2 Describing Motion

Care spent in developing the concepts of kinematics in this chapter will be rewarded in future chapters on dynamics. I personally think it important, though, to relate things to the upcoming idea of energy transfer. This helps connect concepts students generally otherwise see as completely discrete and unconnected.

Suggestions for Presentation

The concepts of speed (both average speed and then instantaneous speed) and acceleration can be easily demonstrated. Before any demonstrations, though, it is important to draw on your students' experience.

First provide the students with a set of distance-time graphs and have them predict what everyday motions would be represented by each graph. Before they have much experience with this notion, they will propose some interesting solutions, such as walking up a ramp to create a distance-time graph that has a constant positive slope.

Then ask questions about how to graph a constant speed, straight line trip between two familiar places. How does the distance travelled vary with time? How do they know (speedometer tells them how many miles per hour)? How does the speed vary with time (assuming they're on cruise control)? You can then introduce the velocity-time graphs using the same motions. Comparing the distance-time graph and velocity-time graph for familiar motions will help convince them that the area under the velocity-time graph yields distance travelled, and that the slope of the distance-time graph yields velocity. Turning around and going back to the point of origin means a negative velocity, etc. At this point, most will abandon the idea of walking up a ramp to make a graph, realizing that the graph is not the motion, but instead is a representation of it. You can extend this with acceleration-time graphs. It is probably helpful to use some of the graphs from the text. For example, ask what motion is represented by Figure 2.15, and then have students predict the distance-time graph for that motion and the acceleration-time graph for that motion, revealing that those are shown in Figures 2.14 and 2.16, respectively. You can even create "meaningless" graphs (e.g. distance-time with a single vertical line, or a circle) to get students engaged and thinking "outside the box."

It also helps to think "inside the box," specifically the Everyday Phenomenon Box 1.2, which relates the real-life situation of a 100-meter dash to the abstraction of its graph. Show a YouTube video of such a sprint first and have students analyze the motion verbally before graphing.

If you are fortunate enough to have a demonstration setup involving a fan cart, dynamics track, and motion sensor coupled to a computer, you can then demonstrate in real time both the motion of an object and the graphical representation of that motion. With the fan turned on, the cart will experience essentially constant acceleration; with the fan turned OFF, a gentle shove will give it essentially a constant velocity. Again, have students predict what the various graphs would look like for a demonstrated motion *before* running the demonstration. Then run the demonstration with the motion sensor so that they can *see* where their predictions fell short of the reality. In this way, students are more likely to make valuable conceptual shifts. Another interesting alternative is, assuming you have the equipment and space, to make the students "walk" the graphs while watching the output of the motion sensor, thus feeling the motion for themselves.

If such equipment is not available, a two-meter air track with photocell timers is also illustrative. One can even get by with a croquet ball rolling across a board or a small metal car on a track, a meter stick and a timer. The key point students must note is that a speed determination involves two measurements, distance and time. Show first for a body moving on a horizontal surface that the average speed is the same over various portions of its path. Though this is apparent without taking actual measurements, it will more likely be striking if measurements are taken.

To study acceleration, set the track or board at a small angle. About a 1/2 cm drop in 2.0 meters works well. With the body starting from rest, measure time successively to travel predetermined distances. Rather than using equal spatial distances, it is more instructive to choose distances that will involve equal time intervals such as 10, 40, 90 and 160 cm. It is good to try this in advance since some tracks may not be quite straight and will give you problems. It is a good idea to take more than one measurement for the time on each of the distances so that students can see what the uncertainties are. Since the instantaneous velocity is equal to the average velocity at the mid-point in the time interval, the acceleration in each interval is found from the changes in average velocity and corresponding changes in the time-midpoints (actually the change in time-midpoint is the same as the changes in the time interval itself. Students will probably find this reasonable without going into the rationale behind it). Typical values with such an air track timing by hand are as follows:

s (cm)	t (sec)	v_{av} (cm/s)	a (cm/s^2)
0	0		
	(1.4)	3.6	
10	2.8		2.4
	(4.2)	10.3	
40	5.7		2.1
	(7.2)	16.7	
90	8.7		2.7
	(10.1)	24.5	
160	11.6		

You may prefer to plot v vs. t to get the slope. The result will look better than getting a from successive interval data as above.

