OCR A A Level Physics: Pressure, density and Archimedes' principle solutions

Matching solutions and teaching prompts for the class review

Specification points covered

- 3.2.1(c) Understand weight of an object, W = mg.
- 3.2.1(d) Define and identify tension, normal contact force, upthrust and friction.
- 3.2.1(e) Draw and interpret free-body diagrams.
- 3.2.4(a) Define density; ρ = m / V.
- 3.2.4(b) Define pressure; p = F / A for solids, liquids and gases.
- 3.2.4(c) Use p = hρg to calculate pressure in fluids; understand upthrust and Archimedes' principle.

Teaching focus

Keep pressure distinct from force; use gauge pressure consistently; insist that Archimedes' principle refers to the weight of fluid displaced; and describe floating equilibrium using equal, opposite forces rather than 'no forces'.

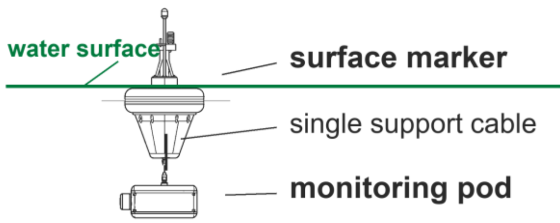


Figure 1

1. Define density. [1 mark]

Answer / mark points: Density is mass per unit volume; ρ = m / V.	
Teacher prompt / common error: Require mass per unit volume. Do not accept 'how heavy something is for its size' as a complete definition.	

2. An aluminium pressure housing has mass 1.62 kg and volume 600 cm³. Calculate its density in kg m⁻³. [2 marks]

Answer / mark points: 600 cm^3 = 600 × 10^{-6} m^3 = 6.00 × 10^{-4} m^3. ρ = 1.62 / (6.00 × 10^{-4}) = 2.70 × 10^3 kg m^{-3}.	
Teacher prompt / common error: The key conversion is 1 cm^3 = 10^{-6} m^3. Density must be reported in kg m^{-3}.	

3. Define pressure and state its SI unit. [2 marks]

Answer / mark points: Pressure is the normal force per unit area; p = F / A. Its SI unit is the pascal, Pa, equivalent to N m^{-2}.	
Teacher prompt / common error: Distinguish pressure from force. The force in p = F / A is normal to the area.	

1. Preparing the equipment continued

4. An equipment case exerts a downward force of 3.60 kN on a rectangular face measuring 0.40 m by 0.30 m. Calculate the pressure exerted on the loading platform. [2 marks]

Answer / mark points: $A = 0.40 \times 0.30 = 0.120\ m^2$ and $F = 3.60 \times 10^3$ N. $p = F / A = 3.60 \times 10^3 / 0.120 = 3.00 \times 10^4$ Pa = 30.0 kPa.

Teacher prompt / common error: Convert kN to N and use the contact area, not the total surface area of the case.

5. The same case is turned onto a 0.60 m by 0.40 m face. Without repeating the full calculation, state how the pressure changes and explain why. [2 marks]

Answer / mark points: The area doubles from $0.120\ m^2$ to $0.240\ m^2$ while the force is unchanged. Because $p = F / A$, the pressure halves to 15.0 kPa.

Teacher prompt / common error: The weight is unchanged. Pressure changes because the same normal force is distributed over a different area.

2. Pressure beneath a liquid surface

6. The top face of the monitoring pod is 6.00 m below the seawater surface. Calculate the gauge pressure due to the seawater at this depth. [1 mark]

Answer / mark points: $p_t$op = $h\rho g = 6.00 \times 1025 \times 9.81 = 6.03 \times 10^4$ Pa = 60.3 kPa.

Teacher prompt / common error: This is gauge pressure due to the seawater only. Atmospheric pressure is not added.

7. The bottom face of the pod is 6.40 m below the surface. Calculate the gauge pressure at the bottom face. [1 mark]

Answer / mark points: $p_b$ottom = $6.40 \times 1025 \times 9.81 = 6.44 \times 10^4$ Pa = 64.4 kPa.

Teacher prompt / common error: Pressure is larger at the greater depth. Keep the quantities in SI units.

