Chapter 2 — DESCRIBING MOTION

This chapter moves the students from their general feelings for describing motion to a quantitative description of motion. We treat only one-dimensional motion so that when students get their first look at acceleration, it is mainly a rate of change of speed that is stressed. They are told to expect an expansion of this definition later.

Features

- Fastest and Slowest—a look at fast and slow speeds
- Immoderate Genius—a biosketch of Galileo Galilei

2-1 AVERAGE SPEED

Goals

- Define average speed and its special relationship with space and time.
- Discuss how to gather the necessary distance and time information for determining average speed.

Content The average speed is the distance traveled divided by the time elapsed.

Teaching Tips These early sections are always slow moving. We've never felt comfortable leaving these ideas until later because the fact remains that in physics we need to develop ways to objectively measure what we're talking about. Because motion is such a central part of our material world, it behooves us to start with this topic.

We start with a general discussion of motion, illustrating the ideas by displaying a simple motion in front of a strobe light. We discuss the ambiguities of the terms fast and slow and the need to use numbers to describe motion. The section becomes more palatable if examples are drawn from students' everyday experiences.

2-2 IMAGES OF SPEED

Goals

- Introduce stroboscope photographs.
- Build an awareness of the different ways that speeds can be measured.
- Show how the units of speed, space, and time are combined.
- (Computing) Demonstrate how to use the definition of average speed to predict useful outcomes of motions.
- (Computing) Give students some practice calculating average speeds.
- Problem Solving) Introduce distance-time graphs.
- (Problem Solving) Show that slopes on distance-time graphs give the speeds.
- (Problem Solving) Give students more practice calculating average speeds.
- (Problem Solving) Show speeds in different units of time.

Content To measure speed you need to know where the object is located at various times. One way to do this is to use a strobe photograph that contains both distance and time information about the object's motion.

The time elapsed can be obtained from the formula for the average speed given the average speed and the distance traveled. Similarly, the distance traveled can be obtained from the average speed formula given the time elapsed.

Teaching Tips This section blends with the previous section by focussing on how we measure speeds. A couple of interesting examples to discuss are:

- The speed of the "crawler vehicle" that carries the Space Shuttles to their launch pad. News people joke about its speed being measured in furlongs per fortnight (one-eighth mile per 14 days). Using a strobe photograph with the crawler would be overkill.
- A housefly easily moves with a speed of about 3 ft/s. (That's about 2 mph.) A strobe photograph might work here but you'd have a little trouble convincing the fly to move in just one-dimension.
- A bullet leaves a gun at speeds around 1500 ft/s. Strobe photos would not work because the times needed are too short to expose the film. Later we will discuss how this can be measured indirectly with the conservation laws (Ch 6).
- This section and the one that follows blend with the first one making a complete lecture. Here is our first opportunity to show the students the type and minimum level of mathematics that we will be using as well as the importance of using consistent units in calculations.

Computing *Average Speed* We calculate the time required to travel a distance of 60 miles at an average speed of 50 mph and then the distance traveled during 8 hours of averaging 50 mph.

Problem Solving 2.1 This section discusses graphs of motions. A relatively simple classroom exercise involves our students. We create "walking graphs." With a simple timer, and a "pace" as a unit of length, we have students observe us walking and make graphs of our motion. Next, we reverse the procedure and graph hypothetical motions and have the students predict how we will "walk" the graph.

Problem Solving 2.2 This section gives the students more practice in manipulating the average speed formula. In the first example we calculate the average speed of a family car with three different time units.

Video Encyclopedia 1 #8 *Constant Velocity*

2-3 INSTANTANEOUS SPEED

Goals

- Introduce the limiting value of a ratio, justifying the concept of instantaneous speed.
- (Problem Solving) Show that the slope on a position-time graph is equal to the instantaneous speed.
- (Problem Solving) Introduce the velocity-time graphs.

Content Even though the value of an instant of time goes to zero, the distance traveled also approaches zero so that the ratio that defines speed still has a definite, non-zero value.

