# Past-paper walk-through

## Density and pressure ▪ 4.3

eXercise

# Questions in this set

- 9702/11 N25 Q16 ▪ 1 mark
- 9702/12 N25 Q15 ▪ 1 mark
- 9702/12 N25 Q16 ▪ 1 mark
- 9702/14 N25 Q12 ▪ 1 mark
- 9702/21 N25 Q2 ▪ 12 marks
- 9702/11 J25 Q14 ▪ 1 mark
- 9702/11 J25 Q16 ▪ 1 mark
- 9702/12 J25 Q14 ▪ 1 mark
- 9702/13 J25 Q13 ▪ 1 mark
- 9702/14 J25 Q13 ▪ 1 mark

## Questions in this set

- 9702/12 M25 Q10 ▪ 1 mark
- 9702/21 N24 Q1 ▪ 7 marks

# Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

# Question 16

9702/11 N25 ▪ Q16 ▪ 1 mark

The formula for the upthrust on a block of wood partially submerged in water is shown.

$$F = \rho g V$$

What do the symbols $\rho$ and $V$ represent? **[1]**

**A** $\rho$: density of water; $V$: volume of whole block

**B** $\rho$: density of water; $V$: volume of block below surface of water

**C** $\rho$: density of wood; $V$: volume of whole block

**D** $\rho$: density of wood; $V$: volume of block below surface of water

# Question 16

| | $\rho$ | $V$ |
|---|---|---|
| **A** | density of water | volume of whole block |
| **B** | density of water | volume of block below surface of water |
| **C** | density of wood | volume of whole block |
| **D** | density of wood | volume of block below surface of water |

# Solution 16

- **A** $\rho$: density of water; $V$: volume of whole block
- **B** $\rho$: density of water; $V$: volume of block below surface of water ✓
- **C** $\rho$: density of wood; $V$: volume of whole block
- **D** $\rho$: density of wood; $V$: volume of block below surface of water

## Why

- Upthrust equals the weight of fluid displaced, so $\rho$ is the density of the water, not the wood.
- Only the submerged part displaces anything, so $V$ is the volume below the surface.
- The wood's density decides how deep it floats, but it does not appear in this formula.

# Question 15

9702/12 N25 ▪ Q15 ▪ 1 mark

The mass and volume of an object are varied.

Which two changes, when made together, **must** increase the density of the object? **[1]**

**A** decrease mass, decrease volume

**B** decrease mass, increase volume

**C** increase mass, decrease volume

**D** increase mass, increase volume

# Question 15

| | mass | volume |
|---|---|---|
| **A** | decrease | decrease |
| **B** | decrease | increase |
| **C** | increase | decrease |
| **D** | increase | increase |

# Solution 15

**A** decrease mass, decrease volume

**B** decrease mass, increase volume

**C** increase mass, decrease volume ✓

**D** increase mass, increase volume

## Why

- Density is $m/V$, so it rises when the mass rises or the volume falls.
- Increasing the mass while decreasing the volume does both, so the density must increase.
- B moves both the wrong way; with A and D the result depends on which change is larger.

# Question 16

9702/12 N25 ▪ Q16 ▪ 1 mark

On Earth, a solid object that is fully submerged in a liquid experiences an upthrust $U_E$. On Mars, the same object, fully submerged in the same liquid, experiences an upthrust $U_M$.

The acceleration of free fall on Mars is $3.7$ m s$^{-2}$.

Assume that the liquid's density and the object's volume have the same values on Earth and Mars.

What is the ratio $\frac{U_M}{U_E}$? **[1]**

**A** 0.38

**B** 1.0

**C** 2.7

# Question 16

**D** 3.6

# Solution 16

**A** 0.38 ✓

**B** 1.0

**C** 2.7

**D** 3.6

## Why

- Upthrust is $\rho g V$, and both the density and the volume are unchanged, so it simply follows $g$.
- $U_M/U_E = g_M/g_E = 3.7/9.81 = 0.38$.
- C is the same ratio the other way up, $9.81/3.7 = 2.7$.

