CHAPTER 17
PHYSICS OF SOLID

MULTIPLE CHOICE

1. **An n-type semi-conductor is obtained by doping Ge or Si with**
   A. trivalent impurities — B. Pentavalent impurities
   C. Monovalent impurities — D. none of these
2. **First super conductor was discovered in**
   A. 1880 — B. 1890 — C. 1990 — D. 1911
3. **The SI unit of stress is the same as that of**
   A. Momentum — B. Pressure — C. Force — D. Length
4. **A solid having regular arrangement of molecules throughout its structure is called:**
   A. Polymeric solid — B. Crystalline solid
   C. Glassy solids — D. None
5. **Plastics and synthesis rubber are:**
   A. Amorphous solids — B. Polymeric solids
   C. Crystalline solids — D. Glassy solids
6. **Stress is mathematically expressed as:**
   A. $\sigma = F \times A$ — B. $\sigma = \frac{F}{A}$ — C. $\sigma = \frac{A}{F}$ — D. $\sigma = \frac{F}{A^2}$
7. **Polythene, polystyrene and nylon are examples of:**
   A. Amorphous solids — B. Glassy solids
   C. Polymeric solids — D. Crystalline solids
8. **When stress changes the shape of body it is called:**
   A. Volumetric stress — B. Shear stress
   C. Tensile stress — D. Compression stress
9. **The maximum stress which a body can bear is called its**
   A. Ultimate tensile stress — B. permanent stress
   C. plastic stress — D. yield stress
10. **Nm^{-2} is called**
    A. ohm — B. ampere
    C. volt — D. pascal
11. **Which of the following is an example of a ductile material?**
    A. Lead — B. Copper
    C. Glass — D. Lead & Copper
12. **The substances which break just after the elastic limit is reached are called**
    A. Poor substance — B. Brittle substances
    C. ductile substances — D. Soft substances

13. **The materials whose resistivity becomes zero below a certain temperature are called**

A Good conductors B Super conductors
C semiconductors D. insulators

14. **A Pentavalent impurity in Si gives**

A a free electron B. a free electron & a hole
C. A free hole D. no free particle

15. **The temperature below which some substances show superconductivity is called**

A. Super temperature B. Critical Temperature
C. Absolute zero temperature D. Kelvin Temperature

16. **Which one of the following is not a semiconductor?**

A Copper B. Silicon
C Germanium D Gallium Arsenide

17. **Which type of solids have definite melting point**

A Crystalline solids B Amorphous solids
C. both A & B D None of these

18. **A well known example of an intrinsic semi-conductor is**

A. Germanium B. Phosphorous C Aluminium D Cobalt

19. **In n-type material, minority carriers are**

A Free electrons B Holes
C Protons D Mesons

20. **SI unit of modulus of elasticity is:**

A Ampere B Volt
C. Pascal D Coulomb

21. **Young's modulus mathematically expressed as:**

A. $Y = \frac{F/A}{\Delta l/l}$ B. $Y = \frac{F \times A}{\Delta l/l}$ C $Y = \frac{\Delta l/l}{F/A}$ D. $\frac{A \times l}{F \times l}$

22. **The maximum stress that a material can with stand is called its:**

A Yield strength B. Plastic strength
C Maximum stress D Ultimate tensile strength

23. **Substances which break just after the elastic limit is reached are called:**

A. Ductile substances B Brittle substances
C Hard substances D Soft substances

24. **With rise in temperature, the conductivity of semi-conductor material:**

A Increases exponentially B Decreases linearly
C Decreases exponentially D None

25. **The substances which have partially filled conduction bands are called:**

A Insulator B Semiconductor
C Conductors D Transistor

26. **The process of adding small amount of impurity into pure semi conductor lattice is called:**

A Mixing B. Doping

C. Dropping D. Introducing

27. **N-type semi-conductor is obtained by doping germinium or silicon with:**
A. Pentavalent impurity B. Trivalent impurity
C. Tetravalent impurity D. Divalent impurity

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C. conductors D. superconductors

29. **The material whose resistivity becomes zero below a certain temperature is called:**
A. Conductor B. Semiconductor
C. Superconductor D. Insulators

30. **Magnetism lags behind the magnetizing current this phenomenon is called:**
A. Saturation B. Retentively
C. Coercively D. Hysteresis

31. **A material with large coercivity and high retentivity is most useful of make:**
A. An electromagnet B. Permanent magnet
C. A transformer core D. None

32. **The most suitable metal for making permanent magnet is:**
A. Iron B. Aluminium C. Copper D. Steel

33. **What type of impurity is to be added to the semiconductor material to provide holes?**
A. Monovalent B. trivalent
C. tetravalent D. Pentavalent

Answers:

1. B	**2. D**	**3. B**	**4. B**	**5. B**	**6. B**	**7. C**
8. B	**9. A**	**10. D**	**11. D**	**12. B**	**13. B**	**14. A**
15. B	**16. A**	**17. C**	**18. A**	**19. B**	**20. C**	**21. A**
22. A	**23. B**	**24. A**	**25. B**	**26. B**	**27. A**	**28. B**
29. C	**30. D**	**31. B**	**32. D**	**33. B**		

SHORT & LONG QUESTIONS

Q1: Describe the classification of solids?

Ans: Classification of solids:

a. Crystalline solids:

i. In crystalline solids there is a regular arrangement of molecules. The neighbours of every molecule are arranged in a regular pattern that is constant throughout the crystal There is, thus an ordered structure in crystalline solids.

ii. It should be noted that atoms, molecules or ions in a crystalline solid are not static For example, each atom in a metal crystal vibrates about a fixed point with an

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15. B	**16. A**	**17. C**	**18. A**	**19. B**	**20. C**	**21. A**
22. A	**23. B**	**24. A**	**25. B**	**26. B**	**27. A**	**28. B**
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ii. It should be noted that atoms, molecules or ions in a crystalline solid are not static For example, each atom in a metal crystal vibrates about a fixed point with an amplitude that increases with rise in temperature. It is the average atomic positions which are perfectly ordered over large distances.

iii. The cohesive forces between atoms, molecules or ions in crystalline solids maintain the strict long-range order inspite of atomic vibrations.

iv. Every crystalline solid has a definite melting point.

v. The vast majority of solids, e.g., metals such as copper, iron and zinc, ionic compounds such as sodium chloride, ceramics such as zirconia are crystalline.

b. Amorphous or glassy solids:

i. The word amorphous means without form or structure.

ii. In amorphous solids there is no regular arrangement of molecules like that in crystalline solids. We can, therefore, say that amorphous solids are more like liquids with the disordered structure frozen in.

iii. Ordinary glass, which is a solid at ordinary temperature, has no regular arrangement of molecules. On heating, it gradually softens into a paste like state before it becomes a very viscous liquid at almost 800^0C. Thus amorphous solids are also called glassy solids.

iv. Amorphous or glassy solids have no definite melting point.

c. Polymeric solids:

i. Polymers may be said to be more or less solid materials with a structure that is intermediate between order and disorder.

ii. They can be classified as partially or poorly crystalline solids.

iii. Polymers form a large group of naturally occurring and synthetic materials.

iv. Plastics and synthetic rubbers are termed 'Polymers' because they are formed by polymerization reactions in which relatively simple molecules are chemically combined into massive long chain molecules or "three dimensional" structures.

v. These materials have rather low specific gravity compared with even the lightest of metals, and yet exhibit good strength-to-weight ratio.

vi. Polymers consist wholly or in part of chemical combinations of carbon with oxygen, hydrogen, nitrogen and other metallic or non-metallic elements.

vii. Polythene, polystrene and nylon etc., are examples of polymers. Natural rubber is composed in the pure state entirely of a hydrocarbon with the formula $(C_5H_8)_n$.

Q2: What is meant by unit cell and crystal lattice?

Ans: Unit cell:

A crystalline solid consists of three dimensional patterns that repeat itself over and over again. This smallest three dimensional basic structure is called unit cell.

Crystal lattice:

The whole structure obtained by the repetition of unit cell is known as crystal lattice.

