# 1 Concepts of Motion

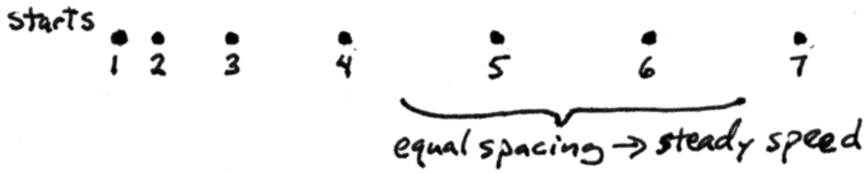
## 1.1 Motion Diagrams

## 1.2 The Particle Model

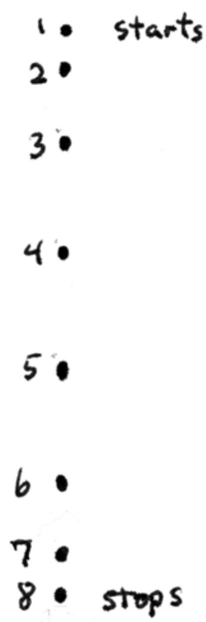
**Exercises 1–5:** Draw a motion diagram for each motion described below.

- Use the particle model to represent the object as a particle.
- Six to eight dots are appropriate for most motion diagrams.
- Number the positions in order, as shown in Figure 1.4 in the text.
- Be neat and accurate!

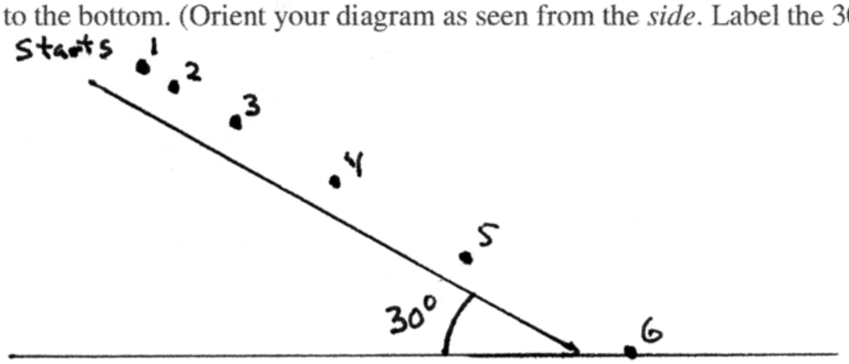
1. A car accelerates forward from a stop sign. It eventually reaches a steady speed of 45 mph.



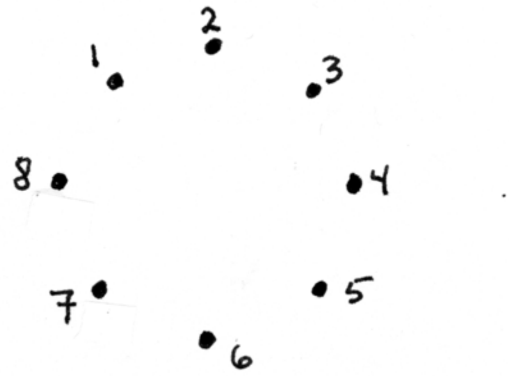

2. An elevator starts from rest at the 100th floor of the Empire State Building and descends, with no stops, until coming to rest on the ground floor. (Draw this one *vertically* since the motion is vertical.)




3. A skier starts *from rest* at the top of a 30° snow-covered slope and steadily speeds up as she skies to the bottom. (Orient your diagram as seen from the *side*. Label the 30° angle.)

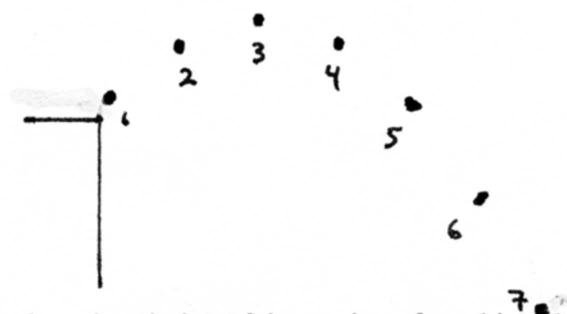


4. The space shuttle orbits the earth in a circular orbit, completing one revolution in 90 minutes.




5. Bob throws a ball at an upward 45° angle from a third story balcony. The ball lands on the ground below.

equal horizontal spacing

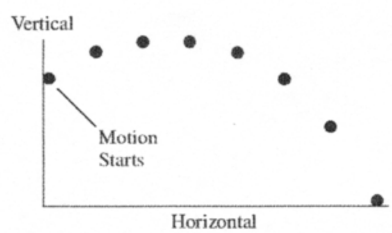



**Exercises 6–9:** For each motion diagram, write a short description of the motion of an object that will match the diagram. Your descriptions should name *specific* objects and be phrased similarly to the descriptions of Exercises 1 to 5. Note the axis labels on Exercises 8 and 9.

6.


A car brakes to a stop from a speed of 40 km/hr.
(Any linear motion of an object slowing down to a stop.)

8.



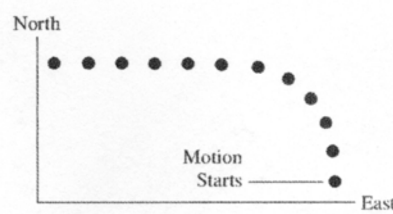

Sally launches a water balloon from her second-floor dorm window in an attempt to hit her ex-boyfriend.
(projectile motion)

7.


Mikey drops a rock off of a cliff.

