Chapter 9: Mechanical Properties of Fluids - Answer Key

NCERT Physics Class 11

BACK EXERCISES - SOLUTIONS

9.1 Blood Pressure and Atmospheric Pressure

Explain why:

(a) The blood pressure in humans is greater at the feet than at the brain

Answer: Due to gravitational effect on fluid pressure. Using $P = P_0 + \rho gh$:

- Blood is a fluid with density $\rho \approx 1060$ kg/m^3
- Height difference h between feet and brain ≈ 1.5-1.8 m
- Pressure difference: $\Delta P = \rho gh = 1060 \times 9.8 \times 1.6 \approx 16{,}600$ Pa ≈ 125 mmHg
- **Result:** Feet experience higher pressure than brain due to hydrostatic pressure

(b) Atmospheric pressure at 6 km height decreases to nearly half, though atmosphere extends >100 km

Answer: Atmospheric density decreases exponentially with altitude

- Air is compressible (unlike liquids)
- Higher altitude → lower pressure → lower density
- Most atmospheric mass concentrated in lower layers
- At 6 km: pressure ≈ 0.5 atm because ~50% of atmosphere's mass is below this height
- **Key Point:** Pressure depends on weight of air column above, not total atmospheric height

(c) Hydrostatic pressure is scalar even though pressure is force divided by area

Answer: Pressure at a point acts equally in all directions

- Force F in numerator is always normal force component (scalar magnitude)
- Direction is automatically perpendicular to any surface element
- Pascal's law: pressure same in all directions at a point
- **Result:** No preferred direction can be assigned to pressure at a point

9.2 Surface Tension and Contact Angles

Explain why:

(a) Mercury-glass contact angle is obtuse, while water-glass is acute

Answer: Different intermolecular attractions

- **Mercury-glass:** $S_{sl} > S_{la} \rightarrow \cos\theta < 0 \rightarrow \theta > 90°$ (obtuse)
  - Mercury atoms attract each other more strongly than to glass
  - High surface energy at mercury-glass interface
- **Water-glass:** $S_{sl} < S_{la} \rightarrow \cos\theta > 0 \rightarrow \theta < 90°$ (acute)
  - Water molecules form hydrogen bonds with glass surface
  - Lower surface energy at water-glass interface

(b) Water spreads on glass while mercury forms drops

Answer: Related to contact angles

- **Water on glass:** $\theta < 90°$ (acute) → good wetting → spreads out
- **Mercury on glass:** $\theta > 90°$ (obtuse) → poor wetting → forms spherical drops
- **Energy principle:** System minimizes total surface energy

(c) Surface tension is independent of surface area

Answer: Surface tension is an intensive property

- **Definition:** S = Force per unit length = Energy per unit area
- **Analogy:** Like density being independent of volume
- **Physical meaning:** Depends only on molecular properties, not system size
- Larger surface → proportionally larger force, but $S = F/l$ remains constant

(d) Water with detergent has small contact angles

Answer: Detergents are surfactants (surface active agents)

- Reduce surface tension of water-air interface
- From contact angle equation: $S_{la} \cos \theta + S_{sl} = S_{sa}$
- Smaller S_{la} → larger $\cos \theta$ → smaller θ
- **Result:** Better wetting, easier penetration into fabrics

(e) Liquid drop under no external forces is spherical

Answer: Sphere minimizes surface area for given volume

- Surface energy ∝ surface area
- Minimum energy → minimum surface area
- Mathematical result: sphere has smallest surface area for given volume
- **No external forces:** Only surface tension determines shape

9.3 Fill in the Blanks

(a) Surface tension generally *decreases* with temperature Reason: Higher temperature → more molecular motion → weaker intermolecular bonds → lower surface energy

(b) Viscosity of gases *increases* with temperature, viscosity of liquids *decreases* with temperature Reason:

- **Gases:** Higher T → more molecular collisions → more momentum transfer → higher viscosity
- **Liquids:** Higher T → more molecular mobility → easier flow → lower viscosity

(c) For solids: shearing force ∝ *shear strain*, for fluids: shearing force ∝ *rate of shear strain* Reason:

- **Solids:** Elastic deformation, stress proportional to strain
- **Fluids:** Viscous flow, stress proportional to strain rate ($d\gamma/dt$)

(d) Flow speed increase at constriction follows *conservation of mass* Reason: Continuity equation $A_1v_1 = A_2v_2$ comes from mass conservation

(e) Wind tunnel model has *greater* speed for turbulence than actual plane Reason: Reynolds number $Re = \rho vL/\eta$ must match; smaller model (L) requires higher v

9.4 Bernoulli's Principle Applications

Explain why:

