Acceleration due to gravity (g) = 9.8 m/s² (since W = mg, m = W / g = 98 N / 9.8 m/s² = 10 kg)

To find: Frictional force (f)

Concept:

This problem involves the work-energy theorem in a resistive medium. The initial potential energy is converted into kinetic energy and work done against friction.

Loss in Potential Energy = Gain in Kinetic Energy + Work done against friction

Formulas:

$PE_{initial} = mgh$

$KE_{final} = \frac{1}{2}mv_{final}^2$

Work done against friction = f × h (since friction acts over the height of fall)

Calculations:

Calculate the mass (m):

$m = W / g = 98\ N / 9.8\ m/s^2 = 10\ kg$

Set up the energy balance equation:

$PE_{initial} = KE\_final + (f \times h)$

$mgh = \frac{1}{2}mv\_final^2 + fh$

Substitute the values:

$(10\ kg)(9.8\ m/s^2)(10\ m) = \frac{1}{2}(10\ kg)(12\ m/s)^2 + f(10\ m)$

$980\ J = 5\ kg \times 144\ m^2/s^2 + 10f$

$980\ J = 720\ J + 10f$

$10f = 980\ J - 720\ J$

$10f = 260\ J$

$f = 260\ J / 10\ m = 26\ N$

Therefore, the frictional force acting on the object is 26 N.

4.5 A 75 watt fan is used for 8 hours daily for 30 days. Find:

(i) energy consumed in electrical units

(ii) electricity bill o'f an if one unit cost is Rs.22.5?

Given

Power of fan = p = 75 W = 0.075 kW

Time to use in a day = 8 h

No. of days = 30

Total time = t = 8 × 30 = 240 h

To Find

Energy consumed = ?

Electrical bill = ?

Cost for one unit = Rs 22.5

Solution:

i. Energy consumed = p × t = 0.075 × 240 = 18 kWh

ii. Electrical bill = energy consumed × cost for one unit = 18 × 22.5 = Rs 405

4.6 If an object of mass 2 kg is thrown up from ground reaches a height of 5m and falls back to the Earth (neglecting air resistance), calculate:

(i) **Work done by gravity when object reaches at 5m height.**

(ii) **Work done by gravity when the object comes back to the Earth.**

(iii) **Total work done by gravity in upward and downward motion. Also mention physical significance of the result.**

Given

Mass of object = m = 2 kg

Height reached by object = h = 5 m

Solution:

(i) Work done for the height 5 m = W_1 = ?

$W_1 = -mgh = -2 \times 9.8 \times 5 = -98\ J$

(ii) Work done for downward motion = W_2 = ?

$W_2 = mgh = 2 \times 9.8 \times 5 = 98\ J$

(iii) Total work done = $W = W_1 + W_2 = -98 + 98 = 0\ J$

Physical Significance of the Result:

The physical significance of the total work done by gravity being zero in a closed path (object goes up and comes back down to the starting point) is that gravity is a conservative force. For any conservative force, the net work done over a closed loop is always zero. This implies that no mechanical energy is lost or gained from the system due to the action of gravity over a complete cycle

4.7 An electrical motor of one horse power is used to run a water pump. Water pump takes 15 minutes to fill a tank of 400 liters at a height of 10m. Find:

(a) **Actual work done by electric motor to full the tank**

(b) **Actual output work done**

Given

Power of motor = P = 1 hp = 746 watt

Time taken = t = 15 min = 15 × 60 = 900 s

Volume of water = 400 litre = $400 \times 10^{-3}\ m^3$

Mass of water = Density x volume

$= 1000 \times 400 \times 10^{-3} = 400\ kg$

Height = h = 10 m

(a) Work done by electric motor = W_{input} = ?

$W = P \times t = 746 \times 900 = 671400\ J$

(b) work done on water = W_{output} = mgh = $400 \times 9.8 \times 10 = 39200\ J$

$$\text{Percentage efficiency} = \eta = \frac{W_{output}}{W_{input}} \times 100$$

$$\eta = \frac{39200}{671400} \times 100 = 5.84\ \%$$

(Note: The efficiency of the pump can be calculated as Output Work / Input Work = 39.2 kJ / 671.4 kJ ≈ 5.84%, indicating that a significant amount of input energy is lost, likely as heat due to inefficiencies in the motor and pump.)

4.8 A passenger just arrived at the airport and dragging his suitcase to luggage checks in desk. He pulls strap with a force of 200 N at an angle of 45°to the floor to displace it 50mtothedesk.Determine the value of work done by him on the suitcase.

Given

Pulling force = F = 200 N

Angle = θ = 45°

Displacement = d = 50 m

To Find

Work done = W = ?

Solution:

$W = Fd \cos\theta$

$W = (200)(50) \cos 45^\circ$

$W = 7071\ J = 7\ kJ$

4.9 A 1200 kg car is running at a speed of 40 km h⁻¹. How much power will be expended by it to accelerate at 2 m s⁻²?

Given:

Mass of car (m) = 1200 kg

Speed (v) = 40 km h^{-1} (This is the instantaneous speed at which power is being expended for acceleration)

Acceleration (a) = 2 m s^{-2}

To find: Power expended (P)

Concept:

Power can be defined as the product of force and velocity (P = F · v). To accelerate the car, a net force is required.

Formulas:

Force (F) = ma (Newton's Second Law)

Power (P) = Fv

Calculations:

Convert speed to m/s:

$v = 40\ km\ h^{-1} = 40 \times (1000\ m / 3600\ s) = 40 \times (5/18)\ m/s \approx 11.11\ m/s$

Calculate the force required for acceleration:

$F = ma = 1200\ kg \times 2\ m/s^2 = 2400\ N$

Calculate the power expended:

$P = Fv = 2400\ N \times 11.11\ m/s$

$P = 26664\ W$

Convert power to kilowatts (kW):

$P = (26664 / 1000)\ kW = 26.664\ kW$

Therefore, the power expended by the car to accelerate at 2 m s^{-2} while moving at 40 km h^{-1} is approximately 26.67 kW.

4.10. A 200 g apple is lifted to 10 m and then dropped. What is its velocity when it hits the ground? Assume that 75% of work done in lifting the apple is transferred to K.E. by the time it hits the ground.

Given

Mass of apple = m = 200 g = 0.2 kg

Height = 10 m

K.E = 75 % of Work done

To Find

v = ?

Solution:

$W = mgh = 0.2 \times 9.8 \times 10 = 19.6\ J$

As K.E = 75% W

$\frac{1}{2}mv^2 = \frac{75}{100} \times W$

$\frac{1}{2}(0.2)v^2 = \frac{75}{100} \times 19.6$

$v^2 = \frac{1}{0.2}2 \times 0.75 \times 19.6 = 147$

$v = 12.1\ m\ s^{-1}$

* * *

CHAPTER 5

SOLIDS AND FLUID DYNAMICS

STUDENT LEARNING OBJECTIVES

After studying this chapter, 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 $E_r = -fcx^2$ 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 superfluidity [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 contamers 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 golfball (the Magnus effect), the use of Venture ducts in filter pumps and car engineers to adjust the flow of fluid, etc.

MATTER:

Everything, which has, mass and occupies space, is called matter.

Or

Matter is compact form of energy.

Types of Matter:

Matter is classified into following four groups, i.e.

i. Solid
ii. Liquid
iii. Gas
iv. Plasma (a gas having ionized atoms)

SOLID

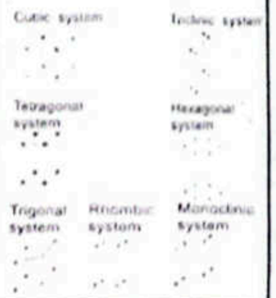
Solid is one of the four fundamental states of matter. The molecules in a solid are closely packed together and contain the least amount of kinetic energy.

SOLID STATE PHYSICS

The branch of physics concerned with the study of structure and properties (e.g. mechanical, electrical, magnetic etc.) of solids is known as solid state physics.

For Your Information

There are seven different crystals systems based on the geometrical arrangement of their atoms and the resultant geometrical structures.

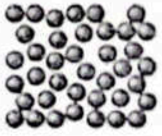


5.1 CLASSIFICATION OF SOLIDS

Q. Distinguish Between the Structure of Crystalline, Glassy, Amorphous and Polymeric Solids.

Ans

Using X-ray technique, the order of arrangement of atoms in solids can be studied. On the basis of arrangement of atoms, ions and molecules, solids are classified into three categories.

Crystalline Solids	Amorphous Solids	Polymeric Solids
Definition		
Solids in which atoms irons are molecules all arrays in a regular and repeating pattern that is constant throughout the crystal there is this ordered structure in crystalline solids	The solids in which there is no regular arrangement of molecules like that in crystalline soils are called amorphous solid amorphous are also called velocity solids	A polymeric solid is a material made of **long-chain molecules (polymers)**, which are formed by repeating smaller units (monomers) joined by **covalent bonds**. These solids can be **amorphous (disordered)** or **semi-crystalline (partially ordered)**
Other names		
Crystalline solids are called true solids	amorphous solids are also called glasses solids are non-crystalline solids	polymeric solids are also called intermediate solids and partially or poorly crystalline solids
Examples		
Metals like cu, Fe, Zn and some compound like sodium chloride and ceramics like zirconia are crystalline solids.	Ordinary glass is an amorphous solid.	Polythene, polystyrene, nylon and natural rubber $(C_5H_8)_m$ such solids contain carbon with O_2, N_2, H_2 etc.
Diagram		
		

Melting point		
Crystalline solids have sharp or definite melting point.	On heating glass gradually soften into a paste like state before becoming a viscose liquid at 800C. Amorphous solids do not have sharp melting point.	Polymeric solids do not have sharp melting point
Advantages		
When crystalline solids cuts with a sharp-edged tool, they split into two pieces and the newly generated surfaces are plain, smooth and shiny	Amorphous solids are generally more soluble and faster dissolving than their crystalline counterparts. They are inexpensive to produce.	These materials have rather low specific gravity compared with even the lightest of metals yet exhibit good strength to weight ratio. Their properties, like flexibility and strength, are determined by factors such as chain length and intermolecular forces.

Q. What is crystal lattice, Explain its significance?

Ans

UNIT CELL:

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

CRYSTAL LATTICE:

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

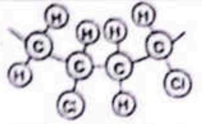
-OR-

A crystalline solid consists of three dimensional patterns of unit cell that repeat it over and over again.

For example:

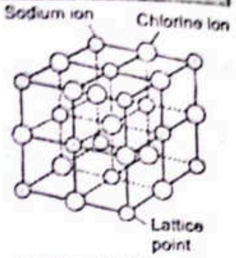
The pattern of NaCl particles has a cube shape. In a cube crystal, all the sides meet at right angles.

For your information



Parts of a PVC molecule

For your information



NaCl crystal lattice

MULTIPLE CHOICE QUESTIONS

- **Which type of solid has a disordered arrangement of molecules and softens gradually upon heating?**
  (a) Crystalline (b) Amorphous (c) Polymeric (d) Metallic

Answer: (b) Amorphous

Explanation: Amorphous solids, like glass, lack a regular molecular structure and do not have a sharp melting point, softening over a range of temperatures.

- **The atoms, molecules, or ions in a crystalline solid primarily vibrate about:**
  (a) Random positions (b) Moving positions (c) Fixed equilibrium positions (d) Free paths

Answer: (c) Fixed equilibrium positions

Explanation: In crystalline solids, particles are arranged in a regular, ordered pattern and vibrate around specific, fixed lattice points.

- **Which of the following is an example of a polymeric solid?**
  (a) Quartz (b) Sodium Chloride (c) Polythene (d) Diamond

Answer: (c) Polythene

Explanation: Polythene is a synthetic material formed from long chains of simple molecules, characteristic of polymeric solids.

- **What is a key difference in the melting behavior between crystalline and amorphous solids?**
  (a) Crystalline solids melt at higher temperatures.
  (b) Amorphous solids melt at higher temperatures.
  (c) Crystalline solids have a definite melting point.
  (d) Amorphous solids have a definite melting point.

Answer: (c) Crystalline solids have a definite melting point.

Explanation: The ordered structure of crystalline solids breaks abruptly at a specific temperature, defining a sharp melting point, unlike amorphous solids which soften gradually.

- **Which technique is commonly used to study the arrangement of atoms in crystalline solids?**
  (a) Optical Microscopy (b) X-ray Diffraction (XRD)
  (c) Electron Spin Resonance (ESR) (d) Nuclear Magnetic Resonance (NMR)

Answer: (b) X-ray Diffraction (XRD)

Explanation: XRD is a primary technique for determining the atomic and molecular structure of crystals, based on the diffraction pattern produced by X-rays interacting with the crystal lattice.

SLO BASED SHORT QUESTIONS & ANSWERS

- **How do cohesive forces contribute to the properties of crystalline solids?**

Ans: Cohesive forces maintain the strict long-range order in crystalline solids despite atomic vibrations, giving them a defined structure.

- **Why are amorphous solids sometimes called "glassy solids"?**

Ans: They are called "glassy solids" because their disordered structure is essentially "frozen in" like a highly viscous liquid at ordinary temperatures.

- **What are plastics and synthetic rubbers classified as, and why?**

Ans: They are classified as polymeric solids because they are formed by polymerization reactions into long-chain or three-dimensional massive molecules.

- **Can atoms in a crystalline solid be considered completely static? Explain.**

Ans: No, atoms in a crystalline solid vibrate about fixed points, with the amplitude increasing with temperature; it is their *average* positions that are ordered.

- **Give an example of a naturally occurring polymer.**

Ans: Natural rubber is an example of a naturally occurring polymer.

For Your Information

Q: **How can the arrangement of molecules, atoms, or ions within all types of crystalline solids be studied?**

Ans: The arrangement can be studied using various techniques such as X-ray Diffraction (XRD) and Transmission Electron Microscopy (TEM).

Q: **What are "glassy solids" also called and what is their characteristic regarding melting point?**

Ans: Amorphous solids are also called glassy solids. This type of solid has no definite melting point.

5.2 DEFORMATION

Q. What is deformation? Discuss its types with examples.

Ans

DEFINITION OF DEFORMATION:

If an external force applied on an object, it produces change in in length, volume or shape of a body, then this force is called deformation.

TYPES OF DEFORMATION

There are three types of deformation

1. Linear Deformation

2. Volume Deformation
3. Shear Deformation

1. **Linear Deformation**

Linear deformations the change in length, when a body is subjected to some external force.

Example: Stretching of a rubber

2. **Volume Deformation:**

Volume deformation is the change in volume, when a body is subjected to some external force.

Example: Compression of underground rocks and fossils.

3. **Shear deformation:**

Shear deformation is the change in shape, when a body is subjected to some external force.

Example: Deformation of sole of shoe while jogging

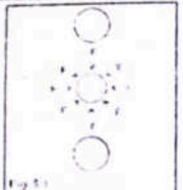
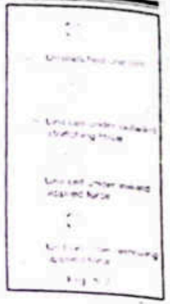


Fig 5.1
(a) Original rubber ball
(b) Squeezed rubber ball subjected force F by the hand
(c) rubber ball after removing force



MULTIPLE CHOICE QUESTIONS

- **The change in shape, length, or volume of a body due to an external force is called:**
  (a) Elasticity (b) Stress (c) Strain (d) Deformation

Answer: (d) Deformation

Explanation: Deformation is the general term for any change in the physical dimensions or shape of a body.

