TOPIC 1 Classification of Solids

SQ 5.1.1 What is a crystalline solid?

Definition

In crystalline solids there is a regular arrangement of atoms and molecules. The neighbours of every molecule are arranged in a regular pattern that is consistent throughout the crystal.

Result

There is thus an ordered structure in crystalline solids.

SQ 5.1.2 Which techniques are used to study the arrangement in crystalline solids?

Techniques

The arrangement of molecules, atoms or ions within crystalline solids can be studied using X-ray Diffraction (XRD) and Transmission Electron Microscopy (TEM).

SQ 5.1.3 Are the atoms in a crystalline solid static?

Answer

No. Each atom in a crystal vibrates about a fixed point with an amplitude that increases with a rise in temperature.

Order

It is the average atomic positions which are perfectly ordered over large distances.

SQ 5.1.4 What maintains the long-range order in a crystalline solid?

Answer

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

SQ 5.1.5 Why does a crystalline solid melt suddenly?

Reason

For every crystal there is a temperature at which the vibrations become so great that the structure suddenly breaks up and the solid melts.

Result

The transition from solid order to liquid disorder is therefore abrupt or discontinuous, so every crystalline solid has a definite melting point.

SQ 5.1.6 Give examples of crystalline solids.

Examples

Quartz, calcite, sugar, mica and diamond are crystalline solids. Most solids like metals and ceramics have a crystalline structure.

SQ 5.1.7 What does the word amorphous mean?

Answer

The word amorphous means without form or structure. Thus in amorphous solids there is no regular arrangement of molecules like that in crystalline solids.

SQ 5.1.8 Why are amorphous solids described as liquids with frozen structure?

Answer

Amorphous solids are more like liquids with the disordered structure frozen in, because their molecules have no regular arrangement.

SQ 5.1.9 Why are amorphous solids also called glassy solids?

Reason

Ordinary glass, which is a solid at ordinary temperature, has no regular arrangement of molecules. On heating it gradually softens into a paste like state before becoming a very viscous liquid at almost $800\,^{\circ}\mathrm{C}$.

Result

Such solids are therefore also called glassy solids.

SQ 5.1.10 Do amorphous solids have a definite melting point? Give examples.

Answer

No, this type of solid has no definite melting point.

Examples

Plastic, glass and fused silicon are amorphous solids.

SQ 5.1.11 What are polymeric solids?

Definition

Polymers are solid materials with a structure that is intermediate between order and disorder. They can be classified as partially or poorly crystalline solids.

SQ 5.1.12 How are polymers formed?

Answer

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

SQ 5.1.13 What is the advantage of polymers over metals?

Answer

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

SQ 5.1.14 Of what are polymers chemically composed?

Answer

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

SQ 5.1.15 Give examples of polymers.

Examples

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

SQ 5.1.16 Differentiate between crystalline and amorphous solids.

Crystalline Solids	Amorphous Solids
There is a regular arrangement of atoms and molecules.	There is no regular arrangement of molecules.
They have a definite melting point.	They have no definite melting point.
Quartz, calcite and diamond are examples.	Plastic, glass and fused silicon are examples.

TOPIC 2 Mechanical Properties of Solids

SQ 5.2.1 What is deformation?

Definition

Deformation, that is a change in shape, length or volume, is produced when a body is subjected to some external force.

SQ 5.2.2 Explain deformation using a rubber ball.

Explanation

If we hold a soft rubber ball in our hand and squeeze it, the shape or volume of the ball changes. However, if we stop squeezing and open our hand, the ball returns to its original spherical shape.

SQ 5.2.3 Explain deformation using a rubber string.

Explanation

If we hold two ends of a rubber string and move our hands apart, the length of the string increases under the applied force. The greater the applied force, the larger the increase in length. On removing the force the string returns to its original length.

SQ 5.2.4 How are atoms held in crystalline solids?

Answer

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

SQ 5.2.5 When is a body said to be in a state of stress?

Answer

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

SQ 5.2.6 Define elasticity.

Definition

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

TOPIC 3 Stress, Strain and Young's Modulus

SQ 5.3.1 Define stress and write its formula.

Definition

Stress is defined as the force applied per unit area to produce any change in the shape, volume or length of a body.

Formula

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

SQ 5.3.2 Write the SI unit of stress.

SI Unit

The SI unit of stress is newton per square metre ($\mathrm{N\,m^{-2}}$), which is given the name pascal (Pa).

SQ 5.3.3 Name the three kinds of stress.