# Question 12

9702/14 N25 ▪ Q12 ▪ 1 mark

The diagram shows a stationary sphere that is just fully submerged in a liquid. The radius of the sphere is $r$ and the density of the liquid is $\rho$. The acceleration of free fall is $g$.

The air exerts pressure $P_{\mathrm{A}}$ on the surface of the liquid.

What is the pressure at the lowest point of the sphere? **[1]**

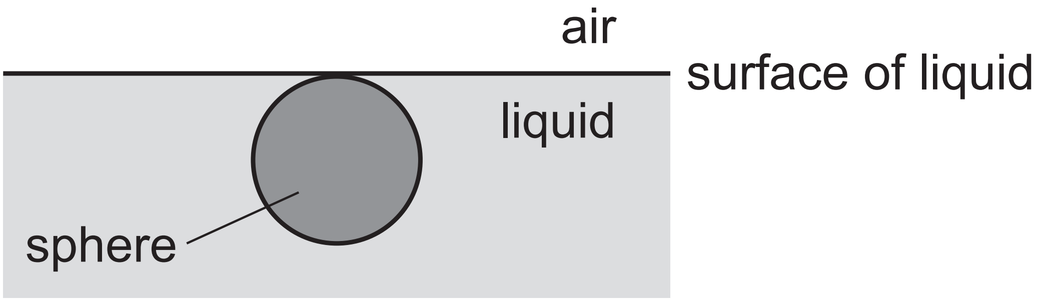
**A** $P_{\mathrm{A}} + \frac{4}{3}\pi r^3 \rho g$

**B** $P_{\mathrm{A}} - \frac{4}{3}\pi r^3 \rho g$

**C** $2r\rho g + P_{\mathrm{A}}$

**D** $2r\rho g - P_{\mathrm{A}}$

# Question 12



# Solution 12

**A** $P_{\mathrm{A}} + \frac{4}{3}\pi r^3 \rho g$

**B** $P_{\mathrm{A}} - \frac{4}{3}\pi r^3 \rho g$

**C** $2r\rho g + P_{\mathrm{A}}$ ✓

**D** $2r\rho g - P_{\mathrm{A}}$

## Why

- "Just fully submerged" puts the top of the sphere level with the liquid surface.
- Its lowest point is therefore a depth $2r$ below the surface.
- $p = P_A + \rho g(2r)$ – the air pressure plus the weight of the liquid column above.

# Question 2

9702/21 N25 ▪ Q2 ▪ 12 marks

**(a)(i)** Define pressure. **[1]**

**(a)(ii)** Explain how hydrostatic pressure results in an upthrust force acting on a solid object immersed in a liquid. **[2]**

**(b)(i)** On Fig. 2.1, draw labelled arrows from the ball to show the directions of the three forces that act on the ball as it falls. **[3]**

**(b)(ii)** Determine the SI base units of $\eta$. **[2]**

**(c)(i)** Show that the upthrust force acting on the ball is $2.8 \times 10^{-3}$ N. **[1]**

**(c)(ii)** Determine the terminal speed $v$ of the ball. **[3]**

# Solution 2

## (a)(i)

**Mark scheme**

- (normal) force per (unit cross-sectional) area **B1**

# Solution 2

## (a)(ii)

**Mark scheme**

- (due to difference in depth there is a) difference in pressure between top and bottom (of ball) **B1**
- (due to pressure difference, upwards) force on bottom of ball is greater
- (than downwards force on top of ball, so resultant force is upwards) **B1**

# Solution 2

## (b)(i) Worked steps

Three forces, and only three — do not add a “reaction”.

- **Weight**, vertically downwards.
- **Upthrust**, vertically upwards (the liquid pushes harder on the bottom than the top).
- **Viscous drag**, vertically upwards — it opposes the motion, and the ball is falling.