- **A material's ability to return to its original shape after the removal of an external force is known as:**
  (a) Plasticity (b) Hardness (c) Elasticity (d) Brittleness

Answer: (c) Elasticity

Explanation: Elasticity is the property that allows a body to regain its original dimensions after the deforming force is removed, provided the elastic limit is not exceeded.

- **What causes distortion in solid bodies at an atomic level when subjected to an external force?**
  (a) Increase in temperature
  (b) Displacement of atoms from equilibrium positions
  (c) Breaking of atomic bonds
  (d) Change in material density

Answer: (b) Displacement of atoms from equilibrium positions

Explanation: External forces cause atoms in crystalline solids to be displaced from their stable equilibrium positions, leading to distortion.

- **If a rubber ball does not return to its original shape after being squeezed, it has undergone:**
  (a) Elastic deformation (b) Ideal deformation (c) Plastic deformation (d) No deformation

Answer: (c) Plastic deformation

Explanation: If a body does not regain its original shape after the force is removed, it means it has undergone permanent, or plastic, deformation.

- **Which of the following is necessary to produce deformation in a body?**
  (a) Internal cohesive forces (b) Thermal expansion (c) External force (d) Atmospheric pressure

Answer: (c) External force

Explanation: Deformation is directly caused by the application of an external force that alters the body's shape, length, or volume.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is the condition under which a body regains its original shape after an external force is removed?**

Ans: The external applied force must not have been too great, i.e., within the elastic limit of the material.

- **How do inter-atomic cohesive forces relate to a material's resistance to deformation?**

Ans: Inter-atomic cohesive forces hold atoms in their equilibrium positions, and their strength determines how much external force is needed to cause distortion.

- **Give a common example of elastic deformation from daily life.**

Ans: Stretching a rubber band and releasing it, or squeezing a rubber ball and letting it go.

- **What is implied when a body is said to be in a "state of stress" due to an external force?**

Ans: It implies that internal restoring forces are generated within the body to counteract the external force and resist deformation.

- **If a solid body is deformed, what happens to the atoms holding it together?**

Ans: The atoms are displaced from their equilibrium positions, leading to a change in the body's overall shape or size.

5.3 STRESS, STRAIN, AND YOUNG'S MODULUS:

Q. **What is Stress? Discuss its types.**
What is Strain? Discuss its types.
What is Young's Modulus? Discuss its types.

STRESS:

Force per unit area that can produce a deformation in the body is called stress.

Symbol:

It is represented by a symbol σ.

Formula

Mathematically, stress is given by:

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

Unit:

The unit of stress is Nm^{-2} which is also called Pascal.

Types of stress:

i. **Linear Stress:**

Force per unit area that produce change in the length of a body is called linear stress.

Tensile stress: If the linear stress increases the length of a body, it is called tensile stress.

Compressive stress: If the linear stress decreases the length of a body, it is called compressive stress.

Formula:

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

ii. **Volume Stress:**

Force per unit area that produce change in the volume of a body is called volume stress.

Formula:

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

iii. **Shear Stress:**

Force per unit area that produce change in the shape of a body is called shear stress.

Formula:

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

STRAIN:

Measure of deformation when stress is applied is called strain.

Symbol:

It is represented by a symbole.

Formula

Mathematically, stress is given by;

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

Unit:

Strain is the ratio between two same quantities, so it has no unit.

Types of strain:

i. **Linear strain:**

Fractional change in length of a body is called linear strain.

- **Tensile strain:**
  - If the stress increases the length of a body, the strain produced is called tensile strain.
- **Compressive strain:**

If the stress decreases the length of a body, the strain is called compressive strain.

Formula:

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

ii. **Volume Strain:**

Fractional change in volume of a body is called volume strain.

$$\text{Volume Strain} = \varepsilon = \frac{\Delta v}{v}$$

iii. **Shear Strain**

Strain produced due to shear stress is called shear strain.

$$\text{shear strain} = \varepsilon = \frac{\Delta a}{a} \tan\theta$$

Fig. 5.3(a): Tensile strain

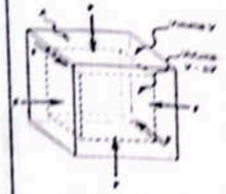


Fig. 5.3(b): Volumetric strain

Fig. 5.3(c): Shear strain

Table 5.1: Elastic constants for some

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

For your information

Although it is named after the 19th century British Scientist Thames Young, the concept was developed in 1727 by Leonhard Euller.

MODULUS OF ELASTICITY

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

Formula

Modulus of elasticity is given by;

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

Unit

The unit of modulus of elasticity Nm^{-2} or Pascal.

Dependence

It depends upon following factors:

(i) Nature of material

(ii) Temperature

Physical Meaning

Numerical value of modulus of elasticity gives an idea about how much rigid a body will be.

Example

- Rubber has less value of modulus of elasticity.
  That is why it is not very rigid (less elastic).

- Steel has more value of modulus of elasticity.
  That is why it is very rigid (more elastic).

Types of Modulus of Elasticity

i. **Young's Modulus (Y):**

The ratio of linear stress (tensile or compressive) to linear strain (tensile of compressive) is called Young's modulus.

Formula:

$$Y = \frac{\text{linear stress}}{\text{linear strain}} = \frac{F/A}{\Delta L/L}$$

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

Existence:

Young's modulus exists only for solids.

ii. **Bulk Modulus (K):**

The ratio of volume stress to volume strain is called Bulk modulus.

Formula:

$$K = \frac{\text{volume stress}}{\text{volume strain}} = \frac{F/A}{\Delta V/V}$$

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

Existence:

Bulk modulus exists for solid, liquid and gases.

iii. **Shear Modulus (G)**

The ratio of shear stress to shear strain is called shear modulus.

Formula:

$$G = \frac{\text{shear stress}}{\text{shear strain}} = \frac{F/A}{\Delta a/a}$$

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

Existence:

Shear modulus exists only for solids.

MULTIPLE CHOICE QUESTIONS

- **The SI unit of stress is equivalent to:**

(a) Joule (b) Newton per meter (c) Pascal (d) Watt

Answer: (c) Pascal

Explanation: Stress is force per unit area (N/m^2), which is defined as Pascal (Pa).

- **Which type of strain is dimensionless?**

(a) Tensile strain (b) Volumetric strain (c) Shear strain (d) All of the above

Answer: (d) All of the above

Explanation: Strain is defined as a ratio of two lengths (or volumes), making it a dimensionless quantity.

- **If a force is applied to a body that changes its volume, the resulting stress is called:**

(a) Tensile stress (b) Shear stress (c) Volume stress (d) Compressive stress

Answer: (c) Volume stress

Explanation: Volume stress, or bulk stress, specifically refers to stress that causes a change in the volume of a body

- **Young's Modulus is a measure of a material's:**

(a) Ductility (b) Brittleness (c) Stiffness (d) Malleability

Answer: (c) Stiffness

Explanation: Young's Modulus quantifies a material's resistance to elastic deformation under tensile or compressive stress, which is a measure of its stiffness.

- **When shear stress is applied to a rigid body, what type of deformation is primarily observed?**

(a) Change in length (b) Change in volume (c) Change in shape (d) Change in density

Answer: (c) Change in shape

Explanation: Shear stress causes one part of the body to slide relative to another, resulting in a change in the body's overall shape, without necessarily changing its length or volume significantly.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Why does strain have no units?**

Ans: Strain is a ratio of two quantities of the same dimension (e.g., length/length or volume/volume), so their units cancel out, making it dimensionless.

- **Distinguish between tensile stress and compressive stress.**

Ans: Tensile stress tends to stretch or elongate a body, while compressive stress tends to shorten or compress it.

- **What is the significance of the tangent of the angle θ in the context of shear strain?**

Ans: In shear strain, tan θ represents the ratio of the lateral displacement (Δx) to the distance between the shearing surfaces (y), directly defining the shear strain.

- **How does the Young's modulus of a material relate to its ability to deform?**

Ans: A higher Young's modulus indicates that the material is stiffer and requires a larger stress to produce a given amount of strain (deformation).

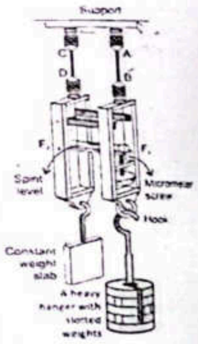
- **Can a material have tensile stress without experiencing tensile strain? Explain.**

Ans: No, according to the definition, stress is applied *to produce* any change in shape, volume, or length. If a tensile stress is applied, a corresponding tensile strain must occur, even if very small.

5.4 DETERMINATION OF YOUNG'S MODULUS OF A WIRE

Q. How can we determine young's Modulus by Searl's method?

Ans



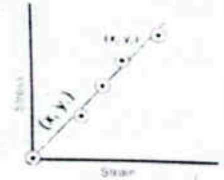
The magnitude of Young's modulus for a material in the form of wire can be found out mostly with the help of Searle's apparatus as shown in Fig.

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.

Procedure:

The following procedure is adopted for finding Young's modulus of a wire experimentally.

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 gauge. The diameter should be measured at several different points along the wire and take average.
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 the stress and strain by the following formula:

$$Stress = \frac{weight}{Areaofwire} = \frac{F}{A} = \frac{mg}{\pi r^2}$$

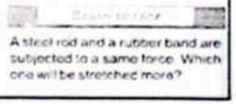
$$Strain = \frac{\Delta L}{L_o} = \frac{ChangeinLength}{OriginalLength}$$

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 wire.

Brain Teaser

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

Ans: A rubber band will be stretched more, because its modulus of elasticity is smaller than steel rod.


Brain teaser

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

MULTIPLE CHOICE QUESTIONS

- **In Searle's apparatus, what is the purpose of the reference wire?**

(a) To apply the primary load
(b) To act as a control for temperature and sagging
(c) To measure the diameter of the test wire
(d) To provide tension for the spirit level

Answer: (b) To act as a control for temperature and sagging

Explanation: The reference wire compensates for any changes in length due to temperature fluctuations or sagging of the support, ensuring that only the elongation due to the applied load on the test wire is measured.

- **What instrument is used to measure the diameter of the wire in Searle's method?**

(a) Metre scale (b) Vernier caliper (c) Screw gauge (d) Measuring tape

Answer: (c) Screw gauge

Explanation: A screw gauge provides high precision for measuring small diameters, essential for accurate area calculations.

- **How is the elongation (extension) of the test wire primarily measured in Searle's apparatus?**

(a) By observing the direct change in length with a ruler
(b) Using a spring balance attached to the wire
(c) By adjusting a micrometer screw to restore a spirit level to horizontal
(d) By measuring the mass of displaced water

Answer: (c) By adjusting a micrometer screw to restore a spirit level to horizontal

Explanation: The micrometer screw is carefully adjusted to bring the spirit level back to its horizontal reference position, and the change in its reading gives the precise extension.

- **The stress-strain graph plotted from Searle's apparatus data should ideally be:**

(a) A curve indicating plastic deformation (b) A straight line passing through the origin
(c) A parabolic curve (d) A horizontal line

Answer: (b) A straight line passing through the origin

Explanation: Within the elastic limit where Hooke's Law applies, stress is directly proportional to strain, resulting in a straight line graph passing through the origin.

- **What does the slope of the stress-strain graph represent in Searle's experiment?**

(a) Strain energy (b) Elastic limit (c) Young's Modulus (d) Ultimate tensile strength

Answer: (c) Young's Modulus

Explanation: By definition, Young's modulus is the ratio of stress to strain (Stress/Strain), which corresponds to the slope of the linear portion of the stress-strain graph.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Why is it important for the reference wire and test wire to be of the same material and equal length in Searle's apparatus?**

Ans: To ensure that any thermal expansion/contraction or sagging affects both wires equally, allowing only the extension due to the applied load on the test wire to be measured accurately.

- **Explain how the spirit level is used to detect and measure elongation in Searle's method.**

Ans: When the test wire elongates, the horizontal bar (frame F2) tilts, causing the spirit level to go off balance. Adjusting the micrometer screw to restore the spirit level to horizontal directly measures the elongation.

- **Why is the diameter of the wire measured at several points and averaged?**

Ans: To account for any irregularities or non-uniformity in the wire's diameter, ensuring a more accurate calculation of the cross-sectional area.

- **What formula is used to calculate the stress applied to the wire in Searle's experiment?**

Ans: Stress = $F/A=(mg)/(\pi r2)$, where m is the mass added, g is acceleration due to gravity, and r is the radius of the wire.

- **What would a non-linear stress-strain graph imply about the material being tested in Searle's apparatus?**

Ans: A non-linear graph would imply that the material has exceeded its proportional limit and Hooke's Law is no longer obeyed, indicating either elastic or plastic deformation depending on the re

For Your Information

Q: **Who developed the concept of Young's Modulus, and when?**

Ans: Although it is named after the 19th-century British Scientist Thomas Young, the concept was developed in 1727 by Leonhard Euler.

Q: **What does the area under a force-extension graph represent?**

Ans: The area under a force-extension graph represents the work done to stretch the material. This work done is also equal to the elastic potential energy stored in the material.

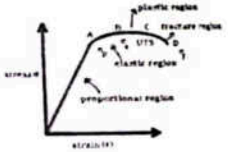
5.5 ELASTIC DEFORMATION, PLASTIC DEFORMATION AND ELASTIC LIMIT:

Q.

Ans

ELASTIC LIMIT AND YIELD STRENGTH:

The mechanical properties of a material can be determined in tensile test by universal testing machine. In a tensile test, a metallic wire is extended in a mechanical testing machine and a deforming force is applied. During the deformation, an electric device fitted in the machine measures a specified deformation rate and stresses generated in the wire. A typical Force elongation diagram or stress-strain curve is plotted for a ductile material is shown in fig.



From the figure, we see that the stress is proportional to the strain up to the point A and is called proportional limit (σ_P)

Proportional Limit (σ_P):

It is defined as;

The maximum stress, which a material can suffer without losing straight line proportionality between stress and strain.

For all practical purposes, the proportional limit (δ_P) can be regarded as identical with the elastic limit (σ_e).

Hook's Law:

According to Hook's law, the strain is directly proportional to stress, as obeyed in the region OA.

Elastic Limit (σ_e):

It is defined as "the maximum stress that a material can withstand without having a permanent change in its shape"

Elastic Deformation

Deformation produced which is temporary and the material can regain its original shape or dimension such a temporary deformation is also known as elastic deformation.

Plastic Deformation

If the stress is increased beyond the elastic limit, then deformation becomes permanent and the body does not regain its original shape or dimension after the stress is removed such deformation is called plastic deformation.

Plasticity:

If the stress is increased beyond the elastic limit, then deformation becomes permanent and the body does not regain its original shape or dimension after the stress is removed This phenomenon is called plasticity.

Yield Point

The point at which the material transforms from elastic to plastic is known as the yield point.

Ultimate Tensile Strength (UTS):

It is defined as;

The maximum stress that a material can withstand and can be regarded as a normal strength of the material.

It is denoted by δ_m it is represented by the point C strain-stress curve.

Fracture Stress:

The stress at which the material breaks is known as fracture stress.

Once the point C corresponding to UTS is crossed, the material breaks.

Ductile Substances:

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

For examples; lead, copper, wrought iron etc.

Brittle Substances:

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

For example; glass, high carbon steel etc.

