AP Physics C: Mechanics

Unit 1 Problem Set — Kinematics

Topics 1.1 – 1.5, plus a mixed general-review set

The 42nd Period • Name: ______________________ Date: ___________

Section	Topic	Problems
1.1	Scalars and Vectors	1 – 10
1.2	Displacement, Velocity, and Acceleration	11 – 20
1.3	Representing Motion (motion graphs)	21 – 30
1.4	Reference Frames and Relative Motion	31 – 40
1.5	Motion in Two or Three Dimensions	41 – 50
General Review	Mixed topics from 1.1 – 1.5	51 – 70

Instructions: Show all work for full credit. Use $g = 9.8 \text{ m/s}^2$ unless otherwise noted. Vector quantities should be reported with both magnitude and direction. Problems marked (FRQ) are multi-part free-response style and should be answered in complete parts (a), (b), (c), etc. Numbering is continuous across the entire packet (1–70). Answers to the odd-numbered problems only appear on a separate page at the end of this packet — do not turn to that page until you have attempted every problem.

Section 1.1 | Scalars and Vectors

Classifying quantities, vector components, graphical and analytical addition/subtraction

1. A student lists the following quantities: mass, displacement, speed, velocity, distance traveled, acceleration, time, and kinetic energy. Classify each quantity as a scalar or a vector, and explain the general distinction between the two categories.

2. A hiker's displacement has a magnitude of 12.0 m and points 35° above the positive x-axis. Find the x- and y-components of the displacement.

3. A force vector has components F_x = -6.0 N and F_y = 8.0 N. Find the magnitude of the force and the angle it makes with the positive x-axis.

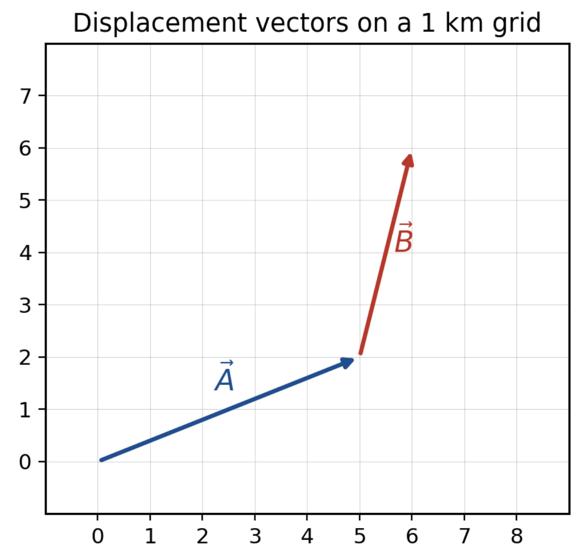

Figure 1.1.9 — Displacement $\vec{A}$ is followed by displacement $\vec{B}$ (grid squares = 1 km).

4. Two displacement vectors, A and B, are shown tip-to-tail in Figure 1.1.9. Using the graphical (tip-to-tail) method, describe how you would find the resultant displacement R = A + B, and estimate its magnitude and direction from the grid.

5. Vector A = (3.0, -5.0) m and vector B = (-7.0, 2.0) m. Find the components of C = A − B, and then find the magnitude of C.

6. Express the vector with magnitude 9.0 m/s directed 150° from the positive x-axis in unit-vector notation (in terms of î and ĵ).

7. Three force vectors act on a ring, with components given in the table below.

Vector	F_x (N)	F_y (N)
F_1	12.0	5.0
F_2	-8.0	3.0

F_3	-2.0	-9.0

Table 1.1.7 — Components of three concurrent forces.

(a) Find the components of the resultant force $F_{net} = F_1 + F_2 + F_3$.

(b) Find the magnitude and direction of F_{net}.

8. A plane flies 120 km due east, then 90 km due north. Using the Pythagorean theorem and trigonometry (not a scale drawing), find the magnitude and direction of the plane's total displacement from its starting point.

9. Vector P has magnitude 5.0 m at 20° above the x-axis, and vector Q has magnitude 5.0 m at 200° from the positive x-axis. Find P + Q both graphically (describe the construction) and analytically (using components), and comment on what you notice about the two answers.

10. A student claims that a vector's magnitude can be negative as long as its direction is reversed to compensate. Evaluate this claim. Then, give an example of three nonzero, non-parallel displacement vectors that sum to exactly zero, and explain geometrically why this is possible.

Section 1.2 | Displacement, Velocity, and Acceleration

Average vs. instantaneous quantities, calculus-based 1-D kinematics, free fall

11. A particle moves along the x-axis according to $x(t) = 2.0t^3 - 9.0t^2 + 12.0t$, where x is in meters and t is in seconds.

(a) Find the velocity function $v(t)$ by differentiating $x(t)$.

(b) Find all times $t \geq 0$ at which the particle is momentarily at rest.

12. A particle's velocity is given by $v(t) = 4.0t - t^2$, in m/s, for t in seconds.

(a) Find the acceleration function $a(t)$.

(b) Find the time at which the velocity is a maximum, and justify your answer using $a(t)$.

13. For the particle in Problem 11, find the average velocity between $t = 1.0$ s and $t = 4.0$ s. Explain why this is not equal to the instantaneous velocity at $t = 2.5$ s in general.

14. A particle has velocity $v(t) = 6.0 - 3.0t$ (m/s). Using integration, find its displacement between $t = 0$ and $t = 4.0$ s. Sketch (in words) what the corresponding v-t graph and the signed area under it represent physically.

