Past-paper walk-through

Vectors and Motion in Two Dimensions ▪ 1.5

eXercise

Questions in this set

- 2026 Q1
- 2021 Q1
- 2017 Q4
- 2015 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.]

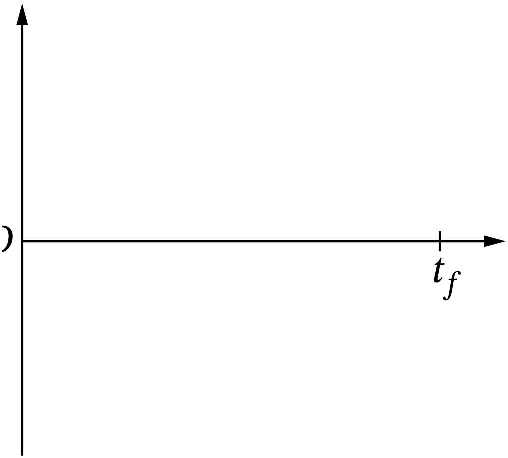
(a)(ii) Derive an expression for the speed of the water exiting the nozzle. Express your final answer in terms of θ_0, h_1, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

(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

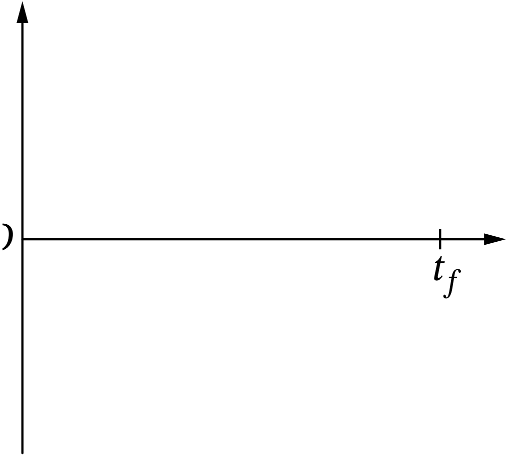
Question 1

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.

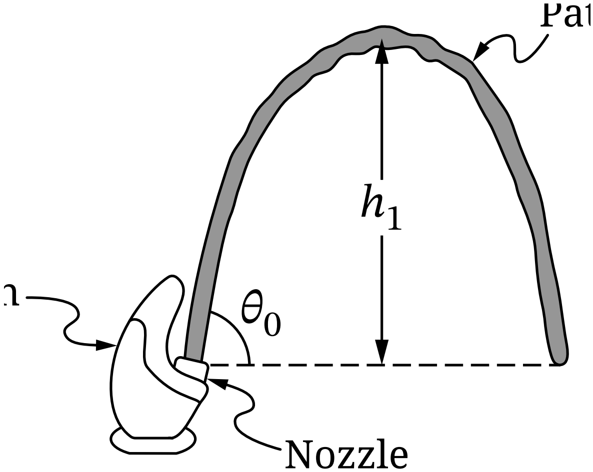
Question 1



Question 1



Question 1



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.

(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

Question 1

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 1

2021 ▪ Q1

[Figure: A stunt cyclist rides down a curved ramp from height H_0 at the top, reaching a launch point at angle θ_0 from the horizontal at the bottom of the ramp. The cyclist becomes airborne, flying over six parked cars lined up in a row, covering a horizontal distance X_0 while in the air (shown as a dotted arc trajectory), and lands on a second ramp on the far side of the cars. Note: Figure not drawn to scale.]

A stunt cyclist builds a ramp that will allow the cyclist to coast down the ramp and jump over several parked cars, as shown above. To test the ramp, the cyclist starts from rest at the top of the ramp, then leaves the ramp, jumps over six cars, and lands on a second ramp.

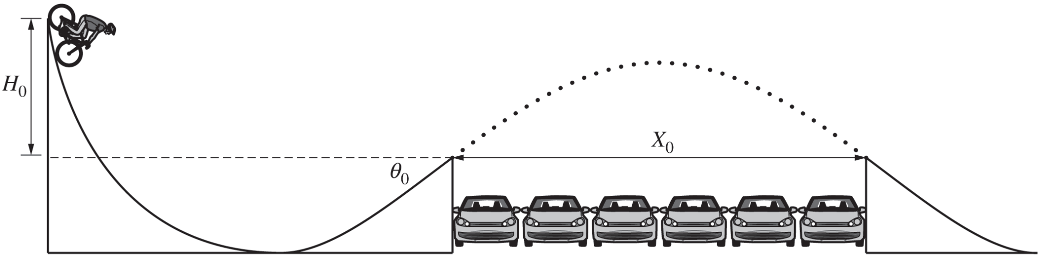
H_0 is the vertical distance between the top of the first ramp and the launch point. θ_0 is the angle of the ramp at the launch point from the horizontal. X_0 is the horizontal

Question 1

distance traveled while the cyclist and bicycle are in the air. m_0 is the combined mass of the stunt cyclist and bicycle.

