Complete Chapter 1 · Free Sample

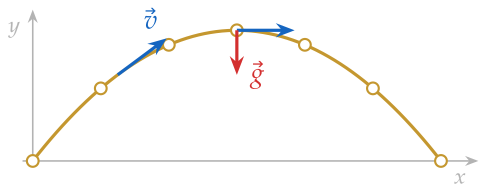
AP Physics 1

Algebra-Based

Practice Workbook

Chapter 1: Kinematics

Key Concepts · 19 Multiple-Choice Questions
5 Free-Response Questions · Fully Worked Solutions



BY

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AP Physics 1: Algebra-Based Practice Workbook
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The problems, explanations, strategies, and diagrams in this sample are original instructional materials. For final review, students should also consult the current official AP Physics 1 course and exam materials.

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StepByStep Science Publishing creates study materials around one principle: lasting understanding grows through deliberate practice. Our books transform complex subjects into focused, connected steps that help students build sound reasoning, confident problem-solving habits, and strong exam performance.

About This Free Sample

This PDF gives you the complete Chapter 1 study experience from *AP Physics 1: Algebra-Based Practice Workbook*. More than a collection of questions, the chapter teaches a repeatable way to move from a physical situation to an exam-ready response.

The Workbook Method

1. **Represent** Translate the situation into the representation that exposes the physics: a diagram, graph, table, or equation.
2. **Reason** Identify the governing model, connect it to the evidence, and explain why it applies.
3. **Solve and Check** Carry the reasoning through the algebra, then test the units, signs, limiting cases, and physical meaning.

In this complete study unit, you will review the essential ideas of kinematics, work through 19 exam-style MCQs and 5 AP-style FRQs covering all four FRQ types—MR, TBR, LAB, and QQT—and finish with a focused *Exam Readiness* checklist.

Use the Sample as a Practice Loop

ATTEMPT ⟶ **COMPARE** ⟶ **CORRECT** ⟶ **RETRY**

Attempt every problem before opening its solution. For MCQs, commit to an answer and your reasoning in about two minutes. For FRQs, first write the governing principle, representation, and algebraic setup. Then compare your work, correct the exact step that failed, and retry the problem without looking at the solution.

Edition details and purchase links for the complete workbook appear after Chapter 1 ⟶

Sample Contents

A complete 40-page study unit with every worked solution included.

Chapter 1

Kinematics

Key Concepts

Kinematics | Exam Weight: 10 – 15%

This unit covers the description of motion in one and two dimensions, including displacement, velocity, acceleration, reference frames, and projectile motion.

Essential Equations

Definitions:

- $\Delta x = x_f - x_i$ (*displacement; a vector*)
- $\bar{v} = \dfrac{\Delta x}{\Delta t}$ (*average velocity; uses displacement, not distance*)

Constant acceleration (1-D):

- $v_x = v_{x0} + a_x t$ (*no Δx*)
- $x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$ (*no v_x*)
- $v_x^2 = v_{x0}^2 + 2 a_x (x - x_0)$ (*no t*)

Free fall from rest:

- $v = g t, \quad h = \frac{1}{2} g t^2, \quad v^2 = 2 g h$ (*special case: $v_0 = 0$, $a = g$*)

Projectile motion (air resistance negligible):

- Components: $v_{0x} = v_0 \cos\theta, \quad v_{0y} = v_0 \sin\theta$
- Horizontal: $x = v_{0x} t$ (*constant velocity; $a_x = 0$*)
- Vertical: use the three kinematic equations with $a_y = -g$
- Horizontal launch: $t = \sqrt{2h/g}, \quad D = v_0\sqrt{2h/g}$ ($v_{y0} = 0$)
- Max height: $h = v_0^2/(2g)$ (*vertical throw; $v = 0$ at peak*)

Relative velocity:

- $\vec{v}_{A/C} = \vec{v}_{A/B} + \vec{v}_{B/C}$ (*velocity addition; watch signs for direction*)

Key Distinctions

Distance vs. Displacement

Distance is total path length (scalar, always ≥ 0). Displacement is change in position (vector, can be negative). *Matters when:* an object reverses direction—distance increases but displacement may decrease.

Average Velocity vs. Average Speed

Avg. velocity $= \Delta x/\Delta t$ (uses displacement). Avg. speed $=$ distance$/\Delta t$. *Matters when:* the object reverses—avg. speed $>$ |avg. velocity|.

Velocity vs. Acceleration

$v = 0$ does **not** mean $a = 0$. At the peak of a vertical throw, $v_y = 0$ but $a = g$ downward. *Matters when:* any question asks about the "highest point" of a trajectory.

Horizontal vs. Vertical Motion

Independent in projectile motion. Time of flight depends **only** on vertical displacement and v_{y0}; horizontal speed does not affect fall time. *Matters when:* a horizontal launch problem asks how mass or v_0 affects time.

Key Representations

Graph	Slope =	Area under curve =
$x(t)$	instantaneous velocity v	—
$v(t)$	instantaneous acceleration a	displacement Δx
$a(t)$	—	change in velocity Δv
d vs. t^2	$\frac{1}{2}a$ (*from rest*)	—

Reading $v-t$ graphs: a straight line $\Rightarrow$ constant a; velocity crossing zero $\Rightarrow$ direction reversal; equal areas (rectangle vs. triangle) can mean equal displacements even when speeds differ at every instant.

Reading $x-t$ graphs: straight line $\Rightarrow$ constant velocity; decreasing magnitude of slope $\Rightarrow$ slowing down; parabola through origin $\Rightarrow$ constant acceleration from rest.

Common AP Traps

! **Trap:** Students assume that zero velocity means zero acceleration.
Fix: Acceleration depends on net force, not velocity. At the peak of a throw, $v = 0$ but $a = g$ downward—always.

! **Trap:** Students write $(2v_0)^2 = 2v_0^2$ instead of $4v_0^2$.
Fix: $(2v_0)^2 = 2^2 \cdot v_0^2 = 4v_0^2$. Since $h \propto v_0^2$, doubling the launch speed **quadruples** the max height, not doubles it.

! **Trap:** Students assume fall time is proportional to height ($t \propto h$).
Fix: From $h = \frac{1}{2}g\,t^2$: $t \propto \sqrt{h}$. Quadrupling the height only doubles the fall time.

! **Trap:** Students draw a "force of motion" arrow on free-body diagrams for projectiles.
Fix: After leaving the hand or surface, the **only** force on a projectile (no air resistance) is gravity. Velocity is not a force—horizontal motion continues by inertia.

! **Trap:** Students forget the $\frac{1}{2}$ in $d = \frac{1}{2}a\,t^2$, or place the factor of 2 in the wrong position when solving for t.
Fix: From $h = \frac{1}{2}g\,t^2$: $t = \sqrt{2h/g}$, **not** $\sqrt{h/(2g)}$.

MULTIPLE-CHOICE QUESTIONS

Problems

MCQ 1.1 *Topic 1.1 · Skill 3.B · ⋆*

A car travels 5 km due north and then 3 km due south along a straight road. Which of the following correctly describes the car's distance traveled and displacement?

(A) The distance traveled is 8 km and the magnitude of the displacement is 8 km.

(B) The distance traveled is 2 km and the magnitude of the displacement is 2 km.

(C) The distance traveled is 8 km and the magnitude of the displacement is 2 km.

(D) The distance traveled is 2 km and the magnitude of the displacement is 8 km.

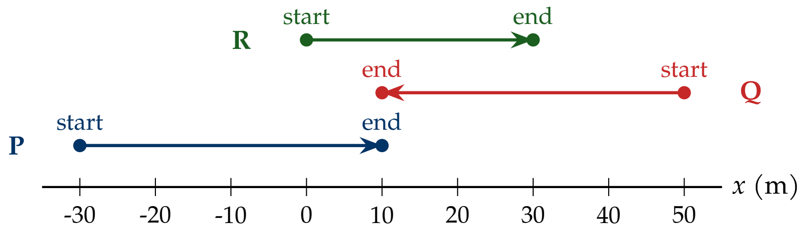
MCQ 1.2 *Topic 1.1 · Skill 2.B · ⋆*

An object moves 12 m to the right, then 5 m to the left, and finally 3 m to the right along a straight line. Which of the following is most nearly the magnitude of the object's total displacement?

(A) 4 m (B) 10 m (C) 14 m (D) 20 m

MCQ 1.3 *Topic 1.1 · Skill 2.C · ⋆⋆*

Three objects P, Q, and R move along a straight track. The diagram below shows the initial and final positions of each object; arrows indicate the direction of displacement.



Which of the following correctly compares the *magnitudes* of the displacements of the three objects?

(A) $|\Delta x_P| > |\Delta x_Q| > |\Delta x_R|$

(B) $|\Delta x_P| = |\Delta x_Q| > |\Delta x_R|$

(C) $|\Delta x_R| > |\Delta x_P| > |\Delta x_Q|$

(D) $|\Delta x_P| = |\Delta x_Q| = |\Delta x_R|$

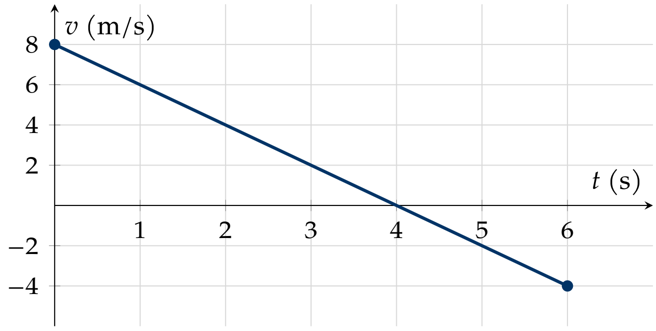
MCQ 1.4 — *Topic 1.2 · Skill 2.B · ⋆⋆*

A runner completes a straight 200 m track in 25 s, then turns around and jogs 80 m back along the same track in 40 s. Which of the following is most nearly the magnitude of the runner's average velocity for the entire trip?

(A) 1.8 m/s (B) 3.1 m/s (C) 4.3 m/s (D) 8.0 m/s

MCQ 1.5 — *Topic 1.3 · Skill 3.B · ⋆⋆*

The velocity–time graph below shows the motion of an object along a straight line.



Which of the following statements about the object's motion is correct?

(A) The object changes direction at $t = 4$ s and has a constant acceleration throughout the motion.

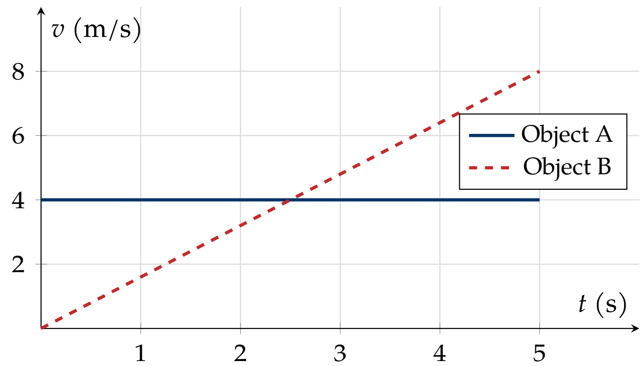
(B) The object changes direction at $t = 4$ s and has a changing acceleration throughout the motion.

(C) The object is momentarily at rest at $t = 4$ s but does not change direction.

(D) The object has zero acceleration at $t = 4$ s.

MCQ 1.6 — *Topic 1.3 · Skill 2.C · ⋆⋆*

Objects A and B both start from the same position at $t = 0$. Their velocity–time graphs are shown below.



Which of the following correctly compares the displacements of the two objects at $t = 5$ s?

(A) Object A has a greater displacement than Object B.

(B) Object B has a greater displacement than Object A.

(C) Both objects have the same displacement at $t = 5\,\text{s}$.

