Unit 05 Solids and Fluid Dynamics

STUDENT'S LEARNING OUTCOMES (SLO's)

After studying this unit, the students will be able to:

- Distinguish between the structures of crystalline, amorphous, and polymeric solids.
- Describe that deformation of solids in one dimension [That it is caused by a force and that in one dimension, the deformation can be tensile or compressive.]
- Define and use the terms stress, strain and the Young's modulus
- Describe an experiment to determine the Young's modulus of a metal wire.
- Describe and use the terms elastic deformation, plastic deformation and elastic limit
- Justify why and apply the fact that the area under the force-extension graph represents the work done
- Determine the elastic potential energy of a material [That is deformed within its limit of proportionality from the area under the force-extension graph. Also state and use for a material deformed within its limit of proportionality]
- State and use Archimedes' principle and flotation
- Justify how ships are engineered to float in the sea
- Define and apply the terms: steady (streamline or laminar) flow, incompressible flow and non - viscous flow as applied to the motion of an ideal fluid.
- State and use equation of continuity to solve problems
- Explain that squeezing the end of a rubber pipe results in increase in flow velocity
- Justify that the equation of continuity is a form of the principle of conservation of mass.
- Justify that the pressure difference can arise from different rates of flow of a fluid [Bernoulli effect]
- Explain and apply Bernoulli's equation for horizontal and vertical fluid flow.
- Explain why real fluids are viscous fluids.
- Describe how viscous forces in a fluid cause a retarding force on an object moving through it.
- Describe super fluidity [As the state in which a liquid will experience zero viscosity. Students should know the implications of this state e.g. this allows for super fluids to creep over the walls of containers to
- 'empty' themselves. It also implies that if you stir a superfluid, the vortices will keep spinning indefinitely.]
- Analyze the real-world applications of the Bernoulli effect [For example, atomizers in perfume bottles, the swinging trajectory of a spinning cricket ball and the lift of a spinning golf ball (the Magnus effect), the use of Venture ducts in filter pumps and car engineers to adjust the flow of fluid, etc.]

5.1 CLASSIFICATION OF SOLIDS

Q1. What are crystalline solids? Describe their atomic arrangement.

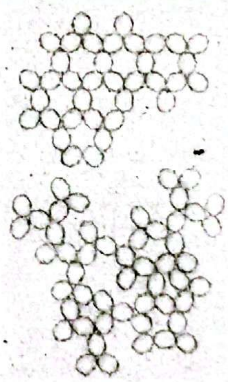
Ans. Crystalline Solids

Definition

Crystalline solids are materials in which the atoms, ions, or molecules are arranged in a highly ordered and repeating three dimensional pattern.

In crystalline solids, the orderly structure extends throughout the entire solid, giving it a definite geometric shape and specific physical properties.

For you information



Glassy and crystalline-solid short and long-range order.

Characteristics of Crystalline Solids

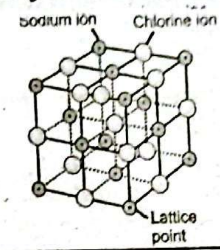
1. **Definite shape and volume**
   Due to the rigid and fixed arrangement of particles.
2. **Sharp melting point**
   They melt at a specific temperature.
3. **Anisotropy**
   Physical properties vary depending on the direction of measurement (e.g., electrical conductivity, refractive index).

4. **Long-range order**
The regular arrangement of particles extends over large distances.

Examples

(i) **Ionic crystals:** Sodium chloride (NaCl).
(ii) **Covalent crystals:** Diamond quartz (SiO_2)
(iii) **Metallic crystals:** Iron (Fe), Copper (Cu)
(iv) **Molecular crystals:** Ice, sugar.

For you information



NaCl crystal lattice

Q 2. What are amorphous solids? How are atoms arranged in them?

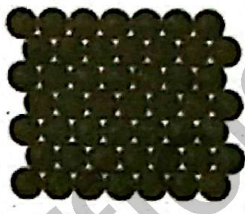
Ans. Amorphous Solids

Definition

Amorphous solids are solids in which the atoms, ions, or molecules are not arranged in a regular, repeating pattern.

Characteristics of Amorphous Solids

1. **No regular shape or regular structure**
Particles are randomly arranged.
2. **No sharp melting point**
They soften over a range of temperatures
3. **Isotropy**
Physical properties are the same in all directions.
4. **Short-range order**
Particles are ordered only over short distances.
Examples: Glass, plastic, rubber, pitch, amorphous silicon, etc.


Crystalline solids


Amorphous solids

Q 3. What are polymeric solids? Explain.

Ans. Polymeric Solids

Definition

Polymeric solids are solids made up of long chains of repeating units (monomers) connected by covalent bonds.

Characteristics of Polymeric Solids

1. **Made of large molecules (polymers)**
Repeating structure units
2. Held together by covalent bonds within chains and van der Waals forces or hydrogen bonds between chains.
3. **Can be amorphous or semi-crystalline**
Often lack perfect order, but some regions may be crystalline.
4. Low density and light weight.
5. **Good insulators**
Poor conductors of heat and electricity.
Examples: Polyethene, nylon, rubber.
Polymeric solids are widely used in packaging, textiles, automotive parts, electronics, and many other applications due to their versatility.

MCQ's

1. **Which one of the following is crystalline solid?**
(A) Zirconia ✓ (B) Glassy solid
(C) Natural rubber (D) Polystyrene
2. **A solid having regular arrangement of molecules throughout its structure is called:**
(A) Super solid (B) Perfect solid
(C) Plasma (D) Crystalline solid ✓
3. **What are the substances called which undergo plastic deformation until they break:**
(A) Brittle substances (B) Ductile substances ✓
(C) Amorphous solids (D) Polymeric solids

4. **Which one of the following is polymeric solid?**
(A) Glass (B) Nylon ✓
(C) Copper (D) Zinc

5. **The number of crystalline systems are:**
(A) Three (B) Five
(C) Seven ✓ (D) Fifteen

6. **The atoms, ions and molecules of crystalline materials maintain their long range order due to:**
(A) adhesive force (B) cohesive forces ✓
(C) electrostatic forces (D) Van der Waal's force

7. **In glass, molecules are irregularly arranged so it is also known as:**
(A) Liquid (B) Gas –liquid
(C) Solid liquid ✓ (D) Glass-liquid-glass

8. **Which one of the following is the example of crystalline solid?**
(A) Plastic (B) Glass
(C) Rubber (D) Zirconia ✓

9. **An example of crystallihe solids is:**
(A) Glass (B) Rubber
(C) Quartz ✓ (D) Plastic

10. **In a crystalline solid, the smallest repeating unit is called:**
(A) Lattice point (B) Unit cell ✓
(C) Crystalline face (D) Crystal grain

11. **Crystalline solids have:**
(A) No definite shape
(B) Irregular arrangement of particles
(C) Long-range order in particle arrangement ✓
(D) Amorphous structure

12. **An example of amorphous solids is:**
(A) Quartz (B) Sodium chloride
(C) Diamond (D) Glass ✓

13. **Amorphous solids are also known as:**
(A) Metallic solids (B) Supercooled liquids ✓
(C) Ionic solids (D) Polymeric solids

14. **A true statement for amorphous solids is:**
(A) They do not have sharp melting point.
(B) They are isotropic.
(C) They soften over a range of temperatures.
(D) They have long-range order. ✓

15. **Polymeric solids are made up of:**
(A) Metal atoms
(B) Ions arranged in a lattice
(C) Long chains of repeating units ✓
(D) Discrete molecules held by van der Waal's forces

16. **A natural polymeric solid is:**
(A) PVC (B) Nylon
(C) Teflon (D) Rubber ✓

5.2 MECHANICAL PROPERTIES OF SOLIDS

Q 4. What is meant by deformation of solids? Explain in detail.

Ans. Deformation of Solids

Definition

Deformation of solids is the change in shape or size of a solid material under the influence of external forces.

Explanation

If we hold a soft rubber ball in our hand and then squeeze it, the shape or volume of the ball will change. However, if we stop squeezing the ball, and open our hand, the ball will return to its original spherical shape. Fig. 1.

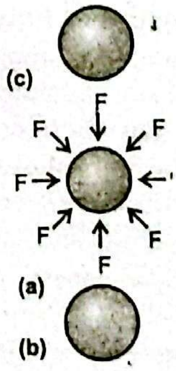
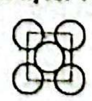


Fig. 1

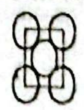
(a) Original rubber ball
(b) Squeezed rubber ball subjected force F by the hand
(c) Rubber ball after removing force

Similarly, if we hold two ends of a rubber string in our hands, and move our hands apart to some extent, the length of the string will increase under the action of the applied force exerted by our hands. Greater the applied force, larger will be the increase in length. Now on removing the applied force, the string will return to its original length. From these examples, it is concluded that deformation (i.e., change in shape, length or volume) is produced when a body is subjected to some external force.

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. Under the influence of external force, distortion occurs in the solid bodies because of the displacement of the atoms from their equilibrium position and the body is said to be in a state of stress. 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. Figure 2

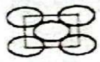


(a) Unstretched unit cell

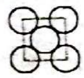


Illustrates deformation produced in a unit cell of a crystal subjected to an external applied force.

(b) Unit cell under outward stretching force



(c) Unit cell under inward applied force



(d) Unit cell after removing applied force

Fig. 2

Elasticity

Definition

The ability of the body to return to its original shape is called elasticity.

5.3 STRESS, STRAIN AND YOUNG'S MODULUS

5. Explain the following:

(i) Stress **(ii) Strain** **(iii) Young's modulus**

Ans. (i) Stress

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

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

Unit: The SI unit of stress (σ) is newton per square metre ($N\ m^{-2}$), or pascal (Pa).

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 a stress changes volume, it is called volume stress.

Shear Stress: When a stress changes the shape, it is called shear stress.

(ii) Strain

Definition

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".

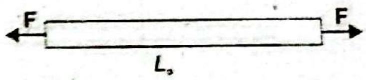


Fig. 3(a):Tensile strain

If ΔL is the change in length and L_o is the original length; Fig. 3(a), then strain is given by

$$\text{Strain } (\varepsilon) = \frac{\text{Change in length } (\Delta L)}{\text{Original length } (L_o)}$$

Unit: Since strain is the ratio of lengths, it is dimensionless and therefore, has no units.

Tensile Strain: If strain is due to tensile stress, it is called tensile strain.

Compressive Strain: If strain is produced as a result of compressive stress, it is termed as compressive strain.

Volumetric Strain: When the applied stress changes the volume, the change in volume per unit volume is known as volumetric strain.

From Fig. 3(b),

$$\text{Volumetric strain } (\varepsilon_v) = \frac{\Delta V}{V_o}$$

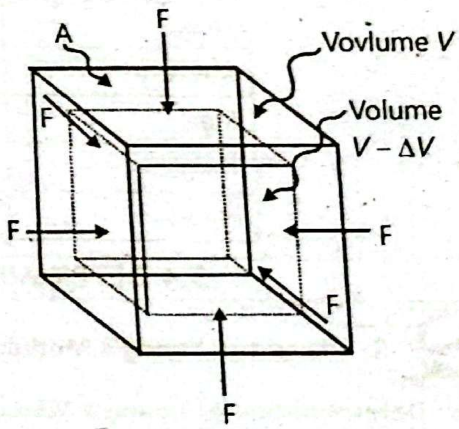


Fig. 3(b): Volumetric strain

Let y be the distance between two opposite faces of a rigid body, Fig. 3(c), which are subjected to shear stress one of its face slides through a distance Δx, then shear strain is produced which is given by

$$\text{Shear strain } (\gamma) = \frac{\Delta x}{y} = \tan\theta$$

However, for small value of angle θ, measured in radian $\tan\theta \cong \theta$, so that;

$$\gamma = \theta$$

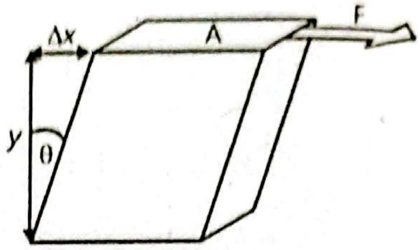


Fig. 3(c): Shear strain

(iii) Young's Modulus

Definition

The stress applied per unit strain is called Young's modulus

i.e., $$Y = \frac{\text{Tensile stress}}{\text{Tensile strain}}$$

$$Y = \frac{F/A}{\Delta L/L_o}$$

It has the same units as that of stress i.e., N m^{-2} or pascal (Pa).

The value of Young's modulus of different material is given in Table 5.1.

Table 1: Elastic constants for some materials

Material	Young's Modulus 10^9 N m^{-2}	Bulk Modulus 10^9 N m^{-2}	Shear Modulus 10^9 N m^{-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	6
Steel	200	160	84
Tungsten	390	200	150
Water	0	2.2	0

5.4 DETERMINATION OF YOUNG'S MODULUS OF A WIRE

Q6. How can Young's Modulus of a wire be determined? Explain.

Ans. Determination of Young's Modulus of a Wire

There are various methods to determine the Young's modulus of a wire. One of the method is **Searle's method.**

Experimentally, the magnitude of Young's modulus for a material in the form of wire can be found out mostly with the help of **Searle's apparatus**. It consists of two wires, reference wire and test wire of equal lengths of same material having same diameters attached to a rigid support. Both wires are connected to horizontal bars (frames F_1 and F_2) at the other ends. Hang a constant weight to the hook of horizontal bar of reference wire and hanger on test wire so that wire remains stretched and free from kinks.

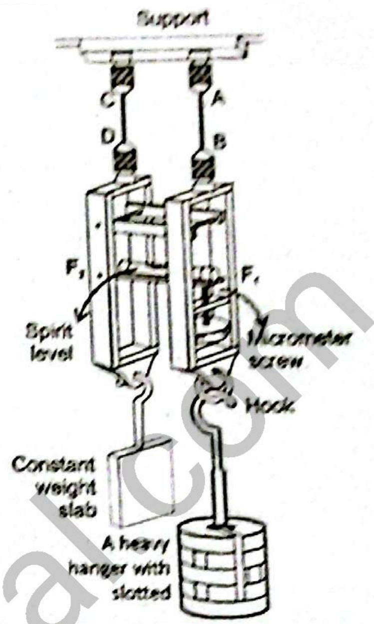


Fig. 4: Searle's apparatus

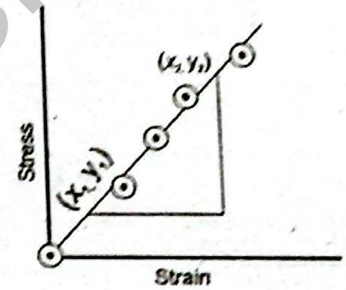
Procedure

1. Measure the initial length L_o of the wire using a metre scale.
2. Measure the diameter 'd' of the wire using a screw guage.
3. Adjust the spirit level so that it is in horizontal position by turning the micrometer. Record the micrometer reading to use it as the reference reading
4. Load the test wire with a further weight, the spirit level tilts due to elongation of the test wire.
5. Adjust the micrometer screw to restore the spirit level in the horizontal position. Subtract the first micrometer reading from the second micrometer reading to obtain the extension of the test wire.
6. Calculate stress and strain from the following formula:

$$\text{Stress} = \frac{\text{Weight}}{\text{Area of wire}} = \frac{F}{A} = \frac{mg}{\pi r^2}$$

$$\text{Strain} = \frac{\Delta L}{L_o} = \frac{\text{Change in length}}{\text{Original length}}$$

7. Repeat the above steps by increasing load on test wire to obtain more values of stresses and strains.
8. Plot the above values on stress strain graph, it should be straight line. Now determine the value of slope Y. The value of slope is equal to Young's modulus of the wire.



5.5 ELASTIC DEFORMATION, PLASTIC DEFORMATION AND ELASTIC LIMIT

Q 7. What is meant by elastic deformation, plastic deformation and elastic limit? Explain.

Ans. Elastic Deformation

Definition

It is the temporary change in the shape or size of a material when a force is applied, and the material returns to its original shape and size once the force is removed.

In a tensile test machine, metal wire is extended at a specified deformation rate, and stresses generated in the wire during deformation are continuously measured by a suitable electronic device fitted in the mechanical testing machine. Force-elongation diagram or stress-strain curve is plotted automatically on X-Y chart recorder. A typical stress-strain curve for a ductile material is shown in Fig. 5.