The nature of distance can be demonstrated by putting a golf ball into a cup. Students can easily see that one straight shot is equivalent to two or three bad putts before the ball enters the cup. Having established how distances combine, it is now easy to present the directional concepts of velocity and acceleration.

Most physicists and instructors of higher level physics classes are used to using displacement and discussing the vector nature of displacement. The vector nature of displacement is not discussed in this text. Instead vectors are not introduced until the difference between velocity and speed is discussed. Be aware that if you choose to use the term 'displacement' without explaining how it is different from 'distance,' students will most likely be confused. Students seem more comfortable with waiting to introduce velocity and speed before incorporating vectors.

Students may find the units of acceleration confusing when presented as m/s^2. You can start out with an example that gives mixed time units such as those in which car performance is expressed. A car which can start from rest and reach a velocity of 90 km/hr in 10 seconds, has an average acceleration of 9 km/hr-s which means that on the average the velocity increases by 9 km/hr each second. This can then be converted to the more useful equivalent form of 9000 m/hr-s = 2.5 m/s^2.

Debatable Issues

"*A radar gun used by a police officer measures your speed at a certain instant in time, whereas an officer in a plane measures the time it takes for you to travel the known distance between two stripes painted on the highway. What is the difference in nature between these two types of measurement and which is the fairer basis for issuing a speeding ticket?*"

Would your answer change if one stripe occurred before a rest area and the other occurred after the rest area? Which method would be better for picking out an erratic driver who sporadically zips past cars then lags a bit? The radar is determining an instantaneous velocity, while the airplane method figures average velocity. Which method would be better for filtering out the dangerous drivers in thick traffic, like that described in Everyday Phenomenon Box 1.1? Which would be easier to foil?

Clicker Questions

Please see the instructor resources at www.mhhe.com/griffith for a PowerPoint file of suggested clicker questions for this chapter. The use of these questions is a good way to engage the class and inform them of the important concepts. These questions can be used to give the instructor an idea of whether students understand the ideas presented and also often offer a reality check for the students' perception of their own understanding.

Answers to Questions

Q1
- a. Speed is distance divided by time, so it will be measured in *boogles/bops*
- b. Velocity has the same units as speed, so it will also be measured in *boogles/bops.*
- c. Acceleration is change in speed divided by time, so the units will be *boogles/bops*^{2}.

Q2
- a. The unit system of inches and days would give velocity units of inches per day and acceleration of inches per day squared.
- b. This would be a terrible choice of units! The distance part would be huge while the time part would be miniscule!

Q3 Since fingernails grow slowly, a unit such as mm/month may be appropriate.

Q4
- a. The winner of a race must have the greater average speed, so the plodding tortoise is the leader here.
- b. Since the hare has the higher average speed taken over short intervals, he is likely to have the greater instantaneous speed.

Q5 In England "doing 80" likely means driving at 80 km/hour which would be a reasonable highway speed. In the US it means 80 mi/hr. Stating a number without the proper units leaves us uncertain as to what it means.

Q6 A speedometer measures instantaneous speed; the speed that you are driving at a particular instant of time. You can note how it responds immediately as you speed up (accelerate) or slow down (brake).

Q7 In low density traffic, the speed is more likely to be constant, therefore the average and the instantaneous speed will be close for relatively long periods. In high density traffic, the speed is likely to be changing often so that only for short periods the instantaneous speed will equal the average.

Q8 The radar gun measures instantaneous speed - the speed at the instant the radar beam hits the car and is reflected from it. An airplane spotter measures average speed; timing a car between two points which are a known distance apart.