(D) The comparison cannot be made without knowing the accelerations.

MCQ 1.7 *Topic 1.3 · Skill 2.A · ⋆⋆⋆*

An object starts from rest and accelerates uniformly with acceleration a for a time t_1. It then continues at constant velocity for an additional time t_2. Which of the following is a correct expression for the total displacement of the object?

(A) $\frac{1}{2} a t_1^2 + a t_1 t_2$

(B) $a t_1^2 + a t_1 t_2$

(C) $\frac{1}{2} a (t_1 + t_2)^2$

(D) $a t_1 t_2$

MCQ 1.8 *Topic 1.3 · Skill 2.B · ⋆⋆*

A ball is dropped from rest from the top of a 45 m tall building. Air resistance is negligible. Using $g \approx 10\,\text{m/s}^2$, which of the following is most nearly the speed of the ball just before it reaches the ground?

(A) 15 m/s (B) 21 m/s (C) 30 m/s (D) 45 m/s

MCQ 1.9 *Topic 1.3 · Skill 2.D · ⋆⋆*

An object is released from rest and falls freely from a height h above the ground. If the height is increased to $4h$, by what factor does the time to reach the ground change?

(A) The time increases by a factor of 2.

(B) The time increases by a factor of 4.

(C) The time increases by a factor of 8.

(D) The time increases by a factor of 16.

MCQ 1.10 *Topic 1.3 · Skill 3.C · ⋆⋆*

A student observes the position–time graph of an object moving in one dimension and claims that the object is slowing down during a certain time interval. Which of the following features of the graph, if true, would best support the student's claim?

(A) The graph is a straight line with a positive slope.

(B) The graph is curved and the magnitude of its slope is increasing over time.

(C) The graph is curved and the magnitude of its slope is decreasing over time.

(D) The graph has a constant negative slope.

MCQ 1.11 *Topic 1.4 · Skill 3.B · ⋆⋆*

Observer A stands on the ground. Observer B rides in a car moving to the right at constant velocity. A ball is dropped from rest as seen by Observer A. Which of the following quantities will both observers measure to have the same value?

(A) The ball's velocity at the moment it is released.

(B) The ball's displacement after 1 s.

(C) The ball's acceleration during the fall.

(D) The ball's speed when it reaches the ground.

MCQ 1.12 *Topic 1.4 · Skill 2.B · ⋆*

A boat travels due east at 6 m/s relative to the water. The water flows due east at 2 m/s relative to the ground. Which of the following is most nearly the speed of the boat relative to the ground?

(A) 2 m/s (B) 4 m/s (C) 6 m/s (D) 8 m/s

MCQ 1.13 *Topic 1.5 · Skill 2.A · ⋆⋆*

A projectile is launched with initial speed v_0 at an angle θ above the horizontal over flat ground. Air resistance is negligible. Which of the following is a correct expression for the speed of the projectile at the highest point of its trajectory?

(A) 0 (B) $v_0 \sin\theta$ (C) $v_0 \cos\theta$ (D) v_0

MCQ 1.14 *Topic 1.5 · Skill 2.A · ⋆ ⋆ ⋆*

A ball is launched horizontally from the edge of a table of height h with initial horizontal speed v_0. Air resistance is negligible. Which of the following is a correct expression for the horizontal distance d the ball travels before reaching the floor?

(A) $v_0 \sqrt{\dfrac{h}{2g}}$

(B) $v_0 \sqrt{\dfrac{2h}{g}}$

(C) $\dfrac{v_0 h}{g}$

(D) $\dfrac{v_0^2}{2g}$

MCQ 1.15 *Topic 1.5 · Skill 2.D · ⋆ ⋆ ⋆*

A projectile is launched horizontally from a cliff of height h with initial speed v_0. Air resistance is negligible. If the height of the cliff is doubled, which of the following correctly describes how the time of flight and the horizontal range change?

(A) Both the time of flight and the horizontal range double.

(B) The time of flight increases by a factor of $\sqrt{2}$ and the horizontal range increases by a factor of $\sqrt{2}$.

(C) The time of flight doubles and the horizontal range increases by a factor of $\sqrt{2}$.

(D) The time of flight increases by a factor of $\sqrt{2}$ and the horizontal range doubles.

MCQ 1.16 *Topic 1.5 · Skill 3.B · ⋆*

A projectile is launched at an angle above the horizontal. Air resistance is negligible. Which of the following statements about the projectile at the highest point of its trajectory is correct?

(A) Both the velocity and the acceleration of the projectile are zero.

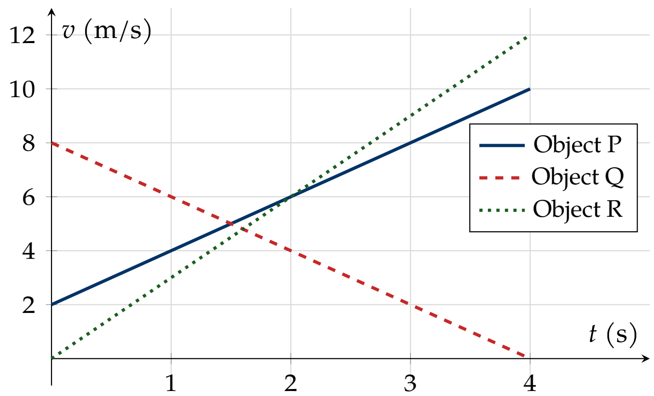
(B) The velocity of the projectile is zero and the acceleration is g directed downward.

(C) The velocity of the projectile is directed horizontally and the acceleration is g directed downward.

(D) The velocity of the projectile is directed horizontally and the acceleration is zero.

MCQ 1.17 *Topic 1.3 · Skill 2.C · ⋆⋆*

The velocity–time graph below shows the motion of three objects P, Q, and R during the same 4 s interval. Each object moves along a straight line.



Which of the following correctly ranks the magnitudes of the accelerations of the three objects from greatest to least?

(A) $|a_R| > |a_P| > |a_Q|$

(B) $|a_R| > |a_P| = |a_Q|$

(C) $|a_Q| > |a_R| > |a_P|$

(D) $|a_P| = |a_Q| = |a_R|$

MCQ 1.18 *Topic 1.2 · Skill 2.B · ⋆⋆*

A car moving in a straight line has a velocity of 12 m/s at $t = 2$ s and a velocity of 27 m/s at $t = 7$ s. Which of the following is most nearly the magnitude of the car's average acceleration during this interval?

(A) 2.0 m/s^2 (B) 3.0 m/s^2 (C) 5.4 m/s^2 (D) 7.8 m/s^2

MCQ 1.19 *Topic 1.4 · Skill 2.B · ⋆⋆*

Car A travels due east at 30 m/s and car B travels due west at 20 m/s, both measured relative to the ground, along the same straight highway. Which of the following is most nearly the speed of car A as measured by an observer riding in car B?

(A) 10 m/s (B) 20 m/s (C) 30 m/s (D) 50 m/s

Solutions

Solution: MCQ 1.1

$\boxed{\text{C}}$ **Fast Path:**

$$\text{Distance (scalar)} = 5 + 3 = 8\,\text{km}$$
$$\text{Displacement (vector)} = 5 - 3 = 2\,\text{km north}$$

(A) × Treats displacement as a scalar, adding both legs ($5 + 3 = 8$) instead of subtracting.
(B) × Confuses distance with displacement; uses the vector result (2 km) for both quantities.
(D) × Reverses the two quantities—assigns the scalar sum to displacement and the vector difference to distance.

Key Principle: Distance is a scalar (total path length); displacement is a vector (net change in position). They are equal only when the object moves in a single direction without reversing.

Solution: MCQ 1.2

$\boxed{\text{B}}$ **Fast Path:** Choose rightward as positive:

$$\Delta x = (+12) + (-5) + (+3) = +10\,\text{m}$$

(A) × Subtracts every segment: $12 - 5 - 3 = 4$. Treats the final rightward move as if it were leftward.
(C) × Reverses the sign of the leftward leg: $12 + 5 - 3 = 14$.
(D) × Adds all magnitudes: $12 + 5 + 3 = 20$. This is the total distance, not the displacement.

Key Principle: Displacement is a vector sum—direction matters. Add segments with signs that reflect their directions in a chosen coordinate system.

Solution: MCQ 1.3

$\boxed{\text{B}}$ **Fast Path:** Read arrow lengths from the number line:

$$|\Delta x_P| = |10 - (-30)| = 40\,\text{m}$$
$$|\Delta x_Q| = |10 - 50| = 40\,\text{m}$$
$$|\Delta x_R| = |30 - 0| = 30\,\text{m}$$

So $|\Delta x_P| = |\Delta x_Q| > |\Delta x_R|$.

(A) × Treats Q's leftward (negative) displacement as having a smaller magnitude than P's rightward displacement. Magnitude ignores direction.
(C) × Confuses final position with displacement magnitude, or misreads the diagram arrows.
(D) × Ignores that R covers only 30 m while P and Q each cover 40 m. Possibly assumes all arrows represent the same displacement because P and Q share the same endpoint.

Key Principle: The magnitude of displacement is $|\Delta x| = |x_f - x_i|$. Direction (sign) does not affect the magnitude—a 40 m displacement to the left is the same size as a 40 m displacement to the right.

Solution: MCQ 1.4

$\boxed{\text{A}}$ **Fast Path:**

$$\text{Net displacement} = 200 - 80 = 120\,\text{m}$$
$$\text{Total time} = 25 + 40 = 65\,\text{s}$$
$$|\bar{v}| = \frac{120\,\text{m}}{65\,\text{s}} \approx 1.8\,\text{m/s}$$

(B) × Uses only the outbound distance as displacement: $200/65 \approx 3.1\,\text{m/s}$.
(C) × Calculates average *speed* instead of average velocity, using total distance: $(200 + 80)/65 \approx 4.3\,\text{m/s}$.
(D) × Uses only the first leg: $200/25 = 8.0\,\text{m/s}$. Ignores the return segment entirely.

Key Principle: Average velocity equals net displacement divided by total time. It differs from average speed, which uses total distance.

Solution: MCQ 1.5

$\boxed{\text{A}}$ **Fast Path:** The graph is a straight line, so acceleration is constant:

$$a = \frac{v_f - v_i}{t_f - t_i} = \frac{(-4) - 8}{6 - 0} = -2\,\text{m/s}^2$$

The velocity crosses zero at $t = 4\,\text{s}$; since v changes sign from positive to negative, the object reverses direction at that instant.

(B) × Correctly identifies the direction change but claims the acceleration is changing. A straight v-t line has constant slope.
(C) × Recognises that $v = 0$ at $t = 4\,\text{s}$ but fails to note that v changes sign, which means the object *does* change direction.
(D) × Confuses zero velocity with zero acceleration. The acceleration is the slope of the line, which is nonzero and constant.

Key Principle: On a velocity–time graph, a straight line means constant acceleration, and a sign change in velocity indicates a reversal of direction.

Solution: MCQ 1.6

$\boxed{\text{C}}$ **Fast Path:** Displacement = area under the v-t curve:

$$\begin{aligned} \text{Object A (rectangle):} \quad & \Delta x_A = 4 \times 5 = 20\,\text{m} \\ \text{Object B (triangle):} \quad & \Delta x_B = \tfrac{1}{2} \times 8 \times 5 = 20\,\text{m} \end{aligned}$$

The displacements are equal.

(A) × Assumes that constant velocity always produces a greater displacement than accelerating motion.
(B) × Focuses on Object B's higher final speed ($8\,\text{m/s}$ vs. $4\,\text{m/s}$) without computing the areas.
(D) × The accelerations are known from the graphs; no additional information is needed to compare.

Key Principle: Displacement is the area under a velocity–time graph. A rectangle and a triangle can enclose the same area even when the velocities differ at every instant.