(Any downward acceleration from rest.)

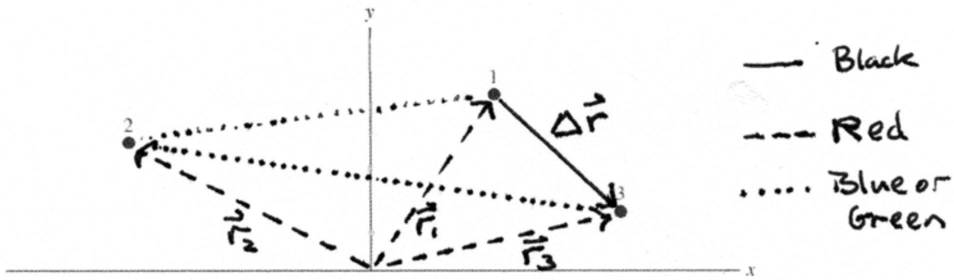
9.




A man walks steadily along a path that turns from north towards the west and continues directly west.
(Any turning from north to west at constant speed.)

## 1.3 Position and Time

10. The figure below shows the location of an object at three successive instants of time.

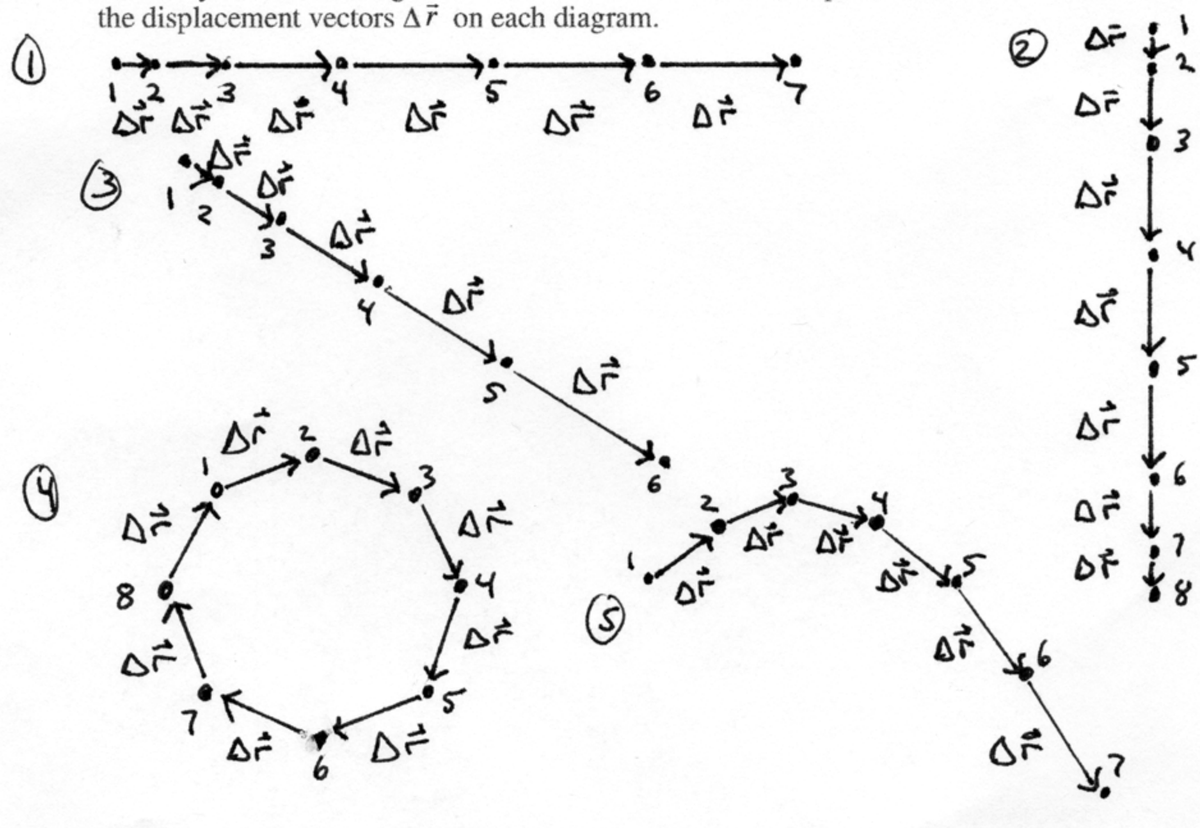



a. Use a **red** pencil to draw and label on the figure the three position vectors $\vec{r}_1$, $\vec{r}_2$, and $\vec{r}_3$ at times 1, 2, and 3.
b. Use a **blue** or **green** pencil to draw a possible trajectory from 1 to 2 to 3.
c. Use a **black** pencil to draw the displacement vector $\Delta\vec{r}$ from the initial to the final position.

11. In Exercise 10, is the object's displacement equal to the distance the object travels? Explain.

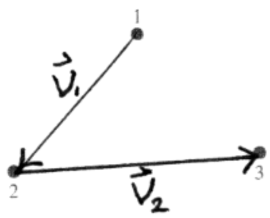
No, the displacement is the black arrow, $\Delta\vec{r}$. The distance traveled is the sum of the lengths of the blue or green arrows.

12. Redraw your motion diagrams from Exercises 1 to 5 in the space below. Then add and label the displacement vectors $\Delta\vec{r}$ on each diagram.



