Past-paper walk-through

Fluids and Conservation Laws ▪ 8.4

eXercise

Questions in this set

- 2026 Q1
- 2025 Q4
- 2018 Q4

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 1

2026 ▪ Q1

Water exits the nozzle of a fountain at an angle θ_0 above the horizontal.
At time $t = 0$, a droplet of water exits the nozzle and follows the path shown in Figure 1. The droplet reaches a maximum height h_1 above the nozzle.
[Figure 1: Side-view diagram of a fountain. A curved gray arc labeled "Path" rises from the nozzle to a peak and comes back down. A vertical double-headed arrow labeled h_1 marks the height from the dashed horizontal line at the nozzle up to the peak of the path. At the base, "Fountain" labels the fountain body, "Nozzle" labels the opening, and the angle θ_0 is marked between the nozzle direction and the dashed horizontal line. A small coordinate axis to the right shows $+y$ (up) and $+x$ (right). Note: Figure not drawn to scale.]
At $t = t_f$, the droplet returns to the same height at which the droplet exited the nozzle.

Question 1

(a)(i) On the axes shown in Figure 2, **sketch** graphs of the horizontal and vertical components of the velocity of the water droplet as functions of t from $t = 0$ to $t = t_f$. [Figure 2: Two blank coordinate-axis grids side by side for sketching. Left graph: y-axis labeled "Horizontal Velocity Component", x-axis labeled t with origin O and a tick mark at t_f. Right graph: y-axis labeled "Vertical Velocity Component", x-axis labeled t with origin O and a tick mark at t_f. Both axes have arrows indicating positive directions upward and to the right, and each also extends slightly below the horizontal axis.]

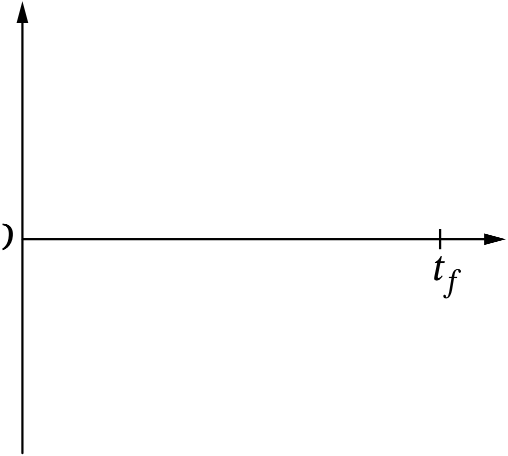
(a)(ii) Derive an expression for the speed of the water exiting the nozzle. Express your final answer in terms of θ_0, h_1, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

(a)(iii) The nozzle has a circular cross-section with radius r_0. **Derive** an expression for the volume flow rate of the water exiting the nozzle. Express your final answer in terms

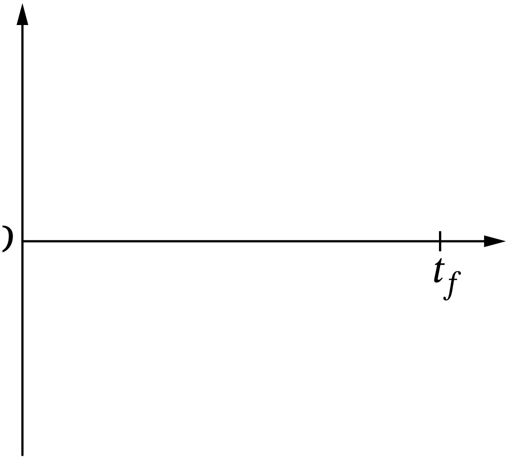
Question 1

of θ_0, h_1, r_0, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 1



Question 1



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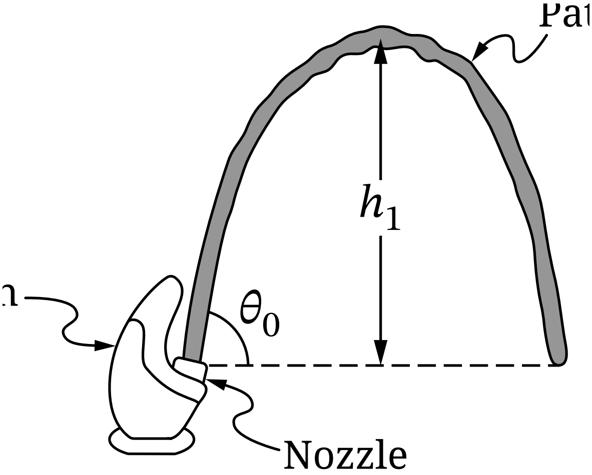

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At $t = t_f$, the droplet returns to the same height at which the droplet exited the nozzle.

