1 Concepts of Motion

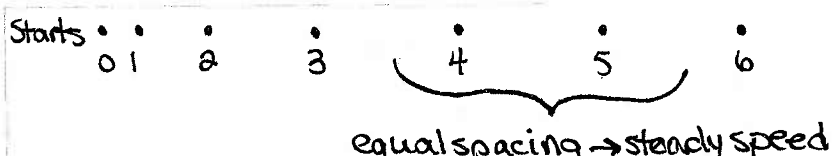
1.1 Motion Diagrams

1.2 The Particle Model

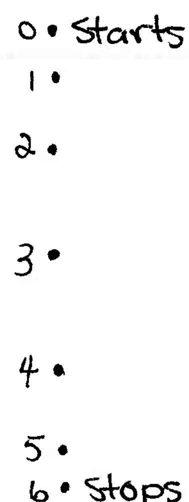
Exercises 1–5: Draw a motion diagram for each motion described below.

- 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!

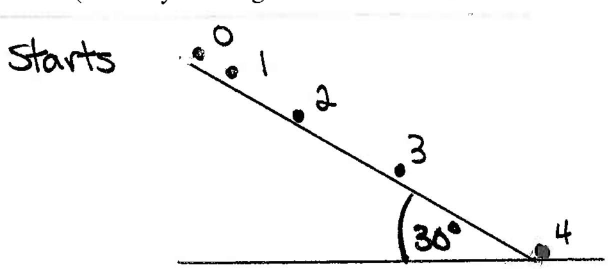
1. A car accelerates forward from a stop sign. It eventually reaches a steady speed of 45 mph.



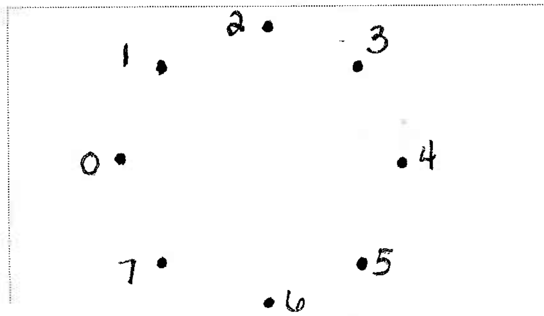
2. An elevator starts from rest at the 100th floor of the Empire State Building and descends, with no stops, until coming to rest on the ground floor. (Draw this one *vertically* since the motion is vertical.)



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.)

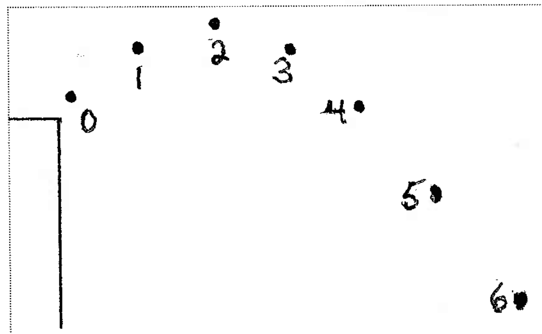


4. The space shuttle orbits the earth in a circular orbit, completing one revolution in 90 minutes.



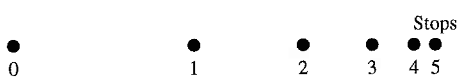
5. Bob throws a ball at an upward 45° angle from a third-story balcony. The ball lands on the ground below.

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.

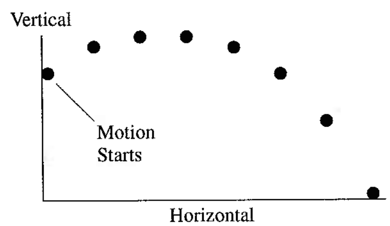


A car breaks to a stop from a speed of 40 km/hr.
(Any linear motion of an object slowing down to a stop.)

7.

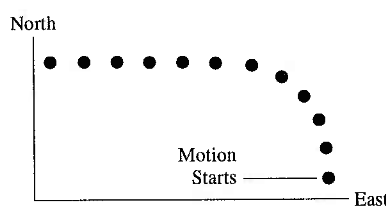
Mikey drops a rock off of a cliff.
(Any downward acceleration from rest.)

8.



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

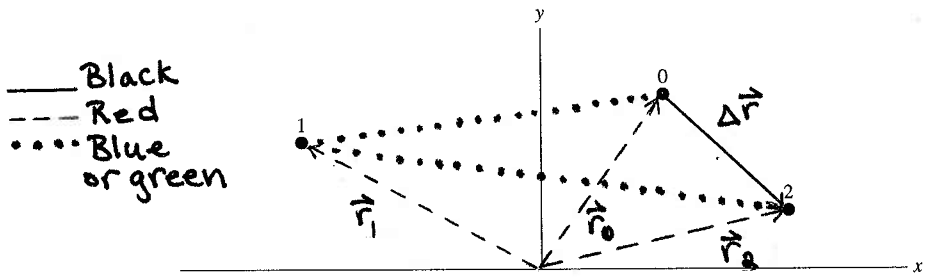
9.