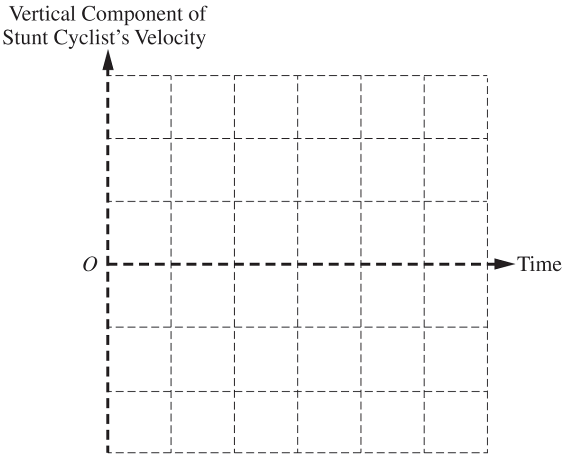
(a) Derive an expression for the distance X_0 in terms of H_0, θ_0, m_0, and physical constants, as appropriate.

Question 1



Note: Figure not drawn to scale.

Question 1



Question 1

2021 ▪ Q1

[Figure: A stunt cyclist rides down a curved ramp from height H_0 at the top, reaching a launch point at angle θ_0 from the horizontal at the bottom of the ramp. The cyclist becomes airborne, flying over six parked cars lined up in a row, covering a horizontal distance X_0 while in the air (shown as a dotted arc trajectory), and lands on a second ramp on the far side of the cars. Note: Figure not drawn to scale.]

A stunt cyclist builds a ramp that will allow the cyclist to coast down the ramp and jump over several parked cars, as shown above. To test the ramp, the cyclist starts from rest at the top of the ramp, then leaves the ramp, jumps over six cars, and lands on a second ramp.

H_0 is the vertical distance between the top of the first ramp and the launch point. θ_0 is the angle of the ramp at the launch point from the horizontal. X_0 is the horizontal distance traveled while the cyclist and bicycle are in the air. m_0 is the combined mass of the stunt cyclist and bicycle.

Question 1

(b) If the vertical distance between the top of the first ramp and the launch point were $2H_0$ instead of H_0, with no other changes to the first ramp, what is the maximum number of cars that the stunt cyclist could jump over? Justify your answer, using the expression you derived in part (a).

Question 1

2021 ▪ Q1

[Figure: A stunt cyclist rides down a curved ramp from height H_0 at the top, reaching a launch point at angle θ_0 from the horizontal at the bottom of the ramp. The cyclist becomes airborne, flying over six parked cars lined up in a row, covering a horizontal distance X_0 while in the air (shown as a dotted arc trajectory), and lands on a second ramp on the far side of the cars. Note: Figure not drawn to scale.]

A stunt cyclist builds a ramp that will allow the cyclist to coast down the ramp and jump over several parked cars, as shown above. To test the ramp, the cyclist starts from rest at the top of the ramp, then leaves the ramp, jumps over six cars, and lands on a second ramp.

H_0 is the vertical distance between the top of the first ramp and the launch point. θ_0 is the angle of the ramp at the launch point from the horizontal. X_0 is the horizontal distance traveled while the cyclist and bicycle are in the air. m_0 is the combined mass of the stunt cyclist and bicycle.

Question 1

(c) On the axes below, sketch a graph of the vertical component of the stunt cyclist's velocity as a function of time from immediately after the cyclist leaves the ramp to immediately before the cyclist lands on the second ramp. On the vertical axis, clearly indicate the initial and final vertical velocity components in terms of H_0, θ_0, m_0, and physical constants, as appropriate. Take the positive direction to be upward.
[Graph grid: vertical axis labeled "Vertical Component of Stunt Cyclist's Velocity" (unlabeled numeric scale, dashed gridlines); horizontal axis labeled "Time", origin marked O; empty dashed grid for the student to sketch on.]

