



The Big Idea

Speed represents how quickly an object is moving through space. Velocity is speed with a direction, making it a *vector* quantity. If an object's velocity changes with time, the object is said to be accelerating. As we'll see in the next chapters, understanding the acceleration of an object is the key to understanding its motion.

Key Definitions

Vectors

$\mathbf{x} = \mathbf{x}(t)$ = position (m)

$\Delta \mathbf{x}$ = displacement = $\mathbf{x}_f - \mathbf{x}_i$

$\mathbf{v} = \mathbf{v}(t)$ = velocity (m/s)

$\mathbf{v}_0$ = initial velocity

$\mathbf{v}_f$ = final velocity

$\Delta \mathbf{v}$ = change in velocity = $\mathbf{v}_f - \mathbf{v}_i$

$\mathbf{a}$ = instantaneous acceleration (m/s²)

Scalars

t = time (s)

d = distance (m) = $|\Delta \mathbf{x}_1| + |\Delta \mathbf{x}_2| + \dots$

v = speed (m/s) = $|\mathbf{v}|$

Symbols

$\Delta(\text{anything})$ = final value – initial value

$(\text{anything})_0$ = value of that quantity at time $t = 0$

Key Equations

- $\mathbf{v}_{\text{avg}} = \Delta \mathbf{x} / \Delta t$

- $\mathbf{a}_{\text{avg}} = \Delta \mathbf{v} / \Delta t$

The "Big Three"

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

- $v(t) = v_0 + a t$

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

Key Concepts

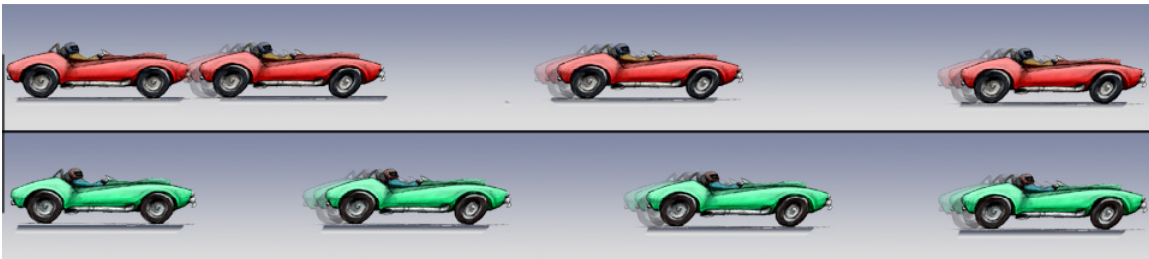
- When you begin a problem, define a positive (+ $\mathbf{x}$) direction and negative ($-\mathbf{x}$) direction. For instance the positive direction can be "towards the right" and the negative direction "towards the left." Use these directions consistently with velocity $\mathbf{v}$ and acceleration $\mathbf{a}$.
- Be sure you understand the difference between average velocity (measured over a long period of time) and instantaneous velocity (measured at a single moment in time).
- Gravity near the Earth pulls an object downwards toward the surface of the Earth with an acceleration of 9.8 m/s^2 ($\approx 10 \text{ m/s}^2$). In the absence of air resistance, all objects will fall with the same acceleration. Air resistance can cause low-mass, large area objects to accelerate more slowly.
- Deceleration* is the term used when an object's *speed* is decreasing due to an acceleration in the opposite direction of its velocity.

- The Big Three equations allow you to draw the position and velocity of something as a function of time. This is a nice way to visualize motion. $x(t)$ produces a parabola in t , while $v(t)$ produces a straight line in t . The slope of a $x(t)$ graph equals the instantaneous velocity. The slope of a $v(t)$ graph equals the acceleration.
- At first, you might get frustrated trying to figure out which of the Big Three equations to use for a certain problem, but don't worry, this comes with practice. Making a table that identifies the variables given in the problem and the variables you are looking for can sometimes help.