Tensile Stress

When the stress changes length.

Volume Stress

When the stress changes the volume.

Shear Stress

When the stress changes the shape.

SQ 5.3.4 Define strain.

Definition

Strain is a measure of the deformation of a solid when stress is applied to it. In the case of deformation in one dimension, strain is defined as the fractional change in length.

SQ 5.3.5 Write the formula for longitudinal strain.

Formula

$$\varepsilon = \frac{\text{Change in length}}{\text{Original length}} = \frac{\Delta L}{L_0}$$

SQ 5.3.6 Why does strain have no units?

Reason

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

SQ 5.3.7 Differentiate between tensile strain and compressive strain.

Answer

If the strain is due to tensile stress it is called tensile strain, and if it is produced as a result of compressive stress it is termed compressive strain.

SQ 5.3.8 Define volumetric strain and write its formula.

Definition

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

Formula

$$\varepsilon_v = \frac{\Delta V}{V_0}$$

SQ 5.3.9 Define shear strain and write its formula.

Definition

If one face of a rigid body slides through a distance Δx when the distance between two opposite faces is y, then shear strain is produced.

Formula

$$\varepsilon_s = \frac{\Delta x}{y} = \tan\theta$$

SQ 5.3.10 **Why is shear strain equal to θ for small angles?**

Reason

For small values of the angle θ measured in radian,

$\tan\theta = \theta$

so that the shear strain is simply

$\varepsilon_s = \theta$

SQ 5.3.11 **Define Young's modulus and write its formula.**

Definition

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

Formula

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

SQ 5.3.12 **Write the SI unit of Young's modulus.**

SI Unit

Young's modulus has the same unit as that of stress, that is $\mathrm{N\,m^{-2}}$.

SQ 5.3.13 **Who developed the concept of Young's modulus?**

Answer

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

SQ 5.3.14 **Differentiate between stress, strain and Young's modulus.**

Stress	Strain	Young's Modulus
It is the force applied per unit area.	It is the fractional change in length.	It is the ratio of stress to strain.
Its unit is $\mathrm{N\,m^{-2}}$.	It has no unit.	Its unit is $\mathrm{N\,m^{-2}}$.

SQ 5.3.15 **A steel wire 12 mm in diameter is pulled with a force of 10000 N. Find the tensile stress.**

Solution

$$\sigma = \frac{F}{A} = \frac{10000}{3.14 \times (6 \times 10^{-3})^2}$$

Result

$\sigma = 88.46 \times 10^6\,\mathrm{N\,m^{-2}}$

SQ 5.3.16 **For a stress of 88.46×10^6 N m^{-2} and Y = 200×10^9 N m^{-2}, find the strain.**

Solution

$$\varepsilon = \frac{\sigma}{Y} = \frac{88.46 \times 10^6}{200 \times 10^9}$$

Result

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

SQ 5.3.17 **A wire of length 11 m has a strain of 4.4×10^{-4}. Find its extension.**

Solution

$\Delta L = \varepsilon \times L_0 = 4.4 \times 10^{-4} \times 11$

Result

$\Delta L = 4.84 \times 10^{-3}\,\mathrm{m}$

TOPIC 4 Determination of Young's Modulus of a Wire

SQ 5.4.1 **By which method is Young's modulus of a wire found experimentally?**

Answer

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

SQ 5.4.2 **Describe the construction of Searle's apparatus.**

Construction

It consists of two wires, a reference wire and a test wire, of equal lengths and of the same material having the same diameters, attached to a rigid support.

Both wires are connected to horizontal bars at the other ends.

SQ 5.4.3 **Why is a constant weight hung on the reference wire?**

Reason

A constant weight is hung on the hook of the horizontal bar of the reference wire, and a hanger on the test wire, so that the wire remains stretched and free from kinks.

SQ 5.4.4 **How is the initial length and diameter of the wire measured in Searle's method?**

Length

The initial length L_0 of the wire is measured using a metre scale.

Diameter

The diameter is measured using a screw gauge at several different points along the wire, and the average is taken.

SQ 5.4.5 **How is the reference reading obtained in Searle's method?**

Method

The spirit level is adjusted so that it is in a horizontal position by turning the micrometer. The micrometer reading is then recorded to be used as the reference reading.

SQ 5.4.6 **How is the extension of the test wire obtained?**

Method

The test wire is loaded with a further weight, so the spirit level tilts due to elongation. The micrometer screw is then adjusted to restore the spirit level to the horizontal position.

