Solids and Fluid Dynamics

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

Cohesive Force
Attraction between molecules of the same substance.

Viscosity
The friction between layers of a flowing fluid. It measures the force needed to slide one layer over another.

SQ 5.2 Differentiate between streamline and turbulent flow of a fluid.

Streamline Flow	Turbulent Flow
Smooth and regular flow.	Irregular and unsteady flow.
Each particle follows a fixed streamline.	Particle paths keep changing.
Streamlines never cross.	Eddies form and velocity changes abruptly.

SQ 5.3 How does pressure change with depth in fluids?

Liquid Pressure
At depth h in a fluid of density ρ
$P = \rho g h.$

Conclusion
Pressure increases with depth.

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

Bernoulli's Equation (Ideal Fluid)
$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$
According to Bernoulli's theorem, "where speed is high, pressure will be low".

Conclusion
High speed means low pressure.

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

Volume Flow Rate
Volume V crossing area A in time t gives
$$\frac{V}{t} = Av.$$

Equation of Continuity
$A_1 v_1 = A_2 v_2$
Area × velocity stays constant.

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

We can study the variation in velocity of a fluid at different points in a hose of varying diameter by the equation of continuity.
$Av = \text{constant}$
or
$$v \propto \frac{1}{d^2}$$

Results
Velocity is more from narrow diameter.
Velocity is less from wider diameter.

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

Upthrust
A body feels an upward force equal to the weight of fluid displaced.

Floating
Upthrust balances its weight.

Sinking
Weight exceeds the upthrust.

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

Observation
When Archimedes sat in a bath tub, water came out. He felt lighter in the water.

Discovery
A body gets an upthrust equal to the weight of fluid displaced. He tested the king's crown with it.

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

Low Pressure
Air between person and train moves fast, so its pressure falls. According to Bernoulli's theorem, "where speed is high, pressure will be low".

Danger
The higher pressure behind and the lower pressure in front create a pressure difference that pushes the person towards the train.

SQ 5.10 What are some potential applications of superfluidity?

High-Field Magnets
Superfluid helium-4 is a coolant for high-field magnets.

Particle Detectors
Used in advanced particle detectors.

Research
Its study helps explain superconductivity.

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

Quantity	Definition	Formula	SI Unit
Stress	Force per unit area.	$\sigma = F/A$	pascal (Pa)
Strain	Fractional change in length.	$\varepsilon = \Delta L/L$	None
Young's Modulus	Stress per unit strain.	$Y = \sigma/\varepsilon$	pascal (Pa)

CRQ 5.1 The ratio stress/strain remains constant for small deformation. What happens to this ratio when the deformation becomes very large?

Small Deformation
Within the elastic limit the ratio stays constant.

Large Deformation

Beyond the limit of proportionality the ratio falls and the material may break permanently.

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

Water on Glass

Adhesion to glass exceeds cohesion in water, so water wets and spreads.

Mercury on Glass

Cohesion exceeds adhesion, so mercury forms globules.

CRQ 5.3 **According to Bernoulli's theorem, pressure in a pipe of uniform radius should remain uniform, but actually it decreases along the pipe. Why?**

Ideal Fluid

Bernoulli's equation assumes zero viscosity, so pressure would stay uniform.

Real Fluid

Viscosity causes friction and turns energy into heat, so a pressure drop is needed to keep it flowing.

CRQ 5.4 **Why are the wings of an aeroplane rounded outward on top and comparatively flat underneath?**

Air Speed

Air moves faster over the curved top than under the flat base. According to Bernoulli's theorem, "where speed is high, pressure will be low".

Lift

Lower pressure above gives an upward pressure difference.

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

Ideal Fluid	Real Fluid	Superfluid
No viscosity and incompressible.	It has viscosity.	Zero viscosity with frictionless flow.
Cannot exist practically.	Water, petrol and honey are real fluids.	Helium-4 near absolute zero is a real example.

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

Importance

Superfluids flow without losing energy and pass through the narrowest spaces. It explains superconductivity and matter near absolute zero.

Example

Helium-4 cools cryogenic research and magnets.

MCQ 5.1 **The region of stress-strain curve which obeys Hooke's law is:**

A proportional limit **B** elastic region **C** plastic region **D** yield limit

SOLUTION: Hooke's law is obeyed up to the proportional limit.