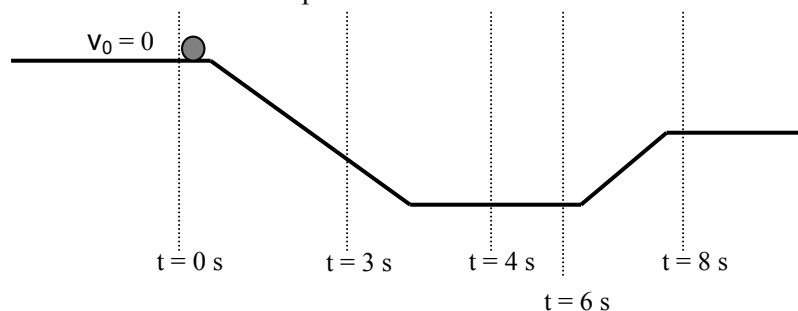
One-Dimensional Motion Problem Set

1. Answer the following questions about one-dimensional motion.
 - a. What is the difference between distance d and displacement Δx ? Write a few sentences explaining this.
 - b. Does the odometer reading in a car measure distance or displacement?
 - c. Imagine a fox darting around in the woods for several hours. Can the displacement Δx of the fox from his initial position ever be larger than the total distance d he traveled? Explain.
 - d. What is the difference between acceleration and velocity? Write a paragraph that would make sense to a 5th grader.
 - e. Give an example of a situation where an object has an upward velocity but a downward acceleration.
 - f. What is the difference between average and instantaneous velocity? Make up an example involving a trip in a car that demonstrates your point.
 - g. If the position of an object is increasing linearly with time (i.e., Δx is proportional to t), what can we say about its acceleration? Explain your thinking.
 - h. If the position of an object is increasing non-linearly with time (i.e., Δx is not proportional to t), what can we say about its velocity? Explain your thinking.
2. A cop passes you on the highway. Which of the following statements must be true at the instant he is passing you? You may choose more than one answer.
 - a. Your speed and his speed are the same.
 - b. Your position x along the highway is the same as his position x along the highway.
 - c. Your acceleration and his acceleration are the same.
3. If a car is slowing down from 50 MPH to 40 MPH, but the x position is increasing, which of the following statements is true? You may choose more than one.
 - a. The velocity of the car is in the $+x$ direction.
 - b. The acceleration of the car is in the same direction as the velocity.
 - c. The acceleration of the car is in the opposite direction of the velocity.
 - d. The acceleration of the car is in the $-x$ direction.

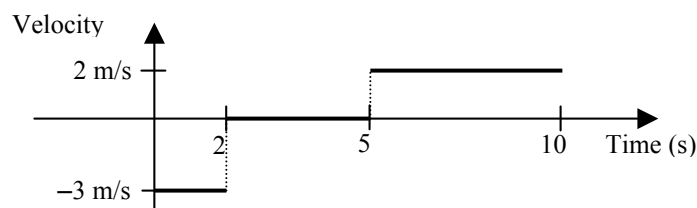
4. A horse starts from rest and gallops forward with an acceleration of 3 m/s^2 . Which of the following statements is necessarily true? You may choose more than one.
- The horse is increasing its speed by 3 m/s every second, from 0 m/s to 3 m/s to 6 m/s to 9 m/s .
 - The speed of the horse will triple every second, from 0 m/s to 3 m/s to 9 m/s to 27 m/s .
 - The horse will cover 3 m of ground in the first second.
 - The horse will cover 1.5 m of ground in the first second.
5. Below are images from a race between Ashaan (above) and Zyan (below), two daring racecar drivers. High speed cameras took four pictures in rapid succession. The first picture shows the positions of the cars at $t = 0.0$. Each car image to the right represents times 0.1 , 0.2 , and 0.3 seconds later.



