# 1

# CONCEPTS OF MOTION

## Conceptual Questions

**1.1.** Option (a) has three significant figures—the trailing zero is significant because it indicates increased precision; Option (b) has two significant figures—this is more clearly revealed by using the scientific notation: $0.99 = 9.9 \times 10^{-1}$; Option (c) has two significant figures—the leading zeros are not significant but we can locate the decimal point; and Option (d) has two significant figures.

**1.2.** Option (a) has two significant figures—the leading zeros before the decimal point merely locate the decimal point and are not significant; Option (b) has three significant figures—the trailing zeros after the decimal point are significant because they indicate increased precision; Option (c) has two significant figures; and Option (d) has three significant figures—the trailing zeros after the decimal point are significant because they indicate increased precision.

**1.3.** Without numbers on the dots we cannot tell if the particle in the figure is moving left or right, so we can't tell if it is speeding up or slowing down. If the particle is moving to the right it is speeding up. If it is moving to the left it is slowing down.

**1.4.** Because the velocity vectors get longer for each time step, the object must be speeding up as it travels to the left. The acceleration vector must therefore point in the same direction as the velocity, so the acceleration vector also points to the left. Thus, $a_x$ is negative as per our convention (see Tactics Box 1.4).

**1.5.** Because the velocity vectors get shorter for each time step, the object must be slowing down as it travels in the 2 *y* direction (down). The acceleration vector must therefore point in the direction opposite to the velocity; namely, in the +*y* direction (up). Thus, $a_y$ is positive as per our convention (see Tactics Box 1.4).

**1.6.** The particle position is to the left of zero on the *x*-axis, so its position is negative. The particle is moving to the right, so its velocity is positive. The particle's speed is increasing as it moves to the right, so its acceleration vector points in the same direction as its velocity vector (i.e., to the right). Thus, the acceleration is also positive.

**1.7.** The particle position is below zero on the *y*-axis, so its position is negative. The particle is moving up, so its velocity is positive. The particle's speed is increasing as it moves in the positive direction, so its acceleration vector points in the same direction as its velocity vector (i.e., up). Thus, the acceleration is also positive.

**1.8.** The particle position is above zero on the *y*-axis, so its position is positive. The particle is moving up, so its velocity is positive. The particle's speed is increasing as it moves in the positive direction, so its acceleration vector points in the same direction as its velocity vector (i.e., up). Thus, the acceleration is also positive.

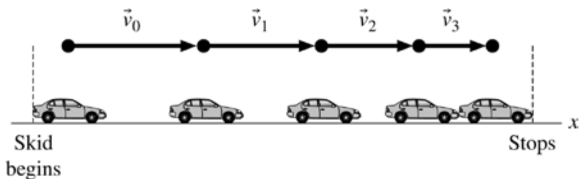
## Exercises and Problems

## Exercises

### Section 1.1 Motion Diagrams

**1.1. Model:** Model the car as a particle. Imagine a car moving in the positive direction (i.e., to the right). As it skids, it covers less distance between each movie frame (or between each snapshot).

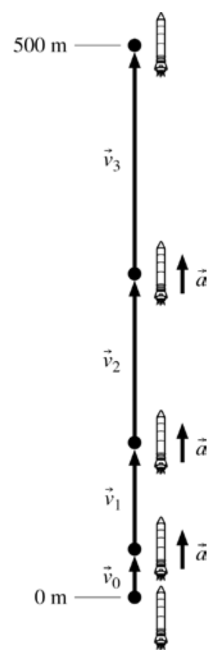
**Solve:**




**Assess:** As we go from left to right, the distance between successive images of the car decreases. Because the time interval between each successive image is the same, the car must be slowing down.

**1.2. Model:** Model the rocket as a particle. We have no information about the acceleration of the rocket, so we will assume that it accelerates upward with a constant acceleration.

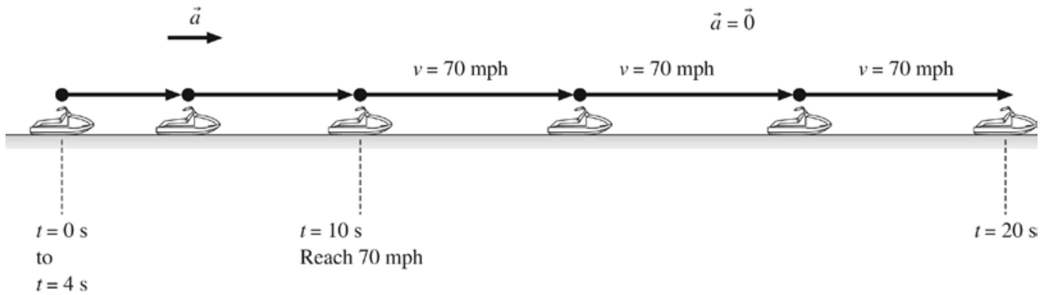
**Solve:**




**Assess:** Notice that the length of the velocity vectors increases each step by the same amount.

**1.3. Model:** Model the jet ski as a particle. Assume the speeding up time is less than 10 s, so the motion diagram will show the jet ski at rest for a few seconds at the beginning.

**Solve:**




**Assess:** Notice that the acceleration vector points in the same direction as the velocity vector because the jet ski is speeding up.

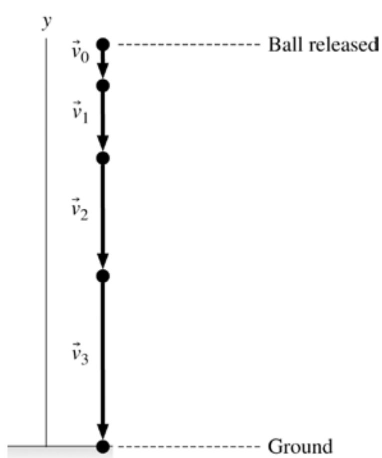
### Section 1.2 Models and Modeling

**1.4. Solve: (a)** The basic idea of the particle model is that we will treat an object *as if* all its mass is concentrated into a single point. The size and shape of the object will not be considered. This is a reasonable approximation of reality if (i) the distance traveled by the object is large in comparison to the size of the object and (ii) rotations and internal motions are not significant features of the object's motion. The particle model is important in that it allows us to *simplify* a problem. Complete reality—which would have to include the motion of every single atom in the object—is too complicated to analyze. By treating an object as a particle, we can focus on the most important aspects of its motion while neglecting minor and unobservable details.
**(b)** The particle model is valid for understanding the motion of a satellite or a car traveling a large distance.
**(c)** The particle model is not valid for understanding how a car engine operates, how a person walks, how a bird flies, or how water flows through a pipe.