Result

Subtracting the first micrometer reading from the second gives the extension of the test wire.

SQ 5.4.7 **Write the formulas used to calculate stress and strain in Searle's method.**

Stress

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

Strain

$$\varepsilon = \frac{\Delta L}{L_0}$$

SQ 5.4.8 **How is Young's modulus finally obtained from the readings?**

Method

The values of stress and strain obtained for increasing loads are plotted on a stress-strain graph, which should be a straight line.

Result

The value of the slope of this straight line is equal to Young's modulus of the wire.

TOPIC 5 Elastic Deformation, Plastic Deformation and Elastic Limit

SQ 5.5.1 How is a stress-strain curve obtained?

Method

In a tensile test machine a metal wire is extended at a specified deformation rate, and the stresses generated in the wire are continuously measured by a suitable electronic device.

Result

A force-elongation diagram or stress-strain curve is plotted automatically on an X-Y chart recorder.

SQ 5.5.2 Define proportional limit.

Definition

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

SQ 5.5.3 Which law is obeyed in the region OA of the stress-strain curve?

Answer

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

SQ 5.5.4 What happens between points A and B of the stress-strain curve?

Answer

From A to B, stress and strain are not proportional, although the material is still elastic.

SQ 5.5.5 Define elastic limit.

Definition

If the load is removed at any point between O and B, the curve is retraced and the material returns to its original state. The point B is called the yield point, and the value of stress at B is known as the elastic limit.

SQ 5.5.6 Define plasticity.

Definition

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

SQ 5.5.7 Define ultimate tensile strength.

Definition

The ultimate tensile strength is defined as the maximum stress that a material can withstand, and it can be regarded as the nominal strength of the material.

SQ 5.5.8 What happens once the point of ultimate tensile strength is crossed?

Answer

Once the point corresponding to the ultimate tensile strength is crossed, the material breaks at point D, corresponding to the fracture stress.

SQ 5.5.9 What are ductile substances? Give examples.

Definition

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

Examples

Lead, copper and wrought iron are ductile substances.

SQ 5.5.10 What are brittle substances? Give examples.

Definition

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

Examples

Glass and high carbon steel are brittle. Beryllium, bismuth and chromium are also brittle metals.

SQ 5.5.11 Differentiate between elastic and plastic deformation.

Elastic Deformation	Plastic Deformation
The material returns to its original state when the load is removed.	The material is permanently changed and does not recover its original shape.
It occurs in the region up to the elastic limit.	It occurs beyond the yield stress or elastic limit.

TOPIC 6 Strain Energy in Deformed Materials

SQ 5.6.1 What is strain energy?

Definition

When a body is deformed by a force, work is done against the elastic restoring force. It is stored in the body as its potential energy and is called strain energy.

SQ 5.6.2 To what is the strain energy of a body equal?

Answer

It is equal to the gain in potential energy of the molecules of the body, due to the displacement of these molecules from their mean positions.

SQ 5.6.3 Why is the average stretching force taken as half of F?

Reason

Since the extension is directly proportional to the stretching force within the elastic limit, the force increases uniformly from zero to F. Hence the average force that stretches the spring through x is $\frac{1}{2}F$.

SQ 5.6.4 **Derive the expression for energy stored in a stretched spring.**

Derivation

The work done is the average force multiplied by the distance moved, so

$W = \frac{1}{2}Fx.$

From Hooke's law

$F = kx$

therefore

Result

$W = \frac{1}{2}kx^2$

SQ 5.6.5 **Write the strain energy stored in a deformed body.**

Formula

$U = \frac{1}{2}Fx = \frac{1}{2}kx^2$

SQ 5.6.6 **What does the area under a force-extension graph represent?**

Answer

The area under the force-extension graph represents the work done to stretch the material, which is also equal to the elastic potential energy stored in the material.

SQ 5.6.7 **A spring with spring constant 200 N m⁻¹ is stretched by 0.1 m. Find the energy stored.**

Solution

$U = \frac{1}{2}kx^2 = \frac{1}{2}(200)(0.1)^2$

Result

$U = 1\,\mathrm{J}$

TOPIC 7 Archimedes' Principle and Floatation

SQ 5.7.1 **What everyday observations suggest an upward force in a liquid?**

Observations

An air-filled balloon shoots up to the surface when released under water, and the same happens with a piece of wood.
A mug filled with water feels light under water but feels heavy as soon as we take it out of water.

