SHORT QUESTIONS

17.1 Distinguish between crystalline, amorphous and polymeric solids.

Ans. **(i) Crystalline Solid:** The solids whose atoms or molecules are arranged in a regular manner which is repeated periodically inside the crystal in three dimensions are called crystalline solids. e.g., metals such as copper, iron, zinc, sodium chloride and ceramics.

Note: They have definite melting point.

(ii) Amorphous or Glassy Solids: The solids which have no regular arrangement of their atoms or molecules are called amorphous solids. e.g., ordinary glass.

Note: They have no definite melting point.

(iii) Polymeric Solids: Polymeric may be more or less solid materials with a structure that is intermediate between order and disorder. So we can say that such solids are partially or poorly crystalline solids. e.g., plastic and synthetic rubbers.

Note: Their specific gravity is very low.

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

Ans. **Stress:** The force per unit area is called stress. Mathematically

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

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

The unit of stress is $\mathbf{N/m^2}$ or **Pa**.

Strain: The change in the dimensions of a body produced by the action of the deforming force is called strain. It has no unit. There are three types

(i) Tensile Strain: When the deforming force changes the length of the body, it is called tensile strain. i.e.,

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

(ii) Volumetric Strain: When the deforming force changes the volume of the body, it is called volumetric strain i.e.,

$$\text{Volumetric strain} = \frac{\text{Change in volume}}{\text{Total volume}} = \frac{\Delta V}{V}$$

(iii) Shear Strain: When the deforming force changes the shape of the body, it is called shear strain i.e.,

$$\text{Shear strain} = \frac{\Delta a}{a}$$

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. **Modulus of Elasticity:** It is defined as the ratio of stress to strain. Mathematically

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

Where stress is measured in N/m^2 or Pa and strain has no unit so modulus of elasticity is measured in N/m^2. Hence the unit of modulus of elasticity and stress are same.

There are three kinds of modulus of elasticity.

(i) Young's Modulus: The ratio of stress to tensile strain is called the young's modulus mathematically

$$Y = \frac{F/A}{\frac{\Delta l}{l}} = \frac{F \times l}{A \times \Delta l}$$

(ii) Bulk Modulus: The ratio of stress to volumetric strain is called the bulk modulus mathematically

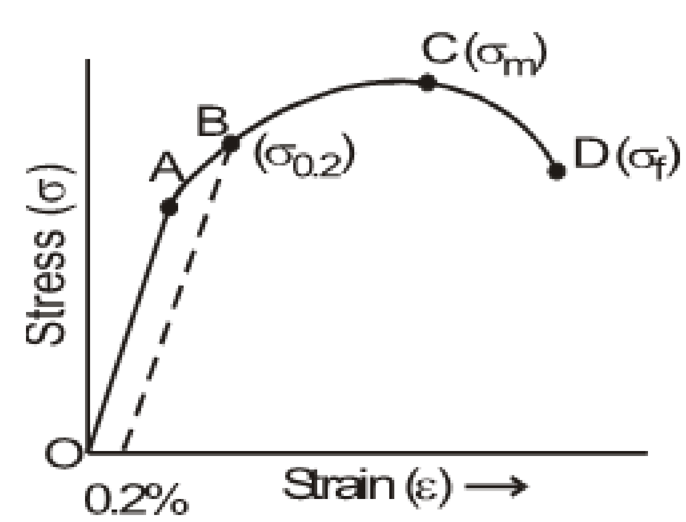
$$K = \frac{F/A}{\frac{\Delta V}{V}} = \frac{F \times V}{A \times \Delta V}$$

(iii) Shear Modulus: The ratio of stress to shear strain is called shear modulus mathematically

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

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

Ans. The stress-strain curve for a ductile material is as shown in figure



(i) Elastic Limit: It is defined as the greatest stress that a material can endure without any permanent change in the shape or dimensions. It is denoted by σ_e.

(ii) Yield Point: If we cross the elastic limit, then deformation becomes permanent. It is represented by the point B known as yield point because if we now cross the yield point then the length of wire increases more rapidly as compared to the stress applied.

