Physics — Standard 2.2: Kinematics and Motion Graphs

FBD · Motion Graphs · Kinematic Equations · Projectile Motion · Hard Practice Set

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About this set: Standard 2.2 is tested as four complete problems, each requiring full work and correct units. This set mixes free body diagrams, motion graphs, the Big 5 kinematic equations, vector components, and projectile motion — every tool the standard actually covers — at a range of difficulty from foundational to the hardest tested version. Use g = 9.8 m/s^2 throughout.

PROBLEM 1

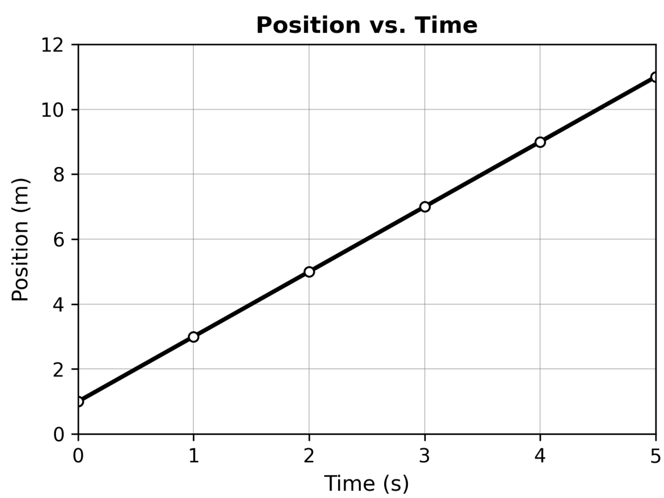
Foundational — Big 5, basic plug-and-solve

A car accelerates from rest at 3.2 m/s^2 for 6 seconds. Find the car's final velocity and the distance it travels.

PROBLEM 2

Foundational — reading velocity from a position-time graph

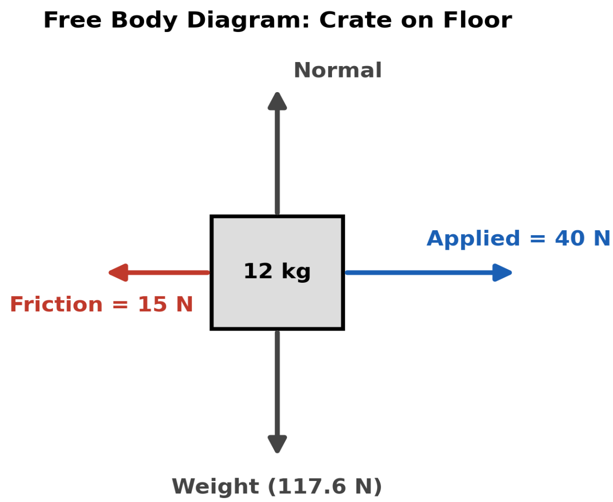
The position-time graph below shows an object moving in a straight line. Find the object's velocity using the slope of the graph.



PROBLEM 3

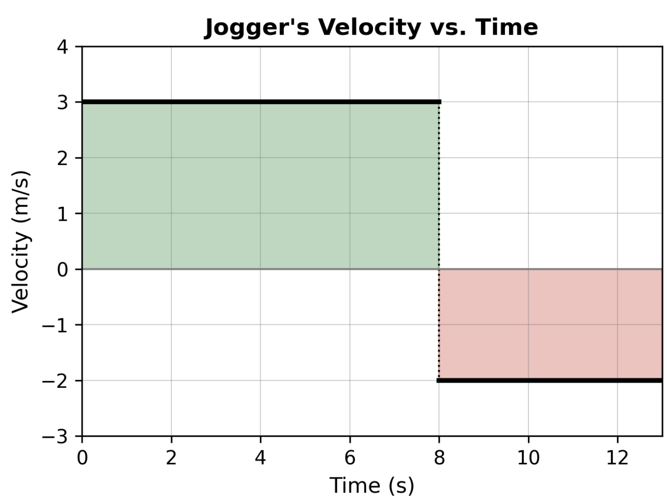
FBD — net force, acceleration, and predicting motion

The free body diagram below shows the forces acting on a 12 kg crate being pushed across a floor. Find the net horizontal force, the resulting acceleration, and state whether the crate speeds up, slows down, or moves at constant velocity.



PROBLEM 4 *Motion graph — signed area, displacement vs. distance*

A velocity-time graph shows a jogger running at +3 m/s for 8 s, then turning around and jogging at –2 m/s for the next 5 s. Find the jogger's total displacement and total distance traveled.

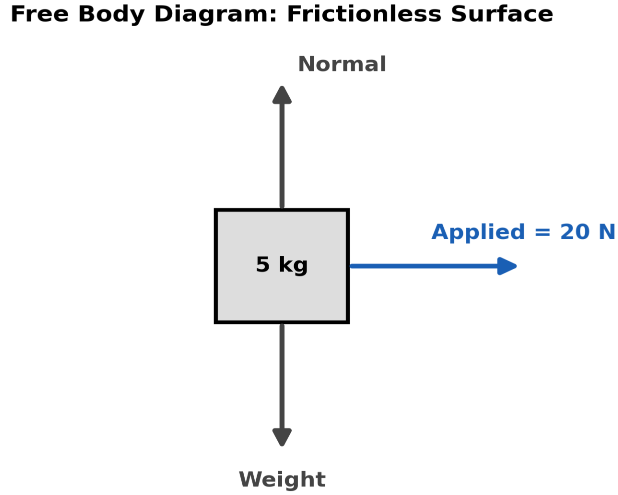


PROBLEM 5 *Big 5 — realistic application, braking distance*

A driver traveling at 28 m/s slams the brakes, decelerating at 6.5 m/s^2. Find the distance needed to stop. If a pedestrian is standing 50 m ahead, does the car stop in time?

