

Physics

Kinematics Model

I. Overview

Active Physics introduces the concept of *average* velocity and average acceleration. This unit supplements Active Physics by addressing the concept of *instantaneous* velocity and instantaneous acceleration with the “Kinematics Model”. This guide will introduce a “Kinematics Model” problem solving strategy (Part II) and solve a constant acceleration problem using this strategy (Part III). Part IV gives students examples and Part V provides extra quantitative and qualitative HW problems.

II. Kinematics Model Problem Solving Strategy

A problem solving strategy for addressing problems involving constant acceleration for objects (i.e. the “Kinematics Model”) is given below:

Step 1: List Equations (the organizational part)

Here students list all equations that are applicable to the problem. At this point, they should not be attempting to choose which equation to use. Completing this step is purely an organizational step. The meaning of each of the variables is described below in step 2.

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v = v_0 + at$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

Step 2: List Variables (the Physics part)

After reading the problem statement, students will extract the given numerical information from that problem statement, and assign these correct numerical values to the correct variables. This step is the “Physics” of the problem. If students can complete this step correctly, step 3 described below is purely a mathematical step.

x_0 = initial displacement (i.e. the object’s position at time = 0 s)

x = final displacement (i.e. the object’s position at time = t)

v_0 = initial velocity (i.e. the object’s velocity at time = 0)

v = final velocity (i.e. the object’s velocity at time = t)

a = acceleration (i.e. the constant acceleration of the object during the time interval)

t = time (i.e. the total time of the object’s motion)

Note that x_0 and x are used which implies horizontal motion. However, y_0 and y can be used to denote vertical motion (falling under the influence of gravity) as done in Activity 8 “Projectile Motion” in Active Physics.

Step 3: Solve (the mathematical part)

After completing Step 2, the known and unknown variables will be listed. If step 2 is completed correctly, this step concludes with choosing which of the three kinematic equations to use based on the known and unknown variables. As mentioned above, this step is a purely mathematical step, using math as a tool to arrive at the correct answer. The following section models how this strategy can be used to solve a constant acceleration problem.

III. Example

A car goes from 40 m/s to 80 m/s in a distance of 200 m. What is its acceleration during this time?

Given: (student draws a picture of physical situation here)

Find: a (student lists the variable(s) representing the quantities that need to be calculated)

Solution:

1. List Equations

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v = v_0 + at$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

2. List Variables

$$x_0 = 0 \text{ [m]}$$

$$x = 200 \text{ [m]}$$

$$v_0 = 40 \text{ [m/s]}$$

$$v = 80 \text{ [m/s]}$$

$$a = \boxed{} \quad (\text{the empty box represents an unknown quantity})$$

$$t = \boxed{}$$

3. Solve

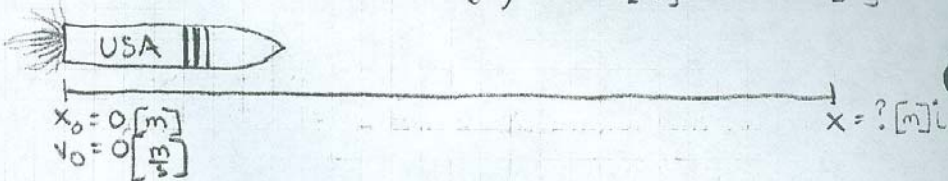
We need to solve for "a", the acceleration of the car. The first two equations will not work because they both have "a" and "t" as unknowns. Therefore, we have to use the third equation to solve for a.

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{80^2 - 40^2}{2(200 - 0)} = 12[m / s^2]$$

IV. Student Samples

The three sample problems below illustrate the use of the Kinematics Model.

25) Given: $a = 9.8 \left[\frac{m}{s^2} \right] i$ $v = \left(\frac{1}{10} \right) 3.0 \cdot 10^8 \left[\frac{m}{s} \right] = 3.0 \cdot 10^7 \left[\frac{m}{s} \right] i$



$x_0 = 0 \left[m \right]$
 $v_0 = 0 \left[\frac{m}{s} \right]$

Find: (a) t
 (b) x

Solution: ① List Equations
 $x = x_0 + v_0 t + \frac{1}{2} a t^2$
 $v = v_0 + a t$
 $v^2 = v_0^2 + 2a(x - x_0)$

② List Variables
 $x_0 = 0 \left[m \right]$
 $x = \boxed{} \left[m \right] i$
 $v_0 = 0 \left[\frac{m}{s} \right]$
 $v = 3.0 \cdot 10^7 \left[\frac{m}{s} \right] i$
 $a = 9.8 \left[\frac{m}{s^2} \right] i$
 $t = \boxed{} \left[s \right]$