(iii) Ultimate Tensile Stress (UTS): It is defined as the maximum stress that a material can withstand and is represented by the point C. If point C is crossed then material will break.

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

Ans. **Strain Energy:** The potential energy stored in a body by virtue of an elastic deformation equal to the work done that must be done to produce this deformation is called strain energy.

According to force-extension graph

$$\text{Work done} = \text{Area of } \Delta AOB$$

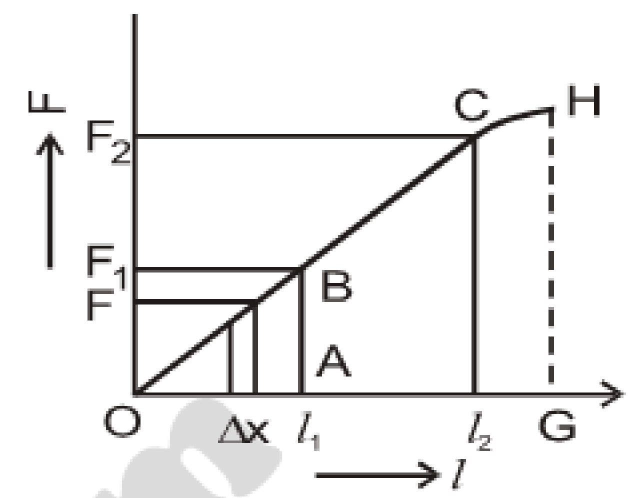
$$= \frac{1}{2} \times OA \times AB$$

$$= \frac{1}{2} l_1 \times F_1$$

As $$E = \frac{F_1/A}{l_1/L}$$

$$= \frac{F_1}{A} \times \frac{L}{l_1}$$

$$F_1 = \frac{E \times A l_1}{L}$$



Therefore;

$$\text{Work done} = \text{Strain energy}$$

$$= \frac{1}{2} \times l_1 \times \left[\frac{EAl_1}{L}\right]$$

$$\text{Strain energy} = \frac{1}{2} \times \frac{EA l_1^2}{L}$$

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

Ans. Electron of an isolated atoms are bounded to the nucleus and can only have distinct energy levels. However. When a large number of atoms N are brought close to one another to form a solid, each energy level of the isolated atom splits into N sub-levels under the action of force exerted by other atoms in the solid. These sub-levels are called energy state and they are very close to each other so that we can say that they forms continuous energy band. In b/w two energy bands, there is a range of energy states which cannot be occupied by electron. These are called forbidedden energy states. There are three most important energy bands

(i) Valence energy band.

(ii) Conduction energy band.

(iii) Completely field energy band.

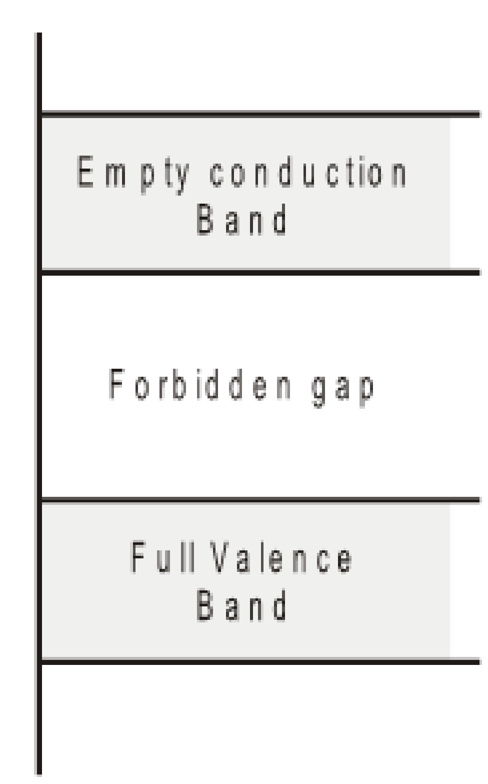
Energy band theory can be applied to distinguish between insulators, conductors and semi-conductors.

