AP Physics 1

Unit 1 Problem Set: Kinematics

Topics 1.1–1.5 | 70 Problems | The 42nd Period

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Instructions: Show all work, including relevant equations, substitutions, and units, for full credit. Where a graph, table, or diagram is provided, use the data given to answer the associated question(s). Take g = 10 m/s^2 unless otherwise noted. Unless stated otherwise, treat rightward/eastward and upward as the positive direction.

Answers to all odd-numbered problems begin on a separate page at the end of this set.

Topic 1.1 – Scalars and Vectors in One Dimension

Distinguishing scalar and vector quantities, sign conventions, and vector addition along a single axis.

1. Classify each of the following quantities as a **scalar** or a **vector**: (a) distance (b) displacement (c) speed (d) velocity (e) time (f) acceleration (g) mass.

2. A runner runs 400 m due east and then turns around and runs 400 m due west back to the starting point. Find (a) the total distance traveled and (b) the displacement for the trip.

3. Explain why velocity is classified as a vector quantity while speed is classified as a scalar quantity. Support your answer with a specific example of a situation in which an object's speed remains constant while its velocity changes.

4. A car moving along a straight road undergoes a displacement of +50 m, and then a second displacement of −20 m. Find the car's net displacement for the two moves combined.

5. Two displacement vectors act along the same line: the first has a value of +15 m and the second has a value of −8 m. Find the resultant (sum) of the two vectors.

6. A hiker walks 3 km due north and then continues walking an additional 5 km due north. Using vector addition, find the hiker's total displacement for the trip.

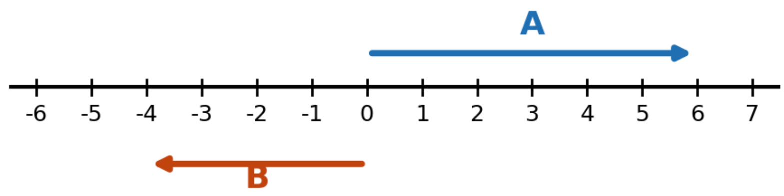
7. An object moving along the x-axis undergoes three consecutive displacements: 12 m in the +x direction, 20 m in the −x direction, and 4 m in the +x direction. Find (a) the total distance traveled and (b) the net displacement.

8. A ball on a pool table modeled as a one-dimensional number line starts at position +2 m and ends at position −3 m. Determine the magnitude and direction of the ball's displacement vector.

9. The table below gives the position of an object at five instants of time. Use the table to find the displacement of the object during each 1-second interval (0–1 s, 1–2 s, 2–3 s, 3–4 s), and the total displacement from t = 0 s to t = 4 s.

t (s)	0	1	2	3	4
x (m)	0	4	8	6	2

10. The number line below shows two displacement vectors, A and B, drawn to scale along the same axis. Using the diagram, find the vector sum A + B, and state its magnitude and direction.



Vectors A and B along a common axis.

Topic 1.2 – Displacement, Velocity, and Acceleration

Average velocity and average acceleration from displacement–time and velocity–time data.

11. A car travels 150 m in 5.0 s along a straight track. Find the car's average velocity.

12. A sprinter's velocity increases from 0 to 9.0 m/s in 3.0 s. Find the sprinter's average acceleration.

13. The table below gives the position of a cart at five instants of time. Find the average velocity of the cart during each 1-second interval, and find the average velocity for the entire 4-second trip.

t (s)	0	1	2	3	4
x (m)	0	2	8	18	32

14. A cyclist travels 120 m east in 15 s, and then travels an additional 80 m east in 10 s. Find the cyclist's average velocity for the entire trip.

15. A ball moving in the +x direction has its velocity decrease from 20 m/s to 5 m/s over a time interval of 2.5 s. Find the ball's average acceleration, including direction.

16. During one time interval, a car's average velocity is +3 m/s. During the next, equal time interval, its average velocity is +7 m/s. Is the car speeding up or slowing down? Justify your answer using the definition of acceleration.

17. A car traveling in the negative direction has its velocity change from −10 m/s to −30 m/s over a time interval of 8.0 s. (a) Find the car's average acceleration. (b) Is the car speeding up or slowing down? Justify your answer by comparing the signs of the velocity and the acceleration.