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.

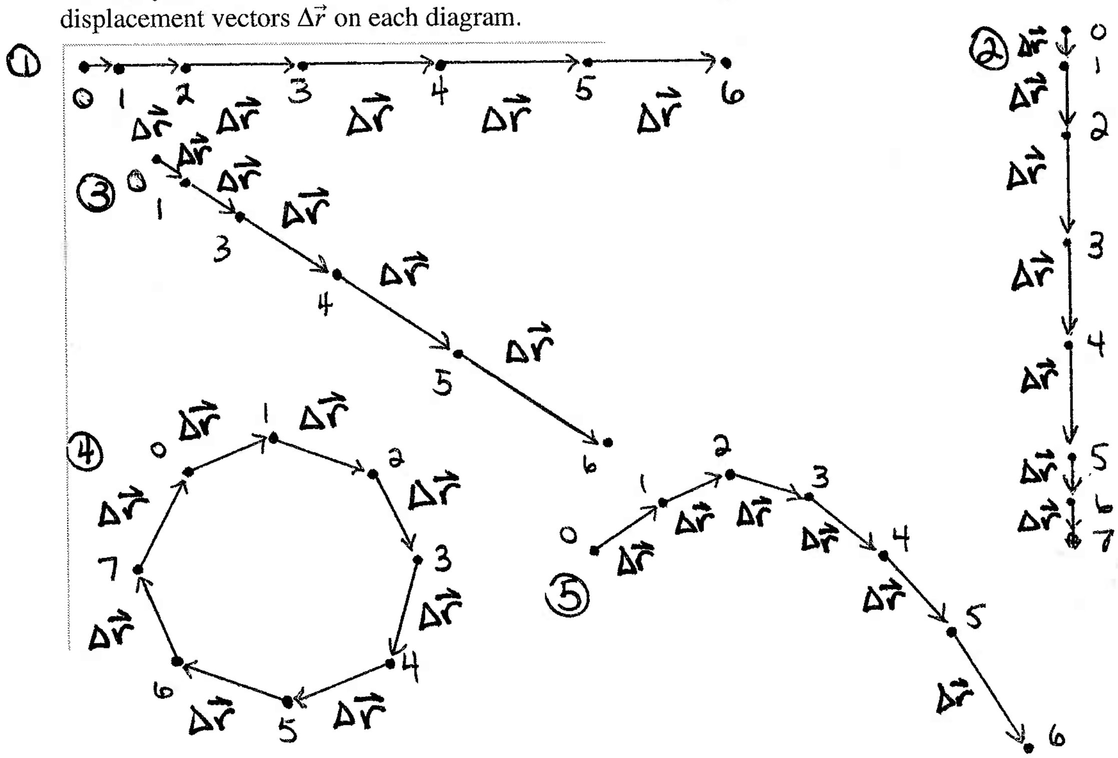


a. Use a **red** pencil to draw and label on the figure the three position vectors $\vec{r}_0$, $\vec{r}_1$, and $\vec{r}_2$ at times 0, 1, and 2.
b. Use a **blue** or **green** pencil to draw a possible trajectory from 0 to 1 to 2.
c. Use a **black** pencil to draw the displacement vector $\Delta\vec{r}$ from the initial to the final position.

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

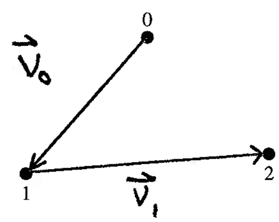
No, the displacement is the black arrow, $\Delta\vec{r}$. The distance traveled is the sum of the lengths of the blue or green arrows.

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

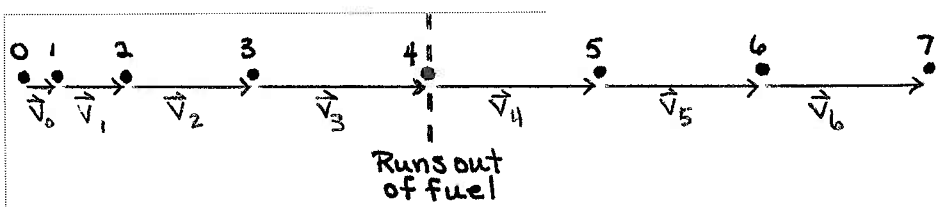
13. The figure below shows the positions of a moving object in three successive frames of film. Draw and label the velocity vector $\vec{v}_0$ for the motion from 0 to 1 and the vector $\vec{v}_1$ for the motion from 1 to 2.



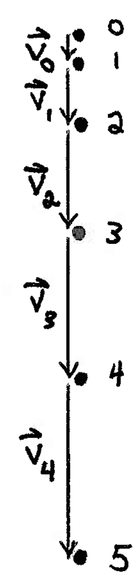
Exercises 14–20: Draw a motion diagram for each motion described below.

- Use the particle model.
- Show and label the *velocity* vectors.