Solution: MCQ 1.7

$\boxed{\text{A}}$ **Fast Path:**

$$\begin{aligned} \text{Phase 1 (from rest):} \quad & d_1 = \tfrac{1}{2}\, a\, t_1^2, \qquad v_f = a\, t_1 \\ \text{Phase 2 (constant } v_f\text{):} \quad & d_2 = (a\, t_1)\, t_2 = a\, t_1\, t_2 \\ \text{Total:} \quad & d = \tfrac{1}{2}\, a\, t_1^2 + a\, t_1\, t_2 \end{aligned}$$

(B) × Omits the factor of $\frac{1}{2}$ in Phase 1, using $d_1 = a\, t_1^2$ instead of $\frac{1}{2}\, a\, t_1^2$.
(C) × Treats the entire motion as uniformly accelerated for the combined time $(t_1 + t_2)$, ignoring that the object stops accelerating after t_1.
(D) × Accounts only for the constant-velocity phase and drops the displacement accumulated during acceleration.

Key Principle: When motion has distinct phases, analyse each phase separately using the appropriate kinematic model and add the displacements.

Solution: MCQ 1.8

$\boxed{\text{C}}$ **Fast Path:**

$$v^2 = v_0^2 + 2gh = 0 + 2(10)(45) = 900 \implies v = 30\,\text{m/s}$$

(A) × Finds the fall time correctly ($t = \sqrt{2h/g} = 3\,\text{s}$) but then divides h by t: $45/3 = 15\,\text{m/s}$. This gives the average speed, not the final speed.
(B) × Omits the factor of 2: $v = \sqrt{gh} = \sqrt{450} \approx 21\,\text{m/s}$.
(D) × Confuses height with speed, effectively setting $v = h = 45\,\text{m/s}$. A dimensional check would catch this error.

Key Principle: For an object dropped from rest, $v^2 = 2gh$. Always verify that the answer has the correct units and is dimensionally consistent.

Solution: MCQ 1.9

$\boxed{\text{A}}$ **Fast Path:**

$$h = \tfrac{1}{2}gt^2 \implies t = \sqrt{\frac{2h}{g}}$$

$$h \to 4h: \quad t' = \sqrt{\frac{2(4h)}{g}} = 2\sqrt{\frac{2h}{g}} = 2t$$

The time increases by a factor of 2.

(B) × Assumes $t \propto h$ (linear) instead of $t \propto \sqrt{h}$.
(C) × Uses $t \propto h^{3/2}$, which has no physical basis.
(D) × Assumes $t \propto h^2$, confusing the relationship with its inverse $h \propto t^2$.

Key Principle: For free fall from rest, $h \propto t^2$, so $t \propto \sqrt{h}$. Quadrupling the height doubles the fall time.

Solution: MCQ 1.10

$\boxed{\text{C}}$ **Fast Path:** "Slowing down" means the magnitude of velocity is decreasing. Since velocity is the slope of the x-t graph, the magnitude of that slope must be getting smaller over time—a curve that is "flattening out."

(A) × A straight line has constant slope ⇒ constant velocity. The object is neither speeding up nor slowing down.
(B) × An *increasing* magnitude of slope means the speed is increasing—the object is speeding up, not slowing down.
(D) × A constant negative slope means constant velocity in the negative direction—not slowing down.

Key Principle: On a position–time graph the slope equals the instantaneous velocity. "Slowing down" corresponds to a decreasing magnitude of that slope, regardless of the sign of the velocity.

Solution: MCQ 1.11

$\boxed{\text{C}}$ **Fast Path:** Both observers are in inertial frames (constant velocity). The only force on the ball is gravity, so both measure the same acceleration: $a = g$, directed downward. Velocity, displacement, and speed all differ because Observer B adds a horizontal relative-velocity component.

- **(A)** × Observer A sees the ball released from rest ($v = 0$), but Observer B sees it with an initial horizontal velocity to the left (equal and opposite to the car's velocity). The initial velocities differ.
- **(B)** × Observer A sees purely vertical displacement, while Observer B sees a diagonal displacement that also has a horizontal component. The displacements differ.
- **(D)** × Because Observer B assigns a horizontal velocity component, the final speed (magnitude of the total velocity vector) is larger in B's frame than in A's frame.

Key Principle: Acceleration is the same in all inertial reference frames. Velocities differ by a constant $\vec{v}_{\text{rel}}$, but since that constant vanishes upon differentiation, $\vec{a}$ is frame-invariant.

Solution: MCQ 1.12

$\boxed{\text{D}}$ **Fast Path:**

$$v_{\text{boat/ground}} = v_{\text{boat/water}} + v_{\text{water/ground}} = 6 + 2 = 8\,\text{m/s}$$

- **(A)** × Subtracts the larger from the smaller, obtaining only the water speed.
- **(B)** × Subtracts the current from the boat speed: $6 - 2 = 4\,\text{m/s}$. This would apply if the water flowed opposite to the boat.
- **(C)** × Ignores the water current entirely and reports only the boat's speed relative to the water.

Key Principle: Velocities in the same direction add: $\vec{v}_{A/C} = \vec{v}_{A/B} + \vec{v}_{B/C}$. Always check whether the current aids or opposes the motion before choosing the sign.

Solution: MCQ 1.13

$\boxed{\text{C}}$ **Fast Path:** Decompose the initial velocity: $v_{0x} = v_0 \cos\theta, \quad v_{0y} = v_0 \sin\theta$. At the peak, $v_y = 0$ while $v_x = v_{0x}$ is unchanged (no horizontal acceleration). Therefore the speed at the peak is

$$v_{\text{peak}} = v_x = v_0 \cos\theta$$

(A) × Confuses $v_y = 0$ at the peak with the total velocity being zero. The horizontal component $v_x = v_0 \cos\theta$ persists throughout the flight.
(B) × Uses the initial *vertical* component $v_0 \sin\theta$. This is the component that equals zero at the peak, not the speed at the peak.
(D) × Assumes the speed never changes, ignoring that the vertical component decreases to zero at the peak. Only the horizontal component is constant.

Key Principle: In projectile motion, horizontal velocity is constant ($a_x = 0$) and vertical velocity varies. At the peak, $v_y = 0$ so the speed equals the horizontal component: $v_{\text{peak}} = v_0 \cos\theta$.

Solution: MCQ 1.14

$\boxed{\text{B}}$ **Fast Path:**

$$\text{Vertical:} \quad h = \tfrac{1}{2} g\, t^2 \quad \Longrightarrow \quad t = \sqrt{\frac{2h}{g}}$$

$$\text{Horizontal:} \quad d = v_0\, t \quad \Longrightarrow \quad d = v_0 \sqrt{\frac{2h}{g}}$$

(A) × Places the factor of 2 in the denominator: $\sqrt{h/(2g)}$. Results from incorrectly solving $h = \frac{1}{2} g\, t^2$ as $t = \sqrt{h/(2g)}$ instead of $t = \sqrt{2h/g}$.
(C) × Uses $t = h/g$ (from $h = g\, t$, omitting the $\frac{1}{2}$), giving $d = v_0 h/g$.
(D) × Conflates this with the stopping-distance formula $d = v_0^2/(2g)$, which applies to a different physical situation.

Key Principle: In a horizontal launch, the fall time is governed entirely by the vertical motion ($h = \frac{1}{2} g\, t^2$). The horizontal range is $d = v_0\, t$ because horizontal velocity is constant.

Solution: MCQ 1.15

$\boxed{\text{B}}$ **Fast Path:**

$$t = \sqrt{\frac{2h}{g}} \quad \Longrightarrow \quad h \to 2h: \; t' = \sqrt{\frac{2(2h)}{g}} = \sqrt{2}\, t$$

$$R = v_0\, t \quad \Longrightarrow \quad R' = v_0\, (\sqrt{2}\, t) = \sqrt{2}\, R$$

Both the time and range increase by a factor of $\sqrt{2}$.

(A) × Assumes both quantities are linearly proportional to h.
(C) × Correctly finds the range factor ($\sqrt{2}$) but incorrectly claims the time doubles.
(D) × Correctly finds the time factor ($\sqrt{2}$) but incorrectly claims the range doubles. Since $R = v_0 t$ and v_0 is unchanged, the range scales the same way as t.

Key Principle: For a horizontal launch, both the fall time and the horizontal range are proportional to $\sqrt{h}$. Doubling h increases each by a factor of $\sqrt{2}$.

Solution: MCQ 1.16

$\boxed{\text{C}}$ **Fast Path:** At the highest point:

$$v_y = 0, \qquad v_x = v_0 \cos\theta \neq 0, \qquad a = g \text{ (downward, always)}$$

The velocity is therefore horizontal and nonzero; gravity never "turns off," so $a = g$ downward at all times during the flight.

(A) × Assumes zero vertical velocity means zero total velocity *and* zero acceleration. The horizontal component persists, and gravity acts throughout.
(B) × Correctly states $a = g$ downward but claims the total velocity is zero. Only the vertical component vanishes at the peak.
(D) × Correctly identifies the horizontal velocity but claims zero acceleration. In projectile motion $a = g$ is constant and never zero.

Key Principle: In projectile motion (no air resistance), the acceleration is always g downward. At the peak, only $v_y = 0$; the horizontal velocity $v_x = v_0 \cos\theta$ persists throughout the flight.

Solution: MCQ 1.17

$\boxed{\text{B}}$ **Fast Path:** Acceleration = slope of the v-t graph:

$$a_P = \frac{10-2}{4} = +2.0\,\text{m/s}^2 \implies |a_P| = 2.0\,\text{m/s}^2$$
$$a_Q = \frac{0-8}{4} = -2.0\,\text{m/s}^2 \implies |a_Q| = 2.0\,\text{m/s}^2$$
$$a_R = \frac{12-0}{4} = +3.0\,\text{m/s}^2 \implies |a_R| = 3.0\,\text{m/s}^2$$

Ranking: $|a_R| > |a_P| = |a_Q|$.

(A) × Treats Q's negative slope as having a smaller magnitude than P's positive slope. The magnitude of −2.0 equals the magnitude of +2.0.
(C) × Misreads the graph or confuses the sign of the slope with its magnitude, ranking the decelerating object highest.
(D) × Assumes all straight lines on a v-t graph represent the same acceleration, ignoring that the slopes differ.

Key Principle: The magnitude of acceleration is the absolute value of the slope of the velocity–time graph. A negative slope (deceleration) can have the same magnitude as a positive slope (speeding up).

Solution: MCQ 1.18

$\boxed{\text{B}}$ **Fast Path:**

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{27 - 12}{7 - 2} = \frac{15\,\text{m/s}}{5\,\text{s}} = 3.0\,\text{m/s}^2$$

(A) × Divides Δv by t_f instead of Δt: $15/7 \approx 2.1\,\text{m/s}^2$, rounded to $2.0\,\text{m/s}^2$.
(C) × Divides the final velocity by Δt: $27/5 = 5.4\,\text{m/s}^2$. Uses v_f instead of Δv.
(D) × Adds the two velocities and divides by Δt: $(12 + 27)/5 = 7.8\,\text{m/s}^2$. Confuses the sum of velocities with the change in velocity.

Key Principle: Average acceleration is the *change* in velocity divided by the *elapsed* time: $\bar{a} = \Delta v/\Delta t = (v_f - v_i)/(t_f - t_i)$. Use Δt, not t_f.

Solution: MCQ 1.19

$\boxed{\text{D}}$ **Fast Path:** Take east as positive, so $v_A = +30\,\text{m/s}$ and $v_B = -20\,\text{m/s}$:

$$v_{A/B} = v_A - v_B = (+30) - (-20) = +50\,\text{m/s}$$

The speed of A as seen from B is 50 m/s.