MULTIPLE CHOICE QUESTIONS

- **In the stress-strain curve, the region where the material will return to its original state if the load is removed is called:**

(a) Proportional limit (b) Elastic region (c) Plastic region (d) Fracture point

Answer: (b) Elastic region

Explanation: The elastic region (from O to B) is where deformation is temporary and reversible; the material recovers its original shape upon load removal.

- **What is the "yield point" on a stress-strain curve?**

(a) The point where the material breaks
(b) The maximum stress the material can withstand
(c) The point beyond which plastic deformation begins
(d) The point where Hooke's Law is strictly obeyed

Answer: (c) The point beyond which plastic deformation begins

Explanation: The yield point (Point B, also known as the elastic limit) marks the boundary between elastic and plastic deformation; beyond this, permanent deformation occurs

- **Substances that break just after the elastic limit is reached, with little plastic deformation, are known as:**

(a) Ductile substances (b) Malleable substances (c) Brittle substances (d) Elastic substances

Answer: (c) Brittle substances

Explanation: Brittle materials show very little plastic deformation and fracture abruptly once their elastic limit is exceeded

- **What does the Ultimate Tensile Strength (UTS) represent on a stress-strain curve?**

(a) The stress at which the material first deforms
(b) The stress at which the material becomes elastic
(c) The maximum stress a material can withstand before necking/fracture
(d) The stress at which Hooke's Law is no longer valid

Answer: (c) The maximum stress a material can withstand before necking/fracture

Explanation: UTS (Point C) is the peak stress the material can endure before it starts to narrow significantly (necking) and eventually fails

- **If a material's stress-strain curve shows a significant region from point B to C, this indicates the material is:**

(a) Brittle (b) Extremely stiff (c) Ductile (d) Perfectly elastic

Answer: (c) Ductile

Explanation: The region from B to C represents plastic deformation; materials that undergo extensive plastic deformation before breaking are classified as ductile.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is the significance of the "proportional limit" in relation to Hooke's Law?**

Ans: The proportional limit is the greatest stress a material can withstand while maintaining a direct, linear proportionality between stress and strain, meaning Hooke's Law is obeyed up to this point.

- **When does a material enter the "plasticity" region of its stress-strain curve?**

Ans: A material enters the plasticity region when the stress applied to it increases beyond its elastic limit (yield stress), leading to permanent deformation.

- **Give an example of a ductile substance and a brittle substance.**

Ans: Ductile: Copper; Brittle: Glass

- **What is meant by "fracture stress"?**

Ans: Fracture stress is the value of stress at which the material ultimately breaks or fractures.

- **How is a force-elongation diagram typically generated in a tensile test?**

Ans: It is usually plotted automatically by an electronic device in a mechanical testing machine that continuously measures stress while the wire is extended at a specified deformation rate.

5.6 STRAIN ENERGY IN DEFORMED MATERIALS

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

Ans

When stress is applied deformation is produced in a material. The work done in deforming the material is called strain energy in deformed material.

Explanation

Experimentally, extension produced in a spring is directly proportional to the stretching force within the elastic limit. As the force F stretches the wire, so it does some amount of work on the wire, which is equal to the product of force F and the extension 'x'. This work done is stored as strain energy. A graph is plotted between the force F and the extension 'x' in the spring as shown in the fig.

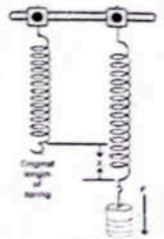


Fig. 5.6

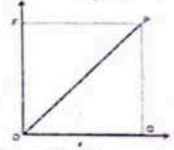


Fig. 5.7

Calculation of Work Done

Consider a material in the form of a spring as shown in Figure 5.6 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 Figure. 5.7 Thus, the average force that stretches the spring through x is

$$\text{Average Force} = F_{av} = \frac{0+F}{2} = \frac{F}{2} = \frac{1}{2}F$$

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

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

$$\text{Work done} = \frac{1}{2}F(x)$$

From Hooke's law $F = kx$

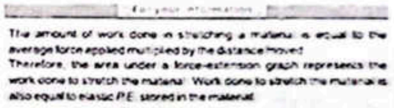
$$\text{Work done} = \frac{1}{2}F(x) = \frac{1}{2}kx(x) = \frac{1}{2}kx^2 = \text{Area of } \Delta\, OPQ$$

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. As, the force is expressed in Newton and extension in meter, so work done is also expressed in joule

For Your Information

Q: What does the area under a force-extension graph represent?

Ans: The area under a force-extension graph represents the work done to stretch the material. This work done is also equal to the elastic potential energy stored in the material



For your 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.

MULTIPLE CHOICE QUESTIONS

- **When a body is deformed by a force within its elastic limit, the work done is stored as:**

(a) Kinetic energy (b) Chemical energy (c) Potential energy (d) Thermal energy

Answer: (c) Potential energy

Explanation: Work done against elastic restoring forces during deformation is stored as elastic potential energy, also known as strain energy

- **The work done in stretching a material is equal to the area under its:**

(a) Stress-strain graph (b) Force-extension graph (c) Force-velocity graph (d) Pressure-volume graph

Answer: (b) Force-extension graph

Explanation: For a variable force, the work done is the integral of force with respect to displacement, which corresponds to the area under the force-extension graph.

- **For a spring stretched by a force F through an extension x within its elastic limit, the average force applied is:**

  (a) F (b) 2F (c) 1/2 F (d) F/x

Answer: (c) 1/2 F

Explanation: Since the force increases uniformly from zero to F (due to Hooke's Law), the average force is half of the final force.

- **If a spring has a spring constant k and is stretched by x, the elastic potential energy stored is:**

  (a) kx (b) 2kx (c) 1/2 kx (d) $1/2\ kx^2$

Answer: (d) $1/2\ kx^2$

Explanation: This is the standard formula for elastic potential energy stored in a spring, derived from the work done.

- **What happens to the potential energy of the molecules in a body when it is deformed?**

  (a) It decreases (b) It remains unchanged (c) It increases (d) It is converted into kinetic energy

Answer: (c) It increases

Explanation: Work done during deformation displaces molecules from their equilibrium positions, increasing their potential energy.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Why is work done against an elastic restoring force when a body is deformed?**

Ans: As a body is deformed, internal elastic forces develop that try to restore it to its original shape, and work must be done against these forces.

- **What is the relationship between work done by a stretching force and the strain energy stored in a spring?**

Ans: The work done by the stretching force is equal to the strain energy stored in the spring.

- **For what condition is the force-extension graph a straight line?**

Ans: The force-extension graph is a straight line when the material is stretched within its elastic limit, obeying Hooke's Law.

- **If you double the extension of a spring, how does the stored elastic potential energy change?**

Ans: The stored elastic potential energy ($1/2\ kx^2$) would become four times greater (since it depends on x^2).

- **What is the physical origin of the potential energy stored in deformed materials at a molecular level?**

Ans: It's due to the increased potential energy of the molecules arising from their displacement from their stable mean positions within the material structure.

5.7 ARCHIMEDES' PRINCIPLE AND FLOATATION:

Q. State and explain the archimede's principle and floatation and its application in detail?

Ans

Definition:

"When an object is totally or partially immersed in a liquid, an up thrust acts on it equal to the weight of the fluid it displaces"

Explanation: 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 underwater. 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.

More than two thousand years ago, the Greek scientist, 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.

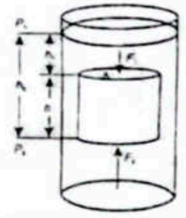


Fig. 5.8: Upthrust on a body immersed in a liquid is equal to the weight of the liquid displaced.

Derivation:

Consider a solid cylinder of cross-sectional area A and height h immersed in a liquid as shown in Fig. 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:

$$h_1 - h_2 = h$$

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

$$P_1 = \rho g h_1 \quad \text{---------} \quad \text{i}$$

and $$P_2 = \rho g h_2 \quad \text{---------} \quad \text{ii}$$

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

Then $$F_1 = P_1A = \rho g h_1 A$$

and $$F_2 = P_2A = \rho g h_2 A$$

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

$$F_2 - F_1 = \rho g h_2 A - \rho g h_2 A$$

$$F_2 - F_1 = \rho g A(h_2 - h_1) \quad \dots\dots\dots\dots\dots \text{iii}$$

or $$\text{Up thrustofliquid} = \rho gAh$$

$$\text{Up thrust} = \rho\, g\, V \quad \dots\dots\dots\dots\dots \text{iv}$$

Here V is the **volume** of the cylinder and is equal to the volume of the liquid displaced by the cylinder; therefore, ρg Vis 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 Archimede's principle.

FLOATATION:

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

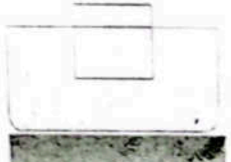
Explanation:

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.

Archimedes' principle is applicable on liquids as well as on gases. We find numerous applications of this principle in our daily life.

APPLICATIONS OF ARCHIMEDES' PRINCIPLE

1. **Hot-air Balloon:** Rises and floats because its overall density (hot air + balloon) is less than the surrounding cooler air, resulting in an upthrust greater than its weight. The quantity of hot air is varied to control ascent/descent.



2. **Wooden Block Floating on Water:** Floats because the weight of an equal volume of water is greater than the weight of the block. It displaces water equal to its own weight.

3. **Ships and Boats:** Designed to displace a large volume of water such that the upthrust equals their total weight (including cargo and passengers), allowing them to float even though they are made of dense materials like steel.

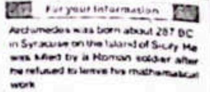
4. **Submarine:** A submarine can travel over as well as under water using the same principle of floatation. It uses ballast tanks to control its buoyancy.

- **Floating:** Tanks are empty, weight is less than upthrust, it floats partially above water.
- **Diving:** Tanks are filled with seawater, increasing weight until it's greater than upthrust, causing it to dive.
- **Surfacing:** Tanks are emptied (air replaces water), decreasing weight to less than upthrust, allowing it to rise.

For Your Information

Q: **When and where was Archimedes born, and how did he die?**

Ans: Archimedes was born about 287 BC in Syracuse on the Island of Sicily. He was killed by a Roman soldier after he refused to leave his mathematical work.



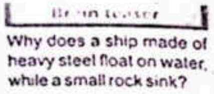
For your information

Archimedes was born about 287 BC in Syracuse on the Island of Sicily He was killed by a Roman soldier after he refused to leave his mathematical work

Brain Teaser

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

Ans: A ship floats because its average density (including the air inside its hull) is less than that of water, allowing it to displace a weight of water equal to its own weight. A small rock sinks because its density is greater than water, and it displaces less water than its own weight.



Brain teaser

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

MULTIPLE CHOICE QUESTIONS

- **According to Archimedes' principle, the upthrust on an object immersed in a fluid is equal to:**

(a) The volume of the object (b) The mass of the object
(c) The weight of the fluid it displaces (d) The density of the fluid

Answer: (c) The weight of the fluid it displaces

Explanation: This is the direct statement of Archimedes' principle, quantifying the buoyant force.

- **An object floats in a fluid if its weight is:**

(a) Greater than the upthrust (b) Equal to or less than the upthrust
(c) Equal to the density of the fluid (d) Independent of the upthrust

Answer: (b) Equal to or less than the upthrust

Explanation: If the weight is less than or equal to the maximum possible upthrust (when fully immersed), the object will float. For a floating object, the upthrust exactly balances its weight.

- **What causes an apparent reduction in the weight of an object when it is submerged in a liquid?**

(a) Decrease in gravitational force (b) Increase in object's density
(c) Upward buoyant force from the liquid (d) Surface tension of the liquid

Answer: (c) Upward buoyant force from the liquid

Explanation: The buoyant force acts upwards, opposing gravity, making the object feel lighter.

- **A submarine dives underwater when:**

(a) Its weight becomes less than the upthrust
(b) Its ballast tanks are emptied of seawater
(c) Its weight increases to be greater than the upthrust
(d) Its density decreases

Answer: (c) Its weight increases to be greater than the upthrust

Explanation: By filling ballast tanks with seawater, the submarine's overall weight increases, making it denser than water and causing it to sink.

- **Hot-air balloons rise and float because:**

(a) They are lighter than cold air
(b) The air inside them is denser than the surrounding air
(c) The upthrust from the surrounding air is greater than their total weight
(d) They displace more air than their own volume

Answer: (c) The upthrust from the surrounding air is greater than their total weight

Explanation: The hot air inside the balloon is less dense than the surrounding cooler air, so the weight of the displaced air (upthrust) is greater than the total weight of the balloon, causing it to ascend.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is the definition of "upthrust" in the context of fluids?**

Ans: Upthrust (or buoyant force) is the upward force exerted by a fluid on an object that is totally or partially immersed in it.

- **How is the volume of displaced fluid related to the volume of a completely immersed object?**

Ans: The volume of the displaced fluid is exactly equal to the volume of the completely immersed object.

- **State the principle of floatation.**

Ans: The principle of floatation states that a floating object displaces a fluid having weight equal to the weight of the object.

- **Explain how a wooden block floats on water, considering its density relative to water.**

Ans: A wooden block floats because its average density is less than that of water. It displaces a volume of water whose weight is equal to its own weight.

- **Besides liquids, on what other type of fluid is Archimedes' principle applicable?**

Ans: Archimedes' principle is also applicable to gases.

For Your Information

Q: **When and where was Archimedes born, and how did he die?**

Ans: Archimedes was born about 287 BC in Syracuse on the Island of Sicily. He was killed by a Roman soldier after he refused to leave his mathematical work.

5.8 STEADY, NON-VISCOUS AND IDEAL FLUID:

Q. **Define Fluid Mechanics and its types.**

Ans

FLUID

"A substance which can flow is called fluid."

There are two types of fluids: i. Liquids ii. Gases

FLUID MECHANICS:

"The branch of physics in which deals with the study of fluid statics and fluid dynamic is called fluid mechanics."

FLUID STATICS:

"Fluid statics is the branch of physics in which deals with the study of fluids at rest."

Example: Honey in jar

FLUID DYNAMICS:

"The branch of physics in which we study about the motion of the fluid, is called Fluid dynamics."

Example: Blood flowing, gas in cylinder

VISCOSITY:

"Viscosity measures how much force is required to slide one layer of liquid over another layer." **-or-**"It is the internal friction between different layers of a flowing fluid."

It is denoted by Greek latter **"η (eta)"**.

$$\eta = \frac{F}{6\pi r v}$$

There are two types of substance:

i. Substance that do not flow easily because they have **large coefficient of viscosity**. e.g., Thick tar, honey.

ii. Substances which flow easily because they have **small coefficient of viscosity**. e.g., Water.

Unit

$$\text{As, } F = 6\pi\eta r v$$

$$\text{As } \eta = \frac{F}{6\pi r v}$$

$$= \frac{N}{\frac{m\,m}{s}}$$

$$= \frac{Ns}{m^2}$$

or

$$\eta = \frac{kg\frac{m}{s^2}s}{m^2}$$

$$\eta = kgm^{-1}s^{-1}$$

Dimensions:

$$[\eta] = [ML^{-1}T^{-1}]$$

Q. What do you mean by stream line or laminar flow and turbulent flow?

Ans

FLUID FLOW

Moving fluids are of great importance to study the behavior of the fluid in motion, we consider their flow through the pipes. There are two types of flow of fluids.

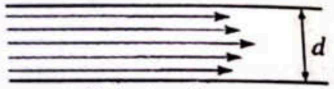
Fig. 5.12: The velocities of the particles at different points on streamline.