15. A rock is dropped from rest from the top of a 78 m cliff.

(a) How long does it take to reach the ground?

(b) What is its speed just before impact?

16. A car starts from rest and accelerates uniformly at 2.5 m/s² for 6.0 s.

(a) Find the car's velocity at $t = 6.0$ s.

(b) Find the distance the car travels during this time.

17. A jogger's position was recorded at several times, shown in the table below.

t (s)	0	2.0	4.0	6.0	8.0
x (m)	0	9.0	20.0	34.0	51.0

Table 1.2.17 — Position of a jogger at 2-second intervals.

(a) Find the jogger's average velocity over the full interval, $t = 0$ to $t = 8.0$ s.

(b) Find the average velocity between $t = 4.0$ s and $t = 6.0$ s, and compare it to your answer in part (a). What does this comparison tell you about the jogger's motion?

18. Explain the difference between average velocity and instantaneous velocity in terms of a position-time graph. Then describe a specific type of motion for which the average velocity over an interval exactly equals the instantaneous velocity at every point during that interval.

19. A driver traveling at 24 m/s applies the brakes, producing a constant deceleration of 4.0 m/s^2.

(a) How much time is required for the car to stop?

(b) What distance does the car travel while braking?

20. The acceleration of a particle moving along the x-axis is $a(t) = 6.0t$ (m/s^2). At $t = 0$, the particle has velocity $v_0 = -2.0$ m/s and position $x_0 = 5.0$ m.

(a) Integrate $a(t)$ to find $v(t)$, using the initial condition to evaluate the constant of integration.

(b) Integrate $v(t)$ to find $x(t)$, and find the particle's position at $t = 3.0$ s.

Section 1.3 | Representing Motion

Reading and interpreting position-time, velocity-time, and acceleration-time graphs

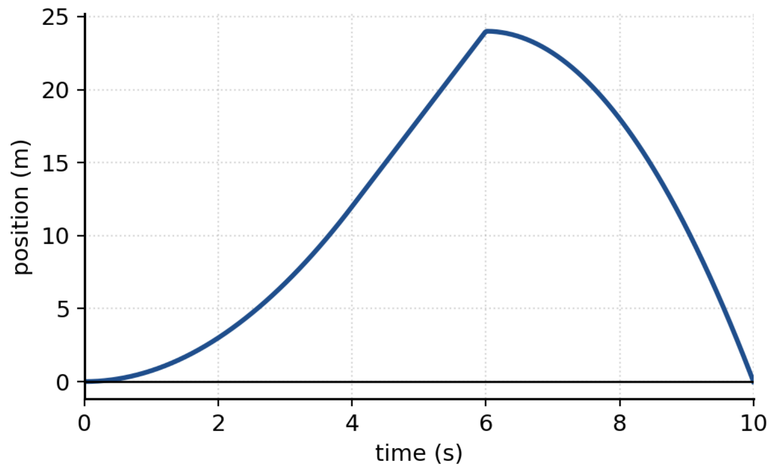

Figure 1.3.21 — Position vs. time for an object moving along a line.

21. Using Figure 1.3.21:

(a) Describe the object's motion in words over each labeled interval (0–4 s, 4–6 s, and 6–10 s).

(b) Estimate the object's instantaneous velocity at t = 5.0 s.

(c) At what time, or times, is the object's velocity equal to zero? Explain how you know.

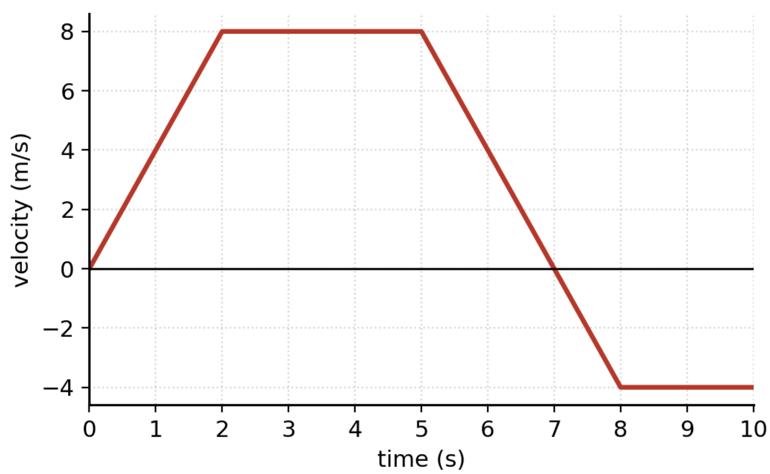

Figure 1.3.22 — Velocity vs. time for an object moving along a line.

22. Using Figure 1.3.22:

(a) Find the object's acceleration during the interval 0–2 s.

(b) Find the object's total displacement from t = 0 to t = 10 s.

(c) Is the object ever at rest? Justify your answer.

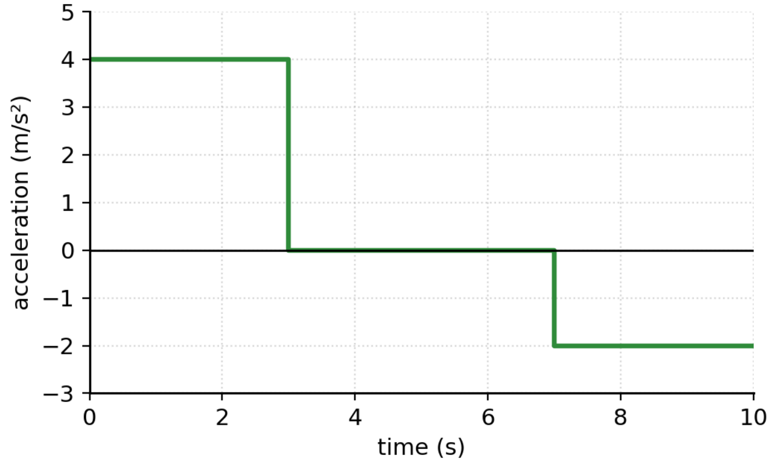

Figure 1.3.23 — Acceleration vs. time for an object moving along a line.

