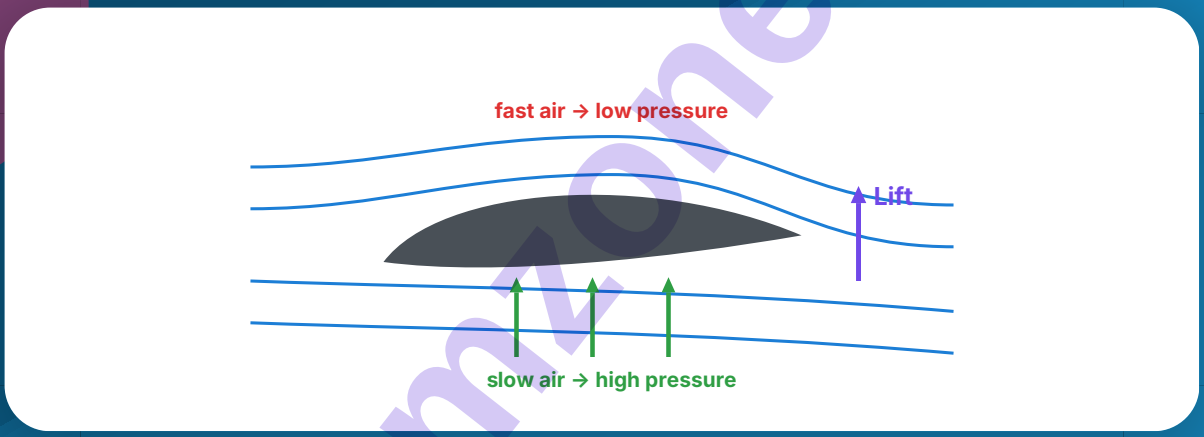
PHYSICS · CLASS 11 · NEW SYLLABUS

UNIT 5

Solids and Fluid Dynamics

Complete Study Booklet



Long Questions | Short Questions | MCQs | Solved Exercise

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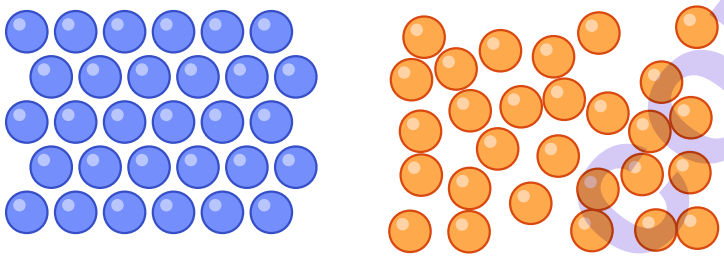
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PART A

Long Questions

Q1 **How would you classify solids on the basis of the arrangement of atoms? Explain with examples.**

Solids are of three types: **(1) crystalline**, **(2) amorphous or glassy** and **(3) polymeric**.



a) Crystalline: regular, long-range order (b) Amorphous: no regular order

Arrangement of atoms in crystalline and amorphous solids

1. Crystalline solids

Solids in which atoms and molecules are arranged in a particular, regular fashion. *Examples:* quartz, calcite, sugar, mica, diamond.

1. The atoms and molecules are arranged in a regular 3-D pattern, e.g. metals (Cu, Fe, Zn), ionic compounds (NaCl) and ceramics (zirconia). Crystal structure is studied by X-ray diffraction and transmission electron microscopy (TEM).
2. Atoms vibrate about their mean positions; the amplitude increases with temperature.
3. Cohesive forces between atoms, molecules or ions maintain strict **long-range order** in spite of the vibrations.
4. At a particular temperature the vibrations become so large that the structure breaks and the solid melts. Every crystalline solid has a **definite melting point**.

2. Amorphous or glassy solids

Solids with no particular arrangement of their atoms, molecules or ions. *Examples:* glass, plastics.

1. With no regular arrangement, they are more like a liquid with its disordered structure frozen in.
2. On heating, glass softens into a paste-like state before becoming a very viscous liquid at about 800 °C — hence “glassy solids”.
3. They have **no definite melting point**.
4. They are in a **meta-stable** state and can undergo structural changes over time.

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3. Polymeric solids

More or less solid materials with a structure between order (solid) and disorder (liquid). *Examples:* rubber, fibres, plastics.

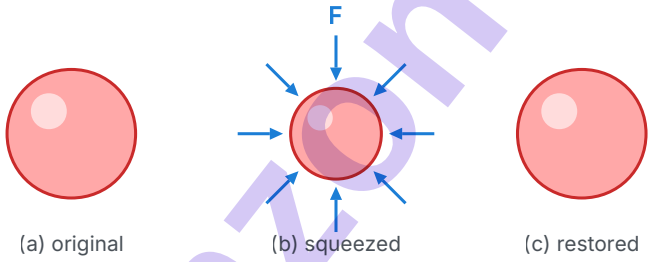
1. They are partially or poorly crystalline, e.g. natural rubber, a hydrocarbon $(C_5H_8)_n$. Plastics and synthetic rubber are formed by **polymerization**, in which simple molecules combine into massive long-chain molecules with a 3-D structure.
2. They have low specific gravity compared with even the lightest metals.
3. They are chemical combinations of carbon with oxygen, hydrogen, nitrogen and other elements, e.g. polythene, polystyrene and nylon.
4. Many polymers are good electrical and thermal **insulators**.

Q2 Define and explain (i) deformation (ii) elastic deformation (iii) elasticity.

(i) Deformation

The change in shape or size (volume, length, etc.) of a body due to an applied force.

Pressing a soft rubber ball reduces its volume; stretching a rubber string increases its length.



A rubber ball deformed by forces and then restored

(ii) Elastic deformation

A temporary change in shape or size that disappears when the stress is removed.

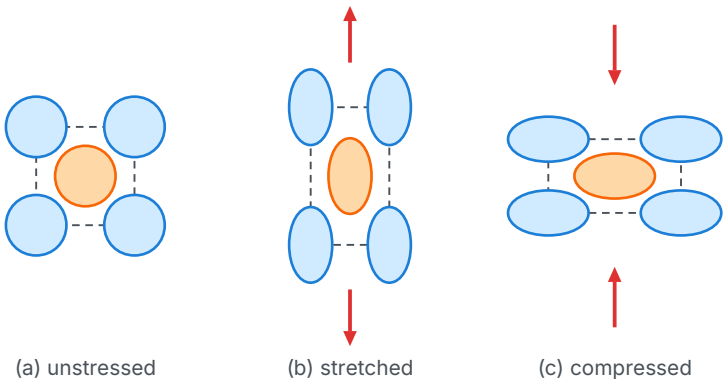
On removing the force, the ball and the string return to their original state. In a crystalline solid the atoms are held in regular positions by cohesive forces. An external force displaces them from their mean positions; when it is removed they return.

(iii) Elasticity

The property of a material by which it regains its original shape and size after the deforming force is removed.

The figure shows a unit cell of a crystal stretched and compressed by an external force. Mechanical test results are expressed in terms of **stress** and **strain**.

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Deformation of a unit cell of a crystal

Q3 **Define stress and strain with their SI units. Explain the types of strain and the three elastic moduli (Young's, bulk and shear).**

Stress

The force applied per unit area to produce a change in shape, volume or length of a body.

Stress = $\sigma = \frac{F}{A}$ SI unit: N m^{-2} = pascal (Pa)

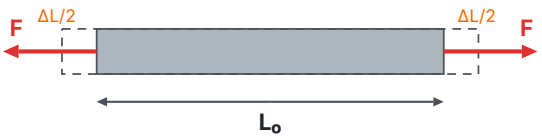
A stress that changes length is **tensile** (or compressive) stress; one that changes volume is **volume** stress; one that changes shape is **shear** stress.

Strain

The fractional change in length, volume or shape caused by stress. Strain is a ratio, so it has **no unit**.

(i) Tensile strain — fractional change in length:

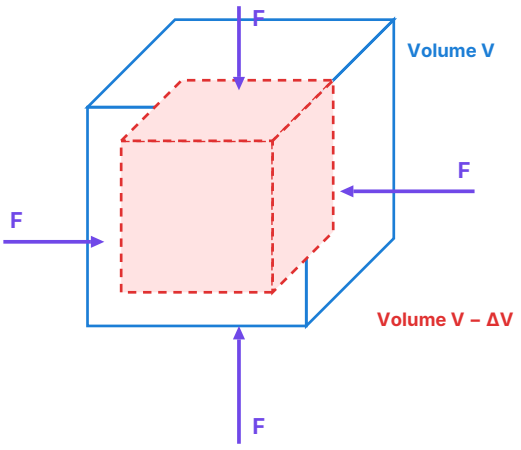
$$\varepsilon = \frac{\Delta L}{L_0}$$



Tensile strain

(ii) Volume strain — fractional change in volume:

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

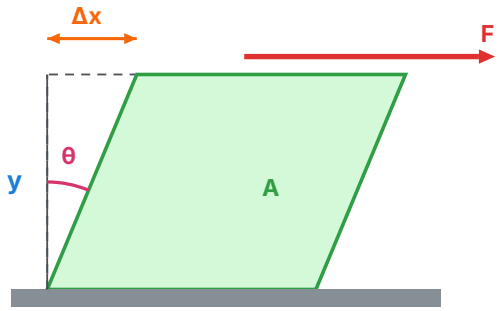


Volume strain

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(iii) Shear strain — change in shape when layers slide over each other. If the top face (height y above the base) slides through Δx:

$$\gamma = \frac{\Delta x}{y} = \tan\theta \approx \theta \text{ (small } \theta\text{, in radians)}$$



Shear strain

Elastic constants (moduli)

An elastic modulus is the **ratio of stress to strain**. All three have unit N m^{-2} (Pa).