③ Solve

(a) $v = v_0 + a t \rightarrow v - v_0 = a t \rightarrow t = \frac{v - v_0}{a}$
 $= \frac{3.0 \cdot 10^7 - 0}{9.8} = \boxed{3.06 \cdot 10^6 \left[s \right]}$

(b) $x = x_0 + v_0 t + \frac{1}{2} a t^2$
 $= 0 + 0 \cdot 3.06 \cdot 10^6 + \frac{1}{2} \cdot 9.8 \cdot (3.06 \cdot 10^6)^2$
 $= \boxed{4.6 \cdot 10^{13} \left[m \right] i}$

27) Given: Nonaccelerating Region | Accelerating Region |
 $v_0 = 1.50 \cdot 10^5 \left[\frac{m}{s} \right]$ | $x = 0.01 \left[m \right] i$ | $v = 5.70 \cdot 10^6 \left[\frac{m}{s} \right]$

Find: a

Solve: ① List Equations
 $x = x_0 + v_0 t + \frac{1}{2} a t^2$
 $v = v_0 + a t$
 $v^2 = v_0^2 + 2a(x - x_0)$

② List Variables
 $x_0 = 0 \left[m \right]$
 $x = 0.01 \left[m \right] i$
 $v_0 = 1.50 \cdot 10^5 \left[\frac{m}{s} \right] i$
 $v = 5.70 \cdot 10^6 \left[\frac{m}{s} \right] i$
 $a = \boxed{} \left[\frac{m}{s^2} \right] i$
 $t = \boxed{} \left[s \right]$

③ Solve

$$v^2 = v_0 + 2a(x - x_0) \rightarrow v^2 - v_0 = 2a(x - x_0) \rightarrow a = \frac{v^2 - v_0}{2(x - x_0)}$$
$$= \frac{(5.70 \cdot 10^6)^2 - (1.50 \cdot 10^5)}{2(.01 - 0)} = \boxed{1.62 \cdot 10^{15} \left[\frac{m}{s^2} \right] i}$$

② Given:

$$a_1 = 2.0 \left[\frac{m}{s^2} \right]$$

$$a_2 = 1.0 \left[\frac{m}{s^2} \right]$$



$$v_1 = 20 \left[\frac{m}{s} \right] i$$

Find: (a) t (total time)
(b) x_2 (total distance)

Solution: ① List Equations

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$
$$v = v_0 + a t$$
$$v^2 = v_0 + 2a(x - x_0)$$

② List Variables

$x_{01} = 0 [m]$	$x_{02} =$ <input type="text"/>
$x_1 =$ <input type="text"/> $[m] i$	$x_2 =$ <input type="text"/>
$v_{01} = 0 \left[\frac{m}{s} \right] i$	$v_{02} = 20 \left[\frac{m}{s} \right] i$
$v_1 = 20 \left[\frac{m}{s} \right] i$	$v_2 = 0 \left[\frac{m}{s} \right] i$
$a_1 = 2.0 \left[\frac{m}{s^2} \right] i$	$a_2 = -1.0 \left[\frac{m}{s^2} \right] i$
$t_1 =$ <input type="text"/> $[s]$	$t_2 =$ <input type="text"/>

③ Solve

$$(a) t = t_1 + t_2; v = v_0 + a t \rightarrow t = \frac{v - v_0}{a}$$

$$t_1 = \frac{20 - 0}{2.0} = 10 [s] \quad t_2 = \frac{20 - 0}{1.0} = 20 [s]$$

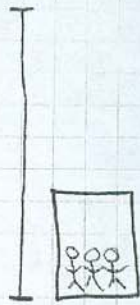
$$\boxed{t = 30 [s]}$$

$$(b) x_1 = x_{02}; x_{02} = x_0 + v_0 t_1 + \frac{1}{2} a t_1^2$$
$$= 0 + 0 \cdot 10 + \frac{1}{2} \cdot 2.0 \cdot 10^2$$
$$x_{02} = 100 [m]$$

$$x_2 = x_{02} + v_{02} t_2 + \frac{1}{2} a t_2^2$$
$$= 100 + 20 \cdot 20 + \frac{1}{2} \cdot -1 \cdot 20^2$$

$$\boxed{x_2 = 300 [m] i}$$

31) Given:



$$a = 1.22 \left[\frac{m}{s^2} \right]$$

$$v = \left[\frac{305 \text{ m}}{\text{min}} \right] \left[\frac{1 \text{ min}}{60 \text{ sec}} \right] = 5.1 \left[\frac{m}{s} \right]$$