(A) × Treats both cars as moving in the same direction and subtracts: $30 - 20 = 10\,\text{m/s}$. Ignores that opposite directions carry opposite signs.
(B) × Reports car B's ground speed (20 m/s) instead of the relative speed.
(C) × Reports car A's ground speed (30 m/s), ignoring the motion of the observer's frame entirely.

Key Principle: The velocity of A relative to B is $v_{A/B} = v_A - v_B$. When the two motions are oppositely directed, their signs are opposite, so the relative speed is the *sum* of the ground speeds.

Free-Response Questions

Problems

Chapter 1 FRQ Roadmap

Use this roadmap to pick a problem by FRQ type, the concept it trains, and difficulty. Problems 1.1–1.4 form the *Core Four*: one of each AP FRQ type, together exercising every Learning Objective in Unit 1. Problem 1.5 is an *Extension* that adds explicit coverage of scalars/vectors and reference frames.

Legend. **MR** Mathematical Routines (10 pts, 20–25 min) • **TBR** Translation Between Representations (12 pts, 25–30 min) • **LAB** Experimental Design & Analysis (10 pts, 25–30 min) • **QQT** Qualitative/Quantitative Translation (8 pts, 15–20 min). Difficulty: ⋆ foundational, ⋆⋆ exam-level, ⋆ ⋆ ⋆ exam-stretch.

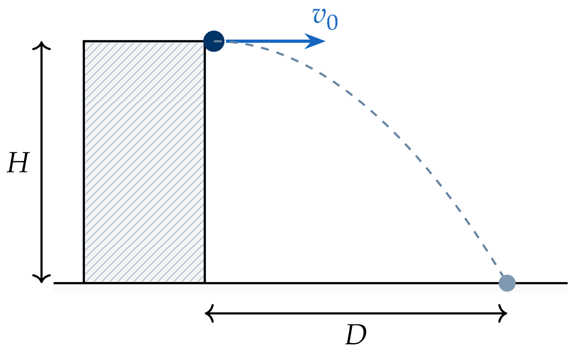
#	Type	Topics	What this problem trains	Level
Core Four — start here				
1.1	MR	1.2, 1.5	Projectile motion: independence of horizontal and vertical components; why mass does not affect range.	⋆⋆
1.2	TBR	1.2, 1.3	Constant velocity vs. constant acceleration; reading catch-up and equal-speed events off an x–t graph.	⋆ ⋆ ⋆
1.3	LAB	1.2, 1.3	Designing a kinematics experiment; linearizing d vs. t^2 to extract acceleration from a slope.	⋆⋆
1.4	QQT	1.2, 1.3	Free fall: connecting a qualitative scaling claim to functional dependence $h \propto v_0^2$.	⋆ ⋆ ⋆
Extension — after the core				
1.5	TBR	1.1, 1.4	Relative motion on a moving walkway; velocity addition and frame-dependent x–t representations.	⋆⋆

Topics: 1.1 Scalars and Vectors in 1D • 1.2 Displacement, Velocity, Acceleration • 1.3 Representing Motion • 1.4 Reference Frames and Relative Motion • 1.5 Vectors and Motion in 2D.

Problem 1.1

Topics 1.2, 1.5 · Skills 1.A, 2.A, 2.B, 3.B, 3.C · MR · ⋆⋆

A ball is launched horizontally from the edge of a cliff of height H with an initial speed v_0, as shown in the figure. The ball experiences negligible air resistance.



(a)

i. On the dot below, draw and label arrows that represent the forces (not components) exerted on the ball while it is in the air after it leaves the cliff. Each arrow should start on, and point away from, the dot. The relative lengths of the arrows should reflect the relative magnitudes of the forces.

ii. **Derive** an expression for the time t it takes the ball to reach the ground. Express your answer in terms of H, v_0, g, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

iii. **Derive** an expression for the horizontal distance D from the base of the cliff to where the ball lands. Express your answer in terms of H, v_0, g, and physical constants, as appropriate.

iv. **Calculate** the horizontal distance D if $H = 45\,\mathrm{m}$ and $v_0 = 12\,\mathrm{m/s}$.

(b) A second ball of mass $2m$ (where m is the mass of the original ball) is launched from the same cliff with the same initial horizontal speed v_0.

Indicate whether the horizontal distance traveled by the second ball is greater than, less than, or equal to D.

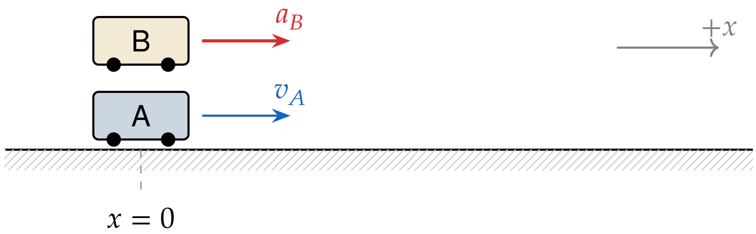
________ Greater than   ________ Less than   ________ Equal to

Justify your answer using physical principles.

Problem 1.2

Topics 1.2, 1.3 · Skills 1.A, 1.C, 2.A, 2.D, 3.B, 3.C · TBR · ⋆ ⋆ ⋆

Two carts, Cart A and Cart B, are on a long, straight, horizontal track. At time $t = 0$, both carts are at position $x = 0$. Cart A moves to the right with constant velocity v_A. Cart B starts from rest at $x = 0$ and accelerates uniformly to the right with acceleration a_B.



(**a**) In the space below, draw a motion diagram for Cart B for the time interval from $t = 0$ to some later time $t_f > 0$. The diagram should include:

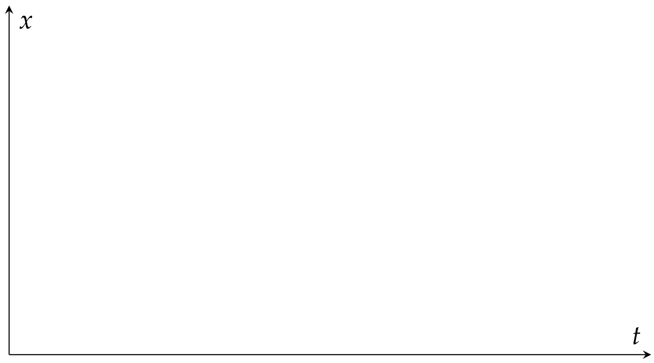
- At least five dots representing the position of Cart B at equally spaced time intervals
- A velocity vector at each dot

(**b**)

i. **Derive** an expression for the time t_m at which Cart B has the same speed as Cart A. Express your answer in terms of v_A, a_B, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

ii. **Derive** an expression for the time t_c at which Cart B is at the same position as Cart A for the first time after $t = 0$. Express your answer in terms of v_A, a_B, and physical constants, as appropriate.

(**c**) On the axes below, sketch graphs of position x as a function of time t for both Cart A and Cart B from $t = 0$ to a time after t_c. Label each curve "A" and "B."



(**d**) At time t_m (when both carts have the same speed), is Cart B ahead of, behind, or at the same position as Cart A?

________ Ahead of Cart A   ________ Behind Cart A   ________ At the same position as Cart A

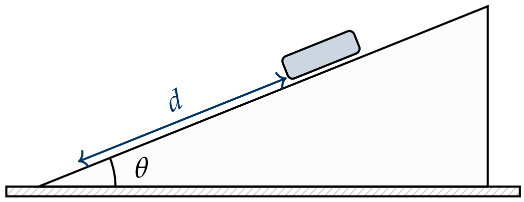
Justify your answer by referencing the graphs you sketched in Part (c).

Problem 1.3

Topics 1.2, 1.3 · Skills 1.B, 2.B, 2.D, 3.A, 3.B, 3.C · LAB · ⋆⋆

A group of students wants to determine the acceleration of a cart that is released from rest and rolls down a ramp inclined at a fixed angle θ. The students have access to the following equipment:

- A low-friction cart
- A ramp of adjustable length
- A meterstick
- An electronic stopwatch
- Tape to mark positions on the ramp



(a) Describe an experimental procedure the students could use to collect the data needed to determine the acceleration of the cart. Include any steps necessary to reduce experimental uncertainty.

(b) Describe how the data collected in Part (a) could be graphed and how that graph would be analyzed to determine the acceleration of the cart.

In a separate experiment, students release a different cart from rest on a ramp and measure the time t for the cart to travel various distances d down the ramp. The data are shown in the table below.

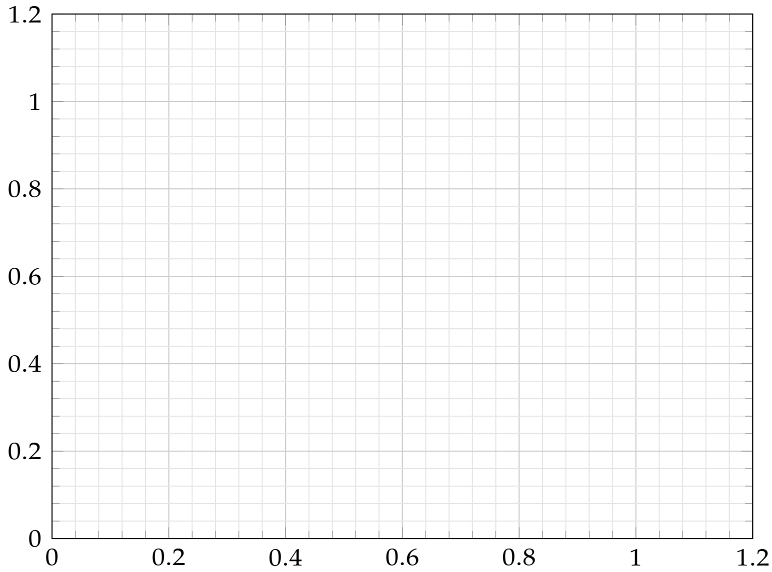
Distance d (m)	Time t (s)	t^2 (s^2)
0.20	0.46	
0.40	0.64	
0.60	0.76	
0.80	0.91	
1.00	1.01	

(c)

i. **Indicate** two quantities that, when graphed, yield a straight line whose slope can be used to calculate the acceleration of the cart. Fill in the blanks and complete the third column of the table above if needed.

Vertical axis: ____________________ Horizontal axis: ____________________

ii. On the grid below, **plot** the data points for the quantities indicated in Part (c) i. **Label** the axes with variable names, units, and an appropriate scale. **Draw** a straight best-fit line through the data.

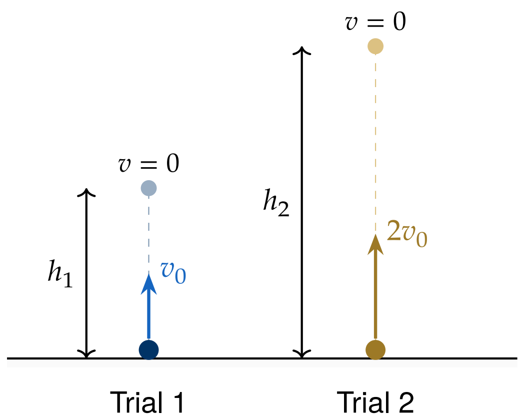


(d) Using the best-fit line, **calculate** an experimental value for the acceleration of the cart. Show your work, including how you determined the slope from two points on the best-fit line (not data points).

Problem 1.4

Topics 1.2, 1.3 · Skills 2.A, 2.D, 3.B, 3.C · QQT · ⋆ ⋆ ⋆

A ball is thrown straight up from ground level. In **Trial 1**, the ball is thrown with initial speed v_0 and reaches a maximum height h_1 before returning to the ground. In **Trial 2**, the ball is thrown straight up from the same position with initial speed $2v_0$ and reaches a maximum height h_2. Air resistance is negligible in both trials.