(i) Young's modulus — tensile stress / tensile strain:

$$\mathbf{Y = \frac{F/A}{\Delta L/L_0} = \frac{F\,L_0}{A\,\Delta L}}$$

(ii) Bulk modulus — volume stress / volume strain:

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

(iii) Shear modulus — shear stress / shear strain:

$$\mathbf{G = \frac{F/A}{\tan\theta} = \frac{F/A}{\Delta x/y} = \frac{F\,y}{A\,\Delta x}}$$

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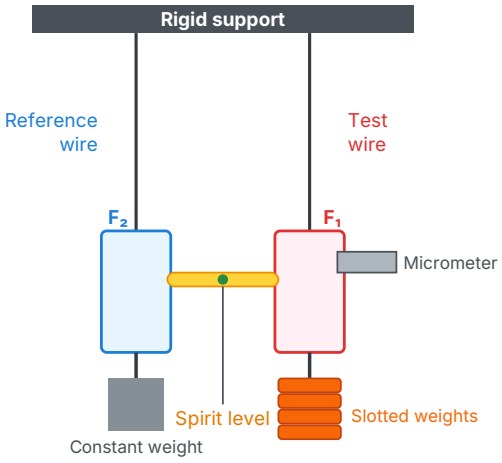
Elastic constants for some materials ($\times 10^9$ N m^{-2})

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

Q4 **How is Young's modulus of a wire determined experimentally by Searle's apparatus? Describe its construction and procedure.**

Construction

Two wires of the same material, equal length and equal diameter — a **reference** (auxiliary) wire and a **test** wire — hang from a rigid support. Their lower ends are attached to frames F_2 and F_1, joined by a **spirit level**; a **micrometer screw** on the test frame adjusts the level. A constant weight keeps the reference wire taut and free of kinks; a hanger with slotted weights loads the test wire.



Searle's apparatus

Procedure

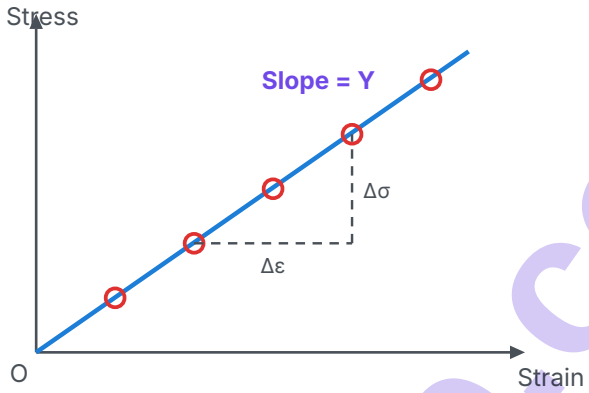
1. Measure the initial length L_0 of the wire with a metre rule.
2. Measure the diameter d of the wire with a screw gauge at several points along it.
3. Turn the micrometer until the spirit level is horizontal; record this reference reading.
4. Add a further weight to the test wire; the spirit level tilts as the wire stretches.

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5. Re-adjust the micrometer to make the level horizontal again. The difference between the two readings is the extension ΔL.
6. Calculate stress and strain:

$$\sigma = \frac{F}{A} = \frac{mg}{\pi r^2} \qquad \varepsilon = \frac{\Delta L}{L_0}$$

7. Repeat with increasing loads to get more values of stress and strain.
8. Plot stress against strain. The graph is a straight line whose **slope gives Young's modulus Y**.



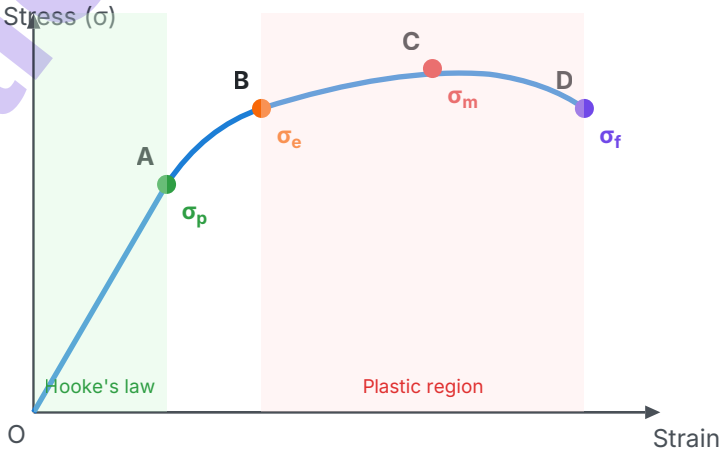
Stress–strain graph: slope = Y

Brain Teaser

A steel rod and a rubber band are subjected to the same force. Which stretches more?
Steel has a far larger elastic modulus, so it shows less strain under the same stress. The rubber band stretches more.

Q5 **Draw a stress-strain curve for a ductile material and describe the related terms.**

In a tensile test a metal wire is extended at a set rate while the stress is measured electronically, and a stress–strain curve is drawn automatically on an X-Y recorder.



Stress–strain curve of a typical ductile material

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Proportional limit (O to A): stress increases linearly with strain up to A. **Hooke's law** (strain ∝ stress) is obeyed in region OA. The stress at A is the proportional limit σ_p. From A to B stress and strain are no longer proportional.

Elastic limit: if the load is removed anywhere between O and B, the material returns to its original length; region OB is **elastic**. B is the **yield point** and the stress there is the elastic limit σ_e.

Plastic deformation (B to C): beyond the elastic limit the specimen is permanently changed and does not recover its shape — this is **plasticity**.

Ultimate tensile strength: point C is the maximum stress σ_m the material can withstand — its nominal strength.

Fracture stress: after C the material breaks at D; the stress there is σ_f.

Ductile substances

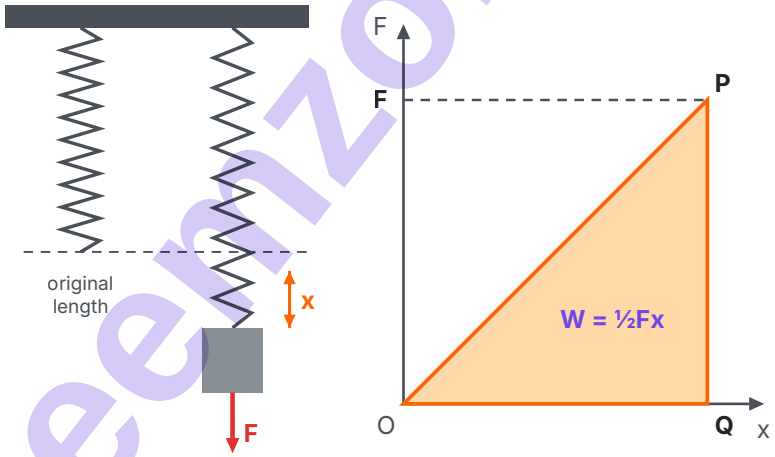
Undergo plastic deformation until they break, e.g. lead, copper, wrought iron.

Brittle substances

Break just after the elastic limit is reached, e.g. glass, high-carbon steel, beryllium, bismuth, chromium.

Q6 What is strain energy in a deformed material? Derive its expression.

When a body is deformed, work is done against the elastic restoring force. This work is stored as **potential energy** of the molecules displaced from their mean positions — the **strain energy**.



Spring stretched by F through x, and its force–extension graph

A spring is stretched by force F through extension x. Within the elastic limit the extension is proportional to the force, so the force rises uniformly from 0 to F; the average force is ½F:

W = average force × extension = ½ F x …(1) = area of triangle OPQ

By Hooke's law F = kx:

$$E = W = \tfrac{1}{2}(kx)(x) = \tfrac{1}{2}kx^2$$

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For Your Information

The area under a force–extension graph equals the work done in stretching the material, which equals the elastic P.E. stored in it.

Q7 State and prove Archimedes' principle.

An air-filled balloon released under water shoots up to the surface, and a mug of water feels lighter under water than outside. More than 2000 years ago Archimedes noticed that an **upward force** acts on an object in a liquid, causing an apparent loss of weight. This force is the **upthrust** (buoyant force).

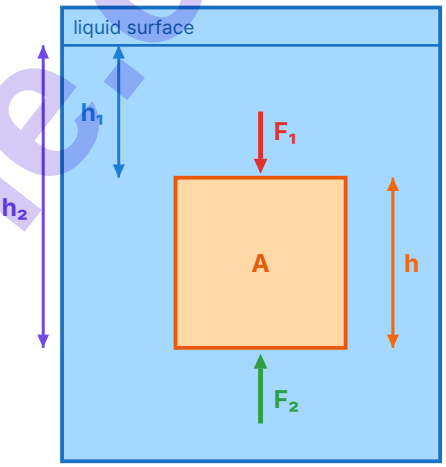
> **Archimedes' principle:** when an object is totally or partially immersed in a liquid, an upthrust acts on it equal to the weight of the liquid it displaces.

Proof

A solid cylinder of cross-section A and height h is immersed in a liquid of density ρ, with its top and bottom faces at depths h_1 and h_2, so $h_2 - h_1 = h$ … (1).