1) Streamline or laminar flow
2) Turbulent flow

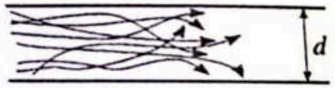
STREAM LINE FLOW:

"If <u>every particle</u> that passes through a <u>particular point</u>, moves exactly the <u>same path</u> as followed by the <u>particles which passed</u> that point earlier. Then the flow is called streamline or laminar flow."

Explanation:



(a) Laminar Flow



(b) Turbulent Flow

(i) **Line of Flow:**
The path followed by a particle of the fluid is called line of flow.

(ii) **Stream Line:**
If each particle of the fluid moves along a smooth path, then line of flow is called a stream line as shown in figure.

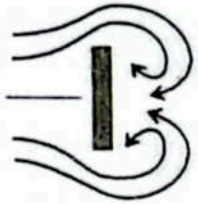
(iii) **Steady Flow Condition:**
The different stream lines cannot cross each other. This condition is called steady Flow condition.
The direction of stream lines is the same as the direction of the velocity of fluid at that point.

- **Streamline:** The smooth path followed by fluid particles in laminar flow. The tangent to any point on a streamline gives the direction of flow. Different streamlines cannot cross each other.
- **Steady Flow:** The velocity of a fluid particle at any given point does not change with time.

Examples:

(i) Dolphins have streamlined bodies to assist their movement in water.

(ii) Formula one racing car have a streamlined design.



TURBULENT FLOW:

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

Above a certain velocity of the fluid flow, the motion of the fluid becomes unsteady and irregular. In this case particles of the fluid cannot follow the same path. Such a motion is called the turbulent flow.

Explanation:

Under this condition (unsteady or irregular flow) the velocity of the fluid changes abruptly as shown in fig. In this case exact path of the particles of the fluid cannot be predicted.

Question: What is ideal fluid?

Conditions of Ideal Fluid

In order to study the behavior of fluid flow we must consider the followings conditions

1) The fluid is non-viscous, i.e., $\eta = 0$
2) The fluid is incompressible, i.e., ρ = constant
3) The fluid motion is steady, i.e., v = constant
4) The particles of fluid be non-rotating.

The fluid possessing above properties is called ideal fluid.

Question: Define rate of flow.

RATE OF FLOW:

"It is the volume passing through any cross section of pipe per unit time."

- **Formula:** If fluid flows with velocity v through a pipe of cross-sectional area A for time t, then distance $l = vt$. Volume $V = A \times l = A \times v \times t$.

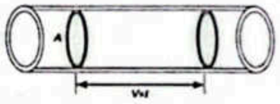


Fig. 5.14: Rate of flow of a liquid

$$\text{Rate of flow} = \frac{\text{Volume}}{\text{Time}}$$

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

Or

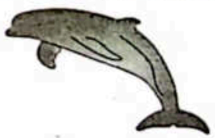
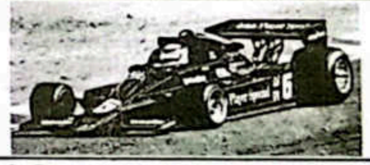
$$\text{Volume} = V = Avt$$

$$\text{Rate of Flow} = \frac{\text{Volume}}{t}$$

So

$$\text{Rate of Flow} = \frac{Avt}{t} = Av$$

In SI Unit it is measured in cubic metre per second ($m^3 s^{-1}$).
Sometimes, it is also measured in litres per second (Ls^{-1}).

For Your Information	
	
Dolphins have streamlined bodies to assist their movement in water	Formula One racing cars have a streamed design

MULTIPLE CHOICE QUESTIONS

- **In which type of fluid flow does every particle follow the exact same path as previous particles that passed that point?**
  (a) Turbulent flow (b) Unsteady flow (c) Streamline flow (d) Viscous flow

Answer: (c) Streamline flow

Explanation: Streamline (or laminar) flow is characterized by smooth, predictable paths where streamlines do not cross.

- **Which of the following is NOT a condition for an ideal fluid?**
  (a) It is viscous (b) Its density is constant (c) Its motion is turbulent (d) Its flow is steady

Answer: (a) It is viscous

Explanation: Ideal fluids are defined by *non-viscous*, incompressible, and steady flow.

- **The rate of flow of a fluid is defined as the:**
  (a) Mass of fluid passing per unit time (b) Volume of fluid passing per unit time
  (c) Velocity of fluid at a point (d) Pressure of fluid at a point

Answer: (b) Volume of fluid passing per unit time

Explanation: The rate of flow (or volume flow rate) specifically measures the volume of fluid that passes through a given cross-section per unit time.

- **If two streamlines were to cross each other, what would be the implication for the fluid flow?**
  (a) The flow would be steady (b) The fluid would be incompressible
  (c) The flow would be turbulent (d) The velocity would be constant

Answer: (c) The flow would be turbulent

Explanation: Streamlines indicate the direction of flow; if they cross, it implies multiple velocity directions at one point, which is characteristic of turbulent, unsteady flow.

- **What is the SI unit for the rate of flow of a fluid?**
  (a) N m-2 (b) kg s-1 (c) m3 s-1 (d) J s-1

Answer: (c) m3 s-1

Explanation: The rate of flow is volume per unit time, so its SI unit is cubic meters per second.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What distinguishes a "steady flow" from an "unsteady flow"?**

Ans: In steady flow, the velocity of fluid particles at any given point does not change with time, whereas in unsteady flow, it changes abruptly and irregularly.

- **Why are the smooth paths followed by fluid particles in laminar flow called streamlines?**

Ans: They are called streamlines because the tangent to any point on them gives the exact direction of flow of a fluid, representing a "stream" of particles.

- **What is meant by an "incompressible" fluid?**

Ans: An incompressible fluid is one whose density remains constant regardless of pressure changes, meaning its volume does not significantly change under pressure.

- **How does the velocity of particles in turbulent flow differ from that in streamline flow?**

Ans: In turbulent flow, the velocity of fluid particles changes abruptly and irregularly, whereas in streamline flow, it is smooth and constant at any given point.

- **What is the formula for the rate of flow of a fluid in terms of cross-sectional area and velocity?**

Ans: Rate of flow = Av, where A is the cross-sectional area and v is the flow velocity.

- **Explain what do you understand the term viscosity? (AJK 2021 GI) (GRW, LHR, SGD 2021 GII) (GRW 2023 GII)**

Ans. The frictional effect between different layers of a flowing fluid is described as viscosity. Viscosity measures, how much force is required to slide one layer of the liquid over another layer.

It is represented by Greek letter η and fine it as

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

$$\Rightarrow \eta = \frac{F_D}{6\pi r v}$$

- **Define Viscosity and Drag force. (LHR 2017 GII) (MTN, LHR, BWP 2018 GI) (MTN 2018 GII) (RWP 2019) (SGD, BWP 2019 GI) (DGK, MTN 2019 GII) (AJK 2021)**

Ans. **Viscosity:** The frictional effect between different layers of a flowing fluid is described as viscosity. Viscosity measures, how much force is required to slide one layer of the liquid over another layer.

Drag Force: An object moving through a fluid experience a retarding force called as drag force.

The drag force F_D on a sphere of radius '*r*' moving slowly with a speed '*v*' through fluid of viscosity 'η' is given by stoke's law, as $F_D = 6\pi\eta r v$

So, the drag force depends upon viscosity of medium, radius of sphere and speed of sphere.

- **Find the dimension and hence the SI unit of coefficient of viscosity. (FBD 2021 GI)**

Ans. As $\eta = \frac{F_D}{6\pi r v}$

Dimension:

$$\eta = \frac{[MLT^{-2}]}{[L][LT^{-1}]} = [ML^{-1}T^{-1}]$$

SI units:

$$\eta = Nm^{-2}s^{-1}$$

$$or\ \frac{kgms^{-2}]}{[m][m\ s^{-1}]} = [kgm^{-1}s^{-1}]$$

5.9 EQUATION OF CONTINUITY

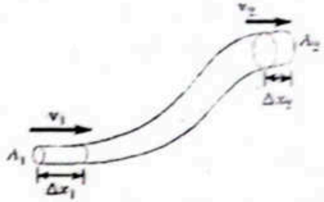
Q. **What is equation of continuity? Explain.**

Ans

The equation of continuity is a fundamental principle in fluid dynamics, based on the conservation of mass for an incompressible fluid in steady flow.

Statement:

- "The product of cross-sectional area of the pipe and the fluid speed at any point along the pipe is a constant. This constant equals the volume flow per second of the fluid or simply flow rate." Hence Rate of flow of a fluid remains constant.



Mathematically: AV = Constant

Explanation:

Consider a fluid flowing through a pipe of non-uniform size. The particles in the fluid move along the streamlines in a steady state flow. In a small time Δt, the fluid at the lower end of tube moves a distance Δx_1, with a velocity V_1.

If A_1 is area of cross-section of this end, then the mass of the fluid in the shaded region is $\rho = \frac{m}{V}$ and $m = \rho V$

Scientific Fact

Euler obtained the continuity equation for a incompressible fluid with a large number of terms in 1752. Later it was translated by C. Truesdell from English in 1954.

DERIVATION

Consider a fluid flowing through a pipe of non-uniform size **(Fig. 5.15)**.

Mass flowing into point 1 (lower end) in time Δt:

- Distance covered: $\Delta x_1 = v_1\Delta t$ (Equation 1)
- Volume: $V_1 = A_1\Delta x_1 = A_1 v_1 \Delta t$
- Mass: $\Delta m_1 = V_1\rho_1 = A_1 v_1 \Delta t \rho_1$

Mass flowing out of point 2 (upper end) in time Δt:

- Distance covered: $\Delta x_2 = v_2\Delta t$
- Volume: $V_2 = A_2\Delta x_2 = A_2 v_2 \Delta t$
- Mass: $\Delta m_2 = V_2\rho_2 = A_2 v_2 \Delta t \rho_2$ (Equation 2)

Conservation of 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 through A_2 in the same time.

Therefore, $\Delta m_1 = \Delta m_2$ (Comparing equations 1 and 2)

- $A_1 v_1 \Delta t \rho_1 = A_2 v_2 \Delta t \rho_2$ (Equation 3)
- $A_1 v_1 \rho_1 = A_2 v_2 \rho_2$ (Equation 4)

For Incompressible Fluid: Since density is constant for the steady flow of incompressible fluid ($\rho_1 = \rho_2 = \rho$), the equation of continuity becomes:

- $A_1 v_1 = A_2 v_2$ (Equation 5)

$$\mathbf{A \times V = \text{Constant}}$$

This equation is known as the equation of continuity.

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.

Interpretation: This equation states that in steady flow, the rate of flow of the fluid inward is equal to the rate of flow of the fluid outward, justifying the conservation of mass. Since density is constant for the steady flow of incompressible fluid.

Note: Equation of continuity obeys law of conservation of mass.

MULTIPLE CHOICE QUESTIONS

- **The equation of continuity is fundamentally based on the principle of:**

(a) Conservation of energy (b) Conservation of momentum
(c) Conservation of mass (d) Conservation of volume

Answer: (c) Conservation of mass

Explanation: The equation of continuity states that for steady, incompressible flow, the mass flow rate remains constant throughout the pipe, directly reflecting the conservation of mass.

- **For an incompressible fluid in steady flow, the product of the cross-sectional area and the fluid speed (Av) at any point along the pipe is:**

(a) Variable (b) Zero (c) Constant (d) Equal to density

Answer: (c) Constant

Explanation: This is the direct statement of the simplified equation of continuity ($A_1v_1 = A_2v_2$) for incompressible fluids.

- **If a fluid flows from a wider section of a pipe to a narrower section, its speed will:**

(a) Decrease (b) Increase (c) Remain constant (d) Become zero

Answer: (b) Increase

Explanation: According to the equation of continuity (Av=Constant), if the area (A) decreases, the velocity (v) must increase to maintain the constant flow rate.

- **Which of the following conditions is crucial for simplifying the equation of continuity to $A_1v_1 = A_2v_2$?**

(a) The fluid is highly viscous (b) The flow is turbulent
(c) The fluid is incompressible (d) The pipe changes height

Answer: (c) The fluid is incompressible

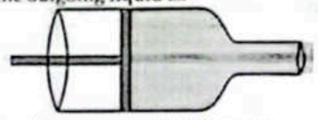
- **Explanation: The densities (ρ_1, ρ_2) cancel out from $A_1v_1\rho_1 = A_2v_2\rho_2$ only if the fluid is incompressible, meaning $\rho_1 = \rho_2$. The equation $A_1v_1 = A_2v_2$ is a statement of:**

(a) Pascal's Law (b) Bernoulli's Principle
(c) Newton's Law of Viscosity (d) Conservation of volume flow rate

Answer: (d) Conservation of volume flow rate

Explanation: The product Av represents the volume flow rate (V/t). The equation states that this rate is conserved throughout the pipe.

- **Following figure shows a liquid being pushed out of a tube by pressing a piston. The cross sectional area of the piston is 1 cm² and that of the tube at the outlet is 20 mm². If the piston is pushed at a speed of 1 cm s⁻¹, then the velocity of the outgoing liquid is:**



(a) 2.5 cm s⁻¹ (b) 5 cm s⁻¹ (c) 7.5 cm s⁻¹ (d) 10 cm s⁻¹

Answer: (b) 5 cm s⁻¹

Explanation: Simply apply equation of continuity;

$$A_1v_1 = A_2v_2$$

$$1\times10^{-4}\,m^2\times10^{-2}\,ms^{-1} = 20\times10-6\,m^2\times v_2$$

$$v_2 = \frac{1\times10^{-4}\times10^{-2}}{20\times10^{-6}} = \frac{1}{20}\times\frac{10^{-6}}{10^{-6}} = 0.05\,ms^{-1} \text{ or } 5\,cms^{-1}$$

SLO BASED SHORT QUESTIONS & ANSWERS

- **When water falls from a tap; its cross-sectional area decreases as it comes down? Explain. (SGD 2022)**

Ans: According to equation of continuity, when water falls it speed increases and its area of cross section decreases. The cross-sectional area of the water stream decreases as it falls from the tap. This is due to principle of the equation of continuity.

- **Equation of Continuity: This principle states that for an incompressible fluid (like water) flowing in a pipe, the product of the fluid's velocity (speed) and its cross-sectional area remains constant at any given point along the flow. Av = Constant**

Ans: Falling Water: As the water falls due to gravity, its speed increases the further it travels.

Maintaining Flow Rate: To maintain a constant flow rate (volume of water per second) despite the increasing speed, the equation of continuity dictates that the cross-sectional area of the stream must decrease.

- **What conditions must a fluid satisfy for the equation of continuity to be applicable in its simplified form ($A_1v_1 = A_2v_2$)?**

Ans: The simplified continuity equation ($A_1v_1 = A_2v_2$) applies when a fluid is **incompressible** (constant density), its flow is **steady** (velocity at a point doesn't change with time), and there are **no sources or sinks** of mass within the flow path.

- **Why is the equation of continuity considered a form of the principle of conservation of mass?**

Ans: It implies that for a fluid in steady flow, the mass of fluid entering a section of the pipe per unit time must be equal to the mass of fluid leaving it per unit time, thus conserving mass.

- **What does the constant value of Av represent in the equation of continuity?**

Ans: It represents the volume flow rate (or flow rate), which is the volume of fluid passing through any cross-section of the pipe per second.