23. The object described by Figure 1.3.23 starts at rest ($v = 0$ at $t = 0$).

(a) Find the object's velocity at $t = 3.0$ s.

(b) Find the object's velocity at $t = 10.0$ s.

(c) Describe, without calculation, what the corresponding velocity-time graph would look like over each interval.

24. An object moves with a position-time graph that is a downward-opening parabola, reaching a maximum position at $t = 3.0$ s and returning to its starting position at $t = 6.0$ s. Sketch (describe in words, segment by segment) the shape of the corresponding velocity-time graph and the corresponding acceleration-time graph.

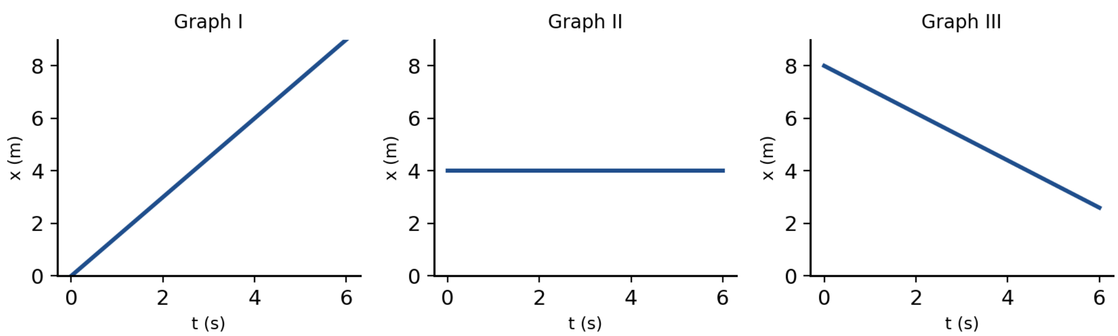

Figure 1.3.25 — Three possible position-time graphs, I, II, and III.

25. A ball is thrown straight up and caught at the same height. Which of the graphs in Figure 1.3.25 (I, II, or III) could represent the ball's speed vs. time during its flight? Explain why the other two graphs are inconsistent with the described motion.

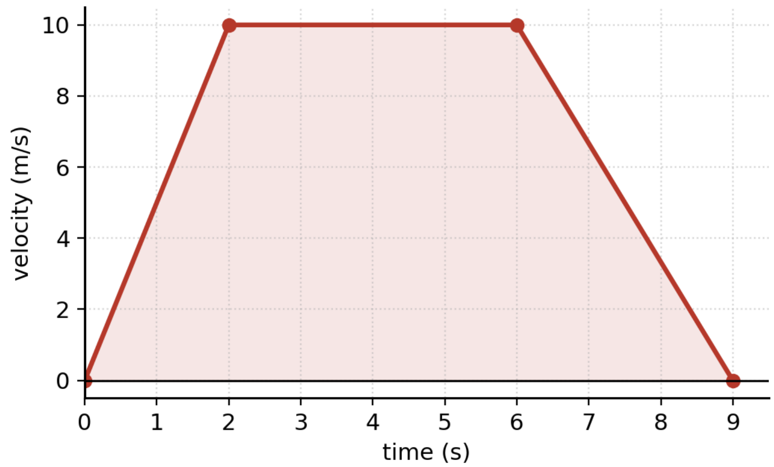

Figure 1.3.26 — Velocity vs. time for a car during a trip.

26. Using Figure 1.3.26, find the car's total displacement over the 9-second interval by computing the geometric area under the graph. Show the individual areas you used.

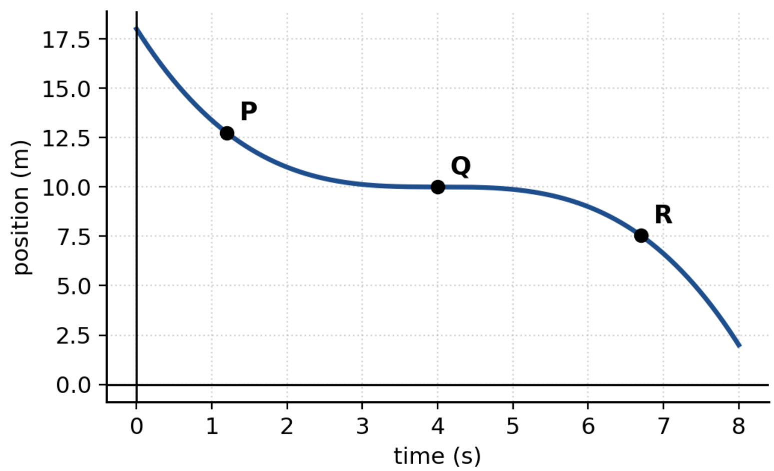

Figure 1.3.27 — Position vs. time, with points P, Q, and R marked.