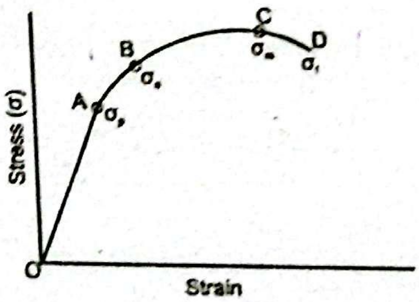


Fig. 5: Stress-strain curve of a typical ductile material.

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).

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

Hooke's law which states that the strain (deformation) is directly proportional to stress (force or load) is obeyed in the region OA. From A to B, stress and strain are not proportional.

Elastic limit

Definition

The elastic limit is the maximum stress or force per unit area that a material can with stand undergoing permanent deformation.

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 state. In the region OB, the material is said to be elastic. The point B is called the yield point. The value of stress at B is known as elastic limit σ_e.

Plastic Deformation

Definition

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, the point C in Fig. 5 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."

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

Q 8. What are ductile and brittle substances? Give examples.

Ans. Ductile substances

Definition

Substances which undergo plastic deformation until they break, are known as ductile substances.

For example, lead, copper and wrought iron are ductile substances.

Brittle Substances

Definition

The substances which break just after the elastic limit is reached, are known as brittle substances.

For example, glass and high carbon steel are brittle. Moreover, Beryllium, Bismuth, Chromium are also brittle metals.

Brain Teaser

A steel rod and a rubber band are subjected to a same force. Which one will be stretched more?

Ans. When a steel rod and a rubber band are subjected to the same force, the rubber band will be stretched much more than the steel rod.

The difference is due to their material properties, specially their elasticity.

mQ's

1. **Which of the following does not undergo plastic deformation?**
   (A) Copper (B) Wrought iron
   (C) Lead (D) Glass ✓
2. **Substances which undergo plastic deformation until they break are known as:**
   (A) Brittle substance
   (B) Ductile substance ✓
   (C) Non-magnetic substance
   (D) Magnetic substance
3. **The Young's modulus of steel is:**
   (A) 2×10^{11} Nm^{-2} ✓ (B) 3.9×10^{-9} Nm^{-2}
   (C) 2×10^9 Nm^{-2} (D) 1.5×10^9 Nm^{-2}
4. **Glass and high carbon steel are examples of:**
   (A) Ductile substance (B) Brittle substance ✓
   (C) Soft substances (D) Hard substances
5. **If stress is increased beyond the elastic limit of material, it becomes permanently changed; this behaviour of material is called:**
   (A) Elasticity (B) Plasticity ✓
   (C) Yield strength (D) Ultimate tensile strength
6. **Which pair of quantities has same dimensions?**
   (A) Stress, power
   (B) Pressure, bulk modulus ✓
   (C) Stress, stain (D) Strain, strain energy
7. **Example of ductile substance is:**
   (A) Glass (B) Wood
   (C) Lead ✓ (D) Oxygen
8. **SI unit of modulus of elasticity is:**
   (A) coulomb (B) volt
   (C) pascal (Nm^{-2}) ✓ (D) ampere
9. **Young's modulus for water is:**
   (A) Zero ✓ (B) 1
   (C) 2 (D) 3
10. **The SI unit of stress is same as that of:**
    (A) Pressure ✓ (B) Force
    (C) Momentum (D) Work

11. **Reciprocal of bulk modulus is:**
(A) Elasticity
(B) Young modulus
(C) Compressibility ✓
(D) Shear modulus

12. **Substance which break just after the elastic limit is reached are called:**
(A) Ductile substance
(B) Hard substances
(C) Soft substances
(D) Brittle substances ✓

13. **A wire is stretched by a force F which produces an extension l. The energy stored in the wire is:**
(A) $F l$
(B) $\frac{1}{2} F l$
(C) $2F l$
(D) $F l^2$ ✓

14. **Dimensions of strain are:**
(A) L^2
(B) L^{-2}
(C) $ML^{-1}T^{-2}$
(D) No dimensions ✓

15. **Young's modulus of lead is:**
(A) $1.5 \times 10^{19}\ Nm^{-1}$ ✓
(B) $7.7 \times 10^9\ Nm^{-2}$
(C) $5.6 \times 10^9\ Nm^{-2}$
(D) $2.2 \times 10^8\ Nm^{-2}$

16. **In cubical crystal, all sides meet at:**
(A) Acute angle
(B) Abtuse angle
(C) Right angle ✓
(D) 45°

17. **The crystalline structure of NaCl is:**
(A) Tetragonal
(B) Cubical ✓
(C) Hexagonal
(D) Trigonal

18. **Young's modulus is the ratio of:**
(A) Strain to stress
(B) Stress to strain ✓
(C) Force to displacement
(D) Load to extension

19. **If the length of wire becomes double under a given force, the strain is:**
(A) Halved
(B) Doubled ✓
(C) Unchanged
(D) Zero

20. **A material with high Young's modulus is:**
(A) Easily stretched
(B) Highly elastic
(C) Soft and ductile
(D) very stiff and resists deformation ✓

21. **A material obeys Hooke's law only within its:**
(A) Breaking point
(B) Yield point
(C) Elastic limit ✓
(D) Plastic region

22. **Strain is defined as:**
(A) Change in length / Original length ✓
(B) Change in volume / Original volume
(C) Force / Change in length
(D) Original length / Change in length

Example 5.1: A steel wire 12 mm in diameter is fastened to a log and is then pulled by a tractor. The length of steel wire between the log and the tractor is 11 m. A force of 10,000 N is required to pull the log. Calculate: (a) the stress and strain in the wire. (b) how much does the wire stretch when the log is pulled? ($E = 200 \times 10^9\ N\ m^{-2}$)

Solution:

Given that;

$D = 12\ mm = 12 \times 10^{-6}\ m$

$r = 6 \times 10^{-3}\ m$

$F = 10,000\ N$

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

$L_o = 11\ m$

To Find:

$\Delta L = ?$

Calculations:

(a) Tensile stress $\sigma = \frac{F}{A} = \frac{10,000\ N}{3.14\ (6 \times 10^{-3}\ m)^2}$

$= 88.46 \times 10^6\ N\ ms^{-2}$

Tensile strain $\varepsilon = \frac{\Delta L}{L_o}$, also

$E = \frac{Stress}{Strain} = \frac{88.46 \times 10^6\ N\ m^{-2}}{Strain}$

$= 200 \times 10^9\ N\ m^{-2}$

$Strain = \frac{88.46 \times 10^6\ N\ m^{-2}}{200 \times 10^9\ N\ m^{-2}}$

$= 4.4 \times 10^{-4}$

(b) Using the relation; Strain $\frac{\Delta L}{L_o}$ or

$\Delta L = Strain \times L_o = 4.4 \times 10^{-4} \times 11\ m = 4.84 \times 10^{-3}\ m$ **Ans.**

Brain Teaser

Why does a ship made of heavy steel float on water, while a small rock sink?

Ans. A ship made of heavy steel floats on water while a small rock sinks because of the principle called buoyancy, which is explained by Archemedes' principle.

Reason

- A steel ship floats because it is shaped to displace a large volume of water. Even though steel is heavy, the ship's shape includes a lot of empty space (air), making its average density less than water. So, the upward buoyant force is enough to keep it float.
- A small rock sinks because it is solid and dense, and displaces very little water relative to its weight. Its density is greater than that of water, so the buoyant force is not enough to keep it up, and it sinks.

5.6 STRAIN ENERGY IN DEFORMED MATERIALS

Q 9. What is meant by strain energy? Derive an expression for energy stored in a stretched material.

Ans. Strain Energy

Definition

Strain energy is the energy stored in a material when it is deformed under stress within the elastic limit. This energy comes from the work done to change the shape or size of the material.

Expression for Energy Stored in a Stretched Material

Consider a material in the form of a spring; Fig. 6. It is stretched by a force F through extension x. As the extension is directly proportional to the stretching force within the elastic limit, therefore, the force increases uniformly from zero to F as shown in Fig. 5.7. Thus, the average force that stretches the spring through distance x is $1/2F$.

Hence work done by the stretching force will be given as:

Work done = Average force × Distance in the direction of the force

or $$W = \frac{1}{2} F \times x$$

From Hooke's law;

$$F = k(x)$$

Therefore $$W = \left(\frac{1}{2} kx\right).(x) = \frac{1}{2} kx^2$$

or $$W = \text{Area of OPQ}$$

The work done by the stretching force is stored in the spring as its strained energy and is equal to the potential energy stored in its molecules.

$$\text{Strain energy stored in the body} = E = \frac{1}{2} F.x = \frac{1}{2} kx^2$$

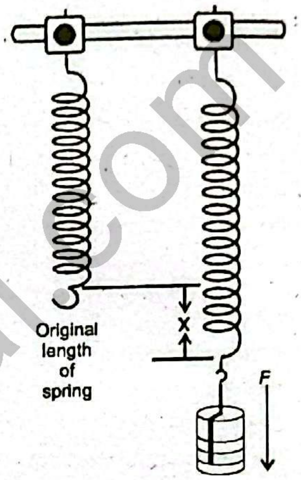


Fig. 6

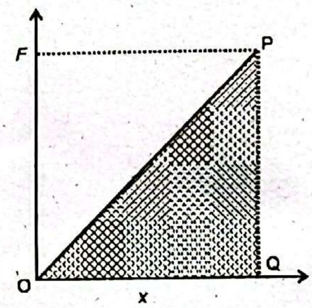


Fig. 7

> **For you information**
>
> The amount of work done in stretching a material is equal to the average force applied multiplied by the distance moved.
> Therefore, the area under a force-extension graph represents the work done to stretch the material. Work done to stretch the material is also equal to elastic P.E. stored in the material.

mCQ's

1. **The strain energy is the energy:**
   (A) Stored in a body due to motion
   (B) Dissipated energy in a vibrating body
   (C) Stored in a body due to deformation ✓
   (D) Lost due to heat generation

2. **Which of the following materials would typically store more strain energy before failure?**
   (A) Brittle materials (B) Ductile materials ✓
   (C) Rigid bodies (D) Fluids

3. **The strain energy in a deformed body is associated with:**
   (A) Permanent deformation (B) Plastic deformation
   (C) Elastic deformation ✓ (D) Fracture energy

4. **Strain energy is recoverable in:**
   (A) Elastic deformation ✓ (B) Plastic deformation
   (C) Creep (D) Fatigue

5. **What happens when a material is deformed beyond its elastic limit?**
   (A) It returns to its original shape completely
   (B) It undergoes plastic deformation ✓
   (C) It becomes stronger
   (D) It melts.

6. **The elastic deformation is a:**
   (A) Permanent change in the shape of a material
   (B) Temporary deformation that disappears when stress is removed ✓
   (C) Fracturing of a material under high stress
   (D) Phase change in the material's crystal structure

7. **Which statement is true about plastic deformation?**
   (A) It is always reversible
   (B) It occurs before elastic deformation
   (C) It is a permanent change in shape ✓
   (D) It only happens at very low temperature

8. Which material is most likely to exhibit elastic deformation only under small loads?
(A) Rubber ✓
(B) Plastic
(C) Mild steel
(D) Glass

9. The point on a stress-strain curve where plastic deformation begins is called:
(A) Breaking point
(B) Proportional limit
(C) Fracture point
(D) Yield point ✓

10. which type of deformation occurs only within the elastic limit of a material?
(A) Plastic
(B) Ductile
(C) Elastic ✓
(D) Brittle

11. The elastic limit is associated with which law?
(A) Pascal's law
(B) Hooke's law ✓
(C) Newton's 3rd law
(D) Boyle's law

12. The unit of elastic limit is the same as:
(A) Strain
(B) Stress ✓
(C) Force
(D) Density

13. When stress exceeds the elastic limit, the material enters the:
(A) Brittle zone
(B) Proportional limit
(C) Plastic region ✓
(D) Elastic zone

14. The material which has high elastic limit:
(A) Steel ✓
(B) Rubber
(C) Glass
(D) Copper

5.7 ARCHIMEDES' PRINCIPLE AND FLOATATION

Q 10. What is Archimedes' principle? Explain in detail for finding upthrust.

Ans. Archimedes' Principle

Statement

When an object is totally or partially immersed in a liquid, an upthrust act on it equal to the weight of the fluid it displaces.

Floatation

The phenomenon by which an object immersed in a fluid is capable to stay at the surface to rise within the fluid due to the upward force exerted by the fluid is known as floatation.

An air-filled balloon immediately shoots up to the surface when released under the surface of water. The same would happen if a piece of wood is released under water. We might have noticed that a mug filled with water feels light under water but feels heavy as soon as we take it out of water.

Archimedes noticed that there is an upward force which acts on an object which is kept inside a liquid. As a result, an apparent reduction in weight of the object is observed. This upward force acting on the object is called the upthrust of the liquid. Archimedes' principle states that:

Explanation

Consider a solid cylinder of cross-sectional area A and height h immersed in a liquid; Fig. 8. Let h_1 and h_2 be the depths of the top and bottom faces of the cylinder respectively from the surface of the liquid. Then

$$h_1 - h_1 = h$$

If P_1 and P_2 are the liquid pressures at depths h_1 and h_2 respectively and ρ is its density, then using equation $P = \rho gh$ of liquid pressure at height h:

$$P_1 = \rho gh_1$$

and $$P_2 = \rho gh_2$$

Let the force F_1 be exerted at the top of cylinder by the liquid due to pressure P_1 and the force F_2 be exerted at the bottom of the cylinder by the liquid due to P_2,

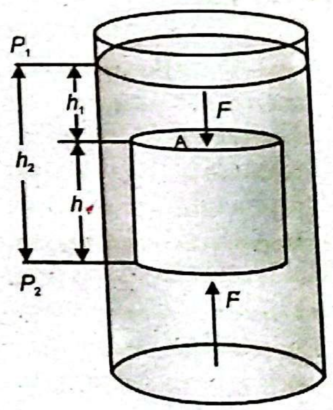


Fig. 8: Upthrust on a body immersed in a liquid is equal to the weight of the liquid displaced.

Then $$F_1 = P_1 A = \rho gh_1 A$$

and $$F_2 = P_2 A = \rho gh_2 A$$

F_1 and F_2 are the forces acting on the opposite faces of the cylinder. Therefore, the net force F will be equal to the difference of these forces. **This net force F on the cylinder is called the upthrust of the liquid.**

Hence $$F_2 - F_1 = \rho gh_2 A - \rho gh_1 A$$

$$= \rho g A (h_2 - h_1)$$

or $$\text{Upthrust of liquid} = \rho g Ah$$

$$\text{Upthrust} = \rho g A$$

Here Ah is the volume V of the cylinder and is equal to the volume of the liquid displaced by the cylinder, therefore, ρgV is the weight of the liquid displaced. This equation shows that an upthrust acts on a body immersed in a liquid and is equal to the weight of liquid displaced, which is Archimedes' principle.

Example 5.2: A wooden cube of sides 10 cm each has been dipped completely in water. Calculate the upthurst of water acting on it.

Solution

Given that;

Length of side $L = 10\ cm = 0.1\ m$

Volume $V = L^3 = (0.1\ m)^3 = 1 \times 10^{-3}\ m^3$

Density of water $\rho = 1000\ kg\ m^{-3}$

To Find:

Upthrust $F = ?$

Calculations:

Using Archimede's principle

Upthrust of water $= \rho gV$

Putting the values

$= 1000\ kg\ m^{-3} \times 9.8\ m\ s^{-2} \times 1 \times 10^{-3}\ m^3 = 9.8\ N$ **Ans.**

Thus, upthrust of water acting on the wooden cube is 9.8 N.

11. State the principle of "floatation". Enlist some applications of Archimedes' principle in our daily life.

Ans. Floatation

An object sinks into a fluid if its weight is greater than the upthrust acting on it. However, an object floats if its weight is equal or less than the upthrust. When an object floats in a fluid, the upthrust acting on it is equal to the weight of the object. In case of floating object, the object may be partially immersed. The upthrust is always equal to the weight of the fluid displaced by the object. This is the principle of floatation. It states that:

A floating object displaces a fluid having weight equal to the weight of the object.

Applications

Following are some important applications of Archimedes' principle.

1. **Hot-air balloon**

   The reason why hot-air balloons; Fig. 9 rise and float in mid-air is because of the density of the hot-air balloon is less than the surrounding air. When the upthrust of the surrounded air is more, it starts to rise. This is done by varying the quantity of hot air in the balloon.

Fig. 9

2. **Wooden block floating on water**

   A wooden block floats on water. It is because the weight of an equal volume of water is greater than the weight of the block. According to the principle of floatation, a body floats if its displaced water is equal to the weight of the body when it is partially or completely immersed in water.