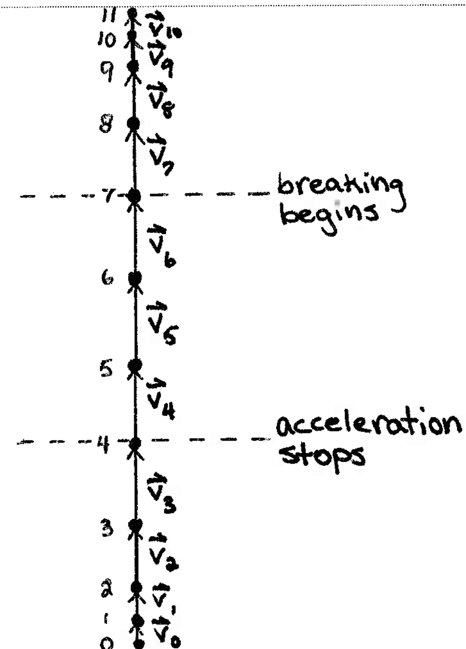
14. A rocket-powered car on a test track accelerates from rest to a high speed, then coasts at constant speed after running out of fuel. Draw a dashed line across your diagram to indicate the point at which the car runs out of fuel.



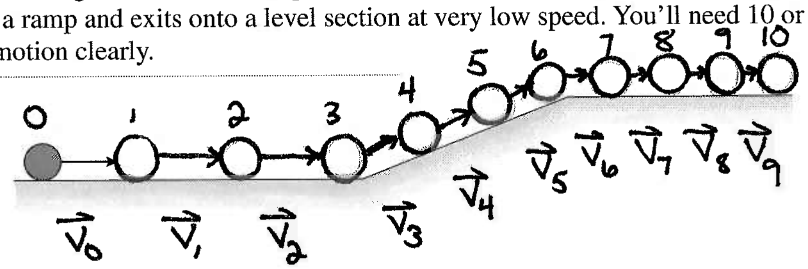
15. Galileo drops a ball from the Leaning Tower of Pisa. Consider the ball's motion from the moment it leaves his hand until a microsecond before it hits the ground. Your diagram should be vertical.



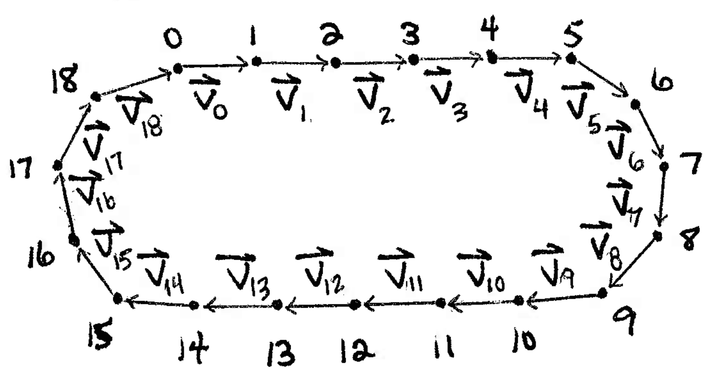
16. An elevator starts from rest at the ground floor. It accelerates upward for a short time, then moves with constant speed, and finally brakes to a halt at the tenth floor. Draw dashed lines across your diagram to indicate where the acceleration stops and where the braking begins. You'll need 10 or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



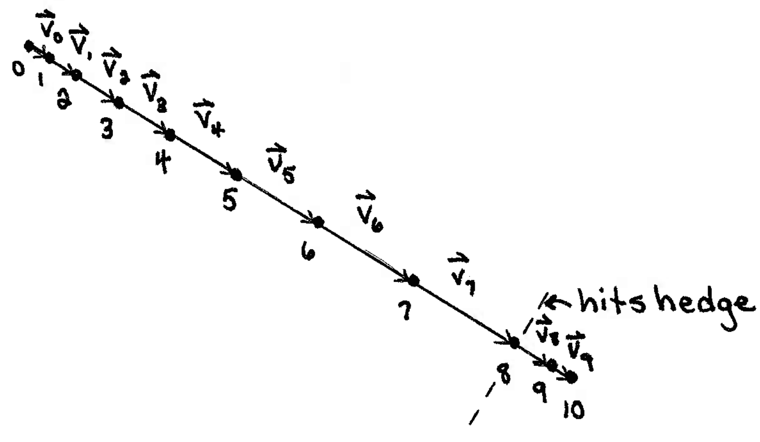
17. A bowling ball being returned from the pin area to the bowler starts out rolling at a constant speed. It then goes up a ramp and exits onto a level section at very low speed. You'll need 10 or 12 points to indicate the motion clearly.