27. For each labeled point in Figure 1.3.27, state whether the object's velocity is positive, negative, or zero, and whether its acceleration is positive, negative, or zero. Justify each answer using the shape (slope and concavity) of the graph.

28. Using the jogger data from Table 1.2.17 (Problem 17), estimate the jogger's instantaneous velocity at t = 4.0 s by using the two surrounding data points (t = 2.0 s and t = 6.0 s). Explain why this method gives an estimate rather than an exact value.

29. An object starts at rest and experiences a constant positive acceleration for 5.0 s, after which the acceleration drops to zero and remains zero. Describe the resulting velocity-time graph, and describe the resulting position-time graph, being explicit about the curvature (or lack of curvature) in each interval.

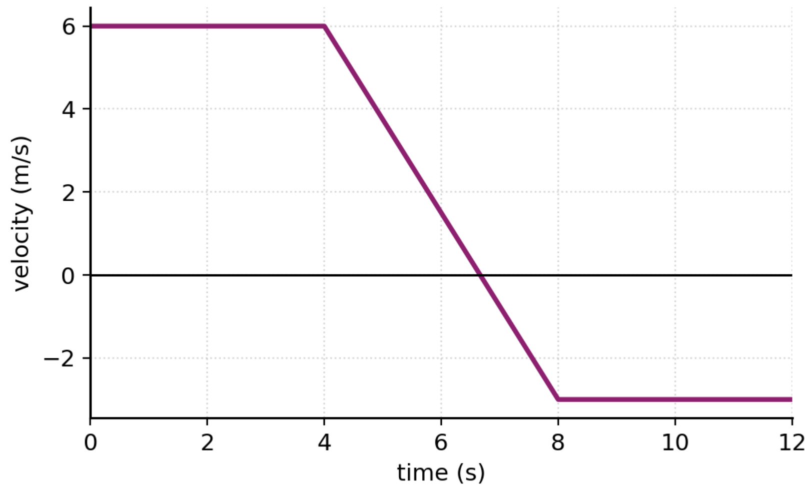

Figure 1.3.30 — Velocity vs. time for a remote-control car.

30. (FRQ) Using Figure 1.3.30:

(a) Find the car's displacement from t = 0 to t = 4.0 s.

(b) Find the car's displacement from t = 4.0 s to t = 12.0 s.

(c) At approximately what time is the car's velocity equal to zero, and what is happening physically to the car's direction of motion at that time?

(d) Find the car's average velocity over the full 12.0 s interval.

Section 1.4 | Reference Frames and Relative Motion

Relative velocity, reference frame transformations, river-crossing and wind-drift problems

31. A boat capable of a speed of 4.0 m/s in still water heads directly across a river that flows at 3.0 m/s. Find the magnitude and direction of the boat's resultant velocity relative to the shore.

32. An airplane has an airspeed of 220 km/h and is headed due north. A wind blows at 45 km/h due east.

(a) Find the plane's resultant ground velocity (magnitude and direction).

(b) If the plane must cover 300 km measured along the ground track found in part (a), how long does the trip take?

33. Two cars are 300 m apart on a straight road, moving toward each other. Car A travels at 15 m/s and Car B travels at 10 m/s. Taking the ground as the reference frame, find the time at which the cars meet.

34. A passenger walks toward the front of a train at 1.5 m/s relative to the train, while the train moves at 22 m/s relative to the ground. Find the passenger's velocity relative to the ground.

35. Rain falls straight down at 6.0 m/s relative to the ground. A car drives horizontally at 18 m/s. Find the velocity of the rain relative to the car (magnitude and the angle from the vertical, as it would appear to a passenger looking out the side window).

36. A boat capable of 5.0 m/s in still water must cross a river that flows at 3.0 m/s and land at a point directly across from its starting point. At what angle, measured from the direction directly across the river, must the boat be pointed? What is the resulting speed of the boat relative to the shore?

37. Explain why two observers in different inertial reference frames, moving at constant velocity relative to one another, can measure different values for an object's velocity but must always agree on the object's acceleration.

38. Observer A, standing on the ground, measures a ball's velocity as 12 m/s to the east. Observer B is in a car moving at 5.0 m/s to the east relative to the ground. What velocity does Observer B measure for the ball? Show the vector relationship you used.

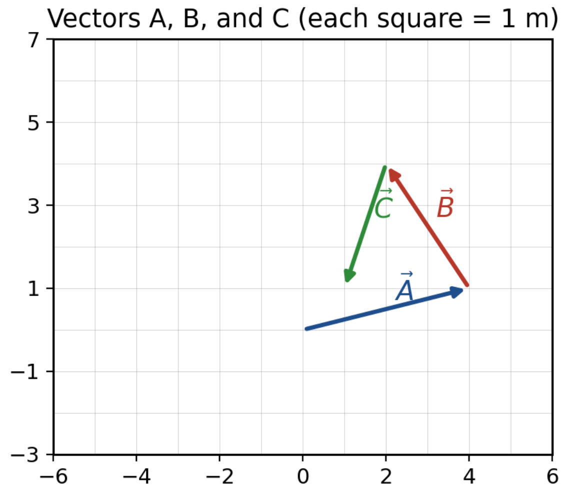

Figure 1.4.39 — Velocity vectors for cyclist A and cyclist B relative to the ground (reuse the vector diagram; treat A and B as velocity vectors, ignore C for this problem).

39. Using the vectors A and B shown in Figure 1.4.39 as the ground velocities of cyclist A and cyclist B, find the velocity of cyclist A relative to cyclist B, $v_{A/B} = v_A - v_B$, in component form.