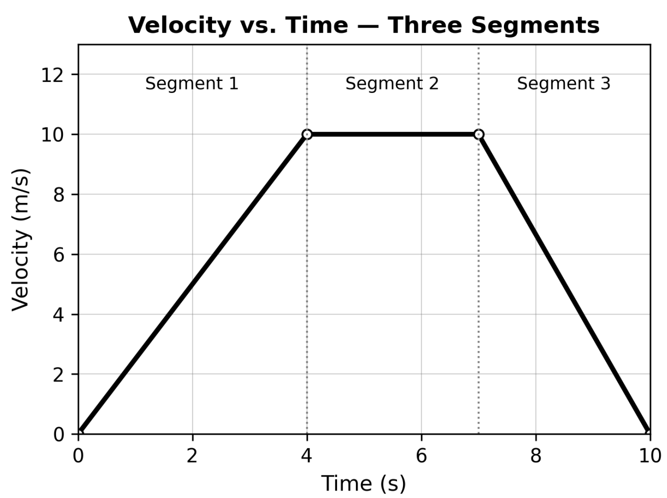
PROBLEM 6 *FBD + Big 5 combined — frictionless surface*

A 5 kg box on a frictionless surface has a 20 N force applied horizontally. Find the box's acceleration, then find how far it travels in 4 seconds, starting from rest.



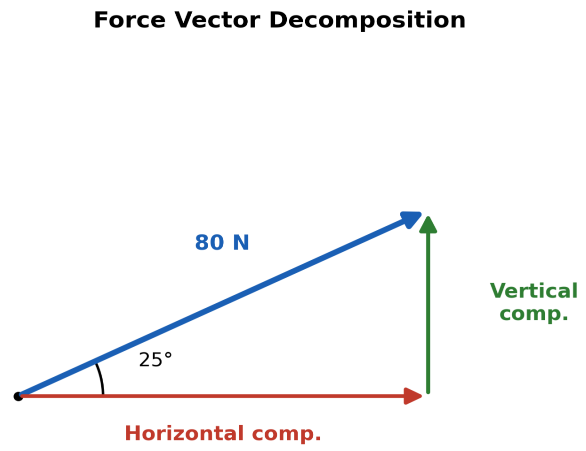
PROBLEM 7 *Motion graph — acceleration from slope, three segments*

The velocity-time graph below shows an object's motion across three segments. Find the acceleration during each segment, and state during which segment the object is slowing down.



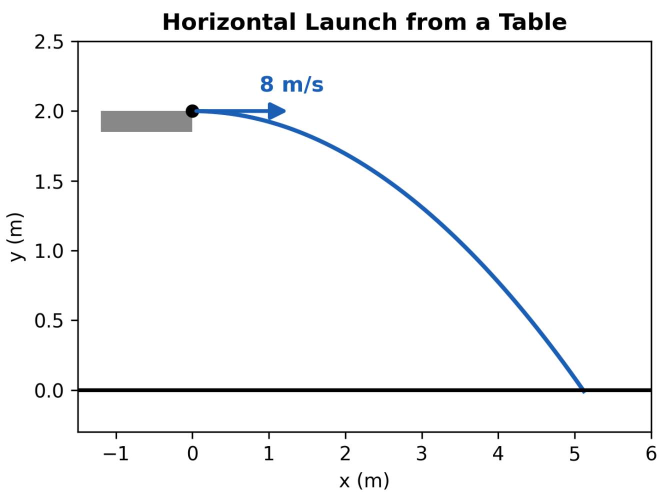
PROBLEM 8 *Vector decomposition — basic*

A force of 80 N is applied at 25° above horizontal to drag a sled. Find the horizontal and vertical components of this force.



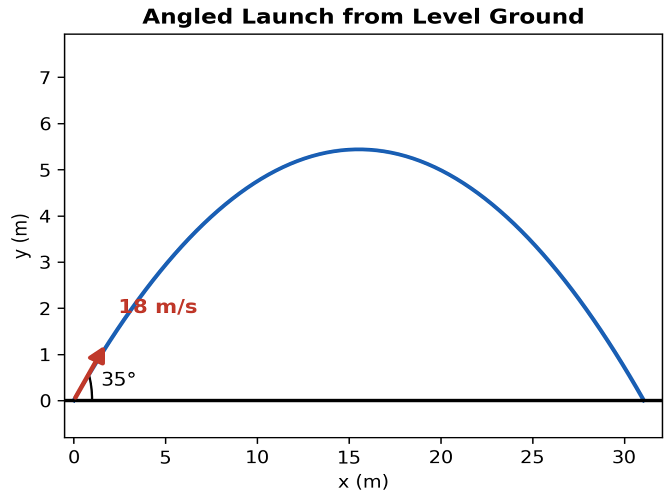
PROBLEM 9 *Projectile motion — horizontal launch*

A ball is launched horizontally at 8 m/s from a 2 m tall table. Find the time it takes to hit the ground and the horizontal distance it travels.



