms/m³.

$$\alpha_e = \epsilon_0(\epsilon_r - 1) / N = 8.85 \times 10^{-12} (1.0024 - 1) / 2.7 \times 10^{25} = 7.9 \times 10^{-40} \text{ Fm}^2$$

4. What are the polar and non polar dielectrics?

The molecules having permanent dipoles are called as polar dielectrics and those do not have permanent dipole moment are called as non – polar dielectrics.

5. Find the dielectric constant of a material which when inserted in parallel capacitor of area 10 mm x 10 mm and distance of separation of 2 mm gives a capacitance of 10^{-9} F.

$$C = \epsilon_r \epsilon_0 A / d : \epsilon_r = Cd / \epsilon_0 A = 10^{-9} \times 2 \times 10^{-3} / 8.854 \times 10^{-12} \times 10^2 \times 10^{-6} = 2259$$

6. What are the ways in which dielectric breakdown can be minimized?

- (i) It should possess high dielectric strength and low dielectric loss.
- (ii) It should have less density and thermal expansion.
- (iii) It should be pure.
- (iv) It should have high resistivity and sufficient mechanical strength.

7. What are active & passive dielectrics?

Active dielectrics: It can easily adopt itself to store the electrical energy in it. Exs: Piezo electrics, Ferro electrics. It is used in production of ultrasonics

Passive dielectrics: Dielectrics which restricts the flow of electrical energy in it. Exs: Glass, Mica, Plastics. It is used in production of sheets, pipes etc.

8. Prove $\chi_e = \epsilon_r - 1$

We know the polarization $\vec{P} = \epsilon_0 \chi_e E^{-1}$

$$\chi_e = \frac{\vec{P}}{\epsilon_0 \vec{E}} \dots\dots\dots (1)$$

$$\frac{\vec{P}}{\vec{E}} = \epsilon_0 (\epsilon_r - 1) \dots\dots\dots (2)$$

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

Comparing equation 1 and 2 we get

$$\chi_e = \epsilon_r - 1 \text{ Thus proved}$$

9. Define dielectric breakdown and dielectric strength.

When external field applied to a dielectric material is greater than the critical field, the dielectric loses its insulating property and becomes conducting. Therefore a large current flows through the material. It is the minimum strength required per unit thickness of the dielectric material to produce dielectric breakdown

10. What is space-charge polarization.

When a dielectric is placed in an electric field diffusion of ions take place along the field direction, giving rise to redistribution of charges in the dielectrics and this phenomenon is known as space-charge polarization

PART – B

1. i) What is polarization?

The process of producing electrical dipoles inside the dielectric by the application of an external electric field is called polarization in dielectrics.

ii) Explain the various types of polarization mechanisms involved in dielectric materials.

Electronic Polarisation

Electronic polarisation is the result of the relative displacement of positively charged nucleus and the electron shells of an atom on the application of external field. This kind of polarization is present in all materials. It is proportional to the volume of the atom and is independent of temperature.

In inert gases, the centres of positive and negative charges in an atom coincide giving rise to zero dipole moment. But when an external field is applied, the electron charge cloud is displaced relative to the nucleus resulting in a net dipole moment.

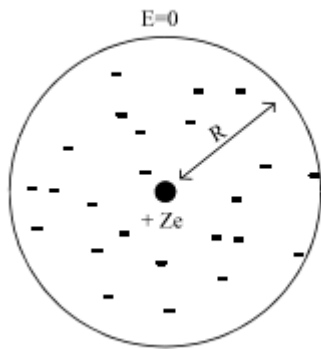


Fig. 5 Atom in the absence of field

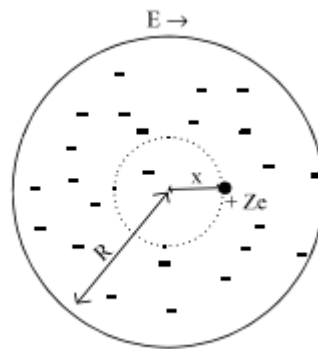


Fig. 6 Atom in the external field

Consider an atom of a dielectric material is placed in a d.c. electric field E . Since the nucleus and electron cloud of that atom have opposite charges, they are acted on by the opposite Lorentz forces in the presence of an external field. The nucleus and the electron cloud move in opposite directions. When the nucleus and electron cloud are shifted from their equilibrium position, an attractive Coulomb force is created and it will tend to maintain original equilibrium position. But the Lorentz force will tend to separate the nucleus and the electron cloud of that atom from their equilibrium position. Finally a new equilibrium will be reached when the two forces are equal and opposite (fig. 6). When there is no external field, the centres of the electron

cloud and nucleus of the atom coincide. In the presence of the field, the electron cloud is displaced by a distance x with respect to the centre of the nucleus.

We can assume that charge in the electron cloud is uniformly distributed over a sphere of radius R , and the spherical shape of the electron cloud is not altered on the application of the external field.

The charge density of the whole charged sphere

$$= \frac{Ze}{\frac{4}{3}\pi R^3}$$

Ze is the total negative charge.

Here, the sphere of radius x is also situated inside the sphere of radius R .

\therefore The number of negative charges in the sphere of radius x ,

$$= \frac{Ze}{\frac{4}{3}\pi R^3} \cdot \frac{4}{3}\pi x^3 = Ze \frac{x^3}{R^3}$$

Now the Coulomb force between the nucleus with positive charge Ze and the electron cloud which is displaced at a distance x from the nucleus is given by,

$$= \frac{Z^2 e^2 x}{4\pi\epsilon_0 R^3}$$

Under equilibrium conditions, the Coulomb attractive force and the Lorentz repulsive force are equal and opposite. Thus,

$$ZeE = \frac{Z^2 e^2 x}{4\pi\epsilon_0 R^3}$$

$$E = \frac{Zex}{4\pi\epsilon_0 R^3}$$

(15)

The dipole moment, due to the shifting of electron cloud,

$$p = Zex$$

Also by definition, $p = \alpha_e E$ (16)

From eqns. (15) and (16)

From eqns. (15) and (16)

$$\frac{Zex}{\alpha_e} = \frac{Zex}{4\pi\epsilon_0 R^3}$$

$$\alpha_e = 4\pi\epsilon_0 R^3 \quad (17)$$

This is the expression for electronic polarisability. It is proportional to the volume of the atom. It can be noted that the electronic polarisability is independent of temperature.

Ionic Polarization

The ionic polarization is due to the relative displacements of cations and anions in opposite directions in an ionic solid, on the application of external field. Ionic solids like NaCl, CsCl exhibit ionic polarisability. Ionic polarization does not occur in covalent crystals such as diamond. Ionic polarisation is also independent of temperature.