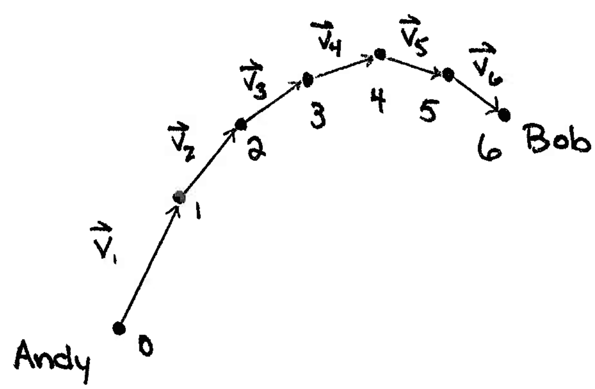
18. A track star runs once around a running track at constant speed. The track has straight sides and semicircular ends. Use a bird's-eye view looking down on the track. Use about 20 points for your motion diagram.



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.



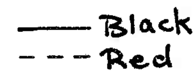
20. Andy is standing on the street. Bob is standing on the second-floor balcony of their apartment, about 30 feet back from the street. Andy throws a baseball to Bob. Consider the ball's motion from the moment it leaves Andy's hand until a microsecond before Bob catches it.



1.5 Linear Acceleration

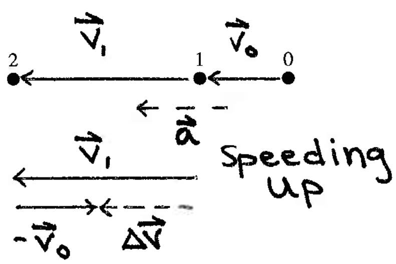
Note: Beginning with this section, and for future motion diagrams, you will "color code" the vectors. Draw velocity vectors **black** and acceleration vectors **red**.

Exercises 21–24: The figures below show an object's position in three successive frames of film. The object is moving in the direction $0 \rightarrow 1 \rightarrow 2$. For each diagram:

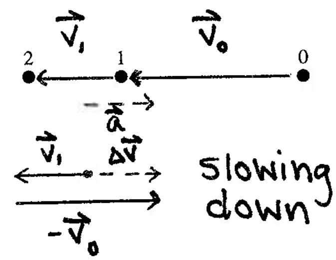


- Draw and label the initial and final velocity vectors $\vec{v}_0$ and $\vec{v}_1$. Use **black**.
- Use the steps of Tactics Box 1.3 to find the change in velocity $\Delta\vec{v}$.
- Draw and label $\vec{a}$ at the proper location on the motion diagram. Use **red**.
- Determine whether the object is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

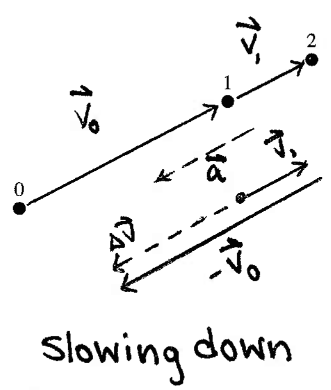
21.



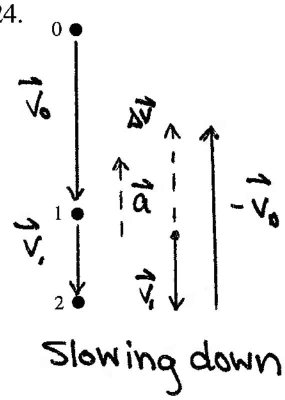
22.



23.



24.

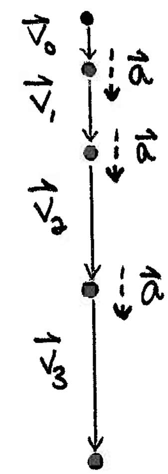


Exercises 25–29: Draw a complete motion diagram for each of the following.

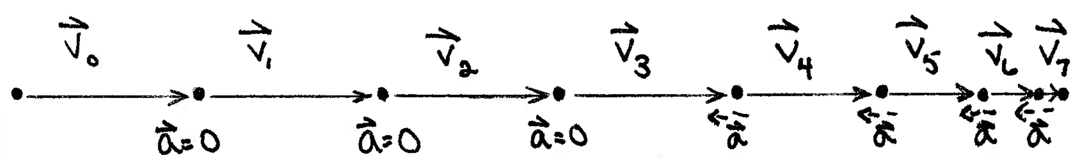
- Draw and label the velocity vectors $\vec{v}$. Use **black**.
- Draw and label the acceleration vectors $\vec{a}$. Use **red**.

——— Black
– – – Red

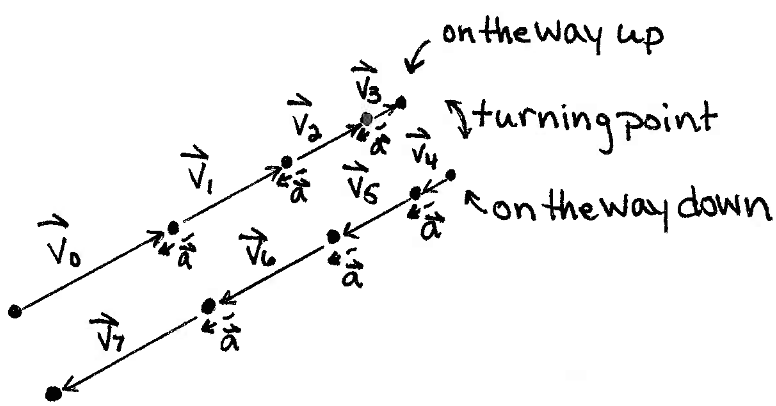
25. Galileo drops a ball from the Leaning Tower of Pisa. Consider its motion from the moment it leaves his hand until a microsecond before it hits the ground.