Crystal lattice in NaCl:

For example, the pattern of NaCl particles has a cube shape. The cube shape of the sodium chloride is just one of several crystal shapes. In a cubic crystal all the sides meet at right angles.

Q3: Illustrate deformation produced in a unit cell of a crystal subjected to an external applied force?

OR

Write a note on elasticity?

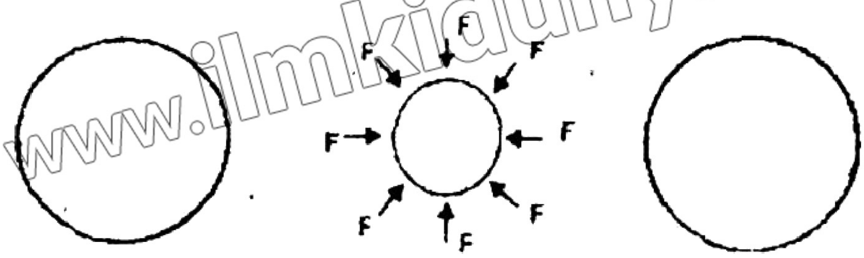
Ans: Deformation in solids:

i. It is concluded that deformation (i.e., change in shape, length or volume) is produced when a body is subjected to some external force.

ii. In crystalline solids atoms are usually arranged in a certain order. These atoms are held about their equilibrium position, which depends on the strength of the inter-atomic cohesive force between them.

iii. When external force is applied on such a body, a distortion results because of the displacement of the atoms from their equilibrium position and the body is said to be in a state of stress.

iv. After the removal of external force, the atoms return to their equilibrium position, and the body regains its original shape, provided that external applied force was not too great. The ability of the body to return to its original shape is called elasticity.



Q4: Differentiate between stress and strain?

Ans: Difference between stress and strain:

Stress:

It is defined as the force applied on unit area to produce any change in the shape, volume or length of a body. Mathematically it is expressed as

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

Unit of stress:

The SI unit of stress (σ) is newton per square metre (Nm^{-2}), which is given the name pascal (Pa).

Note:

Stress may cause a change in length, volume and shape.

Tensile stress:

When a stress changes length, it is called the tensile stress.

Volume stress:

When it changes the volume it is called the volume stress.

Shear stress:

When it changes the shape it is called the shear stress

Strain:

Strain is a measure of the deformation of a solid when stress is applied to it. In the case of deformation in one dimension, strain is defined as the fractional change in length. If M is the change in length and ℓ is the original length, then strain is given by

$$\text{Strain } (\varepsilon) = \frac{\text{Change in length } (\Delta\ell)}{\text{Orignal length } (\ell)}$$

Unit of strain:

Since strain is ratio of lengths, it is dimensionless, and therefore, has no units

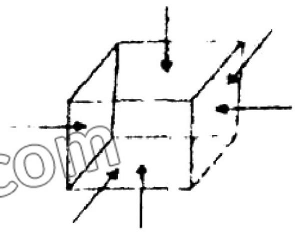
Tensile strain:

If strain ε is due to tensile stress σ, it is called tensile strain.

Compressive strain:

If it is produced as a result of compressive stress σ, it is termed as compressive strain.

Volumetric strain:

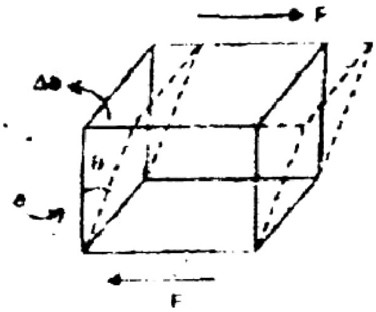


In case when the applied stress changes the volume, the change in volume per unit volume is known as volumetric strain

Thus

$$\text{Volumetric strain} = \frac{\Delta V}{V_0}$$

Shear strain:



When the opposite faces of a rigid cube are subjected to shear stress, the shear strain produced is given by

$$\gamma = \frac{\Delta a}{a} = \tan\theta$$

However, for small values of angle θ, measured in radian, $\tan\theta = \theta$, so that

$$\gamma = \theta$$

Q5: Describe the different elastic constants?

Ans: Elastic constants:

i. Modulus of elasticity:

The ratio of stress to strain is a constant for a given material, provided the external applied force is not too great. This ratio is called modulus of elasticity, and can be mathematically described as

$$\text{Modulus of Elasticity} = \frac{Stress}{Strain}$$

Young's modulus (Y):

In the case of linear deformation, the ratio of tensile (or compressive) stress $\sigma = (F/A)$ to tensile (or compressive) strain $\varepsilon = \Delta\ell/\ell$ is called Young's modulus

$$Y = \frac{F/A}{\Delta\ell/\ell}$$

Bulk modulus (K):

For three dimensional deformations, when volume is involved, then the ratio of applied stress to volumetric strain is called Bulk modulus

$$K = \frac{F/A}{\Delta V/V}$$

Where ΔV is the change in original volume V.

Shear modulus (G):

However, when the shear stress $\tau = (F/A)$ and shear strain ($\gamma = \tan\theta$) are involved, then their ratio is called shear modulus.

$$G = \frac{F/A}{\tan\theta}$$

Q6: Draw a table for elastic constants for some of the materials?

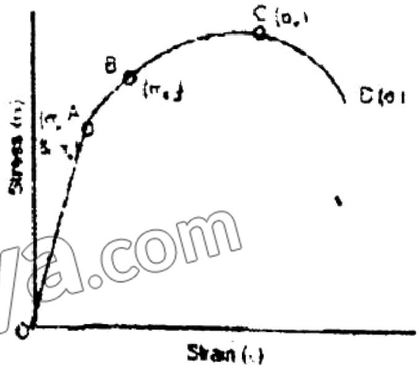
Ans: Elastic constants for some of the materials are given in Table

Elastic constants for some material

Material	Young's Modulus $10^9\ Nm^{-2}$	Bulk Modulus $10^9\ Nm^{-2}$	Shear Modulus $10^9\ Nm^{-2}$
Aluminium	70	70	30
Bone	15	-	80
Brass	91	61	36
Concrete	25	-	-
Copper	110	140	44
Diamond	1120	540	450
Glass	55	31	23
Ice	14	8	3
Lead	15	7.7	5.6
Mercury	0	27	0
Steel	200	160	84
Tungsten	390	200	150
Water	0	2.2	0

Q7: Explain elastic limit and yield strength with the help of a typical stress-strain curve for a ductile material?

Ans: Elastic limit and yield strength:



i. In the initial stage of deformation, stress is increased linearly with the strain till we reach point A on the stress-strain curve. This is called proportional limit (σ_p)

Proportional limit (σ_p):

It is defined as the greatest stress that a material can endure without losing straight line proportionality between stress and strain.

ii. Application of Hooke's law:

Hooke's law which states that the strain is directly proportional to stress is obeyed in the region OA.

iii. Yield point:

From A to B, stress and strain are not proportional, but nevertheless, if the load is removed at any point between O and B, the curve will be retraced and the material will return to its original length. In the region OB, the material is said to be elastic. The point B is called the yield point

iv. Elastic limit (σe):

The value of stress at B is known as elastic limit σ_e

v. Plasticity:

If the stress is increased beyond the yield stress or elastic limit of the material, the specimen becomes permanently changed and does not recover its original shape or dimension after the stress is removed. This kind of behaviour is called plasticity.

The region of plasticity is represented by the portion of the curve from B to C.

vi. Ultimate tensile strength (UTS) σ_m:

The point C in Fig. represents the ultimate tensile strength (UTS)σ_m of the material. The UTS is defined as the maximum stress that a material can withstand and can be regarded as the nominal strength of the material.

vii. Fracture stress (σf):

Once point C corresponding to UTS is crossed, the material breaks at point D, responding the fracture stress (σ_f).

viii. Ductile substances:

Substances which undergo plastic deformation until they break are known as ductile substances. Lead, copper and wrought iron are ductile.

ix. Brittle substances:

Other substances which break just after the elastic limit is reached are known as brittle substances. Glass and high carbon steel are brittle.

Q8: Discuss strain energy in deformed materials with the help of graph?