MCQ 5.2 **Which of the following is more elastic?**

A Rubber **B** Wood **C** Sponge **D** Steel

SOLUTION: Steel has the greatest Young's modulus among these materials.

MCQ 5.3 **Which of the following is polymer solid?**

A Wool **B** Glass **C** Sodium chloride **D** Copper

SOLUTION: Wool is a natural polymer made of protein chains.

MCQ 5.4 **The effect of decrease of pressure with the increase in speed of a fluid in horizontal pipe is:**

A Torricelli's effect **B** Bernoulli's effect **C** Venturi's effect **D** Doppler's effect

SOLUTION: Bernoulli's effect states that pressure decreases where fluid speed increases.

MCQ 5.5 **The pressure will be low when speed of a fluid is:**

A zero **B** high **C** low **D** constant

SOLUTION: According to Bernoulli's principle, high fluid speed corresponds to low pressure.

MCQ 5.6 **As per law of fluid friction for steady streamline flow, the friction:**

A varies proportionally to velocity of fluid **B** varies inversely proportional to pressure **C** does not depend on pressure **D** first increases then decreases

SOLUTION: In steady streamline flow, viscous friction is proportional to fluid velocity.

MCQ 5.7 **If a stone is submerged in water and it weighs less in water than in air, this phenomenon is due to:**

A the reduction of mass in water **B** increase of density in water **C** buoyant force acting upwards **D** the gravitational force acting upward

SOLUTION: The upward buoyant force reduces the stone's apparent weight in water.

MCQ 5.8 **The principle of floatation is a direct application of:**

A Pascal's law **B** Bernoulli's principle **C** Archimedes' principle **D** Newton's third law

SOLUTION: A floating body displaces fluid whose weight equals the body's weight.

MCQ 5.9 **An ideal flow of any fluid must satisfy:**

A Pascal law
B Bernoulli's equation
C Continuity equation only
D Both (b) and (c)

SOLUTION: Ideal fluid flow satisfies both Bernoulli's and continuity equations.

MCQ 5.10 **The lift force experienced by an aeroplane wings is primarily due to:**

A viscosity of air
B density of air
C pressure difference above and below the wing
D gravitational force

SOLUTION: Lower pressure above and higher pressure below the wing produce lift.

MCQ 5.11 **In medical field, a venturi mask, used to deliver a known oxygen concentration to patients operates is based on:**

A Newton's third law
B Archimedes' principle
C Pascal's law
D Bernoulli's principle

SOLUTION: Fast oxygen flow lowers pressure and draws in air by Bernoulli's principle.

MCQ 5.12 **Which of the following is a defining characteristic of a superfluid?**

A Zero viscosity
B Infinite density
C Zero temperature
D Infinite thermal conductivity

SOLUTION: A superfluid flows without viscous resistance.

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

Given Data

$L = 2\,\mathrm{m}$
$A = 2 \times 10^{-6}\,\mathrm{m^2}$
$F = 400\,\mathrm{N}$
$Y = 2 \times 10^{11}\,\mathrm{N\,m^{-2}}$

To Find

Extension, $\Delta L = ?$

Formula

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

Solution

$$\Delta L = \frac{FL}{AY} = \frac{400(2)}{(2 \times 10^{-6})(2 \times 10^{11})}$$

$$\boxed{\Delta L = 0.002\,\mathrm{m}}$$

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

Given Data

$k = 200\,\mathrm{N\,m^{-1}}$
$x = 0.5\,\mathrm{m}$

To Find

Elastic potential energy, $E_p = ?$

Formula

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

Solution

$$E_p = \frac{1}{2}(200)(0.5)^2$$

$$\boxed{E_p = 25\,\mathrm{J}}$$

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

Given Data

$L = 3\,\mathrm{m}$
$A = 1 \times 10^{-6}\,\mathrm{m^2}$
$F = 500\,\mathrm{N}$
$Y = 1.1 \times 10^{11}\,\mathrm{N\,m^{-2}}$

