CHAPTER

16

PHYSICS OF SOLIDS

Q1: What are solids? Discuss their types.

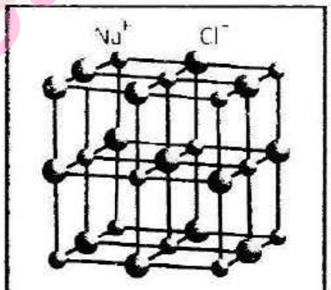
Answer: Solids:

Definition: "Those substances which posses definite shape, colour and volume are known as solids."

Types of Solids:

There are three types of solids which are given below:

1. Crystalline Solids: (ETEA 2012 '13)



NaCl Crystal

1. The solids whose atoms or ions or molecules are arranged in a regular repeated manner in three dimensions are called crystalline solids.
2. Crystals possess both short range and long range order.
3. The arrangement of atoms or molecules of crystalline structure can be studied by using x-ray techniques.
4. The cohesive force between the atoms, molecules or ions, keeps them in particular order for long distance in spite of their fast vibrations.
5. Every crystalline solid has a definite melting point at which the disorder among the atoms or molecules takes place.
6. Metals such as copper, iron, zinc, sodium chloride (NaCl), sucrose, diamond are the examples of crystalline solids.

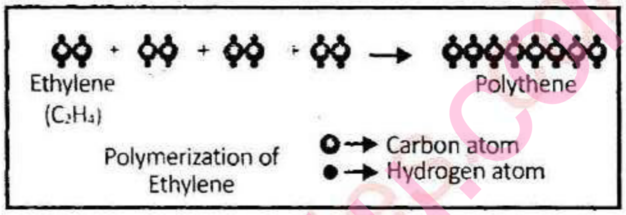
2. Amorphous Solids: (ETEA 2014)

1. The solids which have no regular arrangement of their atoms, molecules or irons are called amorphous solids.
2. The word amorphous means without form or structure. Thus amorphous solids are quite different from crystalline solids.

3. They have no definite melting point, so they are also known as glassy solids.
4. Glass is the example of amorphous solids.

3. Polymeric Solids:

1. The solids of organic compounds are called polymers.
2. They are organic compounds which consist of chemical combination of carbon with oxygen, nitrogen and other metallic or non metallic elements.



3. The molecular structures of polymers are more ordered than amorphous but less than crystalline solids.
4. They consist of fine grains, having a size of 10^3 to $10^4 A^o$ separated by well-defined boundaries.
5. Rubber, wool, silk etc are the examples of polymeric solids.

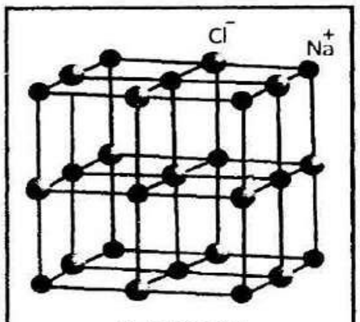
Q2: Define and explain crystal lattice.

Answer: **Crystal Lattice:**

Definition: "The whole structure of a crystal which is obtained by the repetition of unit cells is known as crystal lattice."

Explanation:

A crystalline solid consists of three dimensional pattern which repeats itself over and over again. This smallest three dimensional basis structure is known as unit cell.



NaCl Crystal

Now consider the example of "NaCl" which posses a cubic shape, as shown in the figure. Each side meet with other side at right angle. The other crystal shapes have corners in which one or more of the angles are not right angles.

Q3: Define the following terms: elasticity, deformation, stress, strain.

Answer: 1. **Elasticity:**

"The ability of a material to regain its original shape after the removal of applied force is known as its elasticity."

2. **Deformation:**

"The change which occurs in the shape of a body due to applied force is known as deformation."

3. **Strain:**

"The deforming force per unit area of a body is known as stress."

i.e. $\text{Stress} = \dfrac{\text{Force}}{\text{Area}}$

$$\Rightarrow \boxed{\sigma = \frac{F}{A}}$$

Its unit is "$\dfrac{N}{m^2}$".

4. **Strain:**

"The deformation produced in a body due to stress is known as strain."

If we consider the deformation length wise in a material, then

$$\text{Strain} = \frac{\text{Change in length}}{\text{original length}}$$

$$\Rightarrow \boxed{\varepsilon = \frac{\Delta l}{l}}$$

The strain has no unit, because it is a ratio between two similar quantities.

Q4: State and explain Hooke's law. (ETEA 2012)

Answer: **Hooke's Law:**

This law states that within elastic limit, the stress is proportional to strain. i.e.

$$\text{Stress} \propto \text{Strain}$$

$$\Rightarrow \text{Stress} = \text{Constant} \times \text{Strain}$$

$$\Rightarrow \sigma = (K)\varepsilon$$

$$\Rightarrow \boxed{\frac{\sigma}{\varepsilon} = K} \quad \text{———————} (1)$$

Equation (1) represents the mathematical form of Hooke's law.

In equation (1) "K" is constant and is known as modulus of elasticity. Its value depends upon the nature of the material.

Q5: Distinguish between tensile stress, tensile strain, shear stress and shear strain.

Answer: 1. **Tensile Stress:** "The stress due to which change occurs in length of a material is known as tensile stress."

2. Tensile Strain:

"The strain due to tensile stress is called tensile strain."

3. Shear Stress:

"The stress due to which the shape of the body changes is called shear stress."

4. Shear Strain:

"The strain due to shear stress is known as shear strain."

Q6: Define bulk stress and bulk strain.

Answer: 1. Bulk Stress:

The bulk stress is that stress due to which the volume of a body changes. It is also known as volumetric stress.

2. Bulk Strain:

The strain due to bulk stress is known as bulk strain. It is also known as volumetric strain.

Q7: Define modulus of elasticity. Discuss the types of modulus of elasticity.

Answer: Modulus of Elasticity:

"The ratio between stress and strain is known as modulus of elasticity." i.e.

$$\boxed{\text{Modulus of elasticity} = \frac{\text{Stress}}{\text{Strain}}}$$

The unit of modulus of elasticity is "$\frac{N}{m^2}$".

Types of Modulus of Elasticity:

There are three types of modulus of elasticity which are given below:

1. Young's Modulus:

The ratio between tensile stress and tensile strain is known as young's modulus. i.e.

$$\text{Young's modulus} = \frac{\text{Tensile stress}}{\text{Tensile strain}}$$

$$\Rightarrow \boxed{Y = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta l}{l}\right)}}$$

2. Shear Modulus:

"The ratio between shear stress and shear strain is known as shear modulus." i.e.

$$\text{Shear modulus} = \frac{\text{Shear stress}}{\text{Shear strain}}$$

$$\Rightarrow \boxed{G = \frac{\left(\frac{F}{A}\right)}{\tan\theta}}$$

The angle "θ" represents the measurement through which the body is twisted.

3. Bulk Modulus: (ETEA 2010-11)

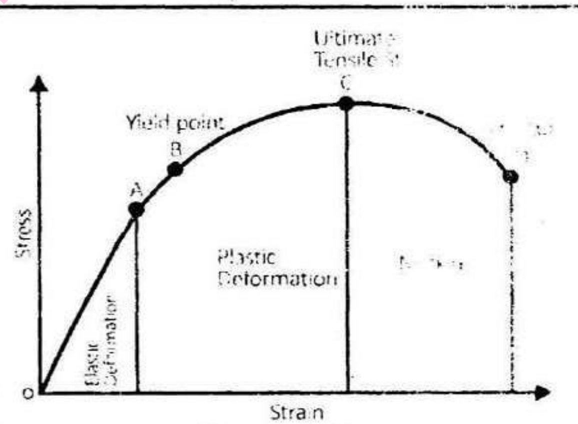
"The ratio of bulk stress and bulk strain is known as bulk modulus." i.e.

$$\text{Bulk modulus} = \frac{\text{Bulk stress}}{\text{Bulk strain}}$$

$$\Rightarrow \boxed{K = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta V}{V}\right)}}$$

Q8: Draw the stress-strain curve for a ductile material. Define the terms elastic limit, yield point and ultimate tensile stress. (ETEA 2012)

Answer:



Stress-Strain Curve

The stress-strain curve for a ductile material is shown in the figure. When the deforming force i.e. stress is allowed to increased, the strain also increases. The curve shows that between point "O" and "A", the stress and strain are proportional and the line "OA" remains straight. The stress at point "A" is known as proportional limit. The proportional limit is defined as "the greatest stress that a material can endure without losing the straight line proportionality is known as proportional limit".