OR

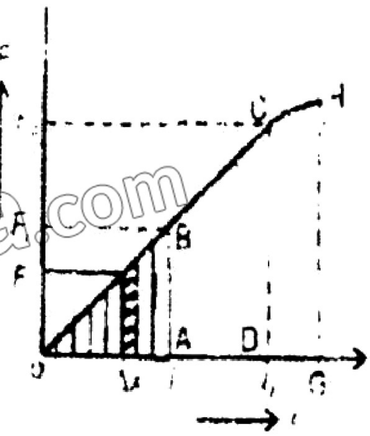
What is mean by strain energy? How can it be determined from force extension graph?

Ans: Strain energy:

Strain energy is the gain in potential energy of the molecules due to their displacement from mean position.

Explanation of strain energy in deformed materials:

i. Consider a wire suspended vertically from one end. It is stretched by attaching a weight at the other end. We can increase the stretching force by increasing the weight. By noting the extension ℓ of the wire for different values of the stretching force F, a graph can be drawn between the force F and the extension ℓ.



ii. If the elastic limit is not exceeded the extension is directly proportional to force F. As the force F stretches the wire, it does some amount of work on wire which is equal to product of force F and the extension ℓ.

iii. Suppose we are required to find the amount of the work done when the extension is ℓ_1. Let the force for this extension be F_1. Fig shows that the force F does not remain constant in producing the extension ℓ_1, it varies uniformly from 0 to F_1. In such a situation the work is calculated by graphical method.

iv. Suppose at some stage before the extension ℓ_1 is reached, the force in the wire is F and that the wire now extends by a very small amount Δx. The extension

Δx is so small that the force F may be assumed constant in Δx, so the work done in producing this small extension is $F \times \Delta x$

v. Work done = Area of $\Delta OAB = \frac{1}{2} OA \times AB = \frac{1}{2} \ell_1 \times F_1$ ...... (1)

This is the amount of strain energy stored in the wire. It is the gain in the potential energy of the molecules due to their displacement from their mean positions. Eq.1 gives the energy in joules when F is in Newton and ℓ in metres.

vi. Eq.1 can also be expressed in terms of modulus of elasticity E. If A is the area of cross-section of the wire and L its total length then

$$E = \frac{F_1}{A} \times \frac{L}{\ell_1}$$

Or

$$F_1 = \frac{EA \times \ell_1}{L}$$

Substituting the value of F_1 in Eq. 1 we have

$$\text{Work done} = \frac{1}{2}\left[\frac{EA \times \ell_1^2}{L}\right] \qquad (2)$$

Note:

i. If the extension is increased from ℓ_1 to ℓ_2, the amount of work done by the stretching force would be given by the area of the trapezium ABCD.

ii. It is also valid for both the linear (elastic) and the non-linear (non-elastic) parts of the force-extension graph. If the extension occurs from O to G, this work done would be the area of OHG.

Q9: Describe the electrical properties of solids?

Ans: Electrical properties of solids:

i. The fundamental electrical property of a solid is its response to an applied electric field, i.e., its ability to conduct electric current.

ii. Good conductors:
The electrical behaviours of various materials are diverse. Some are very good conductors, e.g., metals with conductivities of the order of $10^7\ (\Omega m)^{-1}$.

iii. Insulators:
At the other extreme, some solids, e.g., wood, diamond etc., have very low conductivities ranging between 10^{-10} and $10^{-20}\ (\Omega m)^{-1}$, these are called insulators

iv. Semi conductors:
Solids with intermediate conductivities, generally from 10^{-6} to $10^{-4} (\Omega m)^{-1}$, are termed semiconductors, e.g., silicon, germanium etc.

Q10: Why glass is known as solid liquid?

Ans: Glass is also known as solid liquid because its molecules are irregularly arranged as in a liquid but fixed in their relative positions.

Q11: Discuss the important features of energy band theory? Also discuss insulators, conductors and semi conductors in terms of energy bands?

OR

Describe the formation of bands in solids. Explain the difference amongst electrical behavior of conductors, insulators and semi-conductors in terms of energy band theory.

Ans: Energy band theory:

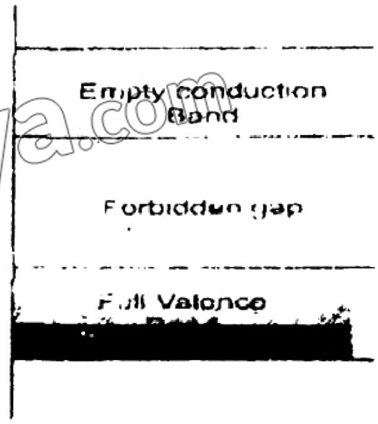
i. Electrons of an isolated atom are bound to the nucleus, and can only have distinct energy levels.

ii. When a large number of atoms, say N, are brought close to one another to form a solid, each energy level of the isolated atom splits into N sub-levels, called states, under the action of the forces exerted by other atoms in the solid.

iii. These permissible energy states are discrete but so closely spaced that they appear to form a continuous energy band.

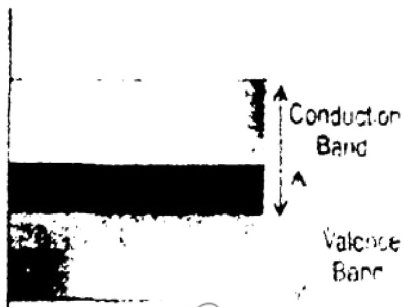
iv. **Forbidden energy gap:**
In between two consecutive permissible energy bands, there is a range of energy states which cannot be occupied by electrons. These are called forbidden energy states, and its range is termed as forbidden energy gap

v. **Valence band:**



The electrons in the outermost shell of an atom are called valence electrons and the energy band occupying these electrons is known as valence band. It is obviously the highest occupied band. It may be either completely filled or partially filled with electrons and can never be empty.

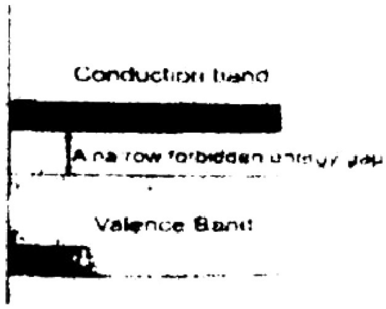
vi. **Conduction band:**
The band above the valence band is called conduction band. In conduction band, electrons move freely and conduct electric current through solids. That is why the electrons occupying this band are known as conductive electrons or free electrons. Any electron leaving the valence band is accommodated by this band. It may be either empty or partially filled with electrons.



vii. The bands below the valence band are normally completely filled and as such play no part in the conduction process. Thus, while discussing the electrical conductivity we will consider only the valence and conduction bands.

Insulators:

Insulators are those materials in which valence electrons are bound very tightly to their atoms and are not free. In terms of energy bands, it means that an insulator, as shown in Fig. has



a) an empty conduction band (no free electrons)

b) a full valence band

c) a large energy gap (several eV) between them

Conductors:

Conductors are those which have plenty of free electrons for electrical conduction. In terms of energy bands, conductors are those materials in which valence and conduction bands largely overlap each other.

There is no physical distinction between the two bands which ensures the availability of a large number of free electrons.

Semiconductors:

In terms of energy bands, semiconductors are those materials which at room temperature have

(i) partially filled conduction band

(ii) a very narrow forbidden energy gap (of the order of 1 eV) between the conduction and valence bands.

Q12: Discuss the behavior of semiconductors at 0K and room temperature?

Ans: Behavior of semiconductors at 0 K:

At 0 K there are no electrons in the conduction band and their valence bands are completely filled. It means at 0 K, a piece of Ge or Si is a perfect insulator

Effect of increasing temperature:

However with increase in temperature, some electrons posses sufficient energy to jump across the small energy gap from valence to conduction band. This transfers some free electrons in the conduction bands and creates some vacancies of electrons in the valence band. The vacancy of electron in the valence band is known as a hole. It behaves like a positive charge. Thus at room temperature, Ge or Si crystal becomes a semiconductor.