- Who is ahead at $t = 0.2 \text{ s}$? Explain.
 - Who is accelerating? Explain.
 - Who is going fastest at $t = 0.3 \text{ s}$? Explain.
 - Which car has a constant velocity throughout? Explain.
 - Graph x vs. t and v vs. t . Put both cars on same graph; label which line is which car.
 - Which car is going faster at $t = 0.2 \text{ s}$?
6. In the picture below, a ball starting at rest rolls down a ramp, goes along at the bottom, and then back up a smaller ramp. Ignore friction and air resistance. Sketch the *vertical* position vs. time and *vertical* speed vs. time graphs that accurately describe this motion. Label your graphs with the times indicated in the picture.



7. Draw the position vs. time graph that corresponds to the velocity vs. time graph below. You may assume a starting position $x_0 = 0$. Label both axes of your graph with appropriate values.



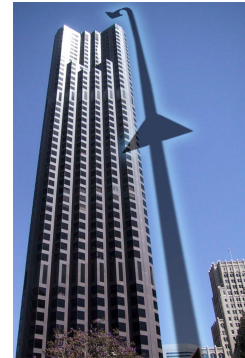
8. Two cars are heading right towards each other but are 12 km apart. One car is going 70 km/hr and the other is going 50 km/hr. How much time do they have before they collide head on?
9. The following data represent the first 30 seconds of actor Crispin Glover's drive to work.

Time (s)	Position (m)	Distance (m)
0	0	0
5	10	10
10	30	30
15	30	30
20	20	40
25	50	70
30	80	120

- a. Sketch the graphs of position vs. time and distance vs. time. Label your x and y axes appropriately.
 - b. Why is there a discrepancy between the distance covered and the change in position during the time period between $t = 25$ s and $t = 30$ s?
 - c. What do you think is going on between $t = 10$ s and $t = 15$ s?
 - d. What is the displacement between $t = 10$ s and $t = 25$ s?
 - e. What is the distance covered between $t = 10$ s and $t = 25$ s?
 - f. What is the average velocity during the first 30 seconds of the trip?
 - g. What is the average velocity between the times $t = 20$ s and $t = 30$ s?
 - h. During which time interval(s) was the velocity negative?
 - i. Sketch the velocity vs. time and speed vs. time graphs. Label your x and y axes appropriately.
10. Sketchy LeBaron, a used car salesman, claims his car is able to go from 0 to 60 mi/hr in 3.5 seconds.
 - a. What is the average acceleration of this car? Give your answer in m/s^2 . (Hint: you will have to perform a conversion.)
 - b. How much distance does this car cover in these 3.5 seconds? Express your answer twice: in meters and in feet.
 - c. What is the speed of the car in mi/hr after 2 seconds?
11. Michael Jordan had a vertical jump of about 48 inches.
 - a. Convert this height into meters.
 - b. Assuming no air resistance, at what speed did he leave the ground?
 - c. What is his speed $\frac{3}{4}$ of the way up?
 - d. What is his speed just before he hits the ground on the way down?

12. You are sitting on your bike at rest. Your brother comes running at you from behind at a speed of 2 m/s. At the exact moment he passes you, you start up on your bike with an acceleration of 2 m/s².
- Draw a picture of the situation, defining the starting positions, speeds, etc.
 - At what time t do you have the same speed as your brother?
 - At what time t do you pass your brother?
 - Draw another picture of the exact moment you catch your brother. Label the drawing with the positions and speeds at that moment.
 - Sketch a position vs. time graph for both you and your brother, labeling the important points (*i.e.*, starting point, when you catch him, etc.)
 - Sketch a speed vs. time graph for both you and your brother, labeling the important points (*i.e.*, starting point, when you catch him, etc.)

13. You are standing at the foot of the Bank of America building in San Francisco, which is 52 floors (237 m) high. You launch a ball straight up in the air from the edge of the foot of the building. The initial vertical speed is 70 m/s. (For this problem, you may ignore your own height, which is very small compared to the height of the building.)