Q9 The vehicle density is the number of vehicles per mile, and is a property of several vehicles. It has nothing to do with vehicle weight.

Q10 When traffic is in a slowly moving jam, the average speeds of different vehicles are essentially the same, at least within a given lane.

Q11 At the front end of the traffic jam, the vehicle density is reduced due to the slower flow behind. Vehicles begin to accelerate and increase the distance between vehicles at the front end of the jam.

Q12 Yes, the velocity changes. The direction of motion has changed after the puck hits the wall, which represents a change in velocity since velocity involves both speed and direction.

Q13 a. Yes. As it moves in a circle the velocity of the ball at each instant is tangent to the circular path. Since this direction changes, the velocity changes even though the speed remains the same.
b. No. Since the velocity is changing, the acceleration is not zero.

Q14 a. No. The velocity changes because the speed and direction of the ball are changing.
b. No. The speed is constantly changing. At the turn-around points the speed is zero.

Q15 No. When a ball is dropped it moves in a constant direction (downwards), but the magnitude of its velocity (speed) increases as it accelerates due to gravity.

Q16 Yes. Acceleration is the change in velocity per unit time. Here the change in velocity is negative (the velocity decreases), so the acceleration is also negative and opposite to the direction of velocity. This is often called a deceleration.

Q17 No. In order to find the acceleration, you need to know the change in velocity that occurs during a time interval. Knowing the velocity at just one instant tells you nothing about the velocity at a later instant of time.

Q18 No. If the car is going to start moving, its acceleration must be non-zero. Otherwise the velocity would not change and it would remain at rest, or stopped.

Q19 No. As the car rounds the curve, the direction of its velocity changes. Since there is a change in velocity (direction even if not magnitude), it must have an acceleration.

Q20 The turtle. As long as the racing car travels with constant velocity (even as large a velocity as 100 MPH), its acceleration is zero. If the turtle starts to move at all, its velocity will change from zero to something else, and thus it does have an acceleration.

Q21 a. Yes. Constant velocity is represented by the horizontal line from t= 0 seconds to t = 2 seconds, which indicates the velocity does not change.
b. Acceleration is greatest between 2 and 4 sec where the slope of the graph is steepest.

Q22 a. Yes. The velocity is represented by the slope of a line on a distance-time graph. You can also see that sometime after pt. B the line has a negative slope indicating a negative velocity.
b. Greater. The instantaneous velocities can be compared by looking at their slopes. The steeper slope indicates the greater instantaneous velocity.

Q23 Yes. The velocity is constant during all three different time intervals, that is in each interval where there is a straight line. Note that while the velocities are constant in these intervals, they are not the same in each.

Q24 a**.** No. The car has a positive velocity during the entire time shown.
b. At pt. A. The acceleration is greatest since the slope between 0 and 2 sec. is greater than between 4 and 6 sec. Between 2 and 4 sec. The slope is zero so the velocity in that interval does not change.

Q25 Between 2 and 4 sec the car travels the greatest distance. Distance traveled can be determined from a velocity-time graph and is represented by the area under the curve, and between 2 and 4 sec. The area is the largest. The car travels the next greatest distance between 4 and 6 sec.

Q26 a. Yes, during the first part of the motion where the instantaneous speed is greatest. The average speed for the entire trip must be less than during this interval since for the rest of the trip the speeds are less.
b. Yes. The velocity changes direction. Even if the magnitude of the velocity (speed) is the same, the different directions make the velocities different. Actually, the change is negative so the car decelerates.

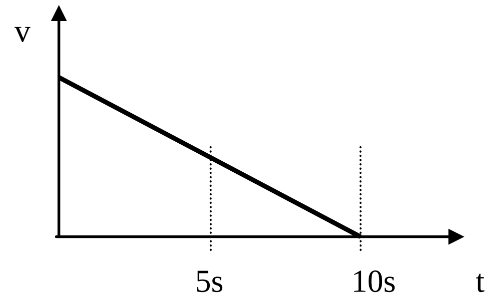
Q27 No. This relationship holds only when the acceleration is constant.