Teaching Tips With some classes we have gone from the table of positions and times to making a graph of the motion. (See Problem Solving 2.3 below.)

Flawed Reasoning Average speed versus instantaneous speed

Problem Solving 2.3 The position-time graph is developed for data obtained from a strobe diagram. We also discuss instantaneous speed as the slope of the curve.

Problem Solving 2.4 We draw the velocity-time graph for the motion in Problem Solving 2.3 and discuss the meaning of the slope as the instantaneous acceleration.

2-4 SPEED WITH DIRECTION

Goals

- Introduce the concept of velocity as a speed with a direction.
- Introduce the concept of displacement.
- Contrast average speed with the magnitude of the average velocity.
- (Problem Solving) Give students practice calculating the change in velocity when the direction changes.

Content Velocity is a vector quantity that has magnitude and direction. Displacement is a vector quantity that gives the straight-line distance and direction from an initial position to a final position.

Teaching Tips We include this section on the definition of velocity because many colleagues wanted to have the complete definition of acceleration in the next section. This can be skipped now if you feel comfortable telling a "half-truth" about acceleration for now.

Problem Solving 2.5 We calculate the change in velocity for a 180° change in direction. Later, when we look at two-dimensional situations, we will cover the vector mathematics.

2-5 ACCELERATION

Goals

- Introduce the concept of acceleration.
- Include the notion that slowing down is also an acceleration.
- Introduce the units for acceleration.
- Mention that acceleration is a vector.
- (Computing) Calculate the acceleration of a car.
- (Problem Solving) Give students more practice calculating average accelerations.

Content Acceleration is the rate of change of velocity. When the motion is one-dimensional in a single direction, this definition reduces to a rate of change of speed. We experience physical effects due to acceleration, but not velocity. Accelerations can be calculated when given the change in velocity and the time elapsed during that change.

Teaching Tips This is the hardest section in the chapter. Students always seem to be boggled by the concept of a rate of change of a rate of change. We have no quick cure other than to explicitly announce this as a trouble spot. A couple of homework problems help develop this concept.

We like to talk about the fact that we "feel" accelerations because it sets the stage for Newton's laws in Chapter 3. However, we don't mention Newton at this stage; the students have enough trouble coping with the concept of acceleration.

Computing *Acceleration* We calculate the acceleration of a car.

Problem Solving 2.6 This section gives the students more practice with calculating acceleration, emphasizing the directions of acceleration and velocity.

Video Encyclopedia 1 #15 *Weight and String Acceleration*

2-6 A FIRST LOOK AT FALLING OBJECTS

Goals

- Introduce the class to their first realistic one-dimensional example.
- Introduce the notion of a thought experiment.

Content In the absence of any frictional forces all objects fall at the same rate.

Teaching Tips It's easy to fall into the trap of making Aristotle come out the fool. This should be avoided, first, because it's not true and, second, because the Aristotelian world view is quite similar to our common experiences and thus close to your students' unexamined ideas about free fall.

We usually do a two-part demonstration here. We begin with the challenge of finding a way to study free fall. Clearly the motion is too fast to see. The first demonstration is to simply drop a ball in front of the class. It's simply impossible for someone to locate positions at certain times with any accuracy. A good scientist looks for alternatives: Because a ball falling in the classroom is actually falling in a fluid (air), it makes sense to examine the motion of balls in some other fluid; one that would slow the ball down to a reasonable rate. We drop marbles in a long tube of colored water (the color is just for effect). The beginning of this chapter has prepared the students for measuring the speed of a falling ball. Aristotle appears to be correct; the marble quickly reaches a constant speed. Now we caution the students that there's no guarantee that these results will be the same in "free fall."

The second demonstration shows that, in fact, free fall does yield different results. We race a feather and a coin in an evacuated tube. So we know we're off the mark with a balls-in-water experiment; but why? The answer comes later.

Film Loops *Modern Day Tower of Pisa Experiment* and *Acceleration Due to Lunar Gravity*

Sprott Feather and coin in an evacuated tube.