18. The table below gives the position of a delivery drone at four instants of time (note that the time intervals are not equal). Find the average velocity of the drone during each interval, and find the average velocity for the entire trip from t = 0 s to t = 9 s.

t (s)	0	2	5	9
x (m)	0	10	40	76

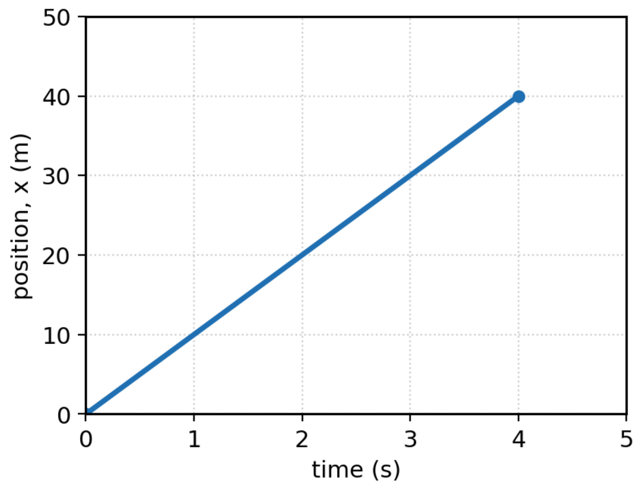
19. A train's velocity decreases uniformly from 40 m/s to 0 m/s over a time interval of 20 s as it comes into a station. Find the train's average acceleration.

20. Jogger A has an average velocity of +2.5 m/s and jogger B has an average velocity of −1.8 m/s. Both joggers start at the same position and each jogs for 60 s. Find (a) the displacement of each jogger, and (b) the distance separating the two joggers after 60 s.

Topic 1.3 – Representing Motion

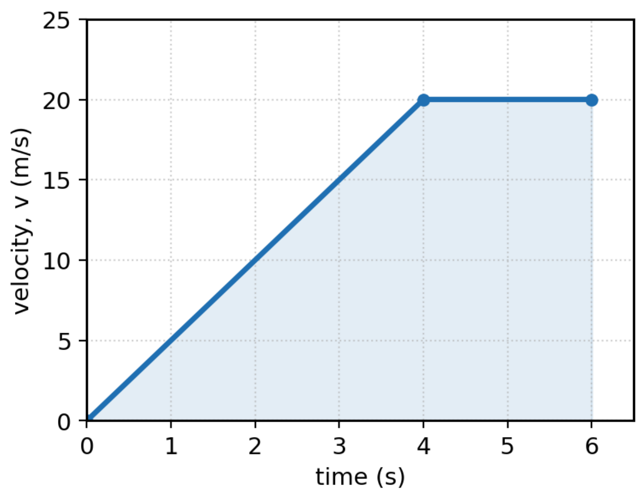
Reading and interpreting position–time, velocity–time, and acceleration–time graphs; applying the kinematic equations for constant acceleration.

21. The position–time graph below shows the motion of a remote-control car. Use the graph to find the car's velocity.



Position vs. time for the remote-control car.

22. The velocity–time graph below shows the motion of a skateboarder. Use the graph to find (a) the skateboarder's acceleration during the first 4.0 s, and (b) the total displacement of the skateboarder from t = 0 s to t = 6.0 s.



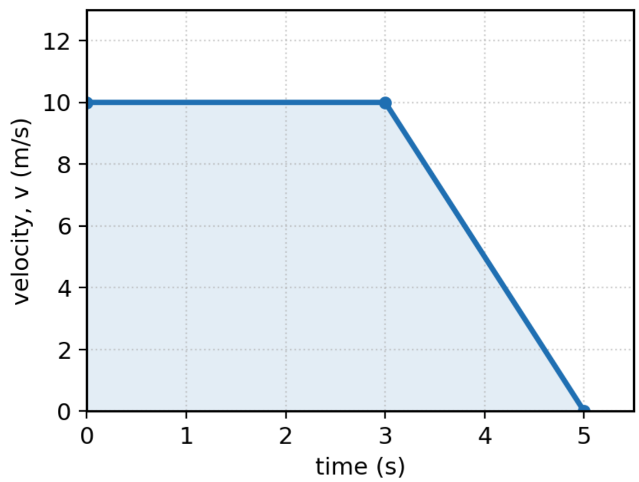
Velocity vs. time for the skateboarder.

23. An object starts from rest and accelerates uniformly at 3.0 m/s^2 for 6.0 s. Find (a) the object's final velocity and (b) the distance it travels.

24. An object is dropped from rest and falls freely for 2.0 s. Using g = 10 m/s^2, find (a) the object's velocity and (b) the distance it has fallen at the end of 2.0 s.

25. An object moving at 15 m/s decelerates uniformly at 2.5 m/s^2. Find (a) the time required for the object to come to rest and (b) the distance it travels while stopping.