Q28 Velocity and distance increase with time when a car accelerates uniformly from rest as long as the acceleration is positive. As long as it accelerates *uniformly*, the acceleration is constant.

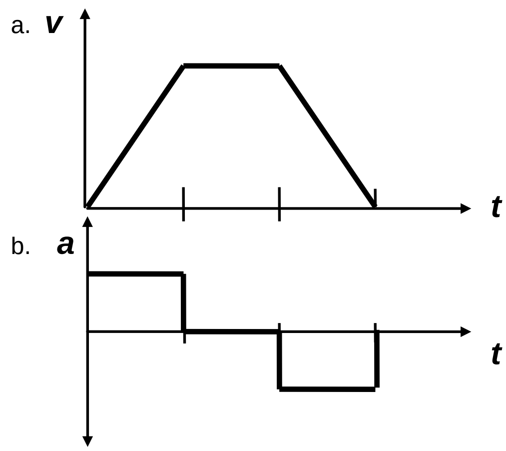
Q29 No. The acceleration is increasing. A constant acceleration is represented by a straight line. Here the curve shown has an increasing, or positive, slope.

Q30 Yes. For uniform accelerati~~on the~~ acceleration is constant. Since acceleration does not change, the average acceleration equals this constant acceleration.

Q31 The distance covered during the first 5 sec is greater than the distance covered during the second 5 sec. Thus since distance = $v_o t + ½at^2$, even though acceleration and time are the same for both intervals, the initial velocity at which the car starts the second interval is less than at the beginning of the first, so it will cover a shorter distance. Graphically, we see that during the first part of the trip, the area under the v-t graph is large, indicating a large distance.

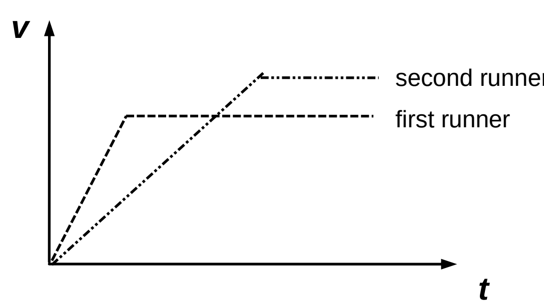


Q32

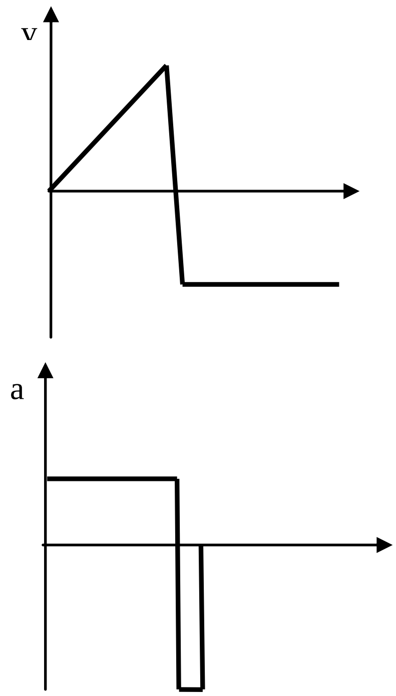


Q33 The second runner. If both runners cover the same distance in the same time interval, then their average velocity has to be the same and the area under the curves on a velocity-time graph are the same. If the first runner reaches maximum speed quicker, the only way the areas can be equal is if the second runner reaches a higher maximum speed which he then maintains over a shorter portion of the interval.