- **If water flows from a pipe into a narrower nozzle, how does the water's speed change, and why?**

Ans: The water's speed increases because the cross-sectional area decreases, and according to the equation of continuity (Av=Constant), velocity must increase to maintain the same flow rate.

- **What happens to the density of an incompressible fluid as it flows through a pipe of varying cross-section?**

Ans: The density of an incompressible fluid remains constant as it flows, regardless of changes in the pipe's cross-section or pressure.

- **In the derivation of the equation of continuity, why is Δt cancelled out from both sides of the equation $\Delta m_1=\Delta m_2$?**

Ans: Δt represents the same small interval of time for both inlet and outlet, implying that the rate of mass flow equals the rate of mass flow out.

5.10 Increase in flow speed

Q. How can the flow velocity of water in a rubber pipe be increased? Explain this phenomenon using the equation of continuity

Ans

The equation of continuity explains how fluid velocity changes with the cross-sectional area of a pipe.

EXPLANATION

- According to the equation of continuity, $A_1V_1= A_2V_2$ or Av=Constant
- This means that if the cross-sectional area (A) of a pipe decreases, the flow velocity (v) of the fluid must increase to maintain a constant flow rate.

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

Fig. 5.16 The speed of water spraying from the end of a garden hose increases as the hose is squeezed with the thumb

Example:

Squeezing the end of a rubber pipe (like a garden hose) decreases the cross-sectional area, leading to an increase in the water's flow velocity.

MULTIPLE CHOICE QUESTIONS

- **Squeezing the end of a garden hose increases the water's exit velocity primarily due to:**

(a) Increased pressure (b) Decreased viscosity (c) Reduced cross-sectional area (d) Increased fluid density

Answer: (c) Reduced cross-sectional area

Explanation: According to the equation of continuity (Av=Constant), reducing the area (A) necessitates an increase in velocity (v) to maintain the same flow rate

- **This phenomenon (increasing flow velocity by squeezing a hose) is a direct application of the:**

(a) Bernoulli effect (b) Archimedes' principle (c) Equation of continuity (d) Pascal's principle

Answer: (c) Equation of continuity

Explanation: The fundamental principle governing the inverse relationship between flow area and velocity for a constant flow rate is the equation of continuity.

- **If the cross-sectional area of a pipe is halved, the flow velocity of an incompressible fluid will:**

(a) Halve (b) Double (c) Quadruple (d) Remain unchanged

Answer: (b) Double

Explanation: To keep Av constant, if A becomes A/2, then v must become 2v.

- **The equation of continuity ($A_1v_1=A_2v_2$) holds true for:**

(a) Viscous fluids only (b) Turbulent flow only (c) Steady, incompressible flow (d) Fluids at rest

Answer: (c) Steady, incompressible flow

Explanation: The simplified form of the continuity equation is derived under the assumptions of steady and incompressible flow.

- **Which of the following is NOT a common application where the equation of continuity is applied?**

(a) Blood flow in arteries (b) Water flow in rivers
(c) Air flow in ventilation systems (d) Measuring boiling points

Answer: (d) Measuring boiling points

Explanation: The equation of continuity deals with fluid flow dynamics and is not directly related to thermometry or boiling points.

SLO BASED SHORT QUESTIONS & ANSWERS

- **How does the equation of continuity explain the increase in water speed when a hose is squeezed?**

Ans: When the hose is squeezed, the cross-sectional area (A) decreases. To maintain a constant volume flow rate (Av), the velocity (v) of the water must increase

- **Give another common example where decreasing the area of flow increases velocity.**

Ans: Water flowing from a tap speeding up as it falls and its stream narrows

- **What principle dictates that squeezing a pipe increases the flow velocity?**

Ans: The principle of conservation of mass, which is embodied by the equation of continuity

- **What assumption about the fluid is necessary for the direct relationship between area and velocity in the equation of continuity?**

Ans: The fluid must be incompressible, meaning its density remains constant

- **If the volume flow rate through a pipe remains constant, and a section of the pipe becomes wider, what happens to the fluid's velocity in that section?**

Ans: The fluid's velocity will decrease in the wider section to maintain the constant volume flow rate

5.11 Bernoulli's Equation

Q:

Q: What is Bernoulli's equation, and what fundamental principle is it based on?

Q: List the assumptions made when deriving Bernoulli's equation.

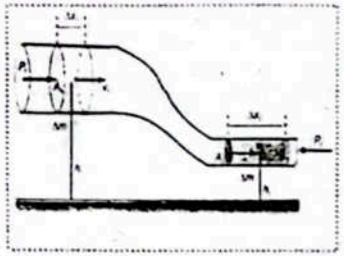
Q: Derive Bernoulli's equation from the principle of conservation of energy.

Q: Explain the meaning of each term in Bernoulli's

Ans

BERNOULLI'S EQUATION

Bernoulli's Equation named after a Swiss physicist Daniel Bernoulli, who discovered it. Bernoulli's equation is the fundamental equation in fluid dynamics that relates pressure to fluid speed and height.It is based on the law of conservation of energy.



Statement:

"Bernoulli's equation states that the sum of the pressure, the K.E per unit volume and P.E. per unit volume in a steady flow of an incompressible and non-viscous fluid remains constant at every point of its path."

Mathematically

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

Where

P = Pressure

v = speed of the fluid

ρ = density of fluid

h = height of the fluid

P = static pressure

$\tfrac{1}{2}\rho v^2$ = dynamic pressure

ρgh = pressure at depth

Derivation:

We use the following assumptions to derive Bernoulli's equation. Fluid is incompressible, non-viscous and flows in a steady state. Consider the flow of the fluid through the pipe in time t. The pipe has uniform cross section area over some length at the both ends. Let

At upper end

A_1 = Area of cross section at upper end
h_1 = Height of the upper end
P_1 = Pressure at the upper end
$F_1 = P_1A_1$ = Force at the upper end

At lower end

A_2 = Area of cross section at lower end
h_2 = Height of the lower end
P_2 = Pressure at the lower end
$F_2 = P_2A_2$ = Force at the lower end

Work done At the upper end:

Work done on the fluid at upper end in moving through the distance Δx_1 is given by

$$W_1 = F_1\Delta x_1 = P_1A_1\Delta x_1 \qquad \because P=\frac{F}{A}$$

As $\quad \Delta x_1 = v_1t \qquad \because \quad S=vt$

So $\quad W_1 = P_1A_1v_1t$

Work done At the lower end:

Work done on the fluid at lower end in moving through the distance Δx_2 is given by

$$W_2 = -P_2A_2v_2t$$

Negative work indicates that the work is done against the fluid force.

Net Work Done:

The net work done is

$$W = W_1 + W_2$$

Putting values of W_1 and W_2 we get

$$W = P_1A_1v_1t - P_2A_2v_2t$$

But we know that $\quad A_1v_1 = A_2v_2 = Av \quad \because$ By Eq. of continuity

Hence, $\quad W = (P_1 - P_2)\,Avt$

$W = (P_1 - P_2)V \qquad$ because $V = Avt$

If m is the mass and ρ is the density of the of the fluid then $V=m/\rho$

Therefore $\quad W = (P_1 - P_2)\dfrac{m}{\rho}$ ——————(1)

Change in K.E and Change in P.E:

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

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

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

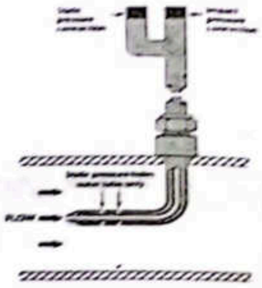
Application of Law of conservation of energy:

Applying Law of conservation of energy i.e. work energy principle.

$$W = \Delta(K.E) + \Delta(P.E)$$

For Your Information

A pitot tube is used to measure fluid flow velocity. The tube is pointed into the flow and the difference between the stagnation pressure at the tip of the probe and the static pressure at its side is measured, yielding the dynamic pressure from which the fluid velocity is calculated using Bernoulli's equation.



Point To Ponder

A Venturi tube can be used to determine the velocity of a fluid that is flowing within it. This is in contrast to a pitot tube, which is used to determine the velocity of a fluid flowing past

Brain teaser

How does the shape of a curveball in baseball relate to Bernoulli's principle?

Explanation: The spin of a curveball causes air to move faster on one side and slower on the other. According to Bernoulli's principle, the faster-moving air creates lower pressure, while the slower-moving air creates higher pressure. This pressure difference generates a sideways force (Magnus effect) that causes the ball to curve

$$(P_1 - P_2)\frac{m}{\rho} = \frac{1}{2}mv_2^2-\frac{1}{2}mv_1^2+mgh_2$$

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

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

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

This equation is called Bernoulli's equation.

MULTIPLE CHOICE QUESTIONS

- **Bernoulli's equation is a statement of the conservation of:**

(a) Mass (b) Momentum (c) Energy (d) Pressure

Answer: (c) Energy

Explanation: Bernoulli's equation states that the sum of static pressure, kinetic energy per unit volume, and potential energy per unit volume is constant along a streamline for an ideal fluid, reflecting energy conservation.

- **Which of the following is NOT an assumption made when deriving Bernoulli's equation?**

(a) The fluid is viscous (b) The fluid is incompressible
(c) The fluid flows steadily
(d) There are no external forces acting other than gravity

Answer: (a) The fluid is viscous

Explanation: Bernoulli's equation is derived for an *ideal* fluid, which is defined as non-viscous. Viscosity would lead to energy loss, making the sum not constant.

- **The term 1/2 ρv2 in Bernoulli's equation represents:**

(a) Static pressure (b) Hydrostatic pressure (c) Dynamic pressure (d) Potential energy

Answer: (c) Dynamic pressure

Explanation: This term represents the kinetic energy per unit volume of the fluid due to its motion, often called dynamic pressure.

- **For a horizontal pipe, if the speed of the fluid increases, what happens to its static pressure?**

(a) It increases (b) It decreases (c) It remains constant (d) It becomes zero

Answer: (b) It decreases

Explanation: For horizontal flow, the potential energy term is constant. If kinetic energy (1/2 ρv2) increases (due to higher speed), the static pressure (P) must decrease to keep the total sum constant.

- **The term ρgh in Bernoulli's equation represents:**

(a) Static pressure (b) Dynamic pressure
(c) Hydrostatic pressure or potential energy per unit volume
(d) Total pressure

Answer: (c) Hydrostatic pressure or potential energy per unit volume

Explanation: This term accounts for the pressure due to the fluid's height or its gravitational potential energy per unit volume.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What are the three main terms that sum up to a constant in Bernoulli's equation?**

Ans: Static pressure (P), dynamic pressure (1/2 ρv2), and hydrostatic pressure or potential energy per unit volume (ρgh)

- **Why is Bernoulli's equation only an approximation for real fluids?**

Ans: Because real fluids have viscosity, which causes energy dissipation due to friction, violating the assumption of non-viscous flow.

- **Explain how a pressure difference can arise from different rates of flow of a fluid.**

Ans: According to Bernoulli's principle, if the flow rate varies, leading to changes in fluid speed, then the pressure must change inversely to maintain the conservation of energy.

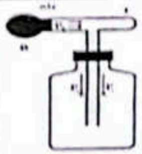
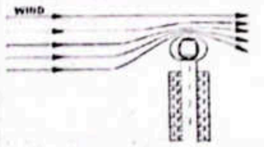
- **In a horizontal pipe with varying cross-section, which term in Bernoulli's equation can be considered constant?**

Ans: The potential energy per unit volume term (ρgh) can be considered constant because the height is uniform.

- **What happens to the total mechanical energy of an ideal fluid as it flows along a streamline?**

Ans: The total mechanical energy (sum of pressure, kinetic energy, and potential energy per unit volume) remains constant.

INTRESTING INFORMATION

	
A stream of air passing over a tube dipped in a liquid will cause the liquid to rise in the tube as shown. This effect is used in perfume bottles and paint sprayers.	A chimney works best when it is tall and exposed to air currents, which reduces the pressure at the top and force the upward flow of smoke.

5.12 USES OF BERNOULLI'S EQUATION

Q.

Q1: Explain how the design of an aeroplane wing generates lift based on Bernoulli's principle.

Q2: Describe the Magnus effect and its application in the swing of a spinning ball.

Q3: How does a filter pump work using the principles of fluid dynamics?

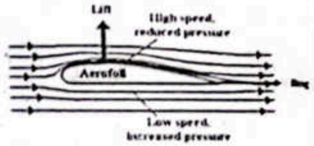
Q4: What is the purpose of a carburetor, and how does Bernoulli's principle apply to its function?

Q5: How paint spray works?

Q6: State Torricelli's theorem and explain its derivation from Bernoulli's equation.

Q7: What is the implication of Bernoulli's equation for horizontal pipe flow regarding speed and pressure?

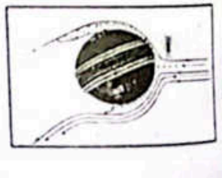
Ans



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

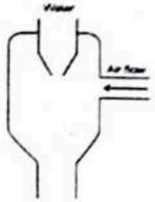
1. **Aeroplane wings: (Lift of Aeroplane)**
   - Wings are designed to deflect air, causing streamlines to be closer (faster air) above the wing and farther apart (slower air) below.
   - Faster air above means lower pressure (Bernoulli's principle), and slower air below means higher pressure.
   - This pressure difference generates an upward force called lift.

   $P_A - P_B = \frac{1}{2}\rho(v_B^2 - v_A^2) \Rightarrow P_A > P_B$ Where $V_A < V_B$



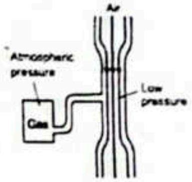
2. **Swing of a ball(Magnus Effect):**
   - When a spinning ball (e.g., cricket or golf ball) moves through air, the air on one side moves faster (due to spin matching direction of air flow) and on the other side moves slower (due to spin opposing air flow).
   - This speed difference creates a pressure difference (lower pressure on faster side, higher pressure on slower side).
   - The resulting sideways force causes the ball to curve (Magnus effect).

   $P_A - P_B = \frac{1}{2}\rho(v_B^2 - v_A^2) \Rightarrow P_A > P_B$ Where $V_A < V_B$



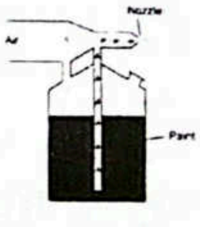
3. **Filter Pump (Venturi Effect):**
   - A filter pump has a constriction where water flows faster.
   - This increased speed leads to a drop in pressure (Bernoulli's principle).
   - Atmospheric pressure then pushes air in from a side tube, which mixes with water and is expelled, creating a vacuum.

   $P_A - P_B = \frac{1}{2}\rho(v_B^2 - v_A^2) \Rightarrow P_A > P_B$ Where $V_A < V_B$



4. **Carburetor(Venturi Effect):**
   - Uses a Venturi duct to mix air and petrol for an engine.
   - Air flows rapidly through the narrow duct, creating low pressure.
   - This low pressure draws petrol vapor into the air stream, forming the correct mixture.

   $P_A - P_B = \frac{1}{2}\rho(v_B^2 - v_A^2) \Rightarrow P_A > P_B$ Where $V_A < V_B$



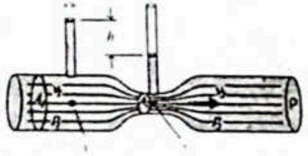
5. **Paint Sprayer:**
   - A stream of air blown rapidly over the top of a tube dipped in liquid creates a low-pressure area (Bernoulli's effect).
   - Atmospheric pressure then pushes the liquid up the tube, where it gets atomized by the fast-moving air.