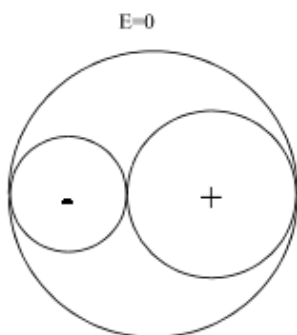


Fig. 7 (a) Ionic molecule in the absence of external field

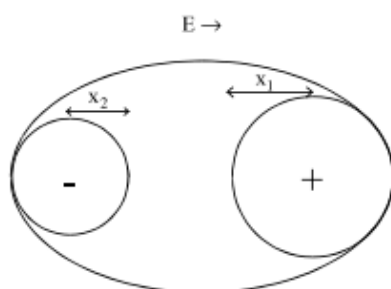


Fig.7 (b) Ionic molecule in an external field

Let an electric field E is applied to an ionic molecule in the positive x - direction. Then the positive ion moves to the right and negative ion moves to the left. If there are one cation and one anion in each unit cell of the ionic crystal, the resultant dipole moment per unit cell,

$$p = e (x_1 + x_2) = \alpha_i E \quad (18)$$

where x_1 - shift of the positive ion and x_2 - shift of the negative ion with respect to their equilibrium position. α_i - ionic polarisability.

Let F be the force due to the application of static electric field. Also let x_1 and x_2 be the restoring forces on positive ion and negative ion respectively, where k_1 and k_2 are the restoring force constants which depend on the mass of the ion and angular frequency of the molecule.

$$\text{At equilibrium, } F = k_1 x_1 = k_2 x_2$$

where, m_+ - mass of the positive ion.

$$\beta_1 = m_+ \omega_0^2 \quad \text{and} \quad F = eE$$

Similarly for negative ion,

$$x_2 = \frac{eE}{m_- \omega_0^2} \quad (20)$$

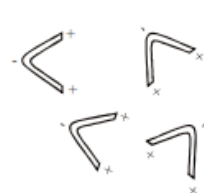
where m_- is the mass of the negative ion

Thus the ionic polarisability is inversely proportional to square of the natural vibrating frequency of the ionic molecule.

Orientational Polarisation

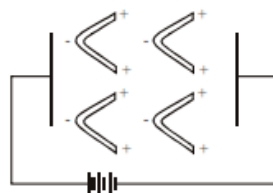
Polar molecules are the molecules which have permanent dipole moments even in the absence of an electric field as shown in fig. 9

The orientation polarization arises due to the presence of polar molecule in the dielectric medium. When a dielectric which consists of polar molecules is kept in an electric field, the molecules align themselves along the field direction. So there is a resultant dipole moment along the field direction, as shown in figure 9.



Without field

Fig.8



With field

Fig. 9

Explanation

In the case of a CH_3Cl molecule, the +ve and -ve charges do not coincide. The Cl^- has more electronegativity than hydrogen. Therefore the chlorine atoms pull the bonded electrons towards it more strongly than hydrogen atoms. Therefore, even in the absence of field, there exists a net dipole moment.

Orientation polarization

$$P_o = \frac{N\mu^2 E}{3k_B T}$$

where N is the number of atoms

(or)

where - Orientational Polarizability

$$\alpha_0 = \frac{\mu^2}{3k_B T}$$

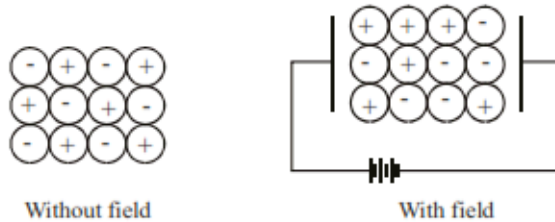
(22)

Space-charge polarization

The space-charge polarization occurs due to diffusion of ions, along the field direction and giving rise to redistribution of charges in the dielectrics.

Explanation

Without the application of external field, the ions are orderly arranged as shown in fig. 10 (a).



Now, when the field is applied, the ions diffuse with respect to the direction of applied field as shown in fig. Thus the polarization occurs, known as space charge polarization.

Normally, this type of polarization occurs in ferrites and semiconductors and will be very small.

2. i) What is meant by internal field?

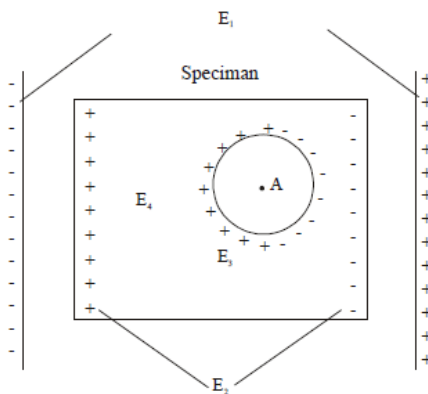
When a dielectric is kept in an external electric field (E), two fields are exerted due to (i) external field and (ii) dipole moment created. These long ranges of coulomb forces which are created due to the dipoles are called internal field (or) local field in dielectric.

$$E_{\text{int}} = E + \frac{P}{3\epsilon_0}$$

ii) Deduce an expression for internal field and hence obtain Clausius-Mosotti equation.

When a dielectric material is kept in an external field it exerts a dipole moment in it. Therefore two fields are exerted. They are,

1. Due to external field
2. Due to dipole moment

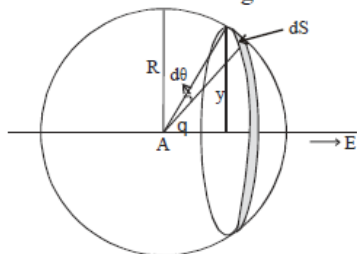


This long range coulombic force which is created due to the dipoles is called as internal field or local field. This field is responsible for polarising the individual atoms or molecules.

Lorentz method for finding internal field

Let us assume, a dielectric material to placed in an external field. Consider an imaginary sphere in the solid dielectric of radius 'r'.

Here the radius of the sphere is greater than the radius of the atoms. i.e. there are many atomic dipoles within the sphere. A small elemental ring is cut with thickness ds . Let y be the radius of the small ring as shown in fig. 2



The electric field at the centre of the sphere is called internal field, which arises due to the following four factors

$$E_{\text{int}} = E_1 + E_2 + E_3 + E_4 \quad (4.1)$$

where,

E_1 = Field due to the charge on the plates. (externally applied)

E_2 = Field due to the polarization charges on the plane surface of the dielectric.

E_3 = Field due to the polarized charges induced at the spherical surface.

E_4 = Field due to the atomic dipoles inside the sphere considered.