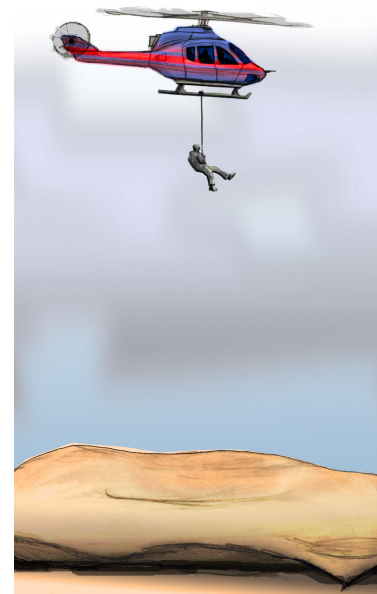


- How high up does the ball go?
- How fast is the ball going right before it hits the top of the building?
- For how many seconds total is the ball in the air?

14. Measure how high you can jump vertically on Earth. Then, figure out how high you would be able to jump on the Moon, where acceleration due to gravity is 1/6th that of Earth. Assume you launch upwards with the same speed on the Moon as you do on the Earth.
15. A car is smashed into a wall during Weaverville's July 4th Destruction Derby. The car is going 25 m/s just before it strikes the wall. It comes to a stop 0.8 seconds later. What is the average acceleration of the car during the collision?

16. A helicopter is traveling with a velocity of 12 m/s directly upward. Directly below the helicopter is a very large and very soft pillow. As it turns out, this is a good thing, because the helicopter is lifting a large man. When the man is 20 m above the pillow, he lets go of the rope.

- What is the speed of the man just before he lands on the pillow?
- How long is he in the air after he lets go?
- What is the greatest height reached by the man above the ground? (Hint: this should be greater than 20 m. Why?)
- What is the distance between the helicopter and the man three seconds after he lets go of the rope?



17. You are speeding towards a brick wall at a speed of 55 MPH. The brick wall is only 100 feet away.

- What is your speed in m/s?
- What is the distance to the wall in meters?
- What is the minimum acceleration you should use to avoid hitting the wall?

18. What acceleration should you use to increase your speed from 10 m/s to 18 m/s over a distance of 55 m?

19. You drop a rock from the top of a cliff. The rock takes 3.5 seconds to reach the bottom.

- What is the initial speed of the rock?
- What is the magnitude (i.e. *numerical value*) of the acceleration of the rock at the moment it is dropped?
- What is the magnitude of the acceleration of the rock when it is half-way down the cliff?
- What is the height of the cliff?

20. An owl is flying along above your farm with positions and velocities given by the formulas

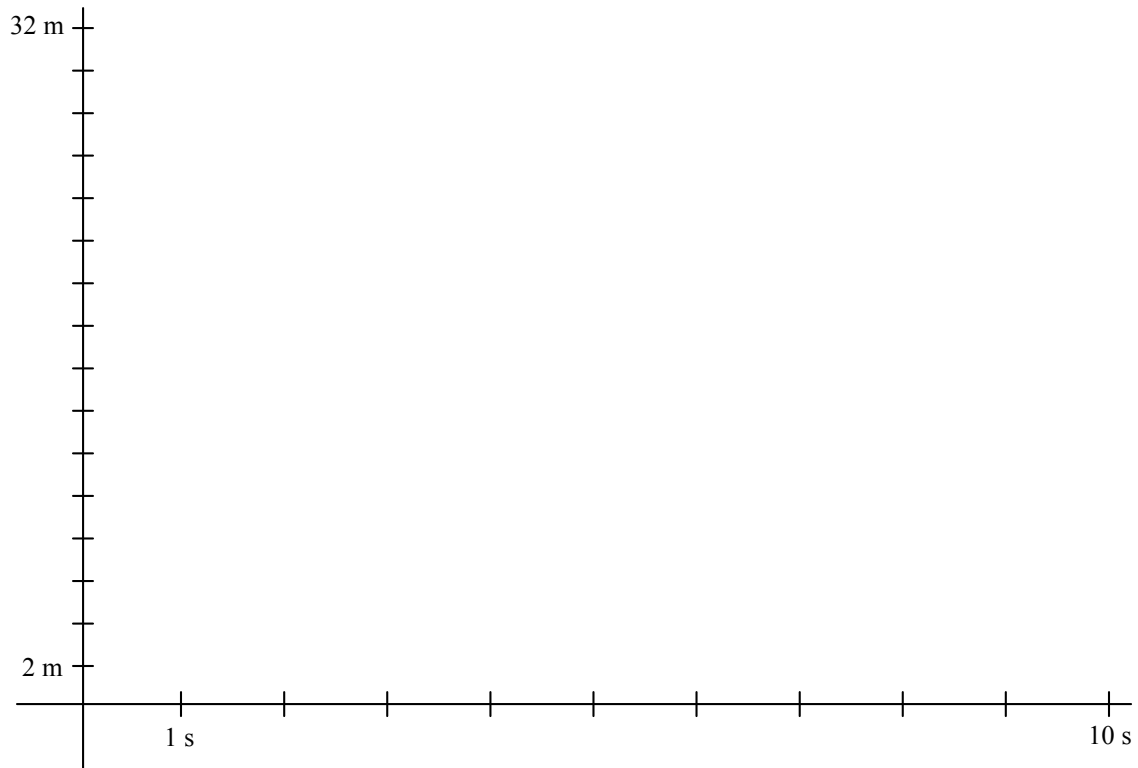
$$x(t) = 5.0 + 0.5t + (\frac{1}{2})(0.3)t^2 \quad ; \text{ where } t \text{ is in seconds and } x \text{ is in meters from the barn}$$