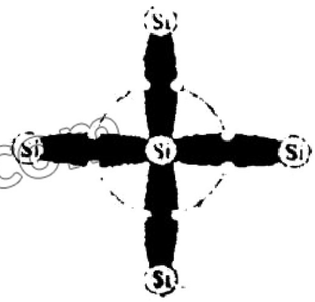
Q13: Differentiate between intrinsic and extrinsic semi-conductor? OR How a silicon crystal is made n-type and p-type semi-conductor by the process of doping?

OR

Distinguish between intrinsic and extrinsic semi-conductors. How would you obtain n-type and p-type material from pure silicon? Illustrate it by schematic diagram.

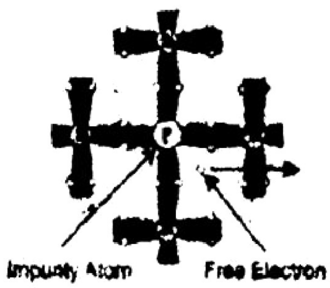
Ans: Intrinsic semi-conductor:

A semi-conductor in its extremely pure form is known as intrinsic semi-conductor.



Doping:

The electrical behaviour of semiconductor is extremely sensitive to the purity of the material. It is substantially changed on introducing a small amount of impurity into the pure semi-conductor lattice. The process is called doping, in which a small number of atoms of some other suitable elements are added as impurity in the ratio of 1 to 10^6



Extrinsic semi-conductor:

The doped semi-conducting materials are called extrinsic semi-conductors.

Behavior of intrinsic semi-conductor:

i. Pure element of silicon and germanium are intrinsic semi-conductors

ii. These semi-conductor elements have atoms with four valence electrons.

iii. Each atom with its four valence electrons, shares an electron from its neighbours. This effectively allocates eight electrons in the outermost shell of each atom which is a stable state.

iv. This sharing of electrons between two atoms creates covalent bonds. Due to these covalent bonds electrons are bound in their respective shells.

Doping of silicon crystal (Extrinsic semi-conductors):

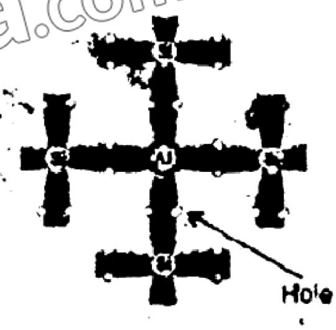
a. n-type semi-conductor:

When a silicon crystal is doped with a pentavalent element, e.g., arsenic, antimony or phosphorous etc., four valence electrons of the impurity atom form covalent bond with the four neighbouring Si atoms, while the fifth valence electron provides a free electron in the crystal. Such a doped or extrinsic semi-conductor is called n-type semi-conductor.

ii. The phosphorous atom is called a donor atom because it readily donates a free electron which is thermally excited into the conduction band.

b. p-type semi-conductor:

i. When a silicon crystal is doped with a trivalent element, e.g. aluminium, boron gallium or indium etc., three valence electrons of the impurity atom form covalent bond with the three neighbouring Si atoms, while the one missing electron in the covalent bond with the fourth neighbouring Si atom, is called a hole which in fact is vacancy where an electron can be accommodated. Such a semiconductor is called p-type semi-conductor.

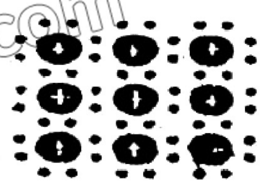


ii. The aluminium atom is called an acceptor atom because it is easy for the aluminium ion core to accept a valence electron from a nearby silicon atom, thus creating a hole in the valence bond

Q14: Explain the electrical conduction by electrons and holes in semiconductors? Describe the effect of the application of battery to a semi-conductor?

Ans: Electrical conduction by electrons and holes in semiconductors:

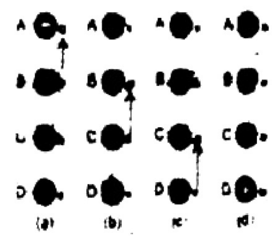
i. Consider a semi-conductor crystal lattice, e.g., Ge or Si as shown in Fig.



ii. The circles represent the positive ion cores of Si or Ge atoms, and the blue dots are valence electrons. These electrons are bound by covalent bond.

iii. Effect of temperature:

At room temperature they have thermal kinetic motion which, in case of some electrons, is so vigorous that the covalent bond is unable to keep them bound. In such cases the electrons break the covalent bond and get themselves free leaving a vacant seat for an electron, i.e. a hole



iv. Whenever a covalent bond is broken, an electron-hole pair is created. Both the electrons and the holes move in the semi-conductor crystal lattice as explained below.

Explanation:

i. Consider a row of Si atoms in crystal lattice. Suppose a hole is present in the valence shell of atom A. As hole is a deficiency of electron, so the core of atom A would have a net positive charge. This attracts an electron from a neighbouring atom say B. Thus the electron moves from B to A and the hole (+ve charge) shifts to B

ii. Now an electron is attracted from C to B and a hole is created at C and positive charge appears at C. This process is repeated between the atoms C and D with the result that the electron moves from D to C and the hole (+ve charge) appears at D.

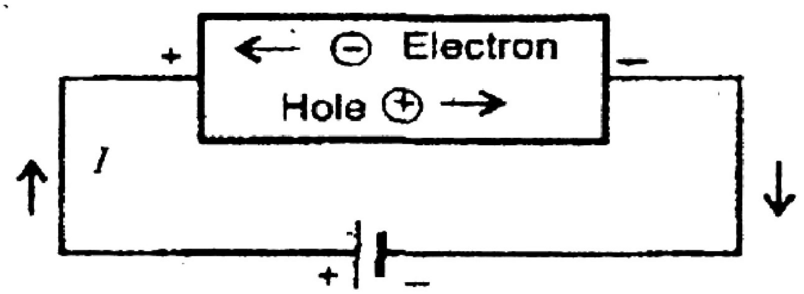
iii. Thus we notice that if a hole is present in any valence shell, it cannot stay there but it moves from one atom to other with the electron moving in opposite direction

iv. Secondly we notice that the appearance of hole is accompanied by a positive charge. Thus a moving hole is equivalent to a moving positive charge.

v. **Special case of electrons and holes:**

Considered a special case in which the electron and the hole are moving in a straight line. Actually their motion is random because positively charged core of the atom can attract an electron from any of its neighbouring atoms.

vi. In semi-conductors there are two kinds of charge carriers: a free electron (-e) and a hole (+e).



Application of battery to a semi-conductor:

i. When a battery is connected to a semi-conductor, it establishes an electric field across it due to which a directed flow of electrons and holes takes place.

ii. The electrons drift towards the positive end, whereas the holes drift towards the negative end of the semi-conductor.

iii. The current I flowing through the semi-conductor is carried by both electrons and holes.

iv. It may be noted that the electronic current and the hole current add up together to give the current I.

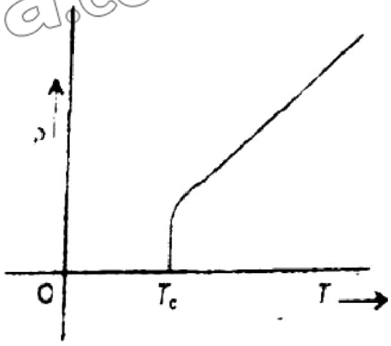
Q15: What is meant by superconductors? Also describe the critical temperatures of different superconductors?

Ans: Superconductors (perfect conductors):

Superconductors are alloys that, at certain temperatures, conduct electricity with no resistance.

Critical temperatures (T_c):

There are some materials whose resistivity becomes zero below a certain temperature T_c called critical temperature as shown in resistivity-temperature graph in Fig.



Below this temperature, such materials are called superconductors.

Characteristics of Superconductors (perfect conductors):

i. Superconductors offer no resistance to electric current and are, therefore, perfect conductors.

ii. Once the resistance of a material drops to zero, no energy is dissipated and the current, once established, continues to exist indefinitely without the source of an emf.

First superconductor:

The first superconductor was discovered in 1911 by Kmaerlingh Ornes when it was observed that electrical resistance of mercury disappears suddenly as the temperature is reduced below 4.2 K. Some other metals such as aluminium (T_c= 1.18 K), tin (T_c = 3.72 K), and lead (T_c = 7.2 K) also become superconductors at very low temperatures.