3. **Ships and boats**

   Ships and boats are designed on the same principle of floatation. They carry passengers and goods over water. It would sink in water if its total weight becomes greater than the upthrust of water

Fig. 10 (a): A ship floating over water

4. **Submarine**

   A submarine can travel over as well as under water using the same principle of floatation.

   It floats over water when the weight of water equal to its volume is greater than its weight. Under this condition, it is similar to a ship and remains partially above water level. It has a system of tanks which can be filled with and emptied from seawater. When these tanks are filled with seawater, the weight of the submarine increases. As soon as its weight becomes greater than the upthrust, it dives into water and remains under water. To come up on the surface, the tanks are made empty from seawater.

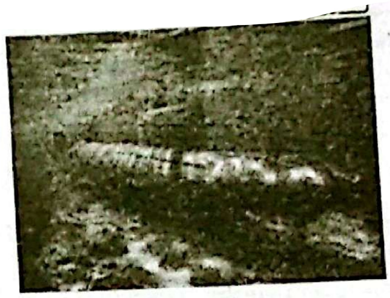


Fig. 10 (b):submarine

Example 5.3: An empty meteorological balloon weighs 80 N. It is filled with 10 cubic metres of hydrogen. How much maximum contents the balloon can lift besides its own weight? The density of hydrogen is 0.09 kg m^{-3} and the density of air is 1.3 kg m^{-3}.

Solution:

Given that;

Weight of the balloon $w = 80\ N$

Volume of hydrogen $V = 10\ m^3$

Density of hydrogen $\rho_1 = 0.09\ kg\ m^{-3}$

Density of air $\rho_2 = 1.3\ kg\ m^{-3}$

To Find:

Weight of hydrogen $w_1 = ?$

Weight of the contents $w_2 = ?$

Calculations:

Upthrust F = Weight of air displaced

$= \rho_2 gV$

$= 1.3\ kg\ m^{-3} \times 9.8\ m\ s^{-2} \times 10\ m^3$

$= 127.4\ N$

Weight of hydrogen $w_1 = \rho_1 Vg$

$= 0.09\ kg\ m^{-3} \times 10\ m^3 \times 9.8\ ms^{-2}$

$= 8.82\ N$ **Ans.**

Total weight lifted $F = w + w_1 + w_2$

To lift the contents, the total weight of the balloon should not exceed F.

Thus $w + w_1 + w_2 = F$

$80\ N + 8.82\ N + w_3 = 127.4\ N$

or $w_2 = 38.58\ N$ **Ans.**

Thus, the maximum weight of 38.58 N can be lifted by the balloon in addition to its own weight.

mCQ's

1. **The buoyant force on a submerged object is equal to the:**
   (A) Weight of the object (B) Volume of the object
   (C) Weight of the displaced fluid ✓
   (D) Density of the fluid

2. **When an object floats on water, the buoyant force is:**
   (A) Less than weight of the object
   (B) Equal to weight of the object ✓
   (C) Greater than weight of the object
   (D) Zero

3. **Archemedes' principle is used to determine the:**
   (A) Speed of a fluid (B) Temperature of water
   (C) Refractive index of water
   (D) Relative density of a solid or liquid ✓

4. **If a stone is immersed in water, its apparent weight:**
   (A) Increases (B) Decreases ✓
   (C) Becomes zero (D) remains the same

5. **A floating body displaces fluid equal to:**
   (A) Its own weight ✓ (B) Its own volume
   (C) Twice its own volume (D) The density of the fluid

6. **The quantity that affects the buoyant force acting on a body is:**
(A) Volume of the fluid
(B) Density of the fluid
(C) Acceleration due to gravity
(D) All of these ✓

7. **An object sinks in a fluid if its:**
(A) Density is less than that of the fluid
(B) Density is equal to the fluid
(C) Density is greater than that of the fluid ✓
(D) Volume is more than that of the fluid

8. **The principle of floatation is based on:**
(A) Newton's 3rd law (B) Archimedes' principle ✓
(C) Bernoulli's principle (D) Pascal's law

9. **When a floating body is slightly pushed down into the water and released, it will:**
(A) Sink
(B) Oscillate about its mean position ✓
(C) Stay where it was pushed
(D) Jump out of water

10. **The upthrust acting on a floating object is equal to:**
(A) Volume of the object (B) Density of the fluid
(C) Weight of the object ✓
(D) Volume of water displaced

11. **Which of the following changes will not affect whether an object floats or sinks?**
(A) Shape of the object (B) Density of the object
(C) Density of the fluid (D) Mass of the fluid ✓

12. **A submarine can float or sink because it changes:**
(A) Its shape (B) Its volume
(C) Its density ✓ (D) The water density

5.8 STEADY, NON-VISCOUS AND IDEAL FLUID

Q 12. Differentiate between streamline flow and turbulent flow.

Ans. Streamline or Laminar Flow

Definition

If every particle that passes a particular point, moves along exactly the same path, as followed by particles which passed that points earlier, the flow is said to be streamline or laminar flow.

In a steady flow of a fluid, the motion of the particles is smooth and regular; Fig. 11. The smooth path followed by fluid particles in laminar flow is called a streamline. The streamline may be the straight or curved and tangent to any point gives the direction of flow of a fluid. The different streamlines cannot cross each other.

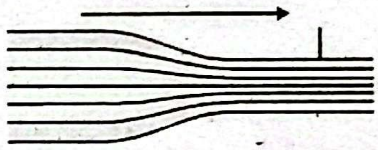


Fig. 11: Streamlines (laminar flow)

Explanation

A fluid flowing in a pipe; Fig. 12 will have certain velocity v at P, a velocity v_2 at Q and so on. If the velocity of a particle of the fluid at P, Q and R does not change with the passage of time, then the flow is said to be steady flow or streamline flow.

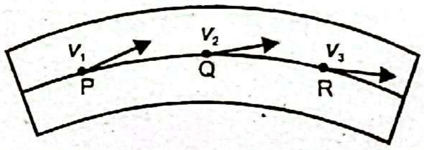


Fig. 12: The velocities of the particles at different points on streamline.

The line PQR which represents the path followed by the particle is called a streamline. It represents the fixed path followed by orderly processing particles. In streamline flow, all the particles passing through P also pass through Q and R. It means that two streamlines cannot cross each other.

Turbulent Flow

Definition

The irregular or unsteady flow of the fluid is called turbulent flow.

Explanation

Above a certain velocity of the fluid flow, the motion of the fluid becomes unsteady and irregular. Under this condition, the velocity of the fluid changes abruptly; Fig. 13. In this case, the exact path of the particles cannot be considered.

If two streamlines cross each other, then the particles will go in one or in the other directions and flow will not be a steady flow. Such a flow is a turbulent flow. When the flow is unsteady or turbulent, there are eddies and whirlpools in the motion and the paths of the particles are continuously changing.

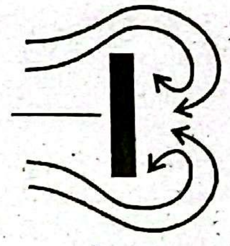


Fig. 13: Turbulent flow

Q 13. What do you know about an ideal fluid, non-viscous fluid and steady flow?

Ans. Ideal Fluid

The behaviour of the fluid which satisfies the following conditions is called ideal fluid:

1. **Non-viscous:** The fluid is non-viscous i.e., there is no frictional force between adjacent layers of the fluid.
2. **Incompressible:** The fluid is incompressible i.e., its density is constant.
3. **Steady:** The fluid motion is steady.
4. **No heat conduction:** It does not exchange heat with its surroundings.
5. **Irrotational:** The flow has no vorticity (in many ideal cases).

Steady Flow

Definition

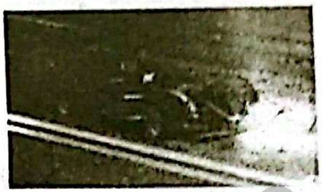
It is a type of fluid flow in which the fluid's velocity at a given point does not change with time.

Non-Viscous Fluid

Definition

A fluid with no viscosity (no internal resistance) to the movement of fluid layers is known as non-viscous fluid.

For your information



Formula One racing cars have a streamlined design.

Dolphins have streamlined bodies to assist movement in water.

Q 14. What is meant by rate of flow of a fluid? Derive a formula for the rate of flow.

Ans. Rate of Flow

Definition

The rate of flow of a fluid through a pipe is the volume of the fluid passing through any section of pipe per unit time.

Formula For Rate of Flow

Consider a fluid flowing through a pipe of area of cross-section A; Fig. 14. Let the velocity of the fluid be v and it flows through the pipe for time t, then the distance covered by the fluid in time is:

$$l = v\,t$$

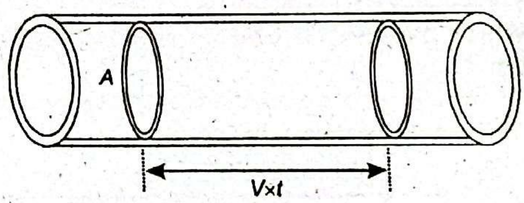


Fig. 14: Rate off flow of a liquid

where l is the length of the pipe through which the fluid passes in time t. Volume of the fluid passing through the pipe in time t, is:

$$A \times l = Avt$$

Thus The rate of flow of the liquid $= \dfrac{\text{Volume}}{\text{Time}}$

$$= \frac{Avt}{t} = Av$$

$$\text{Rage of flow} = Av \qquad \text{......... (i)}$$

Unit: The SI unit of rate of flow is cubic metre per second ($m^3\,s^{-1}$). Sometimes, it is also measured in litres per second (Ls^{-1}).

Steady Flow

Definition

If the overall flow pattern does not change with time, the flow is called steady flow.

In steady flow, every particle of the fluid follows the same flow line as its previous particle.

MCQ's

1. **A steady flow means that:**
(A) The fluid is at rest
(B) The velocity of fluid particle at a point does not change with time✓
(C) The fluid has constant density
(D) The fluid has no viscosity

2. **An ideal fluid is one that:**
(A) Has high viscosity
(B) Is incompressible and non-viscous✓
(C) Has uniform density
(D) Has zero surface tension

3. **Which of the following is not a property of an ideal fluid?**
(A) Incompressibility (B) Zero viscosity
(C) Constant temperature✓
(D) Irrational flow

4. **In a non-viscous fluid:**
(A) No internal friction exists✓
(B) Density varies with pressure
(C) Turbulent flow is common
(D) The flow is always unsteady

5. **Bernoulli's equation is applicable to:**
(A) Viscous fluids only
(B) Compressible and unsteady fluids
(C) Fluids at rest only
(D) Steady, ideal, incompressible flows✓

6. **Which statement is true for an ideal fluid in steady flow?**
(A) There is no loss of mechanical energy✓
(B) The flow is always turbulent
(C) It obeys Pascal's law only
(D) It has surface tension

7. **In steady flow, the streamlines:**
(A) Cross each other frequently
(B) Repeat the direction of flow at that instant✓
(C) Indicate random motion
(D) Represent pressure gradient

8. **A fluid with zero viscosity will:**
(A) Have no density (B) Not flow at all
(C) Experience no drag or friction✓
(D) Always be turbulent

9. **The assumption of zero viscosity is valid for:**
(A) Ideal fluids only✓ (B) Real gases
(C) All liquids (D) High-pressure steam

10. **In a steady flow of an ideal fluid, the streamlines:**
(A) Intersect each other
(B) Show random paths
(C) Area parallel and do not cross✓
(D) Form closed loops

11. **In an ideal fluid, energy loss due to internal frictio is:**
(A) Zero✓ (B) Maximum
(C) Constant (D) Unpredictable

12. **A real fluid differs from an ideal fluid because a rea fluid:**
(A) Has viscosity✓ (B) Has no density
(C) Is perfect elastic (D) Is incompressible

13. **In steady flow of a non-viscous ideal fluid, pressure is lower where:**
(A) Velocity is slower (B) Velocity is higher✓
(C) Altitude is higher (D) Temperature is higher

5.9 EQUATION OF CONTINUITY

Q 15. State and derived equation of continuity.

Or Justify that mass remains conserved when a fluid flows through a pipe.

Ans. Equation of Continuity

Statement

The product of cross-sectional area of the pipe and the fluid speed (i.e., *Av*) at any point along the pipe is a constant. This constant is equal to the volume flow per second of the fluid or simply the flow rate.

Thus $$Av = \text{Constant} = \frac{\text{Volume}}{\text{Time}}$$

Derivation of Equation of Continuity

Consider a fluid flowing through a pipe of non-uniform size.

The particles in the fluid move along the same lines in a steady state flow; Fig 15.

If we consider the flow for a short interval of time Δt, the fluid at the lower end of the tube covers a distance Δx_1 with a velocity v_1, then distance covered by the fluid is:

$$\Delta x_1 = v_1 \Delta t \quad \text{......(i)}$$

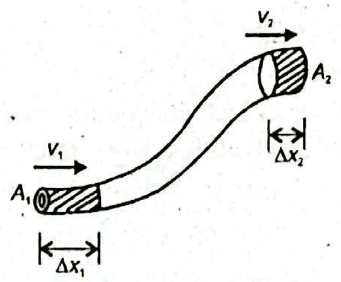


Fig. 15: Steady flow of a fluid

Let A_1 be the area of cross-section of the lower end, then volume of the fluid that flows into the tube at A_1 is:

$$V = A_1 \Delta x_1$$

or

$$V = A_1 v_1 \Delta t$$

If ρ_1 is the density of the fluid, then the mass of the fluid contained in the shaded region (through A_1) is:

$$\Delta m_1 = \text{Volume} \times \text{Density}$$

or

$$\Delta m_1 = A_1 v_1 \Delta t \times \rho_1$$

Similarly, the mass of the fluid that moves with velocity v_2 through the upper end of the pipe having cross-sectional area A_2 in the same time Δt is given by

$$\Delta m_2 = A_2 v_2 \Delta t \times \rho_2$$

where ρ_2 is the density of the fluid flowing out through A_2 and m_2 indicates small mass.

If the fluid is incompressible and the flow is steady, the mass of the fluid is conserved. That is the mass flowing into the bottom of the pipe through A_1 in a time Δt must be equal to the fluid flowing out though A_2 in the same time. Therefore,

$$\Delta m_1 = \Delta m_2$$

So

$$A_1 v_1 \Delta t \times \rho_1 = A_2 v_2 \Delta t \times \rho_2 \quad \text{...... (ii)}$$

or

$$A_1 v_1 \rho_1 = A_2 v_2 \rho_2 \quad \text{...... (iii)}$$

Equation (iii) is called the equation of continuity. Since density is constant for the steady flow of incompressible fluid, therefore, the equation of continuity becomes:

$$A_1 v_1 = A_2 v_2 \quad \text{...... (iv)}$$

Equation (iv) states that in steady flow, the rate of flow of the fluid inward is equal to the rate of flow of the fluid outward.

This equation justifies the conservation of mass of the fluid which is flowing through a pipe.

Example 5.4: A water hose with an internal diameter of 20 mm at the outlet discharge 30 kg of water in 60 s. Calculate the water speed at the outlet. Assume the density of water is 1000 kg m^{-3} and its flow is steady.

Internal diameter of water hose D = 20 mm = 0.02 m

Solution:

Given that;

Radius $r = \frac{D}{2} = \frac{0.02\text{ m}}{2} = 0.01\text{ m}$

Mass of water $m = 30\text{ kg}$

Time taken $t = 60\text{ s}$

Density of water $\rho = 1000\text{ kg m}^{-3}$

To Find:

Speed of water $v = ?$

Calculations:

Mass flow per second $m/t = 30\text{ kg} / 60\text{ s}$

$= 0.5\text{ kg s}^{-1}$

Cross-sectional area $A = \pi r^2$

$= 3.14 \times (0.01\text{ m})^2$

$= 3.14 \times 10^{-4}\text{ m}^2$

From equation of continuity, the mass of water discharging per second through area A is:

$$\rho A v = \text{Mass / Second}$$

$$v = \frac{\text{Mass / Second}}{\rho A}$$

$$v = \frac{0.5\text{ kg s}^{-1}}{1000\text{ kg m}^{-3} \times 3.14 \times 10^{-4}\text{ m}^2}$$

$v = 1.6\text{ m s}^{-1}$ **Ans.**

Tidbits

As the water falls, its speed increases and so its cross sectional area decreases as mandated by the continuity equation.