### Section 1.3 Position, Time, and Displacement

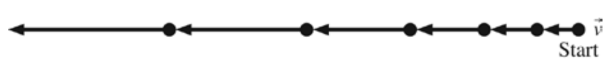
### Section 1.4 Velocity

**1.5. Model:** We model the ball's motion from the instant after it is released, when it has zero velocity, to the instant before it hits the ground, when it will have its maximum velocity.
**Solve:**

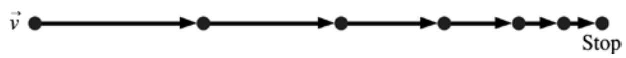



**Assess:** The average velocity keeps increasing with time since the ball is speeding up as it falls.

**1.6. Solve:** The player starts from rest and moves faster and faster to the left.



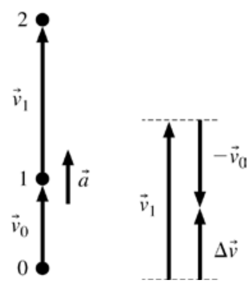
**1.7. Solve:** The player starts with an initial velocity but as he slides he moves slower and slower until coming to rest.




### Section 1.5 Linear Acceleration

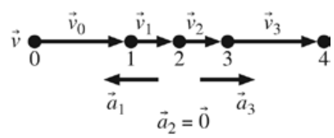
**1.8. Solve: (a)** Let $\vec{v}_0$ be the velocity vector between points 0 and 1 and $\vec{v}_1$ be the velocity vector between points 1 and 2. Speed $v_1$ is greater than speed $v_0$ because more distance is covered in the same interval of time.

**(b)** Acceleration is found by the method of Tactics Box 1.3.




**Assess:** The acceleration vector points in the same direction as the velocity vectors, which makes sense because the speed is increasing.

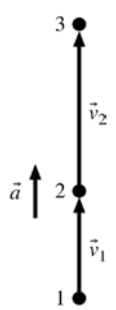
**1.9. Solve:** To find the accelerations, use the method of Tactics Box 1.3:



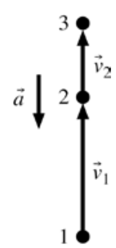

**Assess:** The acceleration vector points in the same direction as the velocity vectors, which makes sense because the speed is increasing.

**1.10. Solve:**

**(a)**

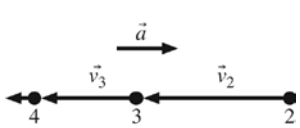



**(b)**

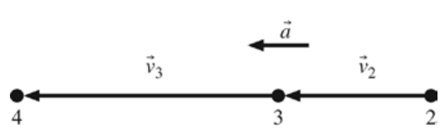



**1.11. Solve:**

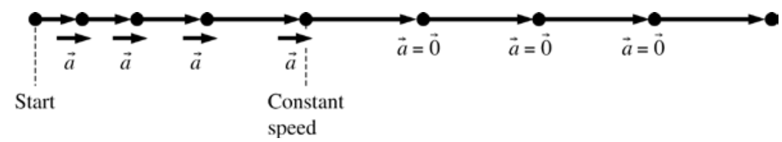
**(a)**



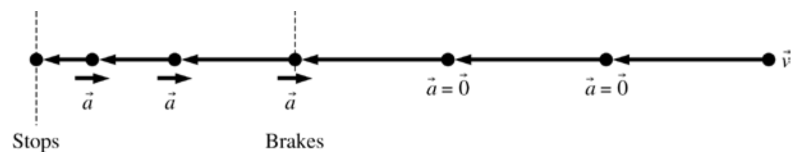

**(b)**



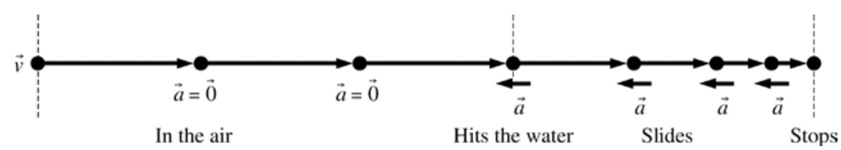
**1.12. Model:** Model the skater as a particle.
**Visualize:** The dots are getting farther apart at the beginning, but after the skater reaches constant speed the dots are equally spaced.
**Solve:**



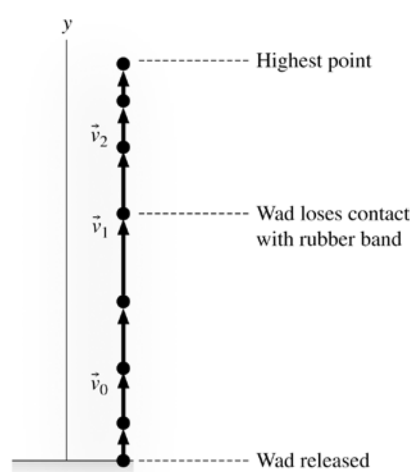

**1.13. Model:** Model the car as a particle.
**Visualize:** The dots are equally spaced until brakes are applied to the car. Equidistant dots on a single line indicate constant average velocity. Upon braking, the dots get closer as the average velocity decreases, and the distance between dots changes by a constant amount because the acceleration is constant.
**Solve:**




**1.14. Model:** Model the goose as a particle. Assume a constant speed before the goose hits the water. Assume a constant acceleration while sliding and slowing on the water.
**Visualize:** The dots are equally spaced until the goose hits the water. Equidistant dots on a single line indicate constant average velocity. Upon hitting the water, the dots get closer as the average velocity decreases, and the distance between dots changes by a constant amount because the acceleration is constant.
**Solve:**



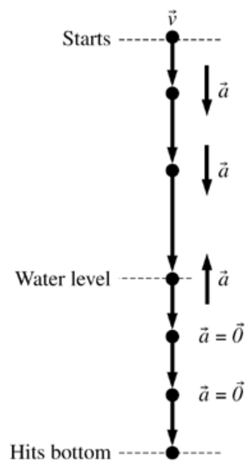

**1.15. Model:** Represent the wad of paper as a particle, ignore air resistance, and assume that the upward acceleration of the wad is constant.




**Visualize:** The spacing of the dots increases and then decreases because the acceleration is first upward (speeding up the wad) and later downward (slowing up the wad).