Now if the stress is further increased, then deformation is produced in the material due to which the curve does not remains a straight line, as shown between point "A" and "B". In this region, the deformation is temporary and the material can gain its original shape, if the stress is removed. The region between points "A" and "B" is known as elastic region.

"The deformation produced in elastic region is known as elastic deformation."

While the point on the curve beyond which elastic deformation vanishes is known as yield point.

In given curve, the point "B" represents the yield point. The stress at yield point is known as elastic limit. The elastic limit can be defined as, "the greatest stress that a material can endure without undergoing any permanent change in shape or dimension is known as elastic limit".

Now if the stress is further increased, then permanent deformation occurs due to which the material cannot regain its original shape. Such deformation is known as plastic deformation. The region between point "B" and "C" is called plastic region. At point "C", the stress on the material is known as ultimate tensile strength. The ultimate tensile strength can be defined as, "the greatest stress that a material can endure without breaking is known as ultimate tensile strength".

At point "D", the material cannot be stretched further and smallest increase in stress can result in breaking the material. If the points "C" and "D" are closer to each other, then the material is said to be brittle. If the points "C" and "D" are not closer to each other, then the material is said to be ductile.

Q9: Discuss the mechanical properties of solids. (ETEA 2007, 2010-11)

Answer: **Mechanical Properties of Solids:**

The mechanical properties of a material are those properties which involve a reaction to an applied load. The mechanical properties of metals determine the range of usefulness of a material and establish the service life that can be expected.

The mechanical properties of solids are used to help us in classifying and identifying the nature of the material. The important mechanical properties of solids are given below:

1. Strength:

It is the general ability of a material which tells us that how great an applied force a material can withstand before breaking.

2. Hardness:

It is a measure of how easily a material can be scratched or indented. The hard materials are mostly brittle and thus they have a low resistance to impact. Diamond is the example of hard material.

3. Brittleness:

It is the property which tells us about the tendency of a material to break easily or suddenly without any extension first. Cast iron, concrete, high carbon steel, ceramics and some polymers like urea formaldehyde are the example of brittle materials.

4. Toughness:

It tells us that a material cannot be break easily. It posses certain limit of elasticity. The tough materials can absorb impact such as sudden forces or shocks such as hammer blows. Toughness is opposite to brittleness.

5. Plasticity:

It tells us about the materials which deforms permanently due small applied forces. Plasticine and clay are the examples of plasticitic materials.

6. Elasticity:

It is the ability of a material to regain its original shape after the removal of applied forces. Rubber, mild steel, nylon etc are the good examples of elastic materials.

7. Stiffness:

The ability of a material to resist bending is called its stiffness. It tells us about the opposition that a material sets up to being distorted by having its shape changed.

8. **Ductility:**

It is the ability to be drawn out into a thin wire or threads. It is a measure of how easily a material can be worked. It relates to the ability of the material to hammered, pressed, bent, cut etc into useful shapes. Ductility is used as quality control measure to assess the level of impurities and proper processing of a material.

Gold, copper, titanium, wrough iron, low carbon steel and brass etc are the examples of ductile materials.

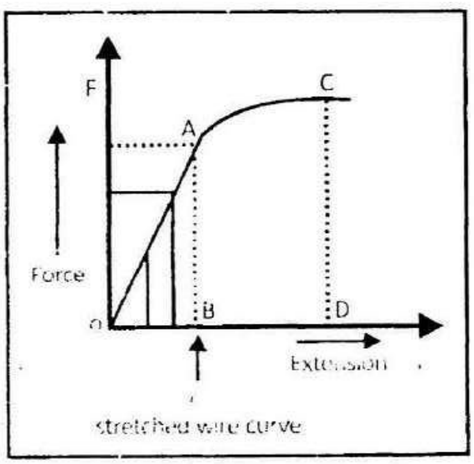
Q10: What is meant by strain energy? How it can be determined from the force extension graph?

Answer: **Strain Energy:**

Definition: "The energy stored in a stretched wire is known as strain energy."

Explanation:

We can obtain mathematical relation for strain energy from the force extension graph, as shown in the figure.



Consider a wire which is suspended from its one end. Now if we apply a stretched force on the other end of the wire by adding weights then extension will occur in the wire.

Let "l_1" represents the extension in the wire due to certain average force $<F>$, then the work done in stretching the wire is given by,

$$Work = <F>\, l_1 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(1)}$$

Now for stretching the wire, the force increases from zero to a certain value "F", then the average force is given by,

$$<F> = \frac{(0+F)}{2} \Rightarrow <F> = \frac{F}{2} \quad \text{\_\_\_\_\_\_\_\_\_\_(2)}$$

Putting equation (2) in equation (1), we get,

$$Work = \frac{Fl_1}{2} \quad \text{\_\_\_\_\_\_\_\_\_\_}(3)$$

This work appears in the form of strain energy in the stretched wire. Thus equation (3) can be also written as,

$$\boxed{Strain\ energy = \frac{1}{2}Fl_1} \quad \text{\_\_\_\_\_\_\_\_\_\_}(4)$$

Strain Energy per Unit Volume [Energy Density]:

For getting the value of strain energy density, we divide both sides of equation (4) by volume "V" of the wire, so we get,

$$Strain\ energy/volume = \frac{1}{2}[Fl_1/volume] \quad \text{\_\_\_\_\_\_\_\_\_\_}(5)$$

Here Strain energy/volume = strain energy density

And Volume = area of cross section of wire x its original length

$\Rightarrow$ Volume = Al

Thus equation (5) $\Rightarrow$

$$Strain\ energy\ density = \frac{1}{2}\left[\frac{Fl_1}{Al}\right]$$

$$\Rightarrow E.D. = \frac{1}{2}\left[\frac{F}{A} \times \frac{l_1}{l}\right] \quad \text{\_\_\_\_\_\_\_\_\_\_}(6)$$

Here F/A = stress and l_1/l = strain

So equation (6) $\Rightarrow$

$$\boxed{E.D = \frac{1}{2}[strss \times strain]} \quad \text{\_\_\_\_\_\_\_\_\_\_}(7)$$

Equation (7) represents the strain energy density i.e. strain energy per unit volume.

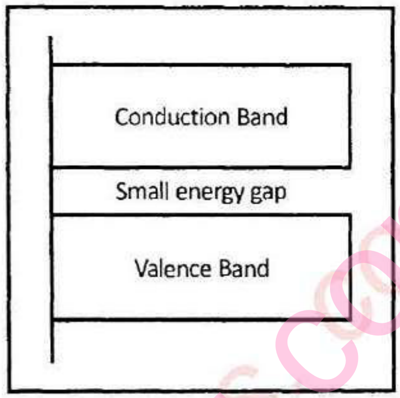
Q11: Discuss the energy band theory of solids.

Answer: **Energy Band Theory:**

Statement: According to this theory, the electrons around the nucleus remain in specific permissible energy levels and sub energy states.

Explanation: These energy states are discrete in nature. However, these states are so closer to each other that they appear in the form of continuous energy bands.