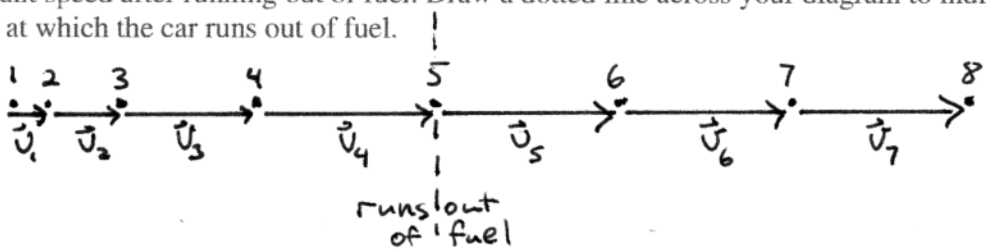
## 1.4 Velocity

13. The figure below shows the positions of a moving object in three successive frames of film. Draw and label the velocity vector $\vec{v}_1$ for the motion from 1 to 2 and the vector $\vec{v}_2$ for the motion from 2 to 3.

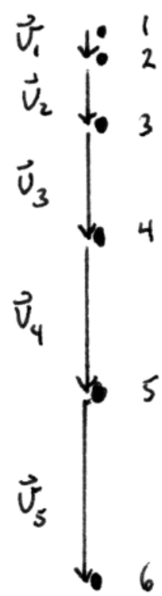



**Exercises 14–20:** Draw a motion diagram for each motion described below.
- Use the particle model.
- Show and label the *velocity* vectors.

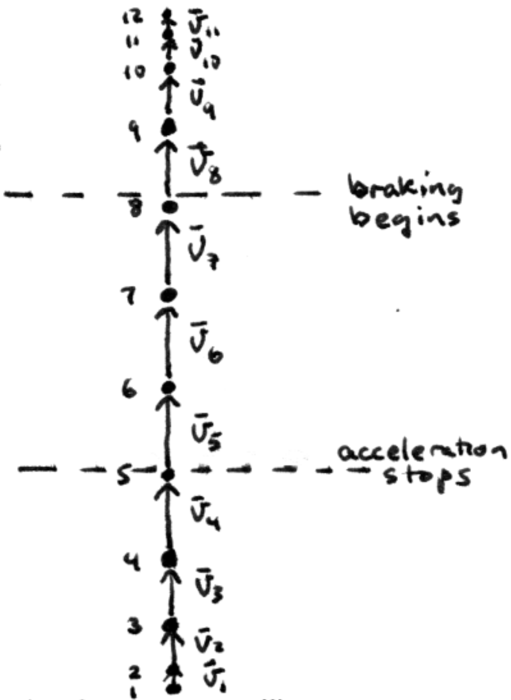
14. A rocket-powered car on a test track accelerates from rest to a high speed, then coasts at constant speed after running out of fuel. Draw a dotted line across your diagram to indicate the point at which the car runs out of fuel.



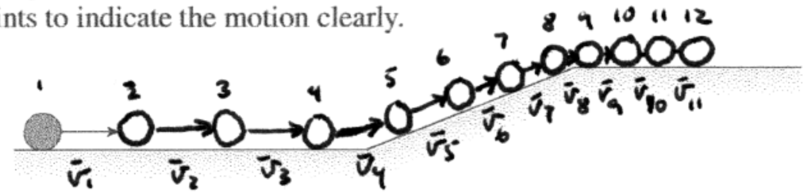

15. Galileo drops a ball from the Leaning Tower of Pisa. Consider the ball's motion from the moment it leaves his hand until a microsecond before it hits the ground. Your diagram should be vertical.



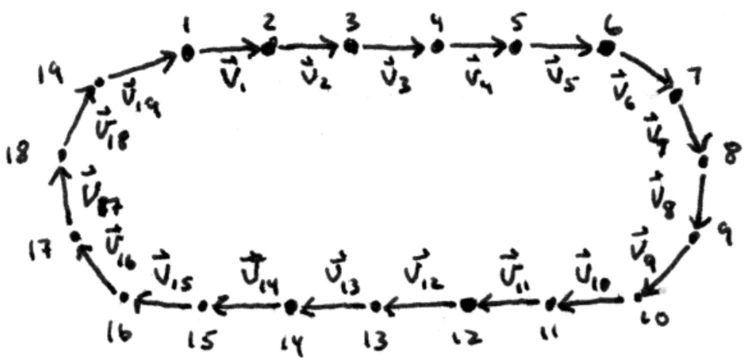
16. An elevator starts from rest at the ground floor. It accelerates upward for a short time, then moves with constant speed, and finally brakes to a halt at the tenth floor. Draw dotted lines across your diagram to indicate where the acceleration stops and where the braking begins. You'll need 10 or 12 points to indicate the motion clearly.



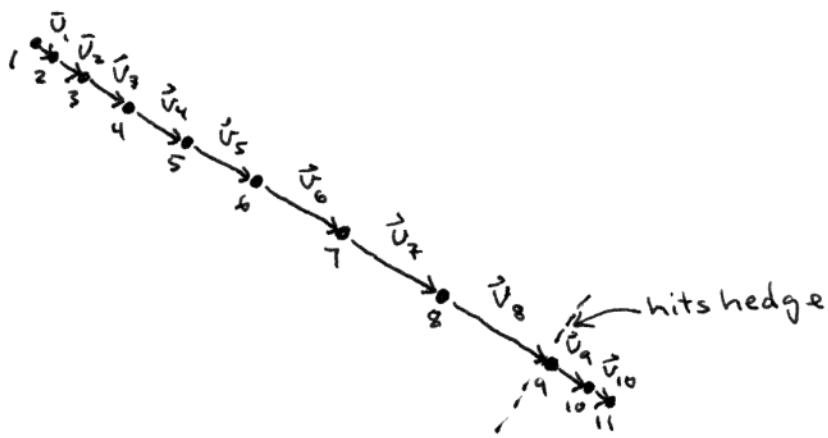

17. A bowling ball being returned from the pin area to the bowler starts out rolling at a constant speed. It then goes up a ramp and exits onto a level section at very low speed. You'll need 10 or 12 points to indicate the motion clearly.