(a) **Indicate** whether h_2 is greater than, less than, or equal to $2h_1$.

______ $h_2 > 2h_1$ ______ $h_2 < 2h_1$ ______ $h_2 = 2h_1$

Justify your answer in terms of the motion of the ball in each trial. Use qualitative reasoning beyond referencing equations.

(b) Starting with a kinematic equation from the reference information, **derive** an expression for the maximum height h reached by a ball thrown straight up with initial speed v_0. Express your answer in terms of v_0, g, and physical constants, as appropriate.

(c) **Indicate** whether the expression derived in Part (b) is or is not consistent with the claim made in Part (a).

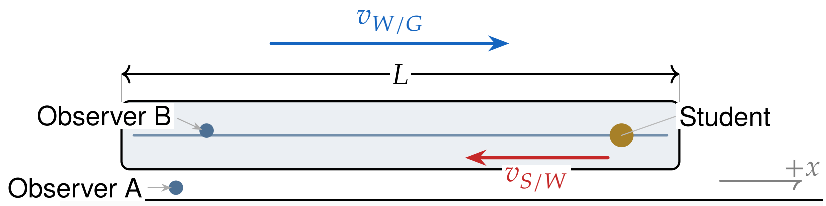
__________ Consistent   __________ Not consistent

Briefly **justify** your answer by referencing specific terms or functional dependence in the expression from Part (b).

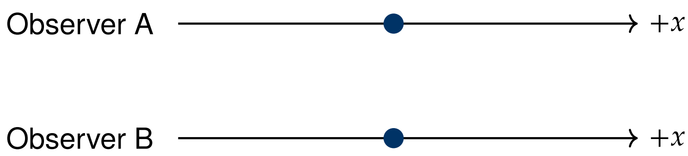
Problem 1.5

Topics 1.1, 1.4 · Skills 1.A, 1.C, 2.A, 2.D, 3.B, 3.C · TBR · ★★

A moving walkway of length L translates to the right with constant speed $v_{W/G}$ relative to the ground. At time $t = 0$, a student standing at the right end of the walkway begins walking to the left with constant speed $v_{S/W}$ relative to the walkway, as shown in the figure. Assume that $v_{W/G} > v_{S/W}$. Observer A stands on the ground next to the walkway, and Observer B stands on the walkway.



(a) On the number lines below, **draw** and **label** arrows that represent the velocity of the student as measured by each observer during a short time interval. On Observer A's number line, also **draw** and **label** an arrow that represents the velocity of the walkway. Each arrow should start on, and point away from, the dot shown. The direction of each arrow should indicate the sign of the velocity, and the relative lengths should reflect the relative magnitudes of the velocities.



(b)

i. The student reaches the left end of the walkway at time t_L. **Derive** an expression for t_L. Express your answer in terms of L, $v_{S/W}$, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

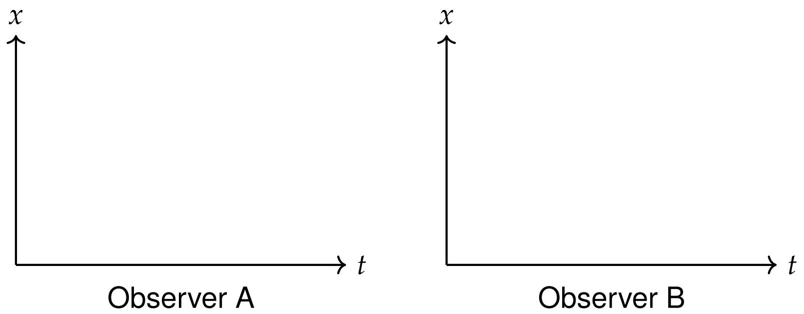
ii. During a short time interval Δt, the displacements $\Delta x_{S/G}$, $\Delta x_{S/W}$, and $\Delta x_{W/G}$ satisfy

$$\Delta x_{S/G} = \Delta x_{S/W} + \Delta x_{W/G}$$

Derive an expression for the student's velocity $v_{S/G}$ relative to the ground. Express your answer in terms of $v_{W/G}$, $v_{S/W}$, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

iii. **Derive** an expression for the student's displacement $\Delta x_{S/G}$ relative to the ground from $t = 0$ until the student reaches the left end of the walkway. Express your answer in terms of L, $v_{W/G}$, $v_{S/W}$, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

(c) On the axes below, **sketch** graphs of the student's position x as a function of time t during the interval from $t = 0$ to $t = t_L$ as measured by Observer A and by Observer B. Label each graph "A" or "B."



(d) A student makes the claim, "Because Observer A and Observer B measure different velocities for the person, they must measure different accelerations for the person as well."
Indicate whether the claim is correct.
Justify your answer by referencing your representations from Parts (a) and (c).

Solutions

Solution 1.1

Step 1 — Identify

Given: A ball is launched *horizontally* from a cliff of height H with initial speed v_0. Air resistance is negligible.

Find: (a) i. Forces on the ball in flight; ii. Time t to reach the ground; iii. Horizontal distance D; iv. Numerical value of D for $H = 45\,\text{m}$, $v_0 = 12\,\text{m/s}$.
(b) Whether doubling the mass changes D.

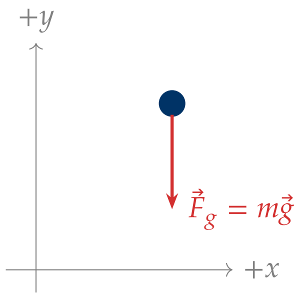
System: The ball (treated as a point particle).

Model: Projectile motion — constant gravitational acceleration $\vec{g}$ downward, no air resistance. Horizontal and vertical motions are independent.

Part (a) i — Free-Body Diagram

Step 2 — Represent

After the ball leaves the cliff, the only force acting on it is the **gravitational force** $\vec{F}_g = m\vec{g}$, directed straight downward. There is no horizontal force (air resistance is negligible) and no contact force (the ball is no longer touching the cliff).



Common Mistake

Do **not** draw a horizontal "force of motion" or "force in the direction of velocity." Velocity is not a force. Once the ball leaves the cliff, no horizontal force acts on it — it continues moving horizontally due to *inertia* (Newton's First Law).

Part (a) ii — Derive the time t to reach the ground

Step 3 — Solve

Fundamental Principle: Kinematic equation for constant acceleration in the vertical direction:

$$y = y_0 + v_{y0}\, t + \tfrac{1}{2} a_y\, t^2 \tag{1.1}$$

Set up the coordinate system. Place the origin at the launch point (top of the cliff) with the positive y-axis pointing upward:

- $y_0 = 0$ (ball starts at the origin),
- $y = -H$ (the ground is a distance H below the launch point),
- $v_{y0} = 0$ (the ball is launched *horizontally* — zero vertical initial velocity),
- $a_y = -g$ (gravitational acceleration, directed downward).

Substitute into (1.1):

$$-H = 0 + (0)\, t + \tfrac{1}{2}(-g)\, t^2$$

$$-H = -\tfrac{1}{2} g\, t^2$$

Solve for t:

$$H = \tfrac{1}{2} g\, t^2 \quad \Longrightarrow \quad t^2 = \frac{2H}{g} \quad \Longrightarrow \quad \boxed{t = \sqrt{\frac{2H}{g}}}$$

(We take the positive root because $t > 0$.)

Common Mistake

A frequent error is to set $v_{y0} = v_0$. The ball is launched *horizontally*, so its entire initial velocity is in the x-direction: $v_{x0} = v_0$ and $v_{y0} = 0$. Confusing the two changes the entire derivation.

Part (a) iii — Derive the horizontal distance D

Fundamental Principle: Kinematic equation for constant velocity in the horizontal direction (since $a_x = 0$):

$$x = x_0 + v_{x0}\,t \tag{1.2}$$

Substitute. With $x_0 = 0$, $x = D$, and $v_{x0} = v_0$:

$$D = v_0 \cdot t$$

Substitute the expression for t from Part (a) ii:

$$\boxed{D = v_0\sqrt{\frac{2H}{g}}}$$

In projectile motion with negligible air resistance, the horizontal and vertical components of motion are **independent**. The time of flight depends only on the vertical displacement and the vertical initial velocity — the horizontal speed does not affect how long the ball is in the air.

Part (a) iv — Calculate D for $H = 45\,\mathrm{m}$, $v_0 = 12\,\mathrm{m/s}$

Substitute the given values into the expression from Part (a) iii, using $g = 9.8\,\mathrm{m/s^2}$:

$$D = (12\,\mathrm{m/s})\sqrt{\frac{2 \times 45\,\mathrm{m}}{9.8\,\mathrm{m/s^2}}} = (12\,\mathrm{m/s})\sqrt{\frac{90\,\mathrm{m}}{9.8\,\mathrm{m/s^2}}} = (12\,\mathrm{m/s})\sqrt{9.18\,\mathrm{s^2}}$$

$$D = (12\,\mathrm{m/s})(3.03\,\mathrm{s}) \qquad \Longrightarrow \qquad \boxed{D \approx 36\,\mathrm{m}}$$

Step 4 — Evaluate

- **Units check:** $[\mathrm{m/s}] \times [\mathrm{s}] = [\mathrm{m}]$ ✓
- **Limiting cases:**
  - If $v_0 \to 0$, then $D \to 0$ (ball drops straight down). ✓
  - If $H \to 0$, then $t \to 0$ and $D \to 0$ (no time to travel horizontally). ✓
  - If H increases, D increases (more time in the air ⇒ more horizontal distance). ✓
- **Reasonableness:** A 45 m cliff is roughly a 15-storey building, and $12\,\mathrm{m/s} \approx 43\,\mathrm{km/h}$. Landing 36 m away is physically sensible.
- **Physical insight:** The time of flight $t = \sqrt{2H/g}$ is set entirely by the height— it equals the fall time of a ball simply dropped from height H. The launch speed fixes only *how far* the ball travels in that time, not *how long* it stays aloft.

Part (b) — Effect of doubling the mass

______	______	**Equal to**
Greater than	Less than	Equal to

Claim: The horizontal distance traveled by the second ball (mass $2m$) is **equal to** D.

Justification using physical principles:
The expression derived in Part (a) iii is $D = v_0\sqrt{2H/g}$. This expression contains v_0, H, and g — it does **not** depend on the mass of the ball.

Why mass does not matter: The only force on the ball (with negligible air resistance) is the gravitational force $\vec{F}_g = m\vec{g}$. By Newton's Second Law, the acceleration of the ball is:

$$\vec{a} = \frac{\vec{F}_g}{m} = \frac{m\vec{g}}{m} = \vec{g}$$

The mass cancels. Therefore all objects in free fall experience the same acceleration $\vec{g}$, regardless of mass. Since both balls are launched with the **same** initial speed v_0 from the **same** height H, they follow identical trajectories and land at the same horizontal distance D.

Common Mistake

A common error is to argue the heavier ball "falls faster" and lands closer to the cliff. This confuses *weight* ($F_g = mg$, which *does* grow with mass) with *acceleration* (which equals g for all objects in free fall): the heavier ball feels a larger force, but its inertia is larger in the same proportion, so the two cancel.

All objects in free fall (negligible air resistance) share the same acceleration g, regardless of mass. Because $F_g = mg$, Newton's Second Law gives $a = F_g/m = g$, independent of mass—which is why projectile-motion equations never contain mass.

Solution 1.2

Step 1 — Identify

Given: Two carts on a straight horizontal track. At $t = 0$ both are at $x = 0$. Cart A moves right with constant velocity v_A. Cart B starts from rest and accelerates uniformly to the right with acceleration a_B.

Find: (a) Motion diagram for Cart B; (b) i. Time t_m when Cart B reaches speed v_A; (b) ii. Time t_c when Cart B catches Cart A; (c) Position-vs-time graphs; (d) Relative position at t_m.