There is a small energy gap between any two energy bands which is known as forbidden energy gap· The electrons cannot stay in the forbidden energy gap·



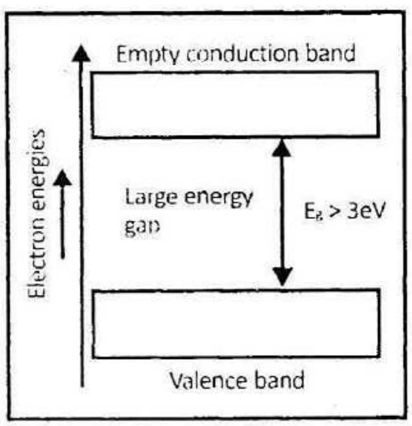
The electrons in the outermost shell are called valence electrons· The energy band of these electrons is known as valence band· The valence band is never empty· It may be fully filled or partially filled with electrons·

Above the valence band, there is another energy band which is known as conduction band· The electrons can move freely in conduction band· The electrons which leave the valence band are accommodated in the conduction band· The conduction band may be empty or partially filled with electrons·

Q12: Explain the difference amongst the electrical behaviours of conductors, insulators and semi conductors on the basis of energy band theory·

Answer: 1· <u>Insulators:</u>

<u>Definition:</u> Those materials in which the electrons are tightly bounded to their atoms and having no free electrons for electric conduction are known as insulators·

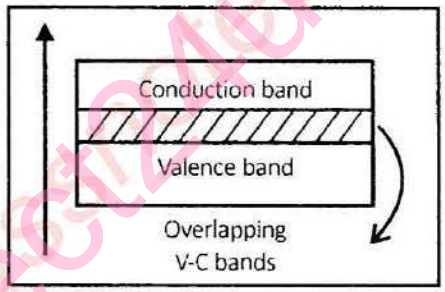


<u>Explanation:</u> The valence electrons have a range of allowed energies which form a "valence band"· The valence band is completely filled· Thus there are no vacant allowed energy levels which would allowed the electrons to gain energy from an applied electric field and move from an occupied state in one atom to an empty state in another·

The energy gap between valence band and conduction band is so large that even thermal excitation and thermal vibration is unable to move electrons from valence band into the conduction band. The electrons in valence band are unable to gain energy from an applied electrical field as there are no vacant energy levels for them to jump into. Thus many insulators possess low conductivity and high resistivity. Thus the insulators are bad conductors of heat and electricity.

2. Conductors:

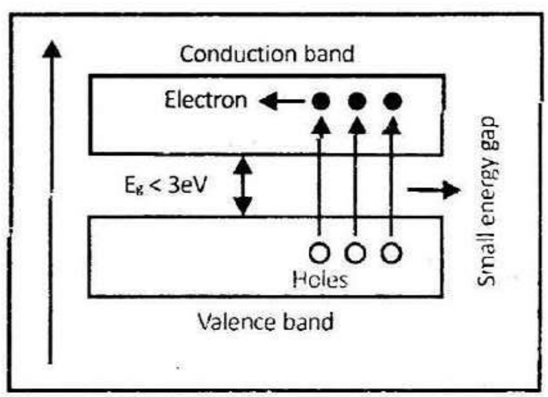
Definition: Conductors are those materials which have large number of free electrons which are responsible for electric conduction.



Explanation: In a conducting material, the energy levels of adjacent atoms have spread to form overlapping conduction band and valence band. The top of valence band is above the bottom of the conduction band. Thus the electrons in the valence band can move easily to a vacant energy levels in the partially filled conduction band. Thus an electric field is able to move electrons from one atom to another and then through the material by providing small amount of energy.

3. Semi-Conductors:

Definition: Those materials whose conductivity lies in between conductors and insulators are called semi conductors.



Explanation: A semi conductor has a filled valence band and an empty conduction band just like insulator. In fact, all the semi conductors are insulators at low temperatures. However, the energy gap in semi conductors is smaller than that of insulators at room temperature. As a result, some electrons will be excited thermally and shifted into the conduction band where they can move freely through the material. When the electrons are shifted into the conduction band, vacancies are produced in valence band. Such vacancies are known as holes.

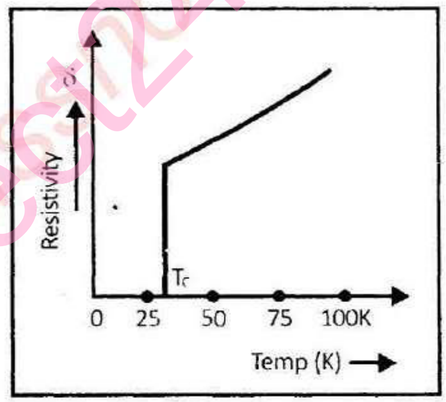
The holes acts as positive charge carriers and can move through the material. When a potential difference is applied across the semi conductor, the holes and electrons drift in opposite directions and both contribute to the current in that material.

Q13: Write a note on super conductors. (ETEA 2011)

Answer: **Super Conductors:**

Definition: The materials whose resistance vanishes at low temperature are known as super conductors and the phenomenon is called super conductivity.

Explanation:



When the temperature of a material is allowed to decrease, its resistance or resistivity also decreases. Finally a stage comes when at a certain temperature the resistance of the material becomes zero. Such temperature is known as critical temperature. It is represented by "T_c". At critical temperature, the material is extremely cold and there is no loss of heat when current passes through super conductors.

Before 1986, it was found that some metals become super conductors at temperature below than 10K. But the maintaining of such low temperature was an expensive task. Then in 1986, it was discovered that some ceramics exhibit super conductivity at 30K.

Then in 1988, it was discovered that some other ceramics like thallium, calcium, barium, copper and oxygen exhibit super conductivity at 125K. Recently, a complex crystalline structure known as yttrium barium copper oxide [$YBa_2Cu_3O_7$] is found to exhibit super conductivity at 163K [-110°C].

Our engineers and scientist are struggling to discover super conductor at high temperature. The electronic filter exhibit super conductivity at some high temperature and are use commercially in cellular phones. Efforts are going on to find materials that could show super conductivity even at room temperature.

The benefit of super conductors is that they can supply electrical energy without any loss. This would save large amount of energy in future. Super conductors have many technological applications, such as magnetic resonance imaging (MRI), magnetic levitation trains, magnetic motors and faster computer chips etc etc.

Q14: Discuss theory of magnetism.

Answer:

The molecule of a magnetic substance is a complete magnet in itself having a north pole and a south pole of equal strength.

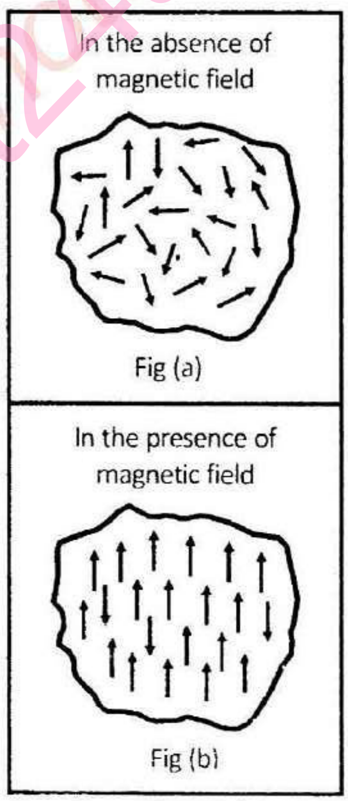


Fig (a)
Fig (b)

1. In an un-magnetized material, the molecular magnets are randomly oriented as shown in figure (a). The north pole of one molecular magnet cancels the effect of the south pole of the other. Thus the substance does not show any net magnetism.
2. When a magnetizing force is applied to the substance, the molecular magnets are turned and tend to align in the same direction with north pole of one molecular magnet facing the south pole of the other, as shown in figure (b). The result is that magnetic field of the molecular magnets aid each other and two definite north and south pole are developed near the ends of the specimen. The strength of the two poles being equal and thus the substance gets magnetized.
3. The extent of magnetization of the substance depends upon the extent of alignment of molecular magnets. When all the molecular magnets are fully aligned, the substance is said to be satu-

rated with magnetism.

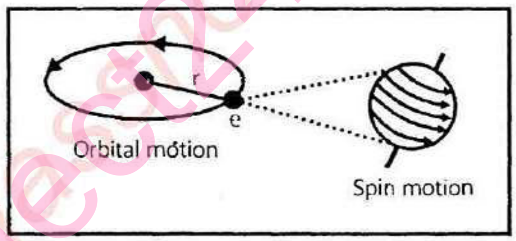
4. When a magnetized substance is heated, the molecular magnets acquire K.E and some of them loss their arrangement. For this reason, a magnet losses some magnetism on heating.