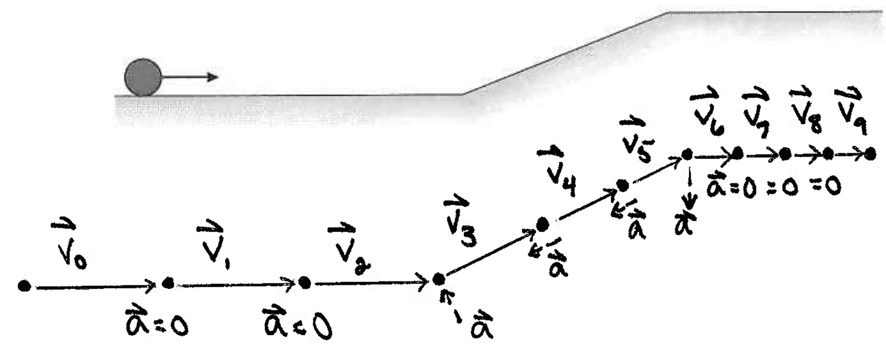
26. Trish is driving her car at a steady 30 mph when a small furry creature runs into the road in front of her. She hits the brakes and skids to a stop. Show her motion from 2 seconds before she starts braking until she comes to a complete stop.



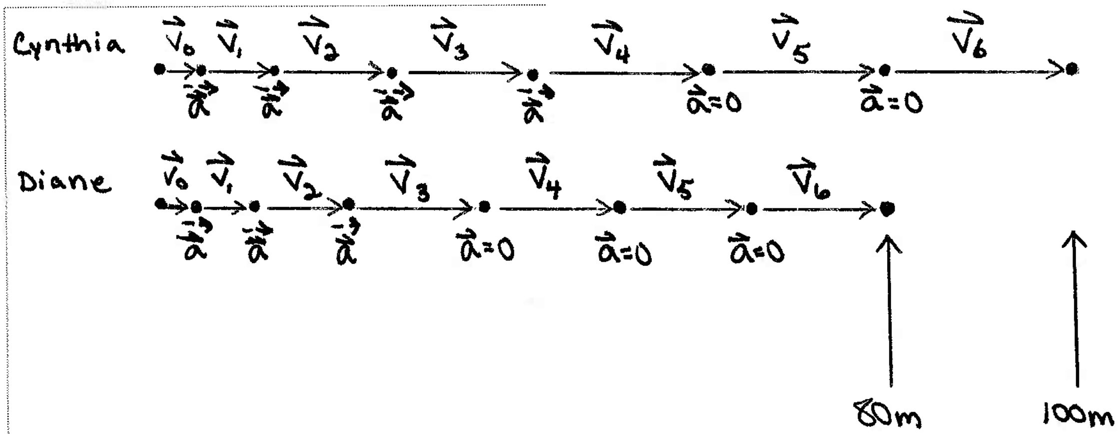
27. A ball rolls up a smooth board tilted at a 30° angle. Then it rolls back to its starting position.



28. 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.



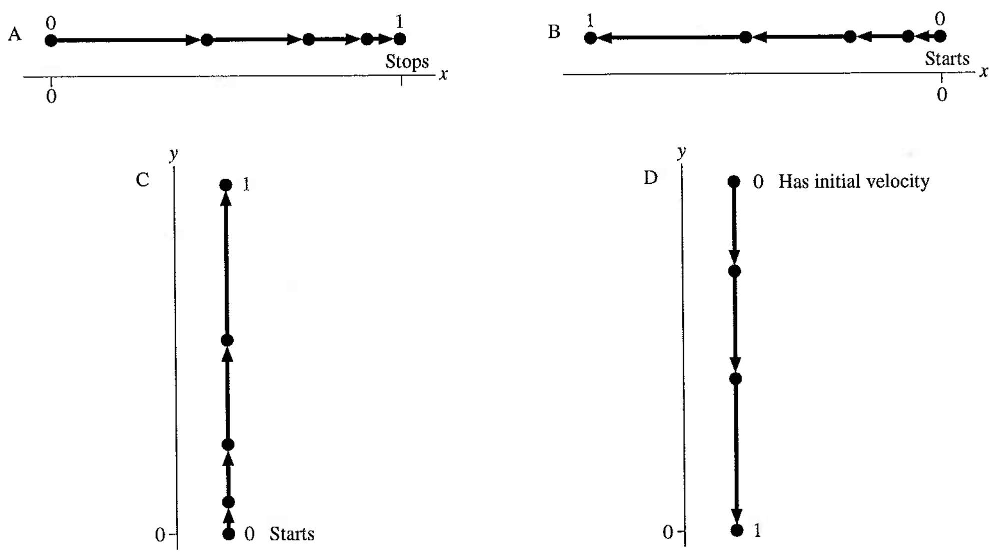
29. Two sprinters, Cynthia and Diane, start side by side. Diane has run only 80 m when Cynthia crosses the finish line of the 100 m dash.