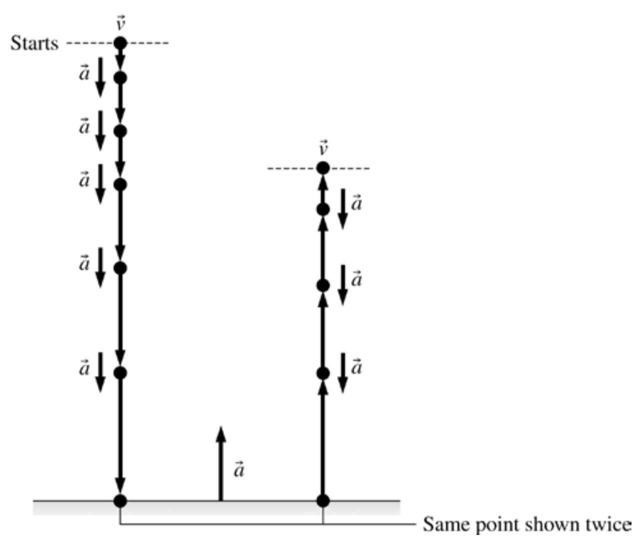
**1.16. Model:** Represent the tile as a particle.

**Visualize:** Starting from rest, the tile's velocity increases until it hits the water surface. This part of the motion is represented by dots with increasing separation, indicating increasing average velocity. After the tile enters the water, it settles to the bottom at roughly constant speed, so this part of the motion is represented by equally spaced dots.




**1.17. Model:** Represent the tennis ball as a particle.

**Visualize:** The ball falls freely for three stories. Upon impact, it quickly decelerates to zero velocity while compressing, then accelerates rapidly while re-expanding. As vectors, both the deceleration and acceleration are an upward vector. The downward and upward motions of the ball are shown separately in the figure. The increasing length between the dots during downward motion indicates an increasing average velocity or downward acceleration. On the other hand, the decreasing length between the dots during upward motion indicates acceleration in a direction opposite to the motion, so the average velocity decreases.




**Assess:** For free-fall motion, acceleration due to gravity is always vertically downward. Notice that the acceleration due to the ground is quite large (although not to scale—that would take too much space) because in a time interval much shorter than the time interval between the points, the velocity of the ball is essentially completely reversed.

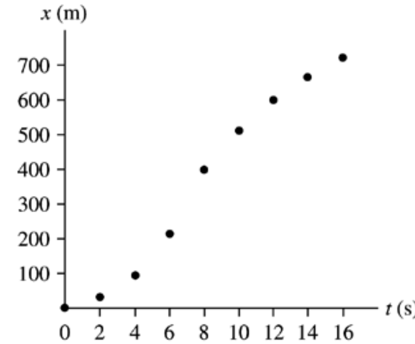
## Section 1.6 Motion in One Dimension

**1.18. Solve:**

(a)

| Dot | Time (s) | *x* (m) |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 2 | 30 |
| 3 | 4 | 95 |
| 4 | 6 | 215 |
| 5 | 8 | 400 |
| 6 | 10 | 510 |
| 7 | 12 | 600 |
| 8 | 14 | 670 |
| 9 | 16 | 720 |

(b)

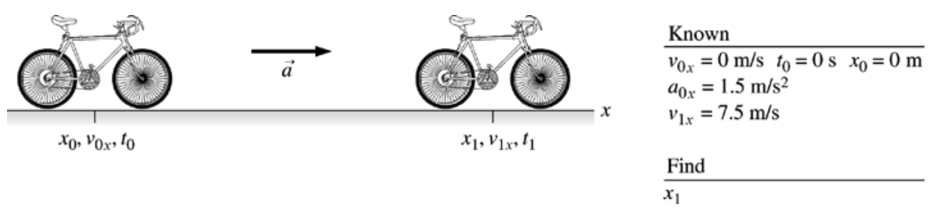



**1.19. Solve:** A forgetful physics professor is walking from one class to the next. Walking at a constant speed, he covers a distance of 100 m in 200 s. He then stops and chats with a student for 200 s. Suddenly, he realizes he is going to be late for his next class, so the hurries on and covers the remaining 200 m in 200 s to get to class on time.

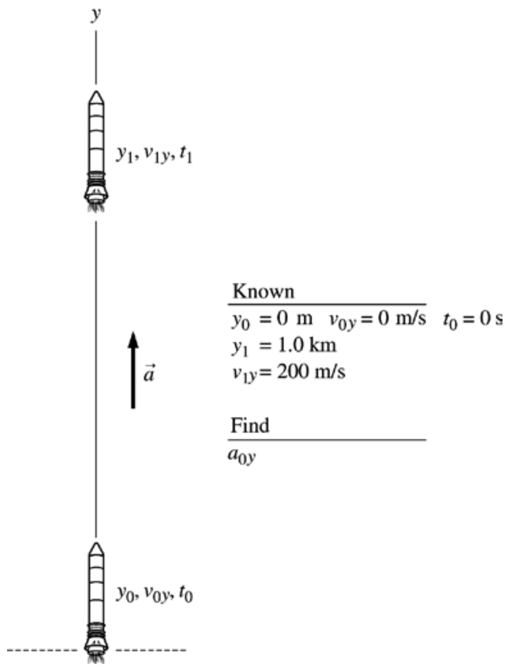
**1.20. Solve:** Eustace the truck driver had a load in a city 120 miles east of El Dorado. He drove west at 60 mph for two hours to El Dorado where he spent an hour unloading the truck and loading up different cargo. He then drove back east at 40 mph for two hours to the final destination 80 miles east of El Dorado.

## Section 1.7 Solving Problems in Physics

**1.21. Visualize:** The bicycle move forward with an acceleration of 1.5 m/s$^2$. Thus, the velocity will increase by 1.5 m/s each second of motion.



**1.22. Visualize:** The rocket moves upward with a constant acceleration $\vec{a}$. The final velocity is 200 m/s and is reached at a height of 1.0 km.




## Section 1.8 Units and Significant Figures

**1.23. Solve: (a)** One significant figure. In scientific notation it is straightforward: ignore all the zeros on the left. **(b)** three significant figures. The zero on the right is significant. **(c)** two significant figures; this is easy to see in scientific notation. **(d)** five significant figures; zeros on the right after the decimal are significant.