(a) To keep paper horizontal, blow over it, not under it

Answer: Bernoulli's principle creates pressure difference

- **Blowing over:** High velocity above → low pressure above
- **Static air below:** Zero velocity → atmospheric pressure below
- **Result:** Upward force ($P_{below} - P_{above}$) keeps paper horizontal
- **Blowing under:** Would create high pressure below, pushing paper down

(b) Fast water jets through finger gaps when closing tap

Answer: Continuity equation $A_1v_1 = A_2v_2$

- **Large area:** Finger gaps create much smaller effective area A_2
- **Conservation of mass:** Same volume flow rate
- **Result:** Much higher velocity v_2 through small gaps
- **Physics:** Speed inversely proportional to cross-sectional area

(c) Syringe needle controls flow rate better than thumb pressure

Answer: Flow rate depends on pressure difference and resistance

- **Needle resistance:** Very high due to small diameter ($\propto 1/r^4$)
- **Thumb pressure variation:** Small effect compared to needle resistance
- **Result:** Needle geometry dominates flow characteristics
- **Control:** Precise flow rate determined by needle diameter, not pressure variations

(d) Fluid outflow creates backward thrust

Answer: Newton's third law (momentum conservation)

- **Fluid momentum:** Mass × velocity leaving vessel
- **Reaction force:** Equal and opposite force on vessel
- **Example:** Rocket propulsion, garden hose recoil
- **Physics:** Rate of momentum change = Force

(e) Spinning cricket ball doesn't follow parabolic trajectory

Answer: Magnus effect due to asymmetric airflow

- **No spin:** Symmetric airflow → parabolic path under gravity alone
- **With spin:** Ball drags air → velocity difference above/below

- **Bernoulli effect:** Pressure difference creates sideways force
- **Result:** Curved trajectory, not simple parabola

9.5 High Heel Pressure Calculation

Given: Mass = 50 kg, heel diameter = 1.0 cm, single heel contact

Solution:

Contact area: $A = \pi r^2 = \pi \times (0.5 \times 10^{-2}\ m)^2 = \pi \times 2.5 \times 10^{-5}\ m^2$
Force: $F = mg = 50 \times 9.8 = 490$ N
Pressure: $P = F/A = 490/(\pi \times 2.5 \times 10^{-5}) = 6.24 \times 10^6$ Pa = 6.24 MPa

Answer: 6.24×10^6 Pa (about 62 atmospheres!)

9.6 Torricelli's Barometer with Wine

Given: Wine density = 984 kg/m^3, atmospheric pressure = 1 atm

Solution: Using P_a = ρgh:

Mercury: $1.01 \times 10^5 = 13{,}600 \times 9.8 \times h_{Hg}$
$h_{Hg} = 0.76$ m = 76 cm

Wine: $1.01 \times 10^5 = 984 \times 9.8 \times h_{wine}$
$h_{wine} = 1.01 \times 10^5/(984 \times 9.8) = 10.5$ m

Answer: Wine column height = 10.5 m

9.7 Off-Shore Structure Safety

Given: Maximum stress = 10^9 Pa, ocean depth = 3 km

Solution:

Ocean pressure at 3 km depth:
$P = P_a + \rho gh = 1.01 \times 10^5 + 1030 \times 9.8 \times 3000$
$P = 1.01 \times 10^5 + 3.03 \times 10^7 = 3.04 \times 10^7$ Pa

Maximum allowable: 10^9 Pa
Actual pressure: 3.04×10^7 Pa
Safety factor: $10^9/(3.04 \times 10^7) \approx 33$

Answer: YES, structure is suitable (actual pressure << maximum stress)

9.8 Hydraulic Lift Design

Given: Maximum car mass = 3000 kg, load piston area = 425 cm^2

Solution:

Maximum load force: $F_2 = mg = 3000 \times 9.8 = 29{,}400$ N
Load piston area: $A_2 = 425\ cm^2 = 0.0425\ m^2$
Required pressure: $P = F_2/A_2 = 29{,}400/0.0425 = 692{,}000$ Pa $\approx 6.9 \times 10^5$ Pa

Answer: Maximum pressure = 6.9×10^5 Pa = 6.9 bar

9.9 U-Tube Manometer Analysis

Given: 10.0 cm water, 12.5 cm spirit, mercury levels equal

Solution: For equal mercury levels, pressures at mercury surface must be equal:

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P_water + ρ_water × g × h_water = P_spirit + ρ_spirit × g × h_spirit
ρ_water × h_water = ρ_spirit × h_spirit (atmospheric pressure cancels)
1000 × 0.10 = ρ_spirit × 0.125
ρ_spirit = 1000 × 0.10/0.125 = 800 kg/m³

Specific gravity of spirit = 800/1000 = 0.8
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Answer: Specific gravity = 0.8

9.10 Mercury Level Difference

Given: Additional 15.0 cm each of water and spirit, mercury specific gravity = 13.6

Solution:

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Initial state: Mercury levels equal
After adding liquids:
- Water column: 10.0 + 15.0 = 25.0 cm
- Spirit column: 12.5 + 15.0 = 27.5 cm

Pressure difference at mercury interface:
ΔP = ρ_water × g × 0.25 - ρ_spirit × g × 0.275
ΔP = g(1000 × 0.25 - 800 × 0.275) = g(250 - 220) = 30g Pa

Mercury level difference:
Δh = ΔP/(ρ_Hg × g) = 30g/(13,600 × g) = 30/13,600 = 0.0022 m = 0.22 cm
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Answer: Mercury level difference = 0.22 cm (water side higher)

9.11 Bernoulli's Equation in River Rapids

Answer: NO, Bernoulli's equation cannot be used

Reasons:

1. **Turbulent flow:** Rapids are inherently turbulent, violating steady flow assumption
2. **Significant viscosity:** Energy loss due to friction and turbulence
3. **Non-uniform flow:** Velocity varies chaotically in space and time
4. **Energy dissipation:** Kinetic energy converted to heat and sound

Valid applications: Smooth, laminar flow with negligible viscosity

9.12 Gauge vs Absolute Pressure in Bernoulli's Equation

Answer: NO, it does not matter

Explanation: Bernoulli's equation involves pressure differences:

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

Whether using absolute or gauge pressures:

- **Absolute:** $P_{abs} = P_{gauge} + P_a$
- **Difference:** $(P_{1,abs} - P_{2,abs}) = (P_{1,gauge} + P_a) - (P_{2,gauge} + P_a) = (P_{1,gauge} - P_{2,gauge})$
- **Result:** Atmospheric pressure cancels out in differences

9.13 Viscous Flow in Horizontal Tube

Given: L = 1.5 m, r = 1.0 cm, mass flow rate = 4.0×10^{-3} kg/s, $\rho_{glycerine} = 1.3 \times 10^3$ kg/m³, η = 0.83 Pa·s

Solution:

Volume flow rate: Q = mass flow rate/density = $(4.0 \times 10^{-3})/(1.3 \times 10^3) = 3.08 \times 10^{-6}\ m^3/s$

For laminar flow in pipe (Poiseuille's equation):
$Q = \pi r^4 \Delta P/(8\eta L)$

Solving for pressure difference:
$\Delta P = 8\eta LQ/(\pi r^4)$
$\Delta P = 8 \times 0.83 \times 1.5 \times 3.08 \times 10^{-6}/(\pi \times (0.01)^4)$
$\Delta P = 8 \times 0.83 \times 1.5 \times 3.08 \times 10^{-6}/(\pi \times 10^{-8})$
$\Delta P = 976$ Pa

Reynolds number check:

$Re = \rho vd/\eta$ where $v = Q/(\pi r^2) = 3.08 \times 10^{-6}/(\pi \times 10^{-4}) = 0.098$ m/s
$Re = (1.3 \times 10^3 \times 0.098 \times 0.02)/0.83 = 3.08 << 2000$

Answer: $\Delta P = 976$ Pa, flow is laminar ($Re << 2000$)

9.14 Aircraft Wing Lift

Given: $v_{upper} = 70$ m/s, $v_{lower} = 63$ m/s, wing area = 2.5 m^2, $\rho_{air} = 1.3\ kg/m^3$

Solution: Using Bernoulli's equation (ignoring height difference):

$P_{lower} + \frac{1}{2}\rho v_{lower}^2 = P_{upper} + \frac{1}{2}\rho v_{upper}^2$
$\Delta P = P_{lower} - P_{upper} = \frac{1}{2}\rho(v_{upper}^2 - v_{lower}^2)$
$\Delta P = \frac{1}{2} \times 1.3 \times (70^2 - 63^2) = \frac{1}{2} \times 1.3 \times (4900 - 3969) = \frac{1}{2} \times 1.3 \times 931 = 605$ Pa

Lift force = ΔP × Area = 605 × 2.5 = 1512 N

Answer: Lift force = 1512 N ≈ 1.5 kN

9.15 Streamline Flow Analysis

Given: Two figures showing fluid flow patterns

Analysis:

- **Figure (a):** Possible - Streamlines don't cross, consistent with continuity equation
- **Figure (b):** Impossible - Streamlines cross, violating fundamental flow principle

Reason: In steady flow, each point has unique velocity direction. Crossing streamlines would mean a fluid particle could move in two different directions simultaneously, which is physically impossible.