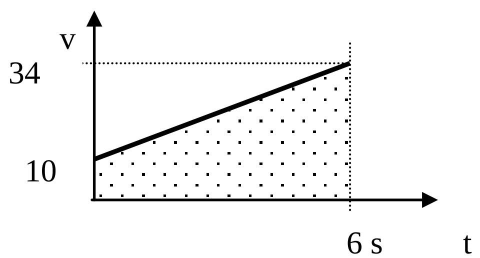
Q34



Q35



Q36



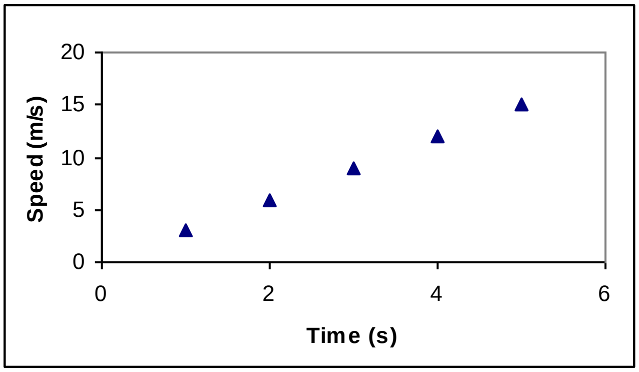
The area of the shaded region is $(6.0\text{ s})(10\text{ m/s})+(6.0\text{ s})(34\text{ m/s}-10\text{ m/s})/2$ = 132 m.

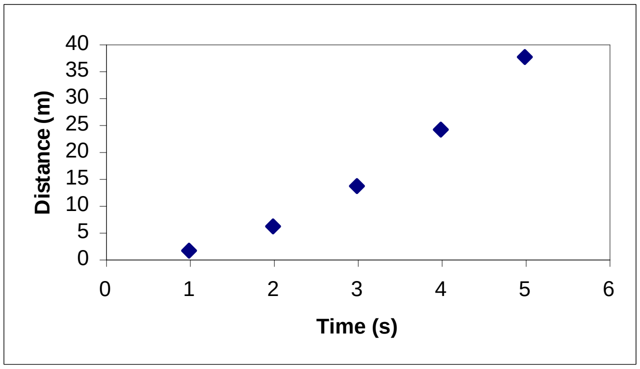
Q37 The speed after 6 seconds is $v=v_o + at$ = 10m/s + (-1m/s^2)(6s) = 4m/s

Answers to Exercises

E1 2.8 km/h
E2 3.6 km/hr
E3 0.4 cm/day
E4 120 mi
E5 300 s
E6 6.2 hours (6 hours 9 minutes)
E7 4.320 km
E8 a. 0.022 km/s
b. 79.2 km/hr
E9 93.3 km/hr
E10 3.5 m/s^2
E11 21 m/s
E12 -3 m/s^2
E13 a. 21.5 m/s
b. 53.25 m
E14 a. 5.3 m/s
b. 10.95 m
E15 a. 16 m/s
b. 88.0 m
E16 a. 1.4 m/s
b. 9.6 m
E17 9.09 s

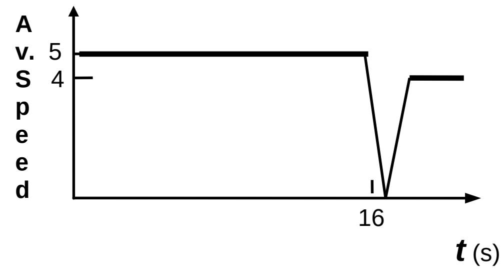
E18 a. Speed: 3 m/s, 6 m/s, 9 m/s, 12 m/s, 15 m/s
b. Distance: 1.5 m, 6 m, 13.5 m, 24 m, 37.5 m



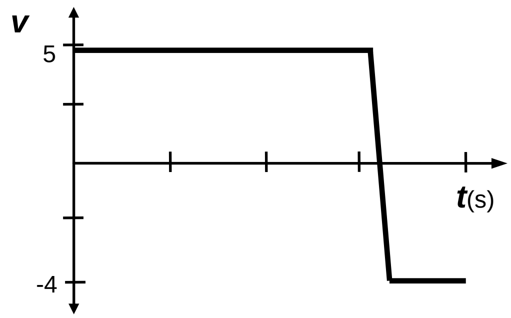


Answers to Synthesis Problems

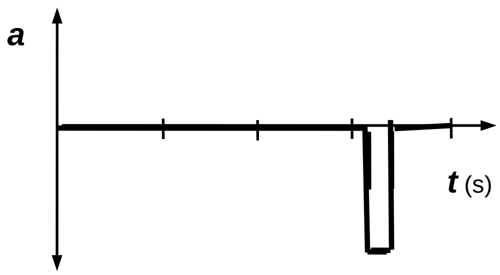
SP1 a. 21s
b.



c.