Macroscopically, we can take (i.e.) The field externally applied (E_1) and the field induced on the plane surface of the dielectric (E_2) as a single field (E). If the dielectric is highly symmetric then the dipoles will cancel with each other and therefore we can take $E_4 = 0$

Equation (1) becomes,

$$E_{\text{int}} = E + E_3 \quad (4.2)$$

To find E_3

In the element ring, let 'q' be on the area ds . Polarization is defined as the surface charges per unit area. If P_N is the component of polarization perpendicular to the area as shown in fig.

4.3. Here $P_N = P \cos \theta = q/ds$ (or) $q = P \cos \theta ds$

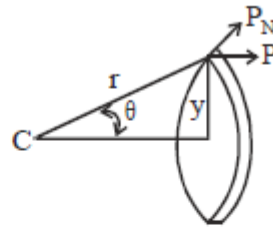


Fig .3

Electric field intensity at 'A' due to charge is given by

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

$$= \frac{P \cos \theta ds}{4\pi\epsilon_0 r^2}$$

Component parallel to the field direction $E_x = E \cos \theta$

$$\therefore E_x = \frac{P \cos^2 \theta ds}{4\pi\epsilon_0 r^2} \quad (4.3)$$

Component perpendicular to the field direction

$$\therefore E_y = \frac{P \cos \theta \sin \theta ds}{4\pi\epsilon_0 r^2} \quad (4.4)$$



If the total surface area of the ring is considered as dA then

$$E_x = E = \frac{P \cos^2 \theta dA}{4\pi\epsilon_0 r^2} \quad (5)$$

where $dA = \text{circumference} \times \text{thickness}$

$$= 2\pi y \times r d\theta \quad \because y = r \sin \theta$$

$$= 2\pi r \sin \theta \times r d\theta$$

$$= 2\pi r^2 \sin \theta d\theta \quad (6)$$

Substituting equation (6) in equation (5), we get

$$\frac{P \cos^2 \theta \sin \theta d\theta}{2\epsilon_0}$$

Electric field intensity due to the elemental ring

$$\frac{P \cos^2 \theta \sin \theta d\theta}{2\epsilon_0}$$

(7)

Electrical field intensity due to the whole sphere can be derived by integrating equation (7) within the limits 0 to π .

$$E_3 = \frac{\int_0^\pi \frac{P \cos^2 \theta \sin \theta d\theta}{2\epsilon_0}}{3} = \frac{2}{3} \frac{P}{2\epsilon_0} \because \int_0^\pi \cos^2 \theta \sin \theta d\theta = \frac{2}{3}$$

$$E_3 = \frac{P}{3\epsilon_0} \quad (8)$$

Substituting equation (8) in equation (2) we can write

$$\therefore E_{\text{int}} = E + \frac{P}{3\epsilon_0} \quad (9)$$

where E_{int} is called internal field or Lorentz field.

Clausius - Mosotti relation

In non-polar dielectrics, the molecules do not possess permanent dipole moments. In the presence of an external field, the induced dipole

moment, p is proportional to the local electric field.

$$p = \alpha E_{\text{local}}$$

$$P = N\alpha E + \frac{P}{3\epsilon_0}$$

$$\frac{P}{E} = N\alpha \left(1 + \frac{P/E}{3\epsilon_0} \right)$$

$$\text{We know } D = \epsilon_0 \epsilon_r E$$

$$\text{Also } D = \epsilon_0 E + P \quad (11)$$

substituting eqn. (12) in eqn. (11), we get

$$= \frac{N\alpha}{3\epsilon_0} \epsilon_0 \epsilon_r + 2$$

$$\therefore \frac{N\alpha}{3\epsilon_0} = \frac{\epsilon_r - 1}{\epsilon_r + 2} \quad (12)$$

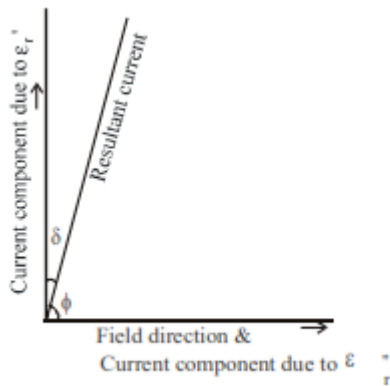
3. i) What do you mean by dielectric loss?

When a dielectric material is subjected to electric field, the electrical energy is absorbed by the dielectric and certain amount of electrical energy is dissipated in the form of heat energy. This is the loss in the energy in the form of heat is called as dielectric loss.

ii) Explain the phenomenon of dielectric loss in detail.

When an a.c. electric field is applied to a dielectric the dipoles tend to follow the field and be in phase with it. However the interaction of the dipole with other dipoles in the medium prevents this. This leads to energy loss known as dielectric loss which appears as heat. This energy loss is connected with , the imaginary part of the dielectric constant. Very often the loss is expressed in terms of a quantity called the loss tangent. This is defined as

$$\tan \delta = \frac{\epsilon_r''}{\epsilon_r'}$$



Here the current component is in phase with the applied field and $\sin \omega t$ is 90° out of phase with the applied field. In an ideal dielectric, where there is no absorption of electrical energy, the value of is equal to zero. Therefore in an ideal dielectric, the current density,

i.e. the current leads the voltage by 90° .

Under these circumstances,

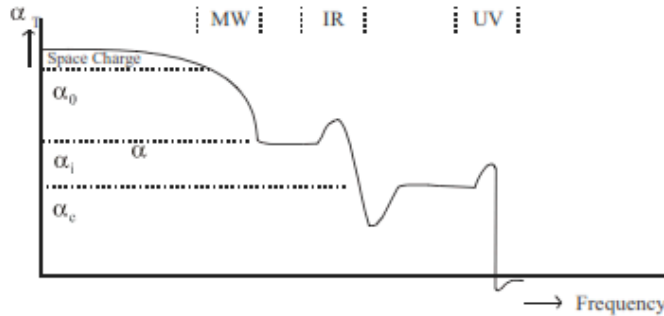
$$\tan \delta = \frac{\epsilon_r''}{\epsilon_r'} = 0 \quad \text{and hence } \delta = 0. \quad (26)$$

If there is a resulting current component in phase with the field (i.e. if $\neq 0$), the resulting current will no longer lead the field by 90° but by $90^\circ - \delta$. Thus if the relative permittivity of a material is a real quantity, there is no loss. At low frequencies ϵ_r is real and there is no loss. At IR and higher frequencies ϵ_r is complex and there is a loss in energy.

iii) Describe the frequency and temperature dependence of polarization.