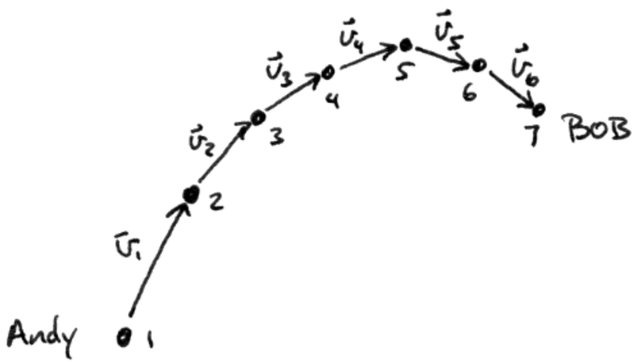
18. A track star runs once around a running track at constant speed. The track has straight sides and semicircular ends. Use a bird's-eye view looking down on the track. Use about 20 points for your motion diagram.



19. A car is parked on a hill. The brakes fail, and the car rolls down the hill with an ever increasing speed. At the bottom of the hill it runs into a thick hedge and gently comes to a halt.




20. Andy is standing on the street. Bob is standing on the second-floor balcony of their apartment, about 30 feet back from the street. Andy throws a baseball to Bob. Consider the ball's motion from the moment it leaves Andy's hand until a microsecond before Bob catches it.



## 1.5 Acceleration

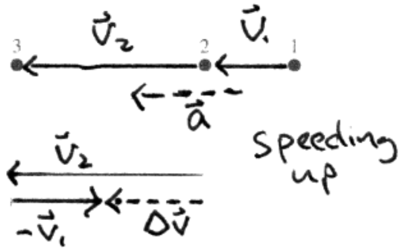
## 1.6 Examples of Motion Diagrams

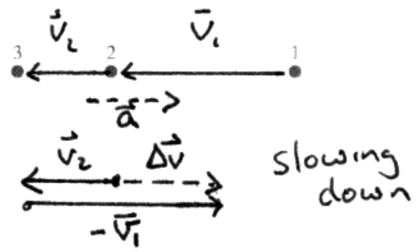
**Note:** Beginning with this section, and for future motion diagrams, you will "color code" the vectors. Draw velocity vectors **black** and acceleration vectors **red**.

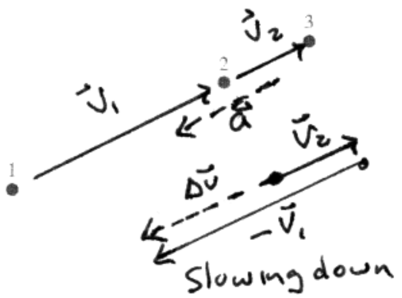
**Exercises 21–26:** The figures below show an object's position in three successive frames of film. The object is moving in the direction $1 \rightarrow 2 \rightarrow 3$. For each diagram:

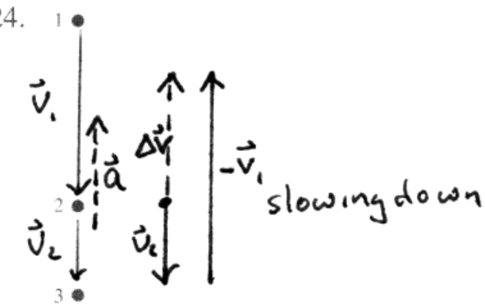
- Draw and label the initial and final velocity vectors $\vec{v}_0$ and $\vec{v}_1$. Use **black**.
- Use the steps of Tactics Box 1.3 to find the change in velocity $\Delta\vec{v}$.
- Draw and label $\vec{a}$ at the proper location on the motion diagram. Use **red**.
- Determine whether the object is speeding up, slowing down, or moving at a constant speed. Write your answer beside the diagram.

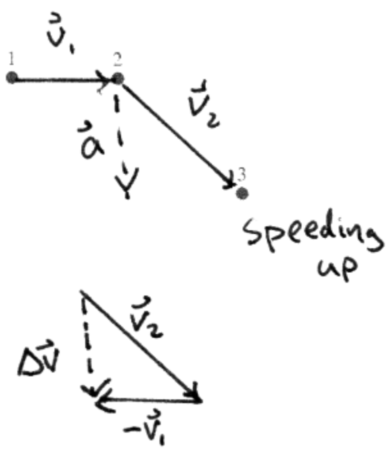
BLACK
RED

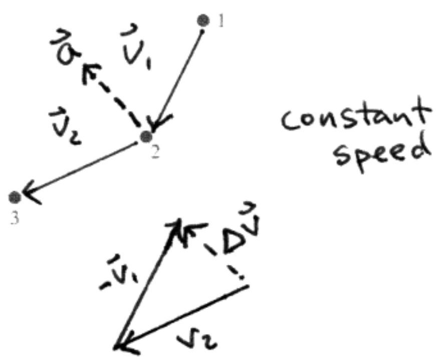
21.



22.



23.



24.



25.



26.