Solution 1

(a) Mark scheme

- Using energy conservation from the top of the ramp to the launch point: $m_0 g H_0 = \frac{1}{2} m_0 v^2 \Rightarrow v = \sqrt{2gH_0}$. Using kinematics for the vertical velocity component (up positive), the cyclist launches at angle θ_0 so $v_{iy} = v\sin\theta_0$; landing at the same height means $v_{fy} = -v\sin\theta_0$, giving flight time $t = \dfrac{2v\sin\theta_0}{g} = \dfrac{2\sin\theta_0\sqrt{2gH_0}}{g}$. The horizontal distance is $X_0 = v_x t = (v\cos\theta_0)\, t = 4H_0\cos\theta_0\sin\theta_0$ (equivalently $X_0 = 2H_0\sin(2\theta_0)$, which is sufficient for the 2nd and 3rd points). Points: (1) using energy conservation to find v, (2) using vertical kinematics to find the time of flight, (3) a correct expression for X_0.

Solution 1

(b)

Mark scheme

- Correct answer: 12 cars. Since $X_0 = 4H_0 \cos\theta_0 \sin\theta_0$ from part (a) is directly proportional to H_0, doubling the vertical distance to $2H_0$ (with θ_0 unchanged) doubles the horizontal distance X_0, so twice as many cars can be jumped as before. Points: (1) an answer and justification that uses the functional dependence of X_0 on H_0 found in part (a), (2) an answer consistent with the part (a) expression.

Solution 1

(c)

Mark scheme

- Sketch: a straight line with constant negative slope. At $t = 0$ (just after leaving the first ramp) the vertical velocity component is $+\sin\theta_0\sqrt{2gH_0}$ (upward); it decreases linearly at rate g and, immediately before landing on the second ramp (same launch height), equals $-\sin\theta_0\sqrt{2gH_0}$ (downward, same magnitude as launch by symmetry). Points: (1) a linear graph with constant negative slope, (2) a graph that starts at $+v_y$ and ends at $-v_y$ using only the given variables.

Question 4

2017 ▪ Q4

[Figure, top pair of diagrams: "Team 1" shows a curved low-friction slide starting at height d above "Table 1", with Block 1 released from rest at the top of the slide (shown as a small square at the top, at the height-d level, connected by a dashed horizontal line to the top of the slide). The slide curves down and flattens out level with the tabletop, launching the block horizontally off the right edge of Table 1, which sits at height h above the floor. "Team 2" shows a similar slide starting at height d above "Table 2" (Table 2's tabletop is lower than Table 1's), with Block 2 released from rest at the top. Because Table 2 is lower, the right end of team 2's slide rises above the tabletop before leveling off, so Block 2 leaves the slide horizontally at the same height h above the floor as Block 1 does. Both d and h are marked with double-headed vertical arrows; the floor is a common horizontal line beneath both tables.]

Question 4

A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

(a) Both blocks are released from rest at the top of their respective slides. Do block 1 and block 2 land the same distance from their respective tables?

_____ Yes _____ No

Justify your answer.

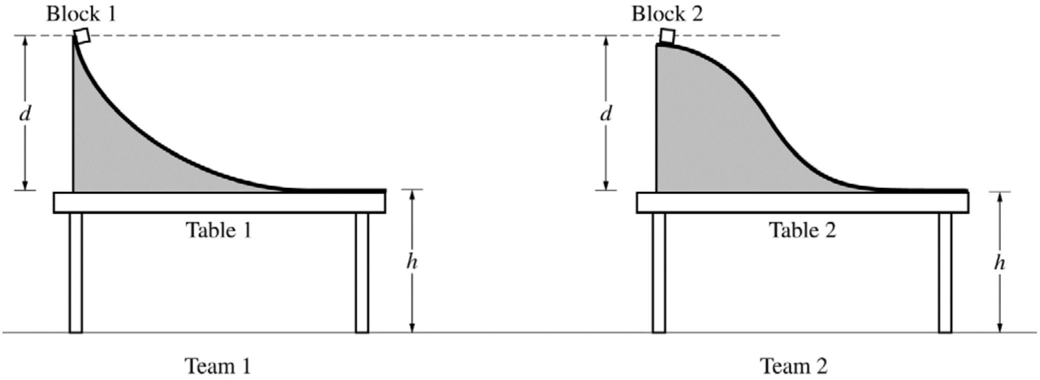
[Figure, bottom pair of diagrams: In another experiment, "Team 1" and "Team 2" use tables and low-friction slides of the same height (tabletops at the same level, table