Video Encyclopedia 1 #14 *Guinea and Feather*

2-7 FREE FALL: MAKING A RULE OF NATURE

Goals

- Describe Galileo's way of slowing down free-fall motion.
- Show a modern strobe photograph of a free-fall experiment.
- Establish the distance versus time relationship for free fall that starts from rest.
- Show that physics is the search for rules, or patterns, in nature.
- (Computing) Calculate the depth of a well.
- (Problem Solving) Discuss the change in distance traveled between different one-second intervals.

Content A falling object in the absence of significant frictional effects exhibits a constant acceleration. The distance traveled from rest is proportional to the time squared.

Teaching Tips We chose to leave the acceleration due to gravity as 10 m/s^2 rather than the more conventional 9.8 m/s^2 to simplify the calculations for these students. For simplicity we also chose to consider an object falling from rest rather than adding the additional complication of an initial velocity.

Computing *Should You Jump?* We calculate the speed after falling 3 s. We use the concept of average speed to calculate the distance fallen during these 3 s.

Problem Solving 2.7 This section generates a table for an object in free fall. Values are calculated for the acceleration, speed, total distance, and distance traveled each second.

Video Encyclopedia 1 #10 *Rolling Ball Incline* #11 *Constant Acceleration* #12 *String and Weights Drop* #13 *Reaction Time Falling Meter Stick*

2-8 STARTING WITH AN INITIAL VELOCITY

Goals

- Discuss the motion of an object that is thrown vertically upward.
- (Problem Solving) Give the complete distance-time relationship for free-fall.

Content When an object is thrown upward, the acceleration due to gravity causes it to slow down by 10 m/s each second until its instantaneous speed is zero at the top of its path.

Teaching Tips This information is not needed for the rest of the book's story line and many professors choose to delete it. We often treat it at least conceptually. If you have been doing the graphing from *Problem Solving*, this section is a good conclusion to that treatment.

Problem Solving 2.8 We develop the relationships for the final velocity and the displacement for motion with an initial velocity. The examples focus on a ball thrown upward.

2-9 A SUBTLE POINT

Goal

- To highlight that finding relationships about nature allows us to predict the outcomes of events.

Content Science is an active process of discovering patterns in nature and creating rules that make up our physics world view.

Teaching Tips We treat this short section as a reading assignment. The points are made often throughout the course.

Computer Animations *Active Figure* Animations are available on the Multimedia Manager Instructor's Resource CD. They are organized by textbook chapter, and each animation comes within a shell that provides information on how to use the animation, exploration activities, and a short quiz.

Answers to the Conceptual Questions

1. From the varying spaces we know that the puck moved different distances in equal amounts of time. The puck in this diagram speeded up, reached a maximum, and then slowed to (approximately) its initial speed.
2. The upper puck speeds up and then slows down. The lower puck appears to be moving at a constant speed.
3. The speed is the slowest in the middle where the dots are closest together.
4. The speed is the fastest at the right end of the path where the dots are the farthest apart.
5. `oo.o..o...o....o.....o.....o.....o....o...o..o..o..o.oo`
6. `o....o....o....o...o..o...o....o.....o......o......o`
7. `oo..o....o......o.......o........o.......o........o......o....o..oo`
8. `oo.o...o.....o.......o.........o........o....oo`
9. The truck has a higher average speed because it travels a longer distance in the same amount of time.
10. The average speeds are the same because both cars travel an average of one mile each minute.
11. You are constantly slowing down so your speed while breaking is always less than 45 mph, which means the average must also be less than 45 mph.
12. Both animals travel the same total distance but the tortoise does it in less time and therefore has a slightly higher average speed.
13. Since both travelers cover the same distance in the same time, their average speeds are the same. However, since Chris spent much of the time at rest, his instantaneous speed would have been much greater than his average for parts of the trip and therefore also greater than Pat's.
14. The book is constantly speeding up and so achieves its greatest speed right before it lands. Since the speed at all other times was less than this, the average speed must be less than the impact speed.
15. The object is speeding up from C to D so the average speed in the interval is greater than the instantaneous speed at C and less than the instantaneous speed at D.
16. The object is slowing down from C to D so the average speed in the interval is less than the instantaneous speed at C and greater than the instantaneous speed at D.
17. You could use a stopwatch to determine the time it takes to travel between two adjacent mile markers along the side of the highway and then divide one mile by the number of seconds. You will need to convert the seconds into hours to yield an answer in mph.