Class of ceramic materials as a superconductor:

In 1986 a new class of ceramic materials was discovered that becomes superconductor at temperatures as high as 125 K.

High temperature superconductor:

Any superconductor with a critical temperature above 77 K, the boiling point of liquid nitrogen, is referred as a high temperature superconductor.

Complex crystalline structure as a superconductor:

Recently a complex crystalline structure known as Yttrium barium copper oxide ($YBa_2Cu_3O_7$) have been reported to become superconductor at 163 K or -110°C by Prof. Yao Lian's Lee at Cambridge University.

Applications of superconductors:

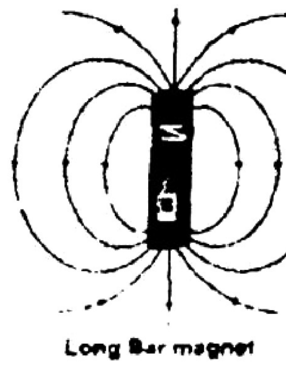
Superconductors have many technological applications such as in magnetic resonance imaging (MRI), magnetic levitation trains, powerful but small electric motors and faster computer chips.

Q16: Discuss magnetic properties of solids? What are the, paramagnetic substances, diamagnetic substances and ferromagnetic substances? Explain the behavior of domains?

Ans: Magnetic properties of solids:

i. The magnetism produced by electrons within an atom can arise from two motions

ii. First, each electron orbiting the nucleus behaves like an atomic sized loop of current that generates a small magnetic field this situation is similar to the field created by the current loop in Fig.



Long Bar magnet

iii. Secondly each electron possesses a **spin** that also gives rise to a magnetic field.

iv. The net magnetic field created by the electrons within an atom is due to the combined field created by their orbital and spin motions.

v. Since there are a number of electrons in an atom, their currents or spins may be so oriented or aligned as to cancel the magnetic effects mutually or strengthen the effects of each other.

vi. An atom, in which there is a resultant magnetic field, behaves like a tiny magnet and is called a magnetic dipole.

vii. The magnetic fields of the atoms are responsible for, the magnetic behaviour of the substance made up of these atoms.

Magnetism:

i. Magnetism is, therefore, due to the spin and orbital motion of the electrons surrounding the nucleus and is thus a property of all substances. It may be mentioned that the charged nucleus itself spins giving rise to a magnetic field. However, it is much weaker than that of the orbital electrons. Thus the source of magnetism of an atom is the electrons.

ii. North and South Pole:

According to the view of magnetism it is concluded that it is impossible to obtain an isolated north pole. The north-pole is merely one side of a current loop. The other side will always be present as a south pole and these cannot be separated. This is an experimental reality.

Paramagnetic substances:

The orbits and the spin axes of the electrons in an atom are so oriented that their fields support each other and the atom behaves like a tiny magnet. Substances with such atoms are called paramagnetic substances.

Diamagnetic substances:

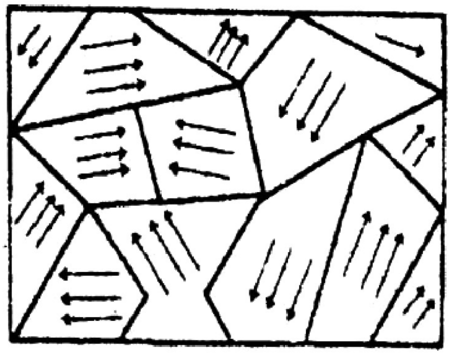
In second type of atoms there is no resultant field as the magnetic fields produced by both orbital and spin motions of the electrons might add upto zero. These are called diamagnetic substances, for example the atoms of water, copper, bismuth and antimony.

Ferromagnetic substances:

There are some solid substances e.g., Fe, Co, Ni, Chromium dioxide, and Alnico (an iron aluminium-nickel-cobalt alloy) in which the atoms co-operate with each other in such a way so as to exhibit a strong magnetic effect. They are called ferromagnetic substances.

Domains:

There exists in ferromagnetic substance small regions called 'domains'. The domains are of macroscopic size of the order of millimetres or less but large enough to contain 10^{12} to 10^{16} atoms.

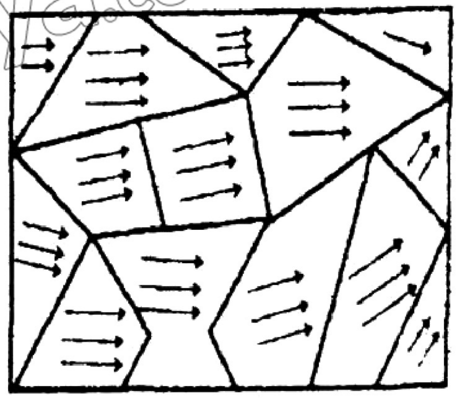


Saturation and un-saturation of domains:

Within each domain the magnetic fields of all the spinning electrons are parallel to one another i.e., each domain is magnetized to saturation.

Each domain behaves as a small magnet with its own north and south poles.

In unmagnetised iron the domains are oriented in a disorderly fashion, so that the net magnetic effect of a sizeable specimen is zero.



Electro magnet:

When the specimen is placed in an external magnetic field as that of a solenoid, the domains line up parallel to lines of external magnetic field and the entire specimen becomes saturated.

The combination of a solenoid and a specimen of iron inside it thus make a powerful magnet and are called an electromagnet.

Domains in iron:

Iron is a soft magnetic material. Its domains are easily oriented on applying an external field and also readily return to random positions when the field is removed. This is, desirable in an electromagnet and also in transformers

Domains in steel:

Domains in steel, on the other hand, are not so easily oriented to order. They require very strong external fields, but once oriented, retain the alignment. Thus steel makes a good permanent magnet and is known as hard magnetic material and another such material is a special alloy Alnico V.

Effect of temperature on domains (Curie temperature):

Thermal vibrations tend to disturb the orderliness of the domains. Ferromagnetic materials preserve the orderliness at ordinary temperatures. When heated, they begin to lose their orderliness due to the increased thermal motion. This process begins to occur at a particular temperature (different for different materials) called Curie temperature. Above the Curie temperature iron is paramagnetic but not ferromagnetic. The Curie temperature for iron is about 750°C.

Q17: Describe the use of magnetic made out of the magnetic materials?

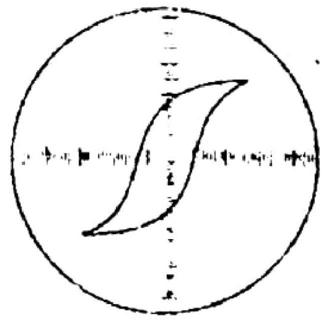
Ans: Magnetic made out of organic materials could be used in optical disks and components in computers, mobile phones. TVs, motors generators and data storage devices. Circuits can make use of ceramic magnets that do not conductors electricity.

Q18: What is meant by hysteresis loop? Discuss its main features?

Ans: Hysteresis loop:

Hysteresis loop is the graph between various values of flux density and intensity of magnetization.

Explanation:

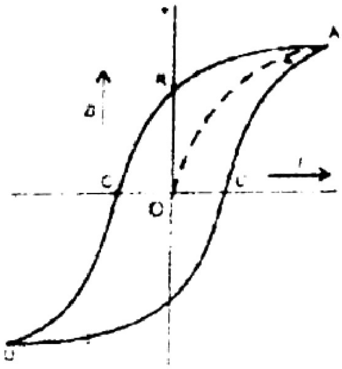


i. To investigate a ferromagnetic material, a bar of that material such as iron is placed in an alternating current solenoid. When the alternating current is at its positive peak value, it fully magnetises the specimen in one direction and when the current is at its negative peak, it fully magnetises it in opposite direction.

ii. As the alternating current changes from its positive peak value to its negative peak value and then back to its positive peak value, the specimen undergoes a complete cycle of magnetization. The flux density versus the magnetization current of the specimen for the various values of magnetizing current of the solenoid is plotted by a CRO as shown in Fig. Such process is called hysteresis loop.

Main features of hysteresis loop:

Its main features are as follows.