   $P_A - P_B = \frac{1}{2}\rho(v_B^2 - v_A^2) \Rightarrow P_A > P_B$ Where $V_A < V_B$

6. **Venturi relation:**

If one of the pipe has a much smaller diameter than the other and the pipes are horizontal so that ρgh terms become equal, therefore, then:

$$\begin{aligned} P_1 + \frac{1}{2}\rho V_1^2 &= P_2 + \frac{1}{2}\rho V_2^2 \\ P_1 - P_2 &= \frac{1}{2}\rho\left(V_2^2 - \frac{1}{2}\rho V_1^2\right) \\ &= \frac{1}{2}\rho(V_2^2 - V_1^2) \end{aligned}$$



As the cross sectional area A_2 is small as compared to the areu A_1, then from equation of continuity $V_1 = (A_2/A_1)V_2$, will be small as compared to V_2.

Thus for flow from a large pipe to a small pipe we can neglect V_1.

On the right hand side of equation, hence,

$$P_1 - P_2 = \frac{1}{2}\rho V_2^2$$

This is known as venturi relation, which is used in venturi-meter.

Venturi-Meter

"A device used to measure speed of liquid flow."

7. **Torricelli's Theorem:**

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

Explanation

Suppose a large tank of fluid has two small orifices A and B on it. Now we find 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.

Therefore, $V_1 \approx 0$.

As Bernoulli's equation is

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

Putting $V_1 = 0$

$$P_1 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

Since $P_1 = P_2 = P$ (Atmospheric pressure)

$$P + \rho g h_1 = P + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

$$\rho g h_1 = \frac{1}{2}\rho V_2^2 + \rho g h_2$$

$$\frac{1}{2}\rho V_2^2 = \rho g h_1 - \rho g h_2$$

$$\frac{1}{2}\rho V_2^2 = \rho g(h_1 - h_2)$$

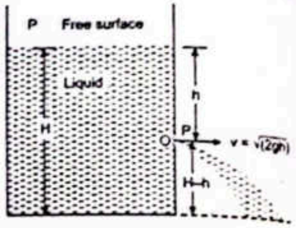
$$\frac{1}{2}V_2^2 = g(h_1 - h_2)$$

$$V_2^2 = 2g(h_1 - h_2)$$

Taking square root on both sides;

$$V_2 = \sqrt{2g(h_1 - h_2)}$$

This is the Torricelli's theorem.



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,

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

Note: 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 as at B shown in figure, 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.

For Your Information

Q: **According to Bernoulli's Equation for a horizontal pipe, what is the relationship between speed and pressure?**

Ans: "Where speed is high, the pressure will be low." Mathematically, P+1/2ρv²=constant.

MULTIPLE CHOICE QUESTIONS

- **The lift of an aeroplane wing is primarily explained by:**
  (a) Newton's third law (b) Archimedes' principle
  (c) Bernoulli's principle (d) Pascal's law

Answer: (c) Bernoulli's principle

Explanation: The shape of the wing creates a pressure difference (lower pressure above, higher pressure below) due to varying air speeds, generating lift.

- **The curving trajectory of a spinning cricket ball (Magnus effect) is a practical application of:**
  (a) Viscous drag (b) Torricelli's theorem
  (c) Bernoulli's equation (d) The continuity equation

Answer: (c) Bernoulli's equation

Explanation: The spin causes air to move faster on one side and slower on the other, creating a pressure difference (Bernoulli effect) that results in a sideways force.

- **A filter pump uses a constriction to increase water speed, which then creates a drop in pressure to draw in air. This is an example of:**
  (a) Pascal's principle (b) Boyle's Law
  (c) Venturi effect (d) Charles's Law

Answer: (c) Venturi effect

Explanation: The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of a pipe, a direct consequence of Bernoulli's principle.

- **Torricelli's theorem relates the speed of efflux from a hole in a tank to the:**
  (a) Area of the hole (b) Viscosity of the fluid
  (c) Depth of the hole from the surface (d) Atmospheric pressure

Answer: (c) Depth of the hole from the surface

Explanation: Torricelli's theorem states that the efflux speed is equal to the velocity gained by falling freely through the height difference between the surface and the hole, v=2gh

- **In a perfume bottle sprayer, how does the atmospheric pressure contribute to spraying the perfume?**
  (a) It decreases the pressure at the nozzle (b) It pushes the perfume up the tube
  (c) It increases the viscosity of the perfume (d) It creates a vacuum in the bottle

Answer: (b) It pushes the perfume up the tube

Explanation: The fast-moving air stream at the top of the tube creates low pressure (Bernoulli effect). The higher atmospheric pressure then pushes the liquid from the reservoir up the tube into the low-pressure air stream, where it is atomized.

SLO BASED SHORT QUESTIONS & ANSWERS

- **How does the shape of an aeroplane wing create a pressure difference for lift?**

Ans: The curved upper surface forces air to travel faster and thus experience lower pressure, while the flatter lower surface results in slower air and higher pressure, creating an upward force.

- **What is the Magnus effect?**

Ans: The Magnus effect is the sideways force on a spinning object moving through a fluid, caused by a pressure difference resulting from the differential speed of fluid flow around the object due to its spin.

- **Briefly explain the function of a Venturi duct in a carburetor.**

Ans: A Venturi duct in a carburetor narrows the airflow, causing it to speed up and create a low-pressure area which then draws petrol vapor into the air stream to mix with air.

- **State Torricelli's theorem in words.**

Ans: Torricelli's theorem states that the speed of efflux of a fluid from a hole in a tank is equal to the velocity that a body would acquire in falling freely from the fluid surface to the level of the hole.

- **In a Venturi meter, why can the speed of fluid in the wider portion be neglected when calculating the pressure difference?**

Ans: In a Venturi meter, the area of the wider section is significantly larger than the narrow section, making the fluid speed in the wider section much smaller, and thus its kinetic energy term negligible compared to that in the narrow section.

For Your Information

Q: **According to Bernoulli's Equation for a horizontal pipe, what is the relationship between speed and pressure?**

Ans: Where speed is high, the pressure will be low." Mathematically, P+21ρv2=constant

Brain Teaser

Q: **How does the shape of a curveball in baseball relate to Bernoulli's principle?**

Ans: The spin of a curveball causes air to move faster on one side and slower on the other. According to Bernoulli's principle, the faster-moving air creates lower pressure, while the slower-moving air creates higher pressure. This pressure difference generates a sideways force (Magnus effect) that causes the ball to curve (Page 102)

5.13 VISCOUS DRAG and STOKE'S LAW

Q.

Q1: What is viscosity, and how does it affect fluid flow? Provide examples of fluids with high and low viscosity.

Q2: Define drag force. How does it depend on the speed of the object moving through a fluid?

Q3: State Stokes' law and explain its applicability.

Ans

Viscosity: Viscosity describes the frictional effect that occurs between different layers of a flowing fluid.

Measuring Viscosity: It determines the amount of force needed to make one layer of a liquid slide over an adjacent layer.

High vs. Low Viscosity:

- Substances that do not flow easily, like thick tar and honey, have a high coefficient of viscosity, often represented by the Greek letter 'η'.
- Substances that flow easily, such as water, have a small coefficient of viscosity.

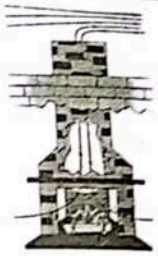
Viscosity and Motion: Because liquids and gases possess a non-zero viscosity, a force is necessary to move an object through them.

For Your 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.

Examples of Viscous Drag:

- Even the relatively small viscosity of air creates a significant retarding force on a car traveling at high speeds.
- When you extend your hand out the window of a fast-moving car, you can feel a considerable force acting on your hand, illustrating the resistance from the air.

Drag Force: An object moving through a fluid experiences a retarding force known as a drag force. This drag force increases as the speed of the object increases.

object moving through a fluid experiences a retarding force is called a drag force,"

Drag Force depends on:

i. Object's shape
ii. Material
iii. Speed
iv. Fluid viscosity

Complexity of Drag Force Calculation: Calculating the exact value of the drag force can be challenging, even in simple scenarios.

Stokes' Law (for a sphere): For a sphere of radius 'r' moving slowly with speed 'v' through a fluid with viscosity 'η', the drag force (F) is given by Stokes' Law: $F=6\pi\eta rv$.

Drag Force at High Speeds: It is important to note that at high speeds, the drag force is no longer simply proportional to the speed.

MULTIPLE CHOICE QUESTIONS

- **Which of the following substances would have a large coefficient of viscosity?**

  (a) Water (b) Air (c) Honey (d) Alcohol

Answer: (c) Honey

Explanation: Honey is a thick substance that flows slowly, indicating a high internal resistance to flow, or high viscosity.

- **The retarding force experienced by an object moving through a fluid is generally called:**

  (a) Buoyant force (b) Cohesive force (c) Drag force (d) Tensile force

Answer: (c) Drag force

Explanation: Drag force is the frictional resistance encountered by an object moving through a fluid.

- **According to Stokes' Law, the drag force on a sphere moving slowly through a fluid is directly proportional to:**

  (a) The square of its speed (b) The square of its radius (c) Its speed (d) Its density

Answer: (c) Its speed

Explanation: Stokes' Law states $F=6\pi\eta rv$, showing a direct proportionality between drag force (F) and speed (v).

- **Why does air cause a large retarding force on a car at high speed, despite having small viscosity?**

  (a) Air density increases at high speed
  (b) Drag force increases significantly with speed
  (c) The car's weight increases
  (d) Air becomes incompressible

Answer: (b) Drag force increases significantly with speed

Explanation: While viscosity might be small, the drag force increases, often proportionally to the square of the speed at high velocities, leading to a substantial retarding force.

- **Stokes' Law is most accurate for objects that are:**

  (a) Moving very fast (b) Irregularly shaped (c) Spherical and moving slowly (d) Highly dense

Answer: (c) Spherical and moving slowly

Explanation: Stokes' Law is specifically derived for the drag on a perfect sphere at low Reynolds numbers, meaning slow, laminar flow.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What does the coefficient of viscosity (η) measure?**

Ans: The coefficient of viscosity measures the internal friction or resistance of a fluid to flow.

- **Why does an object moving through a fluid experience a retarding force?**

Ans: Because liquids and gases have non-zero viscosity, causing frictional effects between the object's surface and the fluid layers, resulting in a drag force.

- **How does the drag force change as the speed of an object moving through a fluid increases?**

Ans: The drag force increases as the speed of the object increases.

- **For what specific shape of object is Stokes' Law derived?**

Ans: Stokes' Law is specifically derived for a sphere.

- **Give an example of a common fluid with relatively low viscosity.**

Ans: Water is a common example of a fluid with a relatively small coefficient of viscosity.

5.14 TERMINAL VELOCITY

Q.

Q1: Define terminal velocity. Explain how a falling object reaches its terminal velocity.

Q2: Derive the formula for the terminal velocity of a spherical raindrop falling through the air, clearly showing the steps.

Q3: What factors influence the terminal velocity of an object?

Ans

TERMINAL VELOCITY

"Maximum constant velocity of an object falling vertically downward when the weight of the object is equal to drag force is called terminal velocity."

Explanation:

"It is maximum uniform velocity acquired by a spherical body in falling under the gravity when drag force becomes equal to the weight of the body."

Expression:

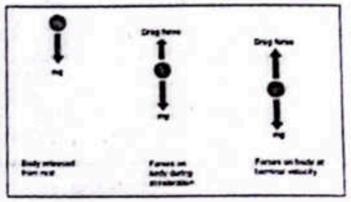
Consider a water droplet (drop of fog or mist) falling vertically. There are two forces acting on it

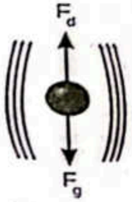
1) The force of gravity acting downward

W $\quad W = mg$

2) The drag force of air acting upward

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





The drag force of air increases as the speed of droplet increases. The net force acting on the droplet is

$$\text{Net Force} = \text{Weight} - \text{Drag force}$$

$$F = mg - 6\pi\eta rv$$

By Newton's second law of motion

$$F = ma$$

So, $\quad ma = mg - 6\pi\eta rv$

As 'v' increases the value of 'a' decreases and at some value of v, 'a' becomes zero. This value of v is called terminal velocity. At this velocity the weight of the droplet becomes equal to the drag force.

So $\quad mg = 6\pi\eta rv_t$

Or $\quad v_t = \dfrac{mg}{6\pi\eta r}$ ——————— (1)

Conclusion (1) Above relation shows that terminal velocity is directly proportional to mass of the water droplet.

Terminal velocity in terms of size: As droplet is spherical so the volume of a sphere is $V = \dfrac{4\pi}{3}r^3$

$$\rho = \frac{m}{V} \quad \text{or} \quad m = \rho V \text{ som} = \frac{4\pi}{3}r^3\rho$$

Putting value of m in equation 1 we get

$$v_t = \frac{4\pi}{3}\rho r^3 \frac{g}{6\pi\eta r}$$

or $\quad v_t = \dfrac{2\rho g r^2}{9\eta}$ .... (2)

or $\quad v_t = \left[\dfrac{2\rho g}{9\eta}\right] r^2 \qquad [\dfrac{2\rho g}{9\eta} = \text{constant}]$

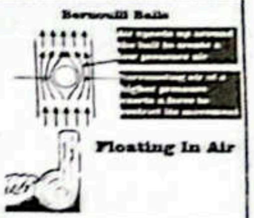
or $\quad v_t \propto r^2$

Conclusion (2) Above relation shows that terminal velocity is directly proportional to square of radius of water droplet i.e. depend upon size of the object.

Can You Do That

A table tennis ball can be made suspended in the stream of air coming from the nozzle of a hair dryer.

The air from nozzle is at very high speed so pressure of air at the nozzle decreases than the surroundings so the ball remains suspended. Because, air at higher pressure traps the ball in a pocket of low pressure and keeps it in a surprisingly stable position.



MULTIPLE CHOICE QUESTIONS

- **An object falling through a fluid reaches terminal velocity when:**
  (a) Its weight becomes zero
  (b) The drag force equals its weight
  (c) The buoyant force equals its weight
  (d) Its acceleration is maximum

Answer: (b) The drag force equals its weight

Explanation: At terminal velocity, the net force on the object is zero, meaning the upward drag force perfectly balances the downward gravitational force (weight).

- **If a spherical raindrop's radius is doubled, its terminal velocity will (assuming Stokes' Law applies):**
  (a) Halve
  (b) Double
  (c) Quadruple
  (d) Remain the same

Answer: (c) Quadruple

Explanation: The formula for terminal velocity ($vt=(2\rho r2g)/(9\eta)$) shows that vt is directly proportional to r2. Doubling r will make r2 four times larger.

- **At terminal velocity, the net force acting on the falling object is:**
  (a) Upward
  (b) Downward
  (c) Zero
  (d) Variable

Answer: (c) Zero

Explanation: When forces are balanced (drag equals weight), the net force is zero, resulting in constant velocity (zero acceleration).

- **Which of the following factors is directly proportional to the terminal velocity of a spherical object falling through a fluid?**
  (a) Viscosity of the fluid (b) Radius of the object (c) Density of the object (d) Square of the viscosity

Answer: (c) Density of the object

Explanation: From the formula $vt=(2\rho r2g)/(9\eta)$, terminal velocity is directly proportional to the density (ρ) of the object.