Frequency dependence

Electronic polarization is very rapid and will complete at the instant. The voltage is applied the reason is that the electrons are very light elementary particles than ions. Therefore even for very high frequency applied voltage i.e., in the optical range ($=10^{15}$ Hz) as shown



in fig. 12, this kind of polarization occurs during every cycle of the applied voltage.

(ii) Ionic polarization is slightly slower than the electronic polarization. Because ions are heavier than the electron cloud. Also the frequency of the applied electric field with which the ions will be displaced is equal to the frequency of the lattice vibrations ($= 10^{13}$ Hz).

At optical frequencies, there is no ionic polarization. If the frequency of the applied voltage is less than 10^{13} Hz i.e., infrared range as shown in fig 12 the ions have enough time to respond during each cycle of the applied field.

(iii) Orientation Polarization is even slower than ionic polarization. the relaxation time for this case varies with respect to the dielectric materials (i.e., solids or liquids) used. Here the polar molecules in a liquid easily reorient themselves compared to solids. This type of polarization occurs at audio and radio frequency ranges. ($= 10^6$ Hz) as shown in fig.12.

(iv) Space charge polarization is the slowest process, because in this case ions have to diffuse (jump) over several interatomic distances. Also this process occurs at very low frequency in the order of 10^2 Hz as shown in fig12

Temperature Dependence

The electronic and ionic polarizations are independent of temperature, whereas orientation and space charge polarizations are temperature dependent.

The orientation polarization decreases with the increase in temperature because the randomizing action of thermal energy decreases the tendency of the permanent dipoles to align along the field direction. Hence in this case decreases.

But in space charge polarization, when the temperature is increased, the ions can easily overcome the activation barrier and hence they diffuse through the inter atomic distances. Thus it gives rise to polarization. So in this case the will increase with the increase in temperature.

4. i) Explain in detail various types of dielectric breakdown mechanisms.

1. Intrinsic breakdown :

The theory of dielectric breakdown was developed using alkali halides as models. The band gap in these materials is substantial. When strong electric field is applied, the electrons in the valence band gain sufficient amount of energy and cross the energy gap. The electrons promoted to the conduction band move freely inside the dielectric and they are accelerated by the applied field. The fast moving conduction electrons collide with the atoms and dislodge more number of electrons. The process goes on as a chain reaction and results in large current flow. The breakdown occurs in this way is intrinsic breakdown.

Characteristics

- i. This can occur even at low temperature
- ii. Relatively high field.
- iii. Thin samples.
- iv. Does not depend on shape of the sample

2. Thermal breakdown :

When a dielectric material is subjected to an alternating electric field, heat is generated due to dielectric loss. If the heat gained by the material is greater than the heat lost to the surrounding, the temperature goes on increasing. As the temperature increases, the conductivity of the dielectric increases. Thus the material loses its insulating property. This is a much slower process than other electronic processes. Thermal breakdown occurs frequently in polymers.

Characteristics

- i. Occur only at high temperature
- ii. Dielectric strength depends on size and shape

3. Chemical breakdown:

When a dielectric is exposed to atmosphere for a longer time, chemical degradation occurs. This chemical degradation encourages breakdown. e.g., degradation of rubber.

Characteristics

- i. It occurs only at low temperature.
- ii. It occurs even in the absence of electric field.
- iii. It depends on concentration of ions, magnitude of leakage current.

4. Discharge breakdown :

Some dielectric materials may contain gaseous voids (cavities). The dielectric strength of gas is smaller. When a strong electric field is applied, electric discharge occurs in the voids with accompanying destruction of the adjacent material. Thus the void grows continuously and ultimately breakdown occurs. This can occur at low voltages where there are large number of occluded gas bubbles in the insulating material.

Characteristics

- i. It occurs at low voltages.
- ii. It occurs due to the presence of occluded gas Bubbles.
- iii. It depends upon the frequency of the applied Voltage.

5. Defect breakdown:

Some dielectric materials may have surface defects like cracks, pores etc. Moisture and other impurities filled up at these places lead to breakdown.

To avoid dielectric breakdown, an insulating material should possess the following properties.

- i. Dielectric and Mechanical strength must be high.
- ii. Thermal conductivity must be high
- iii. Thermal expansion must be low.
- iv. Must be pure and free from surface defects.

ii) Discuss the remedies of dielectric breakdown.

- It should have high resistivity
- It must possess high dielectric strength
- It should have sufficient mechanical strength.

5. i) What is ferro electricity?

Materials which exhibit electric polarisation even in the absence of the applied electric field are known as Ferroelectric materials.

These have permanent dipole moment in each atom or molecule. The dielectric constants of these materials are some three orders of magnitude larger than that in ordinary dielectrics. **Ferroelectricity refers to the creation of enormous value of induced dipole moment in a weak electric field as well as existence of electric polarisation even in the absence of applied electric field.**

ii) Give examples for ferro electric materials.

Barium titanate (BaTiO_3), Potassium dihydrogen phosphate (KH_2PO_4), Ammonium dihydrogen phosphate ($\text{NH}_4\text{H}_2\text{PO}_4$), Lithium Niobate (LiNbO_3) and Rochelle salt ($\text{NaKC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$) are the typical examples of ferroelectric materials.

iii) Write the properties and applications of ferro electric material.

Properties of Ferroelectric materials

1. Ferroelectric materials can be easily polarised even by very weak electric fields.
2. They exhibit dielectric hysteresis. Lagging of polarisation behind the applied electric field is called dielectric hysteresis. Ferroelectricity is a result of dielectric hysteresis (figure 15)
3. Ferroelectric materials possess spontaneous polarisation, which is polarisation that persists when the applied field is zero.
4. They possess permanent electric dipoles and internal electric field which develop spontaneous polarisation at ferroelectric curie temperature.
5. Ferroelectric materials exhibit ferroelectricity when the temperature $T < T_c$. Where T_c = ferroelectric curie temperature. When $T > T_c$, they are converted into Paraelectric materials.
6. They exhibit domain structure as in the case of ferromagnetic materials.
7. Ferroelectric materials exhibit piezoelectricity. Piezoelectricity means the creation of electric polarisation by mechanical stress. Pyroelectricity means the creation of electric polarisation by thermal stress.