Find: (a) y (accel/decel period)
 (b) t (time to complete entire trip)

Solution: ① List Equations

$$y = y_0 + v_{y0}t + \frac{1}{2}at^2$$

$$v_y = v_{y0} + at$$

$$v_y^2 = v_{y0}^2 + 2a(y - y_0)$$

$$v_{avg} = \frac{\Delta x}{\Delta t}$$

② List Variables

$$y_0 = 0 \text{ [m]}$$

$$y = \text{[]}$$

$$v_{y0} = 0 \left[\frac{m}{s} \right]$$

$$v_y = 5.1 \left[\frac{m}{s} \right]$$

$$a = 1.22 \left[\frac{m}{s^2} \right]$$

$$t = \text{[] [s]}$$

③ Solve

(a) $v_y^2 = v_{y0}^2 + 2a(y - y_0) \rightarrow (y - y_0) = \frac{v_y^2 - v_{y0}^2}{2a}$

$$y = \frac{5.1^2 - 0}{2 \cdot 1.22} = 10.6 \text{ [m]} \quad j = y$$

(b) $v_{avg} = \frac{\Delta x}{\Delta t}$

$$\Delta x = 190 - (2 \cdot 10.6) = 168.8 \text{ [m]}$$

$$\Delta t = x$$

$$v_{avg} = 5.1 \left[\frac{m}{s} \right]$$

$$\Delta t = \frac{168.8}{5.1} = 33.1 \text{ sec}$$

$$33.1 \text{ sec} + 10.2 \text{ sec} = t = 43.3 \text{ [s]}$$

(constant v) (accel/decel)

45) Given:



$$v_{y0} = 0 \left[\frac{m}{s} \right]$$

$$g = -9.8 \left[\frac{m}{s^2} \right] j$$

$$v_y = -24 \left[\frac{m}{s} \right] j$$

Find: (a) y
 (b) t

Solution: ① List Equations

$$y = y_0 + v_{y0}t + \frac{1}{2}gt^2$$

$$v_y = v_{y0} + gt$$

$$v_y^2 = v_{y0}^2 + 2g(y - y_0)$$

② List Variables

$$y_0 = 0 \text{ [m]}$$

$$y = \text{[] [m]} j$$

$$v_{y0} = 0 \left[\frac{m}{s} \right] j$$

$$v_y = -24 \left[\frac{m}{s} \right] j$$

$$g = -9.8 \left[\frac{m}{s^2} \right] j$$

$$t = \text{[] [s]}$$

V. Supplemental Problems

This problem set includes a selection quantitative and qualitative problems involving both average velocity/average acceleration AND constant acceleration problems (i.e. Kinematics model).

Unit Conversion Problems

1. If 1 mile = 1.61 km, convert 100 km/h to mi/h.

- a. 62 mi/h
- b. 86 mi/h
- c. 94 mi/h
- d. 102 mi/h

2. If 1 mi = 1.61 km, convert 30.0 m/s to mi/h.

- a. 8.33 mi/h
- b. 18.6 mi/h
- c. 67.5 mi/h
- d. 242 mi/h

3. Which of the following speeds is greatest?

- a. 10 km/h
- b. 10 mi/h
- c. 10 m/s
- d. 10 ft/s

Average Velocity Problems

4. A ly (light year) is the distance that light travels in one year. The speed of light is 3.00×10^8 m/s. How many miles are there in a ly? (1 mi = 1609 m) (1 yr = 365 days)

- a. 9.46×10^{12} mi
- b. 9.46×10^{15} mi
- c. 5.88×10^{12} mi
- d. 5.88×10^{15} mi

5. How many seconds would it take light, traveling at a speed of 186,000 mi/s, to reach us from the sun? The sun is 93,000,000 mi from the earth.