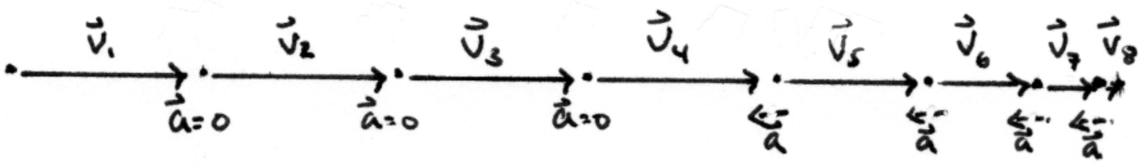
**Exercises 27–34:** Draw a complete motion diagram for each of the following.

- Draw and label the velocity vectors $\vec{v}$. Use **black**.
- Draw and label the acceleration vectors $\vec{a}$. Use **red**.

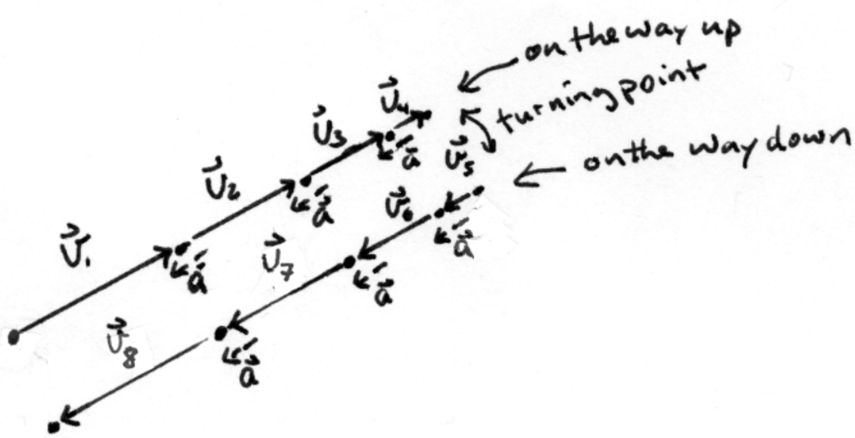
——— Black
– – – Red

27. Galileo drops a ball from the Leaning Tower of Pisa. Consider its motion from the moment it leaves his hand until a microsecond before it hits the ground.

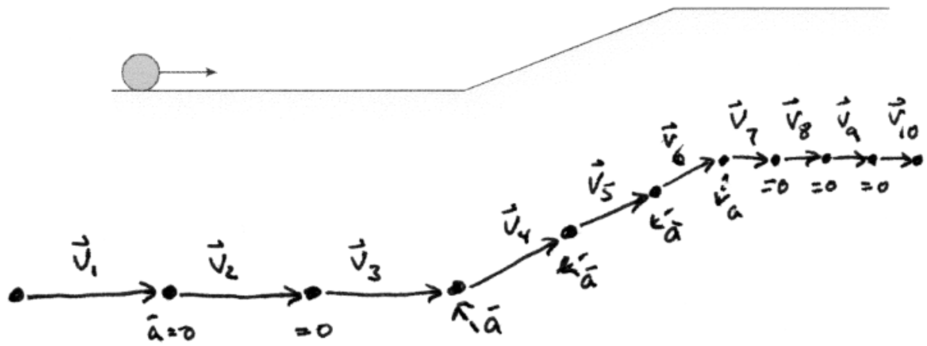

28. Trish is driving her car at a steady 30 mph when a small furry creature runs into the road in front of her. She hits the brakes and skids to a stop. Show her motion from 2 seconds before she starts braking until she comes to a complete stop.