Pressures: $P_1 = \rho g h_1$, $P_2 = \rho g h_2$

Forces: $F_1 = P_1 A = \rho g h_1 A$ (down on top), $F_2 = P_2 A = \rho g h_2 A$ (up on bottom)



Upthrust on a body immersed in a liquid

The net upward force (upthrust) is:

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

Upthrust = ρgV

Since Ah = V is the volume of the cylinder, equal to the volume of liquid displaced, ρgV is the **weight of liquid displaced**. This proves Archimedes' principle.

Brain Teaser

Why does a heavy steel ship float while a small rock sinks?
The ship is hollow, so its average density is less than that of water; the rock's density is greater than water's.

Q8 State the principle of floatation.

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An object **sinks** if its weight is greater than the upthrust on it, and **floats** if its weight is equal to or less than the upthrust. For a floating object, the upthrust equals its weight, and it may be only partially immersed.

> **Principle of floatation:** a floating object displaces a fluid whose weight is equal to the weight of the object.

Q9 Give practical applications of Archimedes' principle.

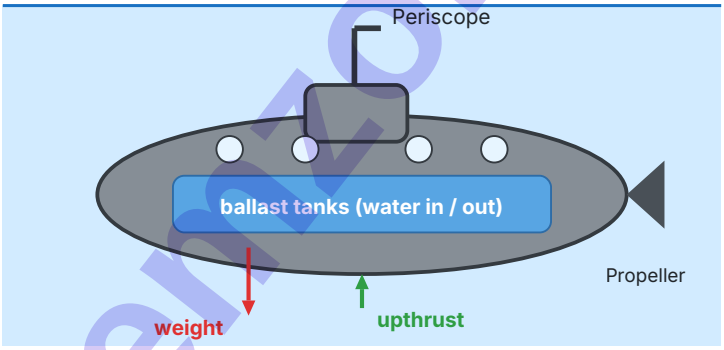
Archimedes' principle applies to liquids and gases.

(i) Hot-air balloon: the hot air inside is less dense than the surrounding air. When the buoyant force exceeds the balloon's weight, it rises; height is controlled by varying the amount of hot air.

(ii) Wooden block on water: it floats because the weight of an equal volume of water is greater than the weight of the block, so it sinks only until the displaced water equals its weight.

(iii) Ships and boats: designed on the principle of floatation; they would sink if their weight (with passengers and cargo) exceeded the upthrust.

(iv) Submarine: it floats when the weight of water equal to its volume is greater than its own weight. It has ballast tanks that can be filled with or emptied of seawater. Filling them increases its weight beyond the upthrust and it dives; emptying them makes it rise.



Submarine: ballast tanks control weight against upthrust

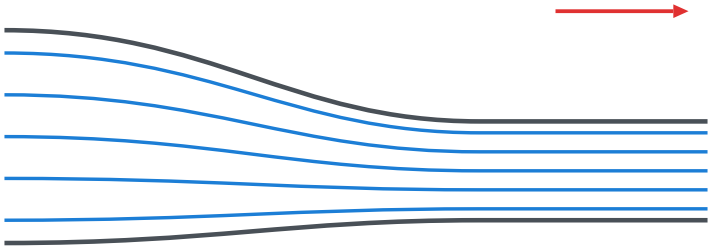
Q10 Differentiate between laminar (streamline) flow and turbulent flow.

Streamline (laminar) flow

> Flow in which every particle passing a particular point follows exactly the same path as the particles that passed that point earlier.

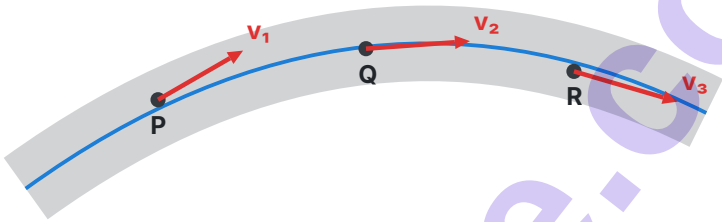
The motion is smooth and regular. The path followed by a particle is a **streamline**; the tangent at any point gives the direction of flow. Streamlines **never cross** each other.

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Streamlines (laminar flow)

Example: in a pipe, a particle has velocity v_1 at P, v_2 at Q and v_3 at R. If these velocities do not change with time, the flow is steady (streamline). PQR is a streamline: every particle passing P also passes Q and R.

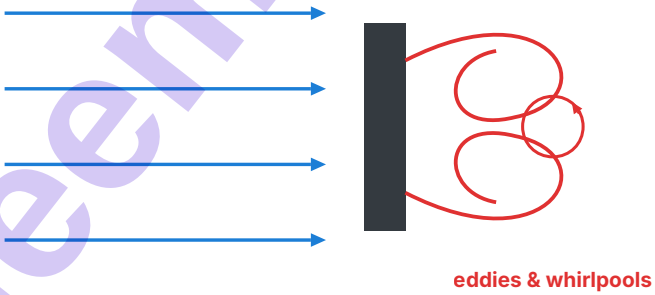


Velocities of particles at different points on a streamline

Turbulent flow

The irregular or unsteady flow of a fluid.

Above a certain speed the flow becomes unsteady; velocity changes abruptly and the exact path of particles cannot be followed. There are **eddies and whirlpools**, and particle paths keep changing.

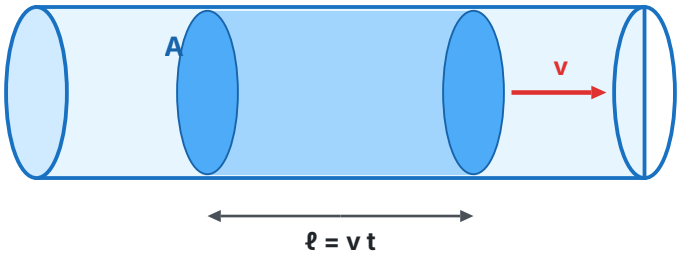


Turbulent flow behind an obstacle

Q11 **Define the rate of flow of a fluid and derive its equation. State its SI unit.**

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

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Rate of flow of a liquid

Fluid flows with velocity v through a pipe of cross-section A. In time t it covers $\ell = vt$, so the volume passing is $A\ell = Avt$:

$$\textbf{Rate of flow} = \frac{\textbf{Volume}}{\textbf{Time}} = \frac{Avt}{t} = Av$$

SI unit: $m^3\ s^{-1}$ (sometimes litres per second, $L\ s^{-1}$).

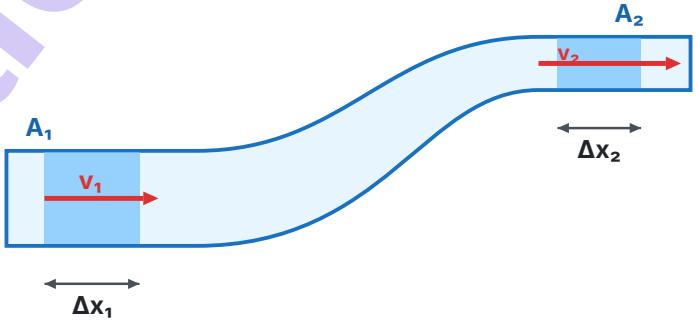
Steady flow: if the overall flow pattern does not change with time, the flow is steady; every particle follows the same line as the one before it.

Q12 State the conditions of an ideal fluid.

1. The fluid is **non-viscous** — no friction between adjacent layers.
2. The fluid is **incompressible** — its density is constant.
3. The fluid motion is **steady**.

Q13 State and prove the equation of continuity.

> The product of the cross-sectional area of a pipe and the fluid speed at any point is constant; this constant is the volume flow rate.



Fluid flowing through a pipe of non-uniform cross-section

At the lower end: area A_1, speed v_1, density ρ_1. At the upper end: A_2, v_2, ρ_2. In time Δt the fluid moves $\Delta x_1 = v_1 \Delta t$ and $\Delta x_2 = v_2 \Delta t$.

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Mass entering: $\Delta m_1 = \rho_1 A_1 \Delta x_1 = \rho_1 A_1 v_1 \Delta t$ ...(1)

Mass leaving: $\Delta m_2 = \rho_2 A_2 \Delta x_2 = \rho_2 A_2 v_2 \Delta t$ ...(2)

By conservation of mass for streamline flow, $\Delta m_1 = \Delta m_2$:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

For an incompressible fluid, $\rho_1 = \rho_2$:

$$A_1 v_1 = A_2 v_2 \quad \text{or} \quad Av = \text{constant} \quad ...(3)$$

Conclusion: $v_1/v_2 = A_2/A_1$. Speed is inversely proportional to cross-sectional area: the fluid moves fastest where the pipe is narrowest.

Tidbits

As water falls from a tap its speed increases, so the stream becomes narrower — as required by the continuity equation.

For Your Information

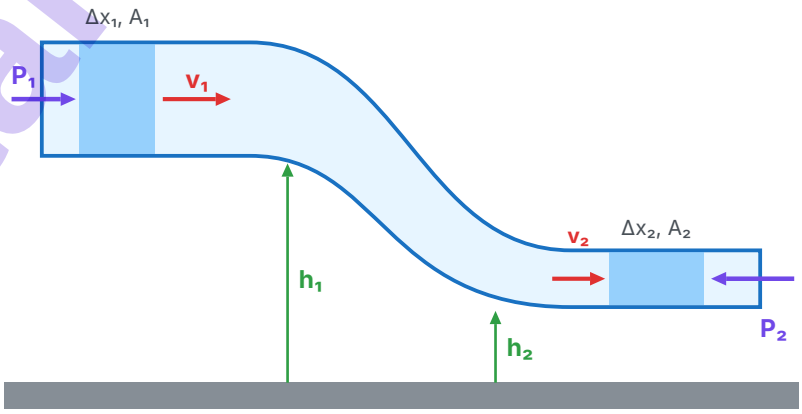
The equation of continuity applies to (i) blood flow in arteries and veins (ii) water flow in rivers and pipes (iii) air flow in ducts and ventilation systems.

