

inkPhysics

ANSWER BOOK

Fluids: pressure, upthrust and viscosity

Materials · Year 12

CIE 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.3.6 · OCR A 3.2.4(b), 3.2.4(c)

20 questions · 61 marks

NAVY EDITION

SECTION A · Warm-up

- A1** $p = \rho gh$, where ρ is the density of the fluid, g the gravitational field strength [2]
and h the depth below the surface (1). It does not depend on the shape or width of the container, nor on the total volume of fluid (1).
- A2** $p = \rho gh = 1000 \times 9.81 \times 2.5$ (1) [2]
 $p = 24525 \text{ Pa} \approx 2.5 \times 10^4 \text{ Pa}$ (1)
- A3** Upthrust is the upward force a fluid exerts on a body in it, caused by pressure [2]
on the lower surface exceeding pressure on the upper surface (1). It equals the weight of fluid displaced by the body (1).
- A4** The upthrust must equal the object's weight, i.e. the object displaces its own [2]
weight of fluid before becoming fully submerged (1). This requires the object's average density to be less than (or equal to) the density of the fluid (1).
- A5** Laminar flow is smooth flow in layers that do not mix (1). Turbulent flow is [2]
chaotic, with eddies and mixing between layers, and occurs above a certain flow speed (1).

SECTION B · Standard

- B1** Upthrust = weight of water displaced (1) [3]
 $= \rho Vg = 1000 \times 3.0 \times 10^{-4} \times 9.81$ (1)
 $= 2.9 \text{ N}$ (1)
- B2** $p = \rho gh = 1025 \times 9.81 \times 30$ (1) [3]
 $p = 3.02 \times 10^5 \text{ Pa}$ (1)
Atmospheric pressure acting on the sea surface must be added for the total (1)
- B3** Pressure in a fluid increases with depth, so the pressure on the object's lower [2]
surface is greater than on its upper surface (1). The upward push on the bottom exceeds the downward push on the top, leaving a net upward force (1).
- B4** Floating: $\rho_{\text{ice}} V_{\text{whole}} g = \rho_{\text{water}} V_{\text{sub}} g$ (1) [3]
 $V_{\text{sub}}/V_{\text{whole}} = 920/1000 = 0.92$ (1)
About 92% of the iceberg is submerged (1)
- B5** The sphere must be small and moving slowly enough that the flow around it is [2]
laminar, with no turbulence (1), in a fluid of uniform viscosity (1).

- B6** Top face: $p = \rho gh = 1000 \times 9.81 \times 0.50 = 4905 \text{ Pa}$ (1). Bottom face, at 0.60 m: $p = 1000 \times 9.81 \times 0.60 = 5886 \text{ Pa}$ (1). Resultant force = (pressure difference) $\times$ area = $(5886 - 4905) \times 0.10^2$ (1) = 9.8 N upwards, which is exactly the upthrust, the weight of water displaced (1). (Equal pressures on the vertical faces cancel.) [4]
- B7** The extra upthrust must equal the person's weight: $\rho g A d = 600$ (1). $d = 600 / (1000 \times 9.81 \times 3.0)$ (1) = $0.020 \text{ m} \approx 2.0 \text{ cm}$ (1). [3]
- B8** Upthrust = weight of air displaced = $\rho V g = 1.2 \times 12 \times 9.81 = 141 \text{ N}$ (1). Resultant force = $141 - 90 = 51 \text{ N}$ upwards (1). The balloon accelerates upwards when released (1). [3]

SECTION C · Stretch

- C1** $F = 6\pi\eta r v$ (1) [3]
 $= 6\pi \times 0.25 \times 1.5 \times 10^{-3} \times 0.12$ (1)
 $= 8.48 \times 10^{-4} \text{ N} \approx 8.5 \times 10^{-4} \text{ N}$ (1)
- C2** At terminal velocity, drag = weight - upthrust = $1.8 \times 10^{-4} \text{ N}$ (1) [4]
 From Stokes' law, $v = F / 6\pi\eta r$ (1)
 $v = 1.8 \times 10^{-4} / (6\pi \times 0.85 \times 1.0 \times 10^{-3})$ (1)
 $v = 0.011 \text{ m s}^{-1} \approx 1.1 \times 10^{-2} \text{ m s}^{-1}$ (1)
- C3** $h = p / \rho g = 101000 / (1000 \times 9.81)$ (1) [3]
 $h = 10.3 \text{ m} \approx 10 \text{ m}$ (1)
 Every 10 m of water adds about one atmosphere, so a diver at 20 m experiences roughly three atmospheres in total: two from the water plus one from the air above it (1)
- C4** The sphere must reach terminal velocity before the first mark, or the measured speed is not the steady Stokes' law speed (1); placing the marks deep allows the acceleration phase to finish (1). Viscosity falls steeply as temperature rises, so a result without its temperature cannot be compared with any other (1). [3]
- C5** $V = (4/3)\pi r^3 = (4/3)\pi \times (0.60 \times 10^{-3})^3 = 9.05 \times 10^{-10} \text{ m}^3$ (1). Weight - upthrust = $(\rho_{\text{steel}} - \rho_{\text{oil}}) V g$ (1) = $6880 \times 9.05 \times 10^{-10} \times 9.81 = 6.11 \times 10^{-5} \text{ N}$ (1). At terminal velocity the viscous drag equals this: $6\pi\eta r v = 6.11 \times 10^{-5} \text{ N}$ (1). $v = 6.11 \times 10^{-5} / (6\pi \times 0.30 \times 0.60 \times 10^{-3}) = 0.018 \text{ m s}^{-1}$ (1). [5]
- C6** At steady (terminal) speed, viscous drag = weight - upthrust = $5.7 \times 10^{-4} \text{ N}$ (1). [4]
 From Stokes' law, $\eta = F / (6\pi r v) = 5.7 \times 10^{-4} / (6\pi \times 1.5 \times 10^{-3} \times 9.5 \times 10^{-3})$ (1) = 2.1 Pa s (1). 2.1 Pa s is above 2.0 Pa s , so the batch meets the requirement (1).

- C7** Throughout the fall the sphere's weight acts downwards and a constant upthrust acts upwards; at release the sphere is at rest, so the viscous drag is zero (1). The resultant force (weight - upthrust) acts downwards, so the sphere accelerates downwards (1). As its speed increases, the viscous drag, given by Stokes' law $F = 6\pi\eta r v$, increases in proportion to the speed (1). The resultant force therefore decreases, so the acceleration decreases (1). Eventually weight = upthrust + drag, and the resultant force is zero (1). The acceleration is then zero and the sphere falls at a constant (terminal) velocity (1). [6]
-