Insulator: Insulators are those substances in which valence electrons are bounded very tightly to their atoms. An insulator has the following properties on the basis of energy band theory.

(i) Conduction band is empty.

(ii) Valence band is completely filled.

(iii) There is a large forbidden energy gap b/w them.

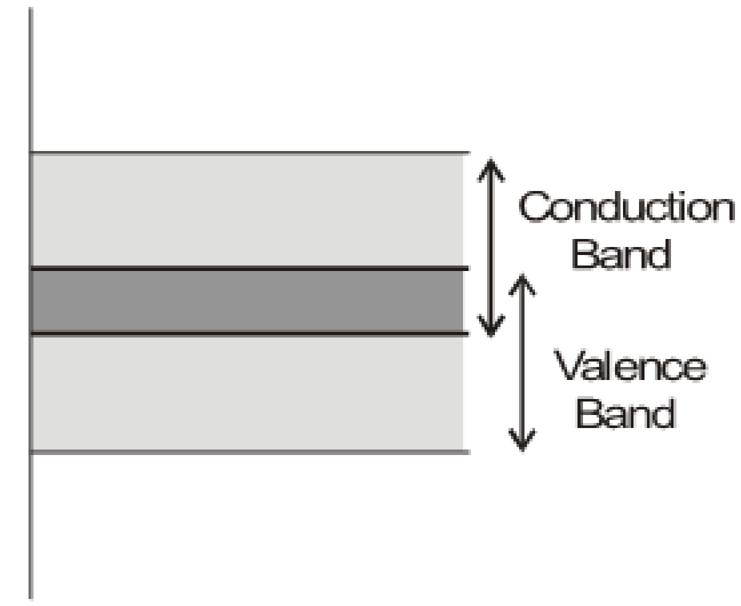


Conductors: According to energy band theory, in conductors, valence and conduction energy bands are overlap each other. There is no physical distinction between the two bands. In conductors,

(i) Conduction band is partially filled.

(ii) Valence band is also partially filled.

(iii) There is no narrow forbidden energy gap between conduction and valence bands.

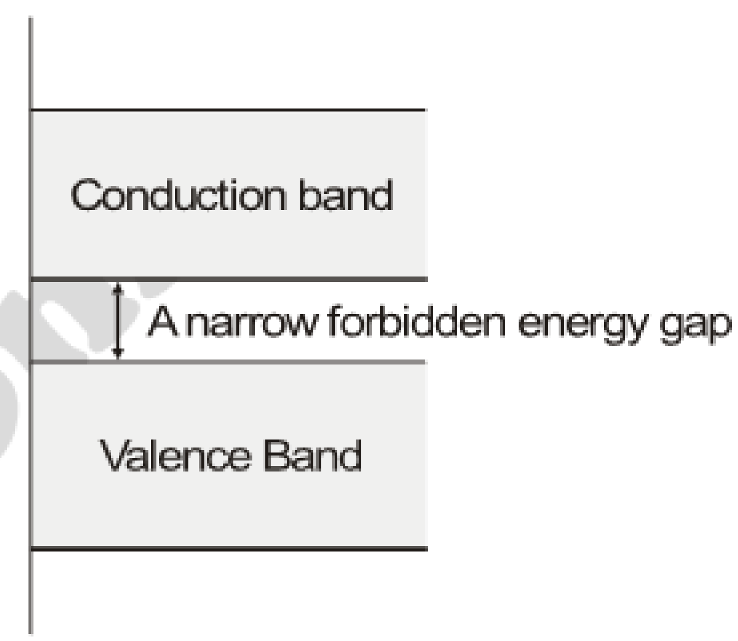


Semi-Conductors: In terms of energy band theory, semi-conductors are those materials which at room temperature have

(i) Partially filled conduction band

(ii) Partially filled valence band.

(iii) A very narrow forbidden energy gap between conduction and valence bands.