1.6 Motion in One Dimension

1.7 Solving Problems in Physics

30. 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	−	−	+	−

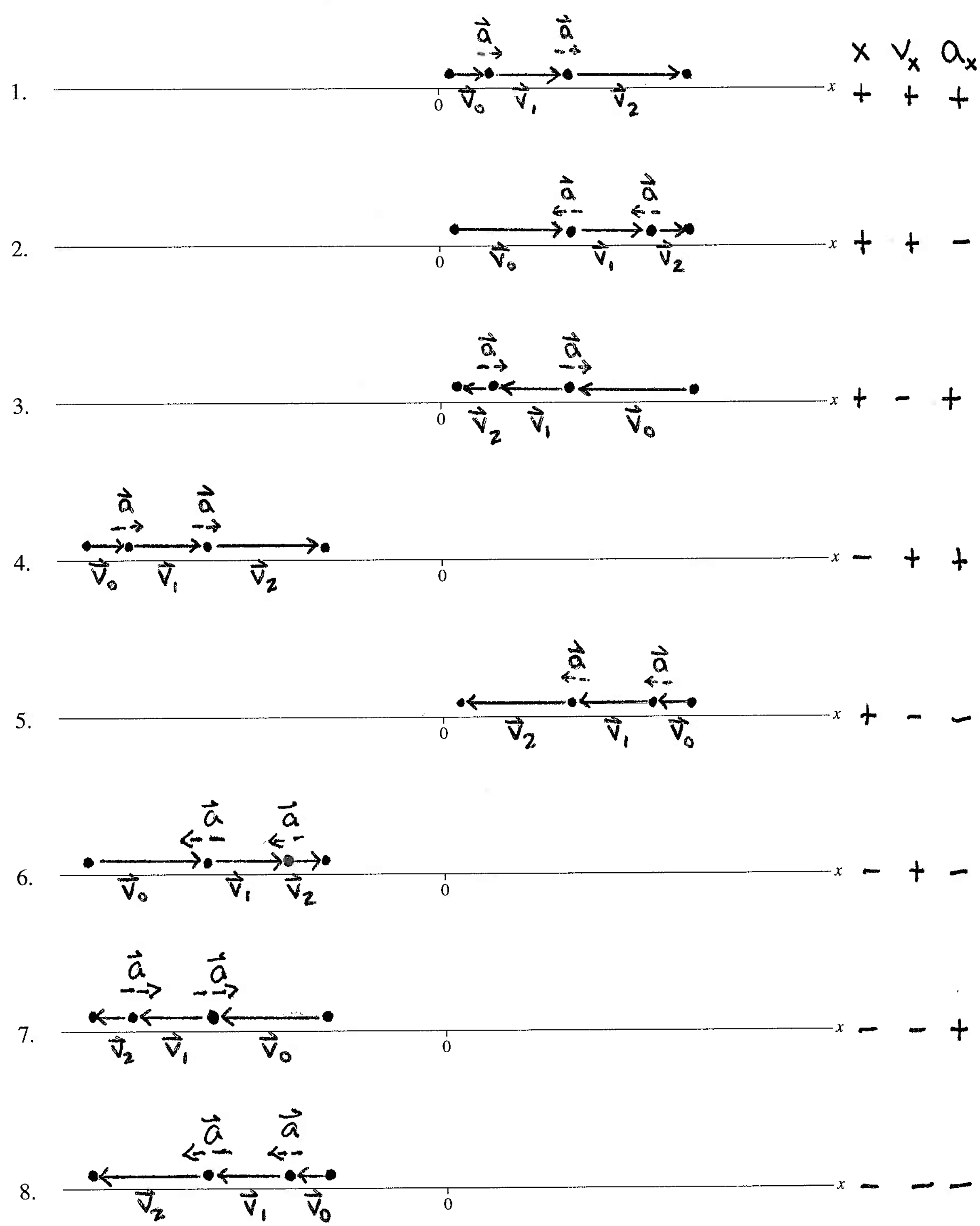
31. The three symbols x, v_x, and a_x have eight possible combinations of *signs*. For example, one combination is $(x, v_x, a_x) = (+, -, +)$.

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.