- a. 500 s
- b. 250 s
- c. 1.7×10^{13} s
- d. 2 s

6. I ran my fastest marathon (42.0 km) in 2 hrs : 57 min. My average speed, in m/s, was:
- a. 6.41 m/s
 - b. 4.56 m/s
 - c. 3.95 m/s
 - d. 2.23 m/s
7. A car travels at 40 km/h for 30 min and 60 km/h for 15 min. How far does it travel in this time?
- a. 20 km
 - b. 35 km
 - c. 37.5 km
 - d. 45 km
8. A motorist travels for 3 h at 80 km/h and at 2 h at 100 km/h. What is her average speed for the trip?
- a. 85 km/h
 - b. 88 km/h
 - c. 90 km/h
 - d. 92 km/h
9. A motorist travels 160 km at 80 km/h and 160 km at 100 km/h. What is the average speed of the motorist for this trip?
- a. 79 km/h
 - b. 89 km/h
 - c. 99 km/h
 - d. 119 km/h
10. A boat can move at 30 km/h in still water. How long will it take to move at 12 km upstream in a river flowing 6 km/h?
- a. 20 min
 - b. 22 min
 - c. 24 min
 - d. 30 min
11. A car drives 8 km at 10 m/s, then 40 km at 25 m/s. What is the average speed?
- a. 15 m/s
 - b. 17.5 m/s
 - c. 20 m/s
 - d. 22.5 m/s

12. An object travels at 4 m/s for 25 s and then at 20 m/s for 15 s. The average speed is:
- a. 8.0 m/s
 - b. 10.0 m/s
 - c. 12.0 m/s
 - d. 15 m/s
13. A plane flies in a straight line for 1800 km. It travels the first half of the distance at 200 km/h and the second half at 300 km/h. What is its average speed?
- a. 3.6 km/h
 - b. 33.6 km/h
 - c. 240 km/h
 - d. 320 km/h
14. A polar bear starts at the North Pole. He travels 1 km South, then 1 km East, then 1 km North, then 1 km West to return to its starting point. This trip takes 30 min. What was the bear's average speed?
- a. 0 km/h
 - b. 0.10 km/h
 - c. 6 km/h
 - d. 8 km/h
15. A polar bear starts at the North Pole. He travels 1 km South, then 1 km East, then 1 km North, then 1 km West to return to its starting point. This trip takes 30 min. What was the bear's average velocity?
- a. 0 km/h
 - b. 0.10 km/h
 - c. 6 km/h
 - d. 8 km/h
16. A car goes 30 km in 15 minutes. What is the car's average speed?
- a. 2 km/h
 - b. 15 km/h
 - c. 47 km/h
 - d. 120 km/h

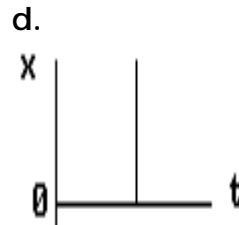
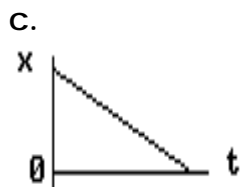
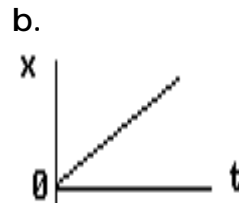
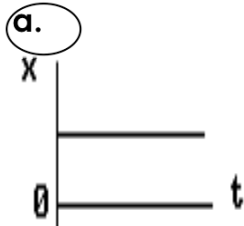
17. An object moves in the $+x$ direction with constant acceleration. It starts out going 15 m/s , and 3 s later it is going 9 m/s . What is its average velocity during this time?
- a. 12 m/s
 - b. 5 m/s
 - c. -6 m/s
 - d. -2 m/s

Conceptual Problems

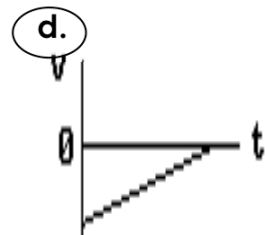
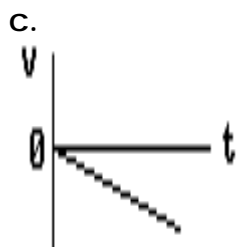
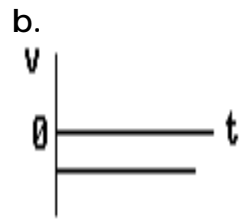
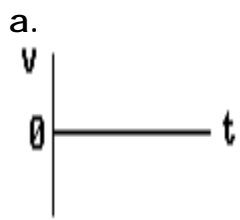
18. **When is the velocity of an object equal to the instantaneous velocity?**
- a. This is always true
 - b. This is never true
 - c. This is the case only when the velocity is constant
 - d. This is the case only when the velocity is increasing at a constant rate
19. **A new car manufacturer advertises that their car can go “from zero to sixty in 8 s”. This is a description of:**
- a. average speed
 - b. instantaneous speed
 - c. average acceleration
 - d. instantaneous acceleration
20. **Can an object’s velocity change direction when its acceleration is constant?**
- a. No, this is not possible because it is always speeding up.
 - b. No, this is not possible because it is always speeding up or always slowing down, but it can never turn around.
 - c. Yes, this is possible, and a rock that is thrown straight up and return to the ground is an example.
 - d. Yes, this is possible, and a car that starts from rest and speeds up is an example.
21. **Can an object have increasing speed while its acceleration is decreasing?**
- a. No, this is impossible because of the way in which acceleration is defined
 - b. No, because if acceleration is decreasing the object will always be slowing down
 - c. Yes, and an example would be an object falling in the absence of air friction
 - d. Yes, and an example would be an object released from the rest in the presence of air friction
22. **Suppose that an object is moving with constant acceleration. Which of the following is an accurate statement concerning its motion?**
- a. In equal times its position (or displacement) increases by equal amounts.
 - b. In equal times its velocity changes by equal amounts.
 - c. In equal times its acceleration changes by equal amounts.
 - d. None of the above is true.