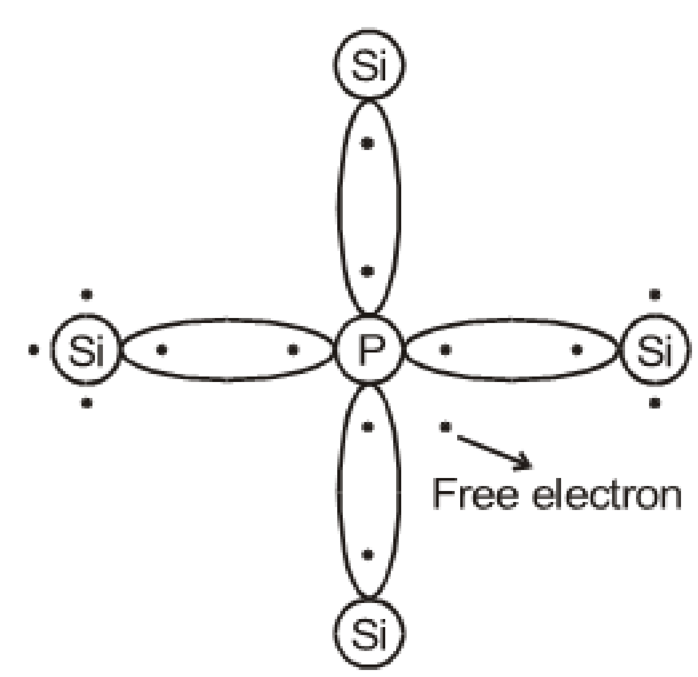


17.7 Distinguish between intrinsic and extrinsic semi-conductors. How would you obtain n-type and p-type material from pure silicon? Illustrate it by schematic diagram.

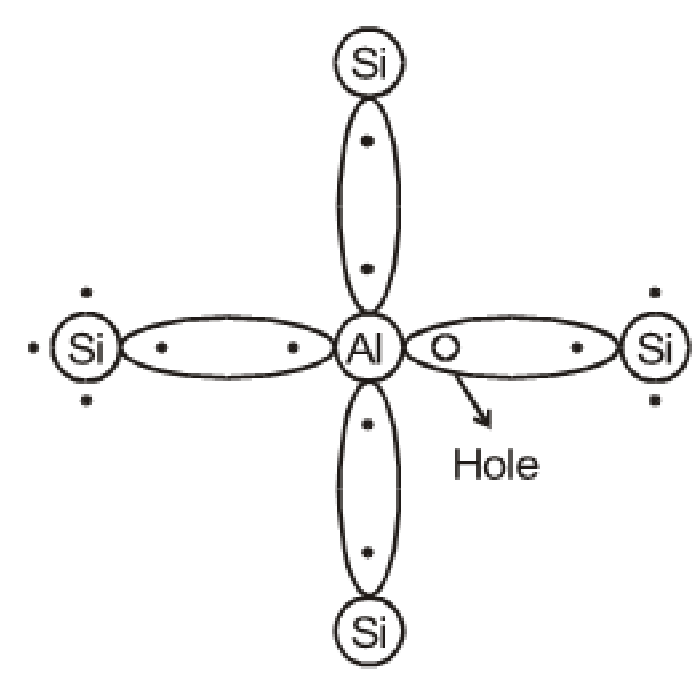
Ans. Semi-conductors in their purest form without any impurity are called intrinsic semi-conductors. Silicon and germinium are **intrinsic semi-conductors**.

Extrinsic Semi-conductors: Those semi-conductors to which some impurities are added to obtain the desired conduction properties are called extrinsic semi-conductors P-type and N-type are the extrinsic semiconductors.

N-type: When a silicon or germinium crystal is doped with pentavalent element such as arsenic antimony or phosphorus, four valence electrons of impurity atom form covalent bond with the four neighbouring Si atoms in the crystal. Such a doped substance is called N-type semi-conductor. Figure show silicon crystal dope with a pentavalent impurity such as phosphorus.



P-type: When a silicon crystal is doped with a trivalent element such as aluminium, boron, gallium or indium etc., three valence electrons of the impurity atom form covalent with three neighbuoring silicon atoms, where as one electron is missing for the fourth Si atom i.e., a hole is created which is vacancy where an electron can be accommodated. Such a semi-conductor is called p-type semi-conductor. The figure shows the P-type semi-conductor.