40. (FRQ) A river 80 m wide flows at 2.0 m/s. A swimmer can swim at 1.2 m/s in still water.

(a) If the swimmer heads straight across (perpendicular to the bank), how long does the crossing take, and how far downstream does the swimmer land?

(b) Explain why heading straight across always gives the minimum possible crossing time, regardless of the current speed.

(c) Is it possible for this swimmer to land at a point directly across the river? Justify your answer using the given speeds.

Section 1.5 | Motion in Two or Three Dimensions

Projectile motion, vector-valued position functions, and uniform circular motion

41. A ball rolls off a horizontal tabletop 1.20 m high with a horizontal speed of 3.30 m/s.

    (a) How long does the ball take to reach the floor?

    (b) How far from the base of the table does the ball land?

42. A projectile is launched from ground level at 30.0 m/s at an angle of 50.0° above the horizontal.

    (a) Find the maximum height reached by the projectile.

    (b) Find the total time of flight.

    (c) Find the horizontal range.

43. A projectile is launched from a height h above the ground with initial speed v_0 at angle θ above the horizontal. Derive an expression, in terms of h, v_0, θ, and g, for the projectile's speed just before it strikes the ground. (Hint: consider using energy-independent kinematics or the y-component of velocity together with the constant x-component.)

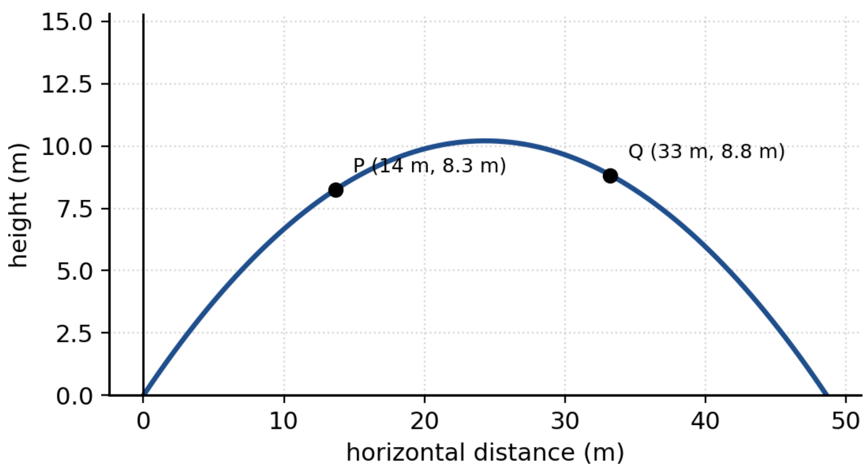

Figure 1.5.44 — Trajectory of a launched ball, with points P and Q marked.

44. A ball follows the trajectory shown in Figure 1.5.44, launched from ground level. Using the coordinates of the marked points and your knowledge of projectile motion, estimate the ball's launch angle and initial speed. Show your reasoning.

45. Two projectiles are launched from the ground with the same initial speed v_0, one at 30° above the horizontal and the other at 60° above the horizontal.

    (a) Show algebraically that the two projectiles land at the same horizontal range.

    (b) Which projectile spends more time in the air? Explain using the relevant kinematics equation.

46. A satellite moves in a circular orbit of radius 7.0×10^6 m with a period of 5.4×10^3 s.

(a) Find the satellite's orbital speed.

(b) Find the satellite's centripetal acceleration.

47. A particle's position is given by the vector function $r(t) = (3.0t^2)\,\hat{i} + (4.0t - t^2)\,\hat{j}$, with r in meters and t in seconds.

(a) Find the velocity vector $v(t) = dr/dt$.

(b) Find the acceleration vector $a(t)$.

(c) Find the time at which the y-component of the velocity is zero, and find the particle's position at that time.

48. A particle undergoes two-dimensional motion with constant acceleration components $a_x = 2.0$ m/s² and $a_y = -9.8$ m/s². At $t = 0$, the particle is at the origin with velocity $v_0 = (5.0\,\hat{i} + 12.0\,\hat{j})$ m/s.

(a) Find the velocity vector $v(t)$.

(b) Find the position vector $r(t)$.

(c) Find the particle's speed at $t = 2.0$ s.

49. A wheel of radius 0.40 m rotates so that a point on its rim moves at a constant speed of 6.0 m/s.

(a) Find the period of the rotation.

(b) Find the centripetal acceleration of the point on the rim.

(c) Explain why this point can have zero tangential acceleration while still having a nonzero acceleration overall.

50. (FRQ) A cannon on a cliff 45 m above a flat plain fires a shell at 60.0 m/s at 35.0° above the horizontal.

(a) Find the time at which the shell reaches its maximum height.

(b) Find the maximum height above the plain reached by the shell.

(c) Find the total time of flight until the shell strikes the plain.

(d) Find the horizontal range, measured from the base of the cliff.

(e) Find the velocity vector (components) of the shell just before impact.

Section General Review | Mixed Problems, Topics 1.1–1.5

Synthesis problems drawing on vectors, calculus-based kinematics, graphs, relative motion, and projectiles

51. A hiker walks 2.0 km at 40° north of east, then 1.5 km due north, over a total time of 50 minutes.

(a) Find the hiker's total displacement (magnitude and direction) using vector components.

(b) Find the hiker's average velocity for the trip.

52. A ball is thrown horizontally at 4.0 m/s from the back of a flatbed truck that is moving forward at 12.0 m/s relative to the ground, from a height of 1.5 m above the truck bed.