Hysteresis loop of steel

1. Hysteresis:

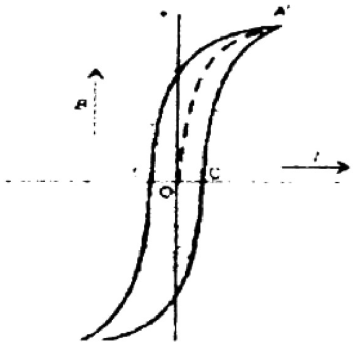
The value of flux density for any value of current is always greater when the current is decreasing than when it is increasing, i.e., magnetism lags behind the magnetizing current. This phenomenon is known as hysteresis. The portion of OA of the curve is obtained when the magnetizing current I is increased and AR is the portion when the current is decreased.

2. Saturation:

The magnetic flux density increases from zero and reaches a maximum value. At this stage the material is said to be magnetically saturated.

3. Remanence or retantivity:

When the current is reduced to zero, the material still remains strongly magnetized represented by point R on the curve. It is due to the tendency of domains to stay partly in line, once they have been aligned.



Hysteresis loop of soft iron
OR – Retentivity
OC = Coercivity

4. Coercivity:

To demagnetize the material, the magnetizing current is reversed and increased to reduce the magnetization to zero. This is known as coercive current represented by C on the curve.

The coerçivity of steel is more than that of iron as more current is needed to demagnetize it. Once the material is magnetized, its magnetization curve never passes through the origin. Instead, it forms the closed loop ACDC'A, which is called hysteresis loop.

5. Area of the loop (hysteresis loss):

The area of the loop is a measure of the energy needed to magnetize and demagnetize the specimen during each cycle of the magnetizing current. This is the energy required to do work against internal friction of the domains. This work, like all work that is done against friction, is dissipated as heat. It is called **hysteresis loss**.

Hard magnetic materials like steel cannot be easily magnetized or demagnetized, so they have large loop area as compared to soft magnetic material such as iron which can easily be magnetized. The energy dissipated per cycle, thus, for iron is less than for steel.

Q19: Describe the uses of hysteresis loop?

Ans: Uses of hysteresis loop:

i. **Suitability of magnetic materials** for different purposes can be studied by taking the specimen through a complete cycle and drawing the hysteresis loop.

ii. A material with high retantivity and large **coercive force** would be most suitable to make a permanent magnet.

iii. The cores of electromagnets used for **alternating currents** where the specimen repeatedly undergoes magnetization and demagnetization should have narrow hysteresis curves of small area to minimize the waste of energy.

Q20: How speed of 500kmh^{-1} is obtained in bullet train?

Ans: A bullet train is lifted above the rails due to magnetic effect, thus friction is reduced to minimum and speed can be enhanced up to 500 kmh^{-1}.

SUMMARY

1. Crystalline solids are those in which there is a regular arrangement of molecules. The neighbours of every molecule are arranged in a regular pattern that is constant throughout the crystal, thus, there is an ordered structure in crystalline solids.
2. In amorphous solids there is no regular arrangement of molecules. These are more like liquids with the disordered structure frozen in.
3. Polymers may be said to be more or less solid materials with a structure that is intermediate between order and disorder. These can be classified as partially or poorly crystalline solids.
4. A crystalline solid consists of three dimensional pattern that repeats itself over and over again. This basic structure is called unit cell.
5. The force applied on unit area to produce any change in the shape, volume or length of a body is called stress.
6. When a long wire of length ℓ with area of cross section A is being pulled by a force F, which results in an increase in length $\Delta\ell$, the stress is called tensile deformation.
7. When a small cylinder is subjected to a force F along the inward drawn normal to its area of cross section A to reduce its length, the stress is called compressive stress and deformation produced by it is called compressive deformation.
8. If a force F is applied tangentially to the surface of the opposite face of a cube to deform or twist it through an angle θ, the stress is termed as shear stress.
9. Strain is a measure of the deformation of a solid when stress is applied to it. In the case of deformation in one dimension, strain is defined as the fractional change in length per unit length. If strain is due to tensile stress, it is called tensile strain and if it is produced as a result of compressive stress, it is termed as compressive strain.
10. The ratio of stress to strain is a constant for a given material, provided the external applied force is not too great. This is called modulus of elasticity.
11. The strain energy can be obtained by the area of the force-extension graph.
12. The electrical behaviour of semi-conductor is substantially changed on introducing a small amount of impurity into the pure semi-conductor lattice. The process is called doping in which a small number of atoms of some

other suitable elements are added as impurity. The doped semi-conducting materials are called extrinsic.

13. When a silicon crystal is doped with a pentavalent element, four valence electrons of the impurity atom form covalent bond with the neighbouring Si atoms while the fifth valence electron provides a free electron in the crystal. Such a doped or extrinsic semi-conductor is called n-type semi-conductor.

14. There are some materials whose resistivity becomes zero below a certain temperature T_c, called critical temperature. Below this temperature, such materials are called superconductors.

15. Substances in which the orbits and the spin axes of the electrons in an atom are so oriented that their magnetic fields support each other and the atom behaves like a tiny magnet are called paramagnetic substances.

16. The substances in which magnetic fields produced by orbital and spin molecules of the electrons add up to zero are called diamagnetic substances.

17. Substances in which the atoms co-operate with each other in such a way so as to exhibit a strong magnetic effect are called ferromagnetic.

SOLUTION OF EXERCISE

17.1. Distinguish between crystalline, amorphous and polymeric solids?

Ans: a. Crystalline solids:

i. In crystalline solids there is a regular arrangement of molecules. The neighbours of every molecule are arranged in a regular pattern that is constant throughout the crystal. There is, thus an ordered structure in crystalline solids.

b. Amorphous or glassy solids:

i. The word amorphous means without form or structure.

ii. In amorphous solids there is no regular arrangement of molecules like that in crystalline solids. We can, therefore, say that amorphous solids are more like liquids with the disordered structure frozen in.

c. Polymeric solids:

i. Polymers may be said to be more or less solid materials with a structure that is intermediate between order and disorder.

ii. They can be classified as partially or poorly crystalline solids.

17.2. Define stress and strain. What are their SI units? Differentiate between tensile, compressive and shear modes of stress and strain.

Ans: See Q4 from SHORT AND LONG QUESTIONS

17.3. Define modulus of elasticity. Show that the units of modulus of elasticity and stress are the same. Also discuss its three kinds.

Ans: Elastic constants:

i. Modulus of elasticity:

The ratio of stress to strain is a constant for a given material provided the external applied force is not too great. This ratio is called modulus of elasticity, and can be mathematically described as other suitable elements are added as impurity. The doped semi-conducting materials are called extrinsic

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Ans: Elastic constants:

i. Modulus of elasticity:

The ratio of stress to strain is a constant for a given material provided the external applied force is not too great. This ratio is called modulus of elasticity, and can be mathematically described as

$$\text{Modulus of Elasticity} = \frac{Stress}{Strain}$$

ii. Young's modulus (Y):

In the case of linear deformation, the ratio of tensile (or compressive) stress $\sigma = (F/A)$ to tensile (or compressive) strain $\varepsilon = \Delta \ell / \ell$ is called Young's modulus.

$$Y = \frac{F/A}{\Delta \ell / \ell}$$

iii. Bulk modulus (K):

For three dimensional deformations, when volume is involved, then the ratio of applied stress to volumetric strain is called Bulk modulus

$$K = \frac{F/A}{\Delta V/V}$$

Where ΔV is the change in original volume V

iv. Shear modulus (G):

However, when the shear stress $\tau = (F/A)$ and shear strain $(\gamma = \tan\theta)$ are involved, then their ratio is called shear modulus.

$$G = \frac{F/A}{\tan\theta}$$

Units of modulus of elasticity:

$$\text{Modulus of Elasticity} = \frac{Stress}{Strain} = \frac{Nm^{-2}}{No\ unit} = Nm^{-2} \text{ or Pa}$$

Units of stress:

$$\text{Stress} = \frac{Force}{Area} = \frac{N}{m^2} = Nm^{-2} \text{ or Pa.}$$

Thus the units of modulus of elasticity and stress are the same.