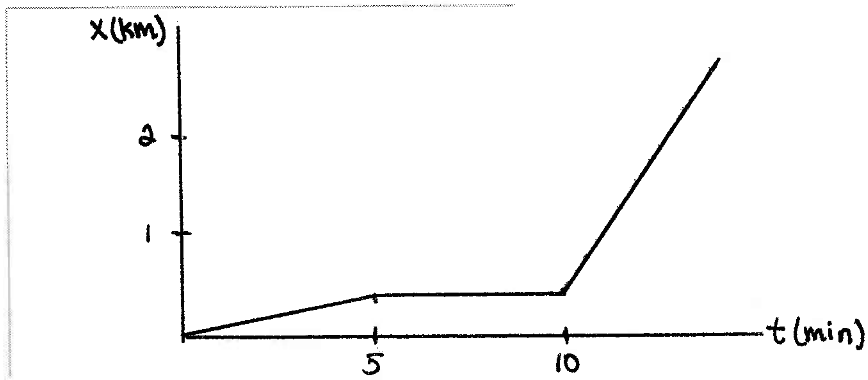
—— Black
- - - Red



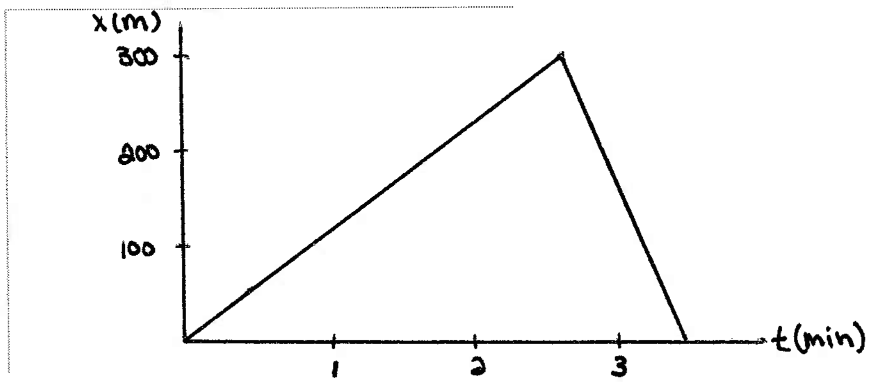
32. Sketch position-versus-time graphs for the following motions. Include a numerical scale on both axes with units that are *reasonable* for this motion. Some numerical information is given in the problem, but for other quantities make reasonable estimates.

Note: A *sketched* graph simply means hand-drawn, rather than carefully measured and laid out with a ruler. But a sketch should still be neat and as accurate as is feasible by hand. It also should include labeled axes and, if appropriate, tick-marks and numerical scales along the axes.

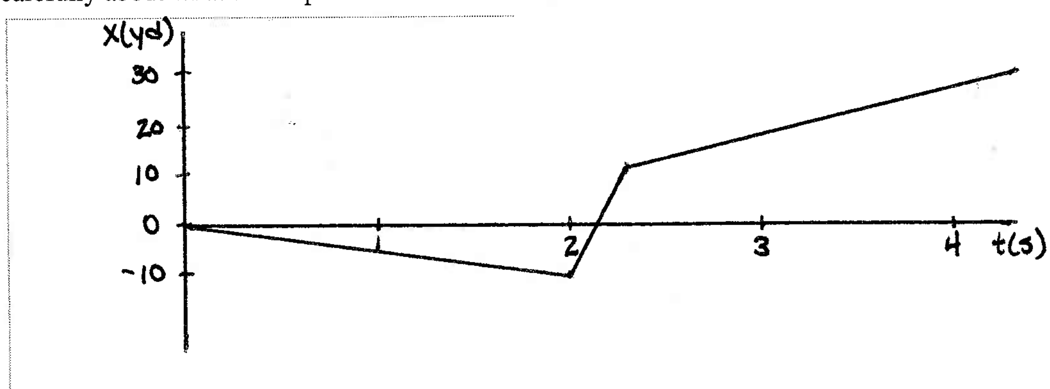
a. A student walks to the bus stop, waits for the bus, then rides to campus. Assume that all the motion is along a straight street.



b. A student walks slowly to the bus stop, realizes he forgot his paper that is due, and *quickly* walks home to get it.

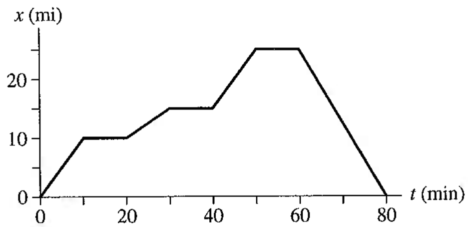


c. The quarterback drops back 10 yards from the line of scrimmage, then throws a pass 20 yards to the tight end, who catches it and sprints 20 yards to the goal. Draw your graph for the *football*. Think carefully about what the slopes of the lines should be.