Q14 Explain briefly the effect of the cross-sectional area of a rubber pipe on the flow velocity of a fluid.

Squeezing a rubber pipe reduces the cross-sectional area through which water flows. By the equation of continuity $A_1 v_1 = A_2 v_2$, if $A_2 < A_1$ then v_2 must increase to keep the flow rate the same. So **squeezing the pipe increases the speed** of the water.

Q15 State and prove Bernoulli's equation relating pressure to fluid speed and height.

For an ideal fluid in streamline flow, the sum of pressure, K.E. per unit volume and P.E. per unit volume remains constant throughout the pipe.



Ideal fluid flowing through a pipe of varying area and height

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At the upper end: area A_1, height h_1, speed v_1, pressure P_1. Pressure P_1 pushes the fluid in through $\Delta x_1 = v_1 t$:

$$W_1 = F_1 \Delta x_1 \cos 0° = P_1 A_1 v_1 t \ldots(1)$$

At the lower end: area A_2, height h_2, speed v_2. The fluid ahead exerts P_2 against the motion over $\Delta x_2 = v_2 t$:

$$W_2 = F_2 \Delta x_2 \cos 180° = -P_2 A_2 v_2 t \ldots(2)$$

Total work = change in K.E. + change in P.E.:

$$P_1 A_1 v_1 t - P_2 A_2 v_2 t = (\tfrac{1}{2} m v_2^2 - \tfrac{1}{2} m v_1^2) + (mgh_2 - mgh_1)$$

$A_1 v_1 t = A_2 v_2 t = V$, the volume that flowed. Dividing by V and using $\rho = m/V$:

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

$$\mathbf{P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g h_2 \ldots(3)}$$

$$\mathbf{P + \tfrac{1}{2}\rho v^2 + \rho g h = \text{constant} \ldots(4)}$$

Equation (3) is Bernoulli's equation; (4) is its general form.

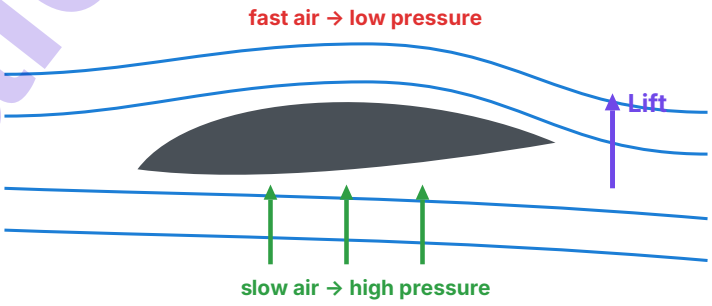
Brain Teaser

How does a curve ball relate to Bernoulli's principle?
The spinning ball drags air so that air moves faster on one side and slower on the other. The faster side has lower pressure, so a sideways (Magnus) force deflects the ball into a curve.

Q16 Give some practical applications of Bernoulli's equation.

Many devices work by the pressure difference that arises from changes in fluid speed.

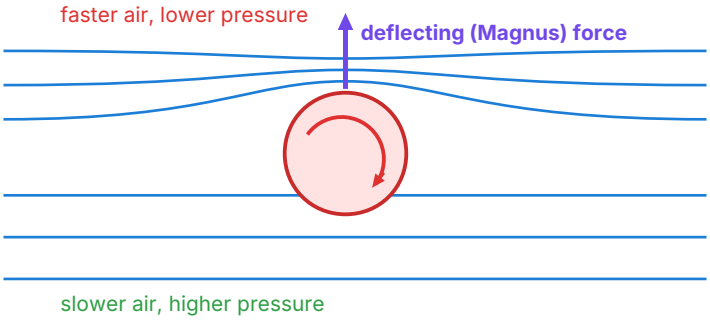
(i) Aeroplane wings: the wing is shaped so the streamlines are closer together above it than below. Air moves faster above, so pressure is lower on top; the pressure difference pushes the wing up — this is **lift**.



Air flow around an aeroplane wing

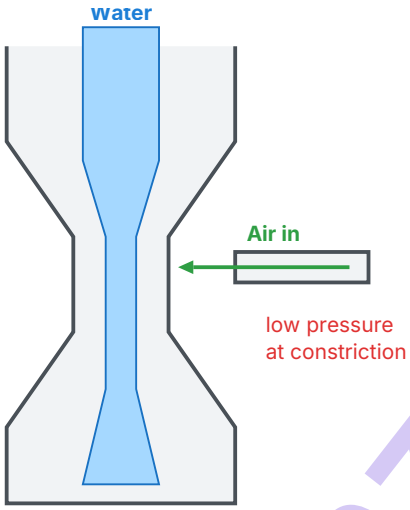
(ii) Swing of a ball: a bowler keeps one side of the ball smooth and the other rough. Air moves faster over the smooth side and slower over the rough side. Faster air gives lower pressure, so the pressure difference creates a sideways force (Magnus effect) and the ball curves in the air.

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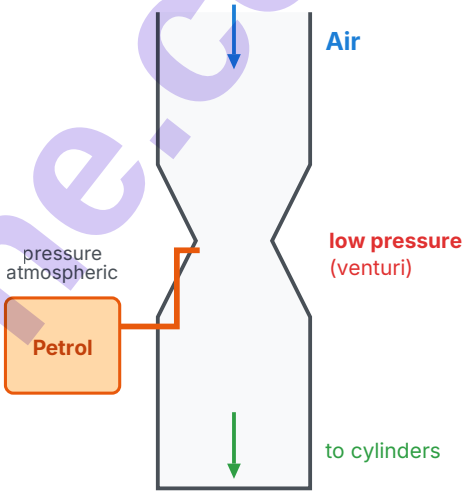
A spinning ball is deflected towards the low-pressure side

(iii) Filter pump: the pump has a constriction in the middle, so the jet of water from the tap moves faster there. The pressure drops, air flows in from the side tube, and air and water leave together through the bottom.

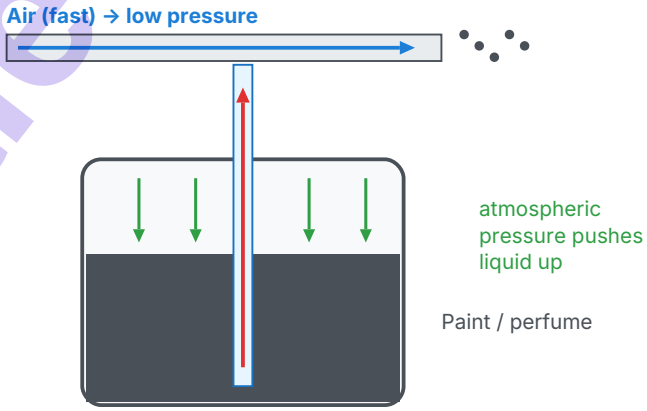


Filter pump

(iv) Carburetor: a car's carburetor uses a Venturi duct. Air moves very fast through the narrow duct, creating low pressure that draws petrol vapour in through a tiny side inlet, giving the right air–petrol mixture for the cylinders.



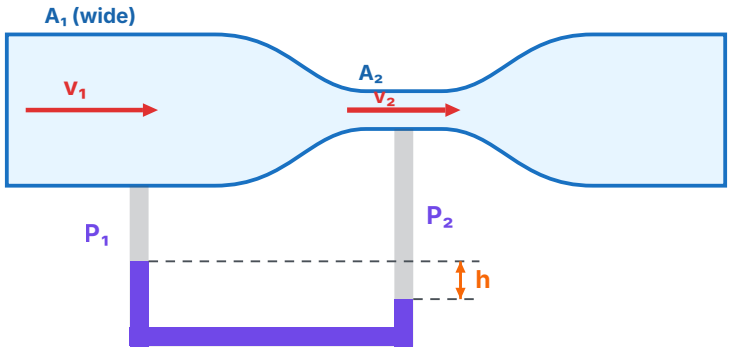
(v) Paint sprayer / perfume atomizer: squeezing the rubber bulb blows air at high speed across the top of a tube dipped in the liquid. The pressure there falls, so atmospheric pressure pushes the liquid up the tube and it is sprayed out as fine drops.



Air moving over a tube dipped in liquid

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(vi) Venturi relation



Venturi meter

A horizontal pipe has a wide part (A_1, v_1, P_1) and a narrow part (A_2, v_2, P_2), with a manometer between them. Since the pipe is horizontal, the ρgh terms cancel:

$$P_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \tfrac{1}{2}\rho v_2^2 \Rightarrow P_1 - P_2 = \tfrac{1}{2}\rho(v_2^2 - v_1^2) \ldots(1)$$

From continuity, $v_1 = A_2 v_2 / A_1$. Since $A_2 \ll A_1$, v_1 is small compared with v_2 and can be neglected:

$$\mathbf{P_1 - P_2 = \tfrac{1}{2}\rho v_2^2 \ldots(2)}$$

This is the **Venturi relation**, used in the Venturi meter to measure the speed of liquid flow.

Interesting Information

Bernoulli's equation for a horizontal pipe shows that **where speed is high, pressure is low**: $P + \tfrac{1}{2}\rho v^2 = \text{constant}$.