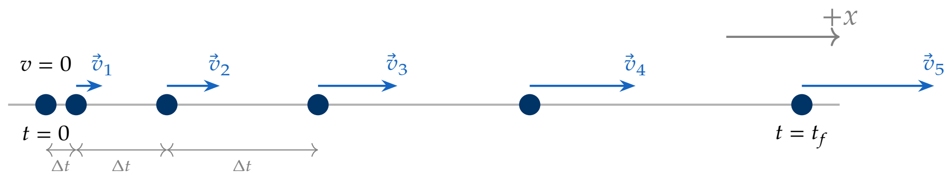
System: Each cart individually (no interaction between them).

Model: Cart A: constant velocity (zero acceleration).
Cart B: constant acceleration from rest (uniformly accelerated motion).

Part (a) — Motion Diagram for Cart B

Step 2 — Represent

Cart B starts from rest and accelerates uniformly to the right. In equal time intervals the cart covers *increasing* distances (since $\Delta x \propto t^2$), so the dots are spaced farther and farther apart. The velocity vector at each dot points to the right and *grows* in length because the cart is speeding up.



Key features:

- The dots are *unequally spaced* — gaps grow with time because the speed is increasing.
- Every velocity vector points in the $+x$ direction (to the right).
- Each successive velocity vector is *longer* than the previous one, reflecting the constant positive acceleration.
- The first dot (at $t = 0$) has no velocity vector because Cart B starts from rest.

Common Mistake

Do not draw equally spaced dots for an accelerating object: equal spacing means constant velocity. For uniform acceleration from rest, consecutive gaps grow as $1 : 3 : 5 : 7 : \ldots$ (the odd-number rule).

Part (b) i — Derive the time t_m when Cart B has the same speed as Cart A

Step 3 — Solve

Fundamental Principle: Kinematic equation for velocity under constant acceleration:

$$v = v_0 + a\,t \tag{1.3}$$

Apply to Cart B. Cart B starts from rest ($v_{B0} = 0$) with constant acceleration a_B:

$$v_B(t) = 0 + a_B\,t = a_B\,t$$

Set $v_B = v_A$ (the condition at time t_m):

$$v_A = a_B\,t_m$$

Solve for t_m**:**

$$\boxed{t_m = \frac{v_A}{a_B}}$$

Part (b) ii — Derive the time t_c when Cart B is at the same position as Cart A

Fundamental Principle: Kinematic equation for position under constant acceleration:

$$x = x_0 + v_0\,t + \tfrac{1}{2}\,a\,t^2 \tag{1.4}$$

Position of Cart A (constant velocity, starting at $x = 0$):

$$x_A(t) = v_A\,t$$

Position of Cart B (accelerating from rest at $x = 0$):

$$x_B(t) = \tfrac{1}{2}\,a_B\,t^2$$

Set $x_A = x_B$ at time t_c:

$$v_A\, t_c = \tfrac{1}{2}\, a_B\, t_c^2$$

Solve for t_c**.** Since we want the first time *after* $t = 0$, we can divide both sides by t_c (which is nonzero):

$$v_A = \tfrac{1}{2}\, a_B\, t_c \qquad \Longrightarrow \qquad \boxed{t_c = \frac{2\, v_A}{a_B}}$$

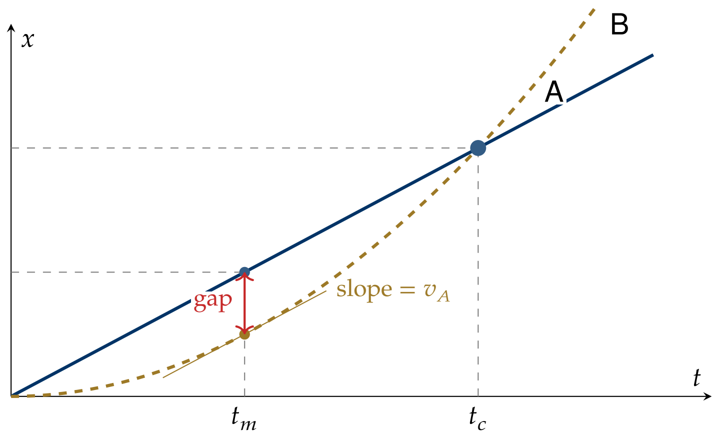
Exam Tip

Notice that $t_c = 2\, t_m$. Cart B catches Cart A at exactly twice the time it takes to match Cart A's speed. This is a useful relationship to remember for checking your answer.

Common Mistake

When $x_A = x_B$ gives $v_A\, t_c = \frac{1}{2}\, a_B\, t_c^2$, do not divide by t_c and lose the $t_c = 0$ root. That root is the trivial start (both at the same point); the meaningful answer is the first time *after* $t = 0$, namely $t_c = 2v_A/a_B$.

Part (c) — Graphs of x vs t for both carts



Graph features:

- **Cart A** (solid line): a *straight line* through the origin with constant slope v_A. This represents constant-velocity motion ($x_A = v_A\, t$).
- **Cart B** (dashed curve): an upward-opening *parabola* starting at the origin with zero slope. This represents uniformly accelerated motion from rest ($x_B = \frac{1}{2} a_B\, t^2$). The slope (instantaneous velocity) increases with time.
- The curves **intersect** at $t = 0$ (both start at $x = 0$) and again at $t = t_c$ (Cart B catches Cart A).
- At $t = t_m$, the **slope of curve B equals the slope of line A** (both have speed v_A), but Cart B is still below Cart A on the graph.
- For $t > t_c$, the parabola is above the straight line — Cart B is ahead of Cart A and pulling away.

Common Mistake

Do not draw Cart B's graph as a straight line. A straight line on an x-vs-t graph means constant velocity (zero acceleration). Cart B is accelerating, so its position-vs-time graph must be a *curve* (specifically, a parabola for constant acceleration).

Part (d) — Is Cart B ahead of, behind, or at the same position as Cart A at time t_m?

________	**Behind Cart A**	________
Ahead of Cart A	Behind Cart A	At the same position as Cart A

Justification from the graph (Part c):
At time t_m, the straight line (Cart A) is **above** the parabola (Cart B) on the x-vs-t graph. Since the vertical axis represents position, a higher curve means a larger position value. Therefore Cart B is **behind** Cart A at time t_m.

Algebraic verification:
At $t_m = v_A/a_B$:

$$x_A(t_m) = v_A \cdot \frac{v_A}{a_B} = \frac{v_A^2}{a_B}$$

$$x_B(t_m) = \tfrac{1}{2}\,a_B\left(\frac{v_A}{a_B}\right)^2 = \tfrac{1}{2}\,a_B \cdot \frac{v_A^2}{a_B^2} = \frac{v_A^2}{2\,a_B}$$

$$x_B(t_m) = \tfrac{1}{2}\,x_A(t_m)$$

Cart B has traveled only **half** the distance that Cart A has traveled by time t_m. Cart B is behind.

Matching speeds does not mean matching positions. When an object accelerating from rest reaches the same instantaneous speed as a constant-velocity object, it has covered only *half* the distance: its average velocity over $[0, t_m]$ is $\bar{v}_B = \tfrac{1}{2}\,v_A$ versus $\bar{v}_A = v_A$. It needs a second interval of length t_m—now moving faster—to close the gap and catch up at $t_c = 2\,t_m$.

Step 4 — Evaluate

- **Units check:** $t_m = v_A/a_B$: $[\mathrm{m/s}]/[\mathrm{m/s^2}] = [\mathrm{s}]$ ✓. $t_c = 2v_A/a_B$: $[\mathrm{m/s}]/[\mathrm{m/s^2}] = [\mathrm{s}]$ ✓.
- **Limiting cases:**
  - If a_B is very large, t_m and t_c are both small (Cart B catches up quickly). ✓
  - If v_A is very large, t_m and t_c are both large (Cart B takes longer to match and overtake a faster Cart A). ✓
  - As $a_B \to 0$, $t_c \to \infty$ (Cart B never catches Cart A if it doesn't accelerate). ✓
- **Internal consistency:** $t_c = 2\,t_m$ makes physical sense: Cart B spends the first half of the interval (0 to t_m) moving slower than Cart A and falling behind, then the second half (t_m to t_c) moving faster than Cart A and closing the gap. By symmetry of the velocity–time graph, the area "lost" in the first half exactly equals the area "gained" in the second half.

- **Physical insight:** The area under each cart's v-vs-t graph gives its displacement. At t_c, the two areas (a triangle for Cart B and a rectangle for Cart A) are equal, confirming $t_c = 2v_A/a_B$.

Solution 1.3

Step 1 — Identify

Given: A cart released from rest rolls down a ramp at fixed angle θ. Equipment: low-friction cart, ramp, meterstick, electronic stopwatch, tape.

Find: (a) Experimental procedure; (b) Graphing strategy; (c) Linearized plot of data; (d) Acceleration from best-fit line.

System: The cart on the ramp.

Model: Constant acceleration from rest along the ramp (low friction). The kinematic equation $d = \frac{1}{2}at^2$ relates distance, time, and acceleration.

Part (a) — Experimental Procedure

1. Use the meterstick to mark several positions along the ramp at known distances d from a fixed starting line (e.g. $d = 0.20\,\text{m}$, $0.40\,\text{m}$, $0.60\,\text{m}$, $0.80\,\text{m}$, $1.00\,\text{m}$). Place tape at each mark.
2. Place the cart at the starting line. Release the cart from rest (do *not* push it). Use the electronic stopwatch to measure the time t for the cart to travel from the starting line to the first tape mark at $d = 0.20\,\text{m}$.
3. Repeat the measurement for each marked distance d, always releasing the cart from rest at the same starting line.
4. **To reduce experimental uncertainty:** for each distance d, perform at least three trials and record the average time $\bar{t}$. This minimizes the effect of random timing errors (human reaction time with the stopwatch).

Common Mistake

A common error on LAB questions is being vague about *what* is measured and *how*. Always specify: the quantity measured (d with the meterstick, t with the stopwatch), what is varied (d), and what is held constant (starting position, angle θ, release from rest). Avoid filler like "gather equipment."

Part (b) — Graphing and Analysis Strategy

Fundamental Principle: For an object starting from rest with constant acceleration a:

$$d = \frac{1}{2}\,a\,t^2$$

This can be rewritten as:

$$d = \left(\frac{1}{2}\,a\right)t^2$$

This has the form $y = mx$ where $y = d$, $x = t^2$, and the slope is $m = \frac{1}{2}a$.

Graphing strategy: Plot d (vertical axis) versus t^2 (horizontal axis). The data should form a straight line through (or near) the origin.
Analysis: Determine the slope of the best-fit line. Since slope $= \frac{1}{2}a$, the acceleration is:

$$\boxed{a = 2 \times \text{slope}}$$

Linearization is the core strategy for LAB questions. When a kinematic equation gives a nonlinear relationship ($d \propto t^2$), plot the data using transformed variables (d vs t^2) so the result is a straight line. The slope of that line encodes the physical quantity you want to determine.