**1.24. Solve: (a)** $4.0\text{ inch} = (4.0\text{ inch})\left(\frac{2.54\text{ cm}}{1\text{ inch}}\right)\left(\frac{10^{-2}\text{ m}}{1\text{ cm}}\right) = 0.1\text{ m}$

**(b)** $33\text{ feet/s} = \left(33\frac{\text{feet}}{\text{s}}\right)\left(\frac{12\text{ inch}}{1\text{ foot}}\right)\left(\frac{1\text{ m}}{39.37\text{ inch}}\right) = 10\text{ m/s}$

**(c)** $30\text{ mph} = \left(30\frac{\text{miles}}{\text{hour}}\right)\left(\frac{1.609\text{ km}}{1\text{ mile}}\right)\left(\frac{10^3\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ hour}}{3600\text{ s}}\right) = 13.5\text{ m/s}$

**(d)** $7\text{ square inches} = (7\text{ inch}^2)\left(\frac{1\text{ m}}{39.37\text{ inches}}\right)^2 = 4.5\times10^{-3}\text{ m}^2 = 4.5\times10^{-3}\text{ square meters}$

**1.25. Solve**: **(a)** $60\text{ in} = (60\text{ in})\left(\frac{2.54\text{ cm}}{1\text{ in}}\right)\left(\frac{10^{-2}\text{ m}}{1\text{ cm}}\right) = 1.52\text{ m}$

**(b)** $1.45\times10^6\text{ yr} = (1.45\times10^6\text{ yr})\left(\frac{365.25\text{ days}}{1\text{ yr}}\right)\left(\frac{8.64\times10^4\text{ s}}{1\text{ day}}\right) = 3.15\times10^{13}\text{ s}$

**(c)** $50\text{ ft/day} = \left(50\frac{\text{ft}}{\text{day}}\right)\left(\frac{12\text{ in}}{1\text{ ft}}\right)\left(\frac{1\text{ m}}{39.37\text{ in}}\right)\left(\frac{1\text{ day}}{8.64\times10^4\text{ s}}\right) = 1.76\times10^{-4}\text{ m/s}$

**(d)** $2.0\times10^4\text{ mi}^2 = \left(2.0\times10^4\text{ mi}^2\right)\left(\frac{1.609\text{ km}}{1\text{ mi}}\right)^2\left(\frac{10^3\text{ m}}{1\text{ km}}\right)^2 = 5.18\times10^{10}\text{ m}^2$

**1.26. Solve:**

**(a)** $30\text{ cm} \approx (30\text{ cm})\left(\dfrac{4\text{ in}}{10\text{ cm}}\right) \approx 12\text{ in}$

**(b)** $25\text{ m/s} \approx (25\text{ m/s})\left(\dfrac{2\text{ mph}}{1\text{ m/s}}\right) \approx 50\text{ mph}$

**(c)** $5\text{ km} \approx (5\text{ km})\left(\dfrac{0.6\text{ mi}}{1\text{ km}}\right) \approx 3\text{ mi}$

**(d)** $0.5\text{ cm} \approx (0.5\text{ cm})\left(\dfrac{1/2\text{ in}}{1\text{ cm}}\right) \approx 0.3\text{ in}$

**1.27. Solve: (a)** $20\text{ ft} \approx (20\text{ ft})\left(\dfrac{1\text{ m}}{3\text{ ft}}\right) \approx 7\text{ m}$

**(b)** $60\text{ miles} \approx (60\text{ miles})\left(\dfrac{1\text{ km}}{0.6\text{ miles}}\right)\left(\dfrac{1000\text{ m}}{1\text{ km}}\right) \approx 100{,}000\text{ m}$

**(c)** $60\text{ mph} \approx (60\text{ mph})\left(\dfrac{1\text{ m/s}}{2\text{ mph}}\right) \approx 30\text{ m/s}$

**(d)** $8\text{ in} \approx (8\text{ in})\left(\dfrac{1\text{ cm}}{1/2\text{ in}}\right)\left(\dfrac{10^{-2}\text{ m}}{1\text{ cm}}\right) \approx 0.2\text{ m}$

**1.28. Solve**: **(a)** $33.3 \times 25.4 = 846$ **(b)** $33.3 - 25.4 = 7.9$ **(c)** $\sqrt{33.3} = 5.77$ **(d)** $333.3 \div 25.4 = 13.1$

**1.29. Solve: (a)** $159.31 \times 204.6 = 32590$. This is reported to 4 significant figures since that is the smallest number of significant figures in the factors.
**(b)** $5.1125 + 0.67 + 3.2 = 9.0$. This is reported to the tenths digit since that is the least significant digit in 3.2.
**(c)** $7.662 - 7.425 = 0.237$. This is reported to the thousandths digit since that is the least significant digit in both of the numbers.
**(d)** $16.5/3.45 = 4.78$. This is reported to three significant figures since that is the smallest number of significant figures in the two numbers.

**1.30. Solve:** The length of a typical car is 15 ft or

$$(15\text{ ft})\left(\frac{12\text{ inch}}{1\text{ ft}}\right)\left(\frac{1\text{ m}}{39.37\text{ inch}}\right) = 4.6\text{ m}$$

This length of 15 ft is approximately two-and-a-half times my height.

**1.31. Solve:** The height of a telephone pole is estimated to be around 50 ft or (using 1 m ~ 3 ft) about 15 m. This height is approximately 8 times my height.

**1.32. Solve:** My barber trims about an inch of hair when I visit him every month for a haircut. The rate of hair growth is

$$\left(\frac{1\text{ inch}}{1\text{ month}}\right)\left(\frac{2.54\text{ cm}}{1\text{ inch}}\right)\left(\frac{10^{-2}\text{ m}}{1\text{ cm}}\right)\left(\frac{1\text{ month}}{30\text{ days}}\right)\left(\frac{1\text{ day}}{24\text{ h}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 9.8 \times 10^{-9}\text{ m/s}$$

$$= \left(9.8 \times 10^{-9}\,\frac{\text{m}}{\text{s}}\right)\left(\frac{10^{6}\ \mu\text{m}}{1\text{ m}}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right) \approx 40\ \mu\text{m/h}$$

**1.33.** **Model:** Estimate the distance between your brain and your hand to be about 0.8 m. This estimate has only one significant figure of precision.