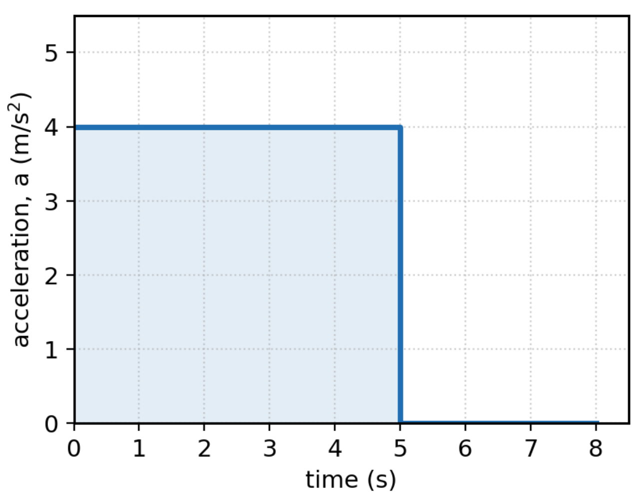
26. The velocity–time graph below shows the motion of a delivery cart. Use the graph to find the cart's total displacement from t = 0 s to t = 5.0 s.



Velocity vs. time for the delivery cart.

27. An object's position is x = 5.0 m at t = 1.0 s and x = 45 m at t = 3.0 s. Find the object's average velocity between t = 1.0 s and t = 3.0 s.

28. The acceleration–time graph below shows the motion of a golf cart that starts from rest at t = 0. Use the graph to find the golf cart's velocity at t = 8.0 s.



Acceleration vs. time for the golf cart.

29. An object starts from rest and accelerates uniformly at 2.0 m/s^2 for 5.0 s. (a) Find the total distance the object travels. (b) Describe the shape of the corresponding position–time graph for this motion, and explain why it has that shape.

30. An object starts with an initial velocity of 4.0 m/s and moves with constant acceleration. The table below gives its position at three instants of time. Use the kinematic equations and the data in the table to determine the object's acceleration.

t (s)	0	2	4
x (m)	0	12	32

Topic 1.4 – Reference Frames and Relative Motion

Converting velocity measurements between reference frames moving relative to one another.

31. A train moves at +25 m/s (east) relative to the ground. A passenger walks at +2 m/s (east) relative to the train. Find the passenger's velocity relative to the ground.

32. A train moves at +25 m/s (east) relative to the ground. A passenger walks toward the back of the train at −2 m/s relative to the train. Find the passenger's velocity relative to the ground.

33. Car A moves at +20 m/s and Car B moves at +15 m/s, both relative to the ground and both heading east. Find the velocity of Car A relative to Car B.

34. Car A moves at +20 m/s (east) and Car B moves at −10 m/s (west, i.e., toward Car A), both relative to the ground. Find the velocity of Car A relative to Car B.

35. A boat moves at 4 m/s relative to the water. The water (current) flows at 3 m/s in the same direction, relative to the ground. Find the boat's velocity relative to the ground.

36. An object moves at +5 m/s as measured by an observer on the ground. A second observer, in reference frame B, moves at +5 m/s relative to the ground. Find the velocity of the object as measured by observer B, and explain the physical meaning of your result.

37. A passenger on a train sees a ball roll away from her, toward the front of the train, at 1.5 m/s relative to the train. The train moves at +18 m/s relative to the ground. Find the ball's velocity relative to the ground.

38. The table below gives the velocity of three reference frames (P, Q, and R) relative to the ground. Find (a) the velocity of P relative to Q, (b) the velocity of Q relative to R, and (c) the velocity of P relative to R.

Reference frame	Velocity relative to ground
P	+12 m/s
Q	+7 m/s
R	−5 m/s

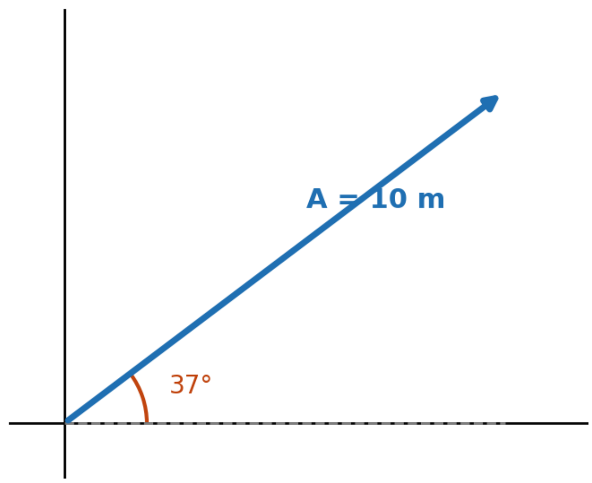
39. An airplane flies at 80 m/s relative to the surrounding air. A tailwind blows at 15 m/s in the same direction the plane is traveling. Find the plane's speed relative to the ground.

40. The same airplane from the previous problem instead flies into a headwind of 15 m/s (opposing the plane's motion). Find the plane's speed relative to the ground.