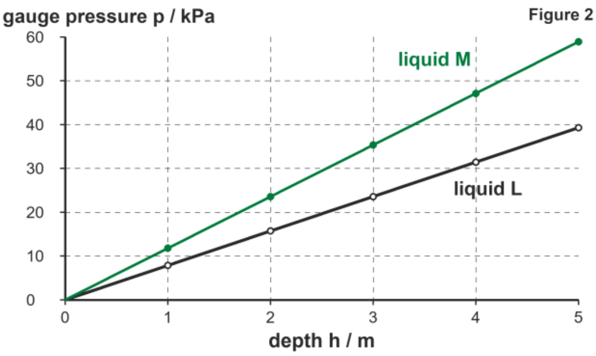
8. Calculate the difference between the gauge pressures on the bottom and top faces of the pod. [1 mark]

Answer / mark points: Δp = $p_b$ottom - $p_t$op = 64 353.6 - 60 331.5 = 4.02×10^3 Pa = 4.02 kPa.

Teacher prompt / common error: Subtract bottom minus top. A pressure difference is not itself a force.

2. Pressure beneath a liquid surface continued

Figure 2



9. Figure 2 shows calibration data for two liquids. Read the gauge pressure in liquid M at a depth of 3.50 m. [1 mark]

Answer / mark points: At h = 3.50 m, the line for M gives p about 41.2 kPa. Accept a value consistent with the graph scale, approximately 41 kPa.
Teacher prompt / common error: Accept sensible interpolation. The line is linear, so a value between marked depths can be read proportionally.

10. Use the line for liquid L in Figure 2 to determine the density of liquid L. [2 marks]

Answer / mark points: Using (0 m, 0 kPa) and (5.00 m, 39.2 kPa), gradient = 39.2 / 5.00 = 7.84 kPa m^{-1} = 7.84×10^3 Pa m^{-1}. Since gradient = ρg, ρ = 7.84×10^3 / 9.81 = 799 kg m^{-3}, approximately 800 kg m^{-3}.
Teacher prompt / common error: Convert the gradient from kPa m^{-1} to Pa m^{-1} before dividing by g.

11. Explain why each line in Figure 2 is straight and passes through the origin. [2 marks]

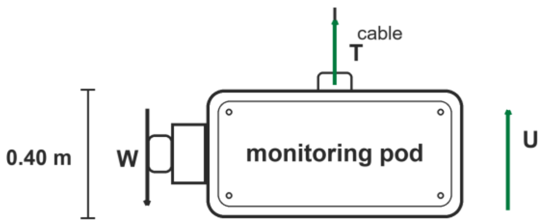
Answer / mark points: For a liquid of constant density and constant g, p = hρg, so gauge pressure is directly proportional to depth and the graph is linear. At the surface h = 0, the pressure due to the liquid is zero, so the line passes through the origin.
Teacher prompt / common error: Preferred language: pressure increases linearly with depth. A quantity increases; it does not 'get more forceful'.

2. Pressure and 3. Upthrust

12. State Archimedes' principle using precise wording. [1 mark]

Answer / mark points: The upthrust on an object in a fluid is equal to the weight of the fluid displaced by the object.
Teacher prompt / common error: The required quantity is the weight of fluid displaced, not its mass, density or volume alone.

Figure 3



mass = 12.0 kg   volume = 8.00×10^{-3} m^3 face area = 0.0200 m^2

top face depth = 6.00 m   bottom face depth = 6.40 m

13. The monitoring pod is stationary and fully submerged. On Figure 3 draw and label the three forces acting on the pod. [2 marks]

Answer / mark points: The three forces are tension T vertically upwards along the cable, upthrust U vertically upwards, and weight W vertically downwards.
Teacher prompt / common error: Velocity and pressure arrows are not forces. T and U act upwards; W acts downwards.

14. The pod has volume 8.00×10^{-3} m^3. Use Archimedes' principle to calculate the upthrust on it in seawater. [1 mark]

Answer / mark points: U = ρVg = 1025 × 8.00 × 10^{-3} × 9.81 = 80.4 N (3 s.f.).
Teacher prompt / common error: For a fully submerged object, displaced-fluid volume equals the object's external volume.

15. The mass of the pod is 12.0 kg. Calculate the tension in the cable while the pod is stationary. [2 marks]

Answer / mark points: W = mg = 12.0 × 9.81 = 117.7 N. Vertical equilibrium gives T + U = W, so T = 117.7 - 80.4 = 37.3 N.
Teacher prompt / common error: Use force equilibrium: two upward forces balance the weight. Do not set tension equal to apparent weight without showing the force balance.