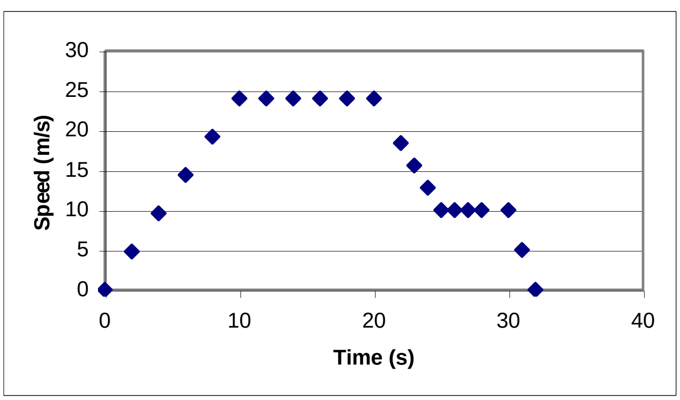


d.

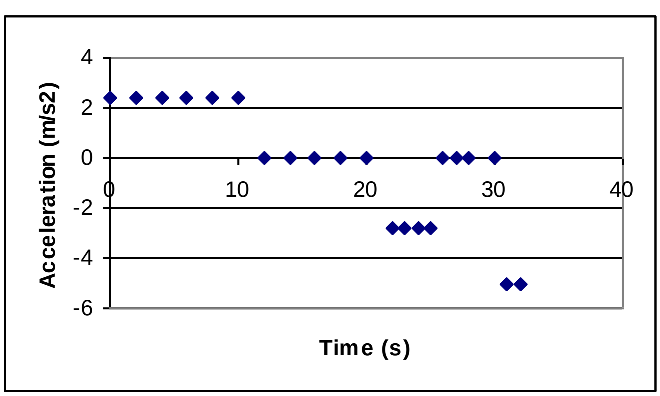


SP2 a. 1 m/s^2
b. 8 m/s^2
c. 2.4 m/s^2
d. No, because the car spends more time accelerating at 1 m/s^2 and only 1 second accelerating more quickly, the average acceleration is closer to 1 m/s^2.

SP3 a.



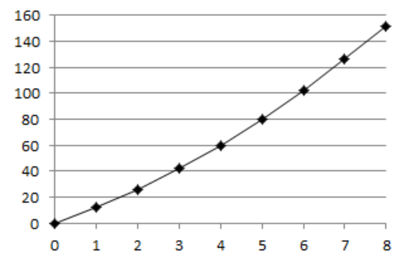
b.



c. Yes. The car never has a negative velocity (that is, it never moves backwards), so its distance must increase.

SP4 a. 8 s
b. 152 m
c.

Time (s)	0	1	2	3	4	5	6	7	8
Distance (m)	0	12	26	42	60	80	102	126	152



Note the parabolic shape of this curve is not obvious over the given time span, but it is indeed a parabola!

SP5 a.

Time (s)	Distance (m) Car A	Car B
1	2.25	10
2	9.0	20
3	20.25	30
4	36	40
5	56.2	50

b. Car A passes car B at approximately 4.5 sec.
c. To find a better time you could graph the distance versus time for each car and see where the two curves cross. To find the exact time when the distance is the same for both cars, note that then $d_A = d_B = ½ a_A t^2 = v_B t$. Thus t_{meet} = 0 s and ($2 v_B/a_A$) = 4.44s