Q17 State and derive Torricelli's theorem.

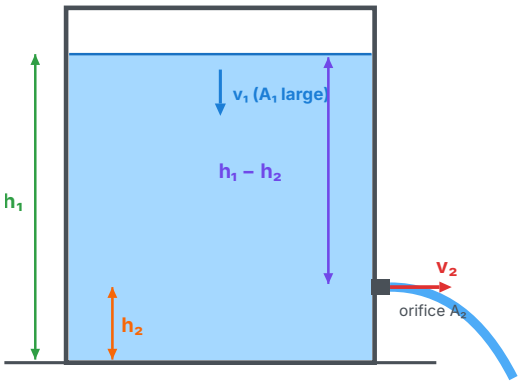
The speed of efflux of a liquid from an orifice equals the speed it would gain by falling freely through the height h (between the liquid surface and the orifice): $v = \sqrt{(2gh)}$, where $h = h_1 - h_2$.

Proof

A tank has a small hole in its wall. A_1 is the area of the top surface and A_2 the area of the orifice. Applying Bernoulli's equation between the top surface and the hole:

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

Both points are open to the air: $P_1 = P_2 = P_a$ (atmospheric):



A tank containing fluid with an orifice

$$\rho g(h_1 - h_2) = \tfrac{1}{2}\rho(v_2^2 - v_1^2)$$

Since $A_1 \gg A_2$, $v_1 \ll v_2$, so v_1^2 can be neglected:

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$g(h_1 - h_2) = \frac{1}{2}v_2^2 \Rightarrow v_2^2 = 2g(h_1 - h_2)$

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

This proves Torricelli's theorem.

Q18 **Explain (i) viscosity (ii) drag force (iii) Stokes' law.**

(i) Viscosity

The frictional effect between different layers of a flowing fluid.

Viscosity measures how much force is needed to slide one layer of a liquid over another. Substances that do not flow easily, like tar and honey, have large coefficients of viscosity (η); those that flow easily, like water, have small ones. Because liquids and gases have non-zero viscosity, a force is needed to move an object through them — even air's small viscosity causes a large retarding force on a fast car.

Viscosities of liquids and gases at 30 °C ($\times 10^{-3}$ 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
Glycerine	6.29

(ii) Drag force

An object moving through a fluid experiences a retarding force called the **drag force**, which increases with the object's speed. It is hard to calculate exactly, but the case of a sphere is very important.

(iii) Stokes' law

For a sphere of radius r moving slowly with velocity v through a fluid of viscosity η, the drag force is:

$F = 6\pi\eta rv$

It is named after George Gabriel Stokes. At high speeds the drag force is **no longer proportional** to speed.

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Do You Know?

A chimney works best when it is tall and exposed to air currents. Fast-moving air across its top lowers the pressure there, which draws smoke upward.

Q19 Define terminal velocity and show that it is directly proportional to the square of the radius of the body.

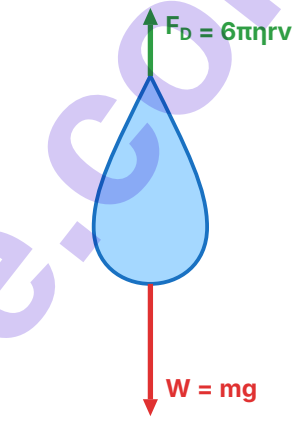
Terminal velocity is the maximum, constant velocity reached by an object falling through a fluid. It is reached when the object's weight equals the drag force.

A spherical water droplet (like fog) falls vertically. Two forces act: its weight mg (down) and the drag force $6\pi\eta rv$ (up). Net downward force:

$$F = mg - 6\pi\eta rv \quad ...(1)$$

As the droplet speeds up the drag increases, until drag equals weight. Then the net force is zero and the velocity stays constant at v_t:

$$0 = mg - 6\pi\eta rv_t$$



Forces on a falling droplet

$$\mathbf{v_t = \frac{mg}{6\pi\eta r} \quad ...(2)}$$

For a given radius, $v_t \propto m$. Now $m = \rho \times$ volume $= \rho(4/3)\pi r^3$, where ρ is the droplet's density:

$$\mathbf{v_t = \frac{4\rho\pi r^3}{3} \times \frac{g}{6\pi\eta r} = \frac{2\rho g r^2}{9\eta} \quad ...(3)}$$

Since $2\rho g/9\eta$ is constant: $\mathbf{v_t \propto r^2}$. Terminal velocity is directly proportional to the square of the radius. In a vacuum ($\eta = 0$) there is no drag, so there would be no terminal velocity.

Tidbits

Parachutes have a large surface area, which increases air resistance (drag). This greatly lowers the terminal velocity so the person lands safely.

Q20 Differentiate between an ideal fluid and a real fluid.

Ideal fluid: has no viscosity and cannot be compressed. It does not exist in practice and is used only in theoretical models.

Real fluid: any fluid that has viscosity, e.g. water, kerosene, castor oil, honey, diesel, petrol. Honey is more viscous than water. Ideal fluids flow without friction; real fluids have viscous flow.

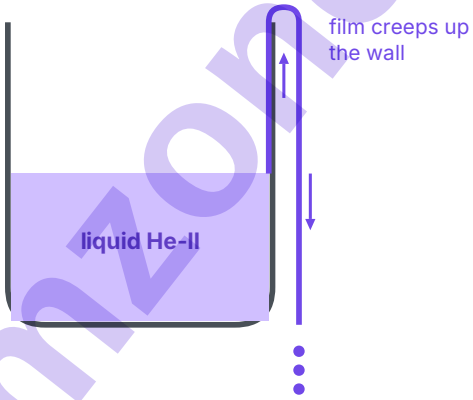
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Ideal fluid	Real fluid
Incompressible (density and volume unchanged by pressure)	Compressible to some extent
Bulk modulus is infinite (no volume change)	Finite bulk modulus
No surface tension	Shows surface tension
Zero viscosity	Has viscosity

Q21 Define and explain superfluidity.

> **Superfluidity** is the property of a fluid having zero viscosity (frictionless flow). A substance with this property is a **superfluid**; it flows without losing kinetic energy.

Superfluids form in some substances at cryogenic temperatures, close to absolute zero. They flow through extremely narrow spaces without resistance and can even "defy gravity" and flow up walls.



Superfluid helium creeping up and over the wall of its container

Properties

- Helium can climb container walls and escape (film flow), and even pass through container walls.
- When stirred, superfluids form persistent vortices; when the container rotates, the liquid inside can stay still.
- They contain a mixture of normal and superfluid components, with more superfluid at lower temperatures.
- Some have very high thermal conductivity. Superfluidity is **not** superconductivity — helium-3 and helium-4 superfluids do not conduct electricity.

Examples

Helium-4 is the most studied: it becomes superfluid a few degrees below its boiling point (about 2.17 K). Others include superfluid helium-3, some Bose–Einstein condensates, atomic rubidium-85, lithium-6 (at 50 nK), atomic sodium, and possibly the interiors of neutron stars.

Applications

1. Superfluid helium-4 is a coolant for high-field magnets; helium-3 and helium-4 are used in advanced particle detectors.

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2. Research on superfluidity helps us understand superconductivity.
3. Liquid helium's high thermal conductivity is used in cryogenics — cooling superconducting magnets, research and medical uses.
4. It is also used in industry for leak testing and making electronic and optical products.

Formula Sheet

#	Formula	Description
1	$\sigma = F/A$	Stress
2	$\varepsilon = \Delta L/L_0$	Tensile (or compressive) strain
3	Volume strain $= \Delta V/V_0$	Volume strain
4	$\gamma = \Delta x/y = \tan\theta \approx \theta$	Shear strain
5	E = stress/strain	Modulus of elasticity
6	$Y = (F/A)/(\Delta L/L_0) = FL_0/A\Delta L$	Young's modulus
7	$K = (F/A)/(\Delta V/V) = FV/A\Delta V$	Bulk modulus
8	$G = (F/A)/\tan\theta = Fy/A\Delta x$	Shear modulus
9	$E = \frac{1}{2}Fx = \frac{1}{2}kx^2$	Strain energy
10	Upthrust $= \rho gV$	Archimedes' principle
11	Rate of flow $= Av$	Volume flow rate
12	$A_1v_1 = A_2v_2$	Equation of continuity
13	$P + \frac{1}{2}\rho v^2 + \rho gh =$ constant	Bernoulli's equation
14	$P_1 - P_2 = \frac{1}{2}\rho v_2^{\,2}$	Venturi relation
15	$v = \sqrt{(2g(h_1 - h_2))}$	Torricelli's theorem
16	$F = 6\pi\eta rv$	Stokes' law (drag force)
17	$v_t = mg/6\pi\eta r = 2\rho gr^2/9\eta$	Terminal velocity

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PART B

Short Questions

Exercise Short Questions

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

(i) Cohesive forces are the attractive forces between molecules of the same substance; they cause effects like surface tension.
(ii) Viscosity is the property of a fluid by which it resists its own flow — the force needed to slide one layer over another. It depends on the nature of the fluid and on temperature: heating **decreases** the viscosity of liquids but **increases** that of gases. SI unit: N s m^{-2}.

5.2 Differentiate between streamline and turbulent flow of a fluid.

In **laminar (streamline)** flow every particle passing a point follows exactly the same path as earlier particles; the flow pattern is fixed. **Turbulent** flow is irregular and unsteady; particles do not follow definite paths and the pattern keeps changing.
Examples: water flowing gently from a narrow pipe (streamline); water gushing from a fully opened tap (turbulent).