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

Ans. In pure semiconductors, number of "holes" are equal to "free electrons". When a certain amount of voltage is applied to a semiconductor, an electric field is generated. Due to this electric field, the holes and free electrons experience the effect of some force. Due to this electric force, electrons get drift velocity on one direction whereas holes get drift velocity in the opposite direction. This is the reason for conduction of electric current inside semiconductors. The total current flowing is equal to the sum of current due to motion of free electrons and the current flowing due to holes.

17.9 Write a note on superconductors.

Ans. Superconductors are those conductors whose resistance reduces to zero below the critical temperature. A ceramic material can work as a superconductor at 125K. $YBa_2Cu_3O_7$ behaves as a superconductor even at 165K. Superconductors are being used in MRI, magnetic levitation trains, faster computer chips. A current set up once in a superconductor ring will go on moving for indefinite period.

17.10 What is meant by para, dia and ferromagnetic substances? Give examples for each.

Ans. **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 e.g. ozone and platinum.

Diamagnetic substance are those substances in which magnetic fields produced due to the spin and orbital motion of the electrons cancel each other effects so these substances cannot be magnetized e.g., copper, bismith, antimony etc.

Ferromagnetic Substances: There are some solid substances 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 substance e.g., Fe, Co, Ni, and Alinco.

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 so it is called hysteresis loss.

In transformer 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.

PROBLEMS WITH SOLUTIONS

PROBLEM 17.1

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

Data

Diameter of cylinder $= d = 1.25$ cm

$= 0.0125$ m

Load $= m = 2500$ kg

To Find

Stress on the bar $= \sigma = ?$

SOLUTION

By formula

$$\boxed{\sigma = F/A}$$

But $F = mg$

$A = \text{Area} = \pi r^2$

As $r = \dfrac{d}{2}$

$$A = \pi\left(\frac{d}{2}\right)^2$$

$$= 3.14\left(\frac{0125}{2}\right)^2$$

$$= 1.22 \times 10^{-4}\,\text{m}^2$$

So, $\sigma = \dfrac{mg}{A}$

$$= \frac{2500 \times 9.8}{1.22 \times 10^{-4}}$$

$$\sigma = 20081.9 \times 10^4$$

$$= 200 \times 10^6 \text{ Pa}$$

$$= 200 \text{ MPa}$$

Result

Stress on the bar $= \sigma = 200$ MPa

PROBLEM 17.2

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

Data

Length of copper wire $= l = 1.0\text{ m}$

Change in length $= \Delta l = 20\text{ cm} = 0.20\text{ m}$

To Find

Tensile strain $= \varepsilon = ?$

Percentage elongation $= ?$

SOLUTION

As we know that

$$\text{Tensile strain} = \varepsilon = \frac{\Delta l}{l} = \frac{0.20}{1.0}$$

$$= 0.20$$

For percentage elongation

$$\text{Percentage elongation} = \frac{\text{Change in length}}{\text{Original length}} \times 100\%$$

$$= \frac{0.2}{1.0} \times 100\%$$

$$= 20\%$$

Result

Tensile strain $= \varepsilon = 0.20$

Percentage elongation $= 20\%$

PROBLEM 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.

Data

Length of wire $= l = 2.5\text{m}$

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

Change in length $= \Delta l = 1.5\text{ mm}$

$= 1.5 \times 10^{-3}\text{m}$

Force $= F = 100\text{N}$

To Find

(i) Tensile strain $= \varepsilon = ?$

(ii) Young's Modulus $= Y = ?$

(iii) Energy stored in the wire $= E = ?$

SOLUTION

(i) For tensile strain

$$\text{Tensile strain} = \boxed{\varepsilon = \frac{\Delta l}{l}}$$

$$\varepsilon = \frac{1.5 \times 10^{-3}}{2.5}$$

$$\varepsilon = 0.6 \times 10^{-3}$$

$$= 6.0 \times 10^{-4}$$

(ii) As we know that

$$\text{Young's Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\frac{\Delta l}{l}}$$