Topic 1.5 – Vectors and Motion in Two Dimensions

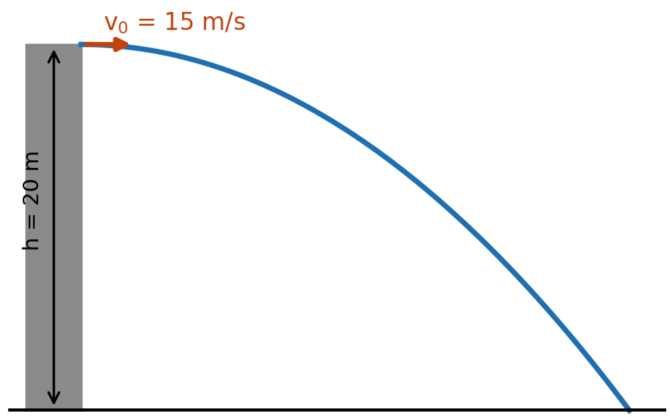
Vector components, vector addition in two dimensions, and projectile motion.

41. The diagram below shows a displacement vector A with a magnitude of 10 m, directed 37° above the horizontal. Find the x- and y-components of vector A. (sin 37° ≈ 0.60, cos 37° ≈ 0.80)



Vector A at 37° above the horizontal.

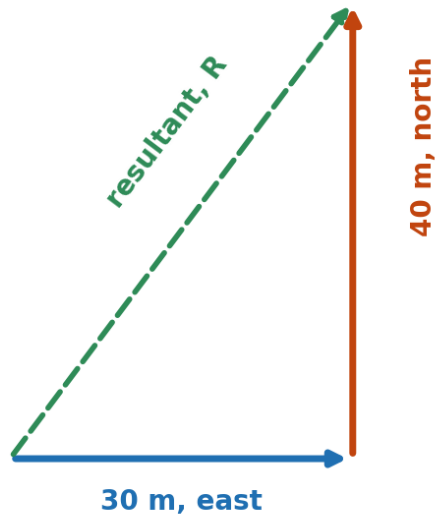
42. The diagram below shows a ball launched horizontally at 15 m/s from the top of a 20 m cliff. Using g = 10 m/s^2, find (a) the time it takes the ball to reach the ground and (b) the horizontal distance the ball travels before landing.



Ball launched horizontally from a 20 m cliff.

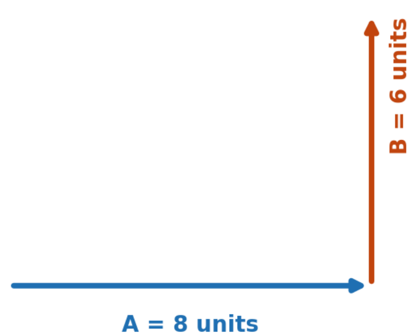
43. A projectile is launched from the ground at 20 m/s, directed 30° above the horizontal. Using g = 10 m/s^2, find (a) the maximum height reached by the projectile and (b) the total time the projectile is in the air.

44. The diagram below shows two perpendicular displacement vectors: 30 m east, followed by 40 m north. Using the diagram, find the magnitude and direction of the resultant displacement.



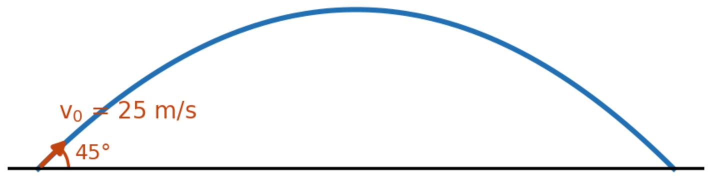
Displacement of 30 m east, then 40 m north.

45. The diagram below shows vector A (8 units, directed east) and vector B (6 units, directed north), added tip-to-tail. Use vector components to find the magnitude and direction of the resultant vector, A + B.



Vectors A and B added tip-to-tail.

46. The diagram below shows a projectile launched from the ground at 25 m/s, directed 45° above the horizontal. Using g = 10 m/s^2, find the horizontal range of the projectile.

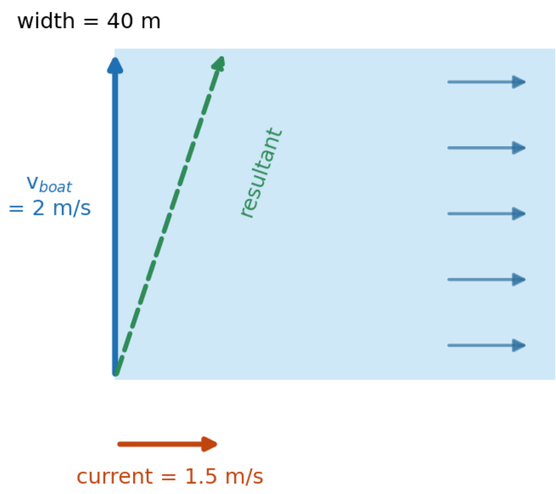


Projectile launched at 45° above the horizontal.