18. Because speed is a ratio, both time and distance are required.
19. No, the average speed doesn't tell us anything about the instantaneous speed.
20. The question cannot be answered with just the average speed because it doesn't tell us anything about instantaneous speeds.
21. A stopwatch and an odometer measure time and distance, allowing us to calculate the average speed; a speedometer measures instantaneous speed.
22. The stopwatch measures time (in seconds), an odometer measures length (in miles or km), and a speedometer measures speed, which is length divided by time interval (mph or kph).
23. The essential difference is direction—velocity is a speed with a direction.
24. This is a velocity because the speed and direction are both given.
25. Object **a** is traveling equal distances during each time interval, which means it is moving at constant speed and has zero acceleration. The same is true of object **b** although its speed is greater. Both objects have the same zero acceleration.
26. To have the same average speeds the cars must travel the same distances between flashes. This is the interval from B to C for car **a**.
27. All of these can be considered to be an accelerator because any change in speed or direction is an acceleration.
28. Anything that changes the speed (or direction) is an accelerator.
29. The bicycle undergoes the greatest change in velocity in the same time interval and therefore has the greatest acceleration.
30. The Integra undergoes a greater change in speed in the 4 second interval and therefore has the greater acceleration.
31. The motorcycle will be going 35 mph and the sports car will only be going 30 mph.
32. The Caravan will be going 70 mph and the Taurus will only be going 65 mph.
33. Carlos could be going 60 mph and slowing while Andrea is going 5 mph and speeding up.
34. At noon, Mary passes Nathan with her cruise control set to 100 mph. Nathan’s speedometer reads only 60 mph, but he is in the process of speeding up.
35. They are falling in a vacuum, or air resistance is negligible for these objects.
36. The missing word is "acceleration."
37. The pebble speeds up by 10 meters per second every second. After 4 seconds its speed is therefore 40 meters per second.
38. The ball slows down by 10 meters per second every second. In two seconds it slows by 20 meters per second and is traveling at 10 meters per second.
39. It stays the same in accordance with Galileo's thought experiment.
40. In a vacuum they would fall with the same acceleration. However, in air the ball made from rubber will be affected more by the air resistance and will lag behind.
41. When you let go of the bowling ball, you both have the same speed. Because the speeds of you and the bowling ball change in exactly the same way, the bowling ball will remain beside you.
42. When you let go of the bowling ball, you both have the same speed. Letting go of the bowling ball simply reduces your weight and, because an object’s weight does not affect its motion, you will rise the same as if you had held the bowling ball.
43. They hit at the same time because there is no air resistance.
44. They hit at the same time because there is no air resistance.
45. Galileo concluded that the object falls with a constant acceleration when air resistance is ignored. Aristotle hypothesized that the object quickly reaches a constant speed.
46. Galileo would conclude that the unwadded paper falls slower because it experiences more air resistance. It's not obvious what Aristotle would say because the amount of "earth" in the paper doesn't

change.