For Your Information

The equation of continuity is applied to:

(i) blood flow in arteries and veins

(ii) water flow in rivers and pipes

(iii) air flow in duct and ventilation systems.

5.10 INCREASE IN FLOW VELOCITY

16. How can we increase flow velocity?

Ans. Increase in Flow Velocity

We can increase the flow velocity of water in a rubber pipe by squeezing it. When we squeeze the rubber pipe, we decrease the cross-sectional area through which the water flows. According to the equation of continuity,

$$A_1v_1 = A_2v_2$$

where A is the cross-sectional area and v is the flow velocity. By decreasing the cross- sectional area ($A_2 < A_1$), the velocity of the water (v_2) must increase to maintain the same flow rate. Therefore, squeezing the rubber pipe increases the flow velocity of fluid.

5.11 BERNOULLI'S EQUATION

17. State and prove Bernoulli's equation.

Ans. Bernoulli's Equation

Statement

The sum of pressure, *K.E.* per unit volume and *P.E.* per unit volume of an ideal fluid throughout its steady flow remains constant.

As the fluid moves through a pipe of varying cross- section and height, the pressure will change along the pipe. Bernoulli's equation is the fundamental equation in fluid dynamics that relates pressure to fluid speed and height.

Derivation of Bernoulli's Equation

In deriving Bernoulli's equation, we assume that the fluid is incompressible, non-viscous and flows in a steady state manner.

Let us consider the flow of the fluid through the pipe in time t; Fig. 16.

The force on the upper end of the fluid is P_1A_1 where P_1 is the pressure and A_1 is the area of cross-section at the upper end. The work done on the fluid, by the fluid behind it, in moving it through a distance Δx_1, will be:

$$W_1 = F_1\Delta x_1 = P_1A_1\Delta x_1$$

Similarly, the work done on the fluid at the lower end is:

$$W_2 = -F_2\Delta x_2 = -P_2A_2\Delta x_2$$

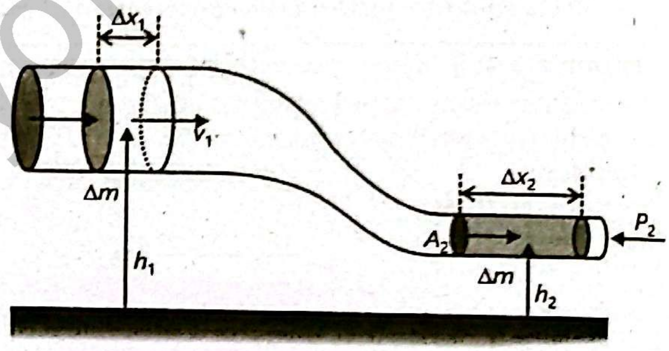


Fig. 16: An ideal flow off fluid through a non-uniform cross-section pip at different heights.

where P_2 is the pressure, A_2 is the area of cross-section of lower end and Δx_2 is the distance moved by the fluid in same time interval t. The work W_2 is taken to be –ve as this work is done against the fluid force. The net work done will be:

$$W = W_1 + W_2$$

$$W = P_1A_1\Delta x_1 - P_2A_2\Delta x_2 \qquad \text{...... (i)}$$

If v_1 and v_2 are the velocities at the upper and lower ends respectively, then

$$W = P_1A_1v_1t - P_2A_2v_2t$$

From equation of continuity;

$$A_1v_1 = A_2v_2$$

Hence $\quad A_1v_1\,t = A_2v_2\,t = V$ (volume)

So $\quad W = (P_1 - P_2)\,V \qquad \text{...... (ii)}$

If m is the mass and ρ is the density, then $V = \dfrac{m}{\rho}$. So, Eq. (ii) becomes:

$$W = (P_1 - P_2)\frac{m}{\rho} \quad \text{...... (iii)}$$

A part of this work is utilized by the fluid in changing its K.E. and a part is used in changing its gravitational P.E.

$$\text{Change in K.E.} = \Delta\text{K.E.} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \quad \text{...... (iv)}$$

$$\text{Change in P.E.} = \Delta\text{P.E.} = mgh_2 - mgh_1 \quad \text{...... (v)}$$

where h_1 and h_2 are the heights of the upper and lower ends respectively.

Applying the law of conservation of energy to this volume of the fluid, we have

$$(P_1 - P_2)\frac{m}{\rho} = \frac{1}{2}m_2^2 - \frac{1}{2}mv_1^2 + mgh_2 - mgh_1 \quad \text{...... (vi)}$$

Rearranging Eq. (vi), we have

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$$

This is Bernoulli's equation and is often expressed as:

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

Brain Teaser

How does the shape of a curv[e]ball in baseball relate to Bernoulli's principle?

Ans. The shape and movement of a curveball in baseball are closely related to Bernoulli's principle, which helps to explain how air pressure differences create lift or movement in a spinning object. The curveball curves because its spinning motion alters air pressure around the ball via Bernoulli's principle, causing it to move in the direction of low pressure-downward and often sideways, depending on the pitcher's grip and release.

5.12 USES OF BERNOULLI'S EQUATION

18. Give some practical applications or uses of Bernoulli's equation.

Ans. Uses of Bernoulli's Equation

A number of devices operate by means of pressure difference that results from changes in the speed of the fluid.

1. Aeroplane Wings

Uplifting of an aeroplane is due to the designing of its wings, which deflect the air so that streamlines are closer together above the wing than below it; Fig. 17. We have seen that where the streamlines are forced closer together, the speed is faster.

Thus, air is travelling faster on the upper side of the wing than on the lower. The pressure will be lower at the top of the wing, and the wing will be forced upward and the lift of an aeroplane is due to this effect.

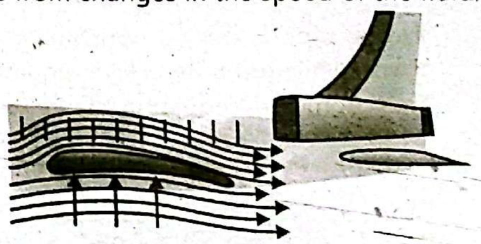


Fig. 17: Lift of an aeroplane

2. Swing of a Ball

When a ball is thrown or kicked with spin or the ball is made smoother on one side by the bowler and remains rough on the other side, the air moves faster over rough side and slows over the smoother Fig. 18.

According to Bernoulli's equation, the faster moving air creates lower pressure, while the slower moving air creates higher pressure. This pressure difference generates a sideways force, known as Magnus effect which causes the ball to curves in the air.

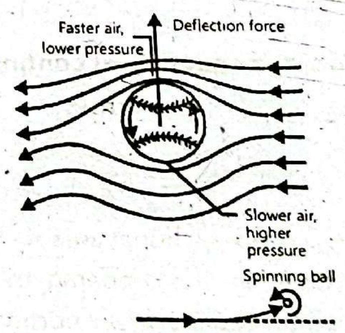


Fig. 18: Turbulent flow

3. Filter Pump

A filter pump has a constriction in the centre, so that a jet of water from the tap flows faster here. This causes a drop in pressure near it and air, therefore, flows in from the side tube. The air and water together are expelled through the lower part of the pump; Fig. 19.

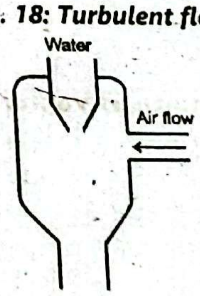


Fig. 19: Turbulent flow

4. **Carburetor**
The carburetor of a car engine uses a Venturi duct to feed the correct mixture of air and petrol to the cylinders. Air is drawn through the duct and along a pipe to the cylinders; Fig. 20. A tiny inlet at the side of duct is fed with petrol.
The air through the duct moves very fast, creating low pressure in the duct, which draws petrol vapours into the air stream.

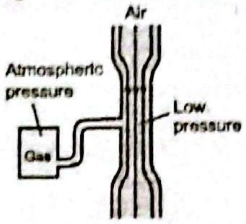


Fig. 20: Carburetor of an engine

5. **Paint Sprayer**
A stream of air passing over a tube dipped in a liquid will cause the liquid to rise in the tube; Fig. 21. This effect is used in perfume bottles and paint sprayers. Actually, when the rubber ball of atomizer is squeezed, the air is blown through tube and it rushes out through the narrow aperture with high speed and it causes fall of pressure. So, the atmospheric pressure pushes the perfume up leading to the narrow aperture.

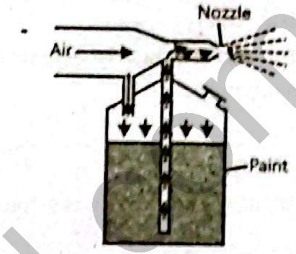


Fig. 21: A stream of air-passing over a tube dipped in a liquid.

6. **Venturi Relation**
Consider a pipe within which a fluid of density ρ is flowing through different areas of cross-section; Fig. 22.
Let A_1 be the cross-sectional area at wide end and A_2 be the cross-sectional area at narrow portion.
Suppose that v_1 and v_2 be the flow speeds at the wide and narrow portions respectively. Pressure P_1 and P_2 indicate the liquid pressure at both the portions by connecting the limbs of the manometer.

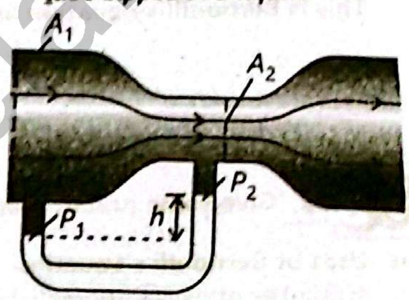


Fig. 22: Venturi meter

As the pipe is placed horizontally, therefore, we consider that average potential energy is the same at both places while using Bernoulli's equation.
Thus, Bernoulli's equation can be written as:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

or $$P_1 - P_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2$$

or $$P_1 - P_2 = \frac{1}{2}\rho (v_2^2 - v_1^2) \qquad \text{...... (i)}$$

> **Interesting Information**
> It is clear from the result of Bernoulli's Equation for horizontal pipe that "where speed is high, the pressure will be low". Mathematically,
> $$P + \frac{1}{2}\rho v^2 = \text{constant}$$

From the equation of continuity:

$$A_1 v_1 = A_2 v_2$$

or $$v_1 = \frac{A_2 v_2}{A_1}$$

As the cross-sectional area A_2 is small as compared to the area A_1 as is clear from the figure, i.e. $A_2 < A_1$. So, v_1 will be small as compared to v_2. Thus, the speed of the fluid is very slow in wider portion of the pipe as compared to the narrow portion, So, we can neglect v_1 on the right-hand side of Eq. (5.23). Hence

$$P_1 - P_2 = \frac{1}{2}\rho v_2^2 \qquad \text{...... (ii)}$$

This is known as Venturi relation. It is used in venturi meter, a device used to measure speed of liquid flow.

7. Torricelli's Theorem

A simple application of Bernoulli's equation is shown in Fig. 5.23. Suppose a large tank of fluid has two small orifices A and B on it. Let us find the speed with which the water flows from the orifice A.

Since the orifices are so small, the efflux speeds v_2 and v_3 will be much larger than the speed v_1 of the top surface of water. We can therefore, take v_1 as approximately zero. Hence, Bernoulli's equation can be written as:

$$P_1 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

But $P_1 = P_2$ = Atmosphere pressure

Therefore, the above equation becomes:

$$v_2 = \sqrt{2g(h_1 - h_2)} \quad \text{...... (iii)}$$

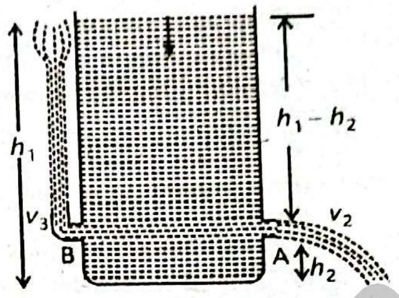


Fig. 23: A tank containing fluid with a orifice.

This is Torricelli's theorem which states that;

The speed of efflux is equal to the velocity gained by the fluid in falling through the distance $(h_1 - h_2)$ under the action of gravity.

Notice that the speed of the efflux of liquid is the same as the speed of a ball that falls through a height $(h_1 - h_2)$. The top level of the tank has moved down a little and the *P.E.* has been transferred into *K.E.* of the efflux of fluid. If the orifice had been pointed upward at B as shown in Fig. 6.4, this *K.E.* would allow the liquid to rise to the level of water tank. In practice, viscous-energy losses would alter the result to some extent.

MCQ's

1. **The equation of continuity is based on the principle of:**
(A) Conservation of energy
(B) Conservation of momentum
(C) Conservation of mass
(D) Conservation of volume

2. **If the cross-sectional area of a pipe decreases, the speed of fluid flow must:**
(A) Increase ✓ (B) Decrease
(C) Remain constant (D) Become zero

3. **In a pipe with constant flow rate, if the area becomes twice as large, the velocity becomes:**
(A) Half ✓ (B) Double
(C) Four times (D) The same

4. **Which physical quantity remains constant in the equation of continuity for an incompressible fluid?**
(A) Pressure (B) Velocity
(C) Density (D) Volume flow rate ✓

5. **Equation of continuity applies best to which type of fluid flow?**
(A) Turbulent flow (B) Unsteady flow
(C) Steady and incompressible flow ✓
(D) Compressed gases only

6. **The product of cross-sectional area and velocity of flow represents:**
(A) Force (B) Acceleration
(C) Mass flow rate (D) Volume flow rate ✓

7. **The quantity which remains constant in the equation of continuity is:**
(A) Volume (B) Mass flow rate ✓
(C) Pressure (D) Area

8. **Torricelli's theorem is derived from which principle?**
(A) Law of conservation of momentum
(B) Law of conservation of energy
(C) Bernoulli's equation ✓
(D) Pascal's law

9. **Torricelli's theorem gives the speed of efflux of a fluid from an orifice as:**
(A) $v = \sqrt{2gh}$ ✓ (B) $v = gt$
(C) $v = \frac{h}{t}$ (D) $v = \sqrt{gh}$

10. **Torricelli's theorem can be used to find:**
(A) The pressure at the surface of a fluid.
(B) The velocity of fluid leaving a hole in a tank. ✓
(C) The volume of the tank.
(D) The viscosity of the fluid.

11. **The velocity of fluid flowing out from a tank depends on:**
(A) Viscosity of the fluid
(B) Shape of the container
(C) Height of the fluid above the opening ✓
(D) Temperature of the fluid

12. **In Torricelli's theorem, what assumption is made about the fluid at the surface?**
(A) It is at rest. ✓ (B) It is under pressure.
(C) It is flowing at high velocity.
(D) It is compressible.