- **Before reaching terminal velocity, a falling raindrop:**
  (a) Moves at constant speed
  (b) Accelerates downwards
  (c) Accelerates upwards
  (d) Experiences no drag force

Answer: (b) Accelerates downwards

Explanation: Initially, the weight is greater than the drag force, resulting in a net downward force and downward acceleration

MULTIPLE CHOICE QUESTIONS

- **Define terminal velocity.**

Ans: Terminal velocity is the constant speed that a freely falling object eventually reaches when the resistance of the medium through which it is falling prevents further acceleration.

- **How does the drag force on a falling object change as its speed increases, approaching terminal velocity?**

Ans: As the object's speed increases, the drag force on it also increases.

- **What are the two main forces acting on a raindrop falling vertically, and how do they balance at** terminal velocity?

Ans: The two main forces are the downward weight (gravity) and the upward drag force. At terminal velocity, these two forces become equal in magnitude and opposite in direction.

- **Why does a heavier, denser object generally have a higher terminal velocity than a lighter, less dense object of the same shape and size?**

Ans: A heavier, denser object has a larger weight, so a greater drag force is required to balance it, which means it must reach a higher speed (terminal velocity) to achieve that greater drag.

- **What role does the viscosity of the fluid play in determining terminal velocity?**

Ans: Terminal velocity is inversely proportional to the fluid's viscosity, higher viscosity means greater resistance, leading to a lower terminal velocity for a given object.

- **An air bubble of 1 cm radius is rising at a steady rate of 2.00 mm/sec through a liquid of density 1.5 gm cm^{-3}(Neglect density of air). If g = 1000 cm/sec^2, then the coefficient of viscosity of liquid is:**

A. 0.166×10^3 poise B. **1.166×10^3 poise** C. 166×10^3 poise D. 16.6×10^3 poise

Solution: $r = 1cm = 10^{-2}m, v = 2\times10^{-3}ms^{-1}, \rho = 1.5gmcm^{-3}, g = 10000cms^{-2}$

$\eta = ?$

$$\boxed{V_t = \frac{2\rho gr^2}{9\eta}} \Rightarrow \eta = \frac{2\rho gr^2}{v_t} = \frac{2\times1.5\times1000}{9\times0.2} = 1.66\times10^3 \text{Poise}$$

- **A lead sphere of mass m falls in a viscous liquid with a terminal velocity " v ". Another lead sphere of mass 8m will fall through the same fluid with a terminal velocity:**

A. v B. 4v C. 8v D. 64v

Solution: $\rho_1 = \rho_2 = \rho = \text{same so,}$

$$\boxed{v_t \propto \frac{m}{F}}$$

When ρ = same

$m \propto V$

$m \propto r^3$

$m' = 8m \text{ so } r' = 2r$

$r \propto m^{\frac{1}{3}}$

So

$$V_t' \propto \frac{m'}{r'} \propto \frac{8}{2r} = 4\frac{m}{rr} = 4V_o$$

5.15 REAL FLUIDS ARE VISCOUS FLUIDS

Q.

- **Q1: What is the primary distinction between an ideal fluid and a real fluid?**
- **Q2: Why is an ideal fluid considered a theoretical concept and not practically existent?**
- **Q3: Provide examples of real fluids and explain how their properties differ from those of an ideal fluid.**
- **Q4: How does the concept of viscosity differentiate real fluids from ideal fluids?**

Ans

IDEAL FLUID

Definition: A hypothetical fluid with zero viscosity and absolute incompressibility. It cannot exist practically.

- **Properties:** No frictional force between layers, constant density, not subjected to surface tension.
- **Bernoulli's Equation:** In an ideal fluid, Bernoulli's equation states that the sum of pressure, kinetic energy per unit volume, and potential energy per unit volume remains constant.

REAL FLUID

- **Definition:** Any fluid that possesses viscosity. All fluids observed in the real world are real fluids.
- **Properties:** Exhibit viscosity (internal friction), meaning they face an opposing force during flow. They are not perfectly incompressible.

- **Examples:** Water, diesel, petrol, honey, kerosene oil, castor oil.
- **Viscosity Differences:** Different real fluids have varying degrees of viscosity (e.g., honey is more viscous than water).

MULTIPLE CHOICE QUESTIONS

- **An ideal fluid is characterized by:**

(a) High viscosity (b) Compressibility (c) Zero viscosity (d) Turbulent flow

Answer: (c) Zero viscosity

Explanation: An ideal fluid is a theoretical concept defined as having no internal friction, i.e., zero viscosity.

- **Which of the following is an example of a real fluid?**

(a) A theoretical non-viscous liquid (b) Water
(c) A perfectly incompressible gas (d) A superfluid

Answer: (b) Water

Explanation: Water, like all common fluids, exhibits viscosity and is thus considered a real fluid. Super fluids have zero viscosity but are a distinct, exotic state.

- **In real fluids, mechanical energy is typically dissipated as heat due to:**

(a) Changes in density (b) Surface tension (c) Viscous forces (d) Gravitational potential energy

Answer: (c) Viscous forces

Explanation: Viscosity causes internal friction within the fluid and between the fluid and its boundaries, leading to the conversion of mechanical energy into heat.

- **Why is Bernoulli's equation an approximation for real fluids, rather than exact? (a) Real fluids are perfectly incompressible (b) Real fluids are non-viscous (c) Real fluids have surface tension (d) Real fluids exhibit viscosity**
  - Answer: (d) Real fluids exhibit viscosity
  - Explanation: Bernoulli's equation assumes non-viscous flow. The presence of viscosity in real fluids means there are energy losses due to friction, making the "constant" in Bernoulli's equation not truly constant.

- **Which statement accurately compares honey and water as real fluids?**

(a) Honey is less viscous than water (b) Water is more viscous than honey
(c) Honey is more viscous than water (d) Both have zero viscosity

Answer: (c) Honey is more viscous than water

Explanation: Honey flows much more slowly than water, indicating it has a higher internal resistance to flow, meaning higher viscosity.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is the main difference in terms of internal friction between an ideal fluid and a real fluid?**

An: An ideal fluid has zero internal friction (non-viscous), while a real fluid possesses non-zero internal friction (viscosity).

- **Why is an ideal fluid considered a theoretical concept and not found in practice?**

Ans: Because all known fluids in the real world exhibit some degree of viscosity and compressibility, making a truly ideal fluid impossible.

- **How does the presence of viscosity affect the flow of a real fluid?**

Ans: Viscosity causes the real fluid to face an opposing force (frictional force) during flow, leading to energy dissipation and pressure drops.

- **Besides viscosity, what is another property that ideal fluids are assumed not to have, but real fluids do?**

Ans: Ideal fluids are assumed to not be subjected to surface tension, whereas real fluids exhibit surface tension.

- **Give two examples of real fluids, one with relatively high viscosity and one with relatively low viscosity.**

Ans: High viscosity: Honey, Castor oil; Low viscosity: Water, Air

5.16 SUPERFLUID

Q.

Q1: Define superfluidity and explain the unique characteristics of superfluids.

Q2: At what conditions do substances exhibit superfluidity? Give an example.

Q3: Describe the behavior of superfluid helium-4.

Q4: What are the current and potential applications of superfluids?

Ans

SUPERFLUID

- Superfluidity is the characteristic property of fluids with zero viscosity i.e., flow is frictionless.
- A substance exhibiting this property is called superfluid.
- Superfluids flow without loss of kinetic energy.
- Superfluid can flow through incredibly narrow spaces without any friction.
- Superfluidity is achieved in some substances at extremely low temperature. This means that once it starts to flow, it keeps moving past any obstacles.
- Superfluids are an exotic state of matter exhibiting zero viscosity at extremely low temperatures.

SUPERFLUIDITY

- **Definition:** A characteristic property of fluids with zero viscosity, meaning they flow without any loss of kinetic energy (frictionless flow).
- **Condition:** Achieved in some substances at extremely low temperatures (close to absolute zero).
- **Behavior:** Can flow through incredibly narrow spaces without friction. If stirred, vortices will keep spinning indefinitely. Can "creep" over the walls of containers.

SUPERFLUID HELIUM-4

- **Example:** The most studied example of superfluidity is **Helium-4**.
- **Transition:** Changes from a normal liquid to a superfluid a few degrees below its boiling point (e.g., -269°C or 4 K).
- **Appearance:** Behaves like a normal clear liquid but has no viscosity.

SUPERFLUIDITY APPLICATIONS

- **Limited Practical Uses (Currently):**
    - Coolant for high-field magnets.
    - Used in advanced particle detectors (both helium-3 and helium-4).
    - Research helps advance knowledge of superconductivity.
- **Liquid Helium (General Properties):** Recognized for great thermal conductivity and used in:
    - Cryogenic applications (cooling superconducting magnets).
    - Scientific research.
    - Medical uses.
    - Leak testing in industry.
    - Production of electronic and optical products.

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.

VORTEX TALENT INFORMATION

A vortex is a region within a fluid (liquid or gas) where the flow revolves around an axis, which can be straight or curved. This rotational motion often creates a low-pressure zone or a cavity at its center, pulling in surrounding fluid and objects.

Common examples include:

- **Whirlpools in water**
- **Tornadoes and dust devils in air**
- **Smoke rings**

MULTIPLE CHOICE QUESTIONS

- **The defining characteristic of a superfluid is:**

(a) High density (b) Zero viscosity (c) High temperature (d) Compressibility

Answer: (b) Zero viscosity

Explanation: Super fluidity is the property of flowing without any resistance or internal friction

- **At what kind of temperature are superfluids typically observed?**

(a) Room temperature (b) High temperature
(c) Extremely low temperature (d) Boiling point of water

Answer: (c) Extremely low temperature

Explanation: Superfluidity is a quantum mechanical phenomenon that occurs in certain substances only when cooled to temperatures very close to absolute zero.

- **What happens if you stir a superfluid?**

(a) It quickly stops spinning
(b) The vortices will keep spinning indefinitely
(c) It solidifies
(d) It loses its zero viscosity

Answer: (b) The vortices will keep spinning indefinitely

Explanation: Due to zero viscosity and frictionless flow, any motion initiated in a superfluid, like vortices, will persist indefinitely.

- **Superfluids can "creep" over container walls because:**

(a) They are highly adhesive (b) They are very dense
(c) They experience no friction (d) They are gases

Answer: (c) They experience no friction

Explanation: The absence of viscosity means there's no drag against the container walls, allowing the superfluid to flow freely over surfaces.

- **Which substance is the most studied example of superfluidity?**

(a) Liquid nitrogen (b) Superfluid hydrogen (c) Liquid helium-4 (d) Liquid oxygen

Answer: (c) Liquid helium-4

Explanation: Liquid helium-4 is the most well-known and studied superfluid, transitioning to a superfluid state at around 2.17 K.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is meant by "frictionless flow" in the context of superfluids?**

Ans: Frictionless flow means that superfluids experience no resistance or energy loss due to internal friction (viscosity) or friction with surfaces they flow over.

- **How does the thermal conductivity of liquid helium compare to other liquids, and what are its general applications?**

Ans: Liquid helium has very great thermal conductivity. Its general applications include cryogenic cooling, scientific research, medical uses (e.g., MRI), and leak testing.

- **What is the implication of zero viscosity in terms of kinetic energy for superfluids?**

Ans: Superfluids flow without loss of kinetic energy, meaning once motion begins, it persists indefinitely without energy dissipation due to friction.

- **Besides being used as a coolant, what is another advanced application of superfluids like helium-3 and helium-4?**

Answer: They are utilized in advanced particle detectors.

- **How does research into superfluidity contribute to understanding superconductivity?**

Ans: Superfluidity in liquid helium is analogous to superconductivity in metals (zero electrical resistance), so studying superfluids can offer insights into the mechanisms behind superconductivity.

* * *

TEXT BOOK EXERCISE WITH SOLUTION

MULTIPLE CHOICE QUESTIONS

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

Explanation: Hooke's law (stress is proportional to strain) is strictly obeyed only up to the proportional limit. The elastic region extends slightly beyond this, up to the elastic limit, where the material still returns to its original shape, but the relationship is no longer perfectly linear.

5.2 **Which of the following is more elastic?**

(a) Rubber (b)Wood
(c) Sponge **(d) Steel**

Explanation: Elasticity refers to a material's ability to return to its original shape after deformation, and more importantly, its resistance to deformation (Young's modulus). Steel has a much higher Young's modulus than rubber, wood, or sponge, meaning it requires a much larger force to produce a given deformation, making it "more elastic" in the scientific sense. Rubber deforms easily but returns, but steel resists deformation much more strongly.

5.3 **Which of the following Is polymer solid?**

(a) Wool (b) Glass
(c) Sodium chloride (d) Copper

Explanation: Wool is a natural polymer made of proteins. Glass is amorphous, sodium chloride is crystalline, and copper is a metal (crystalline).

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

Explanation: This is a direct statement of Bernoulli's principle for horizontal flow: where fluid speed is high, pressure is low. Venturi's effect (or Venturi relation) is a specific application of Bernoulli's principle. Torricelli's effect relates efflux speed to height, and Doppler's effect relates to wave frequency changes.

5.5 **The pressure will be low when speed of a flu id is:**

(a) zero **(b)high**
(c)low (d) constant

Explanation: This is a direct consequence of Bernoulli's principle: for a horizontal flow, an increase in fluid speed corresponds to a decrease in pressure.

5.6 **As per law of flu id friction for steady stream line 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

Explanation: For slow, steady streamline flow, especially for a sphere (Stokes Law), the drag force (friction) is directly proportional to the velocity of the object moving through the fluid (F=6πηrv).

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

Explanation: The apparent loss of weight is due to the upthrust (buoyant force) exerted by the displaced water, which acts upwards, opposing the downward gravitational force.

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

Explanation: The principle of floatation is a special case derived directly from Archimedes' principle, stating that a floating object displaces fluid equal to its own weight.

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)

Explanation: An ideal fluid flow is characterized by being incompressible and non-viscous. These properties allow for the application of both the continuity equation (conservation of mass) and Bernoulli's equation (conservation of energy).

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

Explanation: The shape of the wing causes air to flow faster over the top surface and slower underneath. According to Bernoulli's principle, this speed difference creates a lower pressure above and a higher pressure below, resulting in a net upward lift 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) Arch I modes' principle
(c) Pascal's law **(d) Bernoulli's principle**

Explanation: A Venturi mask uses a constriction to increase the speed of a gas, which in turn lowers its pressure (Bernoulli's principle). This pressure drop creates a suction effect, drawing in ambient air to mix with the oxygen, delivering a precise concentration.

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

Explanation The defining characteristic of a superfluid is zero viscosity, meaning it flows without any resistance or friction. While superfluids are very good thermal conductors, and require extremely low temperatures, zero viscosity is their fundamental property.

SHORT ANSWER QUESTIONS

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

Ans: **(i) Cohesive forces:** The force of attraction among the molecules of same substance called cohesive forces. These forces are responsible for phenomena like surface tension.

(ii) Viscosity: The frictional effect between different layers of a flowing fluid is called viscosity. Viscosity measures, how much force is required to slide one layer of the liquid over another layer.