Applications of Ferroelectric materials

1. Ferroelectric energy converter

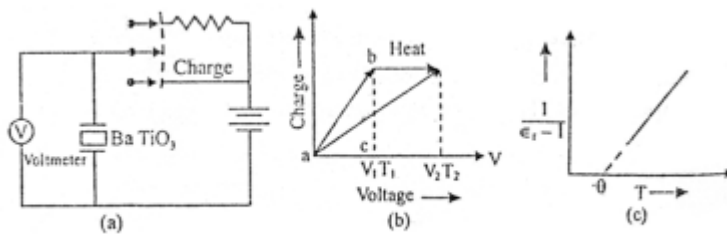
Ferroelectric crystals exhibit the pyroelectric effect. i.e. a change in the temperature of the crystal produces a change in its polarisation. Using this effect, one can convert heat energy in to useful electrical energy. First the capacitor with BaTiO_3 is charged to a voltage of V_1 at a temperature T_1 just below the curie temperature ' θ ' (figure 16)

$$\text{Now } Q = C_1 V_1$$

Where C_1 is the capacitance of the capacitor.

Initial energy $Q V_1 = \text{area of the triangle abc (figure 16).}$

Now the capacitor is isolated from the battery and it is heated up to T_2 . Therefore, the dielectric constant ϵ_r decreases. For BaTiO_3 , when we increase the temperature from 15°C to 30°C , (figure 16).



Since the dielectric constant value decreases, the capacitance value also decreases and at temperature T_2 , the capacitance of the capacitor is equal to C_2 .

$$\text{i.e } C_2 < C_1$$

Since the charge Q in the capacitor is constant and $C_2 < C_1$,

$$Q = C_1 V_1 = C_2 V_2$$

$$\therefore V_2 > V_1$$

$$(\text{or}) V_2 = V_1 C_1 / C_2 = V_1 \epsilon_{r1} / \epsilon_{r2}$$

$$\text{Increase in energy } W = Q (V_2 - V_1)$$

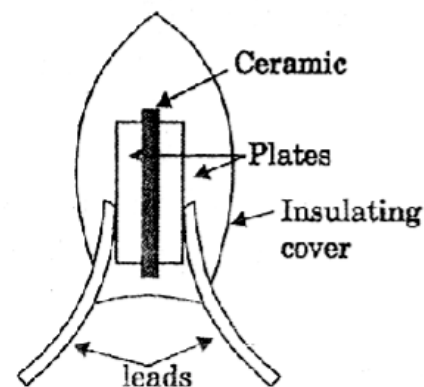
2. The high dielectric constant of ferroelectric crystals is also useful for storing energy in small sized capacitors in electrical circuits.
 3. In optical communication, the ferroelectric crystals are used for optical modulation.
 4. These are used in electro acoustic transducers such as microphone.
6. i) Explain the uses of dielectric materials in capacitors and transformers.

i) Capacitors:

A capacitor is made up of conducting plates and a dielectric. The dielectric may be air, solid insulating material, or a liquid, depending upon the duty of the capacitor and in different electronic circuits.

Capacitors are used in electrical utilities.

Fig 4.14 shows the different types of capacitors. Power capacitors use tissue paper and / or polypropylene films as dielectric. This insulation system is impregnated with either mineral oil or synthetic liquids.



(a) Ceramic capacitor

Many types of capacitors are now used specially for D.C applications.

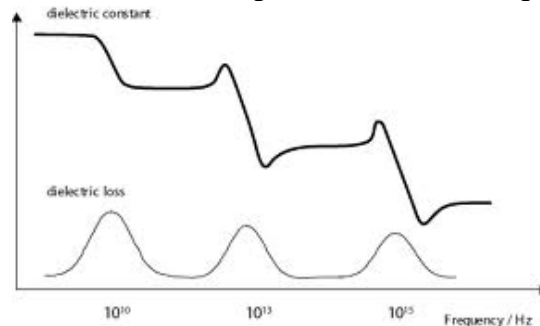
These are in addition to paper capacitors (paper with impregnants like castor oil, synthetic oils, mineral oil, polyesters etc), electrolytic capacitors with aluminium or tantalum, ceramic capacitors with variety of ceramic bodies (tubular, disc, blocking etc) and film dielectric (polystyrene, Teflon, polyethylene etc) capacitors.

ii) Power and distribution transformers

The insulating materials used in power and distribution transformers must possess the following properties.

- * Good electrical properties to withstand the power frequency voltages and impulse over voltages.
- * Good mechanical properties to withstand fabrication and handling during manufacture and electromagnetic forces during over load, short circuit and normal operating conditions.
- * Good thermal stability and low ageing effect.

ii) Draw a graph for the variation of power loss with frequency.



UNIT V - ADVANCED ENGINEERING MATERIALS

PART A

1. What are the types of metallic glasses? Mention few examples.

Types of metallic glasses

Metal- metalloid metallic glasses, Eg: Fe, Co, Ni: Bi, Si, P

Metal-metal metallic glasses Eg: Ni, Nb

2. What is the advantage of using metallic glasses as a transformer core material?

Metallic glasses possess low magnetic losses, high permeability, high saturation magnetization and extreme mechanical hardness. Therefore they are used as transformer core materials.

3. What is glass transition temperature?

The temperature at which the transition from liquid to solid occurs is known as glass transition temperature.

4. Mention different forms of nanomaterials.

Nanorods, nanodots, nanowires, nanobuds, nano composites, Carbon nanotubes and Fullerenes

5. Define pseudo elasticity.

In some types of shape memory alloys, change in shape occurs without any change in temperature. This change in shape is stress induced and is called pseudo elasticity.

6. Name few non-linear optical phenomena.

Higher harmonic generation, Optical mixing, Optical phase conjugation and Soliton

7. What are non-linear materials? Give any two examples.

The materials in which optical properties depend on the intensity of light are called non-linear optical materials. Eg: Lithium niobate, Lithium Tantalate, Barium sodium niobate

8. What are biomaterials?

The materials which are used for structural applications in the field of medicine are known as biomaterials. These materials are used to make devices to replace damaged or diseased body parts in human and animal bodies.

9. What are the types of biomaterials? Mention few biomaterials and their applications.

- Metals & alloys biomaterials
 - Ceramic biomaterials
 - Polymer biomaterials
 - Composite biomaterials
- a) Stainless steel is a predominant alloy widely used in implant and orthopaedic applications
- b) Protosal from cast alloy of Co-Cr-Mo is used to make stem and head of implant hip endoprosthesis.

10. What is Kerr effect?

The Kerr effect is a phenomenon in which the refractive index of a material changes because of an applied electrical field, and the change in the refractive index is proportional to the square of the applied electric field. The Kerr effect is also known as the quadratic electro-optic effect (QEO effect).

UNIT V - ADVANCED ENGINEERING MATERIALS

PART B

1. What are nano phase materials? Explain their properties

Nanophase materials are newly developed materials with grain size at the nanometre range i.e. in the order of 1-100 nm. The particle size in nanomaterials is 1 nm. They are simply called as nanomaterials. They exist in different forms like nanodots, nanorods, nanoparticles and nanotubes etc.