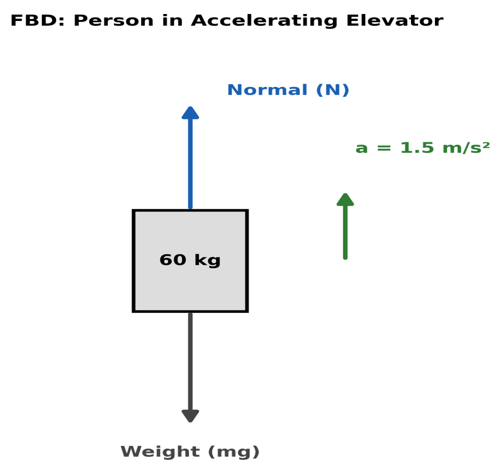
PROBLEM 10 *Projectile motion — angled launch, level ground*

A projectile launches at 18 m/s at 35° above horizontal from level ground. Find the time of flight, the range, and the maximum height.



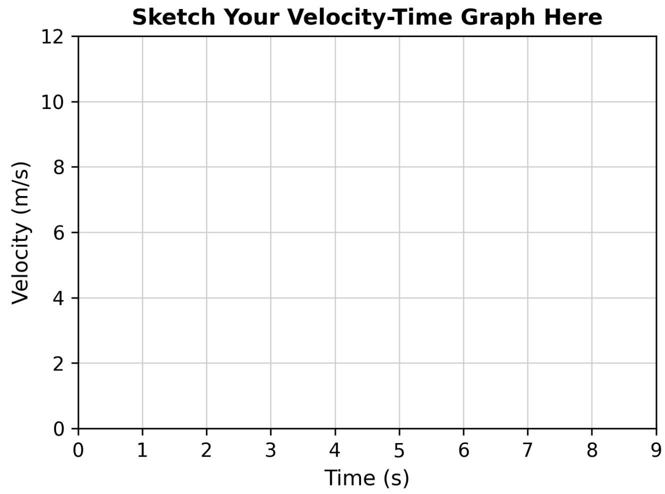
PROBLEM 11 *FBD — Newton's 2nd Law, accelerating reference frame*

A 60 kg person stands in an elevator accelerating upward at 1.5 m/s^2. Find the normal force the elevator floor exerts on the person.



PROBLEM 12 *Motion graph — sketch from a description, area for distance*

An object starts at rest, accelerates uniformly to 10 m/s over 4 seconds, travels at constant velocity for 3 seconds, then decelerates uniformly to rest over 2 seconds. Sketch the velocity-time graph on the grid below, then use the area under your graph to find the total distance traveled.

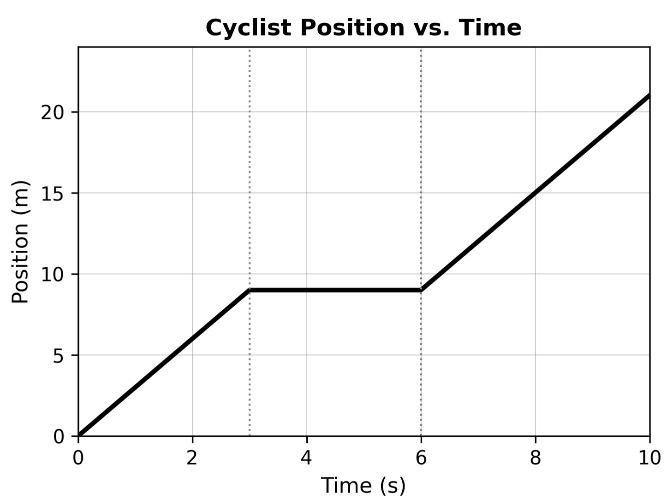


PROBLEM 13 *Big 5 — identifying the missing variable*

A train decelerates from 45 m/s to rest over a distance of 810 m. Find its deceleration. Which kinematic equation did you use, and which variable was missing that made this the correct equation to pick?

PROBLEM 14 *Motion graph — position-time with a stopped interval*

The position-time graph below shows a cyclist's position over 10 seconds, including a section where the cyclist is stopped. Identify the time interval during which the cyclist is stopped, and find the cyclist's velocity during each moving interval.



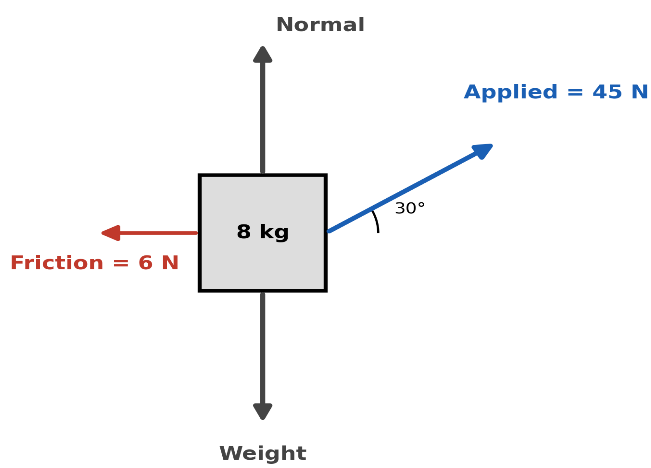
PROBLEM 15 *Projectile motion — angled launch, realistic context*

A soccer ball is kicked at 16 m/s at 50° above horizontal. Find the initial horizontal and vertical velocity components, and the ball's hang time.