Q15: Discuss the modern view about magnetism.

Answer:

According to modern view, the magnetic properties of a substance are due to the orbital and spin motions of electrons in the atoms. We know that an atom consists of central nucleus with electrons revolving around the nucleus in different orbits. Such motion of electrons is called orbital motion.

The electrons also rotate around their own axis. Such motion of electrons is known as spin motion. Due to these two motions, each atom behaves as a magnetic dipole.



1. In the un-magnetized substances, the magnetic dipoles are randomly oriented so that magnetic fields mutually cancel. When the substance is magnetized, the magnetic dipoles are aligned in the same direction. Thus the substance shows net magnetism.

2. No substance is non-magnetic, because the revolving and spinning electrons in each atom cause magnetism.

3. The spin motion of electrons is more responsible for magnetism of a substance.

Q16: Distinguish amongst paramagnetic, diamagnetic and ferromagnetic substances.

Answer:

A. Paramagnetic Materials:

1. Those substances which are composed of such atoms in which the orbit and spin axis of electrons are so oriented that their magnetic field support each other are known as paramagnetic materials.

2. In paramagnetic materials each atom behaves like a tiny magnet.
3. When a paramagnetic substance is placed in a magnetic field, it is weakly magnetized in the direction of applied field.
4. Therefore paramagnetic substances are weakly attracted by a magnet.
5. The relative permeability (μ_r) of paramagnetic materials, is slightly greater than 1.
6. <u>Examples:</u> Aluminum, antimony, pollodium, manganese and other metallic salts are the examples of paramagnetic materials.

B. <u>Diamagnetic Materials:</u> (ETEA 2009)

1. Those substances which are composed of such atoms in which the orbital and spin axis of electrons are so oriented that their magnetic fields cancel each other are called diamagnetic materials.
2. In diamagnetic materials each atom is magnetically neutral.
3. When a diamagnetic substance is placed in a magnetic field, it is weakly magnetized in opposite direction of applied field.
4. Therefore a diamagnetic substance is weakly repelled by a strong magnetic field.
5. Their relative permeability (μ_r) is less than 1.
6. <u>Examples:</u> Bismuth, lead, gold, copper, sodium chloride ($NaCl$).

C. <u>Ferromagnetic Materials:</u> (ETEA 2014)

1. Those substances in which the atom cooperate with each other in such a way so as to exhibit a strong magnetic effect are called ferromagnetic materials.
2. In ferromagnetic substances there are small regions called domains. Each domain is large enough to contain 10^{12} to 10^{16} atom.
3. In each domain the magnetic fields of all the spinning electrons are parallel to each other.
4. Therefore each domain behaves like a small magnet with its own north and south poles.
5. They are strongly attracted by a magnet.
6. <u>Examples:</u> Iron, cobalt, nickel etc are the examples of ferromagnetic substances.

Q17: *Explain in details the origin of ferromagnetism. Discuss the concept of magnetic domains in ferromagnetic materials.*

Answer:

According to domain theory there is a small region inside the ferromagnetic materials, which is known as domain. Each domain can accommodate 10^{12} to 10^{16} atoms. In each domain, the electrons are spinning parallel to each other. So each domain is magnetized upto full extent.

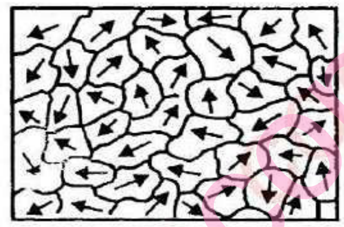


Fig (a): Unmagnetized ferromagnetic material

Now in an un-magnetized material like iron, the domains are not oriented in a proper order, as shown in figure (a). But if we place such materials in the magnetic field of solenoid etc then the domains become oriented in proper order, as shown in the figure (b). They become fully magnetized.

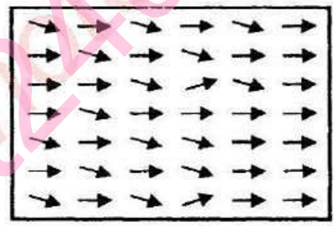


Fig (b): Magnetized ferromagnetic material

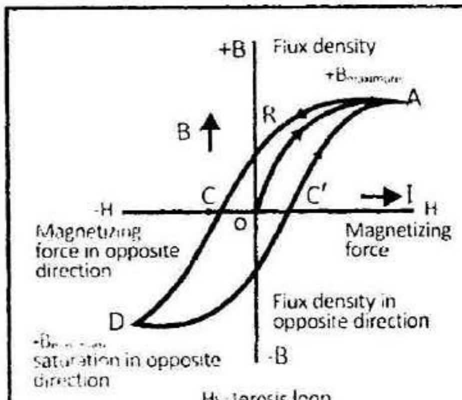
Under such conditions, we can get a powerful electromagnet due to combination of solenoid and specimen of iron.

The domains remain in ordered arrangement at ordinary temperature. At high temperature, the domains losses their ordered arrangement. Such temperature is known as curie temperature.

Q18: *Explain the phenomenon of magnetic hysteresis.*

Answer: Magnetic Hysteresis:

Definition: *"The lagging of flux density "B" behind the magnetizing field "H" is called magnetic hysteresis."*



Hysteresis loop

Explanation:

The graph between various values of flux density "B" of applied magnetic field and the intensity of magnetization "H" of the specimen is in the form of a loop of the magnetized material. Such loop is known as hysteresis loop, as shown in figure.

Main Features of Hysteresis Loop:

1. Hysteresis:

Hysteresis means "the lagging of flux density "B" behind the magnetizing field".

Suppose a ferromagnetic material like iron is placed in an A.C solenoid. In the beginning, the iron is un-magnetized and current is zero.

When the current is allowed to increase, the magnetization occurs at maximum rate. The portion "OA" represents the maximum value of magnetizing current. The portion "AR" represents the value of decreasing current. It has been found that the value of flux density "B' for any value of current is always greater when the current is decreasing than when it is increasing i.e. the flux density lags behind the magnetizing current, such phenomenon is known as hysteresis.

2. Saturation:

A material is said to be saturated, when the flux density reaches to its maximum value. Point "A" represents the magnetic saturation of the material.

3. Retentivity:

When the current reaches to zero, then the materia! sill remains strongly magnetized. It is represented by the point "R" in the given figure. It is because some portion of domain still remains in line. The portion "OR" represents the measure of retentivity of magnetism.

4. Coercivity:

If we want to demagnetize the material, then for such purpose the direction of magnetizing current is reversed. When the material become demagnetized, then the magnetizing current is known as coercive current. The demagnetization of the material is represented by the portion "RC" on the curve. When the material is magnetized, then after demagnetization, the curve never pass through the origin and thus form a loop which is called hysteresis loop.

5. Area of the Loop:

The area of the loop represents the measure of energy which is required for magnetizing or demagnetizing the material. This is the energy which is used to do work against the resistive forces of the domains.

6. Hysteresis Loss:

The energy which is used against the resistive forces of the domain is dissipated as heat. This is called hysteresis loss. The dissipation of this energy depends upon the area of hysteresis loop. i.e. the dissipation of energy will be small if the area of hysteresis loop is small and vice versa.

Thus the material having small area of hysteresis loop can be used in the designing of core of the transformers and other A.C devices for minimizing the loss of energy.

SOLUTIONS OF EXAMPLES & ASSIGNMENTS

EXAMPLE 16.1:
A force of 500N is applied to one end of a cylindrical steel rod of diameter 50cm. What is the tensile stress?

Solution:

Given Data: Force = F = 500N

Diameter of rod = D = 50cm = 0.5m

Radius of rod = $r = \frac{D}{2} = \frac{0.5}{2} = 0.25m$

Required: Tensile stress = σ = ?