13. **Pressure will be low where the speed of fluid is:**
(A) zero (B) High ✓
(C) Low (D) Medium

14. **The law of conservation of energy is the basis of**
(A) Streamline flow (B) Equation of continuity
(C) Bernoulli's equation ✓ (D) Venturi relation

15. **The law of conservation of mass is the basis of**
(A) Bernoulli's equation (B) Equation of continuity✓
(C) Stoke's law (D) Viscosity

16. **Bernoulli's Theorem is applicable to:**
(A) Solids (B) Plasma state
(C) Fluids✓ (D) Liquids

17. **If the Streamlines of fluid are forced closer together than:**
(A) Speed of the Fluid increases✓
(B) Speed of the fluid decrease
(C) Pressure of the fluid increases
(D) Speed of the fluid remains same

18. **Venturi meter is a device used of measure**
(A) Density of fluid (B) Speed of fluid✓
(C) Pressure of fluid (D) Viscosity of fluid

19. **The working of carburetor or car uses**
(A) Equation of continuity (B) Gravitational law
(C) Bernoulli's theorem✓ (D) Stokes low

20. **A horizontal pipe narrows from a diameter of 10cm to 5cm. For a fluid flowing from larger diameter to smaller diameter:**
(A) The velocity and pressure both increases
(B) The velocity increases and pressure decreases✓
(C) The velocity decreases and pressure increase
(D) Velocity and pressure both decreases

21. **Swing is produced to:**
(A) Increase the speed of ball
(B) Decrease speed of ball
(C) Deceive the player✓ (D) Apply the force on ball

22. **The SI unit of flow rate is:**
(A) m^2s^{-1} (B) m^3s^{-2}
(C) m^3s^{-1}✓ (D) m^2s^{-2}

23. **When water falls from tap, its cross-sectional area decrease due to:**
(A) Decrease of speed (B) Increase of speed✓
(C) Air pressure (D) Gravity increase

24. **The ratio of the velocities of water in a pipe lying horizontally at two ends is 1 : 3. The ratio of diameters of pipe at these two ends is:**
(A) 1 : 2 (B) 2 : 1✓
(C) 1 : 4 (D) 4 : 1

25. **When a body acquires terminal velocity, then its acceleration 'a' becomes:**
(A) $a = 0$✓ (B) $a = g$
(C) $a > g$ (D) $a < g$

26. **A chimney works best when it is:**
(A) Tall✓ (B) Wide
(C) Short (D) Narrow

27. **Venturi relation is given is:**
(A) $p = \frac{1}{2}\rho v^2$ (B) $P_1 - P_2 = \frac{1}{2}\rho v^2$✓
(C) $v = 2g\sqrt{(h_1 - h_2)}$ (D) $P_1 - P_2 = \sqrt{\rho g h}$

28. **The fluid is said to be incompressible, if its density is:**
(A) Zero (B) very high
(C) very small✓ (D) Constant

29. **The term $\frac{1}{2}\rho v^2$ in Bernoulli's equation has the same unit as:**
(A) Work (B) Volume
(C) Pressure✓ (D) Force

30. **Let A = Area of cross sectional of pipe v = speed of fluid then 'Av' is called:**
(A) Volume flow rate✓ (B) Energy flow rate
(C) Mass flow rate (D) Pressure flow rate

31. **A hose pipe ejects water at speed of $0.3ms^{-1}$ through a hole of area $10cm^2$, flow rate will be:**
(A) $3m^3 s^{-1}$ (B) $3 \times 10^{-4} m^3 s^{-1}$✓
(C) $30^3 s^{-1}$ (D) $0.03\, m^3 s^{-1}$

32. **Equation of continuity gives the conservation of the:**
(A) Mass✓ (B) Energy
(C) Speed (D) Volume

33. **Product or area of cross section, velocity and time gives:**
(A) Volume✓ (B) Density
(C) Mass (D) Weight

34. **Speed of efflux is measured by the relation.**
(A) $v = \sqrt{gh}$ (B) $v = \sqrt{\frac{gh}{2}}$
(C) $v = \sqrt{2gh}$✓ (D) $v = \sqrt{\frac{4}{3}gh}$

35. **The relation $v_2 = \sqrt{2g\,(h_1 - h_2)}$ is called:**
(A) Torricelli's theorem✓ (B) Venturi relation
(C) Stoke's law (D) Equation of continuity

36. **The speed of efflux is equal to the velocity gained by the falling fluid under the action of gravity through a certain height is called:**
(A) Torricelli's theorem✓ (B) Bernoulli's theorem
(C) Stoke's theorem (D) Venturi's theorem

37. **Formula one racing cars have a:**
(A) Streamlined design✓ (B) Turbulence design
(C) Rectangular design (D) Elliptical design

38. **Laminar flow occurs at:**
(A) High speed (B) Low speed✓
(C) Zero speed (D) Very high speed

39. **If $v_1 = 0.20m\,s^{-1}$ and $v_2 = 2\,m\,s^{-1}$ and density $\rho = 100\,kg\,m^{-3}$, then $p_1 - p_2$ will be:**
(A) $1980\,N\,m^{-2}$✓ (B) $1970\,N\,m^{-2}$
(C) $1960\,N\,m^{-2}$ (D) $1990\,N\,m^{-2}$

40. **A 20 metre high tank is full of water. A hole appears at its middle. The speed of efflux will be:**
(A) $10\,ms^{-1}$ (B) $14\,ms^{-1}$✓
(C) $11.5\,ms^{-1}$ (D) $9.8\,ms^{-1}$

41. **Bernoulli's equation is based upon law of conservation of:**
(A) Mass (B) Linear Momentum
(C) Angular Momentum (D) Energy✓

42. **The Bernoulli's equation is for a fluid which is:**
(A) Viscous (B) Compressible
(C) Inturblen flow (D) In steady flow✓

43. **Pressure is high, where speed is:**
(A) High (B) Low ✓
(C) Constant (D) None

44. **Maximum drag force on 1kg falling sphere is:**
(A) 9.8 N (B) 1 N ✓
(C) 98 N (D) 4.9 N

45. **The product of cross-sectional area of pipe and fluid speed along a pipe always:**
(A) Zero (B) Variable
(C) Constant ✓ (D) 9.8 m s^{-2}

46. **Equation of continuity is the statement of law of conservation of:**
(A) Energy (B) Momentum
(C) Mass ✓ (D) Charge

47. **Bernoulli's equation gives dimensions of:**
(A) $[LT^{-1}]$ (B) $[T^{-1}]$ ✓
(C) $[L^{-1}T^{-1}]$ (D) $[MLT^{-1}]$

48. **In fluid flow, for the equation of continuity $A_1v_1 = A_2v_2$ if velocity of the fluid at one end is doubled, what will be the cross-sectional area at this end?**
(A) Double (B) Half ✓
(C) $(Half)^2$ (D) $(Double)^2$

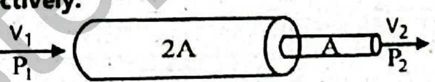
49. **The dimensions of coefficient of viscosity are:**
(A) $[M^{-2}L^{-1}T^{-1}]$ (B) $[ML^{-2}T^{-1}]$
(C) $[ML^{-2}T^{1}]$ (D) $[ML^{-1}T^{-1}]$ ✓

50. **Mass flow per second of the fluid is given by**
(A) ρAv ✓ (B) Av
(C) ρv (D) Av/ρ

51. **The dimensions of pressure are:**
(A) $[M^{-1}L^{2}T^{-2}]$ (B) $[ML^{-1}T]$
(C) $[M^{-1}L^{-2}T^{-2}]$ (D) $[ML^{-1}T^{-2}]$ ✓

52. **For the horizontal pipe, the fluid inside it is flowing horizontally, then Bernoulli's equation can be written as:**
(A) $P + \rho v^2$ = constant (B) $2P + \rho v^2$ = constant
(C) $P + \frac{1}{2}\rho v^2$ = constant ✓ (D) $2P + 2\rho v^2$ = constant

53. **Water flows through a horizontal pipe with two different cross-sectional areas as shown in the figure below. The first section of the pipe has cross-sectional area 2A and the pressure of the water is P_1. Similarly, the cross-sectional area and the pressure of the water in the second section is A and P_2, respectively.**



Assuming v_1 denotes the speed of water flow in the first section and v_2 in second section and ρ denotes the density of water, which of the following equations correctly represents the difference in the pressure of the water in the two sections?
(A) $P_1 - P_2 = 0.5\,\rho\,(v_2^2 - v_1^2)$ ✓
(B) $P_1 - P_2 = \rho\,(v_2^2 - v_1^2)$
(C) $P_1 - P_2 = 1.5\,\rho\,(v_2^2 - v_1^2)$
(D) $P_1 - P_2 = 2\,\rho\,(v_2^2 - v_1^2)$

54. **When a fluid is incompressible, the quantity which is constant is:**
(A) Mass (B) Density ✓
(C) Pressure (D) Force

55. **The product of cross-sectional area of the pipe and the fluid speed at any point along the pipe:**
(A) Remains constant ✓ (B) Is zero
(C) Exponentially increases (D) Exponentially decreases

56. **Stokes' Law is given by**
(A) $F = 6\pi\eta r^2 v$ (B) $F = 6\pi\eta r v^{-1}$
(C) $F = 6\pi^2\eta r^2\rho$ (D) $F = 6\pi\eta r v$ ✓

57. **An object having spherical shape of radius 'r' experiences a retarding force F from of coretarding force to speed:**
(A) $6\pi\eta r^2$ (B) $6\pi\eta/r^2$
(C) $6\pi\eta r$ ✓ (D) $6\pi\eta/r$

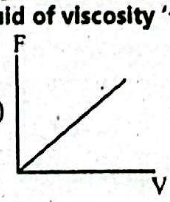
58. **Flow speed of a fluid through a non-uniform pipe increases from 1m s^{-1} to 3m s^{-1}. If change in P.E. is zero, pressure difference between two points will be (density of fluid is 1000 kg m^{-3}).**
(A) 1000 N m^{-2} (B) 9000 N m^{-3}
(C) 8000 N m^{-2} (D) 4000 N m^{-2} ✓

59. **If speed of efflux through a small hole in a large tank is 9.8 m s^{-1}, find the height of the fluid above the hole.**
(A) 1 m (B) 8.8 m
(C) 4.9 m ✓ (D) 19.6 m

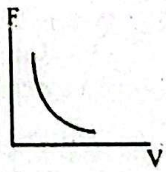
60. **Stoke's law for steady motion in a fluid of infinite extension is given by**
(A) $F = 6\pi\eta r v$ ✓ (B) $F = \frac{4}{3}\pi r^3 \rho g$
(C) $F = 6\pi\eta r^2\rho$ (D) $F = \frac{2gr^2\rho}{9\eta}$

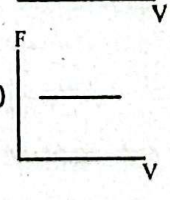
61. **As the water falls from a tap, its cross-sectional area should decrease according to:**
(A) Benoulli's equation (B) Continuity equation ✓
(C) Venturi relation (D) None of these

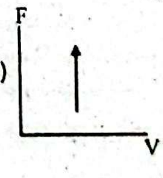
62. **Which of the following is the best graphical representation between drag force 'F' on a spherical object of radius 'r' moving with velocity 'v' through a fluid of viscosity 'η'?**

(A) 

✓

(B) 

(C) 

(D) 

5.13 VISCOUS DRAG AND STOKES' LAW

19. Describe viscous Drag and Stokes' law.

Ans. Viscous Drag

Definition

Viscous drag is the resistive force exerted by a fluid (liquid or gas) on an object moving through it.

This force arises due to the viscosity of the fluid, which is measure of its resistance to deformation or flow.

(i) When an object moves through a viscous fluid, layers of fluid near the surface of the object move with different velocities, creating shear stress.

(ii) the viscous drag opposes the motion of the object and increases with the speed of the object.

Stokes' Law

Stokes' law describes the drag force experienced by a small spherical object moving slowly through a viscous fluid.

Statement

The drag force acting on a small spherical particle moving through a viscous fluid is directly proportional to the radius of the sphere, the viscosity of the fluid, and the velocity of the sphere.

Mathematically;

$$F_d = 6\pi\eta rv$$

where F_d = Drag force

η = Viscosity of the fluid

r = Radius of the sphere

v = Velocity of the sphere relative to the fluid

Conditions for Applicability of Stokes' Law

(i) The particle is spherical

(ii) The flow is laminar

(iii) The particle is small and moves slowly through the fluid

Applications of Stokes' Law

It is used in:

(i) determining the viscosity of a fluid.

(ii) studying the sedimentation of particles in fluids.

(iii) calculating the terminal velocity of small particles in air or other fluids.

(iv) aerosol physics, oil industry, and biological systems (e.g., cell motion in fluid).

For You Information

Viscosities of Liquids and Gases at 30°C

Material	Viscosity 10^{-3} (N s m^{-2})
Air	0.019
Acetone	0.295
Methanol	0.510
Benzene	0.564
Water	0.801
Ethanol	1.000
Plasma	1.6
Glycerin	6.29

Do you know?

A chimney works best when it is tall and exposed to air currents, which reduces the pressure at the top and forces the upward flow of smoke.

5.14 TERMINAL VELOCITY

20. Define terminal velocity of a body and show that terminal velocity is directly proportional to the square of the radius of the body.

Ans. Terminal Velocity

Definition

It is the constant maximum speed that an object reaches when falling through a fluid. One the force of gravity pulling it downward is balanced by the resistive force of drag pushing upward.

At terminal velocity:

- The net force on the object is zero.
- The object stops accelerating and continues falling at a constant speed.

Example of Terminal Velocity

(i) For a sky diver falling through the air:

- Initially, they accelerate due to gravity.
- As their speed increases, air resistance (drag) increases.
- Eventually, drag equals the gravitational force, and they fall at a constant speed. This is **terminal velocity**.

Explanation

Consider a water droplet having radius r such as that of fog falling vertically. The air drag on the water droplet increases with speed. The droplet accelerates rapidly under the over powering force of gravity which pulls the droplet rapidly downward due to force of gravity. However, the upward drag force on it increases as the speed of the droplet increases. The net force on the droplet is:

Net force = Weight – Drag force

As the speed of the droplet continues to increase, the drag force eventually approaches the weight in the magnitude. Finally, when the magnitude of the drag force becomes equal to the weight, the net force acting on the droplet is zero. Then the droplet will fall with constant speed called terminal velocity.

To find the terminal velocity v_t in this case, we use Stokes' law for the drag force. Equating it to the weight of the drop, we have

$$0 = mg - 6\pi\eta r v_t$$

$$v_t = \frac{mg}{6\pi\eta r} \quad \text{...... (i)}$$

The mass of the droplet is ρV, where $V = \frac{4}{3}\pi r^3$ is the volume of the sphere. Substituting above values in the Eq. (i), we have

$$v_t = \frac{2gr^2\rho}{9\eta} \quad \text{...... (ii)}$$

or $v_t \propto r^2$

Example 5.5: A tiny water droplet of radius 0.010 cm descends through air from a high building. Calculate its terminal velocity. Given that η for air = 19×10^{-6} kg m^{-1} s^{-1} and density of water ρ = 1000 kg m^{-3}.

Solution:

Given that;

$r = 1.0 \times 10^{-4}$ m, $\rho = 1000$ kg m^{-3}, $\eta = 19 \times 10^{-6}$ kg m^{-1} s^{-1}

To Find:

$v_t = ?$

Calculations:

Using: $v_t = \frac{2gr^2\rho}{9\eta}$

Putting the above values

$$v_t = \frac{2 \times 9.8 \text{ m s}^{-2} \times (1.0 \times 10^{-4} \text{ m})^2 \times 1000 \text{ kg m}^{-3}}{9 \times 19 \times 10^{-6} \text{ kg m}^{-1} \text{ s}^{-1}}$$

Terminal velocity = 1.1 ms^{-1} **Ans.**

5.15 REAL FLUIDS ARE VISCOUS FLUIDS

21. Are real fluids viscous fluids? Explain.

Ans. Ideal fluid

Definition

It is a fluid that does not have viscosity and cannot be compressed. This type of fluid cannot exist practically.

Real fluid

Definition

All types of fluids that possess viscosity are termed as real fluids.

Examples: Kerosene oil, castor oil and honey etc.

Comparison of Ideal and Real Fluids

An example of ideal fluid cannot be provided because it does not exist in the real world.

However, every fluid that we see around us like water, diesel, petrol, honey, etc. are real fluids. Moreover, differences in viscosity can be found in real life. For example, honey is more viscous than water. Bernoulli's equation states that the speed of fluid flow is increased as a result of a simultaneous decrease in the potential energy of the fluid or a decrease in the static pressure on the fluid. When a fluid is viscous, it essentially refers to the thickness of the fluid or the friction, the fluid faces while fluid flows. Therefore, ideal fluids do not face the opposing force and have a non-viscous flow, while real fluids have a viscous flow. Ideal fluids are incompressible. It is not also subjected to surface tension.