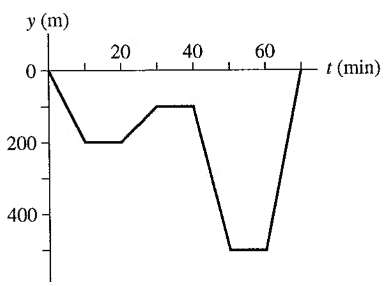
33. Interpret the following position-versus-time graphs by writing a very short "story" of what is happening. Be creative! Have characters and situations! Simply saying that "a car moves 100 meters to the right" doesn't qualify as a story. Your stories should make *specific reference* to information you obtain from the graphs, such as distances moved or time elapsed.

a. Moving car



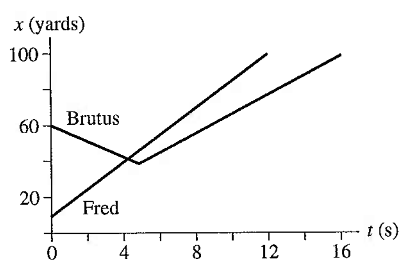
After driving on the interstate for 10 min at 60 mph, I stopped at a rest area. When I got back on the road 10 min later, I was slowed to 30 mph by a construction zone for 10 min. Finally at 60 mph, I got off at my exit 25 mi from home. After searching for 10 min I realized that I left my wallet at home so I drove back, without stops or construction delays, at 75 mph!

b. Submarine



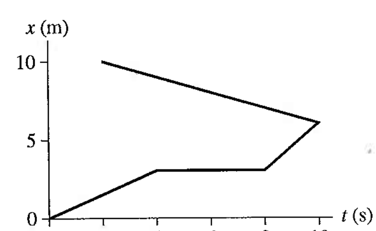
We made a slow dive to 200 m as we entered enemy territory. After cruising for 10 min, we slowly rose up to 100 m to listen for sounds from enemy ships. Oh no! We've been heard. In an evasive move to escape depth charges, we dive to 500 m and make our way out to sea. Safe again, we rise to the surface.

c. Two football players



At the kickoff, Fred recieves the ball on the 10 yd line and heads up field at a sprint. Brutus runs toward Fred in an attempt to tackle him, but misses as Fred crosses the 50 yd line. Brutus vainly tries to catch up, but Fred scores. Foolishly, Brutus continues to run after Fred has already scored.

34. Can you give an interpretation to this position-versus-time graph? If so, then do so. If not, why not?



There is no sensible interpretation because the graph requires the object to be in two places at once!

1.8 Units and Significant Figures

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

a. 9.12 μs $\times \frac{10^{-6}\text{ s}}{1\ \mu\text{s}} = 9.12\times10^{-6}\ \mu\text{s}$

b. 3.42 km $\times \frac{10^{3}\text{ m}}{1\text{ km}} = 3.42\times10^{3}\text{ m}$

c. 44 cm/ms $\times \frac{10^{-2}\text{ m}}{1\text{ cm}} \times \frac{10^{3}\text{ ms}}{1\text{ s}} = 4.4\times10^{2}\ \frac{\text{m}}{\text{s}}$

d. 80 km/hr $\times \frac{10^{3}\text{ m}}{1\text{ km}} \times \frac{1\text{ hr}}{60\text{ min}} \times \frac{1\text{ min}}{60\text{ s}} = 22\ \frac{\text{m}}{\text{s}}$

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

f. 8 in $\times \frac{2.54\text{ cm}}{1\text{ in}} \times \frac{10^{-2}\text{ m}}{1\text{ cm}} = 2\times10^{-1}\text{ m}$

g. 14 in^2 $\times \frac{2.54\text{ cm}}{1\text{ in}} \times \frac{2.54\text{ cm}}{1\text{ in}} \times \frac{10^{-2}\text{ m}}{1\text{ cm}} \times \frac{10^{-2}\text{ m}}{1\text{ cm}} = 9.0\times10^{-3}\text{ m}^2$

h. 250 cm^3 $\times \frac{10^{-2}\text{ m}}{1\text{ cm}} \times \frac{10^{-2}\text{ m}}{1\text{ cm}} \times \frac{10^{-2}\text{ m}}{1\text{ cm}} = 2.5\times10^{-4}\text{ m}^3$

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

36. Use Table 1.5 to assess whether or not the following statements are *reasonable*.

a. Joe is 180 cm tall.

$180\text{ cm} = 18\times10\text{ cm} \approx 18\times4\text{ in} = 72\text{ in} = 6\text{ ft}$

Reasonable

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

$50\times1\ \frac{\text{m}}{\text{s}} \simeq 50\times2\text{ mph} = 100\text{ mph}$

Not Reasonable

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

$25\times1\ \frac{\text{m}}{\text{s}} \approx 25\times2\text{ mph} = 50\text{ mph}$

Reasonable

(Downhill racers reach ~85 mph)

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

2km ~ 1.2miles Not Reasonable

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

$50\frac{km}{hr}$ ~ 30mph Reasonable (Major League pitchers throw at ~100mph)

37. 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?

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

$$\text{error}: \frac{[2.24mph - 2mph]}{2.24mph} = 0.11$$

∴ 11% error

38. 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. 6.21×10^3	3
c. 6210	3	g. 0.62	2	k. 6.21×10^{-3}	3
d. 6210.0	5	h. .62	2	l. 62.1×10^3	3

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

a. $33.3 \times 25.4 =$	8.46×10^2	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. $33.3 \div 45.1 =$	7.38×10^{-1}	g. $33.3^2 =$	1.109×10^3 (leading one)
d. $33.3 \times 45.1 =$	1.502×10^3 (leading one)	h. $\sqrt{33.3} =$	5.77