16. Each horizontal face of the pod has area 0.0200 m^2. Use your answer to Question 8 to verify that the difference between the pressure forces on these faces equals the upthrust from Question 14. [2 marks]

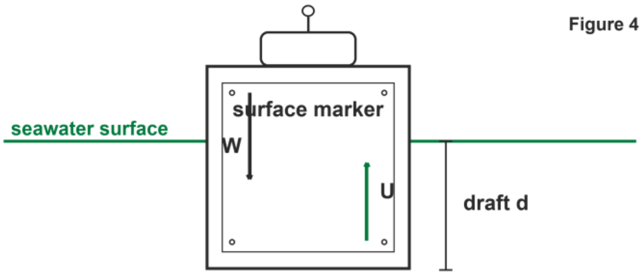
Answer / mark points: $F_b$ottom - $F_t$op = ($p_b$ottom - $p_t$op)A = 4.0221 × 10^3 × 0.0200 = 80.4 N. This equals the Archimedes-principle upthrust; horizontal pressure forces on the side cancel.
Teacher prompt / common error: Pressure acts normal to every surface. Side forces cancel; the larger bottom pressure gives the net upward force.

17. The cable is cut. Drag is negligible at the instant the cable is cut. Calculate the initial acceleration of the pod and state its direction. [2 marks]

Answer / mark points: After the cable is cut, resultant force = W - U = 117.7 - 80.4 = 37.3 N downwards. a = F / m = 37.3 / 12.0 = 3.11 m s^{-2} downwards.
Teacher prompt / common error: At the instant of release the speed is zero, so drag is zero. Upthrust is smaller than weight, giving downward acceleration.

4. Floating equilibrium and design limits

Figure 4



constant cross-sectional area A = 0.120 m^2

18. The surface marker floats at rest. Explain how it can be in equilibrium even though two non-zero forces act on it. [2 marks]

Answer / mark points: Upthrust and weight are both non-zero. They act in opposite directions with equal magnitudes, so the resultant force is zero and the marker has no acceleration.

Teacher prompt / common error: Equilibrium means resultant force is zero, not that no forces act.

19. The unloaded surface marker has mass 78.0 kg and constant horizontal cross-sectional area 0.120 m^2. Use Archimedes' principle to calculate its draft d in seawater. [2 marks]

Answer / mark points: For floating equilibrium, mass of seawater displaced = 78.0 kg. V = m / ρ = 78.0 / 1025 = 0.0761 m^3. d = V / A = 0.0761 / 0.120 = 0.634 m.

Teacher prompt / common error: For a floating body, upthrust = weight, so the mass of fluid displaced equals the marker mass.

20. A 24.0 kg instrument package is fitted inside the marker. Calculate the new draft. [2 marks]

Answer / mark points: Total mass = 78.0 + 24.0 = 102.0 kg. d = m / (ρA) = 102.0 / (1025 × 0.120) = 0.829 m.

Teacher prompt / common error: The cross-sectional area and fluid density are unchanged; the greater total mass requires a greater displaced volume and draft.

21. The maximum safe draft is 0.900 m. Determine the greatest total payload mass that can be added to the unloaded marker. [2 marks]

Answer / mark points: At d = 0.900 m, maximum displaced mass = ρAd = 1025 × 0.120 × 0.900 = 110.7 kg. Maximum payload = 110.7 - 78.0 = 32.7 kg.

Teacher prompt / common error: Find the total mass supported at the limiting draft, then subtract the unloaded marker mass.

22. A pupil says, 'In a denser liquid, the equilibrium upthrust on the same loaded marker must be larger.' Explain why this is incorrect and state how the draft changes. [2 marks]

Answer / mark points: In equilibrium, the upthrust must still equal the unchanged total weight, so it does not become larger. Because U = ρVg, a larger liquid density requires a smaller displaced volume; the draft decreases.

Teacher prompt / common error: The equilibrium upthrust is fixed by the marker's weight. Density changes the displaced volume required to provide it.

Closing review

For a floating object at rest, upthrust equals weight. A change in fluid density changes the displaced volume needed for equilibrium, not the equilibrium value of the upthrust.