MCQ's

1. Which one of the following has the maximum viscosity?
(A) Air (B) Water
(C) Acetone (D) Glycerin✓

2. Drag force depends upon:
(A) Density (B) Acceleration
(C) Radius of sphere✓ (D) Linear acceleration

3. Which has the maximum viscosity?
(A) Honey✓ (B) Water
(C) Air (D) Acetone

4. The drag force *F* on a sphere of radius *r* moving slowly with speed *v* through a fluid of viscosity η is:
(A) $6\pi\eta v_1^2$ (B) $6\pi\eta v_2^2$
(C) $6\pi\eta v$ (D) $6\pi\eta rv$✓

5. Stokes' law holds for:
(A) Motion through free space
(B) Motion of small sphere through viscous medium✓
(C) Bodies of all shapes
(D) All mediums

6. As the speed of the object moving through a fluid increases, the drag force experienced by it:
(A) Decreases (B) Increases✓
(C) Remains same (D) Becomes zero

7. The word "fluid" means
(A) To rise (B) To fall
(C) To flow✓ (D) To stick

8. In the relation; $F = 6\pi\eta rv$, dimensions of coefficient of viscosity η are:
(A) $[ML^{-1}T^{-1}]$✓ (B) $[ML^{-1}T^{1}]$
(C) $[ML^{-2}T^{-1}]$ (D) $[MLT]$

9. pascal is the unit of:
(A) Pressure✓ (B) Force
(C) Tension (D) Weight

10. The unit of viscosity in SI system is:
(A) $kg^{-1}\ ms^{-2}$ (B) $kgm^{-1}\ s^{-1}$✓
(C) $kg^{-1}\ m^{-2}s$ (D) $kg\ ms^{-1}$

11. The frictional effect between different layers of a moving fluid is called:
(A) Fluidity (B) Density
(C) Viscosity✓ (D) Flow rate

12. The property of fluid by which its own molecules are attracted is said to be:
(A) Surface tension (B) Adhesion
(C) Cohesion (D) Viscosity✓

13. As the speed of object moving through a fluid increases, the drag force experienced by it:
(A) Increases✓ (B) Decreases
(C) Remains constant (D) Becomes Zero

14. Viscosity of air at 30°C is:
(A) 6.29×10^{-3} (B) 0.019×10^{-3}✓
(C) 1.00×10^{-3} (D) 0.510×10^{-3}

15. Stokes' Law holds for bodies when they have:
(A) Spherical shape✓ (B) Curved shape
(C) Rectangular shape (D) Oblong shape

16. Drag force is given by
(A) Stokes' law✓ (B) Bernoulli's equation
(C) Equation of continuity (D) Newton's laws

17. The maximum drag force on falling sphere is 9.8 *N*, its weight is:
(A) 1*N* (B) 9.8 *N*✓
(C) 19.8 *N* (D) 4.9 *N*

18. When a body is falling under the action of gravity with terminal velocity, the acceleration is:
(A) Constant (B) Zero✓
(C) Variable (D) $9.8\ m\ s^{-2}$

19. The maximum constant velocity of an object falling vertically downward is called:
(A) Final velocity (B) Terminal velocity✓
(C) Initial velocity (D) None of these

20. If the radius of droplet becomes half, then its terminal velocity will be:
(A) Double (B) Half
(C) Four times (D) One fourth✓

21. A fog droplet falls vertically through air with an acceleration:
(A) Equal to *g* (B) Less than *g*
(C) Zero✓ (D) Greater than *g*

22. Two fog droplets are in freely falling condition. The ratio of their radii is 2:3, the ratio of their terminal velocity will be:
(A) 2 : 3 (B) 4 : 6
(C) 4 : 9✓ (D) 9 : 4

23. Terminal velocity v_t is related with the radius *r* of a spherical object as:
(A) $v_t \propto r^2$✓ (B) $v_t \propto r$
(C) $v_t \propto \frac{1}{r}$ (D) $v_t \propto \frac{1}{r^2}$

24. The velocity of rain drop attains constant value due to:
(A) Air currents (B) Up thrust of air
(C) Surface tension
(D) Viscous force exerted by air✓

25. **Terminal velocity of a particle in the fluid depends on:**
(A) Nature of fluid✓
(B) Acceleration of particle
(C) Force on particle
(D) Angular velocity of particle

26. **The direction of drag force acting on a falling object is:**
(A) Same as velocity
(B) Perpendicular to velocity
(C) Opposite to velocity✓
(D) Perpendicular to gravity

27. **The drag force on a sphere falling in a viscous fluid at low velocity is independent of:**
(A) Radius of sphere
(B) Viscosity of the fluid
(C) Velocity of the sphere
(D) Density of the sphere✓

28. **According to Stokes' law, the drag force on a spherical object moving through a viscous fluid is proportional to:**
(A) The square of its velocity
(B) Its surface area
(C) Its radius and velocity✓
(D) Its volume

29. **At terminal velocity, for a falling object in a fluid:**
(A) Net force is zero✓
(B) Acceleration is maximum
(C) Viscous force is zero
(D) Gravitational force is zero

30. **The drag force increases with the object's:**
(A) Mass
(B) Velocity✓
(C) Volume
(D) Height from which it falls

31. **What happens to terminal velocity if the viscosity of the fluid increases?**
(A) It becomes zero
(B) It increases
(C) It remains the same
(D) It decreases✓

32. **Stokes' law assumes the motion to be:**
(A) Irregular and random
(B) Accelerated
(C) Uniform and steady✓
(D) Oscillatory

33. **In which of the following cases is Stokes' law most accurately applied?**
(A) Raindrops falling through air
(B) A steel ball falling in water
(C) A pollen grain settling in honey✓
(D) A rocket moving through the atmosphere

5.16 SUPERFLUIDS

Q 22. What are superfluids? Explain the term superfluidity.

Ans. Superfluids

Definition

A superfluid is a special phase of matter that exhibits zero viscosity, allowing it to flow without any resistance.

Superfluidity

Superfluidity is the characteristic property of fluids with zero viscosity i.e., flow is frictionless. A substance exhibiting this property is a superfluid. Superfluidity is achieved in some substances at extremely low temperature. For example, in fluid dynamics, a vortex is region in a fluid in which the flow revolves around an axial line, which may be straight or curved. The vortices are generally created at a moving boundary due to frictionless conditions. Vortices move with the fluid and dispersed by the action of viscosity.

Superfluid helium-4 is the most studied example of superfluidity. It changes from a liquid to a superfluids just a few degree below its boiling point of -452°F (-269°C or 4 K). Superfluids helium-4 moving as a normal clear liquid, but it has no viscosity. This means that once it starts to flow, it keeps moving past any obstacles.

> **Tidbit**
> Parachutes increase air resistance (drag) by creating a large surface area, which counteracts the force of gravity. This slows down the persons fall, allowing them to land safely

> **Tidbit**
> Superfluids can "climb" up walls and over edges of containers because they do not experience friction like normal fluids do.

Superfluidity Applications

Currently, there are few practical uses for superfluids.

(i) Superfluid helium-4 serves as a coolant for high-field magnets.
(ii) Both helium-3 and helium-4 are utilized in advanced particle detectors. Researching superfluidity also helps us learn more about superconductivity.
(iii) Liquid helium is recognized for its great thermal conductivity and is used in cryogenic applications, including cooling superconducting magnets, scientific research, and medical uses. Additionally, it is employed in industry for leak testing and in the production of electronic and optical products.

MCQ's

1. **A superfluid is a phase of matter that has:**
(A) Infinite temperature
(B) Infinite density
(C) Zero density
(D) Zero viscosity✓

2. **Which of the following substances exhibits superfluidity at very low temperature?**
(A) Oxygen
(B) Helium-4✓
(C) Nitrogen
(D) Water

3. **Superfluids can:**
(A) Stick to the walls of containers
(B) Flow without friction through narrow capillaries ✓
(C) Remain solid under pressure
(D) Have infinite mass

4. **One of the strange behaviours of superfluid helium is that it can:**
(A) Evaporate instantly (B) Sink into the ground
(C) Climbs up and over the walls of a container
(D) Change colour ✓

5. **In which state of matter does superfluidity typically occur?**
(A) Solid (B) Plasma
(C) Gas (D) Liquid ✓

6. **Superfluidity is a phase of matter that occurs at:**
(A) Room temperature (B) High pressure
(C) High velocity (D) Very low temperatures ✓

7. **Superfluid helium can flow:**
(A) Only downward (B) Against gravity ✓
(C) Only in straight line (D) Only through solids

8. **One experimental demonstration of superfluidity is:**
(A) Magnetic levitation (B) Floating in vacuum
(C) Climbing walls of a container ✓
(D) Emitting visible light

ADDITIONAL SHORT ANSWER QUESTIONS

Q.1 What is the crystalline solid? Give examples.

Ans. Crystalline solids have a regular, repeating arrangement of particles in a definite repeating pattern.
Example: Sodium chloride (NaCl) and quartz (SiO_2).

Q.2 What is a key property of crystalline solids?

Ans. They have sharp melting points and well-defined shapes.

Q.3 What are amorphous or glassy solid? Give two examples.

Ans. Amorphous solids lack a regular and repeating structure, their particles have arranged randomly.
Examples: Glass and plastic.

Q.4 Are amorphous solids true solids? Have they sharp melting point?

Ans. They are considered supercooled liquids with solid-like behaviour.
No, they soften over a range of temperatures.

Q.5 What are polymeric solids? Give two examples.

Ans. Polymeric solids are made up of long chains of repeating molecular units (monomers).
Example: Polyethylene and rubber.

Q.6 Are polymeric solids crystalline or amorphous?

Ans. They can be partly crystalline and partly amorphous, depending on structure and processing.

Q.7 Explain, what do you understand by the term viscosity?

Ans. Viscosity is the internal friction between different layers of a fluid when it is flowing. It is the force required to slide one layer of the fluid over another layer. Viscosity is usually measured by coefficient of viscosity η. Unit of coefficient of viscosity is kg $m^{-1}s^{-1}$, where $\eta = \frac{F}{6\pi r v}$
Substances which do not flow easily have large coefficients of viscosity η. Substances which flow easily have small coefficient of viscosity "η".

Q.8 What is meant by drag force? What are the factors upon which drag force acting upon a small sphere of radius *r*, moving down through a liquid, depend?

Ans. The retarding force experienced by an object moving through a fluid is called **drag force**. According to Stokes law, when a sphere of radius *r* moves slowly through a fluid of coefficient of viscosity η with a speed v. The drag force acting on the sphere is given by

$$F = 6\pi\eta r v$$

Thus drag force depends upon the following factors:
(i) Radius r of the sphere.
(ii) Speed v of the sphere.
(iii) Coefficient of viscosity η of the fluid.

Q.9 Why fog droplets appear to be suspended in air?

Ans. A fog droplet has small size and small weight. When a fog droplet falls through air, very soon drag force acting on the fog droplet becomes equal to the weight of the fog droplet and the fog droplet starts moving vertically downward with the constant terminal velocity. But this terminal velocity is so small that the fog droplet appears to be suspended in the air.

For terminal velocity

$$6\pi\eta r v_t = mg$$

$$v_t \propto mg$$

Q.10 State Bèrnoulli's equation for a liquid in motion and describe some of its applications.

Ans. Bernoulli's Equation

Statement

According to Bernoulli's equation for an incompressible and non-viscous liquid in a steady flow, the sum of pressure, kinetic energy per unit volume and potential energy per unit volume always remains constant.

$$\text{Pressure} + \frac{\text{K.E}}{\text{Volume}} + \frac{\text{P.E}}{\text{Volume}} = \text{constant}$$

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

or

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$$

Some applications of Bernoulli's equation are:

1. Torricelli's theorem.
2. Working of filter pump.
3. Flow through a small orifice.
4. Venturi meter.
5. Working of a chimney for smoke exhaust.
6. Aerodynamic lift of an aeroplane.
7. Swing of cricket ball in the air.

Q.11 A person is standing near a fast moving train. Is there any danger that he will fall towards it?

Ans. When a man is standing near a fast moving train, the velocity of air between the man and the fast moving train also increases because it is being dragged by the train. According to Bernoulli's equation,

$$\left(v \propto \frac{1}{P}\right)$$

When velocity of a fluid increases, the pressure of the fluid decreases. Thus pressure of air between the man and fast moving train decreases. The air on the other side of the man has a smaller velocity and greater pressure. Due to this higher pressure, there is a danger that the man may be pushed towards the fast moving train.

Q.12 Identify the correct answer. What do you infer from Bernoulli's theorem?

(A) Where the speed of the fluid is high the pressure will be low.

(B) Where the speed of the fluid is high the pressure is also high.

(C) This theorem is valid only for turbulent flow of the liquid.

(D) None of these

Ans. (A)

Q.13 Two row boats moving parallel in the same direction are pulled towards each other. Explain.

Ans. When the two boats are moving parallel in the same direction, water between the boats being dragged acquires greater speed. According to Bernoulli's equation,

$$\left(v \propto \frac{1}{P}\right)$$

When speed of a liquid increases pressure of the liquid decreases. Thus pressure of water between the two boats decreases. The greater pressure on the outer sides of the boats pushes the two boats towards each other.

Q.14 Explain how the swing is produced in a fast moving cricket ball?

Ans. Due to spin of the ball, velocity of the air above the ball is greater than that below the ball. Thus according to Bernoulli's equation,

$$\left(v \propto \frac{1}{P}\right)$$

Pressure on the upper side of ball is smaller than the pressure of the air below the ball. The greater pressure below the ball deflects the path of the ball and gives an extra curvature to the ball. This extra curvature given to the ball is called swing of the ball. This swing of ball deceives the batsman.

Q.15 Explain the working of a carburetor of a motor car using by Bernoulli's principle.

Ans. The carburetor of a car uses a venturi duct. This Venturi duct feeds the cylinder a mixture of air and petrol in a correct ratio. Air is drawn through the duct along a pipe to the cylinders. A tiny inlet on the side of the duct is fed with petrol. The air through the duct moves very fast. According to Bernoulli's equation, a low pressure is created in the duct. Due to this low pressure, petrol vapours are drawn into the air stream. This makes the fuel to flow from the tank into the Venturi duct in the form of vapours which mix with air. This mixture of petrol and air is called carbureted air which enters into the ignition chamber for its ignition.

Q.16 What is meant by ideal fluid? State conditions to be satisfied by ideal fluid.

Ans. Anything which can flow is called ideal fluid. An ideal fluid must satisfy the following conditions:

1. The fluid is non-viscous *i.e.,* there is no internal friction between the adjacent layers of the fluid.
2. The fluid is incompressible *i.e.,* density is constant.
3. The fluid motion is steady.

Q.17 How can laminar flow be changed into turbulent flow?

Ans. By changing the velocity of fluid flow, laminar flow can be changed into turbulent flow.

In Laminar flow, each particle of fluid moves along a smooth path whose direction is same as direction of velocity of fluid at that point. Above a certain velocity, this steady flow changes to unsteady and irregular motion which is termed as turbulent flow.

Q.18 When water falls from a top, its cross-sectional area decreases as it comes down. Explain.

Ans. According to equation of continuity

$$Av = \text{constant} \qquad \text{......... (i)}$$

where; A = cross-sectional area of pipe

v = fluid speed at any point

Equation (i) shows that there is an inverse relation between speed of fluid and cross-sectional area.

$$A \propto \frac{1}{v}$$

Therefore, when water falls from a tap, its speed increases and cross-sectional area decreases.

Q.19 Distinguish between crystalline, amorphous and polymeric solids?

Ans.

Crystalline solids	Amorphous Solids	Polymeric Solids
	Definitions	
(i) The solids in which atoms, ions or molecules are arranged in a regular and repeating patterns that is constant throughout the crystal are known as crystalline solids. **(ii)** These solids are ordered structure. **(iii)** These solids are also called true solids.	**(i)** The solids in which there is no regular arrangement of icons or molecules like that in crystalline solids are known as amorphous solids. **(ii)** These solids are not ordered structure. **(iii)** These solids are also called glassy or non-crystalline solids.	**(i)** The more or less solid materials with a structure that is intermediate between ordered and disordered are known as polymeric solids. **(ii)** These solids are partially or poorly ordered structure. **(iii)** These solids are also called intermediate solids and partially or poorly crystalline solids.
	Examples	
Metals like Cu, Fe, Zn and some compounds like sodium chloride and ceramics like zirconia are crystalline solids.	Ordinary glass is an amorphous solid.	Polythene, polystyrene, nylon and Natural rubber $(C_5H_6)_n$. such solids contain carbon with O_2, N_2, H_2 etc.

Q.20 Differentiate between elastic deformation and plastic deformation.

Ans. Elastic deformation is temporary; the solid returns to its original shape after the force is removed. Plastic deformation is permanent; the solid does not return to its original shape after the force is removed.

Q.21 What happens if stress remains within the elastic limit and if stress exceeds the elastic limit?

Ans. In first case, the material returns to its original shape after the force is removed. Whereas in the second case, the material undergoes permanent deformation and does not return to its original shape.

Q.22 How is the elastic limit important in engineering?

Ans. It helps in designing materials and structures that do not permanently deform under load.

Q.23 What is strain energy? What happens to it in plastic deformation?

Ans. Strain energy is the energy stored in a body due to deformation under applied stress.
In plastic deformation, some of the energy is used in permanent deformation and is not recovered.

Q.24 Define stress and strain. What are their SI units? Differentiate between tensile, compressive and shear modes of stress and strain.

Ans.

