Topic 2 Materials
2A Fluids

2A.1 Fluids, density and upthrust

1 1265 kg m^{-3}

2 (a) 1300 kg m^{-3}

(b) 1.3 g cm^{-3}

3 Students' own answers. Volume estimate is likely to be length × width × height in rectangular room, and then multiply by density value of 1.2 from table A to give mass.

4 (a) 0.40 N

(b) 0.042 N downwards

(c) There is a resultant downwards force, so it will accelerate to the bottom (Newton's first law). There, an additional reaction force (Newton's third law) from the bed of the stream will cause a net force of zero so the ball will rest on the bottom stationary (Newton's first law). Extra: initially on reaching the bottom the upwards reaction will be slightly greater to decelerate to rest. Students may also comment on drag forces affecting the rate of acceleration during descent (Newton's second law).

5 1.59 N

6 Students' own answers, using rectangular volume, V = width × depth × height, and density = $\frac{m}{V}$:

e.g. estimated height is 1.7 m; estimated width is 40 cm; estimated depth is 20 cm; estimated mass is 75 kg

$V = wdh = 0.4 \times 0.2 \times 1.7 = 0.136\ m^3$

$\rho = \frac{m}{V} = \frac{75}{0.136} = 550\ kg\ m^{-3}$

Alternative route: The body is mostly water, and humans float, so density must be slightly less than water: estimate $\rho = 900\ kg\ m^{-3}$.

2A.2 Fluid movement

1 Students' own answers

2 Students' own diagrams; streamline flow should have parallel streamlines, while turbulent flow should have uneven flow lines and eddies

3 'At any point' the speed must remain the same over time, but the smoke can move faster or slower as it needs to in order to move over the shape of the car. So, whilst it may move faster up the windscreen than over the roof, at each of those points the speed will be constant over time.

4 Left picture: water surface is smooth, because the flow is laminar, as the water is moving slowly

Right picture: water surface is disturbed in a random/unpredictable way, as the flow is turbulent as the water is moving fast past the bridge supports.

2A.3 Viscosity

1 Water viscosity causes greater drag than air

2 Higher temperature causes reduced liquid viscosity but increases gas viscosity

3 Reduced viscosity would allow greater speeds

4 Decreased viscosity would enable faster flow of liquid chocolate, so faster production

5 Depends on students' own best-fit line, approximate gradient is 1.95×10^{-5}, giving an approximate viscosity of 1.6×10^{-3} Pa s, compared with 20 °C figure in table B of 1.0×10^{-3} Pa s. Answers should discuss possible sources of error to cause this difference.

2A.4 Terminal velocity

1 $F = 1.88 \times 10^{-3}$ N

2 It is not a uniform or small object, and is not likely to fall slowly. Stokes' law does not apply.

3 (a) 3.8×10^9 m s^{-1}

(b) 5.97×10^7 m s^{-1}

(c) Have used Stokes' law, though the answers clearly show that this object is too large and moving too fast for Stokes' law to apply – answer to (a) is faster than the speed of light. Also assumed: viscosity of air at 20 ºC, density of water = 1000 kg m^{-3}.

4 Students' own answers:

e.g. the cat is larger than a golf ball and smaller than a human, so its terminal velocity should be between their terminal velocities: estimate v_{term} = 40 m s^{-1}

5 (a) (i) Volume increases for the same mass, so density reduces with increasing temperature

(ii) Volume increases for the same mass, so density reduces with increasing temperature

(b) Density reduction by glycerine is likely to be more than for the metal of the ball bearing, so upthrust would reduce, likely by only a small amount

(c) Glycerine viscosity falls rapidly with increasing temperature

(d) Stokes' law includes both density comparisons and viscosity. The change in relative densities is likely to be small, but the change in viscosity is much more significant. The gradient is inversely proportional to viscosity, so would increase significantly across the various temperatures used.

(e) The change in viscosity for water is very small, so the differences in terminal velocity, and hence gradient on the graphs, are likely to be imperceptible.