47. The heavier ball hits first because the air resistance will affect the lighter ball more.
48. The golf ball reaches the ground first. The lighter Ping Pong ball reaches its (small) terminal velocity quickly, while the golf ball continues to accelerate to a larger final speed. The average speed of the golf ball is therefore larger, so it covers the same distance in less time.
49. Because of the marble's greater weight, air-resistance will affect it less than the ping-pong ball allowing it to speed up faster. Therefore the marble has the greater acceleration.
50. Because of the ping-pong ball's low weight to size ratio, air-resistance will affect it more than the marble causing it to slow faster. If its speed is changing faster, the ping-pong ball must have the greater acceleration.
51. The accelerations are the same in both cases.
52. The accelerations are the same.
53. The increasing upward force due to the air resistance causes the downward acceleration to continually decrease.
54. Because the acceleration is decreasing as the air resistance increases, the ball's speed increases the most during the first second.
55. The air resistance will cause the ball to slow the ball down more rapidly than it would in a vacuum. The magnitude of the acceleration is therefore greater.
56. The ball is now speeding up as it falls. The air resistance will cause it to speed up less rapidly as it would in a vacuum. The magnitude of the acceleration is therefore less.

Answers to the Exercises

57. $(2193\ \text{mph})\left[\dfrac{1.61\ \text{km}}{1\ \text{mile}}\right] = 3530\ \text{km/h}$

58. $(100\ \text{mph})\left[\dfrac{0.447\ \text{m/s}}{1\ \text{mph}}\right] = 44.7\ \text{m/s}$

59. $\bar{s} = \dfrac{d}{t} = \dfrac{(215-50)\ \text{miles}}{2.5\ \text{h}} = 66\ \text{mph}$

60. $\bar{s} = \dfrac{d}{t} = \dfrac{26.2\ \text{miles}}{3\ \text{h}} = 8.73\ \text{mph}$

61. $\bar{s} = \dfrac{d}{t} = \dfrac{145.3\ \text{miles}}{24\ \text{h}} = 6.05\ \text{mph}$

62. $\bar{s} = \dfrac{d}{t} = \dfrac{10{,}000\ \text{m}}{1577.53\ \text{s}} = 6.34\ \text{m/s}$

63. $d = \bar{s}t = (60\ \text{mph})(8\ \text{h}) = 480\ \text{miles}$

64. $d = \bar{s}t = (10\ \text{m/s})(8\ \text{h})\left[\dfrac{60\ \text{min}}{1\ \text{h}}\right]\left[\dfrac{60\ \text{sec}}{1\ \text{min}}\right]\left[\dfrac{1\ \text{km}}{1000\ \text{m}}\right] = 288\ \text{km}$

65. $\bar{s} = \dfrac{d_1 + d_2}{t} = \dfrac{(4\ \text{mph})(3\ \text{h}) + 0}{5\ \text{h}} = 2.4\ \text{mph}$

66. $\bar{s} = \dfrac{d_1 + d_2}{t} = \dfrac{0 + (75\text{ mph})(2\text{ h})}{3\text{ h}} = 50\text{ mph}$

67. $t = \dfrac{d}{\bar{s}} = \dfrac{100\text{ m}}{25\text{ m/s}} = 4\text{ s}$ compared to 10 s for humans

68. $t = \dfrac{d}{\bar{s}} = \dfrac{4400\text{ km}}{80\text{ km/h}} = 55\text{ h}$

69. $t = \dfrac{d}{\bar{s}} = \dfrac{100\text{ miles}}{4\text{ mph}} = 25\text{ h}$; No

70. $t = \dfrac{d}{\bar{s}} = \dfrac{500\text{ miles}}{125\text{ mph}} = 4\text{ h}$

71. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{60\text{ mph} - 0}{4.8\text{ s}} = 12.5\text{ mph/s}$

72. $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{120\text{ km/h}}{20\text{ s}} = 6\text{ km/h}\cdot\text{s}$

73. $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{70\text{ mph} - 40\text{ mph}}{6\text{ s}} = 5\text{ mph/s}$

74. $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{332.75\text{ mph}}{4.447\text{ s}} = 74.3\text{ mph/s}$

$\bar{s} = \dfrac{d}{t} = \dfrac{0.25\text{ mile}}{4.447\text{ s}}\left[\dfrac{60\text{ s}}{1\text{ min}}\right]\left[\dfrac{60\text{ min}}{1\text{ h}}\right] = 202\text{ mph}$

75. $v_f = v_i + at = 7\text{ m/s} + (10\text{ m/s}^2)(2\text{ s}) = 27\text{ m/s}$