Properties of nanophase particles

a) Mechanical properties

- a. In nanophase materials, the elastic strength is low however; its plastic behavior is high.
- b. In some nanophase materials, it is noted that there is decrease in hardness when the grain size is less than 10 nm.
- c. Higher hardness and mechanical strength when grain size reduces to nano range.
- d. It has very high ductility and superplastic behavior at low temperatures.

b) Magnetic properties

Nanoparticles of non-magnetic solids also exhibit new type of magnetic properties.

- a. Bulk magnetic moment increases with decrease in coordination number. This means that small particles are more magnetic than the bulk material.
- b. The nanomaterials show variation in their magnetic property when they change from bulk state to cluster (nanoparticles) state.
- c. Non-magnetic materials become magnetic when the cluster size reduces to 80 atoms.

c) Chemical properties

The large surface to volume ratio, the variations in geometry and the electronic structure have a strong effect on catalytic properties. The reactivity of small clusters has been found to vary by higher orders of magnitude when the cluster size is changed by only a few atoms.

d) Variation of physical parameters with geometry

Starting from the bulk, the first effect of reducing the particle size is to create more surface sites. This in turn changes surface pressure and interparticle spacing.

i) Interparticle spacing decreases with decrease in grain size for metal clusters. For example in copper, it decreases from 2.52 to 2.23 Å. The change in interparticle spacing and large surface to volume ratio in particles has a combined effect on material properties. Therefore, the nanophase materials have very high strength and super hardness

ii) Melting point reduces with decrease in cluster size

iii) Ionization potential changes with cluster size of the nanograins

iv) The large surface to volume ratio, the variations in geometry and the electronic structure have a strong effect on catalytic properties. The reactivity of small clusters has been found to vary by higher orders of magnitude when the cluster size is changed by only a few atoms.

2. Give the concept, properties and applications of metallic glasses.

Metallic glasses were discovered in 1970. Metals are solids with crystalline property, malleability, ductility etc. Glasses are amorphous materials which are transparent and brittle in nature. Metallic glasses are the newly developed engineering materials which share the properties of both metals and glasses. They have high strength, good magnetic properties and better corrosion resistance.

Ex: Alloys of Fe, Ni, Al and Cu mixed with metalloids such as Si, Ge, As and C.

Properties

- They do not have any crystal defects

- They have tetrahedral close packed structure
- They have high elasticity
- They are highly ductile
- Electrical resistivity is high and it does not vary much with temperature.
- Due to high resistivity, the eddy current loss is very small.
- They possess low magnetic losses, high permeability, high saturation magnetization and extreme mechanical hardness.
- They can act as catalyst

Applications

- They are used as reinforcing elements in concrete, plastic or rubber.
- They are used to make razor blades and different kinds of springs.
- They are used to construct large fly wheels for energy storage.
- They are used in transformers and magnetic shields since they possess low magnetic losses, high permeability, high saturation magnetization and extreme mechanical hardness.
- Used to produce high magnetic fields and magnetic levitation effect
- Used in preparing containers for nuclear waste disposal and magnets for fusion reactors
- Ideal materials for cutting tools and making surgical instruments

3. How are metallic glasses prepared? Explain how the melt spinner device can be used to produce metallic glass.

Metallic glasses are prepared based on the principle of rapid cooling technique called quenching. Metals are taken to glassy state by increasing the rate of cooling [2×10^6 °C/second] and hence atoms won't be able to arrange orderly. This results in amorphous state leading to a new type of material.

Melt spinning system

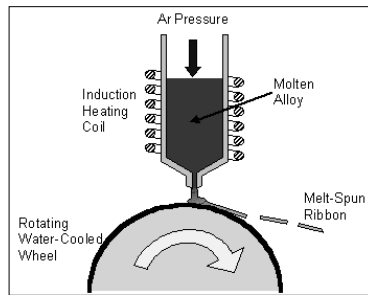
Principle

The cooled molten alloys are fed into highly conducting massive rollers at high speeds to give ribbons of metallic glasses.

Experimental setup

A melt spinner consists of refractory tube with fine nozzle and induction heater coil, spinning copper disc. This disc is rotated at a high speed to generate a high velocity of more than $\sim 50 \text{ ms}^{-1}$. The alloy is melted by induction heating under inert helium or argon atmosphere. Ejection rate can be increased by increasing the pressure inside the refractory tube. A properly superheated molten alloy is ejected under pressure through the nozzle onto the spinning disc. The

dynamic melt puddle impinging on the moving substrate is solidified and it is thrown out of the wheel by centrifugal force after travelling with it over a short distance. Thus, a continuous ribbon is obtained due to rapid quenching and it is wound on a spool.



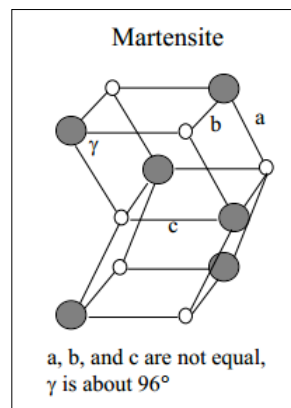
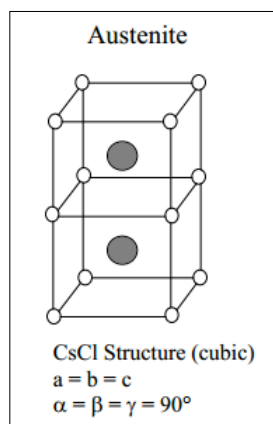
4. What are shape memory characteristics and

Shape memory alloys (SMA) are smart/intelligent materials which show the ability to return to their original shape or size when they are subjected to appropriate thermal procedure. The range of temperature at which SMA switches back to its original shape is called transformation temperature.

Phases of SMA

Martensite and **Austenite** are the two solid phases which occur in SMA as shown in Fig.

- Martensite is relatively soft and it is easily deformable phase which exists at low temperature (monoclinic).
- Austenite – is a phase that occurs at high temperature having a crystal structure and high degree of symmetry (cubic).
- The mechanism involved in SMA is reversible (austenite to martensite and vice versa).