23. A can, after having been given a kick, moves up along a smooth hill of ice (i.e. no friction). It will:
- travel at constant velocity
 - have a constant acceleration up the hill, but a different constant acceleration when it comes back down the hill
 - have the same acceleration, both up the hill and down the hill
 - have a varying acceleration along the hill

24. Which graph represents an object at rest?



25. Which graph represents a constant positive acceleration?



26. Under what condition is average velocity equal to the average of the object's initial and final velocity?

- The acceleration must be constantly changing
- The acceleration must be constant
- The acceleration vector must be pointing in the $+i$ direction
- The acceleration vector must be pointing in the $-i$ direction

27. In which of the following cases will a car move the greatest distance?
- a. A car with speed V_1 travels with constant speed for time t_1 and then accelerates uniformly for t_2 s to speed V_2
 - b. A car with speed V_1 accelerates uniformly to speed V_2 in t_1 seconds and then travels at speed V_2 for t_2 seconds
 - c. It is not possible to answer this question definitely without knowing numerical values for t_1 , t_2 , V_1 , V_2

[Assume acceleration is positive -- Hint: try solving by plugging in your own numbers]

28. The slope of a position versus time graph at a specific point in time gives:
- a. average velocity
 - b. instantaneous velocity
 - c. average acceleration
 - d. instantaneous acceleration

29. The slope of a velocity versus time graph from t_1 to t_2 gives:
- a. average velocity
 - b. instantaneous velocity
 - c. average acceleration
 - d. instantaneous acceleration

30. What is the meaning of a horizontal line on a plot of x vs. t ?
- a. This describes an object moving with constant non-zero speed.
 - b. This describes an object moving with constant non-zero acceleration.
 - c. This describes an object at rest.
 - d. Such a graph has no physical meaning, since it describes an object moving with infinite speed.

31. How is motion toward the negative x direction represented on an x vs. t plot?
- a. By a curve to the left of the vertical axis
 - b. By a curve below the horizontal axis
 - c. By a downward sloping curve
 - d. Such a motion cannot be shown on a simple x vs. t graph

32. What is the meaning of a horizontal line on a plot of v vs. t ?
- a. The object is at rest.
 - b. The object is moving at constant speed.
 - c. The object is speeding up at a constant rate.
 - d. The object is accelerating at a constant non-zero rate.
33. The slope of an " x vs. t " plot at an instant of time is its average velocity.
- a. True
 - b. False
34. The slope of a " v vs. t " plot at an instant of time is its instantaneous acceleration.
- a. True
 - b. False
35. Objects A and B both start at rest. They both accelerate at the same constant rate. However, object A accelerates for twice the time as object B. Compare the final speed of object A to that of object B .
- a. the same speed
 - b. twice as fast
 - c. three times as fast
 - d. four times as fast
36. Objects A and B both start from rest. They both accelerate at the same rate. However, object A accelerates for twice the time as object B. During the times that the objects are being accelerated, compare the distance traveled by object A to that of object B.
- a. the same distance
 - b. twice as far
 - c. three times as far
 - d. four times as far