76. $v_i = v_f - at = 23\text{ m/s} - (10\text{ m/s}^2)(2\text{ s}) = 3\text{ m/s}$

77. $v_f = v_i + at = 5\text{ m/s} + (2\text{ m/s}^2)(4\text{ s}) = 13\text{ m/s}$

78. $t = \dfrac{v_f - v_i}{a} = \dfrac{(-10\text{ m/s}) - (30\text{ m/s})}{-10\text{ m/s}^2} = 4\text{ s}$ (+ is up)

79. $v_f = v_i + at = 0 + (10\text{ m/s}^2)(2\text{ s}) = 20\text{ m/s}$

$d = \bar{v}t = \tfrac{1}{2}(20\text{ m/s} + 0)(2\text{ s}) = 20\text{ m}$

80. $v_f = v_i + at = 0 + (10\text{ m/s}^2)(4\text{ s}) = 40\text{ m/s}$

$d = \bar{v}t = \tfrac{1}{2}(40\text{ m/s} + 0)(4\text{ s}) = 80\text{ m}$

81.

t(s)	v(m/s)	h(m)
0	0	80
1	10	75
2	20	60
3	30	35
4	40	0

82.

t(s)	v(m/s)	h(m)
0	30	0
1	20	25
2	10	40
3	0	45
4	–10	40
5	–20	25
6	–30	0

83. A ball starting from rest requires 3 s to fall 45 m. Therefore the ball is in the air for 3 s and must have a minimum launch speed of 30 m/s.

84. $t = 2 \times \frac{\Delta v}{g} = 2 \times \frac{40\ \text{m/s}}{10\ \text{m/s}^2} = 8\ \text{s}$

$h = \frac{1}{2} g t^2 = \frac{1}{2}\left(10\ \text{m/s}^2\right)\left(4\ \text{s}\right)^2 = 80\ \text{m}$

85. $v_f = v_i + at = 0 + \left(10\ \text{m/s}^2\right)\left(0.13\ \text{s}\right) = 1.3\ \text{m/s}$

86. $v_f = v_i + at = 0 + \left(10\ \text{m/s}^2\right)\left(0.18\ \text{s}\right) = 1.8\ \text{m/s}$

$d = \overline{v}t = \frac{1}{2}\left(1.8\ \text{m/s} + 0\right)\left(0.18\ \text{s}\right) = 0.16\ \text{m}$

Answers to the Problems in *Problem Solving*

1. $\overline{s} = \frac{d}{t} = \frac{370\ \text{km}}{24\ \text{h}} = 15.4\ \text{km/h}$

2. $\overline{s} = \frac{d}{t} = \frac{6000\ \text{km}}{10.2\ \text{h}} = 588\ \text{km/h}$

3. $\overline{s} = \frac{d}{t} = \frac{1.5\ \text{miles}}{2\ \text{min}}\left[\frac{60\ \text{min}}{1\ \text{h}}\right] = 45\ \text{mph}$

4. $\overline{s} = \frac{d}{t} = \frac{60\ \text{miles}}{4\ \text{h}}\left[\frac{1\ \text{h}}{3600\ \text{s}}\right]\left[\frac{1609\ \text{m}}{1\ \text{mile}}\right] = 6.7\ \text{m/s}$

5. $\overline{s} = \frac{d}{t} = \frac{100\ \text{m}}{9.86\ \text{s}}\left[\frac{3600\ \text{s}}{1\ \text{h}}\right]\left[\frac{1\ \text{mile}}{1609\ \text{m}}\right] = 22.7\ \text{mph}$

6. $\overline{s} = \frac{d}{t} = \frac{1\ \text{mile}}{239.4\ \text{s}}\left[\frac{3600\ \text{s}}{1\ \text{h}}\right] = 15\ \text{mph}$

7. $d = \overline{s}_1 t_1 + \overline{s}_1 t_2 = \left(15\ \text{mph}\right)\left(2\ \text{h}\right) + \left(10\ \text{mph}\right)\left(4\ \text{h}\right) = 70\ \text{miles}$