To Find

Stress, $\sigma = ?$; strain, $\varepsilon = ?$

Formula

$$\text{Stress} = \frac{F}{A}, \qquad \text{Strain} = \frac{\text{Stress}}{Y}$$

Solution

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

$$\boxed{\sigma = 5 \times 10^{8}\,\mathrm{N\,m^{-2}}}$$

$$\text{Strain} = \frac{5 \times 10^{8}}{1.1 \times 10^{11}}$$

$$\boxed{\varepsilon = 0.00455}$$

Numerical 5.4 **A block of wood of mass $10\,\mathrm{kg}$ and density $600\,\mathrm{kg\,m^{-3}}$ is floating in water. Calculate the buoyant force acting on the block. Density of water is $1000\,\mathrm{kg\,m^{-3}}$.**

Given Data

$m = 10\,\mathrm{kg}$
$g = 9.8\,\mathrm{m\,s^{-2}}$; the block is floating

To Find

Buoyant force, $F_B = ?$

Formula

For a floating body, $F_B = W = mg$

Solution

$$F_B = (10)(9.8)$$

$$\boxed{F_B = 98\,\mathrm{N}}$$

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

Given Data

$d_1 = 0.05\,\mathrm{m}$
$v_1 = 2\,\mathrm{m\,s^{-1}}$
$d_2 = 0.03\,\mathrm{m}$

To Find

Velocity at the narrow section, $v_2 = ?$

Formula

$A_1v_1 = A_2v_2, \qquad v_2 = \frac{d_1^2 v_1}{d_2^2}$

Solution

$v_2 = \frac{(0.05)^2(2)}{(0.03)^2}$

$\boxed{v_2 = 5.56\,\mathrm{m\,s^{-1}}}$

Numerical 5.6 **Water flows through a horizontal pipe with a velocity of $3\,\mathrm{m\,s^{-1}}$ and pressure of $200000\,\mathrm{Pa}$ at point 1. At the nozzle (point 2), the pressure decreases to atmospheric pressure $101300\,\mathrm{Pa}$ and the velocity increases. Calculate the velocity of the water exiting the nozzle. Density of water is $1000\,\mathrm{kg\,m^{-3}}$.**

Given Data

$v_1 = 3\,\mathrm{m\,s^{-1}}$
$P_1 = 200000\,\mathrm{Pa}$
$P_2 = 101300\,\mathrm{Pa}$
$\rho = 1000\,\mathrm{kg\,m^{-3}}$

To Find

Exit velocity, $v_2 = ?$

Formula

For a horizontal pipe,

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

Solution

$200000 + \frac{1}{2}(1000)(3)^2 = 101300 + \frac{1}{2}(1000)v_2^2$

$204500 = 101300 + 500v_2^2$

$500v_2^2 = 103200$

$v_2^2 = \frac{103200}{500} = 206.4$

$v_2 = \sqrt{206.4}$

$\boxed{v_2 = 14.37\,\mathrm{m\,s^{-1}}}$

Numerical 5.7 **A tank filled with water has a hole at a depth of $5\,\mathrm{m}$ from the water surface. Calculate the velocity of water flowing out of the hole.**

Given Data

$h = 5\,\mathrm{m}$
$g = 9.8\,\mathrm{m\,s^{-2}}$

To Find

Efflux velocity, $v = ?$

Formula

$v = \sqrt{2gh}$

Solution

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

$\boxed{v = 9.9\,\mathrm{m\,s^{-1}}}$

Numerical 5.8 **Calculate the terminal velocity of a spherical raindrop with radius $0.5\,\mathrm{mm}$ falling through air. The coefficient of viscosity of air is $19 \times 10^{-6}\,\mathrm{kg\,m^{-1}\,s^{-1}}$ and density of water is $1000\,\mathrm{kg\,m^{-3}}$.**

Given Data

$r = 0.5\,\mathrm{mm} = 5 \times 10^{-4}\,\mathrm{m}$
$\eta = 19 \times 10^{-6}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
$\rho = 1000\,\mathrm{kg\,m^{-3}}$
$g = 9.8\,\mathrm{m\,s^{-2}}$

To Find

Terminal velocity, $v_t = ?$

Formula

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

Solution

$v_t = \frac{2(5 \times 10^{-4})^2(1000)(9.8)}{9(19 \times 10^{-6})}$

$\boxed{v_t = 28.65\,\mathrm{m\,s^{-1}}}$