Unit 3 · Fluid Mechanics

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 32

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the error

ANSWER U · 3

A film has **two** surfaces, front and back, and each pulls on the wire with T per unit length. So F = 2TL $= 2 \times 0.030 \times 0.050 = \mathbf{3.0 \times 10^{-3}\ N}$.

MARKING SCHEME

- ✓ The mistake: only one surface counted.
- ✓ A film has two surfaces, so F = 2TL.
- ✓ $F = 3.0 \times 10^{-3}$ N.

2 A real setting

ANSWER A · 3

i. $h\rho g = 12 \times 1000 \times 9.8 = \mathbf{1.18 \times 10^5\ Pa}$, more than one atmosphere above the air's pressure.

ii. Torricelli: $v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 12)} = \mathbf{15\ m/s}$.

MARKING SCHEME

- ✓ Gauge pressure $h\rho g$.
- ✓ 1.18×10^5 Pa.
- ✓ $v = \sqrt{(2gh)} = 15$ m/s.

3 Predict, then explain

ANSWER HA · 3

Prediction: it **doesn't overflow** (the level stays the same).

The floating ice displaces its own weight of water. When it melts it becomes water of exactly that weight, which takes up exactly the volume of the water it was displacing. For a cube of volume V: the part under water is 0.92V, and the melted ice has mass 920V kg, which as water fills 920V ÷ 1000 = 0.92V: the hole it leaves is exactly filled.

MARKING SCHEME

- ✓ Prediction: the level stays the same.
- ✓ Floating ice displaces its own weight of water.
- ✓ The melted ice is that same weight of water, so it fills exactly the volume displaced (0.92V each).

4 Show that

ANSWER A · 3

Mass lifted $m = (\text{volume}) \times \rho = \pi r^2 h\rho = \pi r^2 \rho \times \dfrac{2T\cos\theta}{r\rho g} = \dfrac{2\pi r T\cos\theta}{g}$, which is proportional to r.

So the **wide** tube holds up more water, though to a smaller height: the weight held up equals the upward pull of the surface, $T\cos\theta$ round the rim, whose length $2\pi r$ grows with r.

MARKING SCHEME

- ✓ $m = \pi r^2 h\rho$.
- ✓ Substituting h gives $m = 2\pi r T\cos\theta / g \propto r$.
- ✓ The wider tube lifts more water (to a smaller height).

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5 Check the claim

ANSWER HA · 4

i. **No.** From 1.0 mm to 2.0 mm the velocity goes from 1.09 to 4.36 mm/s, four times; from 2.0 to 4.0 mm, 4.36 to 17.4, four times again.

ii. v/r^2 is the same each time (1.09, 1.09, 1.09, 1.09 mm/s per mm^2): $v \propto r^2$, as Stokes' law gives.

iii. $\eta = \dfrac{2r^2(\rho - \sigma)g}{9v} = \dfrac{2 \times (3.0 \times 10^{-3})^2 \times 1200 \times 9.8}{9 \times 9.80 \times 10^{-3}} = \mathbf{2.4\ Pa\ s}$.

MARKING SCHEME

- ✓ He is wrong: doubling r makes v four times.
- ✓ v/r^2 is constant, so $v \propto r^2$.
- ✓ $\eta = 2r^2(\rho - \sigma)g/(9v)$.
- ✓ $\eta = 2.4$ Pa s.

6 Estimate it

ANSWER A · 3

By continuity, the speed falls in proportion as the total area grows: $v = 30 \div 700 \approx 0.043$ cm/s, about **0.4 mm/s**.

So slow a flow gives the blood time to exchange oxygen and food with the cells as it passes.

MARKING SCHEME

- ✓ Continuity: $v \propto 1/A$.
- ✓ About 0.4 mm/s.
- ✓ Slow flow gives time for exchange with the cells.

7 Correct the misconceptions

ANSWER U · 3

1. The pressure at the base, $P_0 + h\rho g$, depends only on the depth and the density, not on the amount of water: it is the same in both.
2. Heating a gas makes it more viscous; only a liquid's viscosity falls with heating.
3. Nothing makes the two streams meet: the air over the top arrives at the back edge before the air below. The wing's shape and tilt make the air above move faster (lower pressure), and the wing turns the air downwards.

MARKING SCHEME

- ✓ Pressure depends on depth and density, not the amount of liquid.
- ✓ A gas's viscosity rises with temperature.
- ✓ "Equal transit time" is wrong: the top air arrives first; shape and tilt speed it up and turn the air down.

8 What if?

ANSWER A · 2

$V \propto r^4$. The new radius is 0.84r, so the flow is $0.84^4 = \mathbf{0.50}$ of what it was: about **halved**, by a narrowing of only 16%.

MARKING SCHEME

- ✓ $V \propto r^4$.
- ✓ $0.84^4 \approx 0.50$: the flow is about halved.

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9 Design it

ANSWER HA · 4

Measure the radius r of a small steel ball, and the densities ρ of the steel and σ of the honey. Drop the ball into a tall jar of honey and time it between two marks a known distance apart, well below the surface, to find its terminal velocity v. Then $\eta = \dfrac{2r^2(\rho - \sigma)g}{9v}$.

Start timing well below the surface because the ball speeds up at first; only once it moves at a steady speed does F + U = W hold. The jar should be tall, so there is room to reach terminal velocity and a long distance to time, and wide, because Stokes' law is for a sphere in fluid stretching far around it (near the walls the drag is larger). Keep the honey's temperature steady, since its viscosity changes quickly with temperature.

MARKING SCHEME

- ✓ Measure r, ρ, σ and the terminal velocity v (distance ÷ time between marks).
- ✓ $\eta = 2r^2(\rho - \sigma)g/(9v)$.
- ✓ Time only after the ball has reached terminal velocity.
- ✓ Tall jar for a long steady stretch, wide jar so the walls don't add drag (temperature kept steady).

10 Think

ANSWER HA · 2

The water between the boats is squeezed through a narrow gap and moves faster past them than the water on their outer sides. By Bernoulli's principle its pressure is lower, so the greater pressure on the outer sides pushes the boats together.

MARKING SCHEME

- ✓ The water between them moves faster.
- ✓ Lower pressure between them, so the outer water pushes them together.

11 Make your own

ANSWER HA · 2

The car's weight is $1500 \times 9.8 = 14\,700$ N, so $A_2/A_1 = 14\,700 \div 300 = \mathbf{49}$. For example, a small piston of 5 cm^2 and a large one of 245 cm^2 (any pair with the large area at least 49 times the small).

MARKING SCHEME

- ✓ A_2/A_1 = weight ÷ effort = 49.
- ✓ A suitable pair of areas in that ratio.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **The Rock That Floats** (exhibit): Pumice floats because its trapped gas bubbles make its average density less than water's: it sinks only until the upthrust equals its weight.
- **Galileo Thermometer** (exhibit): Each sealed bulb floats or sinks by Archimedes' principle: as the warming liquid's density falls, so does each bulb's upthrust, and they sink one by one.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	11	15	**32**

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