(a) Find the ball's initial velocity relative to the ground (magnitude and direction).

(b) Find the ball's horizontal displacement relative to the ground during its fall.

53. A particle's acceleration is given by $a(t) = 4.0 - 0.50t$ (m/s²). At $t = 0$, $v_0 = 2.0$ m/s and $x_0 = 0$.

(a) Integrate to find $v(t)$ and $x(t)$.

(b) Find the time at which the particle's velocity is a maximum.

54. A position-time graph for a cyclist shows the cyclist moving away from the start, slowing to a momentary stop at t = 6.0 s at a maximum distance of 40 m, then returning toward the start, arriving back at t = 14.0 s. At what time is the cyclist's speed greatest, and what feature of the position-time graph tells you this? Is this necessarily the same as the point of greatest acceleration? Explain.

55. A boat crosses a river of width w that flows with current speed v_c. The boat's speed relative to the water is $v_b > v_c$. Explain, using the relative-velocity vector diagram, why pointing the boat straight across the river (rather than angled upstream) always produces the shortest possible crossing time, even though it does not produce the shortest path length.

56. Ball 1 is dropped from rest from a height of 20 m. Exactly 0.40 s later, Ball 2 is thrown straight downward from the same height with an initial speed of 3.0 m/s. Taking downward as positive and t = 0 as the moment Ball 1 is released, find the time at which Ball 2 catches up to Ball 1 (i.e., when they have the same position).

57. A drone's displacement is given by $d = (4.0\,\hat{i} - 2.0\,\hat{j} + 5.0\,\hat{k})$ m.

(a) Find the magnitude of the displacement.

(b) Find the angle the displacement vector makes with the xy-plane.

58. A ball's height above the ground was measured at several times as it rolled up and back down a ramp.

t (s)	0	0.5	1.0	1.5	2.0	2.5
h (m)	0	1.9	3.2	3.9	4.0	3.5

Table G.58 — Height of a ball at 0.5-second intervals.

(a) Estimate the ball's average velocity between t = 1.5 s and t = 2.0 s.

(b) Based on the data, approximately when does the ball reach its maximum height? Explain how you can tell from the table without seeing a graph.

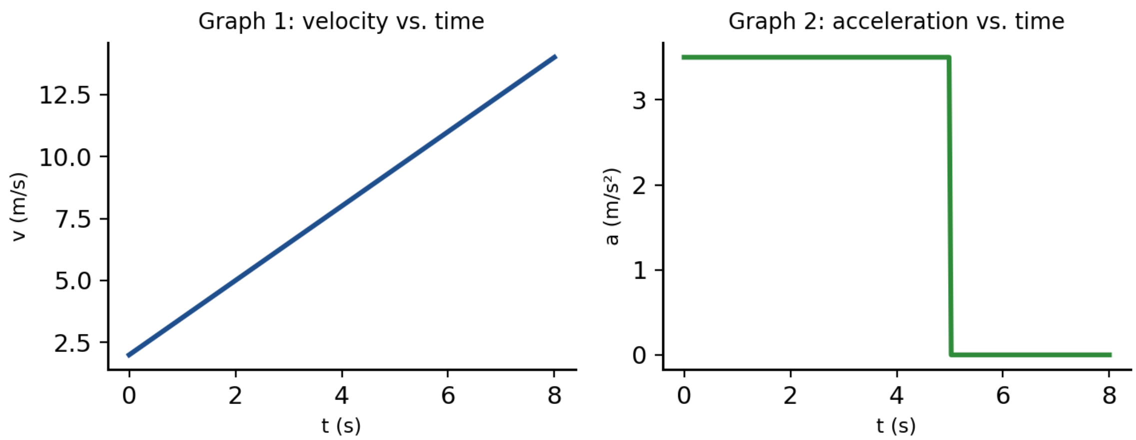

Figure G.59 — Graph 1 (velocity vs. time) and Graph 2 (acceleration vs. time) for two different objects.

59. Do Graph 1 and Graph 2 in Figure G.59 describe the same object's motion? Justify your answer by checking whether the acceleration implied by the slope of Graph 1 is consistent with the acceleration values plotted in Graph 2.

60. A person stands inside an elevator that is accelerating upward at 2.0 m/s^2. The person drops a ball from rest (relative to the elevator) from a height of 1.2 m above the elevator floor.

(a) Find the ball's acceleration relative to the elevator.

(b) Find the time for the ball to hit the elevator floor, as measured by the person inside the elevator.

61. Projectile A is launched horizontally at 15 m/s from a height of 20 m. At the same instant, Projectile B is launched from the ground, 30 m away from a point directly beneath A's launch point, straight upward at 18 m/s, along the same vertical plane as A's motion.

(a) Write x(t) and y(t) for each projectile.

(b) Determine whether the two projectiles collide, and if so, find the time and position of the collision.

62. Which of the following statements is true? Select the best answer and explain why each of the other three is incorrect.

(A) An object can have zero velocity and nonzero acceleration at the same instant.

(B) If an object's speed is constant, its acceleration must be zero.

(C) The direction of the average velocity vector is always the same as the direction of the average acceleration vector.

(D) Displacement and distance traveled are always equal in magnitude.

63. A position-time graph consists of a straight line with positive slope for $0 \le t \le 5$ s, followed by a horizontal segment for $5 \text{ s} \le t \le 8$ s. Which of the following best describes the object's acceleration over the interval $0 \le t \le 8$ s? Select the best answer and justify it using the definition of acceleration as the rate of change of velocity.