Calculation:

We know that,

$$\text{Tensile stress} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} = \frac{F}{\pi r^2} \quad \boxed{\text{Area of rod} = A = \pi r^2}$$

$$\Rightarrow \sigma = \left[\frac{500}{3.14 \times (0.25)^2}\right] N/m^2$$

$$\Rightarrow \sigma = 2547.8\ N/m^2 = 2.5478 \times 10^3\ N/m^2$$

$$\therefore \boxed{\sigma = 2.5 \times 10^3\ N/m^2}$$

EXAMPLE 16·2:

In an experiment to measure Young's modulus, a load of 500kg hanging from a steel wire 2·4m long, of cross section 16cm², was found to stretch the wire 0·30cm from its un-stretched length. What is (a) the stress? (b) the strain (c) the value of Young's modulus for the steel of which the wire is composed?

Solution:

Given Data:

Mass of load = m = 500kg

Length of wire = L = 2·4m

Load = Force = mg = $500 \times 9{\cdot}8 = 4900N$

Area = A = $0{\cdot}16cm^2 = 1{\cdot}6 \times 10^{-5}m^2$

Elongation in length = x = 0·30cm = 0·003m

Required:

a) Stress = σ = ?

b) Strain = ε = ?

c) Young modulus = Y = ?

Calculation:

a) We know that,

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} \Rightarrow \sigma = \left[\frac{4900}{1{\cdot}6 \times 10^{-5}}\right] N/m^2$$

$$\Rightarrow \sigma = 3062{\cdot}5 \times 10^5\ N/m^2$$

$$\Rightarrow \sigma = 3{\cdot}06 \times 10^8\ N/m^2$$

$$\Rightarrow \boxed{\sigma = 3{\cdot}1 \times 10^8\ N/m^2}$$

b) $$\text{Strain} = \frac{\text{elongation in length}}{\text{original length}}$$

$$\varepsilon = \frac{x}{L} = \frac{0{\cdot}003}{2{\cdot}4} \qquad \boxed{\varepsilon = 1{\cdot}25 \times 10^{-3}}$$

c) $$\text{Young modulus} = \frac{\text{stress}}{\text{strain}}$$

$$\Rightarrow Y = \left[\frac{3{\cdot}1 \times 10^8}{1{\cdot}25 \times 10^{-3}}\right] N/m^2$$

$$\Rightarrow \boxed{Y = 2{\cdot}48 \times 10^{11}\ N/m^2}$$

Exercise

Choose the best possible answer:

1. The shear modulus of elasticity G is:

   a) $\frac{Al}{F\theta}$ b) $\frac{Fl}{A\theta}$ c) $\frac{F}{A\theta}$✓ d) $\frac{Al}{F}$

2. The temperature at which material becomes super conductor is called:

   a) Knee temperature b) Critical temperature✓
   c) Absolute temperature d) Zero temperature

3. Which of the following is not ferromagnetic material?

   a) Iron b) Nickel c) Cobalt d) Barium✓

4. The ratio of stress to the strain is............

   a) 0 b) >1 c) Constant✓ d) <1

Solution:

According to Hook's law the stress to strain ratio is constant.

5. A wire is stretched to double of its length. It strain is:

   a) 2 b) 1✓ c) 0 d) 0.5

Solution:

Initial length = L

Final length = 2L

Change in length = ΔL = final length − initial length

$\Rightarrow \Delta L = 2L - L$

$\Rightarrow \Delta L = L$

Now strain = $\frac{\Delta L}{L} = \frac{L}{L} = 1$

6. Which of the modulus of elasticity is involved in compressing a rod to decrease its length?

   a) Young's modulus✓ b) Bulk modulus
   c) Modulus of elasticity d) None of the above

7. A wire is stretched to double of its length. Its strain is:

   a) 2 b) 1✓ c) Zero d) 0.5

Solution:

Initial length = L

Final length = $2L$

Change in length = $\Delta L = 2L - L$

$\Rightarrow \Delta L = L$

Now Strain = $\dfrac{\Delta L}{L}$

$\Rightarrow$ Strain = $\dfrac{L}{L}$ $\Rightarrow$ Strain = 1

8. If both the length and radius of the rod are doubled, then the modulus of elasticity will:

a) Increase b) Decrease

c) Remains the same✓ d) Doubled

Solution:

The modulus of elasticity of a material remains constant. It does not depend upon the shape and size of an object.

9. Curie temperature is a point where:

a) Diamagnetism changes to paramagnetism

b) Paramagnetism changes to diamagnetism

c) Ferromagnetism changes to paramagnetism✓

d) Paramagnetism changes to ferromagnetism

10. A cable breaks if stretched by more than 2mm. It is cut into two equal parts. How much either part can be stretched without breaking?

a) .25m b) 1mm✓ c) 2mm d) 0.5m

Solution.

$$\varepsilon = \frac{\Delta l}{l} \Rightarrow \varepsilon = \frac{2mm}{l} \quad \text{\_\_\_\_\_\_\_\_}(1)$$

When cable is cut into two pieces, then we put $l' = \dfrac{l}{2}$ so we get,

$$\varepsilon = \frac{\Delta l'}{l'} = \frac{\Delta l'}{\frac{l}{2}} = \frac{2\Delta l'}{l}$$

$$\Rightarrow \varepsilon = \frac{2\Delta l'}{l} \quad \text{\_\_\_\_\_\_\_\_}(2)$$

Comparing equation (1) and equation (2), we get,

$$\frac{2\Delta l'}{l} = \frac{2mm}{l} \Rightarrow \boxed{\Delta l' = 1mm}$$

CONCEPTUAL QUESTIONS

Q1: Coercive force of steel is greater than iron, why?

Answer:

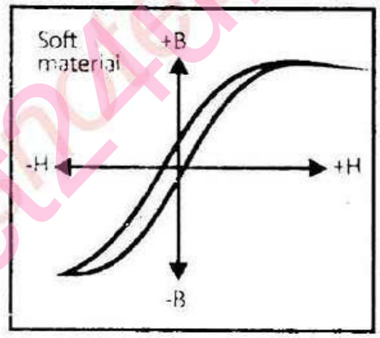
The coercive force of steel is greater than that of the iron.

Reason and Explanation:

Coercive force represents the external field which is needed to demagnetize a fully magnetized material.

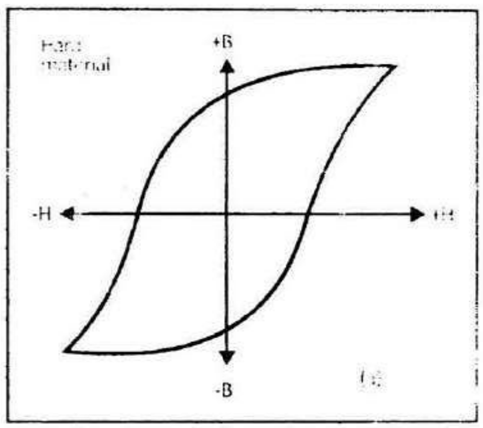
a) Coercive Force of Iron:

Iron is a soft magnetic material. It can be magnetized or demagnetized easily. The domains of iron can be oriented easily by applying external magnetic field. The iron regains its initial state easily after the removal of applied field. The iron has narrow hysteresis loop and thus smaller coercive force is required for magnetizing or demagnetizing the iron.



b) Coercive Force of Steel:

Steel is a hard magnetic material. It cannot be magnetized or demagnetized easily. The domains of steel cannot be oriented easily by applying external magnetic field. The steel retain the alignment even when the applied field is removed. The steel has fat magnetic hysteresis loop and thus large coercive force is required for magnetization. Once a steel is magnetized, then it is very difficult to demagnetize them.



When the magnetizing force is removed, still the domains are permanently aligned and magnetic flux density "B" is still there. Thus strong magnetic field is required to demagnetized the hard material like steel. Due to such properties, the steel is used to make a permanent magnet.

Conclusion:

From the above discussion, it is clear that the coercive force of steel is greater than that of the iron.

Q2: Evaluate the importance of strength and stiffness in a design context.

Answer:

The importance of strength and stiffness in a design context is given below:

1. **Importance of Strength:**

The strength of a material denotes the largest stress that a material can sustain. It tells us that how much greater force the material can support without breaking. The knowledge of strength is important to evaluate bearing capacity of the material for construction. If a structural system has low strength then it may not exist under high stresses and hence may fail.