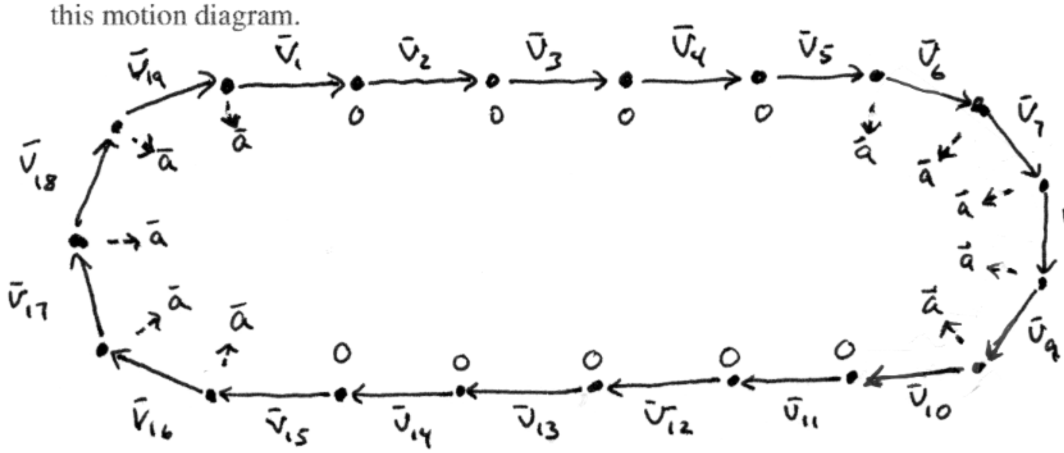

29. A ball rolls up a smooth board tilted at a 30° angle. Then it rolls back to its starting position.



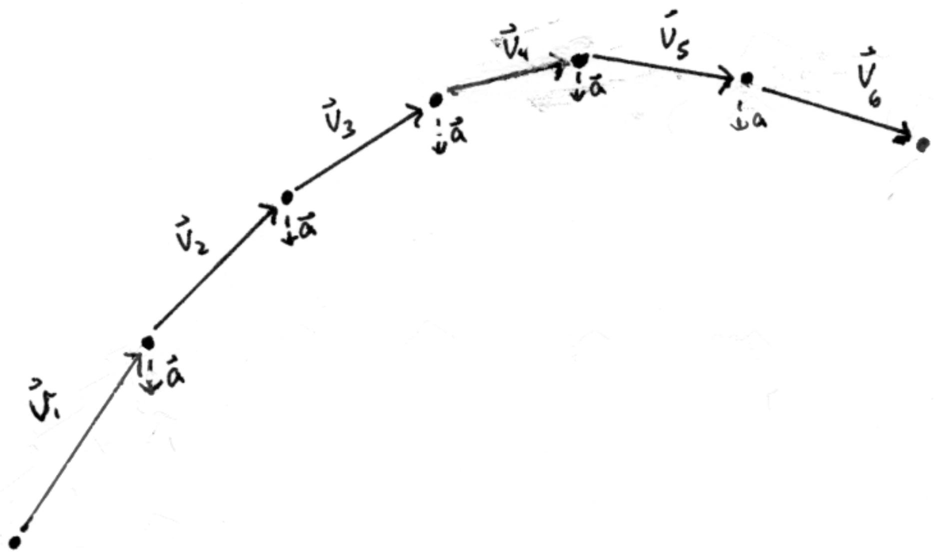
30. A bowling ball being returned from the pin area to the bowler rolls at a constant speed, then up a ramp, and finally exits onto a level section at very low speed.



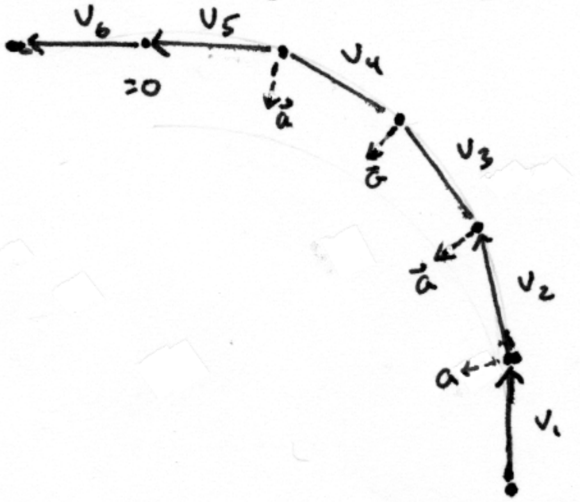

31. A track star runs once around a running track at constant speed. The track has straight sides and semicircular ends. Use a bird's-eye view looking down on the track. Use about 20 dots for this motion diagram.



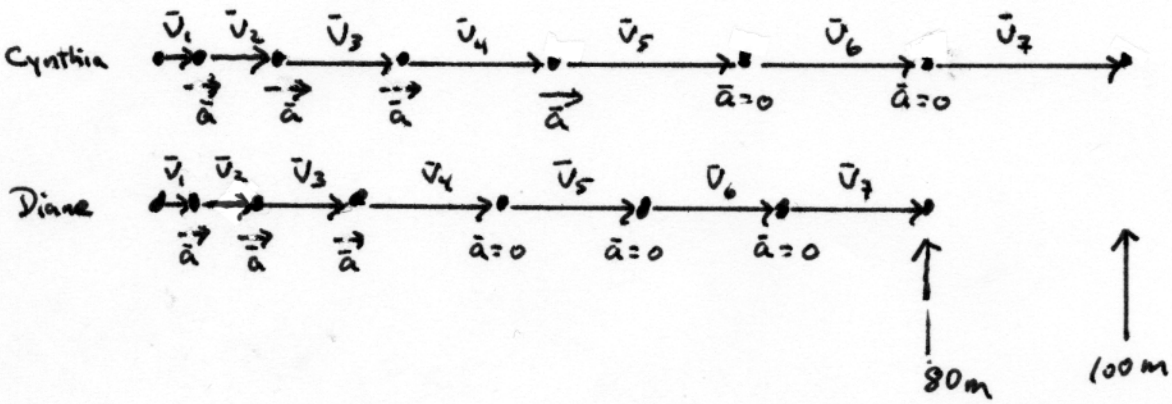

32. A cannon ball is fired from a Civil War cannon up onto a high cliff. Show the cannon ball's motion from the instant it leaves the cannon until a microsecond before it hits the ground.



33. A plane flying north at 300 mph turns slowly to the west without changing speed, then continues to fly west. Draw the motion diagram from a viewpoint above the plane.