$\overline{s} = \frac{d}{t} = \frac{70\ \text{miles}}{6\ \text{h}} = 11.7\ \text{mph}$

8. $d = \bar{s}_1 t_1 = (40 \text{ mph})(2 \text{ h}) = 80 \text{ miles}$

$\bar{s} = \dfrac{d_2}{t_2} = \dfrac{300 \text{ miles} - 80 \text{ miles}}{3 \text{ h}} = 73.3 \text{ mph}$

9. $d = \bar{s}t = (95 \text{ km/h})(12 \text{ h}) = 1140 \text{ km}$

10. $d = \bar{s}t = (1.07 \times 10^5 \text{ km/h})\left[\dfrac{365.25 \text{ days}}{1 \text{ y}}\right]\left[\dfrac{24 \text{ h}}{1 \text{ day}}\right] = 9.38 \times 10^8 \text{ km/y}$

11. $t = \dfrac{d}{\bar{s}} = \dfrac{4470 \text{ km}}{25 \text{ km/h}}\left[\dfrac{1 \text{ day}}{8 \text{ h}}\right] = 22.4 \text{ days}$

12. $t = \dfrac{d}{\bar{s}} = \dfrac{3 \times 10^8 \text{ km}}{2 \times 10^4 \text{ km/h}}\left[\dfrac{1 \text{ day}}{24 \text{ h}}\right]\left[\dfrac{1 \text{ month}}{30 \text{ days}}\right] = 20.8 \text{ months}$

13. $\text{slope} = v = \dfrac{30 \text{ m} - 10 \text{ m}}{5 \text{ s} - 0} = 4 \text{ m/s}$

14. $\text{slope} = v = \dfrac{48 \text{ m} - 29 \text{ m}}{14 \text{ s} - 4 \text{ s}} = 1.9 \text{ m/s}$

15. $\text{slope} = a = \dfrac{18 \text{ m/s} - 2 \text{ m/s}}{3 \text{ s} - 1 \text{ s}} = 8 \text{ m/s}^2$

16. $\text{slope} = a = \dfrac{11 \text{ m/s} - 20 \text{ m/s}}{10 \text{ s} - 6 \text{ s}} = -2.3 \text{ m/s}^2$

17. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{72 \text{ km/h} - 0}{2 \text{ s}} = 36 \text{ km/h} \cdot \text{s}$

18. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{20 \text{ mph} - 4 \text{ mph}}{4 \text{ s}}\left[\dfrac{1 \text{ m/s}}{2.237 \text{ mph}}\right] = 1.79 \text{ m/s}^2$

19. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{254 \text{ mph} - 0}{5.9 \text{ s}} = 43.1 \text{ mph/s}$

$\bar{s} = \dfrac{d}{t} = \dfrac{0.25 \text{ mile}}{5.9 \text{ s}}\left[\dfrac{3600 \text{ s}}{1 \text{ h}}\right] = 153 \text{ mph}$

20. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{69 \text{ mph} - 0}{19.4 \text{ s}} = 3.56 \text{ mph/s}$

$\bar{s} = \dfrac{d}{t} = \dfrac{0.25 \text{ mile}}{19.4 \text{ s}}\left[\dfrac{3600 \text{ s}}{1 \text{ h}}\right] = 46.4 \text{ mph}$

21. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{-80 \text{ km/h} - 100 \text{ km/h}}{2 \text{ min}} = -90 \text{ km/h} \cdot \text{min}$ (+ is north)

22. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{-220 \text{ km/h} - 220 \text{ km/h}}{10 \text{ min}} = -44 \text{ km/h} \cdot \text{min}$ (+ is north)

23. $\bar{a} = \dfrac{\Delta v}{t} = \dfrac{16 \text{ m/s} - (-20 \text{ m/s})}{0.04 \text{ s}} = 900 \text{ m/s}^2$ (+ is up)