5.2 **Differentiate between streamline and turbulent flow of a fluid.**

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

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

Streamline (Laminar) Flow:	**Turbulent Flow:**
• Fluid layers move parallel without crossing or mixing.	• Fluid layers mix and cross each other, creating chaotic patterns.
• **Constant Velocity:** The velocity of a fluid particle at a given point remains constant over time.	• The velocity of a fluid particle at a given point changes in both magnitude and direction.
• **Low Velocity:** Typically occurs at lower speeds and pressures.	• **High Velocity :** Typically occurs at higher speeds and pressures.
• **Examples:** Blood flow in veins, water flowing from a faucet at a low rate, smoke rising from a cigarette	• **Examples:** River flow, water flowing from a faucet at a high rate, traffic flow.

5.3 **How does pressure changes with depth in fluids?**

Ans: In a fluid at rest, pressure increases with depth. The formula for pressure at a depth h is $P = \rho g h$, where ρ is the fluid density and g is the acceleration due to gravity. This is because the weight of the fluid column above a certain point increases with depth.

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

Ans: According to Bernoulli's principle, for a horizontal flow of an ideal fluid, pressure decreases as the speed of the fluid increases. Conversely, pressure increases where the fluid speed decreases. This relationship is important in many fluid dynamics applications and is known as venturi relation.

$$P_A - P_B = \frac{1}{2}\rho(v_B^2 - v_A^2)$$

$$\Rightarrow P_A > P_B$$

Where $V_A < V_B$

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

Ans: The flow rate (volume of fluid per unit time) is directly proportional to both the cross-sectional area (A) of the pipe and the average velocity (v) of the fluid. The relationship is given by the equation of continuity. Flow Rate = Av = Constant i.e

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

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

Ans: The continuity equation is

$$A_1 v_1 = A_2 v_2$$

Where, $A_1 = \pi r_1^2 = \pi\left(\frac{D_1}{2}\right)^2 = \pi\frac{D_1^2}{4}$ and v_1 are the area and velocity at point in a hose.

and $_2 = \pi r_2^2 = \pi\left(\frac{D_2}{2}\right)^2 = \pi\frac{D_2^2}{4}$ and v_2 are the area and velocity at another point.

So equation of continuity becomes

$$\cancel{\pi}\frac{D_1^2}{\cancel{4}}v_1 = \cancel{\pi}\frac{D_2^2}{\cancel{4}}v_2$$

$$\frac{v_1}{v_2} = \frac{D_2^2}{D_1^2}$$

It shows that velocity of the fluid varies inversely with the square of the diameter of the hose. Where the hose narrows (smaller A)

[illegible]

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. For small deformations within the elastic limit, the ratio stress/strain [illegible]

[illegible] constant, [illegible]

Effect on this ratio when the deformation made is very large:

Therefore, when the deformation becomes very large, exceeding the elastic limit and especially the proportional limit, the material enters the plastic deformation region. In this region, the stress-strain relationship is no longer linear, and the ratio of stress to strain will not remain constant. It will decrease as the material deforms plastically, eventually leading to fracture.

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

Ans. This phenomenon is due to the interplay of cohesive and adhesive forces.

- Water on Glass: Water has strong adhesive forces with glass (attraction between water molecules and glass molecules) and weaker cohesive forces (attraction between water molecules themselves). Therefore, the adhesive forces are stronger, causing the water to spread out and wet the surface.
- Mercury on Glass: Mercury has very strong cohesive forces (attraction between mercury atoms) and weak adhesive forces with glass. The mercury atoms are more strongly attracted to each other than to the glass, causing the mercury to bead up into small spherical globules and not wet the surface.

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. In Bernoulli's principle ($P + \frac{1}{2}\rho v^2 + \rho gh$ = constant), we consider an ideal fluid which is incompressible, non-viscous and irrotational but in reality, fluids are not perfectly incompressible, non-viscous and not having irrotational flow. These factors bring the velocity of fluid and the pressure of fluid also change along the pipe even with uniform radius.

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

Ans. The design of wings of an aeroplane rounded outward and flattened inward to provide necessary lift to plane against gravity. The curved upper surface causes air to travel a longer distance that leads air to speed and low pressure. Flattened inner surface causes air to travel short distance that leads to slow air speed and high pressure. This pressure difference provides lift to aeroplane in accordance with Bernoulli's Principle.

$$P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2) \Rightarrow P_1 > P_2$$

Where $v_2 > v_1$

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

Ans. **Real Fluid:** Any fluid that possesses viscosity and is compressible to some extent. All fluids we encounter daily exhibit these properties.

Existence: Really exists in the world e.g. water, oil, air, honey. They experience internal friction (viscous drag) and energy dissipation during flow.

Ideal Fluid: A theoretical fluid with zero viscosity and perfect incompressibility. It flows without any internal friction or resistance to compression.

Existence: Does not exist in the real world. It's an idealization used to simplify fluid dynamics calculations.

Superfluids: An exotic state of matter observed at extremely low temperatures, characterized by zero viscosity. While it's a real physical state, it's distinct from normal real fluids.

Existence: Really exists in the world, but only under very specific and extreme conditions (e.g. liquid helium-4 below 2.17 K).

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

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

- **Quantum Phenomena at Macroscopic Scale:** Superfluidity is a macroscopic quantum phenomenon. Studying it allows physicists to observe and understand quantum mechanical effects (which usually occur at the atomic or subatomic level) on a large, observable scale.
- **Phase Transitions:** It provides insights into phase transitions that occur at extremely low temperatures, such as the transition from a normal liquid to a superfluid state.
- **Connection to Superconductivity:** Superfluidity in liquid helium is analogous to superconductivity in metals

(zero electrical resistance). Studying superfluids can offer insights into the mechanisms behind superconductivity and related phenomena, which have significant technological implications.

- **Fundamental Properties of Matter:** It helps in understanding the fundamental properties of matter under extreme conditions, probing the limits of physical laws.
- **Technological Applications:** While current practical applications are limited, the fundamental understanding gained could lead to future breakthroughs in areas like quantum computing, highly sensitive sensors, and novel cooling technologies.

COMPREHENSIVE QUESTIONS

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

(Detailed notes provided in section 5.1, "Classification of Solids", including Crystalline, Amorphous, and Polymeric solids, their definitions, atomic arrangements, melting points, examples, and study techniques.)

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

(Detailed notes provided in section 5.7, "Archimedes' Principle and Floatation", including the principle statement, derivation of upthrust, and examples of its application.)

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

(Detailed notes provided in section 5.9, "Equation of Continuity", including the statement and derivation showing how $A_1v_1\rho_1 = A_2v_2\rho_2$ directly demonstrates the conservation of mass for any fluid flow, and for incompressible fluids, it simplifies to $A_1v_1 = A_2v_2$.)

5.4 **Explain the term superfluidity.**

(Detailed notes provided in section 5.16, "Superfluids", including its definition, characteristics, conditions for existence, behavior of superfluid helium-4, and its applications.)

5.5 **State and derive equation of continuity.**

(Detailed notes provided in section 5.9, "Equation of Continuity", including its statement, formula, and step-by-step derivation based on the conservation of mass.)

5.6 **State and prove Bernoulli's equation.**

(Detailed notes provided in section 5.11, "Bernoulli's Equation", including its statement, assumptions, and step-by-step derivation using the work-energy theorem and conservation of energy.)

5.7 **Give some practical applications of Bernoulli's equation.**

(Detailed notes provided in section 5.12, "Uses of Bernoulli's Equation", covering Aeroplane Wings, Swing of a Ball (Magnus Effect), Filter Pump, Carburetor, Paint Sprayer/Perfume Bottle, Venturi Relation, and Torricelli's Theorem.)

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

(Detailed notes provided in section 5.14, "Terminal Velocity", including its definition, explanation of how it's reached, and a step-by-step derivation showing $v_t = \dfrac{2gr^2\rho}{9\eta}$ thus demonstrating the r^2 proportionality.)

SOLVED EXAMPLES

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? ($E = 200\times10^9$ N m^{-2})

(a) Tensile stress $\sigma = \dfrac{F}{A} = \dfrac{10,000\,N}{3.14(6\times10^{-3}\,m)^2}$

Tensile strain

$$\varepsilon = \frac{\Delta L}{L_o}, \text{ also } E = \frac{\text{Stress}}{\text{Strain}} = \frac{88.46\times10^6\,N\,m^{-2}}{\text{Strain}} = 200\times10^9\,N\,m^{-2}$$

$$\text{Strain} = \frac{88.46\times10^6\,N\,m^{-2}}{200\times10^9\,N\,m^{-2}} = 4.4\times10$$

(b) Using the relation: Strain =

$$\frac{\Delta L}{L_o} \text{ or } \Delta L = \text{Strain}\times L_o = 4.4\times10^{-4}\times11\,\text{m} = 4.84\times10^{-3}\,\text{m}$$

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.

Given:

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

Volume $V = L^3 = (0.1\text{ m})^3 = 1\times10^{-3}\text{m}^3$

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

Upthrust F = ?

Using Archimedes' principle

Upthrust of water = ρgV

$= 1000\text{ kg m}^{-3}\times9.8\text{ ms}^{-2}\times1\times10^{-3}\text{m}^3 = 9.8$ N

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

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:

Weight of the balloon	w	=	80 N
Volume of hydrogen	V	=	10 m^3
Density of hydrogen	ρ_1	=	0.09 kg m^{-3}
Density of air	ρ_2	=	1.3 kg m^{-3}
Weight of hydrogen	w_1	=	?
Weight of the contents	w_2	=	?

Upthrust F = Weight of air displaced

$= \rho_2 gV$

$= 1.3\text{ kgm}^{-3}\times9.8\text{ ms}^{-2}\times10\text{ m}^3$

$= 127.4$ N

Weight of hydrogen $w_1 = \rho_1 Vg$

$= 0.09\text{ kg m}^{-3}\times10\text{ m}^3\times9.8\text{ m s}^{-2}$

$= 8.82$ N

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

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

Thus $w + w_1 + w_2 = F$

$80\text{ N} + 8.82\text{ N} + w_2 = 127.4$ N

$w_2 = 38.58$

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

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

Radius $r = \dfrac{D}{2} = \dfrac{0.02\,m}{2} = 0.01\,m$

Mass of water $m = 30$kg

Time taken $t = 60$s

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

Speed of water v = ?

Mass flow per second $m/t = 30$ kg / 60s

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

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

$= 3.14\times10^{-4}\text{ m}^2$

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

ρAv = Mass/ Second

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

$$v = \frac{0.5\,kg\,s^{-1}}{1000\,kg\,m^{-3}\times3.14\times10^{-4}\,m^2}$$

$= 1.6\text{ m s}^{-1}$

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

$r = 1.0\times10^{-4}$ m, $\rho = 1000$ kgm^{-3}, $\eta = 19\times10^{-6}$ kg m^{-1}s^{-1}

Putting the above values in Eq. (5.29)

2

$$v_t = \frac{2\times9.8\,m\,s^{-2}\times(1.0\times10^{-4}\,m)^2\times1000\,kg\,m^{-3}}{9\times19\times10^{-6}\,kg\,m^{-1}s^{-1}}$$

Terminal velocity = 1.1 m s^{-1}.

NUMERICAL PROBLEMS

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

Given

Length of steel wire = L = 2 m

Area of corss sectional = A = 2×10^{-6}m^2

Young's Modulus = Y = 2×10^{11} N m^{-2}

Force = F = 400 N

Extension of wire = ΔL = ?

Solution:

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

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

$$\Delta L=\frac{400}{2\times10^{-6}}\times\frac{2^{*}}{2\times10^{11}}=2\times10^{-3}=0.002\ \text{m}$$

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

Given

Spring constant = k = 200 N m^{-1}

Extension = Δx = 0.5 m

Elastic potential energy = E.P.E = ?

Solution:

$F=k\Delta x=200\times0.5=100\ \text{N}$

$$E.P.E=\frac{1}{2}F\times\Delta x$$

$$E.P.E=\frac{1}{2}100\times0.5=25\ \text{J}$$

5.3 **A copper wire of length 3 meters and cross-sectional area of 1x10^{-6}m^2 is subjected to a force of 500 N. Calculate the stress and strain produced in the wire.**

Length of copper wire = L = 3 m

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

Force = F = 500 N

Young's modulus of copper = Y = 1.1 × 10^{11} N m^{-2}

Stress = ?

Strain = ?

Stress

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

$$\sigma=\frac{500}{1\times10^{-6}}=5\times10^{8}\ \text{N m}^{-2}$$

Strain

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

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

$$Y=\frac{5\times10^{8}}{1.1\times10^{11}}=4.545\times10^{-3}=0.00455$$

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 kgm^{-3})**

Given

Mass of wooden block = m = 10 kg

Density of wooden block = ρ_w = 600 kg m^{-3}

Density of water = ρ = 1000 kg m^{-3}

Buouyant force = F = ?

Solution:

When an object float, the buoyant force will be equal to its weight

F = W = mg

F = 10 × 9.8 = 98 N

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

Given

Diameter of pipe = D_1 = 0.05 m

Velocity at this point = v_1 = 2 m s^{-1}

Diameter of narrow end = D_2 = 0.03 m

Velocity at narrow end = v_2= ?

Solution

The continuity equation is:

$$A_1v_1=A_2v_2$$

$$\cancel{\pi}\frac{D_1^2}{\cancel{4}}v_1=\cancel{\pi}\frac{D_2^2}{\cancel{4}}v_2$$

$$\frac{v_1}{v_2}=\frac{D_2^2}{D_1^2}$$

$$v_2=\frac{D_1^2}{D_2^2}\times v_1$$

$$v_2=\frac{0.05^2}{0.03^2}\times2=5.56\ \text{m s}^{-1}$$

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})**

Given:

Speed at point 1 = v_1= 3 m s^{-1}

Speed at point 2 = v_2= 14 m s^{-1}

Pressure at point 1 = P_1 = 200000 Pa

Pressure at point 2 = P_2 = 101300 Pa

Required: Velocity at nozzle = v_2 = ?

Solution:

Using Bernoulli's equation for horizontal pipe

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

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

$$\frac{1}{2}(1000)\,v_2^2=200000-101300+\frac{1}{2}(1000)(3)^2$$

$$500\,v_2^2=98700+4500=103200$$

$$v_2^2=\frac{103200}{500}=206.4$$

$$v_2=14.3\ \text{m s}^{-1}$$

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.**

Given:

Height of water surface for hole= $h_1-h_2=h=5$ m

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

To Find:

Speed of water = v = ?

Calculation:

Using Torricelli's theorem,

$$v=\sqrt{2g(h_1-h_2)}$$

$$v=\sqrt{2\times9.8(5)}$$

$$v=\sqrt{98}$$

$$v=9.9\ \text{m s}^{-1}$$

5.8 **Calculate the terminal velocity of a spherical raindrop with a radius 0.5 mm falling through air.**

Given:

Radius of rain droplet = r = 0.5 mm = 5 × 10^{-4} m

Density of water = ρ = 1000 kg m^{-3}

Coefficient of viscosity = η = 1.9 × 10^{-5} kg m^{-1}s^{-1}

Required:

Terminal Velocity = v_t=?

Solution:

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

Putting the values in formula, we get

$$v_t=\frac{2\times9.8\ \text{m s}^{-2}\times(5\times10^{-4}\text{m})^2\times1000\ \text{kg m}^{-3}}{9\times1.9\times10^{-5}\ \text{kg m}^{-1}\text{s}^{-1}}$$

$$v_t=\frac{2\times9.8\times25\times10^{-8}\times1000}{9\times1.9\times10^{-5}}$$

$$v_t=\frac{2\times9.8\times25\times10^{-8+3+5}}{9\times1.9}$$

$$v_t=28.65\ \text{m s}^{-1}$$

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