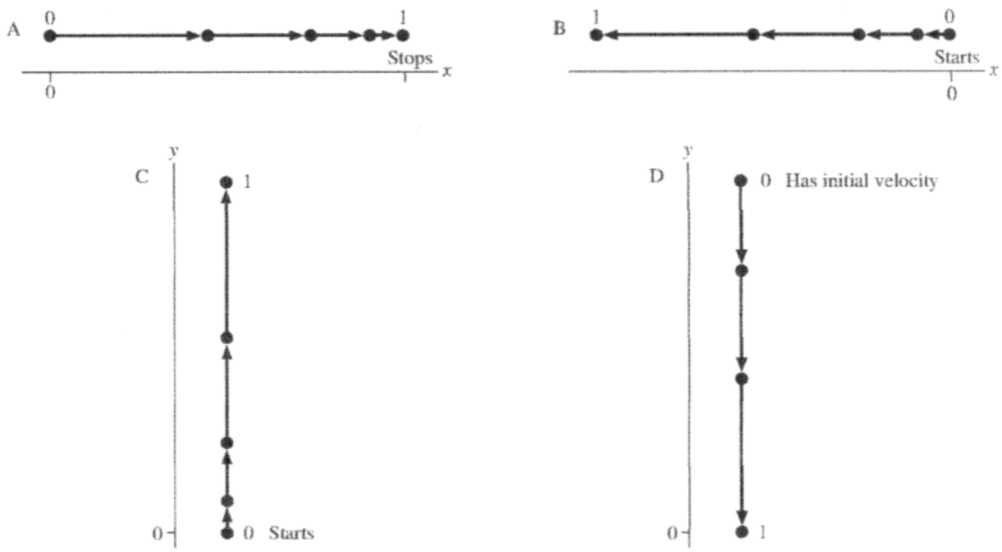

34. Two sprinters, Cynthia and Diane, start side by side. Diane has run only 80 m when Cynthia crosses the finish line of the 100 m dash.



## 1.7 From Words to Symbols

## 1.8 A Problem-Solving Strategy

35. The four motion diagrams below show an initial point 0 and a final point 1. A pictorial representation would define the five symbols: $x_0$, $x_1$, $v_{0x}$, $v_{1x}$, and $a_x$ for horizontal motion and equivalent symbols with $y$ for vertical motion. Determine whether each of these quantities is positive, negative, or zero. Give your answer by writing +, –, or 0 in the table below.




| | A | B | C | D |
|---|---|---|---|---|
| $x_0$ or $y_0$ | 0 | 0 | 0 | + |
| $x_1$ or $y_1$ | + | – | + | 0 |
| $v_{0x}$ or $v_{0y}$ | + | 0 | 0 | – |
| $v_{1x}$ or $v_{1x}$ | 0 | – | + | – |
| $a_x$ or $a_y$ | – | – | + | – |

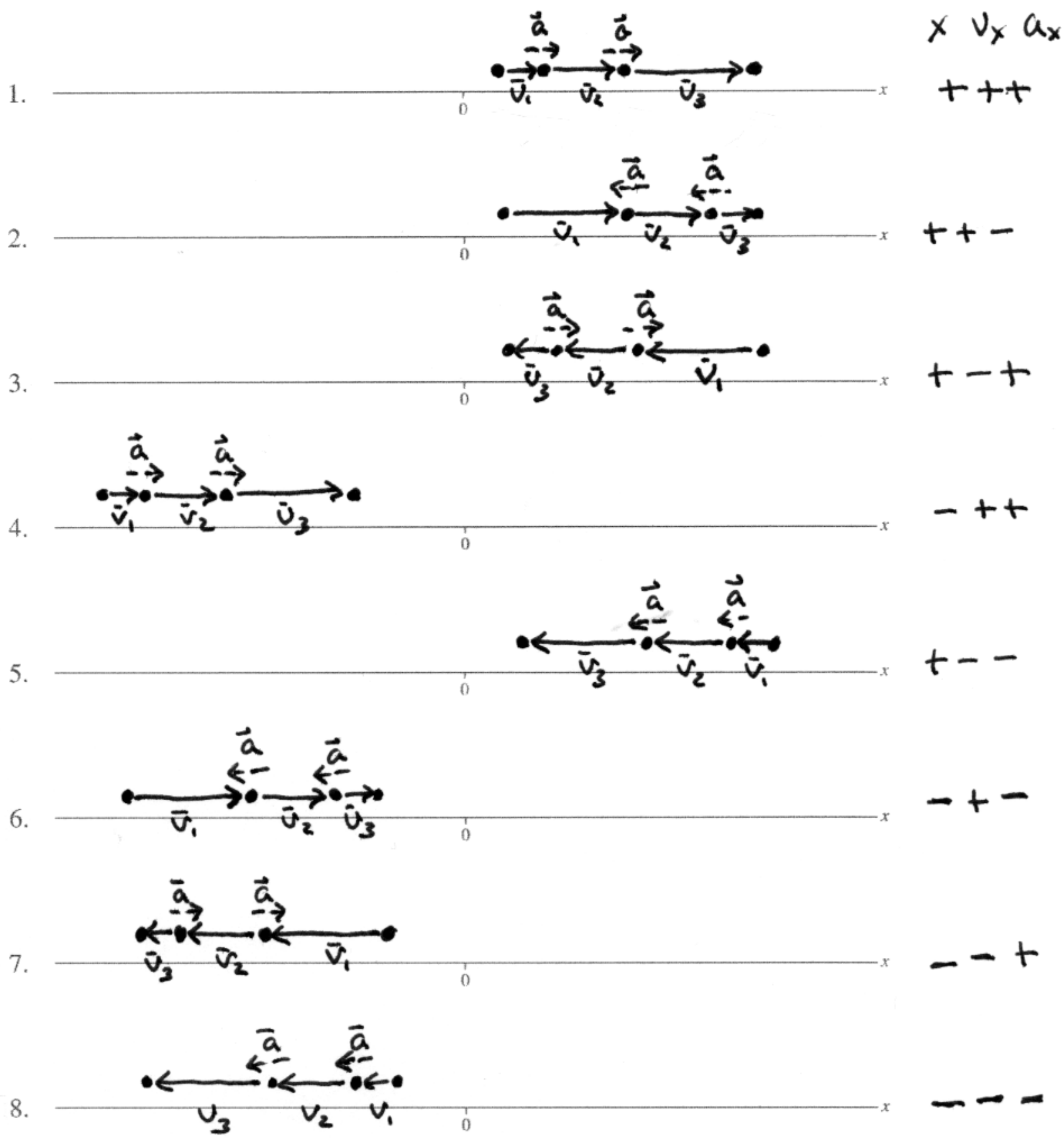
36. The three symbols $x$, $v_x$, and $a_x$ have eight possible combinations of *signs*. For example, one combination is $(x, v_x, a_x) = (+, -, +)$.