SMA

a. **Shape**
The

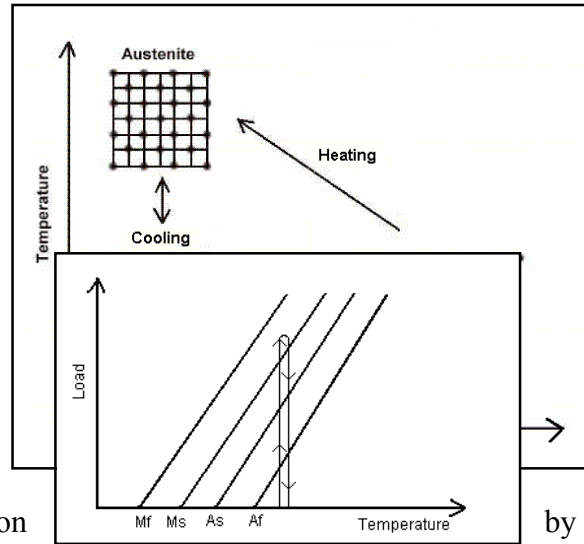
Change

Characteristics of

memory effect

of shape of a material

at low temperature by loading and regaining of original shape by heating it is called shape memory effect. The original shape is recovered due to two different solid phases of the material namely martensite and austenite. On heating, martensite deformed and becomes austenite and upon cooling gets transformed to twinned martensite.



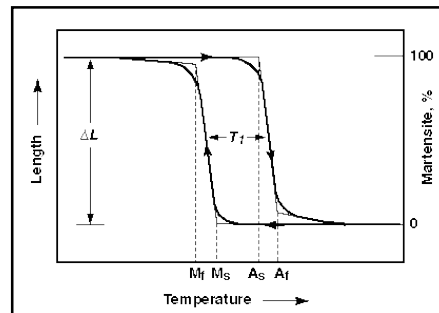
b. Pseudo-elasticity/

The phenomenon by which the change in shape occurs in SMA even without change in temperature is called Pseudoelasticity. This takes place at temperature greater than the austenite formation temperature. The load on the SMA is increased and austenite becomes transformed into martensite simply due to loading.

Super-elasticity

c. Hysteresis

The difference between the transition temperature upon heating and cooling is called hysteresis.



d. SMA's exhibit changes in electrical resistance, volume and length during transformation with temperature

Applications of SMA

- One of the most common applications of SMAs is Microvalves (Actuators)
- Shape memory alloys are used to make toys and ornamental goods.
- They are used in blood clot filters, artificial hearts and dental applications.
- SMAs are used as a thermostat to open and close the valves at required temperature.

Advantages of SMA

- They are very compact in nature

- ii. They are safe and smart
- iii. They are flexible in nature.
- iv. They have non-corrosive nature.

Disadvantages of SMA

- i. They are expensive (high cost)
- ii. They have low efficiency
- iii. Transformation of shape occurs over a range of temperatures
- iv. Structural arrangements may sometime get deformed

5. Discuss the applications of nano materials in various fields.

Applications of nano materials in various fields

a) Materials technology

- Harder metals having hardness 5 times higher than the normal metals can be produced
- Unusual color paints can be produced
- Smart magnetic fluids are used as vacuum seals, cooling fluids etc.
- Used in nanoelectronics devices such as nanotransistors, ceramic capacitors for energy storage etc.
- ZnO thermistors are used in thermal-protection and current-controlling devices

b) Information technology

- Nanoparticles are used for data storage
- Quantum electronic devices have started replacing bulk conventional devices
- Magnetic devices made of Cu-Fe alloy are used in RAM, READ/WRITE heads and sensors
- Nano dimensioned photonic crystals are used in chemical/optical computers

c) Biomedicals

- Biosensitive nanoparticles are used for tagging of DNA and DNA chips
- Controlled drug delivery is possible
- Finds applications as an implant material

d) Energy storage

- Useful in magnetic refrigeration
- Metal nanoparticles are very useful in fabrication of ionic batteries

e) Optical devices

- Nanomaterials are used in making efficient semiconductor laser and CD's
- Nano Zinc Oxide is used to manufacture effective sunscreens
- Used in the coatings for eye glasses to protect from scratch or breakage

6. Explain how nanomaterials are prepared using chemical vapour deposition and pulsed laser deposition techniques.

Preparation of nanomaterials

Top down approach – Bulk materials are broken into nano sized particle

Bottom up approach – Nano materials are produced by building of atom by an atom

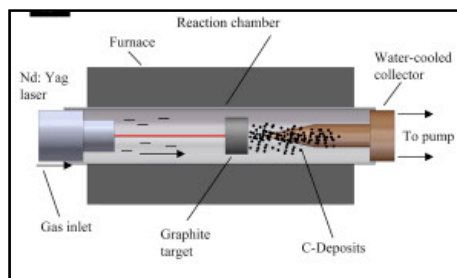
Pulsed laser deposition

Principle

The laser pulse of high intensity and energy is used to evaporate carbon from graphite. These evaporated carbon atoms are condensed to form nanotubes.

Construction

A quartz tube which contains the graphite target is kept inside the high temperature muffle furnace. This quartz tube is filled with argon gas and it is heated to 1473 K. A water cooled copper collector is fitted at the other end of the tube. The target material graphite contains small amount of nickel and cobalt as a catalyst to nucleate the formation of nanotubes.



Working

When an intense pulse of laser beam is incident on the target, it evaporates the carbon from the graphite. The evaporated carbon atoms are swept from the higher temperature, argon gas to the colder collector. When the carbon atoms reach the colder copper collector they condense into nanotubes.

Chemical vapour deposition

The deposition of nano films from gaseous phase by chemical reaction on high temperature is known as chemical vapour deposition. This method is used to prepare nanopowder.

In this technique, initially the material is heated to gaseous state and then it is deposited on a solid surface under vacuum condition to form nanopowder by chemical reaction with the substrate. It involves the flow of a gas with diffused reactants over a hot substrate surface. The gas that carries the reactants is called the carrier gas. While the gas flows over the hot solid surface, the heat energy increases chemical reactions of the reactants that form film during and after the reactions.

The byproduct of the chemical reactions is then removed. The thin film of desired composition can thus be formed over the surface of the substrate.

7. Explain the origin of nonlinear optics. How are second harmonic waves generated?

The field of study concerned with the interaction of light radiation and matter in which the matter responds in a non linear manner to the incident radiation fields is called **non linear optics**. This behavior is known as **non linear effect** and the materials which exhibit this effect are called **non linear materials**.

Second harmonic generation

In a linear medium, polarization (**P**) is directly proportional to electric field (**E**)

$$P \propto E$$

$$P = \epsilon_0 \chi E$$

where ϵ_0 - permittivity of free space,

χ - electrical susceptibility.

In nonlinear medium for higher fields, the nonlinear effects are observed.

$$P = \epsilon_0 (\chi_1 E + \chi_2 E^2 + \chi_3 E^3 + \dots) \quad (1)$$

Where χ_1 is the linear susceptibility and χ_2, χ_3 etc are higher order nonlinear susceptibilities.