47. At a certain instant, a moving object has velocity components v_x = 6 m/s and v_y = 8 m/s, as summarized in the table below. Find the speed of the object and the direction of its velocity vector relative to the x-axis.

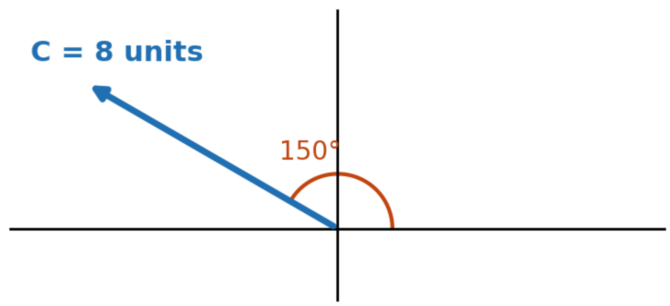
Component	Value at t = 2 s
v_x	6 m/s
v_y	8 m/s

48. The diagram below shows a boat that heads straight across a 40 m wide river, aiming its motion (2 m/s) directly perpendicular to the current (1.5 m/s). Use the diagram to find (a) the time required for the boat to cross the river, (b) the boat's displacement downstream during the crossing, and (c) the magnitude of the boat's resultant velocity relative to the ground.



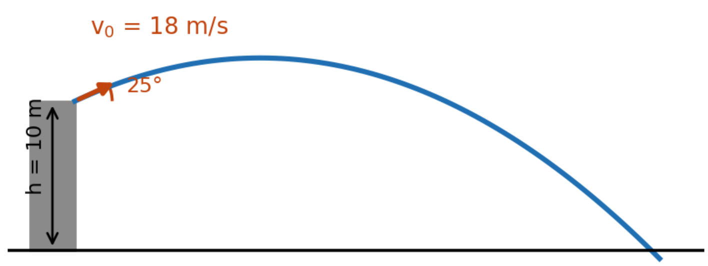
Boat crossing a river with a current.

49. The diagram below shows vector C, with a magnitude of 8 units, directed at an angle of 150° measured counterclockwise from the positive x-axis. Find the x- and y-components of vector C.



Vector C at 150° from the positive x-axis.

50. The diagram below shows a ball launched from the edge of a 10 m cliff at 18 m/s, directed 25° above the horizontal. Using g = 10 m/s^2, find (a) the total time the ball is in the air and (b) the horizontal distance it travels before landing.



Ball launched at an angle from a 10 m cliff.

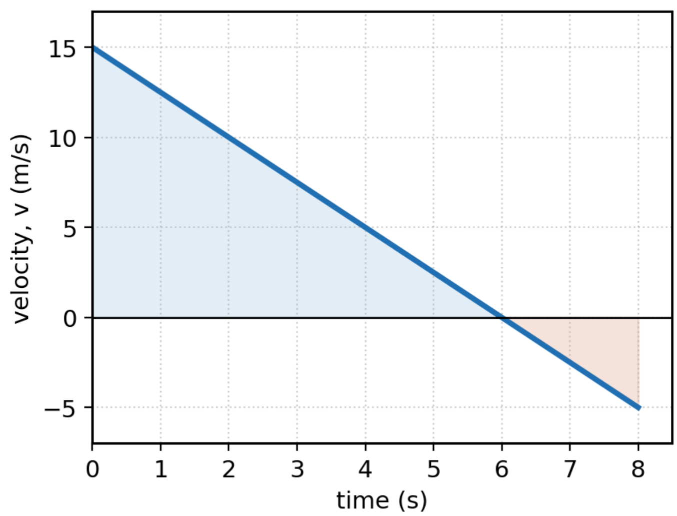
Topic Unit 1 Review – General & Mixed Problems

Problems 51–70 draw on multiple topics from across Unit 1 and are not presented in any particular topic order — just like on the AP Exam.

51. Classify each of the following quantities as a **scalar** or a **vector**: (a) energy (b) force (c) temperature (d) momentum (e) time.

52. A car accelerates uniformly from 12 m/s to 28 m/s while traveling a distance of 40 m. Find the car's acceleration.

53. The velocity–time graph below shows the motion of a remote-control boat along a straight canal, where positive velocity indicates motion away from the dock. Use the graph to find (a) the boat's acceleration, (b) the time at which the boat reverses direction, and (c) the boat's total displacement from t = 0 s to t = 8.0 s.



Velocity vs. time for the remote-control boat.

54. A car starts from rest and accelerates uniformly to 24 m/s in 6.0 s. It then travels at a constant 24 m/s for 10.0 s, and finally decelerates uniformly to rest in 4.0 s. Find (a) the total distance traveled by the car and (b) the car's average velocity for the entire trip.