$$\boxed{Y = \frac{F}{A} \times \frac{l}{\Delta l}}$$

$$= \frac{100}{10^{-5}} \times \frac{2.5}{1.5 \times 10^{-3}}$$

$$= 166.6 \times 10^{8}$$

$$Y = 1.66 \times 10^{10}\ \text{Pa}$$

(iii) For energy stored in a wire

$$\boxed{\text{Energy stored} = \frac{1}{2} F \times \Delta l}$$

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

$$= 7.5 \times 10^{-2}\text{J}$$

Result

(i) Tensile Strain $= \varepsilon = 6.0 \times 10^{-4}$

(ii) Young's modulus $= Y = 1.66 \times 10^{10}$ Pa

(iii) Energy stored in wire $= E = 7.5 \times 10^{-2}$ J

PROBLEM 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?

Data

Percentage increase in length = 0.01%

$$\text{Strain} = \varepsilon = \frac{\Delta l}{l} = 0.01 \times \frac{1}{100} = 10^{-4}$$

$$\text{Young's Modulus} = Y = 12 \times 10^{10}\ \text{Pa}$$

$$\text{Diameter of wire} = d = 0.56\text{mm}$$

$$= 0.56 \times 10^{-3}\text{m}$$

$$\text{Radius of wire} = r = \frac{d}{2} = \frac{0.56 \times 10^{-3}}{2}$$

$$= 0.28 \times 10^{-3}\text{m}$$

To Find

Stress in wire = ε = ?

Force required = F = ?

SOLUTION

As we know that

$$Y = \text{Young's modulus} = \frac{\text{Stress}}{\text{Strain}}$$

$$Y = \frac{\sigma}{\varepsilon}$$

$$\boxed{\sigma = Y \times \varepsilon} \qquad \ldots\ldots \text{(i)}$$

$$= 12 \times 10^{10} \times 10^{-4}$$

$$\sigma = 12 \times 10^{6}$$

$$= 1.2 \times 10^{7}\ \text{Pa}$$

And for the force required

$$\sigma = F/A$$

$$\boxed{F = \sigma \times A}$$

But

$$A = \pi r^2$$

$$= 3.14 \times (0.28 \times 10^{-3})^2$$

$$A = 0.246 \times 10^{-6}$$

Putting in eq. (i)

So, $F = 1.2 \times 10^{7} \times 0.246 \times 10^{-6}$

$= 0.295 \times 10^{1}$

$= 2.95 \text{ N}$

Result

Stress in wire $= \sigma = 1.2 \times 10^{7}$ Pa

Force required $= F = 2.95$N

PROBLEM 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}.

Data

Length of steel wire $= l = 1.0$m

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

Force stretching the wire $= F = 100$N

Young's modulus for steel $= Y = 3.0 \times 10^{11}$ N.m^{-2}

To Find

Work done in stretching the wire $= W = ?$

SOLUTION

By formula

$$\boxed{W = \frac{1}{2} F \times \Delta l} \qquad \ldots\ldots \text{(i)}$$

But $$Y = \frac{F/A}{\frac{\Delta l}{l}}$$

$$Y = \frac{F}{A} \times \frac{l}{\Delta l}$$

$$\Delta l = \frac{F}{A} \times \frac{l}{Y}$$

$$\Delta l = \frac{100}{0.03 \times 10^{-4}} \times \frac{1.0}{3.0 \times 10^{11}}$$

$$\Delta l = 1111.1 \times 10^{-7} \text{m}$$

$$\Delta l = 1.1 \times 10^{-4} \text{m}$$

Putting in eq (i)

$$W = \frac{1}{2} \times 100 \times 1.1 \times 10^{-4}$$

$$= 55 \times 10^{-4}$$

$$= 5.5 \times 10^{-3} J$$

Result

Work done in stretching the wire

$$W = 5.5 \times 10^{-3} \text{ J}$$

PROBLEM 17.6

A cylinder cooper 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).