SQ 5.7.2 **What did Archimedes notice?**

Answer

More than two thousand years ago the Greek scientist Archimedes noticed that there is an upward force which acts on an object kept inside a liquid, resulting in an apparent reduction in weight of the object.

SQ 5.7.3 **What is upthrust?**

Definition

The upward force acting on an object immersed in a liquid is called the upthrust of the liquid.

SQ 5.7.4 **State Archimedes' principle.**

Statement

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

SQ 5.7.5 **Derive the expression for upthrust on an immersed cylinder.**

Derivation

The forces on the top and bottom faces are

$F_1 = \rho g h_1 A$

and

$F_2 = \rho g h_2 A$

The net upward force is

$F = F_2 - F_1 = \rho g A(h_2 - h_1).$

Since $A(h_2 - h_1)$ is the volume V,

Result

$F = \rho g V$

SQ 5.7.6 **What does the expression F = ρgV represent physically?**

Answer

Since V is the volume of the liquid displaced by the cylinder, $\rho g V$ is the weight of the liquid displaced. This is Archimedes' principle.

SQ 5.7.7 **When does an object sink and when does it float?**

Sinking

An object sinks into a fluid if its weight is greater than the upthrust acting on it.

Floating

An object floats if its weight is equal to or less than the upthrust.

SQ 5.7.8 **State the principle of floatation.**

Statement

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

SQ 5.7.9 **To what is the upthrust on a floating object equal?**

Answer

When an object floats in a fluid, the upthrust acting on it is equal to the weight of the object. The upthrust is always equal to the weight of the fluid displaced.

SQ 5.7.10 **Is Archimedes' principle applicable to gases?**

Answer

Yes. Archimedes' principle is applicable to liquids as well as to gases, and we find numerous applications of it in daily life.

SQ 5.7.11 **Why does a hot-air balloon rise?**

Reason

The density of the hot-air balloon is less than that of the surrounding air, so the upthrust of the surrounding air is more and the balloon starts to rise.

Control

This is done by varying the quantity of hot air in the balloon.

SQ 5.7.12 **Why does a wooden block float on water?**

Reason

The weight of an equal volume of water is greater than the weight of the block. According to the principle of floatation, a body floats if the weight of the water it displaces is equal to its own weight.

SQ 5.7.13 How are ships and boats designed?

Answer

Ships and boats are designed on the principle of floatation to carry passengers and goods over water. A ship would sink if its total weight became greater than the upthrust of water.

SQ 5.7.14 How does a submarine float and dive?

Floating

It floats when the weight of water equal to its volume is greater than its weight, and it then remains partially above water level.

Diving

Its tanks are filled with seawater so its weight increases. As soon as its weight becomes greater than the upthrust it dives into water. To come up, the tanks are emptied.

SQ 5.7.15 A wooden cube of side 10 cm is fully dipped in water. Find the upthrust.

Solution

The volume is

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

and the upthrust is

$F = \rho g V$

Calculation

$F = 1000 \times 9.8 \times 1 \times 10^{-3}$

Result

$F = 9.8\,\mathrm{N}$

SQ 5.7.16 A balloon holds 10 m³ of hydrogen. Find the upthrust of air of density 1.3 kg m⁻³.

Solution

The upthrust equals the weight of air displaced, so

$F = \rho_a g V$

Calculation

$F = 1.3 \times 9.8 \times 10$

Result

$F = 127.4\,\mathrm{N}$

SQ 5.7.17 Find the weight of 10 m³ of hydrogen of density 0.09 kg m⁻³.

Solution

$w_h = \rho_h g V = 0.09 \times 9.8 \times 10$

Result

$w_h = 8.82\,\mathrm{N}$

SQ 5.7.18 An 80 N balloon holds hydrogen weighing 8.82 N with an upthrust of 127.4 N. Find the maximum load it can lift.

Solution

To lift the contents,

$w + w_h + w_c = F$

Calculation

$80 + 8.82 + w_c = 127.4$

Result

$w_c = 38.58\,\mathrm{N}$

TOPIC 8 Steady, Non-Viscous and Ideal Fluid

SQ 5.8.1 In how many ways can the flow of a fluid take place?

Answer

When a fluid is in motion, its flow can take place in two ways, either streamline or turbulent.

SQ 5.8.2 Define streamline or laminar flow.

Definition

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

SQ 5.8.3 What is a streamline?

Definition

The smooth path followed by fluid particles in laminar flow is called a streamline. It may be straight or curved, and the tangent at any point gives the direction of flow of the fluid.