PROBLEM 16 *Hardest tier — FBD with an angled force and friction*

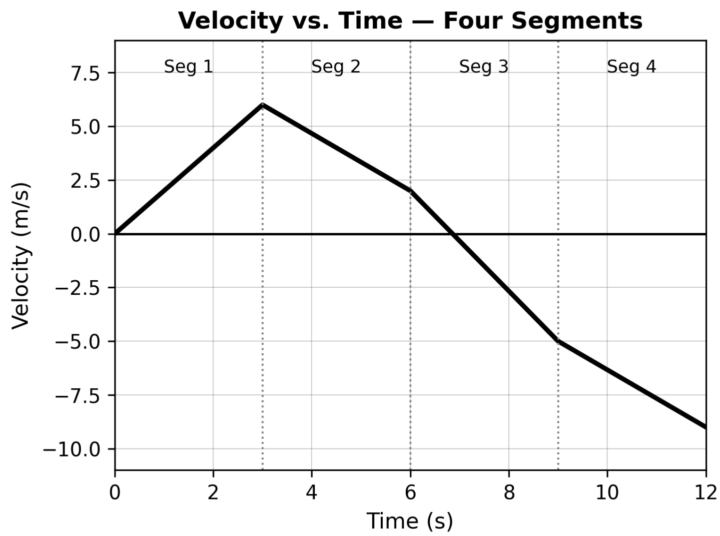
An 8 kg sled is pulled across ice by a rope at 30° above horizontal with 45 N of applied force, while friction provides 6 N of resistance to the sled's motion. Find: (a) the horizontal component of the applied force; (b) the net horizontal force and the resulting acceleration; (c) the normal force the ice exerts on the sled, accounting for the vertical component of the rope's pull; (d) how far the sled travels from rest in 5 seconds, and its velocity at that moment.

FBD: Sled Pulled at an Angle (with Friction)



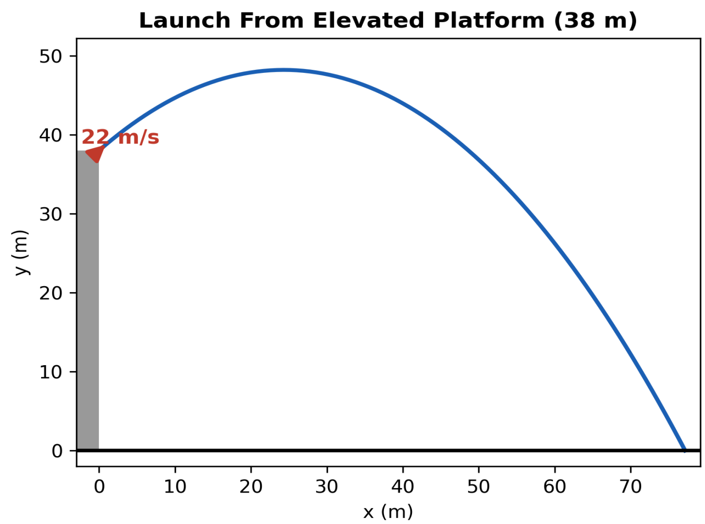
PROBLEM 17 *Hardest tier — motion graph, four segments with sign change*

The velocity-time graph below shows an object's motion over 12 seconds across four segments. Find: (a) the acceleration during each segment; (b) the total displacement; (c) the total distance traveled; (d) the exact time interval during which the object is both moving in the negative direction AND speeding up — not just "which segment."



PROBLEM 18 *Hardest tier — projectile launched from an elevated platform*

A ball is launched from the top of a 38 m building at 22 m/s at 40° above horizontal. Find the total time until it lands at street level, and the horizontal distance it travels.



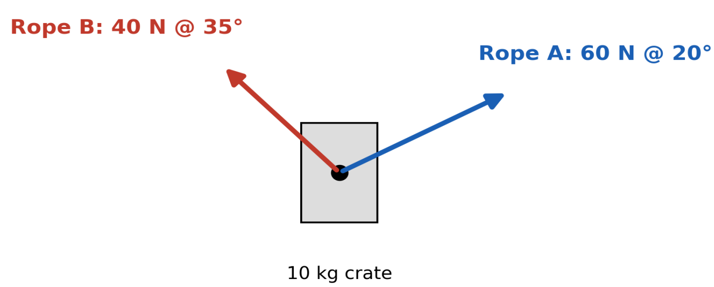
PROBLEM 19 *Hardest tier — system of equations, range and max height given*

A projectile launched from level ground reaches a maximum height of 15 m and lands 96 m from the launch point. Find the launch angle and the initial speed.