a. List all eight combinations of signs for $x$, $v_x$, $a_x$.

| | | | |
|---|---|---|---|
| 1. | + + + | 5. | + – – |
| 2. | + + – | 6. | – + – |
| 3. | + – + | 7. | – – + |
| 4. | – + + | 8. | – – – |

b. For each of the eight combinations of signs you identified in part a:
- Draw a four-dot motion diagram of an object that has these signs for $x$, $v_x$, and $a_x$.
- Draw the diagram *above* the axis whose number corresponds to part a.
- Use **black** and **red** for your $\vec{v}$ and $\vec{a}$ vectors. Be sure to label the vectors.

— Black
- - - Red



## 1.9 Units and Significant Figures

37. Convert the following to SI units. Work across the line and show all steps in the conversion.

a. $9.12\ \mu s \times \frac{10^{-6} s}{1 \mu s} = \boxed{9.12 \times 10^{-6} \mu s}$

b. $3.42\ km \times \frac{10^3 m}{1 km} = \boxed{3.42 \times 10^3 m}$

c. $44\ cm/ms \times \frac{10^{-2} m}{1 cm} \times \frac{10^3 ms}{1 s} = \boxed{4.4 \times 10^2 \frac{m}{s}}$

d. $80\ km/hr \times \frac{10^3 m}{1 km} \times \frac{1 hr}{60 min} \times \frac{1 min}{60 s} = \boxed{2.2 \frac{m}{s}}$

e. $60\ mph \times \frac{5280 ft}{1 mi} \times \frac{12 in}{1 ft} \times \frac{2.54 cm}{1 in} \times \frac{10^{-2} m}{1 cm} \times \frac{1 hr}{3600 s} = \boxed{27 \frac{m}{s}}$

f. $8\ in \times \frac{2.54 cm}{1 in} \times \frac{10^{-2} m}{1 cm} = \boxed{2 \times 10^{-1} m}$

g. $14\ in^2 \times \frac{2.54 cm}{1 in} \times \frac{2.54 cm}{1 in} \times \frac{10^{-2} m}{1 cm} \times \frac{10^{-2} m}{1 cm} = \boxed{9.0 \times 10^{-3} m^2}$

h. $250\ cm^3 \times \frac{10^{-2} m}{1 cm} \times \frac{10^{-2} m}{1 cm} \times \frac{10^{-2} m}{1 cm} = \boxed{2.5 \times 10^{-4} m^3}$

**Note:** Think carefully about g and h. A picture may help.

38. Use Table 1.4 to assess whether or not the following statements are *reasonable*.

a. Joe is 180 cm tall.

$180 cm = 18 \times 10 cm \approx 18 \times 4 in = 72 in = 6 ft$

Reasonable

b. I rode my bike to campus at a speed of 50 m/s.

$50 \times 1 \frac{m}{s} \simeq 50 \times 2 mph = 100 mph$

Not reasonable

c. A skier reaches the bottom of the hill going 25 m/s.

$25 \times 1 \frac{m}{s} \approx 25 \times 2 mph = 50 mph$

Reasonable

(Downhill racers reach ~85mph)

d. I can throw a ball a distance of 2 km.

2 km ~ 1.2 miles   Not reasonable

e. I can throw a ball at a speed of 50 km/hr.

$50 \frac{km}{hr} \sim 30$ mph ; reasonable (major league pitchers throw at ~100 mph)

39. Justify the assertion that 1 m/s ≈ 2 mph by *exactly* converting 1 m/s to English units. By what percentage is this rough conversion in error?

$$\frac{1\,m}{s} \times \frac{3600\,s}{hr} \times \frac{1\,in}{2.54\,cm} \times \frac{1\times10^{2}\,cm}{1\,m} \times \frac{1\,ft}{12\,in} \times \frac{1\,mi}{5280\,ft} = 2.24\text{ mph}$$

error: $\frac{|2.24\,mph - 2\,mph|}{2.24\,mph} = 0.11$

$\therefore$ 11% error

40. How many significant figures does each of the following numbers have?

| | | | | | |
|---|---|---|---|---|---|
| a. 6.21 | 3 | e. 0.0621 | 3 | i. 1.0621 | 5 |
| b. 62.1 | 3 | f. 0.620 | 3 | j. $6.21 \times 10^3$ | 3 |
| c. 6210 | 3 | g. 0.62 | 2 | k. $6.21 \times 10^{-3}$ | 3 |
| d. 6210.0 | 5 | h. .62 | 2 | l. $62.1 \times 10^3$ | 3 |

41. Compute the following numbers, applying the significant figure standards adopted for this text.

| | | | |
|---|---|---|---|
| a. $33.3 \times 25.4 =$ | $8.46 \times 10^2$ | e. $2.345 \times 3.321 =$ | 7.788 |
| b. $33.3 - 25.4 =$ | 7.9 | f. $(4.32 \times 1.23) - 5.1 =$ | $2. \times 10^{-1}$ |
| c. $33.3 \div 45.1 =$ | $7.38 \times 10^{-1}$ | g. $33.3^2 =$ | $1.109 \times 10^3$ (leading one) |
| d. $33.3 \times 45.1 =$ | $1.502 \times 10^3$ (leading one) | h. $\sqrt{33.3} =$ | 5.77 |