Question 4

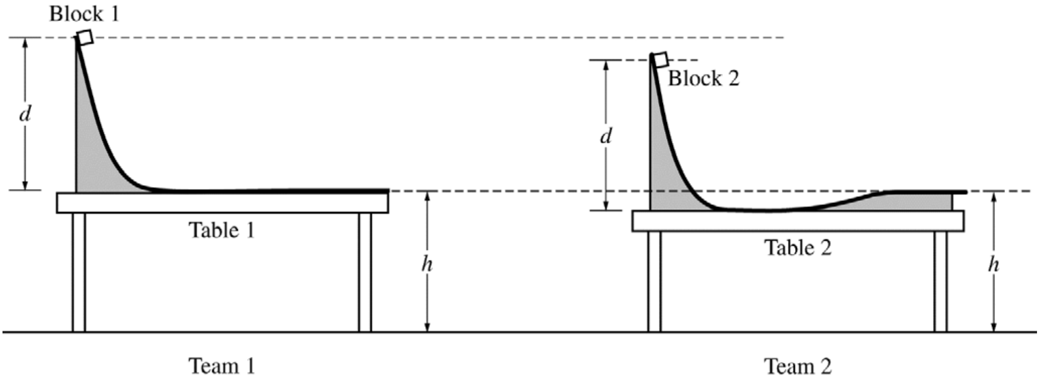
height h equal for both). The two slides have different shapes, as shown: Team 1's slide (Block 1 released from rest at the top, height d above Table 1) curves steeply downward near the top and flattens out quickly, remaining close to tabletop height over most of its horizontal run before leveling off at the tabletop edge. Team 2's slide (Block 2 released from rest at the top, height d above Table 2) stays higher for longer, curving downward more gradually and flattening out only near the tabletop edge. Both blocks leave their slides horizontally at the tabletop, height h above the floor.]

In another experiment, teams 1 and 2 use tables and low-friction slides with the same height. However, the two slides have different shapes, as shown below.

Question 4



Question 4



Question 4

2017 ▪ Q4

[Figure, top pair of diagrams: "Team 1" shows a curved low-friction slide starting at height d above "Table 1", with Block 1 released from rest at the top of the slide (shown as a small square at the top, at the height-d level, connected by a dashed horizontal line to the top of the slide). The slide curves down and flattens out level with the tabletop, launching the block horizontally off the right edge of Table 1, which sits at height h above the floor. "Team 2" shows a similar slide starting at height d above "Table 2" (Table 2's tabletop is lower than Table 1's), with Block 2 released from rest at the top. Because Table 2 is lower, the right end of team 2's slide rises above the tabletop before leveling off, so Block 2 leaves the slide horizontally at the same height h above the floor as Block 1 does. Both d and h are marked with double-headed vertical arrows; the floor is a common horizontal line beneath both tables.]

A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However,

Question 4

team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

(b)(i) Both blocks are released from rest at the top of their respective slides at the same time.

Which block, if either, lands farther from its respective table?

_____ Block 1 _____ Block 2 _____ The two blocks land the same distance from their respective tables.

Briefly explain your reasoning without manipulating equations.

(b)(ii) Which block, if either, hits the floor first?

_____ Block 1 _____ Block 2 _____ The two blocks hit the floor at the same time.

Briefly explain your reasoning without manipulating equations.

Solution 4

(a) Mark scheme

- Correct answer: No — the two blocks do NOT land the same distance from their respective tables. (If the wrong answer is selected, partial credit can still be earned for the justification.) Reasoning by conservation of energy: the change in height (and hence the potential energy converted to kinetic energy) from release to the edge of the table is different for the two blocks — smaller for block 2. So at the edge of the table, block 1 has more kinetic energy than block 2, and hence a larger launch speed. Both launches are horizontal and from tables of the same height, so the two blocks spend the same amount of time in the air (time of flight depends only on drop height, not on horizontal launch speed). Because horizontal distance $d = vt$ and t is the same for both while v differs, the two blocks travel

Solution 4

different horizontal distances — so they do not land the same distance from their respective tables. Points: 1 pt for attempting to use conservation of energy to compare the two blocks; 1 pt for explicitly or implicitly indicating that the launch velocities are different; 1 pt for stating or implying that the time to reach the ground is the same for both blocks.