2. **Importance of Stiffness:**

The stiffness represents the resistance of a material to be distorted in shape, size or in both. The stiffness largely determines the strains of the material, as it is loaded and unloaded. A material having high stiffness will exhibit low deformation under loading. The knowledge of stiffness is important to evaluate loading capacity of the material for construction. If a structural system has low stiffness then it may not exist under high loading and hence fail.

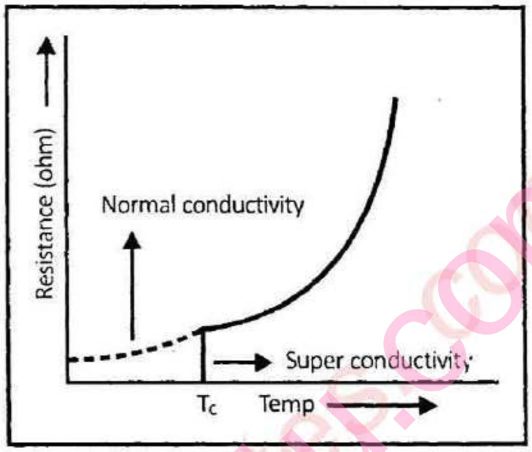
Q3: Discuss the super conductivity of a conductor with the help of a curve.

Answer:

Super Conductors and Super Conductivity:

Those materials whose resistance becomes zero at very low temperature are known as super conductors. The temperature is called critical temperature "T" and the phenomenon is known as super conductivity.

If we plot a graph between temperature and resistance for a certain super conductor, then we see that with decrease in temperature from high value, the resistance of the conductor also decreases. Finally at a certain temperature, the resistance of the conductor becomes zero. Such temperature at which the resistance falls to zero is called critical temperature. It is represented by "T_c".



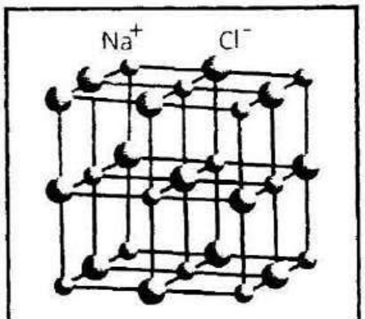
Note: In the given figure, the dashed curve represents the normal conductivity. This region represents the normal conductor whose resistance does not fall to zero even at zero Kelvin.

Q4: Distinguish between crystalline, amorphous and polymer solids.

Answer:

1. Crystalline Solids:

1. The solids whose atoms or ions or molecules are arranged in a regular repeated manner in three dimensions are called crystalline solids.
2. Crystals possess both short range and long range order.
3. The arrangement of atoms or molecules of crystalline structure can be studied by using x-ray techniques.
4. The cohesive force between the atoms, molecules or ions, keeps them in particular order for long distance in spite of their fast vibrations.



NaCl Crystal

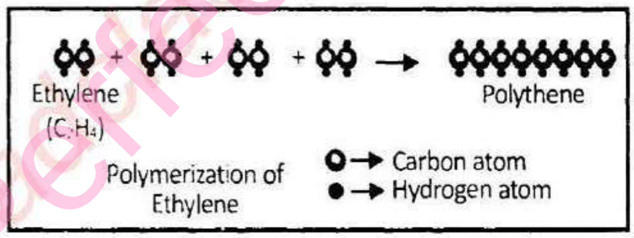
5. Every crystalline solid has a definite melting point at which the disorder among the atoms or molecules takes place.
6. Metals such as copper, iron, zinc, sodium chloride (NaCl), sucrose, diamond are the examples of crystalline solids.

2. Amorphous Solids:

1. The solids which have no regular arrangement of their atoms, molecules or irons are called amorphous solids.
2. The word amorphous means without form or structure. Thus amorphous solids are quite different from crystalline solids.
3. They have no definite melting point. So, they are also known as glassy solids.
4. Glass is the example of amorphous solids.

3. Polymeric Solids:

1. The solids of organic compounds are called polymers.
2. They are organic compounds which consist of chemical combination of carbon with oxygen, nitrogen and other metallic or non metallic elements.
3. The molecular structures of polymers are more ordered than amorphous but less than crystalline solids.
4. They consist of fine grains, having a size of 10^3 to $10^4 A^\circ$ separated by well-defined boundaries.
5. Rubber, wool, silk etc are the examples of polymeric solids.



Polymerization of Ethylene

Q5: What is the difference between elastic deformation and plastic deformation?

Answer:

1. Elastic Deformation:

"The deformation produced in elastic region is known as elastic deformation." The elastic deformation is temporary and the material can regain its original shape after the removal of applied stress.

2. Plastic Deformation:

"The deformation produced in plastic region is known as plastic deformation." In plastic deformation permanent change occurs in the shape of the material. The material cannot regain its original shape after the removal of applied stress.

Q6: Differentiate between paramagnetic, diamagnetic and ferro-magnetic materials with suitable examples.

Answer:

A. <u>Paramagnetic Materials:</u>

1. Those substances which are composed of such atoms in which the orbit and spin axis of electrons are so oriented that their magnetic field support each other are known as paramagnetic materials.
2. In paramagnetic materials each atom behaves like a tiny magnet.
3. When a paramagnetic substance is placed in a magnetic field, it is weakly magnetized in the direction of applied field.
4. Therefore paramagnetic substances are weakly attracted by a magnet.
5. The relative permeability (μ_r) of paramagnetic materials, is slightly greater than 1.
6. <u>Examples:</u> Aluminum, antimony, pollodium, manganese and other metallic salts are the examples of paramagnetic materials.

B. <u>Diamagnetic Materials:</u>

1. Those substances which are composed of such atoms in which the orbital and spin axis of electrons are so oriented that their magnetic fields cancel each other are called diamagnetic materials.
2. In diamagnetic materials each atom is magnetically neutral.
3. When a diamagnetic substance is placed in a magnetic field, it is weakly magnetized in opposite direction of applied field.
4. Therefore a diamagnetic substance is weakly repelled by a strong magnetic field.
5. Their relative permeability (μ_r) is less than 1.
6. Examples: Bismuth, lead, gold, copper, sodium chloride ($NaCl$).

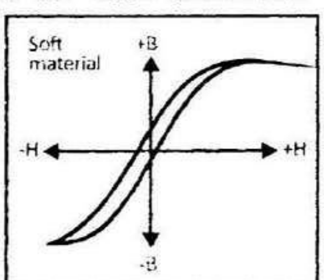
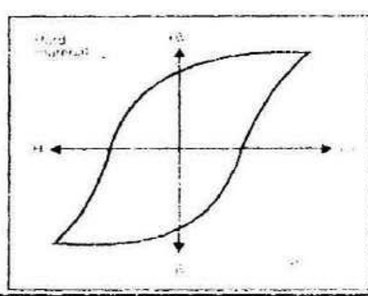
C. <u>Ferromagnetic Materials:</u>

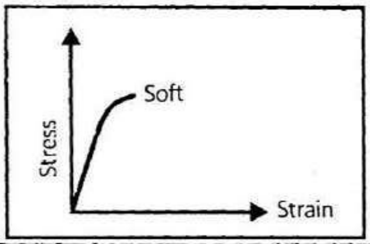
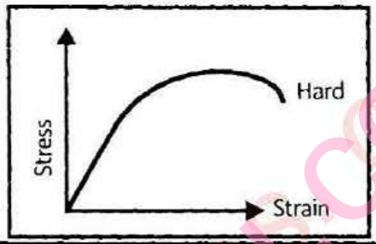
1. Those substances in which the atom cooperate with each other in such a way so as to exhibit a strong magnetic effect are called ferromagnetic materials.
2. In ferromagnetic substances there are small regions called domains. Each domain is large enough to contain 10^{12} to 10^{16} atom.

3. In each domain the magnetic fields of all the spinning electrons are parallel to each other.
4. Therefore each domain behaves like a small magnet with its own north and south poles.
5. They are strongly attracted by a magnet.
6. <u>Examples:</u> Iron, cobalt, nickel etc are the examples of ferromagnetic substances.