Answer: Figure (b) is incorrect due to crossing streamlines

9.16 Spray Pump Flow Analysis

Given: Tube area = 8.0 cm^2, 40 holes each 1.0 mm diameter, flow speed in tube = 1.5 m/min

Solution:

Tube area: $A_1 = 8.0\ cm^2 = 8.0 \times 10^{-4}\ m^2$
Each hole area: $a = \pi(0.5 \times 10^{-3})^2 = \pi \times 2.5 \times 10^{-7}\ m^2$
Total hole area: $A_2 = 40 \times \pi \times 2.5 \times 10^{-7} = \pi \times 10^{-5}\ m^2$
Tube speed: $v_1 = 1.5$ m/min = 0.025 m/s

Using continuity equation: $A_1v_1 = A_2v_2$
$v_2 = A_1v_1/A_2 = (8.0 \times 10^{-4} \times 0.025)/(\pi \times 10^{-5})$
$v_2 = 2.0 \times 10^{-5}/(\pi \times 10^{-5}) = 2/\pi = 0.637$ m/s

Answer: Ejection speed = 0.64 m/s

9.17 Soap Film Surface Tension

Given: Weight supported = 1.5×10^{-2} N, slider length = 30 cm

Solution:

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Force balance: Weight = Surface tension force
W = 2 × S × l  (factor 2 because film has two surfaces)
1.5 × 10⁻² = 2 × S × 0.30
S = (1.5 × 10⁻²)/(2 × 0.30) = 0.025 N/m
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Answer: Surface tension = 0.025 N/m = 25 mN/m

9.18 Film Weight Comparison

Given: Figure (a) weight = 4.5×10^{-2} N

Analysis:

- **Figure (a):** Film stretched across rectangular frame - 2 surfaces
- **Figure (b):** Film in circular loop - 2 surfaces, same total length
- **Figure (c):** Film across single edge - 1 surface

Solution:

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For same liquid and temperature, surface tension S is constant
(a) W_a = 2Sl, so S = W_a/(2l) = 4.5 × 10⁻²/(2l)
(b) Same total perimeter and 2 surfaces: W_b = W_a = 4.5 × 10⁻² N
(c) Only 1 surface: W_c = Sl = W_a/2 = 2.25 × 10⁻² N
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Answer: (b) 4.5×10^{-2} N, (c) 2.25×10^{-2} N

9.19 Mercury Drop Pressure

Given: r = 3.00 mm, $S_{Hg} = 4.65 \times 10^{-1}$ N/m, $P_a = 1.01 \times 10^5$ Pa

Solution:

Excess pressure in drop: $\Delta P = 2S/r$
$\Delta P = (2 \times 4.65 \times 10^{-1})/(3.00 \times 10^{-3}) = 0.93/(3.00 \times 10^{-3}) = 310$ Pa

Pressure inside drop: $P_{inside} = P_a + \Delta P$
$P_{inside} = 1.01 \times 10^5 + 310 = 1.0131 \times 10^5$ Pa

Answer:

- Pressure inside drop = 1.013×10^5 Pa
- Excess pressure = 310 Pa

9.20 Soap Bubble Pressure

Given: r = 5.00 mm, S = 2.50×10^{-2} N/m, depth = 40.0 cm, relative density = 1.20

Solution:

(a) Excess pressure in soap bubble: $\Delta P = 4S/r$ (two surfaces)
$\Delta P = (4 \times 2.50 \times 10^{-2})/(5.00 \times 10^{-3}) = 0.1/(5.00 \times 10^{-3}) = 20$ Pa

(b) Pressure at 40 cm depth:
$P_{outside} = P_a + \rho gh = 1.01 \times 10^5 + (1200 \times 9.8 \times 0.40) = 1.01 \times 10^5 + 4704 = 1.057 \times 10^5$ Pa

Pressure inside bubble: $P_{inside} = P_{outside} + \Delta P = 1.057 \times 10^5 + 20 = 1.0572 \times 10^5$ Pa

Answer:

- Excess pressure = 20 Pa
- Pressure inside submerged bubble = 1.057×10^5 Pa

KEY FORMULAS REFERENCE

Pressure and Hydrostatics

$P = F/A$ (pressure definition)
$P = P_a + \rho gh$ (pressure with depth)
$F_2/F_1 = A_2/A_1$ (hydraulic machines)

Fluid Flow

$A_1v_1 = A_2v_2$ (continuity equation)
$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$ (Bernoulli's equation)
$v = \sqrt{2gh}$ (Torricelli's law)

Viscosity

$\eta = (F/A)/(dv/dy)$ (viscosity definition)
$F = 6\pi\eta av$ (Stokes' law)
$v_t = 2a^2(\rho-\sigma)g/(9\eta)$ (terminal velocity)

Surface Tension

$S = F/(2l)$ (surface tension)
$P_i - P_o = 2S/r$ (drop pressure)
$P_i - P_o = 4S/r$ (bubble pressure)
$h = (2S \cos\theta)/(\rho ga)$ (capillary rise)

Answer Key Complete - All exercise problems solved with detailed explanations and proper reasoning for JEE/NEET preparation.