2A Exam practice

1 B

2 C

3 C

4 B

5 C

6 (a) (i) Laminar: at least two roughly parallel lines before object

Turbulent: lines crossing or showing change in direction of greater than 90°

Laminar flow lines should lead directly to turbulent flow lines

Laminar flow lines should continue until they reach the peak of the obstruction

(ii) Laminar flow:

No abrupt change in velocity of flow

OR no abrupt change in speed or direction of flow (must mention both speed and direction)

OR velocity at a point is constant OR flows in layers / flowlines / streamlined

OR layers do not mix / cross OR layers are parallel

Turbulent flow:

Mixing of layers / flowlines / streamlines OR crossing of layers, etc. OR contains eddies

OR contains vortices / whirlpools OR abrupt / random changes in speed or direction

(b) (i) Greater velocity with lower viscosity

(ii) Lower viscosity so faster flow OR greater velocity

7 Viscosity of the oil decreases at higher temperature, so the rate of flow increases and the oil spreads more quickly.

8 (a) (i) Laminar flow:

No abrupt changes in direction or speed of flow OR air flows in layers / flowlines / streamlines OR no mixing of layers OR layers remain parallel OR velocity at a (particular) point remains constant

Turbulent flow:

Mixing of layers OR contains eddies / vortices OR abrupt random changes in speed or direction

(ii) Relative speed of upper surface of ball to air is greater (than at lower surface) OR the idea that the direction of movement at the top (due to spin) is opposite to / against (direction of) air flow

(b) The ball is applying an upward force on the air, so there must be an equal and opposite force on the ball downwards.

(c) (i) Time = $\frac{2.7}{31}$ = 0.087 s

$s = \frac{1}{2} \times 9.81\ \text{m s}^{-2} \times (0.087\ \text{s})^2$

= 0.037 (m)

(ii) (Extra) downwards force (on the ball)

Greater downwards acceleration

Greater distance fallen OR drops further (in that time) OR needs to drop 15 cm; 4 cm drop not enough

9 (a) (i) Upthrust / U

Weight / W / mg / gravitational force / force due to gravity

(Viscous) drag / fluid resistance / friction / F / D / V

(ii) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate and including the following points:

Initially viscous drag = 0 OR viscous drag is very small

OR resultant force is downwards OR $W > U$ OR $W > U + D$

Viscous drag increases until forces balanced OR resultant / net force zero OR forces in equilibrium

therefore, no acceleration

(iii) $W = U + D$

(b) (i) Mass = $1.0 \times 10^3\ \text{kg m}^{-3} \times 2.1 \times 10^{-9}\ \text{m}^3$

= 2.1×10^{-6} kg

Upthrust = $2.1 \times 10^{-6}\ \text{kg} \times 9.81\ \text{N kg}^{-1}$

= 2.1×10^{-5} N

(ii) $F = 5.7 \times 10^{-5}\ \text{N} - 2.1 \times 10^{-5}\ \text{N} = 3.6 \times 10^{-5}\ \text{N}$

$$v = \frac{3.6 \times 10^{-5}\ \text{N}}{6\pi\eta r}$$

$$v = \frac{3.6 \times 10^{-5}\ \text{N}}{6 \times \pi \times 1.2 \times 10^{-3} \times 8 \times 10^{-4}}$$

$v = 2.0\ \text{m s}^{-1}$

(c) Viscous drag varies in proportion to radius (or area in proportion to radius squared) but weight varies in proportion to radius cubed. Therefore, terminal velocity is proportional to radius squared.

10 Award 1 mark for (QWC) quality of written communication.

Award a maximum of 5 marks from the following expected answer points:

Stone's weight is greater than upthrust

Upthrust is equal to the weight of water displaced, which equals the volume of the stone times the density of the water

(OR: resultant = difference in densities × stone's volume)

Resultant downwards force accelerates stone downwards

Drag increases with speed,

reducing resultant force, thus reducing acceleration

until weight = drag when acceleration is zero

Temperature higher in summer

Water viscosity lower with higher temperature

Correct expression of Stokes' law equation OR Stokes' force equation

Thus terminal velocity is higher in summer