STRESS	STRAIN
Definitions	
Force per unit area that can produce a deformation in the body is called stress.	Measure of deformation when stress is applied is called strain.
Formulas	
$\sigma = \frac{\text{Force}}{\text{Area}}$	$\varepsilon = \frac{\text{Change in length}}{\text{Orignal length}} = \frac{\Delta \ell}{\ell}$
Types	
(i) Tensile stress: If the linear stress increases the length o f a body, it is called tensile stress.	**(i) Tensile strain:** Strain produced due to tensile stress is called tensile strain.
(ii) Compressive stress: If the linear stress decreases the length of a body, it is called compressive stress.	**(ii) Compressive strain:** Strain produced due to compressive stress is called compressive strain.
(iii) Shear stress: Force per unit area that produce change in the shape of a body is called shear stress.	**(iii) Shear strain:** Strain produced due to shear stress is called shear strain.
Units	
The unit of stress is Nm^{-2} which is also called pascal (Pa).	Because strain is the ratio between two same quantities, so it has no unit.

Q.25 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

The ratio of stress to Strain is called modulus of elasticity or elastic modulus.

Hooke's law can be stated as;

"Within elastic limit, stress is directly proportional to strain."

Mathematically;

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

$$\text{Stress} = \text{constant (strain)}$$

or. $$\text{Constant} = \frac{\text{Stress}}{\text{Strain}}$$

Formula:

$$\boxed{E = \frac{\text{Stress}}{\text{Strain}}}$$

Proof: Since strain is a unitless and dimensionless physical quantity.

So The unit of modulus of elasticity = The unit of stress

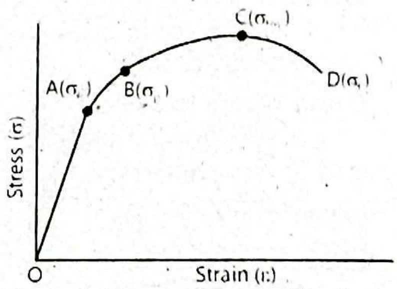
Modulus of Elasticity:

Young's Modulus (Y)	Bulk Modulus (K)	Shear Modulus (G)
	Definitions	
The ratio of linear stress (tensile or compressive) to linear strain (tensile of compressive) is called Young's modulus.	The ratio of volume stress to volume strain is called Bulk modulus.	The ratio of shear stress to shear strain is called shear modulus.
	Existence	
It exists only for solids.	It exists for solid, liquid and gases.	It exists only for solids.
	Formulas	
$Y = \frac{\text{Linear stress}}{\text{Linear strain}} = \frac{F/A}{\Delta\ell/\ell}$ $\boxed{Y = \frac{F \times \ell}{A \times \Delta\ell}}$	$K = \frac{\text{Volume stress}}{\text{Volume strain}} = \frac{F/A}{\Delta V/V}$ $\boxed{Y = \frac{F \times V}{A \times \Delta V}}$	$G = \frac{\text{shear stress}}{\text{shear strain}} = \frac{F.A}{\Delta a/a}$ $\boxed{G = \frac{F/V}{\tan\theta}}$

Q.26 Draw a stress strain curve for a ductile material, and then define the terms: Elastic limit, Yield point and Ultimate tensile stress?

Ans. (i) Elastic limit

From "B" stress and strain are not proportional but still if load is removed at any point between "O" and "B". The curve will be retraced and material will return to its own length in region OB the material is said to be elastic point B is called yield point. Value of stress at "B" is known as elastic limit (σ_e).



Stress strain curve of a typical ductile material

(ii) Yield point

The point on the curve beyond which the permanent deformation occurs is called yield point.

(iii) Ultimate Tensile Stress (UTS)

It is the maximum stress that a material can with stand and can be regarded as nominal strength of the material. Represented as point "C" on graph.

Q.27 What is meant by strain energy? How can it be determined from the force-extension graph?

Ans. Strain Energy

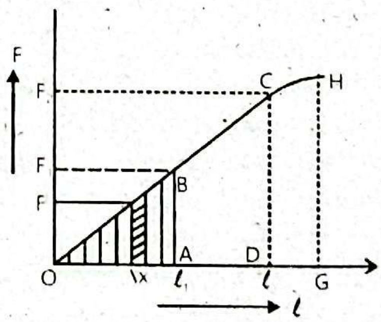
The potential energy stored in the molecules of a body due to its elastic deformation is called strain derivation.

Its value can be determined by calculating the area under the force - extension graph. If the sample obeys Hooke's Law, the strain energy can be calculated by the formula:

Work done = Strain energy

Strain energy = Area of ΔAOB

$$= \frac{1}{2} \times (OA)(AB) = \frac{1}{2}\ell F$$



Energy in stretched wire

Q.28 Why do ships made of iron float on water?

Ans. Because their average density is less than that of water due to their hollow shape, displacing more water.

Q.29 What is the condition for natural floatation?

Ans. When the weight of the object equals the buoyant force, and the object is completely submerged but does not sink or rise.

Q.30 Does velocity remain constant along a streamline in steady flow?

Ans. Yes, the velocity may change from one streamline to another, but remains constant along a single streamline.

Q.31 What causes turbulent flow? What is the nature of velocity in turbulent flow?

Ans. High velocity, large obstacles, or sharp change in flow direction causes turbulent flow.
The velocity and direction of fluid particles change continuously and randomly in turbulent flow.

Q.32 What is the equation of continuity? What does it imply?

Ans. It is the principle that states that the mass flow rate of an incompressible fluid remains constant along a streamline.
The equation of continuity implies that if the area decreases, the velocity increases, and vice versa.

Q.33 Give a real-life example where the equation of continuity is observed.

Ans. Water flows faster through a narrow nozzle than through a wide hose.

Q.34 What is Bernoulli's equation? What does it represent?

Ans. Bernoulli's equation relates the pressure, velocity, and height of a fluid in steady, incompressible, and non-viscous flow.
It represents the conservation of energy in fluid flow.

Q.35 What is the significance of Bernoulli's equation due to pressure difference?

Ans. It explains how airplane wings generate lift due to pressure difference.

Q.36 What happens to fluid velocity at a lower height, assuming pressure and energy are conserved?

Ans. Fluid velocity increases as gravitational P.E. decreases.

Q.37 Name one practical application of Stokes law.

Ans. Measuring the viscosity of fluids or designing sedimentation equipment in industries.

Q.38 What are the conditions for Stokes law to apply?

Ans. The flow should be laminar, and the object should be smooth, spherical, and moving slowly.

Q.39 What is terminal velocity?

Ans. It is the maximum constant velocity attained by a falling object when the net force acting on it becomes zero.

Q.40 Why does an object reach terminal velocity?

Ans. Because the upward force of air resistance balances the downward force of gravity, resulting zero acceleration.

Q.41 What are superfluids?

Ans. A superfluid is a phase of matter that flows without viscosity, meaning it can flow without losing K.E.

Q.42 What is the most notable property of superfluids?

Ans. They can flow through tiny pores and even climbs walls of containers without resistance.

Q.43 Are superfluids a state of matter?

Ans. Yes, they are a unique phase of matter under extremely low temperatures.

SOLVED EXERCISE

MULTIPLE CHOICE QUESTIONS

Tick (✓) the correct answer.

5.1 The region of stress-strain curve which obeys Hooke's law is:
(a) proportional limit✓ (b) elastic region (c) plastic region (d) yield limit

5.2 Which of the following is more elastic?
(a) Rubber (b) Wood (c) Sponge (d) Steel✓

5.3 Which of the following is polymer solid?
(a) Wool✓ (b) Glass (c) Sodium chloride (d) Copper

5.4 The effect of decrease of pressure with the increase in speed of a fluid in horizontal pipe is:
(a) Torricelli's effect (b) Bernoulli's effect (c) Venture's effect✓ (d) Doppler's effect

5.5 The pressure will be low when speed of a fluid is:
(a) zero (b) high✓ (c) low (d) constant

5.6 As per law of fluid friction for steady streamline flow, the friction:
(a) varies proportionally to velocity of fluid✓ (b) varies inversely proportional to pressure
(c) does not depend on pressure (d) first increases then decreases

5.7 If a stone is submerged in water and it weighs less in water than in air, this phenomenon is due to:
(a) the reduction of mass in water (b) increase of density in water
(c) buoyant force acting upwards✓ (d) the gravitational force acting upward

5.8 The principle of floatation is a direct application of:
(a) Pascal's law (b) Bernoulli's principle (c) Archimedes' principle✓ (d) Newton's third law

5.9 An ideal flow of any fluid must satisfy:
(a) Pascal law (b) Bernoulli's equation✓ (c) Continuity equation only (d) Both (b) and (c)

5.10 The lift force experienced by an aeroplane wings is primarily due to:
(a) viscosity of air (b) density of air
(c) pressure difference above and below the wing✓ (d) gravitational force

5.11 In medical field, a venture mask, used to deliver a known oxygen concentration to patients operates is based on:
(a) Newton's third law (b) Archimedes' principle (c) Pascal's law (d) Bernoulli's principle✓

5.12 Which of the following is a defining characteristic of a superfluid?
(a) Zero viscosity✓ (b) Infinite density (c) Zero temperature (d) Infinite thermal conductivity

SHORT ANSWER QUESTIONS

5.1 What is meant by (i) cohesive force (ii) viscosity?

Ans. Cohesive forcesare the attractive forces that act between molecules or particles of the same substance. These forces hold the molecules together, giving the material its structural integrity. In liquids, for example, cohesive forces are responsible for surface tension, as the molecules at the surface are more strongly attracted to each other than to the surrounding air. In solids, cohesive forces help maintain the shape and strength of the material.

Viscosity is a measure of a fluid's resistance to flow. In simple terms, it describes how 'thick' or 'sticky' a fluid is. It depends on the internal friction between the fluid's molecules.

5.2 Differentiate between streamline and turbulent flow of a fluid.

Ans. Streamline (Lamina) Flow:

A smooth, orderly flow of fluid in parallel layers, with no disruption between the layers is called streamline or laminar flow.

In streamline flow, fluid particles move in straight or gently curving paths, and their velocities remain constant at any fixed point. Energy loss is minimal due to reduced friction between layers.

Example: Flow of oil in a narrow tube or water flowing slowly through a smooth pipe.

Turbulent Flow

A chaotic, irregular flow where fluid particles move in random and fluctuating paths is called turbulent flow.

In turbulent flow, velocities change continuously at any point, leading to eddies and vortices. Energy loss is higher due to mixing and internal friction.

Example: River rapids, fast-moving water in pipes, or air turbulence around an airplane wing.

5.3 How does pressure changes with depth in fluids?

Ans. In fluids, pressure increases with depth due to the weight of the fluid above exerting force on the lower layers. This relationship can be described by the following equation:

$$P = P_o + \rho gh$$

Where:

P is the pressure at a given depth, P_o is the surface pressure (at the top of the fluid),ρ is the density of the fluid, and g is the acceleration due to gravity, h is the depth below the surface.

This means that as you go deeper into the fluid, the pressure increases linearly with depth. The deeper you go, the more fluid is above you, leading to an increase in pressure. The rate of increase depends on the fluid's density: denser fluids cause pressure to increase more quickly with depth.

5.4 How is variation in pressure related to speed of a fluid?

Ans. Variation in pressure is related to the speed of a fluid through Bernoulli's principle, which applies to incompressible, non-viscous, and steady flow. It states that;

"When the speed of a fluid increases, the pressure within the fluid decreases, and vice versa."

This is expressed mathematically as:

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

5.5 How is the flow rate related to the cross-sectional area and velocity of the fluid?

Ans. The flow rate (Q) of a fluid is related to the cross-sectional area (A) through which the fluid flows and the velocity (v) of the fluid using the following equation:

$$Q = A \cdot v$$

This equation implies that for a given flow rate, if the cross-sectional area increases, the velocity of the fluid must decrease, and vice versa. This principle is important in understanding fluid dynamics, especially in systems like pipes or channels.

5.6 How do you study the variation in velocity of a fluid at different points in a hose with varying diameter?

Ans. To determine the velocity of a fluid at different points in a hose with varying diameter, you can use the continuity equation from fluid dynamics, which is based on the principle of conservation of mass.The continuity equation is:

$$A_1v_1 = A_2v_2$$

Steps to determine the velocity

1. Measure or calculate the cross-sectional area at different points in the hose. The area A of a circular pipe or hose is given by

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

Where d is the diameter of the hose at the given point.

2. Apply the continuity equation. If you know the velocity at one point and the area at both points (A_1 and A_2), you can solve for the velocity at the other point:

$$v_2 = v_1\left(\frac{A_1}{A_2}\right)$$

This tells you that the velocity will increase when the diameter of the hose decreases (because the area decreases), and conversely, the velocity will decrease when the diameter increases, assuming the flow rate is constant.

Assumptions

(i) The fluid is incompressible (density does not change).

(ii) The flow is steady (the flow rate does not change with time).

This approach will give you the velocity of the fluid at various points along the hose based on changes in its diameter.

5.7 How does an object float or sink according to Archimedes Principle?

Ans. Archimedes' principle states that an object submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid it displaces. Whether an object floats or sinks depends on its density relative to the density of the fluid:

1. **Floating:** If the object is less dense than the fluid, it displaces enough fluid to generate a buoyant force greater than its own weight, causing it to float.
2. **Sinking:** If the object is denser than the fluid, it displaces less fluid than its weight, so the buoyant force is not enough to counteract gravity, and the object sinks.

In summary, the interplay between the object's density and the buoyant force determines if it floats or sinks.

5.8 How does Archimedes reportedly discover the principle that bears his name?

Ans. Archimedes reportedly discovered the principle that bears his name, known as Archimedes' principle, while he was taking a bath. According to the story, he noticed that the water level rose as he got into the tub, and this observation led him to realize that the volume of water displaced must be equal to the volume of the part of his body submerged in the water.

This discovery helped him understand the concept of buoyancy, which states that an object submerged in a fluid experiences an upward force equal to the weight of the displaced fluid. Archimedes is said to have been so excited by the realization that he ran through the streets shouting "Eureka!" which means "I have found it!" This moment of insight is considered one of the most famous "Eureka" moments in history.

5.9 Why standing near fast moving train is dangerous? Explain briefly.

Ans. Standing near a fast-moving train is dangerous due to the "wake" effect, where air pressure changes rapidly as the train moves. This can create strong gusts of wind that might push someone off balance or even pull them closer to the train. Additionally, the sheer force of the moving train can cause debris or objects to be thrown with high velocity, increasing the risk of injury. The proximity to the tracks also poses a danger of accidental contact with the train or being caught by the train's movement.

5.10 What are some potential applications of superfluidity?

Ans. Superfluidity, a phase of matter where a fluid flows with zero viscosity, has several intriguing potential applications across various fields. Here are a few possibilities:

1. **Quantum Computing:** Superfluids can play a role in quantum computing, especially in systems like quantum bits (qubits) that require quantum coherence and low friction environments. Superfluid helium-3, for example, could help stabilize quantum states for more efficient quantum computing.
2. **Energy Transport:** Superfluids can carry energy or information with zero resistance, making them ideal candidates for ultra-efficient energy transfer systems. In a superfluid, there would be no energy losses due to friction, potentially transforming power grids or data transmission.
3. **Frictionless Fluid Flow:** Superfluids can be used in systems requiring frictionless flow, such as in specialized pumps, fluid transport, or in advanced laboratory setups. For instance, in cooling systems, a superfluid could allow for highly efficient heat transfer with minimal energy loss.
4. **Astronomy and Astrophysics:** Superfluidity is theorized to occur in the cores of neutron stars. Understanding superfluids could help in explaining various phenomena in the universe, such as the behavior of matter under extreme conditions.
5. **Precision Measurement:** Superfluid helium is already used in highly sensitive gyroscopes, helping in precise measurements of rotation and magnetic fields. The properties of superfluids enable more accurate instruments for scientific research.
6. **Fundamental Physics Research:** Studying superfluidity in different systems provides insights into quantum mechanics, condensed matter physics, and the behavior of matter at extremely low temperatures. It helps scientists test and refine theories of quantum mechanics and particle physics.

While these applications are largely theoretical or experimental at this point, they could play significant roles in future technological advancements.

5.11 Differentiate between stress, strain and Young's modulus. Write down their SI units.

Ans. Stress

Force applied per unit area on an object is called stress.

It quantifies internal resisting force.

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

Its SI unit is pascal (Pa) or Nm^{-2}.

Strain

The ratio of change in dimension to the original dimension is known as strain.

It measures deformation.

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

As it is a ratio between two similar quantities, therefore, it is unitless (no unit).

Young's Modulus

The ratio of stress to strain in a material within the elastic limit is called Young's modulus.

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

Its SI unit is pascal (Pa) or Nm^{-2}.

CONSTRUCTED RESPONSE QUESTIONS

5.1 The ratio stress/strain remains constant for small deformation. What will be effect on this ratio when the deformation made is very large?