**Solve:** $\text{time} = \dfrac{\text{dist}}{\text{speed}} = \dfrac{0.8 \text{ m}}{25 \text{ m/s}} = 0.032 \text{ s} = 32 \text{ ms}$

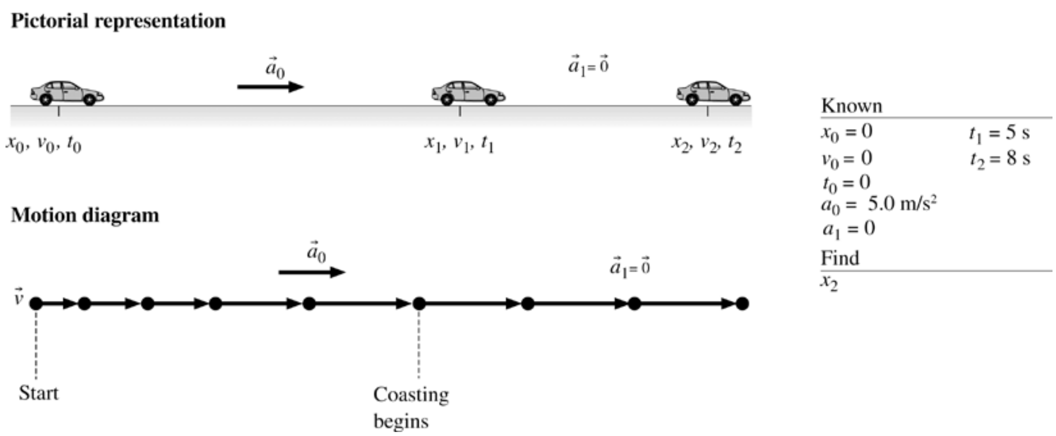
We report this to only one significant figure (because of our distance estimation) as 30 ms.

**Assess:** This sounds like a reasonable amount of time to get a signal from brain to hand.

## Problems

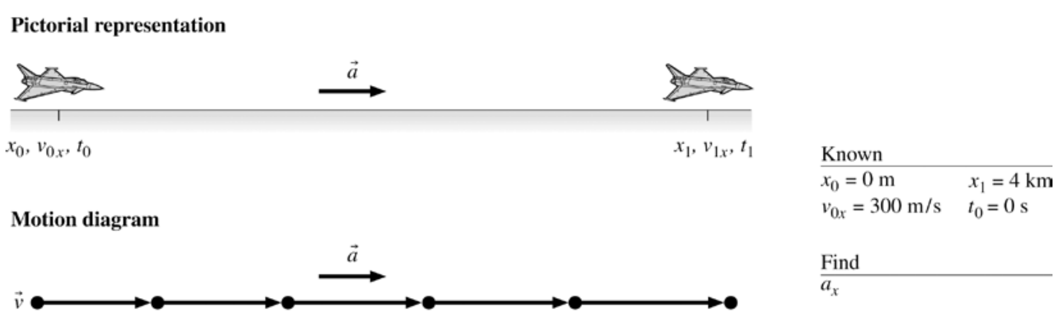
**1.34.** **Model:** Represent the Porsche as a particle for the motion diagram. Assume the car moves at a constant speed when it coasts.

**Visualize:**

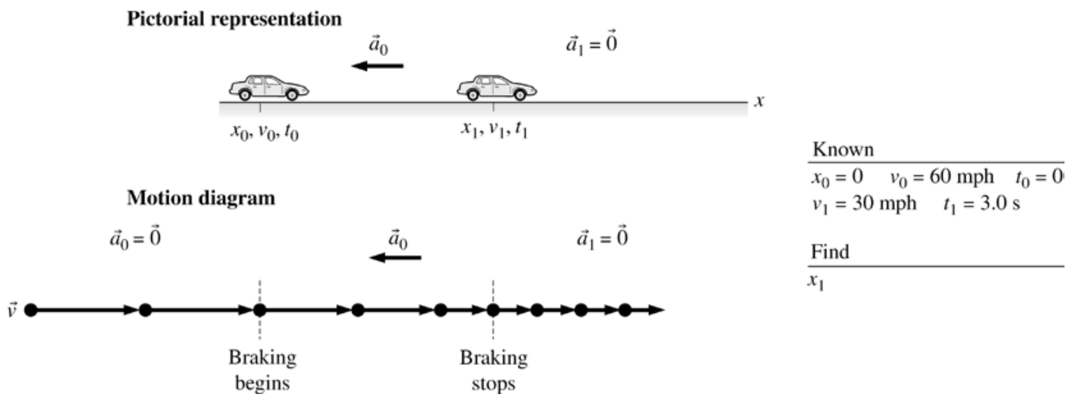



**1.35.** **Model:** Represent the jet as a particle for the motion diagram.

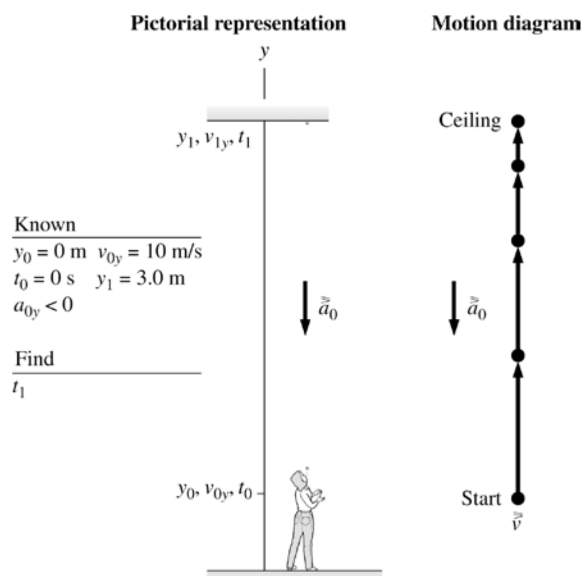
**Visualize:**



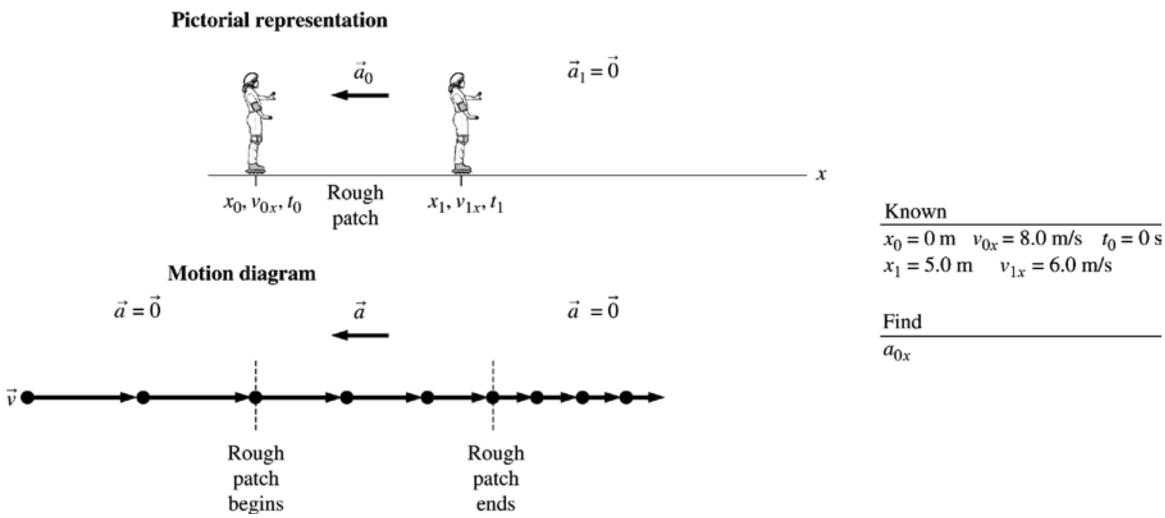
**1.36. Model:** Represent (Sam + car) as a particle for the motion diagram.
**Visualize:**



