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

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SECTION A · Warm-up

A1 $p = \rho gh$, where ρ is the density of the fluid, g the gravitational field strength 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). [2]

A2 $p = \rho gh = 1000 \times 9.81 \times 2.5$ (1)
$p = 24525$ Pa $\approx 2.5 \times 10^4$ Pa (1) [2]

A3 Upthrust is the upward force a fluid exerts on a body in it, caused by pressure on the lower surface exceeding pressure on the upper surface (1). It equals the weight of fluid displaced by the body (1). [2]

A4 The upthrust must equal the object's weight, i.e. the object displaces its own 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). [2]

A5 Laminar flow is smooth flow in layers that do not mix (1). Turbulent flow is chaotic, with eddies and mixing between layers, and occurs above a certain flow speed (1). [2]

SECTION B · Standard

B1 Upthrust = weight of water displaced (1)
$= \rho Vg = 1000 \times 3.0 \times 10^{-4} \times 9.81$ (1)
$= 2.9$ N (1) [3]

B2 $p = \rho gh = 1025 \times 9.81 \times 30$ (1)
$p = 3.02 \times 10^5$ Pa (1)
Atmospheric pressure acting on the sea surface must be added for the total (1) [3]

B3 Pressure in a fluid increases with depth, so the pressure on the object's lower 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). [2]

B4 Floating: $\rho_{ice} V_{whole} g = \rho_{water} V_{sub} g$ (1)
$V_{sub}/V_{whole} = 920/1000 = 0.92$ (1)
About 92% of the iceberg is submerged (1) [3]

B5 The sphere must be small and moving slowly enough that the flow around it is laminar, with no turbulence (1), in a fluid of uniform viscosity (1). [2]

B6 Top face: $p = \rho gh = 1000 \times 9.81 \times 0.50 = 4905$ Pa (1). Bottom face, at 0.60 m: $p = 1000 \times 9.81 \times 0.60 = 5886$ Pa (1). Resultant force = (pressure difference) × 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: $\rho gAd = 600$ (1). $d = 600/(1000 \times 9.81 \times 3.0)$ (1) = 0.020 m ≈ 2.0 cm (1). [3]

B8 Upthrust = weight of air displaced = $\rho Vg = 1.2 \times 12 \times 9.81 = 141$ N (1). Resultant force = 141 - 90 = 51 N upwards (1). The balloon accelerates upwards when released (1). [3]

SECTION C · Stretch

C1 $F = 6\pi\eta rv$ (1) [3]

$= 6\pi \times 0.25 \times 1.5 \times 10^{-3} \times 0.12$ (1)

$= 8.48 \times 10^{-4}$ N ≈ 8.5×10^{-4} N (1)

C2 At terminal velocity, drag = weight - upthrust = 1.8×10^{-4} 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)

$v = 0.011$ m s^{-1} ≈ 1.1×10^{-2} m s^{-1} (1)

C3 $h = p/\rho g = 101000/(1000 \times 9.81)$ (1) [3]

h = 10.3 m ≈ 10 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 $V = (4/3)\pi r^3 = (4/3)\pi \times (0.60 \times 10^{-3})^3 = 9.05 \times 10^{-10}$ m^3 (1). Weight - upthrust = $(\rho_{steel} - \rho_{oil})Vg$ (1) = $6880 \times 9.05 \times 10^{-10} \times 9.81 = 6.11 \times 10^{-5}$ N (1). At terminal velocity the viscous drag equals this: $6\pi\eta rv = 6.11 \times 10^{-5}$ N (1). $v = 6.11 \times 10^{-5}/(6\pi \times 0.30 \times 0.60 \times 10^{-3})$ = 0.018 m s^{-1} (1). [5]

C6 At steady (terminal) speed, viscous drag = weight - upthrust = 5.7×10^{-4} N (1). From Stokes' law, $\eta = F/(6\pi rv) = 5.7 \times 10^{-4}/(6\pi \times 1.5 \times 10^{-3} \times 9.5 \times 10^{-3})$ (1) = 2.1 Pa s (1). 2.1 Pa s is above 2.0 Pa s, so the batch meets the requirement (1). [4]

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 $F = 6\pi\eta rv$, 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]