$$v(t) = 0.5 + (0.3)t \quad ; \text{ where } v \text{ is in m/s}$$

- What is the acceleration of the owl?
- What is the speed of the owl at $t = 0$?
- Fill in the missing elements of the table.

t	x	v
0.0 s	5 m	.5 m/s
1.0 s	5.65 m	.8 m/s
2.0 s	6.6 m	1.1 m/s
3.0 s		
4.0 s		
5.0 s		
6.0 s		
7.0 s		
8.0 s		
9.0 s		
10.0 s		

- d. Plot the x and t points on the following graph. Then, connect your points with a smoothly curving line. Be careful and neat and use pencil.

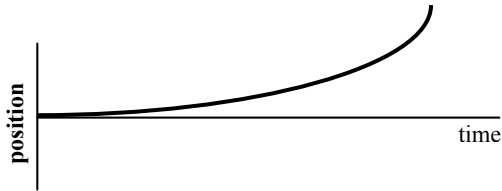


- e. Use the formula to calculate the speed of the owl in m/s at $t = 5$ seconds.
 f. Lightly draw in a tangent to your curve at the $t = 5$ s point. Then, measure the slope of this tangent by measuring the *rise* (in meters) and the *run* (in seconds). What is the slope in m/s?
 g. Were your answers to the last two parts the same? If so, why? If not, why not?
 h. Fill in the following table. This is going to be harder to do, because you are given x or v and are expected to find t . You may have to use the quadratic formula!

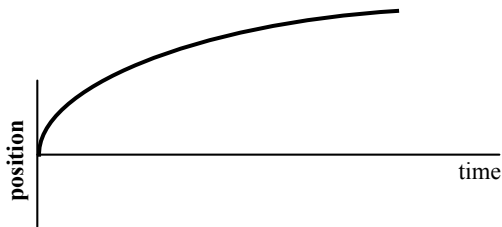
t	x	v
		2.6 m/s
	17.1 m	
		3.14 m/s
	31.4 m	
		5.41 m/s

21. For each of the following graphs, write a few sentences about what kind of motions were made. Try to use the words we have defined in class (speed, velocity, position, acceleration) in your description.

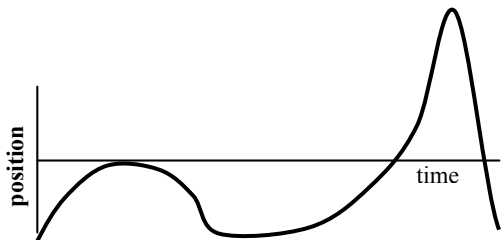
a.



b.



c.



d.