Kinematics Problems

37. An airplane increases its velocity from 100 m/s to 160 m/s, at the average rate of 15m/s^2 . How much time does it take for the complete increase in velocity?
- a. 0.25 s
 - b. 1.22 s
 - c. 4.00 s
 - d. 17.33 s
38. A car traveling 30 m/s is able to stop in a distance d . Assuming the same braking force, what distance does this car require to stop when it is traveling twice as fast?
- a. d
 - b. $\sqrt{2} d$
 - c. $2 d$
 - d. $4 d$
39. A car decelerates uniformly and comes to a stop after 10 s. The car's initial velocity was 50 m/s. What was the car's deceleration rate?
- a. 10 m/s^2
 - b. 8 m/s^2
 - c. 5 m/s^2
 - d. 0.2 m/s^2
40. A jet fighter plane, initially at rest, is launched from a catapult on an aircraft carrier. It reaches a speed of 42 m/s at the end of the catapult, and this requires 2 s. Assuming the acceleration is constant, what is the length of the catapult?
- a. 16 m
 - b. 24 m
 - c. 42 m
 - d. 84 m
41. A car starting from rest moves with constant acceleration of 2 m/s^2 for 10 s, then travels with constant speed for another 10 s, and then finally slows to a stop with constant acceleration of -2 m/s^2 . How far does it travel?
- a. 200 m
 - b. 300 m
 - c. 400 m
 - d. 500 m

42. A car starts from rest and accelerates uniformly at 3 m/s^2 . A second car starts from rest 6 s later from the same point and accelerates uniformly at 5 m/s^2 . How long does it take the second car to overtake the first car?
- a. 12.2 s
 - b. 18.9 s
 - c. 20.6 s
 - d. 24.0 s
43. A car goes from 40 m/s to 80 m/s in a distance of 200 m. What is its acceleration during this time?
- a. 8.0 m/s^2
 - b. 9.6 m/s^2
 - c. 12 m/s^2
 - d. 24 m/s^2
44. An object goes from 14 m/s to 4 m/s in 10 s with constant acceleration. The acceleration is:
- a. -10 m/s^2
 - b. -1.4 m/s^2
 - c. -1.0 m/s^2
 - d. -0.4 m/s^2
45. An object slows from 16 m/s to 4 m/s at a rate of -6 m/s^2 . During this time, how far does the object go?
- a. 8 m
 - b. 12 m
 - c. 20 m
 - d. 32 m
46. A car travels at 15 m/s for 10 s. It then speeds up with a constant acceleration of 2.0 m/s^2 for 15 s. At the end of this time, what is its velocity?
- a. 15 m/s
 - b. 30 m/s
 - c. 45 m/s
 - d. 375 m/s

47. A ball is thrown straight up with a speed of 30 m/s. Using $g = -9.8 \text{ m/s}^2$, the maximum height the ball reaches is:
- a. 30 m
 - b. 45 m
 - c. 90 m
 - d. 135 m
48. A bicycle is traveling at 17 km/h. The brakes are applied, and the speed one second later is 9 km/h. The rate of acceleration is:
- a. 2.2 km/s^2
 - b. -2.2 km/s^2
 - c. 876 m/s^2
 - d. $28,800 \text{ km/hr}^2$
49. An object moves in a straight line in the +x direction. It goes from 10 m/s to 4 m/s in 2 s. What is its average acceleration during this time?
- a. -2 m/s^2
 - b. -3 m/s^2
 - c. -5 m/s^2
 - d. -7 m/s^2
50. An object starts from rest and undergoes uniform acceleration. During the first second it travels 5 m. How far will it move during the next second?
- a. 5 m
 - b. 15 m
 - c. 20 m
 - d. 25 m
51. An object starts from rest and undergoes uniform acceleration. During the first second it travels 5 m. How far will it travel during the third second (i.e. the time from 2 to 3 seconds)?
- a. 5 m
 - b. 25 m
 - c. 45 m
 - d. 65 m

52. An object is moving in a straight line with constant acceleration. Initially it is traveling at 16 m/s. Three seconds later it is traveling at 10 m/s. How far does it move during this time?
- a. 26 m
 - b. 30 m
 - c. 39 m
 - d. 48 m
53. An object starts from rest, and accelerates at a constant 6 m/s^2 . After 3 s, how far has it gone?
- a. 3 m
 - b. 6 m
 - c. 18 m
 - d. 27 m
54. An object starts from rest, and accelerates at a constant 6 m/s^2 . After 3 s, how fast is it going?
- a. 3 m/s
 - b. 6 m/s
 - c. 18 m/s
 - d. 27 m/s
55. An object starts from rest, and accelerates at a constant 6 m/s^2 . After 3 s, what is its acceleration?
- a. 3 m/s^2
 - b. 6 m/s^2
 - c. 18 m/s^2
 - d. 27 m/s^2

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