(A) Positive and constant throughout

(B) Zero throughout

(C) Zero for 0-5 s, then negative for 5-8 s

(D) Zero for 0-5 s, and undefined (due to a corner) at t = 5 s, then zero again

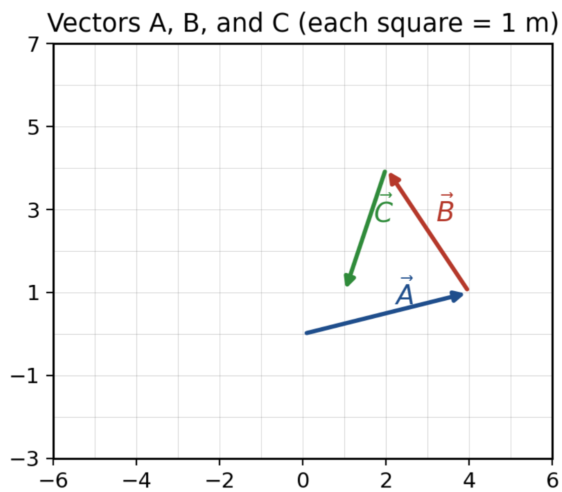

Figure G.64 — Vectors A, B, and C shown tip-to-tail (each grid square = 1 m).

64. Using Figure G.64, the resultant vector R = A + B + C is the single vector drawn from the tail of A to the tip of C.

(a) Read off the approximate components of A, B, and C from the diagram and add them to find R in component form.

(b) Find the magnitude and direction of R.

65. A student walks 40 m east, then 30 m north, then 40 m west, in a total time of 95 s.

(a) Find the total distance traveled.

(b) Find the magnitude of the total displacement.

(c) Find the student's average speed and average velocity, and explain why they are different.

66. A ball is thrown horizontally at 6.0 m/s (relative to the car) from a car window, from a height of 1.1 m, while the car travels at 20.0 m/s due north on a straight road. The ball is thrown out the passenger side, due east relative to the car.

(a) Find the ball's initial velocity relative to the ground, in component form.

(b) Find where the ball lands relative to the point on the ground directly below where it was released.

67. A particle oscillates along the x-axis with velocity $v(t) = v_0 \cos(\omega t)$, where v_0 and ω are constants and the particle starts at $x = 0$.

(a) Integrate $v(t)$ to find $x(t)$.

(b) Find the acceleration $a(t)$ by differentiating $v(t)$, and confirm that $a(t)$ is proportional to $-x(t)$. (You do not need to know about springs to do this — it is a direct calculus check.)

68. Two runners' positions are recorded during a 10 s interval.

t (s)	0	2	4	6	8	10
Runner A: x (m)	0	16	32	48	64	80
Runner B: x (m)	0	6	18	38	58	80

Table G.68 — Position data for two runners during a race.

(a) Which runner has the greater average velocity over the full 10 s? Show the calculation.

(b) Which runner is moving faster at the instant $t = 9$ s? Explain your reasoning using the pattern of the data, without assuming you can compute an exact derivative from the table.

69. Three displacement vectors satisfy $A + B + C = 0$, where $A = (5.0, 2.0)$ m and $B = (-1.0, 6.0)$ m. Find the components and the magnitude of vector C.

70. (FRQ) A two-stage model rocket is launched straight upward from the ground. During Stage 1 ($0 \le t \le 3.0$ s), it accelerates uniformly from rest at 25 m/s². At $t = 3.0$ s, the engine cuts off and the rocket continues upward as a projectile under gravity alone until it reaches maximum height, then falls back to the ground.

(a) Find the rocket's velocity and altitude at the moment of engine cutoff ($t = 3.0$ s).

(b) Find the additional time after cutoff for the rocket to reach maximum altitude, and find that maximum altitude.

(c) Find the total time from launch until the rocket returns to the ground.

(d) Sketch (describe in words, interval by interval) the shape of the rocket's velocity-time graph from launch to landing, noting where the slope changes.

Answer Key

Odd-numbered problems only (1, 3, 5, ... 69)

Final answers are given below; they are not worked solutions. Units and signs matter — check both. Small differences (last digit) may occur depending on rounding choices and $g = 9.8$ vs $9.81\ m/s^2$.

1. mass – scalar; displacement – vector; speed – scalar; velocity – vector; distance – scalar; acceleration – vector; time – scalar; kinetic energy – scalar. Vectors carry direction as well as magnitude; scalars carry magnitude only.

3. Magnitude = 10.0 N; direction ≈ 126.9° from the +x-axis (53.1° above the −x-axis).

5. C = (10.0, -7.0) m; |C| ≈ 12.2 m.

7. (a) F_{net} = (2.0, -1.0) N. (b) $|F_{net}|$ ≈ 2.24 N, directed ≈ 26.6° below the +x-axis.

9. P + Q = 0 (the zero vector). P and Q are antiparallel and equal in magnitude (200° = 20° + 180°), so they cancel exactly, both graphically (tip-to-tail returns to the start) and analytically (components sum to zero).

11. (a) $v(t) = 6.0t^2 - 18.0t + 12.0$. (b) t = 1.0 s and t = 2.0 s.

13. 9.0 m/s [x(1) = 5 m, x(4) = 32 m]. This differs from the instantaneous velocity at the midpoint t = 2.5 s because the motion is not uniform — v(t) is not linear, so the average over the interval is not equal to the value at the interval's midpoint.