PROBLEM 20 *Hardest tier — two-force vector addition on an FBD*

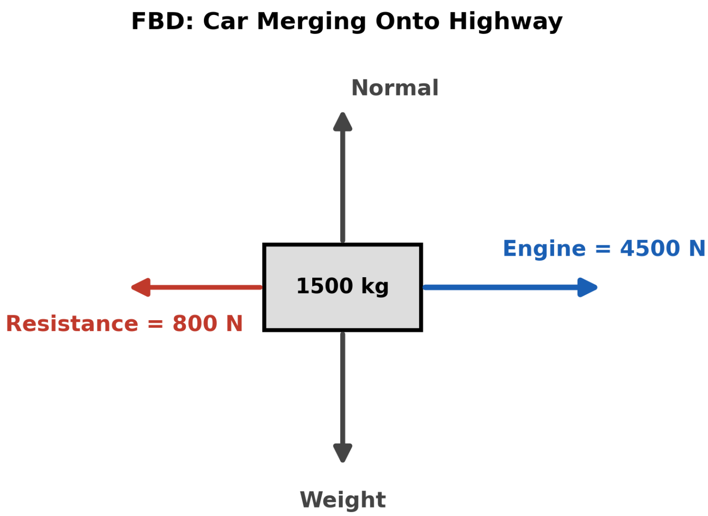
Two ropes pull on a 10 kg crate: Rope A pulls at 60 N at 20° above horizontal to the right, Rope B pulls at 40 N at 35° above horizontal to the left. Find the net force vector (magnitude and direction) acting on the crate, and the resulting acceleration.

Two Ropes Pulling on a Crate



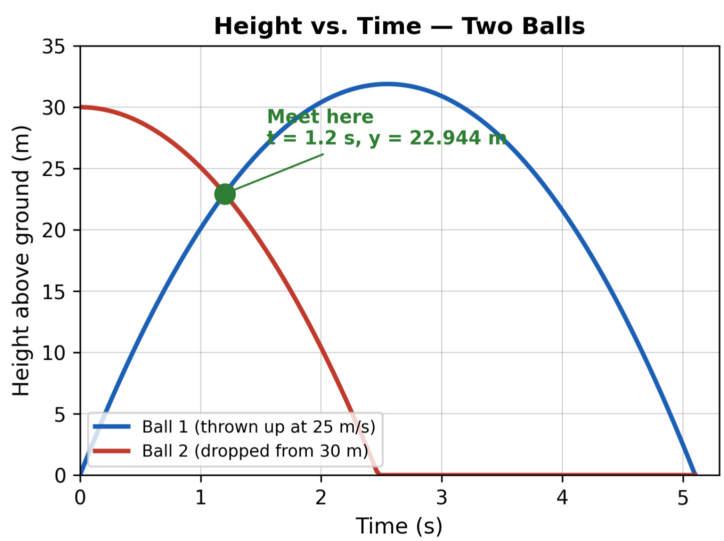
PROBLEM 21 *Capstone — full FBD-to-kinematics package, matching the real test format*

A 1500 kg car merges onto a highway. The engine provides 4500 N of forward force, while air resistance and friction together provide 800 N of resistance. Starting from rest: (a) use the free body diagram to find the net force and the acceleration; (b) find the car's velocity after 8 seconds; (c) find the distance traveled in that time; (d) if the merge lane is only 70 m long, does the car merge successfully before running out of room?



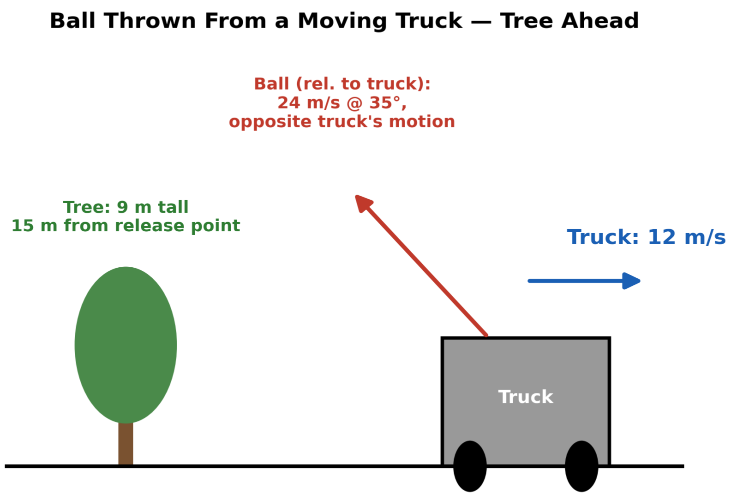
PROBLEM 22 *Hardest tier — two objects meet mid-flight (basic kinematics, no trajectory equation)*

A ball is thrown straight up from the ground at 25 m/s. At the exact same instant, a second ball is dropped from rest from a height of 30 m directly above the launch point. Find the time at which the two balls pass each other, and the height above the ground at which this happens.



PROBLEM 23 *Hardest tier — launch from a moving platform (vector addition + projectile)*

A ball is thrown from a truck moving horizontally at 12 m/s. Relative to the truck, the ball is thrown at 24 m/s at 35° above horizontal, in the direction opposite the truck's motion, from a height of 1.5 m above the ground. (a) Find the ball's horizontal and vertical velocity components relative to the ground, then combine them to find the ball's total speed and direction relative to the ground at the instant it leaves the truck. (b) There is a 9 m tall tree 15 m from the release point, directly in the path the ball is now traveling. Does the ball clear the tree?



Answer Key

Full worked solutions. Units are bolded in every final answer. Each problem lists the single most common mistake students make on that exact problem.

1 Big 5, basic plug-and-solve

$v = v_i + at = 0 + 3.2(6) = 19.2$ m/s.