(b) The fountain nozzle is replaced with a new nozzle with a radius smaller than r_0. The water exits the new nozzle at the same angle θ_0 above the horizontal. The volume flow rate of the water exiting the new nozzle is equal to the volume flow rate of the

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water exiting the original nozzle. A water droplet exiting the new nozzle reaches a maximum height h_2 above the nozzle.

Indicate whether h_2 is greater than, less than, or equal to h_1 by writing one of the following.

- $h_2 > h_1$
- $h_2 < h_1$
- $h_2 = h_1$

Justify your answer. In your justification, include qualitative reasoning beyond mathematical derivations or expressions.

Question 4

2025 ▪ Q4

In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1

[Figure 1: A tank of freshwater with density ρ_1 labeled in the bottom corner. A swimmer wearing scuba gear, mask, and flippers holds a block of mass m in both hands, arms extended forward, underwater.]

In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

(a) Indicate whether a_1 is greater than, less than, or equal to a_2 by writing one of the following in your answer booklet.

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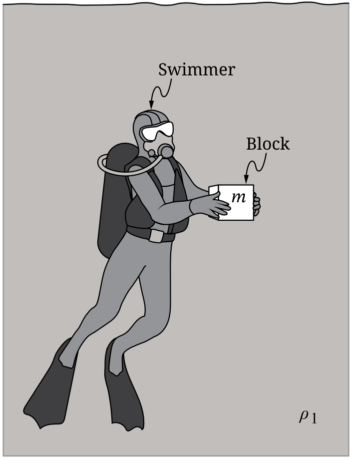
- $a_1 > a_2$
- $a_1 < a_2$
- $a_1 = a_2$

Justify your answer in terms of ALL forces exerted on the block in each scenario. Use qualitative reasoning beyond referencing equations.

Question 4



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(b) Consider the general case where a block of mass m and volume V is completely submerged in a fluid of density ρ.

Question 4

Starting with Newton's second law, **derive** an expression for the initial upward acceleration a of the block when the block is released from rest. Express your answer in terms of m, V, ρ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 4

2025 ▪ Q4

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Question 4

(c) Indicate whether the expression for the acceleration *a* you derived in part B is or is not consistent with the claim made in part A. Briefly **justify** your answer by referencing your derivation in part B.

Solution 4

(a) Mark scheme

- $a_1 < a_2$ (the freshwater block's acceleration is less than the saltwater block's). Justification: both blocks have the same weight mg (same mass), submerged in their respective fluids, so the downward gravitational force is identical in both cases. Since saltwater is denser than freshwater, and buoyant force is proportional to fluid density, the block in saltwater experiences a larger buoyant force than the block in freshwater. With equal weight but a larger buoyant force, the saltwater block has a larger net upward force and therefore a larger acceleration. Point A1 for indicating $a_1 < a_2$; Point A2 for a justification that the blocks have the same weight/mass; Point A3 for a justification that saltwater exerts a larger buoyant

Solution 4

force than freshwater (equivalently, that freshwater exerts a smaller buoyant force than saltwater).

Solution 4

(b) Mark scheme

- Starting from Newton's second law applied to the block: $\Sigma F = m_{\text{sys}} a_{\text{sys}}$, i.e. $F_B - mg = ma$. With the buoyant force $F_B = \rho V g$ (fluid density $\times$ submerged volume $\times g$): $\rho V g - mg = ma$, so $a = \dfrac{\rho V g}{m} - g$. Point B1 for a multistep derivation that includes Newton's second law; Point B2 for indicating $\rho V g$ is the buoyant force; Point B3 for a correct expression for the initial upward acceleration a consistent with the indicated buoyant-force expression. A correct, isolated final expression for a earns both B2 and B3.

Solution 4

(c) Mark scheme

- Yes — the expression derived in part B is consistent with the claim made in part A. In $a = \dfrac{\rho V g}{m} - g$, the acceleration a increases as the fluid density ρ increases, since ρ sits in the numerator of the $\frac{\rho V g}{m}$ term (i.e. a is directly/proportionally related to ρ). Because saltwater has a greater density than freshwater, this confirms the saltwater block has the larger acceleration, matching the $a_1 < a_2$ claim from part A. Point C1 for attempting to address the functional dependence between a and ρ in the part-B expression (using language such as proportional, inversely proportional, related, numerator, or denominator — it need not be used correctly to earn this point); Point C2 for correctly using that functional

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dependence to evaluate the relationship between a and ρ, consistent with both the part-B expression and the part-A claim.