17.4. Draw a stress- strain curve for a ductile material, and then define tin terms: elastic limit, yield point and ultimate tensile stress.

Ans: See Q7. from SHORT AND LONG QUESTIONS

17.5. What is mean by strain energy? How can it be determined from force extension graph?

Ans: See Q8 from SHORT AND LONG QUESTIONS

17.6. Describe the formation of bands in solids. Explain the difference amongst electrical behavior of conductors, insulators and semi-conductors in terms of energy band theory.

Ans: See Q11. from SHORT AND LONG QUESTIONS

17.7. Distinguish between intrinsic and extrinsic semi-conductors. How would you obtain n-type and p-type material from pure silicon? Illustrate it by schematic diagram.

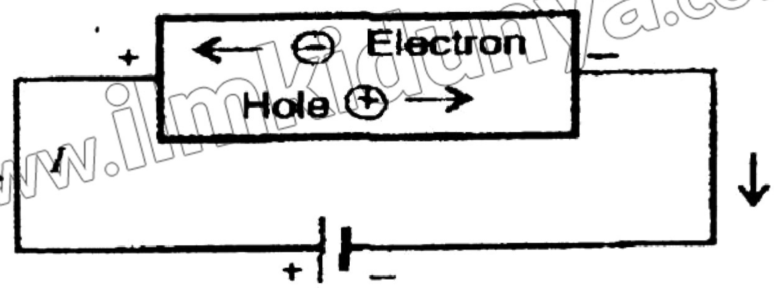
Ans: See Q13. from SHORT AND LONG QUESTIONS

17.8. Discuss the mechanism of electrical conduction by holes and electrons in a pure semi-conductor element.

Ans: Electrical conduction by holes and electrons:

Considered a special case in which the electron and the hole are moving in a straight line. Actually their motion is random because positively charged core of the atom can attract an electron from any of its neighbouring atoms.

In semi-conductors there are two kinds of charge carriers, a free electron (-e) and a hole (+e)



Application of battery to a semi-conductor:

i. When a battery is connected to a semi-conductor, it establishes an electric field across it due to which a directed flow of electrons and holes takes place.

ii. The electrons drift towards the positive end, whereas the holes drift towards the negative end of the semi-conductor.

iii. The current I flowing through the semi-conductor is carried by both electrons and holes.

iv. It may be noted that the electronic current and the hole current add up together to give the current I.

17.9. Write a note on super conductors.

Ans: See Q15 from SHORT AND LONG QUESTIONS

17.10. What is meant by Para, diamagnetic and ferromagnetic substances? Give examples for each.

Ans: See Q16. from SHORT AND LONG QUESTIONS

17.11. What is meant by Hysteresis loss? How is it used in the construction of a transformer?

Ans: Hysteresis loss:

The area of the loop is a measure of the energy needed to magnetize and demagnetize the specimen during each cycle of the magnetizing current. This is the energy required to do work against internal friction of the domains. This work, like all work that is done against friction, is dissipated as heat. It is called **hysteresis loss**.

Use in the construction of transformer:

Hard magnetic materials like steel cannot be easily magnetized or demagnetized, so they have large loop area as compared to soft magnetic material such as iron which can easily be magnetized. The energy dissipated per cycle, thus, for iron is less than for steel. That is why soft iron used in transformers.

SOLUTION OF EXAMPLES

Example 17.1: **A steel wire 12 mm in diameter is fastened to a log and is then pulled by tractor. The length of steel wire between the log and the tractor is 11m. A force of 10,000 N is required to pull the log. Calculate (a) the stress in the wire and (b) the strain in the wire**
(c) How much does the wire stretch when the log is pulled?
($E = 200 \times 10^9$ N m^{-2})

Solution:

Diameter of the wire $= d = 12mm = \frac{12}{1000} = 0.012$ m

Radius of the wire $= r = \frac{0.012}{2} = 0.006$ m

Length of the wire $= \ell = 11$ m

Force required $= F = 10{,}000$ N

Modulus of elasticity $= E = 200 \times 10^9$ Nm^{-2}

(a) Stress $= \sigma = ?$

(b) Strain $= \varepsilon = ?$

(c) Increase in length $= \Delta\ell = ?$

(a) A tensile stress $= \sigma = \frac{F}{A} = \frac{F}{\pi r^2}$ $(\because A = \pi r^2)$

$$\sigma = \frac{10000}{3.14\times(0.006)^2} = \frac{10000}{3.14\times0.000036} = 88.46\times10^6\ N\ m^{-2}$$

$\sigma = 88.46\ MP_a$

(b) Modulus of elasticity $= E = \frac{stress}{Strain}$

$$200 \times 10^9 = \frac{88.46\times10^6}{Strain}$$

$$Strain = \frac{88.46\times10^6}{200\times10^9} = 4.4\times10^{-4}$$

(c) Since Strain $= \varepsilon = \frac{\Delta\ell}{\ell}$

or $\Delta\ell =$ Strain $\times\ \ell$

$\Delta\ell = 4.4\times10^{-4}\times11 = 4.84\times10^{-3}$ m $= 4.84$ mm

SOLUTION OF PROBLEMS

17.1 A 1.25 cm diameter cylinder is subjected to a load of 2500kg. Calculate the stress on the bar in mega pascals.

Solution:

Diameter $= d = 1.25$ cm $= 1.25 \times 10^{-2}$ m

Radius $= r = \frac{d}{2} = 0.625$ cm $= 0.00625$ m

Mass $= m = 2500$ kg

Stress $= \sigma = ?$

Area of cross section $= A = \pi r^2$

Here, $F = W = mg$

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

So we can write the formula for stress as:

$$\sigma = \frac{mg}{\pi r^2}$$

$$\sigma = \frac{2500\times9.8}{(3.14)(0.00625)^2} = \frac{24500}{0.00012265} = 199.755401$$

$\sigma = 199.755401\times10^6$ Pa $=$ Stress $= 200$ MPa

17.2 A 1.0m long copper wire is subjected to stretching force and its length increases by 20cm. Calculate the tensile strain and the percent elongation which the wire undergoes.

Solution:

Diameter of the wire $= d = 12mm = \frac{12}{1000} = 0.012$ m

Radius of the wire $= r = \frac{0.012}{2} = 0.006$ m

Length of the wire $= \ell = 11$ m

Force required $= F = 10{,}000$ N

Modulus of elasticity $= E = 200 \times 10^9\ Nm^{-2}$

(a) Stress $= \sigma = ?$

(b) Strain $= \varepsilon = ?$

(c) Increase in length $= \Delta\ell = ?$

(a) A tensile stress $= \sigma = \frac{F}{A} = \frac{F}{\pi r^2}$ $(\because A = \pi r^2)$

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$\sigma = 88.46\ MP_a$

(b) Modulus of elasticity $= E = \frac{stress}{Strain}$

$$200 \times 10^9 = \frac{88.46\times10^6}{Strain}$$

$$\text{Strain} = \frac{88.46\times10^6}{200\times10^9} = 4.4\times10^{-4}$$

(c) Since Strain $= \varepsilon = \frac{\Delta\ell}{\ell}$

or $\Delta\ell = \text{Strain} \times \ell$

$\Delta\ell = 4.4\times10^{-4}\times 11 = 4.84\times10^{-3}\,m = 4.84$ mm

SOLUTION OF PROBLEMS

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Area of cross section $= A = \pi r^2$

Here, $F = W = mg$

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

So we can write the formula for stress as:

$$\sigma = \frac{mg}{\pi r^2}$$

$$\sigma = \frac{2500\times9.8}{(3.14)(0.00625)^2} = \frac{24500}{0.00012265} = 199.755401$$

$\sigma = 199.755401\times10^6$ Pa $=$ Stress $= 200$ MPa

17.2 A 1.0m long copper wire is subjected to stretching force and its length increases by 20cm. Calculate the tensile strain and the percent elongation which the wire undergoes.