Q7: Distinguish between soft and hard substances by drawing its curves.

Answer:

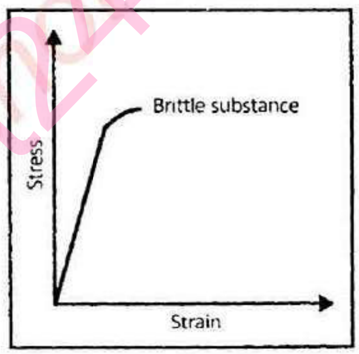
S.#	Soft Magnetic Materials	Hard Magnetic Materials
1.	Soft magnetic materials are those materials which have a smaller area enclosed by their hysteresis loop.	Hard magnetic materials are those materials which have a larger area enclosed by their hysteresis loop.
2.	They have low remnant magnetization.	They have high remnant magnetization.
3.	They have low coercivity.	They have high coercivity.
4.	They have high initial permeability.	They have low initial permeability.
5.	Hysteresis loss is small.	Hysteresis loss is high.
6.	Eddy current loss is small.	Eddy current loss is more for metallic types and low for ceramic types.
7.	Used in transformer cores, motors, generators, electromagnets etc.	Used in making permanent magnets, magnetic separators, magnetic detectors, speakers, microphones etc.
8.	Area of hysteresis loop is small for soft materials. 	Their hysteresis loop is very fat. 

9.	The soft materials can be broken easily just after elastic limit as shown in the figure. 	The hard material cannot be broken just after elastic limit. It undergoes further changes as shown in the figure. 

Q8: What is the difference between brittle and ductile materials?

Answer: 1. Brittle Materials:

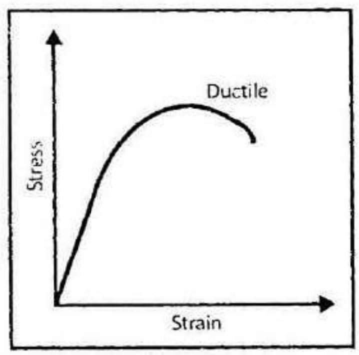
Those substances which can be broken easily just after elastic limit are known as brittle materials as shown in the figure.



These materials have a tendency to break easily or suddenly without any elongation first, such as high carbon steel, shell of egg and glass etc.

2. Ductile Materials:

These are those materials which cannot be broken just after elastic limit. These materials undergoes plastic deformation until it breaks due to applied stress. These materials are able to absorb more energy as compare to brittle materials.



Q9: How can the conductivity of a semiconductor be raised?

Answer:

We can increase the conductivity of a semi conductor in the following manner:

1. By Doping Process:

The conductivity of semiconductor is increased by adding an appropriate amount of suitable impurity called doping. For example, when silicon is doped with electron rich impurity, then the extra electron becomes delocalized. These delocalized electrons increase the conductivity of doped silicon due to the negatively charged electrons. Such materials in which electron acts as majority charge carriers are called N-type semi conductors. While the materials in which the holes acts as majority charge carriers are called P-type semi conductors. When these holes gain energy, they moves towards valence band and thus increase the conductivity of the material.

2. <u>By Increasing the Temperature:</u>

The conductivity of semi conductor increases with increase in temperature. It is because when the temperature increases, the electrons gain sufficient energy and they jumps from conduction band to valence band. In this way, the conductivity of semi conductor increases.

3. When a semi conductor is exposed to light of proper wavelength, it produces excess electrons and hole pairs which increases the conductivity of semi conductors.

4. We can increase the conductivity of semi conductor by applying high fields where super ohmic behavior is observed.

Q10: Is there any difference in the length of a 20 meter steel girder when standing vertically and horizontally?

Answer:

Yes, there is slightly difference in the length of a 20 steel girder when standing vertically and horizontally.

<u>Reason and Explanation:</u>

<u>CASE-1</u>: When the girder is standing vertically, then force per unit area on the ground is very large. As a result, the ground exerts same force on the girder in upward direction. Due to these opposite forces, the girder is under compression. The compressional

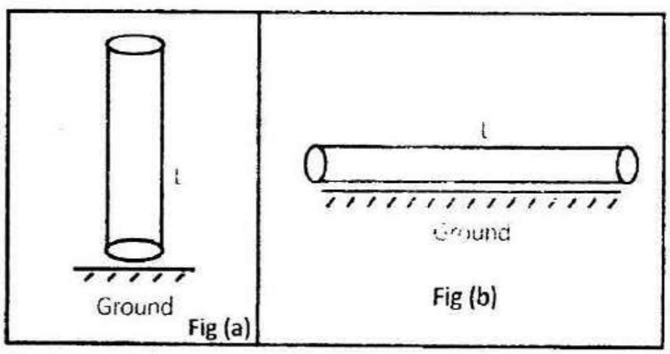


Fig (a) Fig (b)

force on the girder is given by,

$$\text{Compressive stress} = \frac{F}{A} = \frac{W}{A} \quad \text{\_\_\_\_\_\_\_\_(1)}$$

Due to this compressive stress, compressive strain is produced which is given by,

$$\text{Compressive strain} = \frac{\Delta L}{L} \quad \text{\_\_\_\_\_\_\_\_(2)}$$

Equation (2) shows that the length of the girder will decrease slightly when standing vertically.

CASE-2: When the girder is standing horizontally, then force per unit area is smaller due to which the reaction of the earth is also smaller. As a result, the girder remains under negligible compression. Thus the length of the girder nearly remains the same.

Q11: Why would it be advantages to use super conductor in MRI machine?

Answer:

It would be advantageous to use super conductor in MRI machine due to the following reasons:

1. Super conductor provides higher current densities.
2. They provide smaller and lighter designs than room temperature equivalents.
3. They conduct direct current without loss of energy.
4. They are used for creating powerful electromagnetic in MRI scanners.

COMPREHENSIVE QUESTIONS

Q1: Explain the differences between tensile and compressive forces and how they affect equilibrium within a structure?

Answer:

The tensile forces are those forces which tend to extend a certain structural body. While the compressive forces are those forces which tends to compress a structural body. The tensile force are pulling forces due to which length of the structural body increases by amount "Δl".

The compressive forces are pushing forces due to which the length of the structural body decreases by an amount "Δl".

Thus both forces produce deformation in the structure of a body due to which its equilibrium is disturbed. For maintaining the equilibrium, the compressive and tensile forces must balance each other. i.e.

$$\boxed{\text{Tensile forces} = \text{Compressive forces}}$$

Q2: Draw and describe a stress/strain graph and identify the elastic region, plastic flow region, yield stress and ultimate tensile stress.

Answer: See answer of question # 8 in the text.

Q3: Describe the valance band, conduction band and forbidden energy gap with the help of energy level diagram.

Answer: See answer of question # 11, 12 in the text.

Q4: Discuss the super conductivity of a conductor with the help of a curve.

Answer: See answer of question # 13 in the text.

Q5: Describe the mechanical properties of solids.

Answer: See answer of question # 9 in the text.

Q6: Describe hysteresis loop for a ferromagnetic materials by drawing its curve for iron.

Answer: See answer of question # 18 in the text.

Q7: Explain strain energy in a deformed wire by drawing its graph.

Answer: See answer of question # 10 in the text.

NUMERICAL QUESTIONS

Q1: A 1.50cm length of pianos wire with a diameter of 0.25cm is stretched by attaching a 10kg mass to one end. How far is the wire stretched?