5.3 How does pressure change with depth in fluids?

$P = \rho gh$, so pressure increases linearly with depth. The deeper you go, the more fluid lies above, pressing down under gravity, so the pressure rises steadily.

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

By Bernoulli's principle ($P + \frac{1}{2}\rho v^2$ = constant in a horizontal pipe): as the speed of a fluid increases, its pressure **decreases**, and vice versa. Where more energy goes into motion (K.E.), less is left as pressure.

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

Flow rate = A × v. Increasing the area or the speed increases the flow rate. Where the pipe narrows (like a nozzle), the fluid must speed up to keep the flow rate constant (continuity).

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

Apply the continuity equation $A_1v_1 = A_2v_2$ (Av = constant). Where the hose narrows, the fluid speeds up; where it widens, the fluid slows down. This holds for incompressible fluids.

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

An object **floats** if the buoyant force (the weight of the fluid it displaces) is greater than or equal to its own weight. If its weight is greater than the buoyant force, it **sinks**.

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

While taking a bath he noticed that the water level rose as he got in, and realized that the volume of water displaced was related to the volume of his body. This led to Archimedes' principle.

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

The air between the person and the train moves very fast, so by Bernoulli's effect its pressure is low. The slower air behind the person has higher pressure, which can push the person towards the train.

5.10 What are some potential applications of superfluidity?

(i) Superfluid helium-4 cools high-field magnets; helium-3 and helium-4 are used in advanced particle detectors. (ii) Research on superfluidity helps us understand superconductivity. (iii) Liquid helium is used in cryogenics — cooling superconducting magnets, research and medical uses. (iv) Industry uses it for leak testing and making electronic and optical products.

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

Quantity	Definition	Formula	SI unit
Stress	Force per unit area of a material	F/A	Pa (N m^{-2})
Strain	Change in length / original length	ΔL/L	none (dimensionless)
Young's modulus	Tensile stress / tensile strain	Y = σ/ε	Pa (N m^{-2})

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SLO-Based Additional Short Questions + Past Papers (Punjab Boards)

Q1 **Distinguish between a fluid and an ideal fluid.**

Anything that can flow is a **fluid** — liquids and gases. An **ideal fluid** has constant density (incompressible) and zero viscosity. No real fluid is ideal, though air and water are nearly ideal at low pressures.

Q2 **What is viscosity?**

A term describing the internal friction between different layers of a flowing fluid.

Q3 **What is the coefficient of viscosity?**

The tangential force per unit area needed to maintain a unit relative velocity between two layers of a fluid a unit distance apart. It is denoted by η; SI unit N s m^{-2} or kg m^{-1} s^{-1}.

Q4 **What is meant by cohesive force?**

The attractive force between the atoms or molecules of the same substance.

Q5 **What is Stokes' law?**

The drag force on a sphere of radius r moving slowly with velocity v through a fluid of viscosity η is $F = 6\pi\eta rv$.

Q6 **What is an ideal fluid?**

One that is (i) non-viscous — no internal friction between layers, (ii) incompressible — constant density, and (iii) in steady motion.

Q7 **What is the flow rate of a fluid? Write its formula.**

Mass flow rate = mass flowing per second = ρAv. **Volume flow rate** = volume flowing per second = Av. Both remain constant during streamline flow of an ideal fluid.

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Q8 **Define the equation of continuity and write its formula.**

The flow rate of an ideal fluid in streamline flow stays constant: **Av = constant**, i.e. $A_1v_1 = A_2v_2$, where A is the cross-section and v the flow speed.

Q9 **Define Bernoulli's equation and write its mathematical form.**

For steady flow of an incompressible, non-viscous fluid, the sum of pressure P, K.E. per unit volume $\frac{1}{2}\rho v^2$ and P.E. per unit volume ρgh is constant at every point: $\mathbf{P + \frac{1}{2}\rho v^2 + \rho gh = constant}$.

Q10 **What is the relation between speed and pressure of a fluid?**

(i) Pressure is low where speed is high, and vice versa. (ii) For a horizontal pipe: $P + \frac{1}{2}\rho v^2 =$ constant. (iii) Aerodynamic lift and the swing of a cricket ball are practical applications.

Q11 **How does a chimney work?**

A chimney is tall so its top reaches fast-moving air. By Bernoulli's effect the pressure at the top is low, so the hot gases and smoke are drawn up and discharged effectively.

Q12 **Are the atoms, ions or molecules in a crystalline solid static?**

No. They vibrate to and fro about their mean positions.

Q13 **What is meant by amorphous?**

Without structure — amorphous solids have no regular arrangement of molecules.

Q14 **What is meant by deformation of solids?**

The change in shape, length or volume produced when an external force is applied.

Q15 **Define elasticity.**

The ability of a body to return to its original state after the external force is removed.

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Q16 **Define yield point.**

The point on the stress–strain curve beyond which a further increase in stress causes permanent deformation.

Q17 **What are ductile substances? Give examples.**

Substances that undergo plastic deformation until they break, e.g. lead and copper.

Q18 **What are brittle substances? Give examples.**

Substances that break just after the elastic limit is reached, e.g. glass and high-carbon steel.

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PART C

Multiple Choice Questions

Exercise MCQs

1 **The region of the stress–strain curve which obeys Hooke's law is:**

(a) proportional limit
(b) elastic region
(c) plastic region
(d) yield limit

2 **Which of the following is more elastic?**

(a) rubber
(b) wood
(c) sponge
(d) steel

3 **Which of the following is a polymer solid?**

(a) wool
(b) glass
(c) sodium chloride
(d) copper

4 **The effect of decrease of pressure with increase in speed of a fluid in a horizontal pipe is:**

(a) Torricelli's effect
(b) Bernoulli's effect
(c) Venturi's effect
(d) Doppler's effect

5 **The pressure will be low when the speed of the fluid is:**

(a) zero
(b) high
(c) low
(d) constant

6 **As per the law of fluid friction for steady streamline flow, the friction:**

(a) varies proportionally to the velocity of the fluid
(b) varies inversely with pressure
(c) does not depend on pressure
(d) first increases then decreases

7 **A stone submerged in water weighs less than in air. This is due to:**

(a) reduction of mass in water
(b) increase of density in water
(c) buoyant force acting upwards
(d) gravitational force acting upwards

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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

9 **An ideal flow of any fluid must satisfy:**

(a) Pascal’s law **(b)** Bernoulli’s principle
(c) continuity equation only **(d)** both (b) and (c)

10 **The lift force on 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

11 **In the medical field, a Venturi mask, used to deliver a known oxygen concentration, operates on:**

(a) Newton’s third law **(b)** Archimedes’ principle
(c) Pascal’s law **(d)** Bernoulli’s principle

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

Answer Key — Exercise MCQs

1	a	2	d	3	a	4	b	5	b	6	a
7	c	8	c	9	d	10	c	11	d	12	a

Hints

Q1: Hooke’s law (strain ∝ stress) holds only up to the proportional limit (region OA); between A and B the material is still elastic but no longer proportional. Q2: steel has the largest elastic modulus. Q11: the Venturi mask uses the Venturi (Bernoulli) effect — fast oxygen flow lowers pressure and draws in a fixed amount of room air.

SLO-Based Additional MCQs + Past Papers (Punjab Boards)

1 **The drag force ___ as the speed of the object increases:**

(a) decreases **(b)** increases
(c) has no effect **(d)** moderate

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2 **An object moving in a fluid experiences a retarding force called:**

(a) drag force
(b) gravitational force
(c) horizontal force
(d) centripetal force

3 **The drag force on a sphere of radius r moving slowly with speed v through a fluid of viscosity η is:**

(a) $2\pi\eta rv$
(b) $3\pi\eta rv$
(c) $4\pi\eta rv$
(d) $6\pi\eta rv$

4 **A body moves upward through air. The net force on the body is:**

(a) $F = W$
(b) $F = W - F_D$
(c) $F = F_D - W$
(d) $F = F_D + W$

5 **When a fog droplet falls with an acceleration, the net force on it is:**

(a) $mg = F_D$
(b) $mg - F_D$
(c) $F_D - mg$
(d) zero

6 **The law of conservation of mass gives us the equation of:**

(a) rate of flow
(b) continuity
(c) terminal velocity
(d) drag force

7 **For an incompressible fluid in steady flow, the equation of continuity is:**

(a) $A_1/A_2 = v_1/v_2$
(b) $A_2/A_1 = v_1/v_2$
(c) $Av = \text{constant}$
(d) both (b) and (c)

8 **The product of the cross-sectional area of a pipe and the fluid speed at any point is:**

(a) negative
(b) zero
(c) variable
(d) constant

9 **The force required to slide one layer of liquid over another is measured by:**

(a) velocity
(b) acceleration
(c) viscosity
(d) momentum

10 **The viscosity of air in N s m^{-2} is:**

(a) 0.019×10^{-3}
(b) 1.000×10^{-3}
(c) 6.29×10^{-3}
(d) 0.19×10^{-3}

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11 **The viscosity of a liquid with rise in temperature:**

(a) increases **(b)** decreases
(c) remains same **(d)** moderate

12 **The SI unit of viscosity is:**

(a) kg m s^{-1} **(b)** kg m^{-1} s^{-1}
(c) m s^{-1} **(d)** m^{-2} s^{-1}

13 **Which liquid can flow most easily?**

(a) ether **(b)** tar
(c) honey **(d)** all flow at the same rate

14 **The viscosity of a gas with increase in temperature:**

(a) increases **(b)** decreases
(c) remains same **(d)** sometimes increases, sometimes decreases