Solution:

Length of the wire = L = 1 m

Extensions in wire = ΔL = 20 cm = 0.20 m

Tensile strain = $\frac{\Delta L}{L}$

Tensile strain = $\frac{0.20}{1}$ = 0.20

Percentage elongation = $\frac{\Delta L}{L} \times 100\ \%$

Percentage elongation = $\frac{0.20}{1} \times 100\ \%$ = 20%

17.3. A wire 2.5 m long and cross section area 10^{-5} m^2 is stretched 1.5 mm by a force of 100 N in the elastic region.

Calculate: (i) the strain (ii) Young's modulus (iii) the energy stored in the wire.

Solution:

Length of the wire = L = 2.5 m

Area of cross section = A = 10^{-5} m^2

Extension in wire = ΔL = 1.5 mm = 1.5×10^{-3} m

Applied force = F = 100 N

(i) Strain = ε = ?

(ii) Young's Modulus = Y = ?

(iii) Energy Stored (strain energy) = E = ?

(i) Strain = ε = $\frac{\Delta L}{L}$

Strain = $\frac{1.5 \times 10^{-3}}{2.5}$ = 6.02×10^{-4}

(ii) Young's Modulus = Y = $\frac{F/A}{(\frac{\Delta L}{L})}$

$$Y = \frac{F/A}{(\frac{\Delta L}{L})} = \frac{F}{A} \times \frac{L}{\Delta L}$$

$Y = \frac{100 \times 2.5}{10^{-5} \times 1.5 \times 10^{-3}}$ = 1.66×10^{10} N/m^2 or Pa

(iii) Strain energy = $\frac{1}{2} F \Delta \ell$

$E = \frac{1}{2} \times 100 \times 1.5 \times 10^{-3} = 7.5 \times 10^{-2}$ J

17.4 What stress would cause a wire to increase in length by 0.01% if the Young's modulus of the wire is 12×10^{10} Pa. What force would produce this stress if the diameter of the wire is 0.56 mm?

Solution:

Percentage increase in length = 0.01%

Young's modulus = Y = 12×10^{10} Pa

Diameter = d = 0.56 mm

Radius = r = $\frac{d}{2}$ = 0.28 mm = 0.28×10^{-3} m

Stress = σ = ?

Force = F = ?

By definition we have,

Strain × 100 = Percentage elongation

$$\text{Strain} = \frac{\text{Percentage elongation}}{100}$$

Strain $= \varepsilon = \frac{0.01}{100} = 10^{-4}$

Young's Modulus $= \frac{stress}{strain} \Rightarrow Y = \frac{\sigma}{\varepsilon}$

$\Rightarrow \sigma = Y \times \varepsilon$

Stress $= \sigma = 12 \times 10^{10} \times 10^{-4} = 12 \times 10^{6} = 0.12 \times 10^{8}$ Nm^{-2}

The formula for stress is,

Stress $= \frac{Force}{Area}$

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

$F = \sigma \times \pi r^2$

$F = 12 \times 10^{6} \times 3.142 \times (0.28 \times 10^{-3})^2 = 0.12 \times 0.25 \times 10^{2} = 2.96$ N

17.5 The length of a steel wire is 1.0 m and its cross sectional area is 0.03×10^{-4} m^2. Calculate the work done in stretching the wire when a force of 100 N is applied within the elastic region. Young's modulus of steel is 3.0×10^{11} Nm^{-2}.

Solution:

Length of the wire = $L = 1$ m

Area of Cross Section = $A = 0.03 \times 10^{-4}$ m^2

Applied Force = $F = 100$ N

Young's Modulus = $Y = 3.0 \times 10^{11}$ N m^{-2}

Work Done = $W = ?$

Since $Y = \frac{F \times L}{A \times \Delta L} \Rightarrow \Delta L = \frac{FL}{A \times Y}$ (1)

$\Delta L = \frac{100 \times 1}{3 \times 10^{11} \times 0.03 \times 10^{-4}} = 1.1 \times 10^{-4}$ m

As we know that

Work done $= \frac{1}{2} F \Delta \ell$

$E = \frac{1}{2} \times 100 \times 1.1 \times 10^{-4} = 5.6 \times 10^{-3}$ J

17.6 A cylindrical copper wire and a cylindrical steel wire each of length 1.5 m and diameter 2.0 mm are joined at one end to form a composite wire 3.0 m long. The wire is loaded until its length becomes 3.003 m. Calculate the strain in copper and steel wires and the force applied to the wire. (Young's modulus of copper is 1.2×10^{11} Pa and for steel is 2.0×10^{11} Pa).

Solution:

length of Copper wire = $L_c = 1.5$ m

diameter of Copper wire = $d_c = 2$ mm $= 2 \times 10^{-3}$ m

radius of Copper wire = $r_c = 1 \times 10^{-3}$ m

Young's modulus of Copper wire = $Y_c = 1.2 \times 10^{11}$ Pa

length of Steel wire = $L_s = 1.5$ m

diameter of Steel wire = $d_s = 2$ mm

radius of Steel wire = $r_s = 1 \times 10^{-3}$ m

Young's modulus of Steel wire = $Y_s = 1.2 \times 10^{11}$ Pa

Combined length of the wire = $L = 3.0$ m

Extended length of the wire = $L' = 3.003$ m

Extension in wire = $\Delta L = 3.003 - 3 = 0.003$ m

Strain in Copper = ε_c = ?
Strain in Steel = ε_s = ?
Force on wire = F = ?

For strain in copper:

$$\varepsilon_c = \frac{\Delta L_C}{L_C} \text{.................... (a)}$$

For strain in steel:

$$\varepsilon_s = \frac{\Delta L_S}{L_S} \text{........ (b)}$$

Modulus of elasticity of copper wire = $Y_c = \frac{F/A}{\left(\frac{\Delta L_C}{L_C}\right)}$

$$Y_c = \frac{F}{A} \times \frac{L_C}{\Delta L_C} \text{....... (1)}$$

Modulus of elasticity of steel wire = $Y_s = \frac{F/A}{\left(\frac{\Delta L_S}{L_S}\right)} = \frac{F}{A} \times \frac{L_S}{\Delta L_S}$.......... (2)

By dividing Eq. 1 by Eq. 2 we get,

$$\frac{Y_C}{Y_S} = \frac{\Delta L_S}{\Delta L_C} \text{......... (3)} \qquad (\because L_S = L_S = 1.5 \text{ m})$$

Combined length of the string is 0.003 m so we can write it as,

$$\Delta L_s + \Delta L_c = \Delta L = 0.003 \text{ m....... (4)}$$

Using values in equation in (3), we get,

$$\frac{\Delta L_S}{\Delta L_C} = \frac{1.2\times 10^{11}}{2\times 10^{11}} = 0.6$$

$$\Delta L_S = 0.6\, \Delta L_C \text{........ (5)}$$

Using this value in equation, (4) we get,

$$0.6\, \Delta L_C + \Delta L_C = \Delta L = 0.003 \text{ m}$$

$$1.6\, \Delta L_C = 0.003 \text{ m}$$

$$\Delta L_c = \frac{0.003}{1.6}$$

$$\Delta L_C = 1.875 \times 10^{-3} \text{ m...... (6)}$$

Using this value in equation (5) we get,

$$\Delta L_S = 0.6 \times 1.875 \times 10^{-3} \text{ m}$$

$$\Delta L_S = 1.125 \times 10^{-3} \text{ m..... (7)}$$

Putting values in equation (a), we get,

$$\varepsilon_c = \frac{1.875\times 10^{-3}}{1.5} = 1.25 \times 10^{-3}$$

Putting values in equation (b), we get,

$$\varepsilon_S = \frac{1.125\times 10^{-3}}{1.5} = 7.5 \times 10^{-4}$$

The formula for force applied to the wire is:

$$Y_c = \frac{F}{A} \times \frac{L_C}{\Delta L_C} \qquad \left(\because Y = \frac{FL}{A\Delta L}\right)$$

$$F = \frac{Y_C\times \pi r^2 \times \Delta L_C}{L_C}$$

$$F = \frac{1.2\times 10^{11}\times 3.142\times (10^{-3})^2\times 1.875\times 10^{-3}}{1.5} = 4.71 \times 10^2 \text{ N}$$

$$F = 471 \text{ N}$$