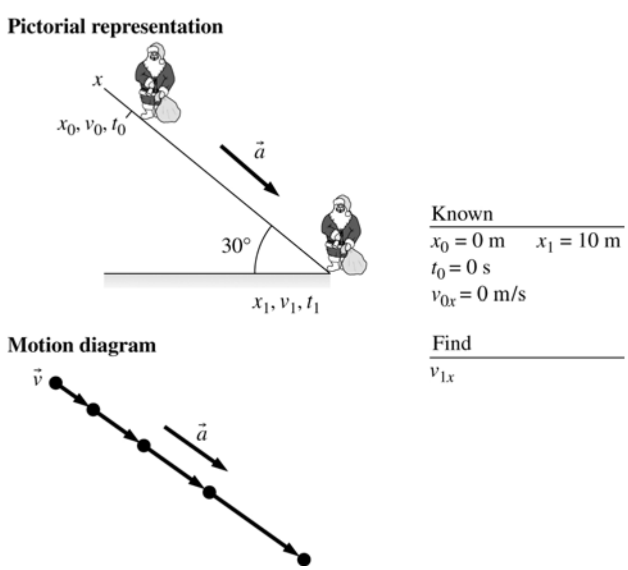

**1.37. Model:** Represent the wad as a particle for the motion diagram.
**Visualize:**



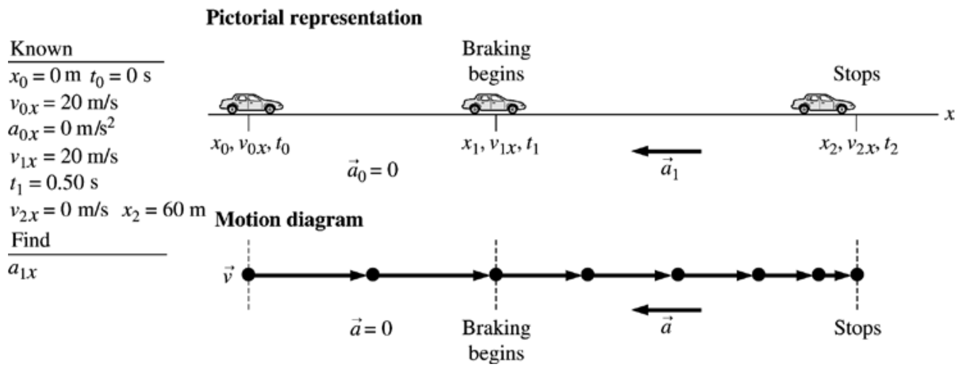
**1.38. Model:** Represent the speed skater as a particle for the motion diagram.
**Visualize:**



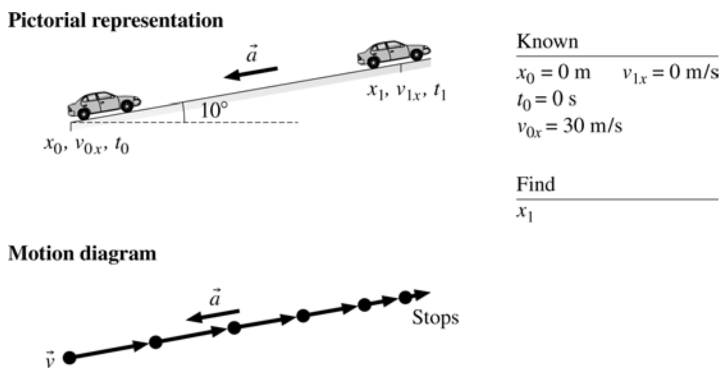

**1.39. Model:** Represent Santa Claus as a particle for the motion diagram.
**Visualize:**



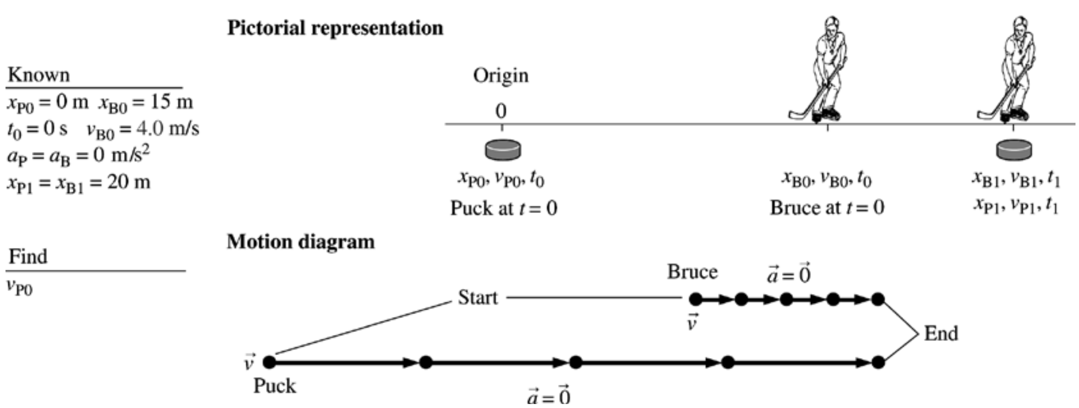
**1.40. Model:** Represent the motorist as a particle for the motion diagram.
**Visualize:**