Question 4

2018 ▪ Q4

A transverse wave travels to the right along a string.
(a)(i) The figure below shows the string at an instant in time. At the instant shown, dot P has maximum displacement and dot Q has zero displacement from equilibrium. At each of the dots P and Q, draw an arrow indicating the direction of the instantaneous velocity of that dot. If either dot has zero velocity, write "$v = 0$" next to the dot.
[Figure: a transverse wave on a string (drawn with cross-hatching to show the string), moving right ("Direction of Wave" arrow shown above); dot P is marked at a trough of the wave (maximum displacement from equilibrium) and dot Q is marked at a zero-crossing point on the curve (zero displacement).]
(a)(ii) The figure below shows the string at the same instant as shown in part (a)i. At each of the dots P and Q, draw an arrow indicating the direction of the instantaneous

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acceleration of that dot. If either dot has zero acceleration, write "$a = 0$" next to the dot.

[Figure: the same transverse wave snapshot repeated, moving right ("Direction of Wave" arrow shown above), with dot P at the trough and dot Q at the zero-crossing point, provided for the student to draw acceleration-direction arrows.]

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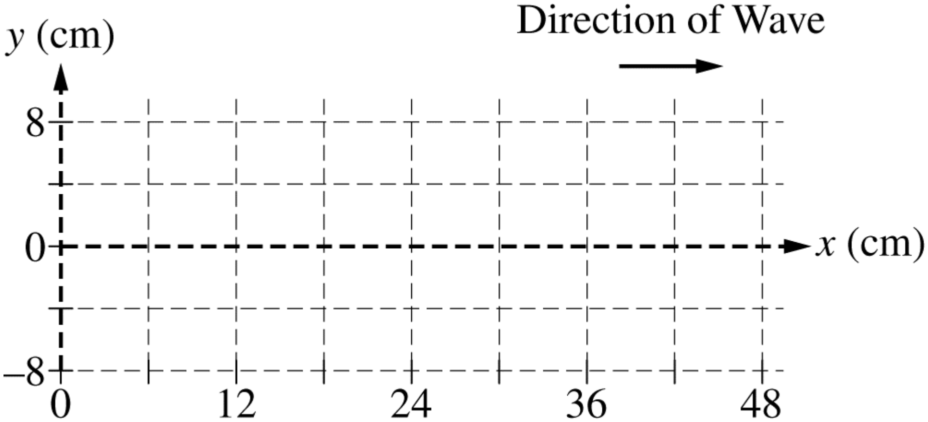

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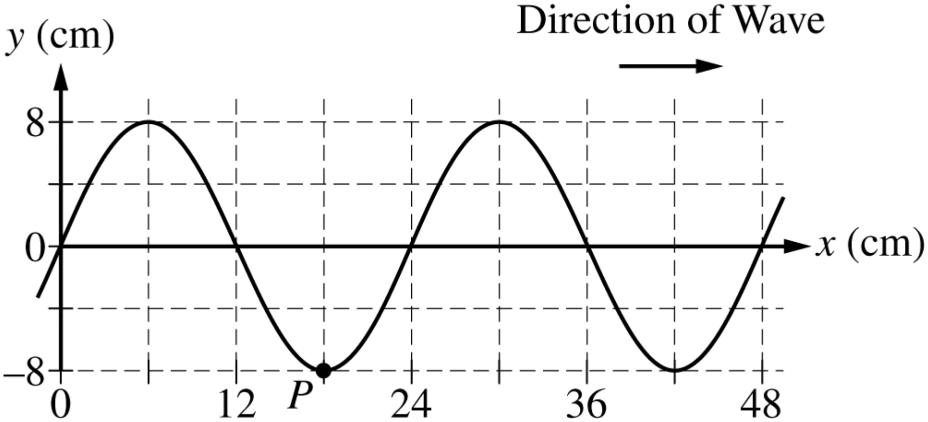