15 **In $F = 6\pi\eta rv$, the dimensions of the coefficient of viscosity η are:**

(a) $[ML^{-1}T^{-1}]$ **(b)** $[MLT^{-1}]$
(c) $[ML^{-2}T^{-1}]$ **(d)** [MLT]

16 **The law of conservation of energy is the basis of:**

(a) Bernoulli's theorem **(b)** Venturi relation
(c) Stokes' law **(d)** equation of continuity

17 **Pressure will be low where the speed of the fluid is:**

(a) low **(b)** high
(c) constant **(d)** zero

18 **Bernoulli's equation is written as:**

(a) $P + \rho gh = \text{constant}$ **(b)** $P - \frac{1}{2}\rho v^2 + \rho gh = 0$
(c) $P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$ **(d)** all of above

19 **The fundamental equation in fluid dynamics relating pressure, speed and height is:**

(a) Bernoulli's equation **(b)** continuity equation
(c) energy equation **(d)** force equation

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20 **A person standing near a fast-moving train can fall:**

(a) towards the train
(b) away from the train
(c) no effect
(d) remains stationary

21 **The pressure of a liquid is high where its speed is:**

(a) high
(b) low
(c) constant
(d) infinite

22 **A chimney works best when it is:**

(a) tall
(b) wide
(c) short
(d) narrow

23 **The unit of $\frac{1}{2}\rho v^2$ in Bernoulli's equation is the same as that of:**

(a) energy
(b) pressure
(c) work
(d) power

24 **The maximum, constant velocity of an object falling vertically in a fluid is:**

(a) $v_t = 2\rho g r^2/9\eta$
(b) $v_t = mg/6\pi\eta r$
(c) $v_t = 2\rho g r/9\eta$
(d) both (a) and (b)

25 **When weight and drag force become equal, the velocity of the body is:**

(a) minimum velocity
(b) terminal velocity
(c) variable velocity
(d) all of above

26 **A fog droplet falling with terminal velocity has an acceleration:**

(a) less than g
(b) greater than g
(c) equal to g
(d) equal to zero

27 **If the radius of a droplet becomes half, its terminal velocity becomes:**

(a) double
(b) half
(c) one-fourth
(d) four times

28 **A solid in which atoms are in a regular order is called:**

(a) crystalline solid
(b) amorphous solid
(c) polymeric solid
(d) glassy solid

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29 **Which of the following is a crystalline solid?**

(a) copper
(b) NaCl
(c) zirconia
(d) all of these

30 **Which of the following is a polymeric solid?**

(a) nylon
(b) plastic
(c) polythene
(d) all of these

31 **A solid with no regular arrangement of molecules is called:**

(a) amorphous
(b) crystalline
(c) copper
(d) none of these

32 **When stress changes the shape, it is called:**

(a) shear stress
(b) tensile stress
(c) compressive stress
(d) volumetric stress

33 **The SI unit of modulus of elasticity is:**

(a) pascal
(b) coulomb
(c) ampere
(d) none of these

34 **Young's modulus is given by:**

(a) (F/A)/(ΔV/V)
(b) (F/A)/(Δℓ/ℓ)
(c) (FA)/(Δℓ/ℓ)
(d) (F/A)/(ΔV)

35 **The ratio of stress to volumetric strain is called:**

(a) shear modulus
(b) Young's modulus
(c) bulk modulus
(d) modulus of elasticity

36 **The ability of a body to return to its original shape is called:**

(a) plasticity
(b) elasticity
(c) strain
(d) stress

37 **The deformation of a body is the change in its:**

(a) shape
(b) length
(c) area
(d) all of these

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38 **The strain due to tensile stress is:**

(a) compressive strain **(b)** shear strain
(c) volumetric strain **(d)** tensile strain

39 **When stress changes the length of a body, it is called:**

(a) tensile stress **(b)** shear stress
(c) compressive stress **(d)** yield stress

40 **The dimension of stress (modulus of elasticity) is:**

(a) $[ML^{-1}T^{-2}]$ **(b)** $[MLT^{-2}]$
(c) $[ML^{2}T^{-2}]$ **(d)** dimensionless

41 **The dimension of strain is:**

(a) [L] **(b)** $[ML^{2}T^{-2}]$
(c) $[ML^{-1}T^{-2}]$ **(d)** dimensionless

42 **When stress is increased beyond the elastic limit and the material is permanently changed, this property is:**

(a) permanent stress **(b)** elasticity
(c) yield strength **(d)** plasticity

43 **The maximum stress that a body can tolerate is called:**

(a) UTS **(b)** permanent stress
(c) elastic strength **(d)** plastic stress

44 **The value of stress beyond which a body is permanently deformed is called:**

(a) yield stress **(b)** maximum stress
(c) minimum stress **(d)** shear stress

45 **The speed of efflux is given by the relation:**

(a) $\sqrt{(g(h_1 - h_2))}$ **(b)** $\sqrt{(g(h_1 + h_2))}$
(c) $\sqrt{(2g(h_1 - h_2))}$ **(d)** $\sqrt{(2g(h_1 + h_2))}$

46 **The speed of fluid flow is measured by a:**

(a) barometer **(b)** hydrometer
(c) sphygmomanometer **(d)** Venturi meter

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47 **The relation $v = \sqrt{(2g(h_1 - h_2))}$ is known as:**

(a) equation of continuity
(b) Bernoulli's equation
(c) Torricelli's theorem
(d) Venturi relation

48 **A Venturi meter is used to measure the:**

(a) speed of fluid
(b) pressure of fluid
(c) volume of fluid
(d) mass of fluid

49 **The decrease in pressure with increase in speed of a fluid (in a constriction) is called the:**

(a) Venturi effect
(b) Torricelli effect
(c) photoelectric effect
(d) Doppler effect

50 **A 10 m high tank is full of water. A hole appears at its middle; the speed of efflux is:**

(a) 5 m/s
(b) 9.9 m/s
(c) 9.8 m/s
(d) 5.11 m/s

51 **A substance which undergoes plastic deformation until it breaks is:**

(a) brittle
(b) ductile
(c) hard
(d) soft

52 **The pressure exerted by a 76 cm column of mercury at 0 °C is:**

(a) 1 atm
(b) 1 N m^{-2}
(c) 1 pascal
(d) 1 cm^{-2}

53 **Stokes' law holds for:**

(a) motion in free space
(b) motion in a viscous medium
(c) motion on a horizontal surface
(d) motion of all types

54 **The equation $F = 6\pi\eta rv$ is called:**

(a) Newton's law
(b) Bernoulli's law
(c) continuity equation
(d) Stokes' law

55 **The SI unit of flow rate is:**

(a) $m^3\ s^{-1}$
(b) $m^3\ s^{-2}$
(c) $m^2\ s^{-1}$
(d) $m^2\ s^{-2}$

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56 **The smooth or steady flow of a fluid is called:**

(a) turbulent flow **(b)** simple flow
(c) laminar flow **(d)** irregular flow

57 **Streamline flow is also called:**

(a) turbulent **(b)** laminar
(c) normal **(d)** ideal

58 **An incompressible fluid having no viscosity is called:**

(a) ideal fluid **(b)** viscous
(c) real **(d)** non-ideal

59 **The unsteady flow of a fluid is called:**

(a) turbulent **(b)** regular
(c) streamline **(d)** fast

60 **A fluid is said to be incompressible if its density is:**

(a) zero **(b)** very high
(c) very small **(d)** constant

Answer Key — Additional MCQs

1	b	2	a	3	d	4	d	5	b	6	b
7	d	8	d	9	c	10	a	11	b	12	b
13	a	14	a	15	a	16	a	17	b	18	c
19	a	20	a	21	b	22	a	23	b	24	d
25	b	26	d	27	c	28	a	29	d	30	d
31	a	32	a	33	a	34	b	35	c	36	b
37	d	38	d	39	a	40	a	41	d	42	d
43	a	44	a	45	c	46	d	47	c	48	a
49	a	50	b	51	b	52	a	53	b	54	d
55	a	56	c	57	b	58	a	59	a	60	d

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Hints

Q4: moving up, both weight and drag act downward, so $F = F_D + W$. Q27: $v_t \propto r^2$, so halving r gives ¼. Q50: $h = 5$ m $\Rightarrow v = \sqrt{(2 \times 9.8 \times 5)} = 9.9$ m/s. Q52: 76 cm of Hg = 1 atmosphere. Q12/Q15: $\eta = F/6\pi rv \Rightarrow$ kg m^{-1} $s^{-1} = [ML^{-1}T^{-1}]$.