The electric field passing through the medium with amplitude E_0 is

$$E = E_0 \cos \omega t \quad (2)$$

Substituting the value of (2) in (1) we have

$$P = \epsilon_0 (\chi_1 E_0 \cos \omega t + \chi_2 E_0^2 \cos^2 \omega t + \chi_3 E_0^3 \cos^3 \omega t + \dots) \quad (3)$$

We know that

$$\left. \begin{aligned} \cos^2 \omega t &= \frac{1 + \cos 2\omega t}{2} \\ \cos^3 \omega t &= \frac{\cos 3\omega t + 3\cos \omega t}{4} \end{aligned} \right\} \quad (4)$$

Substituting equation (4) in (3) we have

$$P = \epsilon_0 \left(\chi_1 E_0 \cos \omega t + \chi_2 E_0^2 \frac{1 + \cos 2\omega t}{2} + \chi_3 E_0^3 \frac{\cos 3\omega t + 3\cos \omega t}{4} + \dots \right)$$

$$\begin{aligned}
 P &= \varepsilon_0 \left(\chi_1 E_0 \cos \omega t + \chi_2 E_0^2 \left(\frac{1}{2} \right) + \chi_2 E_0^2 \left(\frac{\cos 2\omega t}{2} \right) + \chi_3 E_0^3 \left(\frac{\cos 3\omega t}{4} \right) + \chi_3 E_0^3 \left(\frac{3\cos \omega t}{4} \right) \right. \\
 &\quad \left. + \dots \right) \\
 P &= \varepsilon_0 \left(\frac{1}{2} \chi_2 E_0^2 + \chi_1 E_0 \cos \omega t + \frac{3}{4} \chi_3 E_0^3 \cos \omega t + \chi_2 E_0^2 \left(\frac{\cos 2\omega t}{2} \right) + \chi_3 E_0^3 \left(\frac{\cos 3\omega t}{4} \right) + \dots \right) \\
 P &= \varepsilon_0 \left(\frac{1}{2} \chi_2 E_0^2 + \left(\chi_1 + \frac{3}{4} \chi_3 E_0^2 \right) E_0 \cos \omega t + \frac{1}{2} \chi_2 E_0^2 \cos 2\omega t + \frac{1}{4} \chi_3 E_0^3 \cos 3\omega t + \dots \right) \\
 P &= \frac{1}{2} \varepsilon_0 \chi_2 E_0^2 + \varepsilon_0 \left(\chi_1 + \frac{3}{4} \chi_3 E_0^2 \right) E_0 \cos \omega t + \frac{1}{2} \varepsilon_0 \chi_2 E_0^2 \cos 2\omega t + \frac{1}{4} \varepsilon_0 \chi_3 E_0^3 \cos 3\omega t + \dots \quad (5)
 \end{aligned}$$

In the above equation, first term gives rise to dc field across the medium; the second term gives external polarization and is called first or fundamental harmonic polarizability. The third term which oscillates at a frequency 2ω is called second harmonic of polarization and the terms are referred as higher harmonic polarization. Both the first term and third term added together is called optical rectification.

The second harmonic generation is possible only to the crystals lacking inversion symmetry. SHG crystals are quartz, potassium dihydrogen phosphate, ammonium dihydrogen phosphate, barium titanate and lithium iodate.

When the fundamental radiation from Nd:YAG laser is sent through SHG crystal like KDP, conversion takes place to double the frequency i.e. half the wavelength takes place.

8. Explain biomaterials and its modern applications in the field of medicine.

The materials which are used for structural applications in the field of medicine are known as biomaterials. These materials are used to make devices to replace damaged or diseased body parts in human and animal bodies.

Biomaterials should have high compatibility, corrosion resistant and required property. Different materials possess different specific properties.

Classification of biomaterials

i) **Metals and alloys** are used as biomaterials due to their excellent electrical and thermal conductivity and mechanical properties. The types of biomaterials using metals and alloys are cobalt based alloys, titanium, stainless steel, protosal from cast alloy, conducting metals such as platinum.

Applications

- Stainless steel is the predominant implant alloy. This is mainly due to its ease of fabrication and desirable mechanical properties and corrosion resistant.
- Protosal from cast alloy of Co-Cr-Mo is use to make stem and used for implant help endoprosthesis.

- c. Ni-Ti shape memory alloy is used in dental arch wires, micro surgical instruments, blood clot filters, guide wires etc.

ii) **Ceramics** are used as biomaterials due to their high mechanical strength and biocompatibility. Types of bio-ceramic materials include tricalcium phosphate, metal oxides, apatite ceramics, porous ceramics, carbon and alumina.

Applications

- a. Ceramic implants like alumina with some SiO₂ and alkali metals are used to make femoral head.
- b. Tricalcium phosphate is used in bone repairs.
- c. Apatite ceramics are new bio active ceramics. They are regarded as synthetic bone, readily allows bone ingrowth, better than currently used alumina.
- d. Carbon coatings find wide applications in heart valves, blood vessel grafts, percutaneous devices because of exceptional compatibility with soft tissues and blood.

iii) **Bio Polymers**

Biopolymers are macromolecules (protein, nucleic acid and polysachacides) formed in nature during the growth cycles of all organisms.

Applications

Biopolymers find variety of applications as biomaterials. The most prominent among them are collagens and its derivatives. Collagens which are major animal structural proteins are widely used in a variety of forms such as solution, gel, fibers, membranes, sponge and tubing for large number of biomedical applications including drug delivery system, vessels, valves corneal prosthesis, wound dressing, cartilage substitute and dental applications.

iv) **Composite materials** are also used as biomaterials. Sometimes, a single material mentioned above cannot fulfill the complete requirements imposed on specific applications. In such case, combinations of more than one material are required.

Biomaterials in Ophthalmology

Biomaterials are used to improve and maintain vision. Eye implants are used to restore functionality of cornea, lens etc. when they are damaged or diseased. The biomaterials include viscoelastic solutions intraocular lenses, contact lenses, eye shields, artificial tears, vitreous replacements, correction of corneal curvature.

Dental materials

Polymers, composites, ceramic materials and metal alloys are four main groups of materials used for dental applications. A large number of materials are tested for porous dental implants which includes stainless steel, Co-Cr-Mo alloy, PMMA, proplast and Daceon, velour coated metallic implants, porous calcium aluminate single crystal alumina, bioglass, vitreous and pyrolytic carbons. The dental applications include impressions materials, dentine base and ceorons, bridges, inlays and repair of cavities, artificial teeth, repair of alveolar bone, support for mandible.