# Solution 2

Label each arrow with its name.

## Mark scheme

- arrow vertically downwards labelled ‘weight’ **B1**
- arrow vertically upwards labelled ‘upthrust’ **B1**
- arrow vertically upwards labelled ‘(viscous) drag’ **B1**

# Solution 2

## (b)(ii) Worked steps

Get the base units of the drag force first, then divide them out.

- Force in base units: $\mathrm{N} = \mathrm{kg\ m\ s}^{-2}$.
- Rearranging $D = 6\pi\eta rv$ gives $\eta = \dfrac{D}{6\pi rv}$; the $6\pi$ is a pure number.
- Units: $\dfrac{\mathrm{kg\ m\ s}^{-2}}{\mathrm{m} \times \mathrm{m\ s}^{-1}}$
- $\eta$ has base units $\mathrm{kg\ m}^{-1}\ \mathrm{s}^{-1}$

# Solution 2

**Mark scheme**

- SI base units of D: kg m s–2 **C1**
- base units of $\eta$: kg m s–2 / (m $\times$ m s–1)
- $=$ kg m–1 s–1 **A1**

# Solution 2

## (c)(i) Worked steps

Upthrust is the weight of liquid displaced, and the ball is a sphere.

- $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(4.2 \times 10^{-3})^3 = 3.10 \times 10^{-7}\ \mathrm{m}^3$
- $U = \rho_{\text{liquid}} V g = 920 \times 3.10 \times 10^{-7} \times 9.81$
- $U = 2.8 \times 10^{-3}$ N, as required.

# Solution 2

## Mark scheme

- upthrust $= 920 \times (4\ /\ 3) \times \pi \times (4.2 \times 10–3)3 \times 9.81 = 2.8 \times 10–3$ (N) **A1**

# Solution 2

## (c)(ii) Worked steps

At terminal speed the ball stops accelerating, so the three forces balance.

- Upwards = downwards: $U + D = W$, so $D = W - U$.
- $W = 2.4 \times 10^{-3} \times 9.81 = 2.35 \times 10^{-2}$ N, so
  $D = 2.35 \times 10^{-2} - 2.8 \times 10^{-3} = 2.07 \times 10^{-2}$ N.
- $D = 6\pi\eta r v$, so $v = \dfrac{D}{6\pi\eta r} = \dfrac{2.07 \times 10^{-2}}{6\pi \times 4.7 \times 4.2 \times 10^{-3}}$
- $v = 0.056$ m s$^{-1}$

# Solution 2

## Mark scheme

- weight $=$ drag $+$ upthrust **C1**
- $(2.4 \times 10–3 \times 9.81) = (2.8 \times 10–3) + (6\pi \times 4.7 \times 4.2 \times 10–3 \times v)$ **C1**
- $v = 0.056$ m s–1 **A1**

# Question 14

9702/11 J25 ▪ Q14 ▪ 1 mark

A uniform cylinder of weight $25.0$ N is suspended from a newton meter.
The cylinder is fully submerged in water, as shown.
The reading on the newton meter is $10.0$ N.
The water is replaced by a liquid with a density 10% greater than the density of water.
The cylinder remains fully submerged.
What is the new reading on the newton meter? **[1]**

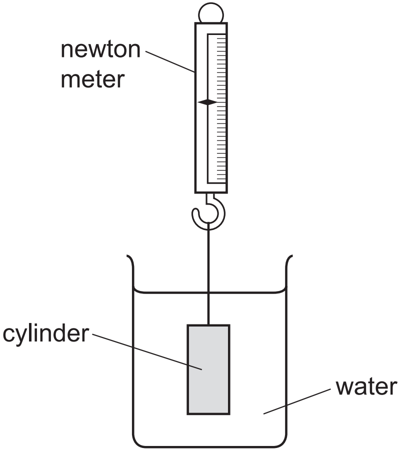
**A** $8.5$ N

**B** $9.0$ N

**C** $11.0$ N

**D** $11.5$ N

# Question 14



# Solution 14

**A** $8.5$ N ✓

**B** $9.0$ N

**C** $11.0$ N

**D** $11.5$ N

## Why

- In water the upthrust is $25.0 - 10.0 = 15.0$ N.
- Upthrust is proportional to the liquid's density, so it becomes $15.0 \times 1.10 = 16.5$ N.
- The meter then reads $25.0 - 16.5 = 8.5$ N.