Solution:

Given Data:

Length of wire $= L = 1.50cm = 0.015m$

Diameter of wire = $D = 0{\cdot}25cm = 2{\cdot}5 \times 10^{-3} m$

Radius of wire = $r = \dfrac{D}{2} = \dfrac{2{\cdot}5 \times 10^{-3}}{2} = 1{\cdot}25 \times 10^{-3} m$

Mass of load = $m = 10kg$

Load = $F = w = mg = 10 \times 9{\cdot}8 = 98N$

Young modulus of steel = $Y = 20 \times 10^{10} N/m^2$

Required:

Change in length = $\Delta L = ?$

Calculation:

We know that the Young Modulus is given by,

$$Y = \frac{Stress}{Strain} = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta L}{L}\right)} = \frac{F \cdot L}{A \cdot \Delta L}$$

$$\Rightarrow Y = \frac{FL}{A \cdot \Delta L} \Rightarrow \Delta L = \frac{FL}{AY} = \frac{FL}{\pi r^2 Y} \qquad \boxed{A = \pi r^2}$$

$$\Rightarrow \Delta L = \left(\frac{98 \times 0{\cdot}015}{3{\cdot}14 \times (1{\cdot}25 \times 10^{-3})^2 \times 20 \times 10^{10}}\right) m$$

$$\Rightarrow \Delta L = \left(\frac{1{\cdot}47}{98{\cdot}125 \times 10^{-6} \times 10^{10}}\right) m$$

$$\Rightarrow \Delta L = 0{\cdot}0149 \times 10^{-4} m$$

$$\Rightarrow \Delta L = 1{\cdot}49 \times 10^{-6} m = 1{\cdot}5 \times 10^{-6} m$$

$$\Rightarrow \boxed{\Delta L = 1{\cdot}5 \times 10^{-6} m}$$

Q2: A cylindrical steel rod 0·50m long and 1cm in radius is subjected to a tensile force of $1 \times 10^4 N$.

a) What is the tensile stress?

b) What is tensile strain?

c) By what amount does the rod stretch?

Solution:

Given Data:

Length of steel rod = $L = 0{\cdot}50m$

Radius of rod = $r = 1cm = 0{\cdot}01m$

Force = $F = 1 \times 10^4 N$

Young modulus = $Y = 20 \times 10^{10} N/m^2$

Area of rod = $A = \pi r^2 = 3.14 \times (0.01)^2 = 0.000314 m^2$

Required:

a) Tensile stress = σ = ?

b) Tensile strain = ε = ?

c) Change in length of rod = ΔL = ?

Calculation:

a) $$\text{Stress} = \frac{\text{Force}}{\text{Area}} \Rightarrow \sigma = \frac{F}{A}$$

$$\Rightarrow \sigma = \left(\frac{1 \times 10^4}{0.000314}\right) N/m^2$$

$$\Rightarrow \boxed{\sigma = 0.31 \times 10^8 N/m^2}$$

b) We know that,

$$\text{Young modulus} = \frac{\text{Stress}}{\text{Strain}}$$

$$\Rightarrow Y = \frac{\sigma}{\varepsilon} \Rightarrow \varepsilon = \frac{\sigma}{Y} = \frac{0.31 \times 10^8}{20 \times 10^{10}}$$

$$\Rightarrow \varepsilon = 0.0155 \times 10^{-2} = 1.55 \times 10^{-4} = 1.6 \times 10^{-4}$$

$$\Rightarrow \boxed{\varepsilon = 1.6 \times 10^{-4}}$$

c) We know that,

$$\text{Strain} = \frac{\Delta L}{L} \Rightarrow \varepsilon = \frac{\Delta L}{L}$$

$$\Rightarrow \Delta L = \varepsilon L = 1.6 \times 10^{-4} \times 0.50 m$$

$$\Rightarrow \boxed{\Delta L = 0.8 \times 10^{-4} m}$$

Q3: A cable has an un-stretched length of 12m and it stretches by 1.2×10^{-4}m when a stress of $6.4 \times 10^8 Nm^{-2}$ is applied. What is the strain energy per unit volume in the cable when this stress is applied?

Solution:

Given Data:

Length of cable = L = 12m

$\Delta L = 1.2 \times 10^{-4} m$

Stress = $\sigma = 6.4 \times 10^8 N/m^2$

Required:

Strain energy per unit volume = E = ?

Calculation:

We know that,

$$E = \frac{1}{2}(\text{stress} \times \text{strain}) = \frac{1}{2}\ \sigma \times \varepsilon\ = \frac{1}{2}\sigma \times \frac{\Delta L}{L}$$

$$\Rightarrow\ E = \frac{1}{2} \times 6.4 \times 10^{8} \times 1.2 \times 10^{-4} / 12$$

$$\Rightarrow\ E = 0.32 \times 10^{4}\ J/m^{3}$$

$$\Rightarrow\ \boxed{E = 3.2 \times 10^{3}\ J / m^{3}}$$

Q4: Young's modulus for a particular wood is $1 \times 10^{10} Nm^{-2}$. A wooden chair has four legs each of length 42cm and cross sectional area $2 \times 10^{-3} m$. Hamza has a mass of 100kg.

a) What is the stress on each leg of the chair when Hamza stands on the chair?

b) By what amount do the chair legs shrink when Hamza stands on the chair?

Solution:

Given Data:

Young modulus = $Y = 1 \times 10^{10} N/m^2$

Length = L = 42cm = 0.42m

Area = $A = 2 \times 10^{-3} m^2$

Mass of Hamza = m = 100kg

Required:

a) Stress = σ = ?

b) ΔL = ?

Calculation:

a) $$\sigma = \frac{F}{A} = \frac{w}{A} = \frac{mg}{A}$$ $\boxed{F = w = mg}$

$$\Rightarrow\ \sigma = \frac{100 \times 9.8}{2 \times 10^{-3}}$$

$$\Rightarrow\ \sigma = 490 \times 10^{3}\ N/m^{2}$$

$$\Rightarrow\ \sigma = 4.9 \times 10^{5}\ N/m^{2}$$

$$\Rightarrow\ \boxed{\sigma = 5 \times 10^{5} N / m^{2}}$$

b) We know that,

$$\text{Young Modulus} = Y = \frac{\sigma}{\varepsilon} \qquad \boxed{\varepsilon = \frac{\Delta L}{L}}$$

$$\Rightarrow \varepsilon = \frac{\sigma}{Y} \Rightarrow \frac{\Delta L}{L} = \frac{\sigma}{Y}$$

$$\Rightarrow \Delta L = \frac{\sigma L}{Y} = \left[\frac{5 \times 10^5 \times 0.42}{(1 \times 10^{10})}\right] m$$

$$\Rightarrow \boxed{\Delta L = 2.1 \times 10^{-5} m}$$

Q5: A force of $1.5 \times 10^4 N$ causes a strain of 1.4×10^{-4} in a steel cable of cross sectional area $4.8 \times 10^{-4} m^2$.

a) What is the Young's modulus of the steel cable?

b) The stress-strain graph is linear for this cable. Calculate the strain energy per unit volume stored in the cable when the cable has a strain of 1×10^{-4}.

Solution:

Given Data:

Force = $F = 1.5 \times 10^4 N$

Strain = $\varepsilon = 1.4 \times 10^{-4}$

Area = $A = 4.8 \times 10^{-4} m^2$

Strain = $\varepsilon' = 1 \times 10^{-4}$

Required:

a) Young modulus = Y = ?

b) Strain energy per unit volume = E = ?

Calculation:

a) We know that,

$$\text{Young Modulus} = Y = \frac{\sigma}{\varepsilon}$$

$$\Rightarrow Y = \frac{\left(\frac{F}{A}\right)}{\varepsilon} = \frac{F}{A\varepsilon}$$

$$= \left[\frac{1.5 \times 10^4}{4.8 \times 10^{-4} \times 1.4 \times 10^{-4}}\right] N/m^2$$

$$\Rightarrow \quad Y = 0{\cdot}22 \times 10^{12}\ N/m^2$$

$$\Rightarrow \quad \boxed{Y = 2{\cdot}2 \times 10^{11}\ N/m^2}$$

b) Strain energy per unit volume $= E = \frac{1}{2}\sigma \times \varepsilon'$

$$\Rightarrow \quad E = \frac{1}{2} \times \frac{F}{A} \times \varepsilon'$$

$$\Rightarrow \quad E = \frac{1}{2} \times \frac{1{\cdot}5 \times 10^4}{4{\cdot}8 \times 10^4} \times 1 \times 10^{-4}$$

$$\Rightarrow \quad E = 0{\cdot}15 \times 10^4\ J/m^3$$

$$\Rightarrow \quad \boxed{E = 1{\cdot}5 \times 10^3\ J/m^3}$$