$x = v_i t + ½at^2 = 0 + ½(3.2)(6^2) = 57.6$ m.

Final answer: v = 19.2 m/s, x = 57.6 m

Common error: Using v = 19.2 m/s as the distance, or forgetting the ½ in the position equation and reporting 115.2 m instead of 57.6 m.

2 Reading velocity from a position-time graph

Slope = (change in position)/(change in time). Using any two points on the line, e.g. (0,1) and (5,11): slope = (11–1)/(5–0) = 2 m/s.

Final answer: v = 2 m/s

Common error: Reading the y-intercept (1 m) as the velocity instead of calculating the slope — the y-intercept is the starting position, not the speed.

3 FBD — net force and predicting motion

Net horizontal force = Applied – Friction = 40 – 15 = 25 N.

$a = F_{net}/m = 25/12 = 2.08$ m/s^2.

Since the net force points in the same direction as the applied force (the direction of motion), the crate speeds up.

Final answer: F_{net} = 25 N, a = 2.08 m/s^2, the crate speeds up

Common error: Forgetting to subtract friction and using the full 40 N as the net force, or computing acceleration but not stating the speeds-up/slows-down conclusion the problem actually asks for.

4 Motion graph — signed area

Area while moving forward: 3 m/s × 8 s = +24 m.

Area while moving backward: –2 m/s × 5 s = –10 m.

Displacement = 24 + (–10) = 14 m. Distance = 24 + 10 = 34 m (distance always adds magnitudes).

Final answer: displacement = 14 m, distance = 34 m

Common error: Reporting displacement and distance as the same number (34 m) — they only match if the jogger never reverses direction.

5 Big 5 — braking distance, realistic interpretation

Using $v^2 = v_i^2 + 2ad$ with $v = 0$ (letting d be the stopping distance): $0 = 28^2 + 2(–6.5)d$.

$d = 28^2/(2×6.5) = 784/13 = 60.3$ m.

Since 60.3 m > 50 m, the car does NOT stop in time — it would still be moving when it reaches the pedestrian's position.

Final answer: stopping distance = 60.3 m, the car does not stop in time

Common error: Computing the stopping distance correctly but never answering the actual question asked (whether the car stops in time) — a numeric answer alone isn't a complete response here.

6 FBD + Big 5 — frictionless surface

$a = F/m = 20/5 = 4$ m/s^2.

$x = v_i t + ½at^2 = 0 + ½(4)(4^2) = 32$ m.

Final answer: a = 4 m/s^2, x = 32 m

Common error: Forgetting the ½ in the position equation and reporting 64 m instead of 32 m.

7 Motion graph — acceleration from slope, three segments

Segment 1 (0–4 s): a = (10–0)/4 = 2.5 m/s^2.

Segment 2 (4–7 s): velocity is constant, so a = 0 m/s^2.

Segment 3 (7–10 s): a = (0–10)/(10–7) = –3.33 m/s^2.

The object is slowing down during Segment 3, since velocity is decreasing while still positive.

Final answer: a_1 = 2.5 m/s^2, a_2 = 0 m/s^2, a_3 = –3.33 m/s^2, slowing down in Segment 3

Common error: Calling Segment 2 'slowing down' because the line is flat — a flat velocity-time graph means constant velocity, zero acceleration, not slowing down.

8 Vector decomposition — basic

Horizontal component = 80cos25° = 72.5 N.

Vertical component = 80sin25° = 33.8 N.

Final answer: F_x = 72.5 N, F_y = 33.8 N

Common error: Swapping sine and cosine — for an angle measured from the horizontal, horizontal is always cosine and vertical is always sine.

9 Projectile motion — horizontal launch

Vertical: $2 = ½(9.8)t^2 \rightarrow t^2 = 4/9.8 = 0.408 \rightarrow t = 0.639$ s.

Horizontal: $x = v_x t = 8(0.639) = 5.11$ m.

Final answer: t = 0.639 s, x = 5.11 m

Common error: Using the horizontal velocity (8 m/s) anywhere in the vertical equation — the two directions never share a variable except time.

10 Projectile motion — angled launch, level ground

$v_x = 18\cos 35° = 14.74$ m/s, $v_y = 18\sin 35° = 10.32$ m/s.
$T = 2v_y/g = 2(10.32)/9.8 = 2.11$ s.
$R = v_xT = 14.74(2.11) = 31.1$ m.
$H = v_y^2/(2g) = 10.32^2/19.6 = 5.44$ m.

Final answer: T = 2.11 s, R = 31.1 m, H = 5.44 m

Common error: Using the full launch speed (18 m/s) instead of the vertical component in the time-of-flight and max-height formulas.

11 FBD — elevator, Newton's 2nd Law

Net upward force needed: $F_{net} = ma = 60(1.5) = 90$ N.
$N - mg = F_{net} \rightarrow N = mg + F_{net} = 60(9.8) + 90 = 588 + 90 = 678$ N.

Final answer: N = 678 N

Common error: Reporting the normal force as just mg (588 N) — when accelerating upward, the normal force must be larger than weight, not equal to it.

12 Motion graph — sketch and area

The graph is a trapezoid: rising from 0 to 10 m/s over 4 s, flat at 10 m/s for 3 s, falling to 0 over 2 s.
Area 1 (rise): ½(4)(10) = 20 m. Area 2 (constant): 10(3) = 30 m. Area 3 (fall): ½(2)(10) = 10 m.
Total distance = 20 + 30 + 10 = 60 m.