# Question 16

9702/11 J25 ▪ Q16 ▪ 1 mark

A submarine is at a depth of $130$ m below the surface of the sea.
The pressure on the submarine due to the sea water is $p$.
The submarine sinks to a depth of $260$ m below the surface.
Assume that the density of sea water is constant.
What is the **difference** between the pressures on the submarine due to the sea water at the two depths? **[1]**

**A** $0$

**B** $0.5p$

**C** $p$

**D** $2p$

# Solution 16

**A** $0$

**B** $0.5p$

**C** $p$ ✓

**D** $2p$

## Why

- The pressure due to the water is $\rho gh$, so it is proportional to the depth.
- Doubling the depth from $130$ m to $260$ m doubles it, to $2p$.
- The difference between the two depths is $2p - p = p$.

# Question 14

9702/12 J25 ▪ Q14 ▪ 1 mark

A wooden block is held stationary in a container of water using a string that is attached to both the wooden block and the bottom of the container.
The wooden block has mass $m$ and volume $V$. The water has density $\rho$. The acceleration of free fall is $g$.
What is the magnitude of the force acting on the block due to the tension in the string? **[1]**

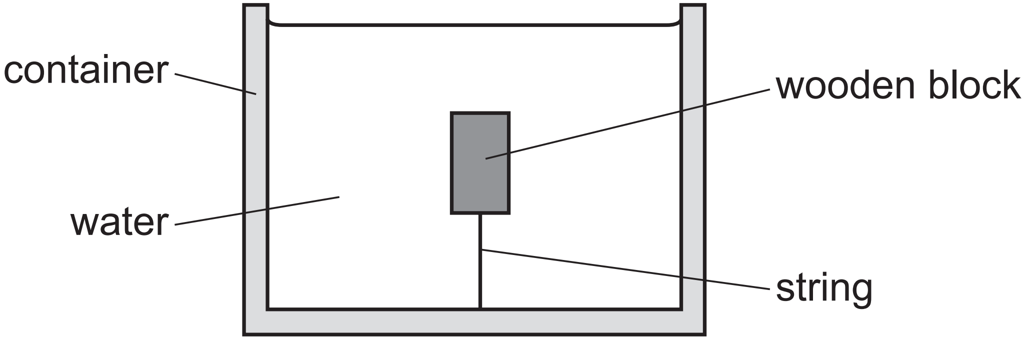
**A** $\rho g V$

**B** $mg + \rho g V$

**C** $mg$

**D** $\rho g V - mg$

# Question 14



# Solution 14

**A** $\rho g V$

**B** $mg + \rho g V$

**C** $mg$

**D** $\rho g V - mg$ ✓

**Why**

- Fully submerged, the block feels an upthrust $\rho g V$ upwards.
- The string holds it down, so the three forces balance: $\rho g V = mg + T$.
- $T = \rho g V - mg$, which is positive precisely because the block would otherwise float.

# Question 13

9702/13 J25 ▪ Q13 ▪ 1 mark

**13** What is the definition of density?

**A** mass of one cubic metre

**B** mass of a unit volume

# Question 13

**C** mass per cubic metre

**D** mass per unit volume

# Solution 13

Answer: **D**

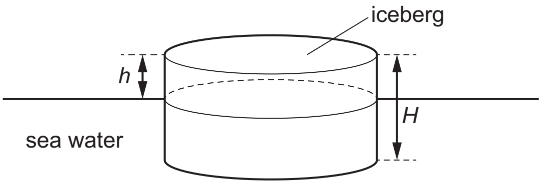
## Why

- Density is defined as mass per unit volume, $\rho = m/V$.
- "Per unit volume" makes it a ratio, so the value does not depend on the units chosen.
- A and C tie the definition to one particular volume instead.