Solution 4

(b)(i) Mark scheme

- Correct answer: the two blocks land the same distance from their respective tables. In this scenario the change in potential energy from release to launch is the same for both blocks (both slides have the same table height h at launch), so by energy conservation ($mg\Delta h = \frac{1}{2}mv^2$, mass cancels) both blocks leave their tables with the same launch speed. Since both launches are horizontal from tables of the same height, the two blocks also spend the same time in the air. With equal launch velocity and equal flight time, $d = vt$ is the same for both, so the two blocks land the same distance from their respective tables. Points: 1 pt for indicating that the change in potential energy from release to launch is the same

Solution 4

for the two cases; 1 pt for an indication (explicit or implicit) that the launch velocities are the same.

Solution 4

(b)(ii) Mark scheme

- Correct answer: Block 1. Although both blocks reach the same launch speed (as established in part (b)(i)), Team 1's slide is initially steeper, so block 1 has a higher average speed while descending its ramp than block 2 has on its ramp. This means block 1 traverses its slide in less time and reaches (and launches off) the edge of its table sooner than block 2 does. Since both blocks are released from rest at the same time, block 1 therefore hits the floor first. Points: 1 pt for indicating that the average speed/velocity on the slide is higher for Team 1 (block 1), OR that block 1 reaches its maximum speed in less time; 1 pt for a valid explanation of why the average speed/velocity is higher for Team 1, OR why block 1 reaches its maximum speed in less time (e.g., the initially steeper ramp).

Question 4

2015 ▪ Q4

[Figure: A raised platform (table) with two spheres, Sphere A and Sphere B, resting at the same height H above the lower ground level. Sphere A is positioned at the edge of the upper level and drops straight down (dashed vertical line to a position on the lower ground directly below). Sphere B is positioned slightly to the right, launched horizontally, and follows a dashed parabolic trajectory landing a horizontal distance D from the point directly below its release point. The height H is marked as the vertical drop from the upper level to the lower ground, and D is marked as the horizontal distance from directly below Sphere B's start to its landing point.]
Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D

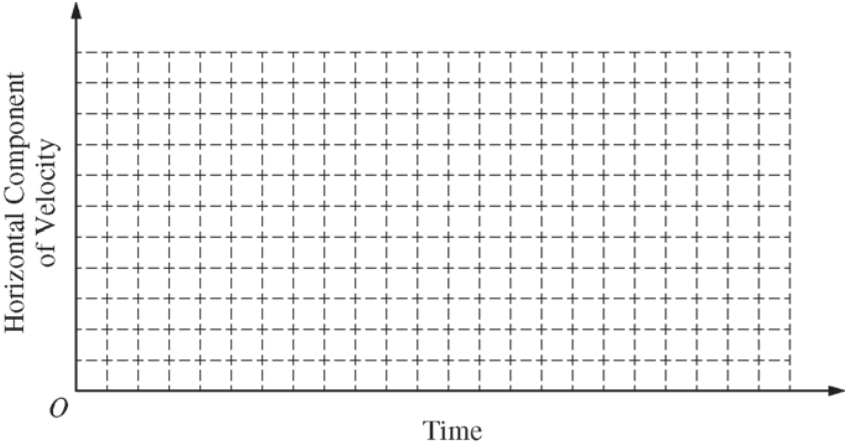
Question 4

before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

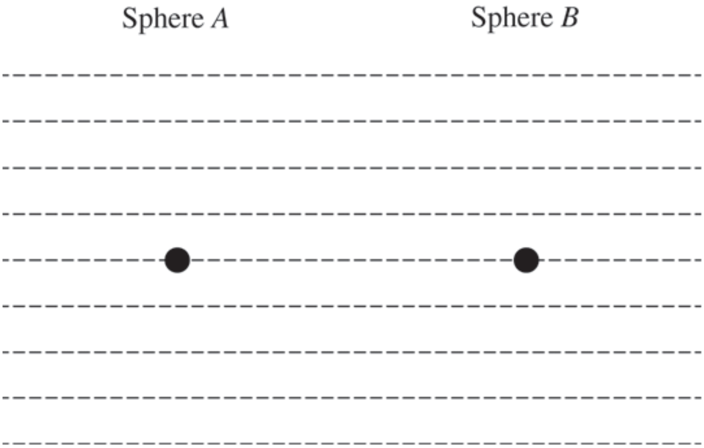
(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.