Final answer: total distance = 60 m

Common error: Treating the rising and falling sections as rectangles instead of triangles, which overcounts the area — both ramps need the ½ in the triangle area formula.

13 Big 5 — identifying the missing variable

Time is not given and not needed, so the correct equation is $v^2 = v_i^2 + 2ad$, where d is distance (the only Big 5 equation missing time).
$0 = 45^2 + 2a(810) \rightarrow a = -2025/1620 = -1.25$ m/s^2.

Final answer: $a = -1.25$ m/s^2 (deceleration), using $v^2 = v_i^2 + 2ad$ because time was the missing variable

Common error: Trying to use $v = v_i + at$ or $x = v_it + ½at^2$ first, both of which require time — neither can be solved without first finding the missing variable some other way.

14 Motion graph — position-time with a stopped interval

The graph is flat (zero slope) from t = 3 s to t = 6 s, so the cyclist is stopped during that interval.

From 0–3 s: v = (9–0)/(3–0) = 3 m/s.

From 6–10 s: v = (21–9)/(10–6) = 3 m/s.

Final answer: stopped from t = 3 s to t = 6 s; velocity = 3 m/s during both moving intervals

Common error: Assuming the cyclist's velocity must be different in the second moving interval just because more time has passed — a flatter or steeper slope before or after the stop is what actually signals a velocity change, not the stop itself.

15 Projectile motion — angled launch, realistic context

v_x = 16cos50° = 10.28 m/s, v_y = 16sin50° = 12.26 m/s.
$T = 2v_y/g$ = 2(12.26)/9.8 = 2.50 s.

Final answer: v_x = 10.28 m/s, v_y = 12.26 m/s, T = 2.50 s

Common error: Forgetting that hang time only depends on the vertical component — plugging the full 16 m/s into the time-of-flight formula instead of v_y.

16 Hardest tier — FBD with angled force and friction

(a) F_x = 45cos30° = 38.97 N. F_y = 45sin30° = 22.5 N.

(b) Net horizontal force = 38.97 – 6 = 32.97 N. a = 32.97/8 = 4.12 m/s^2.

(c) The rope's vertical pull reduces how hard the sled presses down: N = mg – F_y = 8(9.8) – 22.5 = 78.4 – 22.5 = 55.9 N.

(d) $x = ½at^2$ = ½(4.12)(5^2) = 51.5 m. v = at = 4.12(5) = 20.6 m/s.

Final answer: F_x = 38.97 N, a = 4.12 m/s^2, N = 55.9 N, x = 51.5 m, v = 20.6 m/s

Common error: Using the full weight (78.4 N) as the normal force in part (c) — an upward-angled pull always reduces the normal force, since it's partially lifting the object off the surface.

17 Hardest tier — four-segment motion graph

(a) Seg 1: a = (6–0)/3 = 2.0 m/s^2. Seg 2: a = (2–6)/3 = –1.33 m/s^2. Seg 3: a = (–5–2)/3 = –2.33 m/s^2. Seg 4: a = (–9–(–5))/3 = –1.33 m/s^2.

(b) Areas: Seg 1 = +9 m, Seg 2 = +12 m, Seg 3 = –4.5 m, Seg 4 = –21 m. Total displacement = 9+12–4.5–21 = –4.5 m.

(c) Total distance = 9+12+4.5+21 = 46.5 m.

(d) Velocity crosses zero partway through Segment 3, at t = 6 + 2/2.33 ≈ 6.86 s. From that instant through the end of Segment 4 (t = 6.86 s to t = 12 s), the object is moving in the negative direction AND its speed is increasing.

Final answer: a_1=2.0, a_2=–1.33, a_3=–2.33, a_4=–1.33 m/s^2; displacement = –4.5 m; distance = 46.5 m; speeding up in the negative direction from t ≈ 6.86 s to t = 12 s

Common error: Answering part (d) with just 'Segment 4' — the object actually starts moving backward and speeding up partway through Segment 3, the instant velocity crosses zero, not at the next segment boundary.

18 Hardest tier — projectile from an elevated platform

v_y = 22sin40° = 14.14 m/s. Set up: 0 = 38 + 14.14t – 4.9t^2.
Standard form: 4.9t^2 – 14.14t – 38 = 0. Quadratic formula: t = (14.14 ± √(14.14^2 + 4(4.9)(38)))/(2×4.9).
t = (14.14 ± 33.0)/9.8 → reject the negative root → t = 4.58 s.
x = v_xt = 22cos40°(4.58) = 16.85(4.58) = 77.2 m.

Final answer: t = 4.58 s, x = 77.2 m

Common error: A sign error setting up the standard form of the quadratic — write 0 = 38 + 14.14t – 4.9t^2 as 4.9t^2 – 14.14t – 38 = 0 carefully before identifying a, b, c, or the quadratic formula gives the wrong roots entirely.

19 Hardest tier — system of equations from range and height

H = $v_i^2 \sin^2\theta/(2g)$, R = $v_i^2 \sin(2\theta)/g = 2v_i^2 \sin\theta\cos\theta/g$.
Dividing: H/R = sinθ/(4cosθ) = (1/4)tanθ → tanθ = 4H/R = 4(15)/96 = 0.625.
θ = arctan(0.625) = 32.0°.
v_i^2 = 2gH/$\sin^2\theta$ = 2(9.8)(15)/$\sin^2$(32.0°) = 294/0.281 = 1046.3 → v_i = 32.3 m/s.