Part (c) i — Quantities for a Straight-Line Graph

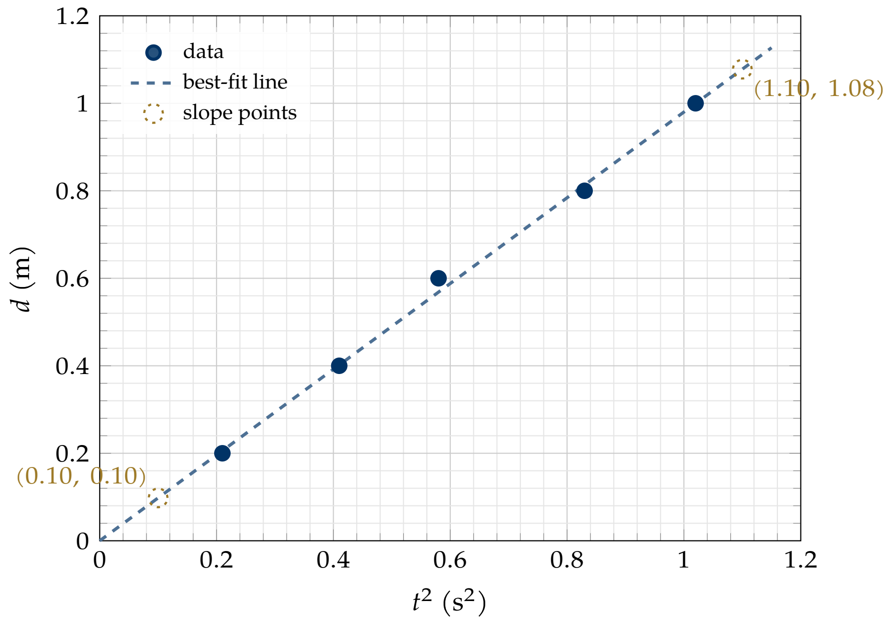
Vertical axis: d (m)   Horizontal axis: t^2 (s^2)

Completed table (third column):

Distance d (m)	Time t (s)	t^2 (s^2)
0.20	0.46	0.21
0.40	0.64	0.41
0.60	0.76	0.58
0.80	0.91	0.83
1.00	1.01	1.02

Part (c) ii — Data Plot with Best-Fit Line

Step 2 — Represent



Graph checklist:

- Both axes are labeled with variable name *and* units.
- All five data points are plotted.
- A straight **best-fit line** is drawn through the trend of the data (not connecting the dots point-to-point).
- Two points *on the line* (circled, not data points) are marked for the slope calculation.

Common Mistake

Do **not** "connect the dots" with line segments. A best-fit line follows the overall *trend*—some points fall slightly above it, others below. And the two points used for the slope must lie **on the line**, not on data points (which carry scatter).

Part (d) — Calculate the Acceleration

Step 3 — Solve

Pick two points on the best-fit line (far apart, not data points):

$$(t_1^2,\ d_1) = (0.10\,\mathrm{s}^2,\ 0.10\,\mathrm{m}) \qquad \text{and} \qquad (t_2^2,\ d_2) = (1.10\,\mathrm{s}^2,\ 1.08\,\mathrm{m})$$

Calculate the slope:

$$\text{slope} = \frac{d_2 - d_1}{t_2^2 - t_1^2} = \frac{1.08\,\mathrm{m} - 0.10\,\mathrm{m}}{1.10\,\mathrm{s}^2 - 0.10\,\mathrm{s}^2} = \frac{0.98\,\mathrm{m}}{1.00\,\mathrm{s}^2} = 0.98\,\mathrm{m/s^2}$$

Relate slope to acceleration. From Part (b), slope $= \frac{1}{2}a$, so:

$$a = 2 \times \text{slope} = 2 \times 0.98\,\mathrm{m/s^2}$$

$$\boxed{a \approx 2.0\,\mathrm{m/s^2}}$$

Exam Tip

On the LAB question, the slope calculation is worth dedicated points. Always show: (1) which two points you chose *on the line*, (2) the slope formula with substituted values, and (3) how you converted the slope into the physical quantity. Using data points instead of points on the line is a common scoring error.

Step 4 — Evaluate

- **Units check:** slope has units $[\mathrm{m}]/[\mathrm{s}^2] = [\mathrm{m/s^2}]$; multiplying by 2 preserves units. ✓
- **Reasonableness:** The acceleration $a \approx 2.0\,\mathrm{m/s^2}$ is less than $g = 9.8\,\mathrm{m/s^2}$, which makes sense for a moderately inclined ramp. The component of gravitational acceleration along the ramp is $g\sin\theta$; for $a \approx 2.0\,\mathrm{m/s^2}$ this gives $\theta \approx 12°$, a reasonable ramp angle. ✓
- **Graph consistency:** The best-fit line passes close to the origin, consistent with the physical expectation ($d = 0$ when $t = 0$). All data points lie near the line, indicating constant acceleration. ✓

For any LAB question: (1) identify the equation linking your measured quantities, (2) **linearize** it so the target appears in the slope, (3) plot the linearized data, (4) draw a best-fit line, and (5) extract the target from the slope using two points *on the line*.

Solution 1.4

Step 1 — Identify

Given: Trial 1: ball thrown straight up with speed v_0, reaches height h_1.
Trial 2: ball thrown straight up with speed $2v_0$, reaches height h_2.
Air resistance is negligible in both trials.

Find: (a) Whether h_2 is $>$, $<$, or $=$ to $2h_1$, with qualitative justification.
(b) Derive h in terms of v_0 and g.
(c) Whether the expression is consistent with the claim.

System: The ball (point particle in free fall).

Model: Free fall with constant downward acceleration g; no air resistance.

Part (a) — Indicate and Justify

$\boldsymbol{h_2 > 2h_1}$	______	______
$h_2 > 2h_1$	$h_2 < 2h_1$	$h_2 = 2h_1$

Claim: $h_2 > 2h_1$.

Qualitative justification (no equations):
In both trials, the ball decelerates at the **same constant rate** (g downward) — this does not change between trials. Only the initial speed changes.

- **What stays the same:** the deceleration (the gravitational acceleration g).
- **What changes:** the initial speed doubles from v_0 to $2v_0$.

In Trial 2 the ball starts with twice the speed, so it takes **twice as long** to decelerate to rest (the gravitational acceleration removes speed at a fixed rate, so twice the initial speed requires twice the time).
During this longer flight, the ball is also traveling **faster on average**: the average upward speed in Trial 2 is double that of Trial 1 (since average speed $= \frac{1}{2}\times$ initial speed for uniform deceleration from v to 0).
The maximum height equals the average speed multiplied by the time of ascent. Since *both* the average speed and the time of ascent double, the height increases by a factor of $2 \times 2 = 4$:

$$h_2 = 4\,h_1 \;>\; 2\,h_1$$

Common Mistake

Many students claim $h_2 = 2h_1$, reasoning "double the speed, double the height." This ignores that the ball also rises for *twice as long* before stopping. Height depends on *both* speed and time, so it scales with the *square* of the launch speed, not linearly.

Part (b) — Derive h in terms of v_0 and g

Step 3 — Solve

Fundamental Principle: Kinematic equation relating velocity, acceleration, and displacement (from the reference information):

$$v^2 = v_0^2 + 2\,a\,(\Delta y) \tag{1.5}$$

Identify the conditions at maximum height:

- $v = 0$ (the ball momentarily stops at its peak),
- $a = -g$ (gravitational acceleration, directed downward),
- $\Delta y = h$ (the displacement from launch to peak).

Substitute into (1.5):

$$0^2 = v_0^2 + 2(-g)(h)$$
$$0 = v_0^2 - 2\,g\,h$$

Solve for h:

$$2\,g\,h = v_0^2 \qquad \Longrightarrow \qquad \boxed{h = \frac{v_0^2}{2g}}$$

Common Mistake

Some students use $v^2 = v_0^2 + 2a\Delta y$ but forget to set $v = 0$ at the maximum height, or use $a = +g$ instead of $a = -g$ (with upward positive). Always define your sign convention explicitly and remember: at the peak, the velocity is instantaneously zero.

Part (c) — Consistency with the Claim

Consistent	
Consistent	Not consistent

Justification using functional dependence:

The expression from Part (b) is $h = \dfrac{v_0^2}{2g}$.

The maximum height h is **proportional to the square** of the initial speed ($h \propto v_0^2$), because v_0^2 appears in the **numerator** and g (a constant) appears in the denominator.

Applying this to the two trials:

- Trial 1: $h_1 = \dfrac{v_0^2}{2g}$
- Trial 2: $h_2 = \dfrac{(2v_0)^2}{2g} = \dfrac{4\,v_0^2}{2g} = 4\,h_1$

Since $h_2 = 4\,h_1$ and $4\,h_1 > 2\,h_1$, the derived expression confirms the claim that $h_2 > 2h_1$. This is **consistent** with Part (a).

Common Mistake

A frequent error is writing $(2v_0)^2 = 2v_0^2$ instead of $(2v_0)^2 = 2^2 \cdot v_0^2 = 4v_0^2$—squaring a product squares *both* factors. Chief Reader Reports list this among the most common algebraic errors on the AP exam.

Functional dependence is the core of QQT questions. When a quantity depends on the *square* of a variable ($h \propto v_0^2$), doubling it *quadruples* the result. Identify the power law in your expression and justify with language like "proportional to" or "inversely proportional to."

Step 4 — Evaluate

- **Units check:** $[v_0^2]/[g] = [\mathrm{m}^2/\mathrm{s}^2]/[\mathrm{m}/\mathrm{s}^2] = [\mathrm{m}]$ ✓
- **Limiting cases:**
  - If $v_0 \to 0$, then $h \to 0$ (no initial speed ⇒ no height gained). ✓
  - If $g \to \infty$, then $h \to 0$ (extremely strong gravity stops the ball almost immediately). ✓
  - If $g \to 0$, then $h \to \infty$ (no gravity means the ball never decelerates). ✓
- **Reasonableness:** For $v_0 = 10\,\mathrm{m/s}$: $h = (10)^2/(2\times 9.8) \approx 5.1\,\mathrm{m}$. Throwing a ball upward at $\sim 10\,\mathrm{m/s}$ ($\approx 36\,\mathrm{km/h}$) and reaching about 5 m is realistic. ✓
- **Physical insight:** The v_0^2 dependence means that small increases in launch speed yield disproportionately large increases in maximum height. This is why the "double the speed" intuition ($h_2 = 2h_1$) is wrong — height grows *quadratically* with speed, not linearly.

Solution 1.5

Step 1 — Identify

Given: A walkway of length L moves to the right with constant speed $v_{W/G}$ relative to the ground. A student at the right end walks to the left with constant speed $v_{S/W}$ relative to the walkway, with $v_{W/G} > v_{S/W}$.

Find: (a) Velocity arrows for the student as measured by Observers A and B, and the walkway velocity for Observer A.
(b) i. An expression for t_L.
(b) ii. An expression for $v_{S/G}$.
(b) iii. An expression for $\Delta x_{S/G}$.
(c) Position-versus-time graphs for the student in the two reference frames.
(d) Whether the two observers must measure different accelerations.

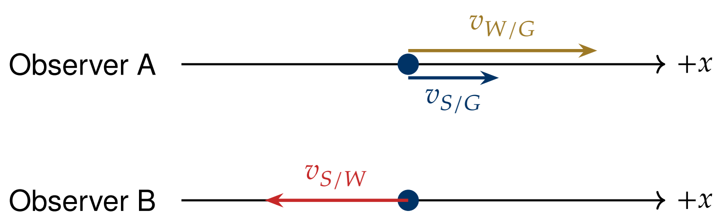
System: The student, described from two reference frames: the ground frame and the walkway frame.

Model: One-dimensional motion with constant velocity in each frame. The ground and walkway frames move at constant velocity relative to each other, so both are inertial frames for this problem.

Part (a) — Velocity Arrows on the Number Lines

Step 2 — Represent

Observer A (on the ground) sees the walkway move right at $v_{W/G}$. Because the walkway outpaces the student's leftward walk, Observer A sees the student move *right* at the smaller speed $v_{S/G} = v_{W/G} - v_{S/W}$. Observer B rides the walkway, so sees the student move left at $v_{S/W}$.



Common Mistake

Do not give Observer A a left-pointing student velocity just because the student is walking left relative to the walkway. Velocity depends on the reference frame. Relative to the ground, the walkway's rightward motion partly cancels the student's leftward walking motion.