# Question 13

9702/14 J25 ▪ Q13 ▪ 1 mark

**13** A cylindrical iceberg of height $H$ floats in sea water. The top of the iceberg is at height $h$ above the surface of the water.




The density of ice is $\rho_i$ and the density of sea water is $\rho_w$.

What is the height $h$ of the iceberg above the sea water?

# Question 13

**A** $\left(1-\frac{\rho_{\mathrm{i}}}{\rho_{\mathrm{w}}}\right)H$ **B** $\left(\frac{\rho_{\mathrm{i}}}{\rho_{\mathrm{w}}}-1\right)H$ **C** $\frac{\rho_{\mathrm{w}}}{\rho_{\mathrm{i}}}H$ **D** $\frac{\rho_{\mathrm{i}}}{\rho_{\mathrm{w}}}H$

# Solution 13

Answer: **A**

**Why**

- Floating means weight equals upthrust: $\rho_i AHg = \rho_w A(H - h)g$.
- The cross-sectional area cancels, leaving $H - h = (\rho_i/\rho_w)H$.
- So $h = H(1 - \rho_i/\rho_w)$.

# Question 10

9702/12 M25 ▪ Q10 ▪ 1 mark

**10** An object is fully submerged in a liquid.

A student determines the ratio $\dfrac{\text{upthrust acting on the object}}{\text{weight of the object}}$.

Which single change would double the value of this ratio?

**A** Use a different liquid that has twice the density and the same volume as the original liquid.

**B** Use a different object that has half the volume and the same density as the original object.

**C** Use a different object that has twice the density and the same volume as the original object.

**D** Use a different object that has twice the volume and the same density as the original object.

# Solution 10

Answer: **A**

**Why**

- Fully submerged, the upthrust is $\rho_{\text{liquid}} g V$ and the weight is $\rho_{\text{object}} g V$ – the same $V$.
- The ratio is therefore just $\rho_{\text{liquid}}/\rho_{\text{object}}$; the volume cancels entirely.
- Doubling the liquid's density doubles it, while B changes nothing and C halves it.

# Question 1

9702/21 N24 ▪ Q1 ▪ 7 marks

1 (a) Define density [1]

(b) Fig. 1.1 shows a cuboidal glass block. z x y Fig. 1.1 (not to scale)

A student measures the mass m of the block and the side lengths x, y and z. The measurements are shown in Table 1.1. Table 1.1 quantity measurement m $(0.243 \pm 0.001)$ kg x $(5.41 \pm 0.01)$ cm y $(11.09 \pm 0.01)$ cm z $(1.62 \pm 0.01)$ cm , ,

(i) Determine the density of the glass.

density = kg m–3 [2]

(ii) Calculate the percentage uncertainty in the density.

percentage uncertainty = % [3]

(c) The true value of the density of the glass is different from the answer in (b)(i) because of a systematic error in the measurements.

Suggest one possible cause of this systematic error [1]