Final answer: θ = 32.0°, v_i = 32.3 m/s

Common error: Trying to solve for the initial speed using only the height or only the range equation — with two unknowns (angle and speed), one equation is never enough; the two formulas must be divided or combined first.

20 Hardest tier — two-force vector addition

Rope A: F_{Ax} = 60cos20° = 56.4 N, F_{Ay} = 60sin20° = 20.5 N.
Rope B: F_{Bx} = –40cos35° = –32.8 N (pulling left), F_{By} = 40sin35° = 22.9 N.
Net: F_x = 56.4 – 32.8 = 23.6 N. F_y = 20.5 + 22.9 = 43.5 N.
Magnitude = √(23.6^2 + 43.5^2) = 49.5 N. Direction = arctan(43.5/23.6) = 61.5° above horizontal, toward Rope A's side.
a = F_{net}/m = 49.5/10 = 4.95 m/s^2.

Final answer: F_{net} = 49.5 N at 61.5° above horizontal, a = 4.95 m/s^2

Common error: Adding the two force magnitudes directly (60 + 40 = 100 N) without breaking each into components first — forces at different angles can never be added as plain numbers.

21 Capstone — full FBD-to-kinematics package

(a) Net force = 4500 – 800 = 3700 N. $a = 3700/1500 = 2.47\ m/s^2$.

(b) $v = v_i + at = 0 + 2.47(8) = 19.7$ m/s.

(c) $x = ½at^2 = ½(2.47)(8^2) = 78.9$ m.

(d) The car needs 78.9 m but only has 70 m of merge lane — it does NOT merge successfully within the available space.

Final answer: a = 2.47 m/s^2, v = 19.7 m/s, x = 78.9 m, the car does not merge in time

Common error: Stopping after part (c) without answering part (d) — this problem is built exactly like the real 4-problem test format, where a numeric answer alone is incomplete without the actual conclusion the question asks for.

22 Hardest tier — two objects meet mid-flight

Ball 1 (thrown up from the ground): $y_1(t) = 25t – 4.9t^2$.

Ball 2 (dropped from 30 m, starting at rest): $y_2(t) = 30 – 4.9t^2$.

The balls pass each other when their heights are equal: set $y_1(t) = y_2(t)$.

$25t – 4.9t^2 = 30 – 4.9t^2$. The $–4.9t^2$ term appears on both sides and cancels completely, leaving a simple linear equation: $25t = 30$.

$t = 30/25 = 1.2$ s.

Substitute back into either height equation: $y = 25(1.2) – 4.9(1.2^2) = 30 – 7.056 = 22.944$ m.

Final answer: the balls pass each other at t = 1.2 s, at a height of 22.944 m

Common error: Trying to solve this with two separate equations and two separate unknowns instead of noticing that setting the two height equations equal to each other cancels the $–4.9t^2$ term entirely — once that's seen, the problem is just one linear equation, not a quadratic.

23 Hardest tier — launch from a moving platform

(a) Relative to the truck: $v_{x,rel} = 24\cos35° = 19.66$ m/s (pointing opposite the truck's motion), $v_{y,rel} = 24\sin35° = 13.77$ m/s (vertical component, unaffected by the truck).

Ground frame: the truck moves at +12 m/s, but the ball's horizontal component relative to the truck points the opposite way, so $v_{x,ground} = 12 – 19.66 = –7.66$ m/s.

Vertical component is unaffected by the truck's horizontal motion: $v_{y,ground} = 13.77$ m/s.

Combine into magnitude and direction: speed = $\sqrt{(7.66^2 + 13.77^2)} = 15.75$ m/s. Direction = arctan(13.77/7.66) = 60.9° above horizontal, pointing backward relative to the truck's original direction of travel (since $v_{x,ground}$ is negative).

(b) This is two basic kinematics steps, not the trajectory equation. First find the time to travel the 15 m horizontally, using only the constant horizontal velocity: $t = 15/7.66 = 1.96$ s.

Then plug that time into the basic vertical position equation, starting from the 1.5 m release height: $y = 1.5 + v_{y,ground}t – ½gt^2 = 1.5 + 13.77(1.96) – 4.9(1.96^2) = 9.67$ m.

Since 9.67 m > 9 m, the ball clears the tree — but only by 0.67 m.

Final answer: (a) $v_{x,ground}$ = –7.66 m/s, $v_{y,ground}$ = 13.77 m/s, speed = 15.75 m/s at 60.9° above horizontal, backward. (b) the ball clears the tree, reaching 9.67 m at that distance versus the tree's 9 m height

Common error: Adding the truck's speed and the ball's relative speed directly (12 + 24 = 36) without first breaking the ball's velocity into components, or without noticing the ball was thrown opposite the truck's motion — when the relative horizontal speed is larger than the platform's speed, the ball can end up moving backward relative to the ground even though the truck moves forward. On part (b), the most common mistake is reaching for the trajectory equation (height as a function of x) instead of just finding the time first and then plugging it into the ordinary vertical position equation — both get the same answer, but the trajectory equation was deliberately left out of this unit, so the two-step version is the one to practice.