SQ 5.8.4 Why can two streamlines not cross each other?

Reason

If two streamlines crossed each other, then the particles would go in one or the other direction and the flow would not be steady. Such a flow would be a turbulent flow.

SQ 5.8.5 Define turbulent flow.

Definition

The irregular or unsteady flow of a fluid is called turbulent flow. Above a certain velocity of flow the motion of the fluid becomes unsteady and irregular.

SQ 5.8.6 What happens to the particles in turbulent flow?

Answer

The velocity of the fluid changes abruptly and the exact path of the particles cannot be considered. There are eddies and whirlpools in the motion and the paths of the particles are continuously changing.

SQ 5.8.7 Differentiate between streamline and turbulent flow.

Streamline Flow	Turbulent Flow
Every particle follows exactly the same path as the previous one.	The flow is irregular and unsteady.
The velocity at a point does not change with time.	The velocity of the fluid changes abruptly.
Streamlines never cross each other.	There are eddies and whirlpools in the motion.

SQ 5.8.8 Write the three conditions satisfied by an ideal fluid.

Conditions

The fluid is non-viscous, that is there is no frictional force between adjacent layers.
The fluid is incompressible, that is its density is constant.
The fluid motion is steady.

SQ 5.8.9 **Define the rate of flow of a fluid.**

Definition

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

SQ 5.8.10 **Derive the formula for the rate of flow.**

Derivation

If the fluid of velocity v flows for time t, the distance covered is

$\ell = vt$

so the volume passing is

$A\ell = Avt$

Result

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

SQ 5.8.11 **Write the units of rate of flow.**

Units

In SI units the rate of flow is measured in cubic metre per second ($\mathrm{m^3\,s^{-1}}$). Sometimes it is also measured in litres per second ($\mathrm{L\,s^{-1}}$).

SQ 5.8.12 **Define steady flow.**

Definition

If the overall flow pattern does not change with time, the flow is called steady flow. In steady flow every particle of the fluid follows the same flow line as its previous particle.

TOPIC 9 Equation of Continuity

SQ 5.9.1 **State the equation of continuity.**

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 is equal to the volume flow per second of the fluid.

Formula

$Av = \text{constant}$

SQ 5.9.2 **Derive the equation of continuity.**

Derivation

The mass entering through A_1 in time Δt is

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

and the mass leaving through A_2 is

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

Since the mass of an incompressible fluid in steady flow is conserved,

$\Delta m_1 = \Delta m_2$

Result

$A_1 v_1 \rho_1 = A_2 v_2 \rho_2$

SQ 5.9.3 **Write the equation of continuity for an incompressible fluid.**

Derivation

Since the density is constant for the steady flow of an incompressible fluid, it cancels from both sides.

Result

$A_1 v_1 = A_2 v_2$

SQ 5.9.4 **What does the equation of continuity state about the rate of flow?**

Statement

In steady flow, the rate of flow of the fluid inward is equal to the rate of flow of the fluid outward.

SQ 5.9.5 **Which conservation law does the equation of continuity justify?**

Answer

This equation justifies the conservation of <u>mass</u> of the fluid which is flowing through a pipe.

SQ 5.9.6 **Give three applications of the equation of continuity.**

Applications

Blood flow in arteries and veins.

Water flow in rivers and pipes.

Air flow in ducts and ventilation systems.

SQ 5.9.7 **A hose of internal diameter 20 mm discharges 30 kg of water in 60 s. Find its cross-sectional area.**

Solution

The radius is

$r = 0.01\,\mathrm{m}$

so

$A = \pi r^2$

Calculation

$A = 3.14 \times (0.01)^2$

Result

$A = 3.14 \times 10^{-4}\,\mathrm{m^2}$

SQ 5.9.8 **Find the speed of water at the outlet of a hose of area 3.14×10^{-4} m² discharging 0.5 kg s⁻¹.**

Solution

Since

$$\rho A v = \frac{\text{mass}}{\text{second}}$$

therefore

$$v = \frac{\text{mass/second}}{\rho A}.$$

Calculation

$$v = \frac{0.5}{1000 \times 3.14 \times 10^{-4}}$$

Result

$v = 1.6\,\mathrm{m\,s^{-1}}$

TOPIC 10 Increase in Flow Velocity

SQ 5.10.1 **How can the flow velocity of water in a rubber pipe be increased?**

Answer

The flow velocity can be increased by <u>squeezing</u> the pipe, which decreases the cross-sectional area through which the water flows.