# Question 1

, ,

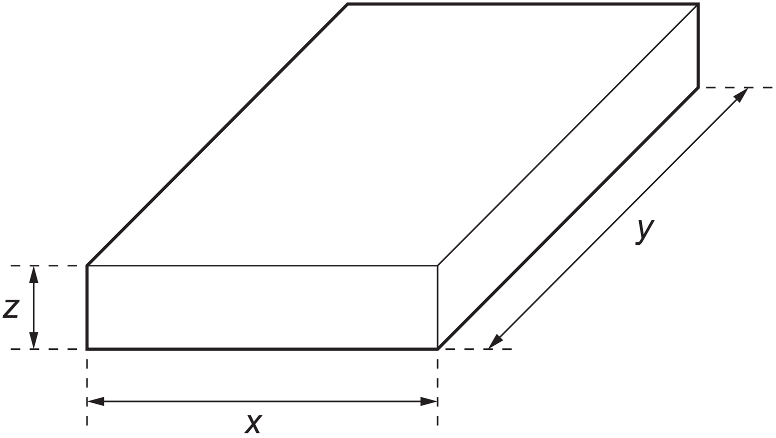
**(a)** Define density. **[1]**

**(b)(i)** A student measures the mass $m$ of a cuboidal glass block and its side lengths $x$, $y$ and $z$: $m = (0.243 \pm 0.001)$ kg, $x = (5.41 \pm 0.01)$ cm, $y = (11.09 \pm 0.01)$ cm, $z = (1.62 \pm 0.01)$ cm. Determine the density of the glass. **[2]**

**(b)(ii)** Determine the percentage uncertainty in the density. **[3]**

**(c)** State one source of systematic error in this experiment. **[1]**

# Question 1



# Question 1

| quantity | measurement |
|---|---|
| $m$ | $(0.243 \pm 0.001)\,\mathrm{kg}$ |
| $x$ | $(5.41 \pm 0.01)\,\mathrm{cm}$ |
| $y$ | $(11.09 \pm 0.01)\,\mathrm{cm}$ |
| $z$ | $(1.62 \pm 0.01)\,\mathrm{cm}$ |

# Solution 1

## (a)

**Mark scheme**

- mass per unit volume

# Solution 1

## (b)(i) Worked steps

Convert every length to metres **before** multiplying — this is where most marks are lost.

- $x = 0.0541$ m, $y = 0.1109$ m, $z = 0.0162$ m
- $V = xyz = 0.0541 \times 0.1109 \times 0.0162 = 9.72 \times 10^{-5}\ \text{m}^3$
- $\rho = \dfrac{m}{V} = \dfrac{0.243}{9.72 \times 10^{-5}}$
- $\rho = 2500\ \text{kg m}^{-3}$

# Solution 1

**Mark scheme**

- density $= 0.243 / (0.0541 \times 0.1109 \times 0.0162)$
- $=$ 2500 kg m–3

# Solution 1

## (b)(ii) Worked steps

Density is a product and quotient of four measured quantities, so **add** their percentage uncertainties. Each length appears once, so each counts once.

- $\dfrac{0.001}{0.243} = 0.41\%$
- $\dfrac{0.01}{5.41} = 0.18\%$
- $\dfrac{0.01}{11.09} = 0.09\%$
- $\dfrac{0.01}{1.62} = 0.62\%$
- Total $\approx 1.3\%$

# Solution 1

Notice which term dominates: the **shortest** length, because the same 0.01 cm is a bigger share of it. That is the measurement to improve.

**Mark scheme**

- (0.001 / 0.243) or (0.01 / 5.41) or (0.01 / 11.09) or (0.01 / 1.62)
- $(\Delta\rho\,/\,\rho) = (\Delta\mathrm{m}\,/\,\mathrm{m}) + (\Delta\mathrm{x}\,/\,\mathrm{x}) + (\Delta\mathrm{y}\,/\,\mathrm{y}) + (\Delta\mathrm{z}\,/\,\mathrm{z})$
- $= (0.001\,/\,0.243) + (0.01\,/\,5.41) + (0.01\,/\,11.09) + (0.01\,/\,1.62)$
- $( = 0.013)$
- percentage uncertainty in $\rho = 0.013 \times 100$
- $= 1.3\%$ (allow 1 s.f. answer of 1%)

# Solution 1

**(c)**

## Worked steps

A systematic error shifts every reading the same way, so it is not fixed by repeating.

- A **zero error** on the calipers or the balance, or
- incorrect **calibration** of either instrument.

## Mark scheme

- zero error (on calipers / balance)
- or
- incorrect calibration (of calipers / balance)
- 9702/21
- October/November 2024