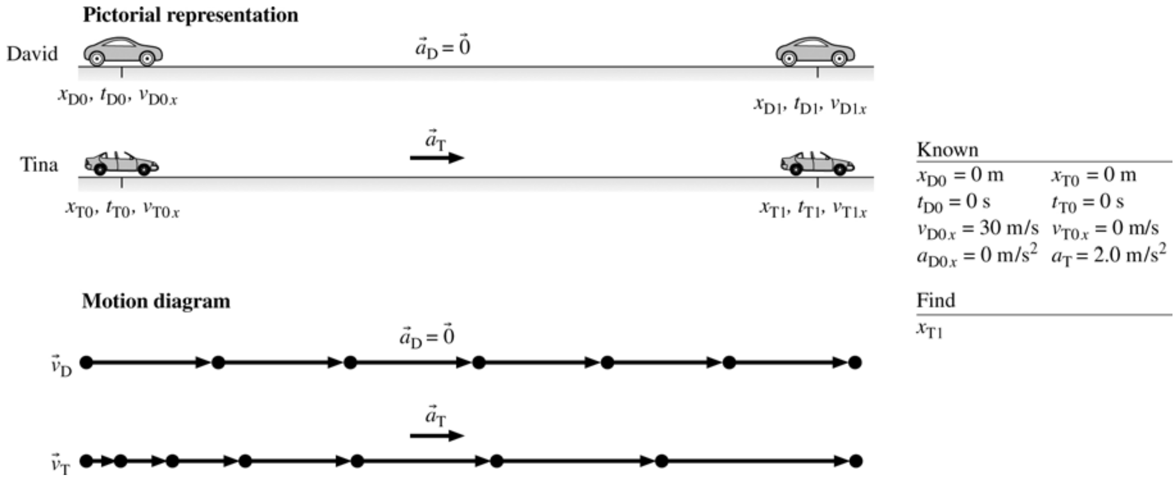

**1.41. Model:** Represent the car as a particle for the motion diagram.
**Visualize:**




**1.42. Model:** Represent Bruce and the puck as particles for the motion diagram.
**Visualize:**



**1.43. Model:** Represent the cars of David and Tina and as particles for the motion diagram.
**Visualize:**




**1.44. Solve:** Isabel is driving the first car in line at a stoplight. When it turns green, she accelerates forward, hoping to make the next stoplight before it turns red. But after she has traveled some distance, that light turns yellow, so she starts to brake, knowing that she cannot make the light, and comes to a stop.

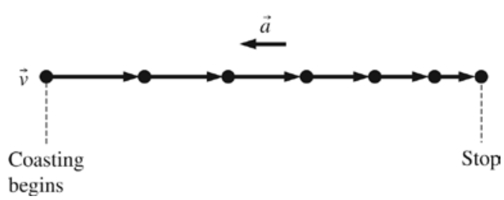
**1.45. Solve:** A car coasts along at 30 m/s and arrives at a hill. The car decelerates as it coasts up the hill. At the top, the road levels and the car continues coasting along the road at a reduced speed.

**1.46. Solve:** Jen skis from rest down a 25° slope with very little friction. At the bottom of the 100-m slope the terrain becomes flat but a little mushy. The slush provides some friction which brings Jen to rest after 70 m on the flat.

**1.47. Solve:** A ball is dropped from a height to check its rebound properties. It rebounds to 80% of its original height.

**1.48. Solve:** Julio jumps out of an airplane and free falls for 8 seconds (air resistance is negligible here). Then he deploys his parachute and he quickly reaches terminal speed (air resistance is not negligible here).

**1.49. Solve:**
**(a)**

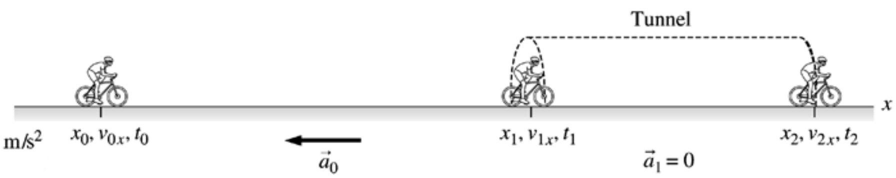



**(b)** A cyclist going at 10 m/s stops pedaling and coasts to a stop in 16 s due to friction. Find the distance traveled while slowing.

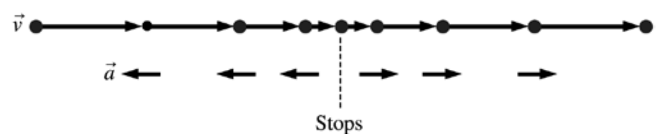
**(c)**

Known
$x_0 = 0$ m $t_0 = 0$ s
$v_{0x} = 100$ km/hour
$v_{1x} = 60$ km/hour
$t_1 = 10$ s $a_{1x} = 0$ m/s$^2$
$v_{2x} = 60$ km/hour
$t_2 = 30$ s

Find
$L = x_2 - x_1$



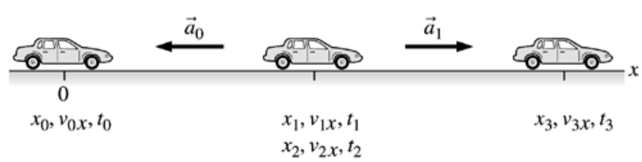

**1.50. Solve:**
**(a)**



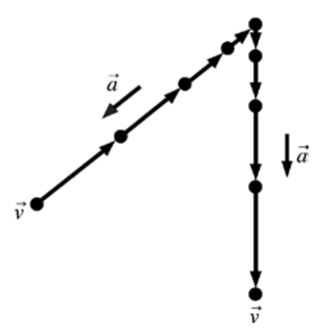

**(b)** Sue passes 3rd Street doing 30 km/h, slows steadily to the stop sign at 4th Street, stops for 1.0 s, then speeds up and reaches her original speed as she passes 5th Street. If the blocks are 50 m long, how long does it take Sue to drive from 3rd Street to 5th Street?
**(c)**

Known
$x_0 = 0$ m $t_0 = 0$ s
$v_{0x} = 30$ km/h
$x_1 = x_2 = 50$ m
$v_{1x} = v_{2x} = 0$ km/h
$t_2 = t_1 + 1.0$ s
$x_3 = 100$ m $v_{3x} = 30$ km/h