Data

Length of copper wire $= l_c = 1.5$ m

Length of steel wire $= l_s = 1.5$ m

Total length of both wire $= l = l_c + l_s$

$= 1.5 + 1.5 = 3$ m

Diameter of steel wire $= d = 2.0$ mm

$= 2.0 \times 10^{-3}$ m

Radius of the wire $= r = \frac{d}{2} = \frac{2.0}{2} \times 10^{-3}$

$r = 1.0 \times 10^{-3}$m

Area of the wire $= A = \pi r^2$

$A = 3.14 \times (1.0 \times 10^{-3})^2$

$A = 3.14 \times 10^{-6}$ m^2

Length of stretched wire $= l' = 3.003$m

Change in length $= \Delta l = l' - l$

$= 3.003 - 3 = 0.003$ m

Young's Modulus for copper wire $= Y_c = 1.2 \times 10^{11}$ Pa

Young's Modulus for steel wire $= Y_s = 2.0 \times 10^{11}$ Pa

To Find

(a) Strain in copper wire $= \varepsilon_c = ?$

(b) Strain in steel wire $= \varepsilon_s = ?$

(c) Force applied to the wire $= F = ?$

SOLUTION

As we know that

$$Y = \frac{F}{A} \times \frac{l}{\Delta l}$$

For copper wire

$$Y_c = \frac{F}{A} \times \frac{l}{\Delta l_c}$$

$$Y_c \times \Delta l_c = \frac{F}{A} \times l$$

$$\frac{F}{A} = \frac{Y_c \times \Delta l_c}{l} \quad \text{...... (i)}$$

For steel wire

$$\frac{F}{A} = Y_s \times \frac{\Delta l_s}{l} \quad \text{...... (ii)}$$

Compare the equation (i) and (ii)

$$Y_c \times \frac{\Delta l_c}{l} = Y_s \times \frac{\Delta l_s}{l}$$

$$\boxed{Y_c \times \Delta l_c = Y_s \times \Delta l_s}$$

$$\frac{Y_c}{Y_s} = \frac{\Delta l_s}{\Delta l_c}$$

$$\frac{1.2 \times 10^{11}}{2 \times 10^{11}} = \frac{\Delta l_s}{\Delta l_c}$$

$$0.6 = \frac{\Delta l_s}{\Delta l_c}$$

$$\therefore \quad \Delta l_s = 0.6\, \Delta l_c \quad \text{...... (iii)}$$

As total extension $= 0.003$ m

$$\therefore \quad \Delta l_s + \Delta l_c = 0.003$$

Putting value of Δl_s

$$\therefore \quad 0.6\, \Delta l_c + \Delta l_c = 0.003$$

$$1.6\, \Delta l_c = 0.003$$

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

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

Putting this value in eq. (iii)

$$\therefore \quad \Delta l_s = 0.6 \times 1.875 \times 10^{-3}$$

$$= 1.125 \times 10^{-3} \text{ m}$$

Now using

(a) $$\varepsilon_c = \frac{\Delta l_c}{l_c}$$

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

$$= 1.25 \times 10^{-3}$$

Now using

(b) $$\varepsilon_s = \frac{\Delta l_s}{l_s}$$

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

$$= 0.75 \times 10^{-3}$$

(c) For applied force

$$Y_c = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\frac{\Delta l_c}{l_1}}$$

$$Y_c = \frac{F}{A} \times \frac{l_1}{\Delta l_c}$$

$$F = Y_c \times \frac{A \times \Delta l_c}{l_1}$$

$$= \frac{1.2 \times 10^{11} \times 3.14 \times 10^{-6} \times 0.001875}{1.5}$$

$$= 4.77 \times 10^{2}\ \text{N}$$

$$F = 477\ \text{N}$$

Result

(a) Strain in copper wire $= \varepsilon_c = 1.25 \times 10^{-3}$

(b) Strain in steel wire $= \varepsilon_s = 0.75 \times 10^{-4}$

(c) Required force $= F = 477$ N