55. A swimmer swims at 1.2 m/s relative to the water, heading straight across a river that is 50 m wide. The river's current flows at 0.8 m/s. Find (a) the time required for the swimmer to cross the river and (b) the magnitude of the swimmer's resultant velocity relative to the ground.

56. A ball is thrown horizontally at 10 m/s from the top of a 25 m cliff. Using g = 10 m/s^2, find (a) the horizontal distance the ball travels before landing and (b) the ball's speed the instant before it strikes the ground.

57. A rock is released from a hot-air balloon that is rising at 3 m/s, so the rock's initial velocity is +3 m/s (upward) at the moment of release. The balloon is 40 m above the ground at that instant. Using g = 10 m/s^2 and taking upward as positive, find (a) the maximum height the rock reaches above its release point and (b) the total time it takes the rock to reach the ground.

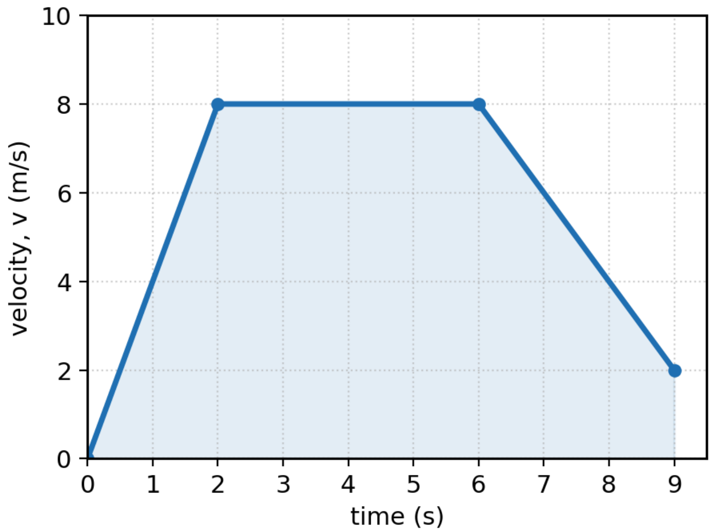
58. The table below gives the position of a remote-control car at five instants of time. (a) Find the average velocity of the car during each 1-second interval. (b) Identify the interval during which the car had the greatest average speed. (c) State whether position and time are each classified as a scalar or a vector quantity.

t (s)	0	1	2	3	4
x (m)	0	3	5	6	12

59. An object undergoes three consecutive one-dimensional displacements, given in the table below. Find (a) the object's total displacement and (b) the total distance it traveled.

Displacement 1	Displacement 2	Displacement 3
+12 m	−5 m	+9 m

60. The velocity–time graph below shows the motion of a cyclist along a straight bike path. Use the graph to find (a) the cyclist's acceleration during the first 2.0 s, (b) the cyclist's displacement from t = 2.0 s to t = 6.0 s, (c) the cyclist's total displacement from t = 0 s to t = 9.0 s, and (d) the cyclist's acceleration during the final segment, from t = 6.0 s to t = 9.0 s.



Velocity vs. time for the cyclist.

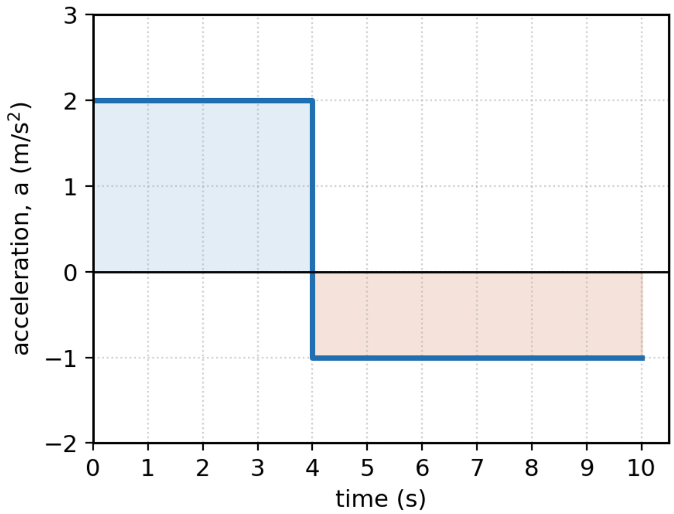
61. An airplane heads due north at 200 km/h relative to the air. A wind blows due east at 50 km/h. Find the magnitude and direction of the airplane's resultant velocity relative to the ground.

62. An object has an initial velocity of 5.0 m/s and a constant acceleration of 1.5 m/s^2 in the same direction. Find the object's displacement after 10 s.

63. Runner A speeds up uniformly from rest to 6.0 m/s over 3.0 s. Runner B, starting from rest at the same time and place, speeds up uniformly to 9.0 m/s over the same 3.0 s. Find (a) which runner has the greater acceleration and (b) which runner travels farther during the 3.0 s, and by how much.