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PART D

Solved Exercise

Exercise Numericals

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

Given: L = 2 m • A = 2×10^{-6} m^2 • F = 400 N • Y = 2×10^{11} N m^{-2}

$$Y = \frac{FL}{A\Delta L} \Rightarrow \Delta L = \frac{FL}{AY} = \frac{400 \times 2}{2 \times 10^{-6} \times 2 \times 10^{11}} = \frac{800}{4 \times 10^{5}}$$

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

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

Given: k = 200 N m^{-1} • x = 0.5 m

$$\text{P.E.} = \tfrac{1}{2}kx^2 = \tfrac{1}{2} \times 200 \times (0.5)^2 = 100 \times 0.25$$

$$\text{P.E.} = 25 \text{ J}$$

5.3 **A copper wire 3 m long with cross-sectional area 1×10^{-6} m^2 is subjected to a force of 500 N. Calculate the stress and strain produced (Y for copper = 1.1×10^{11} N m^{-2}).**

Given: L = 3 m • A = 1×10^{-6} m^2 • F = 500 N • Y = 1.1×10^{11} N m^{-2}

$$\sigma = \frac{F}{A} = \frac{500}{1 \times 10^{-6}} = 5 \times 10^{8} \text{ N m}^{-2}$$

$$\varepsilon = \frac{\sigma}{Y} = \frac{5 \times 10^{8}}{1.1 \times 10^{11}} = 4.55 \times 10^{-3}$$

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

Given: m = 10 kg • ρ_{wood} = 600 kg m^{-3} • ρ_{water} = 1000 kg m^{-3}

The block floats, so by the principle of floatation the buoyant force equals its weight:

$$F_b = mg = 10 \times 9.8 = 98 \text{ N}$$

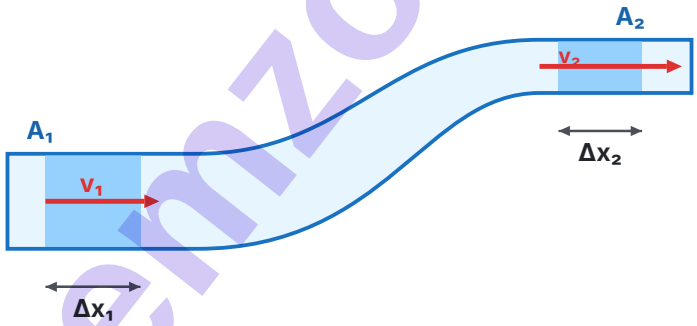
Check: volume of water displaced = 98 / (1000 × 9.8) = 0.01 m^3, while the block's volume = 10/600 = 0.0167 m^3, so 60% of it is under water.

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

Given: d_1 = 0.05 m • v_1 = 2 m s^{-1} • d_2 = 0.03 m

$$A_1v_1 = A_2v_2, \text{ with } A = \pi d^2/4 \Rightarrow v_2 = \frac{d_1^{\,2}\, v_1}{d_2^{\,2}} = \frac{(0.05)^2 \times 2}{(0.03)^2}$$

$$v_2 \approx 5.56 \text{ m s}^{-1}$$



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

Given: $v_1 = 3\ m\ s^{-1}$ • $P_1 = 200\,000\ Pa$ • $P_2 = 101\,300\ Pa$ • $\rho = 1000\ kg\ m^{-3}$ • $h_1 = h_2$

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

$$200\,000 + \tfrac{1}{2}(1000)(3)^2 = 101\,300 + \tfrac{1}{2}(1000)v_2^2$$

$$204\,500 - 101\,300 = 500\,v_2^2 \Rightarrow v_2^2 = 206.4$$

$$\mathbf{v_2 \approx 14.4\ m\ s^{-1}}$$

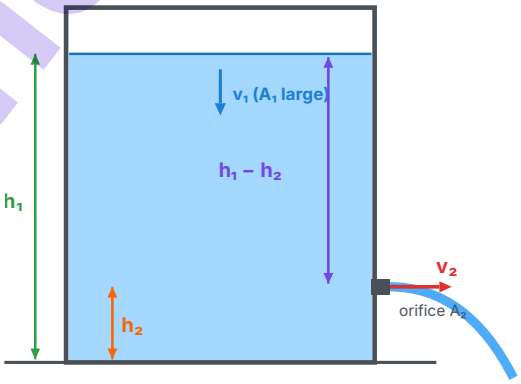
This agrees with the "about 14 m s^{-1}" quoted in the question.

5.7 **A tank filled with water has a hole 5 m below the water surface. Calculate the velocity of the water flowing out of the hole.**

Given: $h = h_1 - h_2 = 5\ m$ • $g = 9.8\ m\ s^{-2}$

$$v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 5)} = \sqrt{98}$$

$$\mathbf{v \approx 9.9\ m\ s^{-1}}$$



Torricelli's theorem

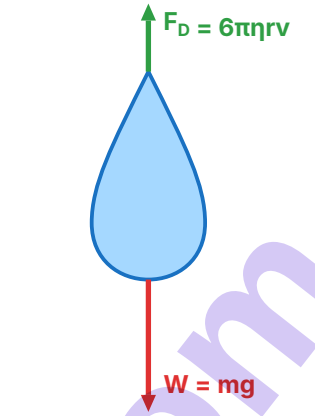
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5.8 **Calculate the terminal velocity of a spherical raindrop of radius 0.5 mm falling through air (η for air = 19 × 10^{-6} kg m^{-1} s^{-1}; ρ for water = 1000 kg m^{-3}).**

Given: r = 0.5 × 10^{-3} m • η = 19 × 10^{-6} kg m^{-1} s^{-1} • ρ = 1000 kg m^{-3}

$$v_t = \frac{2\rho g r^2}{9\eta} = \frac{2 \times 1000 \times 9.8 \times (0.5 \times 10^{-3})^2}{9 \times 19 \times 10^{-6}} = \frac{4.9 \times 10^{-3}}{1.71 \times 10^{-4}}$$

$$v_t \approx 28.7 \text{ m s}^{-1}$$



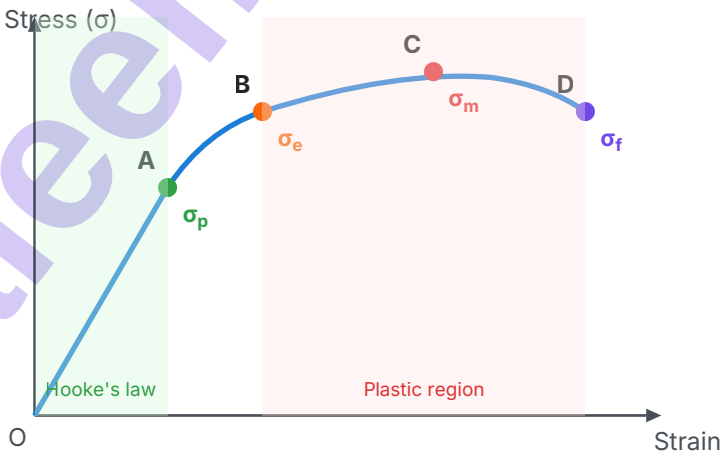
Forces on the raindrop

Stokes' law strictly applies to slow motion, so the real terminal speed of a 0.5 mm raindrop is lower (a few m s^{-1}); 28.7 m s^{-1} is the answer expected by the formula.

Constructed Response Questions

5.1 **The ratio stress/strain stays constant for small deformations. What happens to this ratio when the deformation is very large?**

For large deformations the material goes beyond the proportional (elastic) limit and behaves non-linearly. Stress/strain is no longer constant; the material may deform permanently (plasticity), and the stress–strain relation becomes more complex.



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5.2 **Pure water dropped on a flat glass plate spreads out, while mercury on the same plate forms small globules. Why?**

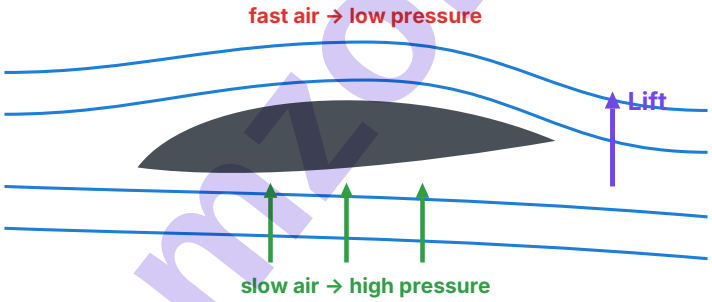
For water, the **adhesive** forces between water and glass are stronger than the cohesive forces within water, so water “wets” the glass and spreads. For mercury, the **cohesive** forces between mercury atoms are much stronger than the adhesive forces with glass, so it does not wet the glass and forms globules.

5.3 **According to Bernoulli’s theorem the pressure of a fluid should be uniform in a pipe of uniform radius, but in fact it keeps decreasing. Why?**

Bernoulli’s theorem assumes an ideal, non-viscous fluid, for which pressure stays constant. Real fluids are viscous, so energy is lost to friction with the pipe walls, causing a gradual pressure drop along the pipe even when the radius is uniform.

5.4 **Why are the wings of an aeroplane rounded outward (on top) and flat on the inner side?**

The curved top and flat bottom create a pressure difference. Air moves faster over the curved top, reducing the pressure there (Bernoulli’s principle), while slower air below exerts higher pressure. This pressure difference lifts the aeroplane.



5.5 **What is the difference between a real fluid, an ideal fluid and a superfluid? Which of these really exist?**

Ideal fluid: hypothetical, with no viscosity and no compressibility; flows without resistance.
Real fluid: actual fluids like water and air, which have viscosity and some compressibility and lose energy to friction.
Superfluid: a fluid with zero viscosity (frictionless).
Existence: real fluids exist in everyday life; superfluids exist only under special laboratory conditions (near absolute zero); ideal fluids are purely theoretical, used to simplify problems.

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

Superfluids show quantum mechanics working on a large, visible scale. Liquid helium-4 below 2.17 K shows (i) **zero viscosity** — flow without energy loss, against classical physics; (ii) **quantized vortices** — rotation happens in discrete steps; and (iii) links to **Bose–Einstein condensation**, where particles occupy the same quantum state.

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