SQ 5.10.2 **Why does squeezing a rubber pipe increase the flow velocity?**

Reason

According to the equation of continuity

$A_1v_1 = A_2v_2$

By decreasing the cross-sectional area, the velocity of the water must increase to maintain the same flow rate.

SQ 5.10.3 **How is the flow rate related to the cross-sectional area of a pipe?**

Answer

The flow rate Av remains constant, so the flow speed is inversely proportional to the cross-sectional area of the pipe.

SQ 5.10.4 **Why does the water speed increase as the cross-sectional area decreases?**

Reason

For an incompressible fluid in steady flow the volume flow rate must remain constant, so a decrease in area is compensated by an increase in speed, as demanded by the continuity equation.

TOPIC 11 Bernoulli's Equation

SQ 5.11.1 **State Bernoulli's equation.**

Statement

The sum of pressure, kinetic energy per unit volume and potential energy per unit volume of an ideal fluid throughout its steady flow remains constant.

Formula

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

SQ 5.11.2 **What assumptions are made in deriving Bernoulli's equation?**

Assumptions

The fluid is incompressible and non-viscous, and it flows in a steady state manner.

SQ 5.11.3 **Why does the pressure change along a pipe of varying cross-section?**

Reason

As the fluid moves through a pipe of varying cross-section and height, its speed and height change, and Bernoulli's equation relates the pressure to fluid speed and height.

SQ 5.11.4 **Write the work done on the fluid at the upper and lower ends of the pipe.**

Upper End

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

Lower End

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

The work W_2 is taken as negative because it is done against the fluid force.

SQ 5.11.5 **Write the net work done on the fluid in terms of pressure and volume.**

Derivation

Since

$A_1v_1t = A_2v_2t = V$

the net work becomes

Result

$W = (P_1 - P_2)V = (P_1 - P_2)\frac{m}{\rho}$

SQ 5.11.6 **How is the net work done on the fluid utilized?**

Answer

A part of this work is utilized by the fluid in changing its kinetic energy and a part is used in changing its gravitational potential energy.

SQ 5.11.7 **Write the change in kinetic energy and potential energy of the flowing fluid.**

Kinetic Energy

$\Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

Potential Energy

$\Delta PE = mgh_2 - mgh_1$

SQ 5.11.8 **Write Bernoulli's equation for two points of a pipe.**

Formula

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

SQ 5.11.9 **Which conservation law is applied in deriving Bernoulli's equation?**

Answer

The law of conservation of energy is applied to the volume of the fluid under consideration.

TOPIC 12 Uses of Bernoulli's Equation

SQ 5.12.1 **On what do devices using Bernoulli's equation operate?**

Answer

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

SQ 5.12.2 **How is the lift of an aeroplane produced?**

Explanation

The wings are designed to deflect the air so that the streamlines are closer together above the wing than below it. Where the streamlines are forced closer together the speed is faster.

Result

The pressure is lower at the top of the wing, so the wing is forced upward and the lift of the aeroplane is due to this effect.

SQ 5.12.3 **Why are the wings of an aeroplane rounded outward on the upper side?**

Reason

The rounded upper surface forces the streamlines closer together above the wing, so the air travels faster there and its pressure becomes lower. This pressure difference produces the upward lift.

SQ 5.12.4 Explain the swing of a ball using Bernoulli's equation.

Explanation

When a ball is thrown with spin, or is made smoother on one side, the air moves faster over the rough side and slower over the smoother side.

Result

The faster moving air creates lower pressure while the slower moving air creates higher pressure. This pressure difference generates a sideways force known as the Magnus effect, which causes the ball to curve in the air.

SQ 5.12.5 How does a filter pump work?

Working

A filter pump has a constriction in the centre, so that a jet of water from the tap flows faster there. This causes a drop in pressure near it, and air therefore flows in from the side tube.

Result

The air and water together are expelled through the lower part of the pump.

SQ 5.12.6 How does the carburetor of a car engine work?

Working

The carburetor uses a Venturi duct to feed the correct mixture of air and petrol to the cylinders. A tiny inlet at the side of the duct is fed with petrol.

Result

The air moves very fast through the duct, creating low pressure which draws petrol vapours into the airstream.

SQ 5.12.7 How does a paint sprayer work?

Working

A stream of air passing over a tube dipped in a liquid causes the liquid to rise in the tube. When the rubber ball of an atomizer is squeezed, air is blown out through a narrow aperture at high speed, causing a fall of pressure.