Part (b) i — Derive an Expression for t_L

Step 3 — Solve

Fundamental Principle: For motion at constant velocity,

$$x_f = x_i + v_x t \tag{1.6}$$

Use Observer B's frame. Choose $x = 0$ at the *left* end of the walkway. Then the student starts at the right end, so $x_i = L$, and reaches the left end at $x_f = 0$. Because the student walks left, the signed velocity is $v_x = -v_{S/W}$.
Substitute:

$$0 = L + (-v_{S/W})t_L$$

$$0 = L - v_{S/W}t_L$$

Solve for t_L:

$$v_{S/W} t_L = L \qquad \Longrightarrow \qquad \boxed{t_L = \frac{L}{v_{S/W}}}$$

Common Mistake

The arrival time is set by the student's speed *relative to the walkway*, not the ground. Using $v_{W/G} - v_{S/W}$ here would lose the frame information that fixes when the student reaches the left end.

Part (b) ii — Derive an Expression for $v_{S/G}$

Fundamental Principle: The displacements satisfy

$$\Delta x_{S/G} = \Delta x_{S/W} + \Delta x_{W/G}$$

Divide by the time interval Δt:

$$\frac{\Delta x_{S/G}}{\Delta t} = \frac{\Delta x_{S/W}}{\Delta t} + \frac{\Delta x_{W/G}}{\Delta t}$$

$$v_{S/G} = v_{S/W,x} + v_{W/G}$$

Apply the sign convention. The student walks left relative to the walkway, so $v_{S/W,x} = -v_{S/W}$. Therefore,

$$v_{S/G} = -v_{S/W} + v_{W/G}$$

$$\boxed{v_{S/G} = v_{W/G} - v_{S/W}}$$

Because $v_{W/G} > v_{S/W}$, the result is positive, so the student still moves to the right relative to the ground.

Common Mistake

Do not add *speeds* without signs. Relative-motion equations use signed velocities: the walkway's is positive, but the student's relative to the walkway is negative (it points left).

Part (b) iii — Derive an Expression for $\Delta x_{S/G}$

Fundamental Principle: For constant velocity,

$$\Delta x = v \Delta t$$

Apply to the student's motion relative to the ground:

$$\Delta x_{S/G} = v_{S/G} t_L$$

Substitute the results from Parts (b) i and (b) ii:

$$\Delta x_{S/G} = (v_{W/G} - v_{S/W}) \left(\frac{L}{v_{S/W}} \right)$$

$$\boxed{\Delta x_{S/G} = \frac{L\left(v_{W/G} - v_{S/W}\right)}{v_{S/W}} = L\left(\frac{v_{W/G}}{v_{S/W}} - 1\right)}$$

Common Mistake

Do not set $\Delta x_{S/G} = \pm L$. The student reaches the left end of a *moving* walkway, so the ground-frame displacement is not just L—it must include the walkway's motion during t_L.

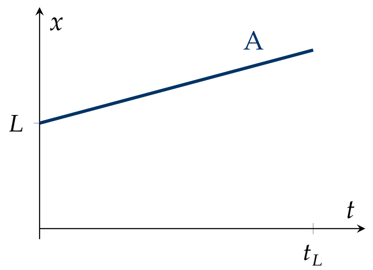
Part (c) — Sketch x Versus t for Observers A and B

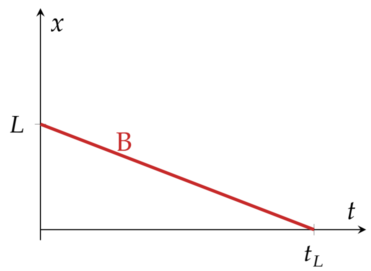
One consistent coordinate choice: Take $x = 0$ at the left end of the walkway at $t = 0$. Then the student starts at $x = L$ in both graphs.

$$x_A(t) = L + (v_{W/G} - v_{S/W})t$$
$$x_B(t) = L - v_{S/W}t$$

Graph features:

- Both graphs are **straight lines** because each observer measures a constant velocity.
- Observer A's graph has a **positive slope** $v_{W/G} - v_{S/W}$.
- Observer B's graph has a **negative slope** $-v_{S/W}$.
- In this coordinate choice, both graphs start at $x = L$ when $t = 0$, and Observer B's graph reaches $x = 0$ at $t = t_L$.





Common Mistake

Do not draw curved graphs. In both frames the student's velocity is constant, so x versus t must be linear. The observers disagree about the *slope*, not about whether the motion is accelerated.

Part (d) — Evaluate the Claim About Acceleration

	Incorrect
Correct	Incorrect

Claim: The statement is **incorrect**.

Justification using Parts (a) and (c):
In Part (a), each observer assigns the student a single velocity arrow: Observer A measures a constant rightward velocity, and Observer B measures a constant leftward velocity.
In Part (c), both x-versus-t graphs are straight lines, so each graph has a constant slope. Constant slope means constant velocity, and constant velocity means zero acceleration:

$$\boxed{a_A = 0 \qquad \text{and} \qquad a_B = 0}$$

So the observers measure *different velocities* but the *same acceleration*.

Relative position and velocity depend on the reference frame, but two observers moving at constant velocity relative to one another measure the same acceleration. Changing frames shifts the slope of an x-versus-t graph by a constant amount; it does not add curvature.

Step 4 — Evaluate

- **Units check:** $[t_L] = [L]/[v_{S/W}] = [\mathrm{m}]/[\mathrm{m/s}] = [\mathrm{s}]$ and $[\Delta x_{S/G}] = [\mathrm{m}] \cdot [\mathrm{m/s}]/[\mathrm{m/s}] = [\mathrm{m}]$. ✓
- **Limiting cases:**
  - If $v_{W/G} = v_{S/W}$, then $v_{S/G} = 0$ and $\Delta x_{S/G} = 0$. The student stays above the same point on the ground while walking to the left end. ✓
  - If $v_{W/G} \to 0$, then $v_{S/G} \to -v_{S/W}$. The situation reduces to ordinary walking left on stationary ground. ✓
  - If $v_{S/W} \to 0$, then $t_L \to \infty$. A student who does not walk never reaches the left end. ✓
- **Reasonableness:** Because $v_{W/G} > v_{S/W}$, $\Delta x_{S/G} > 0$ as expected: even while walking left on the walkway, the student drifts right relative to the ground. ✓
- **Physical insight:** The walkway adds a constant offset to the student's velocity, which shifts velocity and slope but, being time-independent, creates no acceleration. ✓

Exam Readiness

Own These Three Ideas

- Choose the motion model before reaching for an equation. Constant velocity, constant acceleration, projectile, and relative motion each have a different first move.
- Components and frames are bookkeeping, not physics. Projectiles share one time variable across two independent axes ($a_x = 0$, $a_y = -g$); relative-motion problems require every velocity signed in one chosen frame.
- Graphs carry physical meaning, not just shapes. Slopes give rates, signed areas give accumulated change; never rank by peak height alone.

Recognize the Problem

If the problem gives...	Use...	First move
Horizontal launch from height h	Component kinematics	Solve the vertical equation for t from h alone, then $D = v_{0x}\,t$
"Peak," "apex," or "momentarily at rest"	Vertical kinematics	Set $v_y = 0$; keep $a_y = -g$ throughout the flight
One missing variable in constant-a motion	Equation chooser	Pick the equation that omits the variable you don't know and don't need
$v(t)$ graph and a question about Δx or a	Slope or signed area	Slope gives a; signed area gives Δx — not the y-value, not the peak
"Relative to the ground," walkway, current, or train	Relative velocity	Pick $+x$ once, sign every velocity in that frame, then add

Spot the Recurring Patterns

- When a problem gives horizontal launch from height h, fall time depends only on h. The launch speed never enters the time equation — it only sets the range $D = v_{0x}\,t$.
- Whenever a $v(t)$ graph crosses zero, the object reverses direction at that instant. Position has a local extremum there — not a zero.
- When a question asks how a quantity scales — doubling v_0, quadrupling h — check whether the dependence is linear or quadratic first. Ranking distractors typically assume the wrong power.
- For two-segment motion (accelerate, then coast; or coast, then decelerate), solve each segment independently and stitch at the boundary. Treating it as one uniformly accelerated motion overcounts the average velocity.
- Whenever the problem mentions "relative to the ground" versus "relative to the train," pick one inertial frame and never mix. Accelerations agree across inertial frames; velocities do not.
- For comparison between $v(t)$ curves, rank displacement by signed area, not by peak height; rank acceleration by slope, not by y-value. Different shapes can enclose the same displacement.
- At a projectile's peak, only $v_y = 0$. The horizontal velocity v_x is unchanged and $a_y = -g$ throughout. The speed at the apex equals $|v_x|$, not zero.

Know the Most-Tested Scenarios

- Horizontal launch from a tabletop or cliff — range from v_{0x} and a fall time set by h.
- Straight-up throw or vertical drop — find v at the peak, the time to apex, or the speed at impact.
- Two-segment motion — a vehicle accelerates from rest, then travels at constant speed.
- $v(t)$- or $x(t)$-graph comparison — two objects on the same axes, ranked by displacement, speed, or acceleration.
- Relative motion — boat in a current, walker on a moving walkway, or two observers in different inertial frames.

Run Your Final Checks

✓ **Before scaling a fall time with height:** confirm $t \propto \sqrt{h}$, not $t \propto h$. Quadrupling h only doubles the fall time; doubling h multiplies t by $\sqrt{2}$.

✓ **Before reading the velocity at a projectile's peak:** remember $v_y = 0$ *only*. The horizontal component v_x and the downward $a_y = -g$ persist. Speed at the apex is $|v_x|$.

✓ **Before adding relative velocities:** pick a single $+x$, write every velocity with its sign, then apply $\vec{v}_{A/C} = \vec{v}_{A/B} + \vec{v}_{B/C}$. Never sum magnitudes before assigning signs.

✓ **Before ranking on a $v(t)$ graph:** rank displacement by signed area and acceleration by slope. Peak height is not displacement; final y-value is not acceleration.

✓ **Before choosing a constant-acceleration equation:** identify the variable you don't know *and* don't need, then pick the equation that omits it. Choosing by what is given wastes steps.

If you have one minute before the exam, review:

- **Central observation:** kinematics describes motion without causes; choose the model (constant v, constant a, projectile, relative) before picking an equation.
- $v^2 = v_0^2 + 2a\,\Delta x$ — *when t is neither given nor asked*; otherwise use $v = v_0 + at$ or $\Delta x = v_0 t + \frac{1}{2}at^2$.
- Projectiles: one time variable, $a_x = 0$, $a_y = -g$; at the peak $v_y = 0$ only — v_x and a_y are unchanged.
- **Dominant representation:** a $v(t)$ graph — slope is a, signed area is Δx.
- **Most common trap:** assuming $t \propto h$ for a fall instead of $t \propto \sqrt{h}$.

Looking ahead: Chapter 2 asks *what causes* these accelerations. The kinematic equations remain unchanged, but the first move shifts from "identify the motion model" to "draw the free-body diagram," and the central equation shifts from $v = v_0 + at$ to $\sum \vec{F} = m\vec{a}$.

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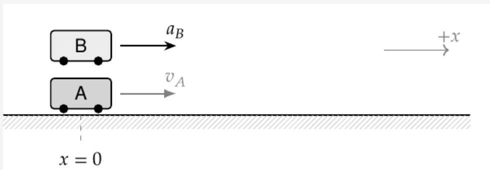

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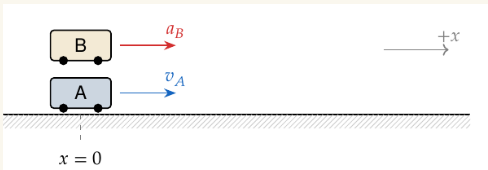

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