Ans. The ratio of stress to strain is called the modulus of elasticity or Young's modulus, and it remains constant only within the elastic limit of a material. This behaviour is described by Hooke's law, which states that stress is directly proportional to strain for small deformations in the elastic region.

When the deformation becomes very large:

1. **Elastic Limit Exceeded:** If the deformation goes beyond the material's elastic limit, it enters the plastic region. In this region:
   (i) The material undergoes permanent deformation, and stress is no longer proportional to strain.
   (ii) The ratio of stress to strain (modulus of elasticity) decreases because the material cannot recover its original shape.
2. **Material Weakening:** If the deformation continues to increase, the material may reach its yield point and eventually fracture. At this stage, the relationship between stress and strain becomes highly nonlinear.

5.2 When pure water falls on a flat glass plate, it spreads on the plate while the mercury, when falls on the same plate gets converted into small globules. Why?

Ans. The difference in behaviour of pure water and mercury on a glass plate arises due to their differing cohesive and adhesive forces:

1. **Pure Water**

(i) Water has strong adhesive forces between its molecules and the glass surface. Adhesion causes water molecules to be attracted to the glass, which spreads the water over the surface.

(ii) The cohesive forces (water molecules attracting each other) are weaker than the adhesive forces, allowing water to spread easily.

2. **Mercury**

(i) Mercury has very strong cohesive forces due to the metallic bonds between mercury atoms, which make the mercury molecules attract each other strongly.

(ii) The adhesive forces between mercury and glass are much weaker. As a result, mercury minimizes its contact with the glass surface and forms small, spherical globules to reduce its surface area and energy.

This difference in the behaviour of water and mercury is also related to the concept of surface tension: mercury has a much higher surface tension than water, further contributing to its tendency to form globules.

5.3 According to Bernoulli's theorem, the pressure of a fluid should remain uniform in a pipe of uniform radius. But actually, it goes on decreasing. Why is it so?

Ans. According to Bernoulli's theorem, the total energy per unit volume of an ideal, incompressible fluid in steady flow remains constant along a streamline. This energy includes pressure energy, kinetic energy, and potential energy. In a pipe of uniform radius, if the flow is steady, the velocity of the fluid should remain constant, and hence the pressure should theoretically remain constant too.

However, in real-life situations, the pressure of the fluid decreases along the length of the pipe due to viscous effects. These effects cause energy loss in the system, which Bernoulli's theorem does not account for because it assumes an ideal fluid with no viscosity. Let us see why this happens:

Reasons for Pressure Drop:

1. **Viscous Friction:** The fluid experiences friction with the walls of the pipe and within its own layers (internal friction). This dissipates mechanical energy as heat, leading to a continuous drop in pressure along the pipe.

2. **Turbulence:** If the fluid flow becomes turbulent, additional energy losses occur due to chaotic and irregular flow patterns, which further contribute to the pressure drop.
3. **Temperature Changes:** In some cases, variations in temperature can change the density and viscosity of the fluid, indirectly affecting pressure.

In summary, while Bernoulli's theorem applies to idealized, non-viscous fluid flow, real-world fluids are affected by viscosity and other dissipative forces, leading to a pressure decrease even in a pipe of uniform radius. This is why we observe a difference between theoretical predictions and practical observations.

5.4 Why wings of an aeroplane are rounded outward while flattened inward?

Ans. The wings of an aeroplane are designed with a curved shape, known as an airfoil, for several reasons related to aerodynamics:

1. **Lift Generation:** The outward curve (convex upper surface) helps generate lift. Air travels faster over the top of the wing and slower underneath. According to Bernoulli's principle, the faster-moving air on top creates lower pressure, while the slower air on the bottom creates higher pressure. This pressure difference produces lift, which is essential for flight.
2. **Reduced Drag:** The outward curve of the wing helps to streamline airflow over the wing, reducing drag and allowing for more efficient flight. The inward curve (concave lower surface) helps the airflow stay attached to the wing, reducing turbulence and further minimizing drag.
3. **Structural Stability:** The outward curve helps distribute the forces acting on the wing more evenly, contributing to the structural integrity and preventing excessive bending.

5.5 What is the difference in real fluid, ideal fluid and superfluid? Which of these really exits in the world? Explain.

Ans. The terms real fluid, ideal fluid, and superfluid are different types of fluids with varying characteristics:

1. **Ideal Fluid**

(i) An ideal fluid is a theoretical concept. It is a fluid that has no viscosity (resistance to flow) and is incompressible. Ideal fluids experience no internal friction, which means they don't lose energy as they flow.

(ii) It does not exist in the real world, but is used as an approximation in many fluid dynamics problems to simplify calculations.

2. **Real Fluid**

Real fluids are the fluids that exist in the real world. They have viscosity, meaning they experience internal friction and lose energy during flow. Examples include water, air, oil, and gases. Real fluids can be compressible or incompressible and exhibit complex behaviors, such as turbulence or laminar flow.

3. **Superfluid**

A superfluid is a state of matter that can flow without any viscosity. It occurs at very low temperatures, close to absolute zero, when certain substances, like liquid helium-4, lose all internal resistance to flow. Superfluids exhibit strange behaviors, such as the ability to flow through tiny pores without any resistance, climb up container walls, and display quantum mechanical effects on a macroscopic scale.

5.6 Why is the study of superfluids important for advancing our knowledge of low temperature physics?

Ans. The study of superfluids is crucial for advancing our understanding of low-temperature physics for several reasons:

1. **New States of Matter:** Superfluids represent a unique state of matter that exhibits remarkable properties, such as the ability to flow without viscosity. This phenomenon occurs at extremely low temperatures, typically near absolute zero, where quantum mechanical effects dominate. Studying superfluids helps us explore how matter behaves under these extreme conditions.
2. **Quantum Mechanics on a Macroscopic Scale:** Superfluids allow the macroscopic manifestation of quantum mechanics. For example, in superfluid helium-4, the entire fluid can exhibit quantum coherence, meaning the particles move in a collective, coordinated manner. This challenges our classical understanding of matter and opens up new avenues for studying quantum phenomena on a large scale.
3. **Understanding Quantum Phenomena:** Superfluids provide a platform for studying fundamental quantum effects, such as quantum vortices, Bose-Einstein condensation (BEC), and the role of particle interactions at very low temperatures. These phenomena are relevant for understanding other areas of quantum physics, including quantum computing and condensed matter physics.

4. **Testing Theories:** Superfluids serve as an experimental system to test theories of quantum mechanics and statistical physics in environments that are difficult to replicate otherwise. For example, the study of superfluids can test models of quantum liquids and help refine our understanding of phase transitions, critical points, and critical phenomena.

5. **Applications to Technology:** Although primarily of interest in fundamental physics, understanding superfluids also has practical applications. For example, the principles behind superfluidity have inspired innovations in cryogenics and are relevant for designing ultra-sensitive instruments like gyroscopes, accelerometers, and quantum sensors.

COMPREHENSIVE QUESTIONS

5.1 Explain in detail the classification of solids with respect to atomic arrangements.

Ans. *See Q. 1, Q. 2 and Q.3.*

5.2 What is Archimedes' principle? Explain it in detail for finding upthrust.

Ans. *See Q. 10.*

5.3 Justify that mass remains conserved when a fluid flows through a pipe.

Ans. *See Q. 15.*

5.4 Explain the term superfluidity.

Ans. *See Q. 22.*

5.5 State and derive equation of continuity.

Ans. *See Q. 15.*

5.6 State and prove Bernoulli's equation.

Ans. *See Q. 17.*

5.7 Give some practical applications of Bernoulli's equation.

Ans. *See Q. 18*

5.8 Define terminal velocity of a body and show that terminal velocity is directly proportional to the square of radius of the body.

Ans. *See Q. 20*

NUMERICAL PROBLEMS

5.1 A steel wire of length 2 metres and cross-sectional area of 2×10^{-6} m² is stretched by a force of 400 N. If the Young's modulus of steel is 2×10^{11} N m^{-2}, calculate the extension of the wire.

Solution:

Given data:

Original length of wire = L = 2 m

Cross-sectional area = $A = 2 \times 10^{-6}$ m

Force = F = 400 N

Young's modulus = $Y = 2 \times 10^{11}$ Nm^{-2}

To Find:

Extension of wire = ΔL = ?

Calculations: To calculate the extension of wire, we use Hooke's law in terms of Young's modulus (Y):

$$Y = \frac{FL}{A\Delta L}$$

or

$$\Delta L = \frac{FL}{AY}$$

Putting the values

$$\Delta L = \frac{400 \text{ N} \times 2 \text{ m}}{2 \times 10^{-6} \text{ m}^2 \times 2 \times 10^{11} \text{ Nm}^{-2}}$$

$$= \frac{800 \text{ Nm}}{4 \times 10^{5} \text{ N}}$$

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

$\Delta L = 2$ mm $= 0.002$ m **Ans.**

Thus, extension of the wire is 0.002 m.

5.2 A spring with a spring constant 200 N m^{-1} is stretched by 0.5 m. Find the elastic P.E. stored in the spring.

Solution:

Given data:

Spring constant = k = 200 Nm^{-1}

Extension = x = 0.5 m

To Find:

Elastic potential energy = $\frac{1}{2}kx^2$

Putting the values

$$\text{Elastic P.E.} = \frac{1}{2} \times 200\ \text{Nm}^{-1} \times (0.5\ \text{m})^2$$

$$= 100\ \text{Nm}^{-1} \times 0.25\ \text{m}^2$$

Elastic P.E. = 25 J **Ans.**

Thus, elastic P.E. stored in the spring is 25 J.

5.3 A copper wire of length 3 metres and cross-sectional area of 1×10^{-6} m^2 is subjected to a force of 500 N. Calculate the stress and strain produced in the wire. (Young's modulus of copper Y = 1.1×10^{11} N m^{-6})

Solution:

Given data:

Length of wire = L = 3 m

Cross-sectional area = A = 1×10^{-6} m^2

Force applied = F = 500 N

To find:

(i) Stress = ?

(ii) Strain = ?

Calculations:

(i) Using the formula:

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

$$\text{Stress} = \frac{500\ \text{N}}{1 \times 10^{-6}\ \text{m}^2}$$

$$= 5 \times 10^{8}\ \text{Nm}^{-2}$$ **Ans.**

To find strain, we need Young's modulus Y for copper:

$$Y_{Copper} = 1.1 \times 10^{11}\ \text{Nm}^{-2}$$

Strain is given by

$$\text{Strain} = \frac{\text{Stress}}{Y}$$

$$\text{Strain} = \frac{5 \times 10^{6}\ \text{Nm}^{-2}}{1.1 \times 10^{6}\ \text{Nm}^{-2}} = 4.545 \times 10^{-3}$$

Strain = 0.00455 **Ans.**

5.4 A block of wood of mass 10 kg and density of 600 kg m^{-3} is floating in water. Calculate the buoyant force acting on the block. (Density of water = 1000 kg m^{-3})

Solution:

Given data:

Mass of block = m = 10 kg

Density of block = ρ = 600 kg m^{-3}

Density of water = 1000 kg m^{-3}

Gravitational acceleration = g = 9.8 ms^{-2}

To Find:

Buoyant force = ?

Calculations: The buoyant force is equal to the weight of the fluid displaced by the submerged part of the object.

Since the block is floating, the buoyant force is equal to the weight of the block. Thus,

$$\text{Weight} = w = mg = 10\ \text{kg} \times 9.8\ \text{ms}^{-2}$$

$$w = 98\ \text{N}$$

Now, buoyant force = Weight of the block

= 98 N **Ans.**

5.5 Water flows through a pipe with a diameter of 0.05 m at a velocity of 2 ms^{-1}. If the pipe narrows to a diameter of 0.03 m, calculate the velocity of water at narrow section.

Solution:

Given data:

Diameter of wide pipe = D_1 = 0.05 m

Velocity of wide pipe = v_1 = 2 ms^{-1}

Diameter of narrow pipe = D_2 = 0.03 m

To Find:

Velocity at narrow section = v_2 = ?

Calculations: We can use principle of conservation of mass for incompressible fluids:

$$A_1 v_1 = A_2 v_2$$

As $$A = \frac{\pi D}{4}, \text{ so}$$

$$A_1 = \frac{\pi D_1}{4} = \frac{\pi\ (0.05\ \text{m})^2}{4}$$

$$= 1.9635 \times 10^{-3}\ \text{m}^2$$

and $$A_2 = \frac{\pi D_2}{4} = \frac{\pi\ (0.03\ \text{m})^2}{4}$$

$$= 7.0686 \times 10^{-4}\ \text{m}^2$$

Applying equation of continuity:

$$A_1 v_1 = A_2 v_2$$

or $$v_2 = \frac{A_1 v_1}{A_2}$$

Putting the values

$$v_2 = \frac{1.9635 \times 10^{-3}\ \text{m} \times 2\ \text{ms}^{-1}}{7.0686 \times 10^{-4}}$$

$$v_2 = 5.56\ \text{ms}^{-1}$$ **Ans.**

Thus, velocity of water in the narrow section is 5.56 ms^{-1}.

5.6 Water flows through a horizontal pipe with a velocity of 3 m s^{-1} and pressure of 200,000 Pa at point 1. At the nozzle (point 2), the pressure decreases to atmospheric pressure 101,300 Pa and the velocity increases to 14 m s^{-1}. Calculate the velocity of the water exiting the nozzle.

(Density of water = 1000 kg m^{-3})

Solution:

Given data:

$P_1 = 200,000\ Pa$

$v_1 = 3\ ms^{-1}$

$P_2 = 101,300\ Pa$

Density of water $\rho = 1000\ kg\ m^{-3}$

To find:

Velocity of water exiting the nozzle = v_2 = ?

Calculations: Using Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Since the pipe is horizontal, $h_1 = h_2$, so the above equation becomes:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

Putting the values

$$200,000\ Pa + \frac{1}{2} \times 1000\ kg\ m^{-3} \times (3\ ms^{-1})^2 = 101,300\ Pa + \frac{1}{2} \times 1000\ kg\ m^{-3} \times v_2^2$$

$$200,000\ Pa + 4500\ kg\ ms^{-2} = 101,300\ Pa + 500\ kg\ m^{-3} \times v_2^2$$

$$204,500 = 101,300 + 500\ v_2^2$$

$$500\ v_2^2 = 204,500 - 101,300$$

$$500\ v_2^2 = 103,200$$

$$v_2^2 = \frac{103,200}{500}$$

$$v_2^2 = 206.4$$

$$v_2 = \sqrt{206.4}$$

$$= 14.37\ ms^{-1}$$ **Ans.**

Thus, velocity of water existing the nozzle is 14.37 ms^{-1}.

5.7 A tank filled with water has a hole at a depth of 5 m from the water surface. Calculate the velocity of water flowing out of the hole.

Solution:

Given data:

Depth from water surface = h = 5 m

Acceleration due to gravity = g = 9.8 ms^{-2}

Calculations: To calculate the velocity of water flowing out of a hole in a tank, we can use Torricelli's law:

$$v = \sqrt{2gh}$$

Putting the values

$$v = \sqrt{2 \times 9.8\ ms^{-2} \times 5m}$$

$$= \sqrt{98\ m^2s^{-2}} = 9.9\ ms^{-1}$$ **Ans.**

5.8 Calculate the terminal velocity of a spherical raindrop with a radius 0.5 mm falling through the air. (7 for air = 19 ×10⁻⁶ kg m⁻¹ s⁻¹ , p= 1000 kg m⁻³ for water)

Solution:

Given data:

Radius of raindrop = r = 0.5 mm = 0.5×10^{-3} m

Gravitational acceleration = g = 9.8 ms^{-2}

Coefficient of viscosity for air = η = $19 \times 10^{-6}\ kg\ m^{-1}\ s^{-1}$

Density of water = ρ = 1000 $kg\ m^{-3}$

To find:

Terminal velocity = v_t = ?

Calculations: Using the formula:

$$v_t = \frac{2gr^2\rho}{9\eta}$$

Putting the values

$$v_t = \frac{2 \times 9.8\ ms^{-1} \times (0.5 \times 10^{-3}\ m)^2 \times 1000\ kg\ m^{-3}}{9 \times 19 \times 10^{-6}\ kg\ m^{-1}\ s^{-1}}$$

$$= \frac{2 \times 9.8 \times 2.5 \times 10^{-7} \times 1000}{9 \times 19 \times 10^{-6}} = \frac{4.9 \times 10^{-3}}{1.71 \times 10^{-4}}$$

$$v_t = 28.65\ ms^{-1}$$ **Ans.**