Result

The atmospheric pressure pushes the perfume up to the narrow aperture.

SQ 5.12.8 Why is average potential energy taken as the same in the Venturi relation?

Reason

Since the pipe is placed horizontally, the heights of the two portions are the same, so the average potential energy is the same at both places.

SQ 5.12.9 Derive the Venturi relation.

Derivation

For a horizontal pipe, Bernoulli's equation gives

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

Since $A_2 \ll A_1$, the speed v_1 is very small compared with v_2 and can be neglected.

Result

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

SQ 5.12.10 What is a Venturi meter used for?

Answer

The Venturi relation is used in a Venturi meter, which is a device used to measure the speed of liquid flow.

SQ 5.12.11 State Torricelli's theorem.

Statement

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

SQ 5.12.12 Derive Torricelli's theorem.

Derivation

Since the orifices are small, the speed of the top surface is taken as approximately zero, and the pressure at both places is atmospheric.

Bernoulli's equation then gives

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

Result

$$v_2 = \sqrt{2g(h_1 - h_2)}$$

SQ 5.12.13 What happens to the potential energy of the tank in Torricelli's theorem?

Answer

The top level of the tank moves down a little and the potential energy has been transferred into the kinetic energy of the efflux of fluid.

SQ 5.12.14 What would happen if the orifice were pointed upward?

Answer

If the orifice were pointed upward, this kinetic energy would allow the liquid to rise to the level of the water in the tank. In practice, viscous energy losses would alter the result to some extent.

SQ 5.12.15 Why is standing near a fast moving train dangerous?

Reason

The air between the person and the train moves with a high speed, so according to Bernoulli's equation its pressure becomes low. The higher atmospheric pressure on the other side then pushes the person towards the train.

SQ 5.12.16 Why does the pressure of a fluid decrease when its speed increases?

Reason

For a horizontal pipe, Bernoulli's equation shows that $P + \frac{1}{2}\rho v^2$ is constant. Therefore, where the speed is high the pressure will be low.

TOPIC 13 Viscous Drag and Stokes' Law

SQ 5.13.1 Define viscosity.

Definition

The frictional effect between different layers of a flowing fluid is described in terms of viscosity of the fluid.

Meaning
Viscosity measures how much force is required to slide one layer of the liquid over another layer.

SQ 5.13.2 Which substances have large and small coefficients of viscosity?

Large Viscosity
Substances that do not flow easily, such as thick tar and honey.
Small Viscosity
Substances which flow easily, like water.

SQ 5.13.3 Why is a force required to move an object through a fluid?

Reason
Since liquids and gases have non-zero viscosity, a force is required if an object is to be moved through them.

SQ 5.13.4 Give an everyday example of the viscosity of air.

Example
Even the small viscosity of air causes a large retarding force on a car as it travels at high speed. If you stick your hand out of the window of a fast moving car, considerable force has to be exerted to move it through the air.

SQ 5.13.5 What is a drag force?

Definition
An object moving through a fluid experiences a retarding force called a drag force. The drag force increases as the speed of the object increases.

SQ 5.13.6 State Stokes' law.

Statement
The drag force F on a sphere of radius r moving slowly with speed v through a fluid of viscosity η is given by:
Formula
$F = 6\pi\eta rv$

SQ 5.13.7 Is the drag force always proportional to speed?

Answer
No. At high speeds the force is no longer simply proportional to speed.

SQ 5.13.8 Write the viscosities of air and water at 30 °C.

Values
The viscosity of air is $0.019 \times 10^{-3}\,\mathrm{N\,s\,m^{-2}}$ and that of water is $0.801 \times 10^{-3}\,\mathrm{N\,s\,m^{-2}}$.

TOPIC 14 Terminal Velocity

SQ 5.14.1 Why does a falling water droplet stop accelerating?

Reason
The droplet accelerates under the force of gravity, but the upward drag force on it increases as its speed increases. Finally the drag force becomes equal to the weight and the net force becomes zero.

SQ 5.14.2 Write the expression for the net force on a falling droplet.

Formula
Net force = Weight − Drag force

SQ 5.14.3 Define terminal velocity.

Definition
When the magnitude of the drag force becomes equal to the weight, the net force acting on the droplet is zero, and the droplet falls with a constant speed called terminal velocity.

SQ 5.14.4 Derive the expression for terminal velocity.