15. (a) t ≈ 4.0 s. (b) v ≈ 39.1 m/s.

17. (a) ≈ 6.4 m/s. (b) 7.0 m/s. The second-interval average exceeds the overall average, so the jogger was moving faster than average during the 4–6 s window — the motion is not uniform.

19. (a) t = 6.0 s. (b) d = 72 m.

21. (a) 0–4 s: speeding up, moving away from start (concave up). 4–6 s: constant velocity (≈6 m/s, straight segment). 6–10 s: slowing, then reversing direction back toward the start (concave down). (b) ≈6 m/s. (c) v = 0 at t ≈ 6 s, where the graph transitions from increasing to decreasing.

23. (a) v(3.0 s) = 12 m/s. (b) v(10.0 s) = 6 m/s. (c) 0–3 s: v rises linearly from 0 to 12 m/s; 3–7 s: v constant at 12 m/s; 7–10 s: v falls linearly from 12 to 6 m/s.

25. None of the three graphs is correct. A ball thrown straight up has speed that decreases from launch value to zero at the top, then increases again as it falls — a V-shaped speed-time graph — which does not match any single monotonic or constant graph.

27. P: $v < 0$, $a > 0$ (moving in the negative direction but slowing). Q: $v = 0$, $a = 0$ (an inflection point of the curve, momentarily at rest). R: $v < 0$, $a < 0$ (moving in the negative direction and speeding up).

29. Velocity-time graph: a straight line of constant positive slope from 0 up to some v_{max} during 0–5 s, then a horizontal line at v_{max} afterward. Position-time graph: concave-up (parabolic) during 0–5 s, transitioning smoothly into a straight line of constant slope v_{max} afterward, with no further curvature.

31. $|v_{boat/shore}|$ = 5.0 m/s, directed 36.9° downstream of straight across.

33. t = 12 s.

35. $|v_{rain/car}| \approx 19.0$ m/s, directed ≈ 71.6° from the vertical (tilted back toward the rear of the car).

37. Velocity depends on reference frame because it differs by the constant relative velocity between frames. Since that relative velocity is constant (inertial frames), its rate of change is zero, so both observers compute the same acceleration for the object.

39. $v_{A/B} = (6.0, -2.0)$ units; magnitude ≈ 6.3, directed ≈ 18.4° below the +x-axis.

41. (a) t ≈ 0.495 s. (b) range ≈ 1.63 m.

43. $v_{final} = \sqrt{v_0^2 + 2gh}$ — independent of the launch angle θ.

45. (a) $R = v_0^2 \sin(2\theta)/g$ is equal for θ = 30° and θ = 60° because sin(60°) = sin(120°). (b) The 60° launch stays in the air longer, since $t = 2v_0 \sin\theta/g$ and sin(60°) > sin(30°).

47. (a) $v(t) = 6.0t\,\hat{i} + (4.0 - 2.0t)\,\hat{j}$. (b) $a(t) = 6.0\,\hat{i} - 2.0\,\hat{j}$ (constant). (c) t = 2.0 s; position = (12.0, 4.0) m.

49. (a) T ≈ 0.42 s. (b) $a_c = 90$ m/s². (c) Tangential acceleration is zero because speed is constant, but the direction of the velocity is continuously changing, which requires a nonzero centripetal (radial) acceleration component — the overall acceleration vector need not be zero even though its tangential component is.

51. (a) Displacement ≈ (1.53, 2.79) km; magnitude ≈ 3.18 km at ≈ 61.2° north of east. (b) Average velocity ≈ 3.82 km/h (≈ 1.06 m/s), directed ≈ 61.2° north of east.

53. (a) $v(t) = 2.0 + 4.0t - 0.25t^2$; $x(t) = 2.0t + 2.0t^2 - 0.0833t^3$. (b) t = 8.0 s.

55. Crossing time depends only on the component of the boat's velocity perpendicular to the bank, $t = w / v_{b\perp}$. Pointing straight across makes the entire boat speed perpendicular to the bank; any other heading reduces this perpendicular component (multiplying it by cos of the heading angle), which increases the crossing time even though the current still carries the boat sideways.

57. (a) |d| ≈ 6.7 m. (b) ≈ 48.2° above the xy-plane.

59. No. Graph 1's constant slope implies a constant acceleration of 1.5 m/s² for the entire interval, but Graph 2 shows acceleration of 3.5 m/s² for t ≤ 5 s and 0 for t > 5 s — neither matches 1.5 m/s², so the two graphs are inconsistent with one another.

61. No collision. Setting $x_A(t) = x_B(t)$ gives t = 2.0 s, but at that time $y_A = 0.4$ m while $y_B = 16.4$ m — the projectiles are about 16 m apart vertically when their horizontal positions match, so they miss each other.

63. D — acceleration is zero on 0–5 s (constant positive velocity) and zero on 5–8 s (zero velocity), with an abrupt, instantaneous (technically undefined) change in velocity at the corner, t = 5 s.

65. (a) Total distance = 110 m. (b) |Displacement| = 30 m (due north). (c) Average speed ≈ 1.16 m/s; average velocity ≈ 0.32 m/s north. They differ because walking east and then west partially cancels in displacement but still adds to the total distance traveled.

67. (a) $x(t) = (v_0/\omega)\sin(\omega t)$. (b) $a(t) = -v_0\omega \sin(\omega t) = -\omega^2 x(t)$, confirming a(t) is proportional to −x(t) with constant ω^2.

69. C = (-4.0, -8.0) m; |C| ≈ 8.94 m.