Find
$t_3$

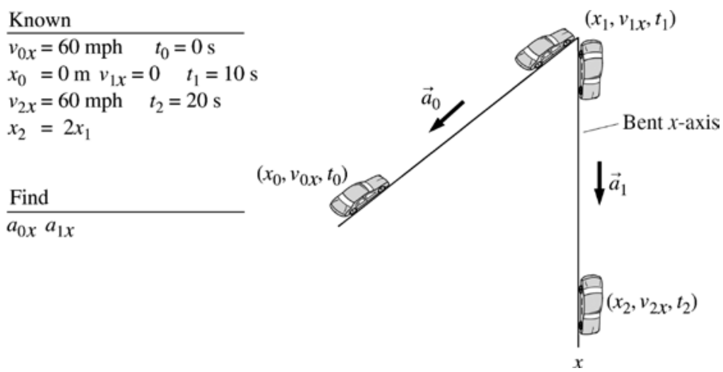



**1.51. Solve:**
**(a)**

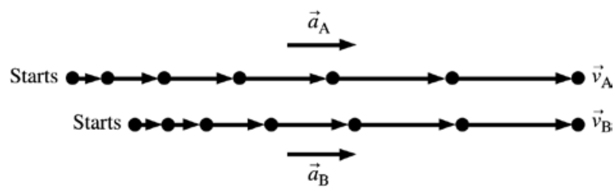



**(b)** Jeremy has perfected the art of steady acceleration and deceleration. From a speed of 60 mph he brakes his car to rest in 10 s with a constant deceleration. Then he turns into an adjoining street. Starting from rest, Jeremy accelerates with exactly the same magnitude as his earlier deceleration and reaches the same speed of 60 mph over the same distance in exactly the same time. Find the car's acceleration or deceleration.

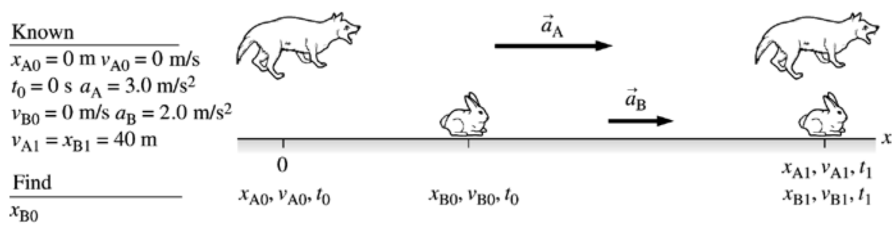
**(c)**




**1.52. Solve:**
**(a)**




**(b)** A coyote (A) sees a rabbit and begins to run toward it with an acceleration of 3.0 $\text{m/s}^2$. At the same instant, the rabbit (B) begins to run away from the coyote with an acceleration of 2.0 $\text{m/s}^2$. The coyote catches the rabbit after running 40 m. How far away was the rabbit when the coyote first saw it?
**(c)**




**1.53. Solve:** Since area = length × width, the smallest area will correspond to the product of the smaller length and the smaller width. Similarly, the largest area will correspond to the product of the larger length and the larger width. Therefore, the smallest area is (32 m)(50 m) = $1.6\times10^3\ \text{m}^2$ and the largest area is (37.5 m)(55 m) = $2.06\times10^3\ \text{m}^2$.

**1.54. Solve:** Since area = length × width, the smallest area will correspond to the product of the smaller length and smaller width. Similarly, the largest area will correspond to the product of the larger length and larger width. Therefore, the smallest area is (100 m)(60 m) = $6.0\times10^3\ \text{m}^2$ and the largest area is (120 m)(70 m) = $8.40\times10^3\ \text{m}^2$.

**1.55. Solve:** The volume of a cylinder is the product of the area of its base and its length. Therefore,

$$\text{Volume} = \pi\left(\frac{\text{diameter}}{2}\right)^2 \times \text{length}$$

Taking $\pi = 3.14$, $\text{Volume} = 235.5\ \text{cm}^3 \approx 236\ \text{cm}^3 = (236\ \text{cm}^3)\left(\dfrac{10^{-2}\ \text{m}}{1\ \text{cm}}\right)^3 = 2.36\times10^{-4}\ \text{m}^3.$

**1.56. Solve:** $9.0\ \text{g/L} = \left(9.0\ \dfrac{\text{g}}{\text{L}}\right)\left(\dfrac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\dfrac{1\ \text{L}}{1000\ \text{mL}}\right)\left(\dfrac{1\ \text{mL}}{1\ \text{cm}^3}\right)\left(\dfrac{100\ \text{cm}}{1\ \text{m}}\right)^3 = 9.0\ \text{kg/m}^3$

**1.57. Solve:**

**(a)** $\text{Mass density} = \dfrac{0.15\ \text{kg}}{210\ \text{m}^3} = 7.14\times10^{-4}\ \text{kg/m}^3 \approx 7.1\times10^{-4}\ \text{kg/m}^3$

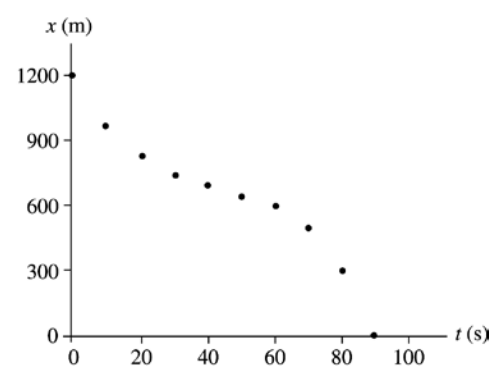
**(b)** $\text{Mass density} = \dfrac{(70/1000)\ \text{kg}}{90\ \text{m}^3} = 7.77\times10^{-4}\ \text{kg/m}^3 \approx 7.7\times10^{-4}\ \text{kg/m}^3$

**1.58. Model:** In the particle model, the car is represented as a dot.
**Solve:**

**(a)**

| **Time *t* (s)** | **Position *x* (m)** |
|---|---|
| 0 | 1200 |
| 10 | 975 |
| 20 | 825 |
| 30 | 750 |
| 40 | 700 |
| 50 | 650 |
| 60 | 600 |
| 70 | 500 |
| 80 | 300 |
| 90 | 0 |

**(b)**




**1.59. Solve:** Susan enters a classroom, sees a seat 40 m directly ahead, and begins walking toward it at a constant leisurely pace, covering the first 10 m in 10 seconds. But then Susan notices that Ella is heading toward the same seat, so Susan walks more quickly to cover the remaining 30 m in another 10 seconds, beating Ella to the seat. Susan stands next to the seat for 10 seconds to remove her backpack.

**1.60. Solve:** A crane operator checks his load of a ton of bricks for 4 s while it is 30 m off the ground, then begins to lower it at constant speed. He lowers it 15 m in 4 s. Then he stops for 4 s to make a second safety check. He then continues lowering the bricks the remaining 15 m in 8 s until they hit the ground.