Derivation
Equating Stokes' drag to the weight gives
$0 = mg - 6\pi\eta r v_t$.
Substituting
$m = \rho V$
with
$V = \frac{4}{3}\pi r^3$
Result
$$v_t = \frac{2gr^2\rho}{9\eta}$$

SQ 5.14.5 On what factors does terminal velocity depend?

Answer
Since
$$v_t = \frac{2gr^2\rho}{9\eta}$$
it increases with the density ρ and with the square of the radius, and decreases with the viscosity η of the fluid.

SQ 5.14.6 Calculate the terminal velocity of a water droplet of radius 0.010 cm in air.

Data
Here
$r = 1.0 \times 10^{-4}\,\mathrm{m}$
$\rho = 1000\,\mathrm{kg\,m^{-3}}$
and
$\eta = 19 \times 10^{-6}\,\mathrm{kg\,m^{-1}s^{-1}}$
Solution
$$v_t = \frac{2 \times 9.8 \times (1.0 \times 10^{-4})^2 \times 1000}{9 \times 19 \times 10^{-6}}$$
Result
$v_t = 1.1\,\mathrm{m\,s^{-1}}$

TOPIC 15 Real Fluids are Viscous Fluids

SQ 5.15.1 Define an ideal fluid.

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

SQ 5.15.2 Define a real fluid and give examples.

Definition
All types of fluids that possess viscosity are termed real fluids.
Examples
Kerosene oil, castor oil and honey are real fluids.

SQ 5.15.3 Why can no example of an ideal fluid be given?

Reason

An example of an ideal fluid cannot be provided because it does not exist in the real world. Every fluid we see around us, like water, diesel, petrol and honey, is a real fluid.

SQ 5.15.4 What does viscosity essentially refer to?

Answer

When a fluid is viscous, it essentially refers to the thickness of the fluid, or the friction the fluid faces while it flows.

SQ 5.15.5 Differentiate between ideal and real fluids.

Ideal Fluid	Real Fluid
It has no viscosity, so its flow is non-viscous.	It possesses viscosity, so its flow is viscous.
It is incompressible and not subject to surface tension.	It can be compressed and is subject to surface tension.
It cannot exist practically.	Water, honey and petrol are real fluids.

SQ 5.15.6 Is honey more viscous than water?

Answer

Yes. Differences in viscosity can be found in real life, for example honey is more viscous than water.

TOPIC 16 Superfluids

SQ 5.16.1 Define superfluidity.

Definition

Superfluidity is the characteristic property of fluids with zero viscosity, that is their flow is frictionless. A substance exhibiting this property is a superfluid.

SQ 5.16.2 What are the special flow properties of superfluids?

Properties

Superfluids flow without loss of kinetic energy. They can flow through incredibly narrow spaces without any friction.

SQ 5.16.3 At what temperature is superfluidity achieved?

Answer

Superfluidity is achieved in some substances at extremely low temperature.

SQ 5.16.4 What is a vortex in fluid dynamics?

Definition

In fluid dynamics a vortex is a region in a fluid in which the flow revolves around an axial line, which may be straight or curved.

SQ 5.16.5 How are vortices created and dispersed?

Answer

The vortices are generally created at a moving boundary due to frictionless conditions. They move with the fluid and are dispersed by the action of viscosity.

SQ 5.16.6 At what temperature does helium-4 become a superfluid?

Answer

Superfluid helium-4 is the most studied example of superfluidity. It changes from a liquid to a superfluid just a few degrees below its boiling point of $-269\,^{\circ}\mathrm{C}$, that is about $4\,\mathrm{K}$.

SQ 5.16.7 Why does superfluid helium-4 keep moving past obstacles?

Reason

Superfluid helium-4 moves as a normal clear liquid but it has no viscosity. This means that once it starts to flow, it keeps moving past any obstacles.

SQ 5.16.8 Why can superfluids climb up the walls of a container?

Reason

Superfluids can climb up walls and over the edges of containers because they do not experience friction like other fluids.

SQ 5.16.9 Give the current applications of superfluids.

Applications

Superfluid helium-4 serves as a coolant for high-field magnets. Both helium-3 and helium-4 are utilized in advanced particle detectors.

Research

Researching superfluidity also helps us learn more about superconductivity.

SQ 5.16.10 Give the uses of liquid helium.

Uses

Liquid helium is recognized for its great thermal conductivity and is used in cryogenic applications, including cooling superconducting magnets, scientific research and medical uses.

Industry

It is also employed in industry for leak testing and in the production of electronic and optical products.