64. A ball is thrown straight upward from the ground at 18 m/s. Using g = 10 m/s^2, find (a) the maximum height reached by the ball, (b) the total time the ball is in the air, and (c) the ball's velocity the instant it returns to its launch height.

65. The acceleration–time graph below shows the motion of a go-kart that starts from rest at t = 0. Use the graph to find (a) the go-kart's velocity at t = 4.0 s, (b) the go-kart's velocity at t = 10 s, and (c) the go-kart's total displacement from t = 0 s to t = 10 s.



Acceleration vs. time for the go-kart.

66. Object A starts at position x = 0 and moves at a constant +8 m/s. At the same instant, Object B starts at position x = 200 m and moves at a constant −5 m/s. Find the time at which the two objects meet, and the position at which they meet.

67. A skier undergoes a displacement of 50 m directed 60° below the horizontal (down a slope). Find the horizontal and vertical components of the skier's displacement.

68. The table below gives the horizontal position, x, and vertical position, y, of a launched ball at five instants of time. Use the table to find (a) the ball's total time of flight, (b) the horizontal range of the ball, and (c) the ball's horizontal velocity component, v_x, and state whether it changes during the flight.

t (s)	0	1	2	3	4
x (m)	0	8	16	24	32
y (m)	0	15	20	15	0

69. A moving walkway at an airport moves at +1.5 m/s. Walker A walks in the same direction as the walkway at an additional 1.0 m/s relative to the walkway, while Walker B walks in the opposite direction at 1.0 m/s relative to the walkway. The walkway is 90 m long. Find (a) each walker's velocity relative to the ground and (b) the time it takes each walker to travel the length of the walkway.

70. An object has an initial velocity of 6.0 m/s and a constant acceleration of 2.0 m/s^2, both directed in the +x direction; take x_0 = 0. (a) Write the object's position equation, x(t). (b) Find the object's position at t = 3.0 s. (c) Find the object's velocity at t = 3.0 s. (d) Describe the shape of the corresponding position–time graph. (e) State whether the object's velocity and acceleration are vectors or scalars, and give the direction of each.

Answer Key

Solutions to odd-numbered problems only (1–69). $g = 10\ m/s^2$ used throughout.

1. distance – scalar; displacement – vector; speed – scalar; velocity – vector; time – scalar; acceleration – vector; mass – scalar.

3. Velocity specifies both magnitude and direction, while speed specifies only magnitude. Example: a car traveling around a curve at a constant 10 m/s has constant speed, but its velocity is continuously changing because its direction of travel is changing.

5. Resultant = (+15 m) + (−8 m) = **+7 m** (7 m in the positive direction).

7. (a) Total distance = 12 + 20 + 4 = **36 m**. (b) Net displacement = 12 − 20 + 4 = **−4 m** (4 m in the −x direction).

9. $\Delta x(0\to1) = +4$ m, $\Delta x(1\to2) = +4$ m, $\Delta x(2\to3) = -2$ m, $\Delta x(3\to4) = -4$ m. Total displacement (0 s to 4 s) = 2 m − 0 m = **+2 m**.

11. $v_{avg} = \Delta x/\Delta t$ = 150 m / 5.0 s = **30 m/s**.

13. v_{avg}: (0–1 s) = 2 m/s, (1–2 s) = 6 m/s, (2–3 s) = 10 m/s, (3–4 s) = 14 m/s. Overall average velocity = 32 m / 4 s = **8.0 m/s**.

15. $a_{avg} = \Delta v/\Delta t$ = (5 − 20 m/s)/2.5 s = **$-6.0\ m/s^2$** (6.0 m/s^2, directed opposite the motion – the ball is decelerating).

17. (a) a_{avg} = (−30 − (−10) m/s)/8.0 s = **$-2.5\ m/s^2$**. (b) The velocity and acceleration have the *same* sign (both negative), so the car is **speeding up** (in the negative direction).

19. a_{avg} = (0 − 40 m/s)/20 s = **$-2.0\ m/s^2$**.

21. $v = \Delta x/\Delta t$ = 40 m / 4 s = **10 m/s** (the slope of the line).

23. (a) $v = v_0 + at = 0 + (3.0)(6.0) =$ **18 m/s**. (b) $x = v_0 t + ½at^2 = 0 + ½(3.0)(6.0)^2 =$ **54 m**.

25. (a) $t = -v_0/a = -15/(-2.5) =$ **6.0 s**. (b) Using $v^2 = v_0{}^2 + 2a\Delta x$: $0 = (15)^2 + 2(-2.5)\Delta x \Rightarrow \Delta x = 225/5.0 =$ **45 m**.