[Two blank labeled diagrams, each showing a single dot on a set of horizontal dashed reference lines, for the student to draw force vectors on: one labeled "Sphere A", one labeled "Sphere B".]

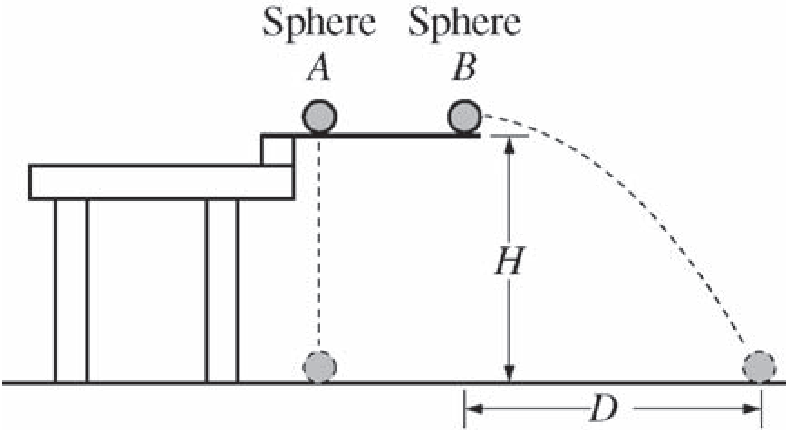
Question 4



Question 4



Question 4



Question 4

2015 ▪ Q4

[Figure: A raised platform (table) with two spheres, Sphere A and Sphere B, resting at the same height H above the lower ground level. Sphere A is positioned at the edge of the upper level and drops straight down (dashed vertical line to a position on the lower ground directly below). Sphere B is positioned slightly to the right, launched horizontally, and follows a dashed parabolic trajectory landing a horizontal distance D from the point directly below its release point. The height H is marked as the vertical drop from the upper level to the lower ground, and D is marked as the horizontal distance from directly below Sphere B's start to its landing point.]

Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

Question 4

(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.
[Blank grid: vertical axis labeled "Horizontal Component of Velocity" (unmarked scale), horizontal axis labeled "Time" starting at O, for the student to sketch both graphs on.]

Question 4

2015 ▪ Q4

[Figure: A raised platform (table) with two spheres, Sphere A and Sphere B, resting at the same height H above the lower ground level. Sphere A is positioned at the edge of the upper level and drops straight down (dashed vertical line to a position on the lower ground directly below). Sphere B is positioned slightly to the right, launched horizontally, and follows a dashed parabolic trajectory landing a horizontal distance D from the point directly below its release point. The height H is marked as the vertical drop from the upper level to the lower ground, and D is marked as the horizontal distance from directly below Sphere B's start to its landing point.]

Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

Question 4

(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).

Solution 4

(a)

Mark scheme

- Free-body diagrams for Sphere A and Sphere B at time $t_f/2$ (mid-flight): each sphere has exactly ONE force acting on it – a single vector pointing straight down, of equal length for both spheres, labeled as the force of gravity (mg). 1 point for sketching only one downward force per sphere and indicating it represents the force of gravity.

Solution 4

(b)

Mark scheme

- Graph of horizontal velocity component vs. time for both spheres: Sphere A's horizontal velocity is a horizontal line at (approximately) ZERO for all time; Sphere B's horizontal velocity is a horizontal line at some CONSTANT NON-ZERO value for all time (no horizontal force acts on either sphere once in flight, so each maintains its own constant horizontal velocity). 1 point for sketching a horizontal line at zero velocity for sphere A and a horizontal line at some non-zero velocity for sphere B.

Solution 4

(c) Mark scheme

- Paragraph explanation: The difference in horizontal motion between the spheres does not affect their vertical motion, because horizontal and vertical motions are independent. Both spheres start with the same vertical velocity. Both spheres have the same vertical acceleration (g), since gravity is the only force acting on each (per part (a)). Because they share the same initial vertical velocity, the same vertical acceleration, and fall the same height, they take the same time to reach the ground – regardless of their differing (and constant, per part (b)) horizontal velocities. Scoring (5 points, 1 each): (1) indicating the difference in horizontal motion does not affect vertical motion; (2) indicating both spheres start with the same vertical velocity; (3) indicating both spheres have the same vertical

Solution 4

acceleration; (4) indicating that falling the same height takes the same time; (5) for containing no incorrect or irrelevant statements, with explicit reference to parts (a) and (b).