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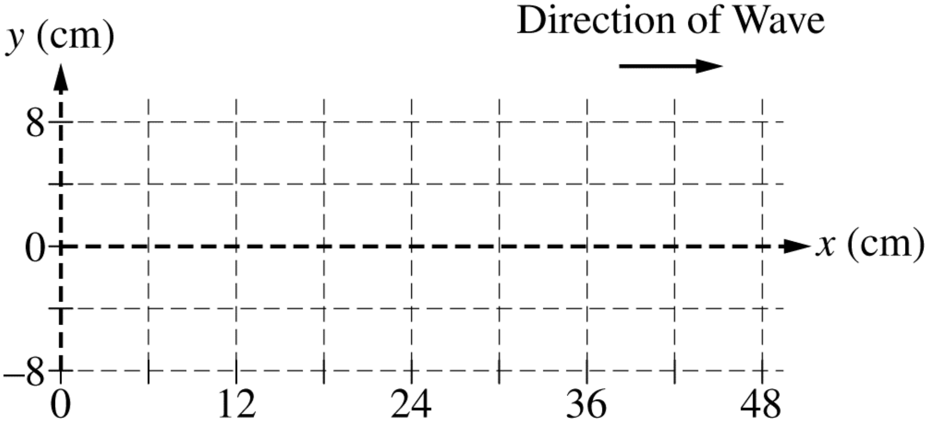

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2018 ▪ Q4

A transverse wave travels to the right along a string.

(b)(i) The figure below represents the string at time $t = 0$, the same instant as shown in part (a) when dot P is at its maximum displacement from equilibrium. For simplicity, dot Q is not shown.

[Figure: a graph of y (cm) vs x (cm) showing a sinusoidal wave of amplitude 8 cm and wavelength 24 cm, with a "Direction of Wave" arrow pointing in the $+x$ direction; dot P is marked on the curve at $x = 12$ cm, $y = 0$.]

On the grid below, draw the string at a later time $t = T/4$, where T is the period of the wave.

[Figure: a blank y (cm) vs x (cm) grid, same scale as above (-8 to 8 cm vertical, 0 to 48 cm horizontal) with a "Direction of Wave" arrow, provided for the student to sketch the string's new shape.]

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Note: Do any scratch (practice) work on the grid at the bottom of the page. Only the sketch made on the grid immediately below will be graded.

(b)(ii) On your drawing above, draw a dot to indicate the position of dot P on the string at time $t = T/4$ and clearly label the dot with the letter P.

Question 4

2018 ▪ Q4

A transverse wave travels to the right along a string.

(c) Now consider the wave at time $t = T$. Determine the distance traveled (not the displacement) by dot P between times $t = 0$ and $t = T$.

Solution 4

(a)(i)

Mark scheme

- At the instant shown, dot P is at maximum displacement from equilibrium, so its instantaneous transverse velocity is zero: write '$v = 0$' next to P. Dot Q is at zero displacement (passing through equilibrium), where its transverse speed is maximum; applying the transverse-wave rule for a wave moving to the right, the arrow at Q points upward. Scoring (2 points, 1 each): (1) writing '$v = 0$' at point P; (2) an upward arrow at point Q.

Solution 4

(a)(ii)

Mark scheme

- At maximum displacement, the restoring effect (and hence acceleration) on a string element is at its maximum, directed back toward equilibrium; at P this is an upward arrow. At Q, which is at zero displacement (the equilibrium position), the transverse acceleration is zero: write '$a = 0$' next to Q. Scoring (2 points, 1 each): (1) an upward arrow at point P; (2) writing '$a = 0$' at point Q.

Solution 4

(b)(i)

Mark scheme

- A transverse wave translates rigidly to the right without changing shape, so at $t = T/4$ the entire waveform is simply the original curve shifted right by one-quarter wavelength (one grid unit), keeping the same amplitude (8 cm) and wavelength (24 cm) – for example, the curve now shows a negative minimum at $x = 0$. Scoring (1 point): for a curve shifted to the right by $1/4$ of a wavelength (1 gridline) with the same wavelength as the original wave (as indicated, for example, by a negative minimum at $x = 0$).

Solution 4

(b)(ii)

Mark scheme

- Dot P is a fixed material point on the string, so it does not move horizontally as the wave passes – only its vertical displacement changes over time. Its x-position therefore stays at its original location, $3/4$ of a wavelength (3 grid units) to the right of the origin, but now lying on the $t = T/4$ curve drawn in part (b)(i). Scoring (1 point): for placing dot P on the shifted string, at the dot's original x-position, $3/4$ of a wavelength (3 grid units) to the right of the origin, clearly labeled P.

Solution 4

(c)

Mark scheme

- In one full period T, a point on a transverse wave completes one full oscillation cycle – from maximum displacement, through equilibrium, to the opposite maximum, back through equilibrium, and back to the starting maximum – traveling a total path length of four amplitudes: 4×8 cm $= 32$ cm. Scoring (1 point): for the correct numerical answer, 32 cm.