27. $v_{avg} = \Delta x/\Delta t$ = (45 − 5)/(3.0 − 1.0) = 40/2.0 = **20 m/s**.

29. (a) $x = ½at^2 = ½(2.0)(5.0)^2 =$ **25 m**. (b) The x-t graph is a **parabola, concave up** – the object starts from rest, and its position increases at an increasing rate because the velocity is continuously growing under constant positive acceleration.

31. $v_{passenger/ground} = v_{passenger/train} + v_{train/ground}$ = 2 + 25 = **+27 m/s (east)**.

33. $v_{A/B} = v_A - v_B$ = 20 − 15 = **+5 m/s** (Car A moves at 5 m/s relative to Car B, in the eastward direction).

35. $v_{boat/ground} = v_{boat/water} + v_{water/ground}$ = 4 + 3 = **7 m/s** (same direction as the boat's heading).

37. $v_{ball/ground} = v_{ball/train} + v_{train/ground}$ = 1.5 + 18 = **19.5 m/s**.

39. $v_{ground} = v_{plane/air} + v_{wind}$ = 80 + 15 = **95 m/s**.

41. A_x = 10 cos 37° = 10(0.80) = **8.0 m**. A_y = 10 sin 37° = 10(0.60) = **6.0 m**.

43. v_{0y} = 20 sin 30° = 10 m/s. (a) Max height = $v_{0y}^2/(2g) = (10)^2/20$ = **5.0 m**. (b) Time of flight = $2v_{0y}/g$ = 20/10 = **2.0 s**.

45. R_x = 8 units, R_y = 6 units. Magnitude = $\sqrt{(8^2 + 6^2)} = \sqrt{100}$ = **10 units**. Direction = $\tan^{-1}(6/8)$ = **36.9° north of east**.

47. Speed = $\sqrt{(6^2 + 8^2)} = \sqrt{100}$ = **10 m/s**. Direction = $\tan^{-1}(8/6)$ = **53.1° above the x-axis**.

49. C_x = 8 cos 150° = 8(−0.866) = **−6.9 units**. C_y = 8 sin 150° = 8(0.50) = **+4.0 units**.

51. energy – scalar; force – vector; temperature – scalar; momentum – vector; time – scalar.

53. (a) a = Δv/Δt = (−5 − 15 m/s)/8.0 s = **−2.5 m/s²**. (b) Setting v = 0: 0 = 15 − 2.5t ⇒ t = **6.0 s**. (c) Displacement (0–6 s, triangle) = ½(6.0)(15) = +45 m; displacement (6–8 s, triangle) = ½(2.0)(−5) = −5 m. Total displacement = 45 − 5 = **+40 m**.

55. (a) t = width/v_{swim} = 50/1.2 = **41.7 s**. (b) Resultant speed = $\sqrt{(1.2^2 + 0.8^2)} = \sqrt{2.08}$ ≈ **1.4 m/s**.

57. Taking up as positive: (a) $0 = (3)^2 - 2(10)h$ ⇒ h = 9/20 = **0.45 m** above the release point. (b) Using $y(t) = 3t - 5t^2 = -40$: $5t^2 - 3t - 40 = 0$ ⇒ t = [3 + √(9 + 800)]/10 = [3 + 28.4]/10 ≈ **3.1 s**.

59. (a) Total displacement = 12 − 5 + 9 = **+16 m**. (b) Total distance = 12 + 5 + 9 = **26 m**.

61. Magnitude = $\sqrt{(200^2 + 50^2)} = \sqrt{42500}$ ≈ **206 km/h**. Direction = $\tan^{-1}(50/200)$ ≈ **14° east of north**.

63. (a) a_A = 6.0/3.0 = 2.0 m/s²; a_B = 9.0/3.0 = 3.0 m/s². **Runner B** has the greater acceleration. (b) x_A = ½(3.0)(6.0) = 9.0 m; x_B = ½(3.0)(9.0) = 13.5 m. **Runner B** travels farther, by **4.5 m**.

65. (a) v(4 s) = 0 + (2.0)(4.0) = **8.0 m/s**. (b) v(10 s) = 8.0 + (−1.0)(6.0) = **2.0 m/s**. (c) Displacement (0–4 s) = ½(0 + 8.0)(4.0) = 16 m; displacement (4–10 s) = ½(8.0 + 2.0)(6.0) = 30 m. Total displacement = 16 + 30 = **46 m**.

67. x = 50 cos 60° = **25 m** (horizontal). y = −50 sin 60° = **−43.3 m** (43.3 m downward).

69. (a) $v_{A/ground}$ = 1.5 + 1.0 = **+2.5 m/s**; $v_{B/ground}$ = 1.5 − 1.0 = **+0.5 m/s**. (b) t_A = 90/2.5 = **36 s**; t_B = 90/0.5 = **180 s**.