SUMMARY

The goals of Chapter 1 have been to introduce the fundamental concepts of motion and to review the related basic mathematical principles.

IMPORTANT CONCEPTS

Motion Diagrams

The particle model represents a moving object as if all its mass were concentrated at a single point. Using this model, we can represent motion with a motion diagram, where dots indicate the object’s positions at successive times. In a motion diagram, the time interval between successive dots is always the same.

Scalars and Vectors

Scalar quantities have only a magnitude and can be represented by a single number. Temperature, time, and mass are scalars.

A vector is a quantity described by both a magnitude and a direction. Velocity and displacement are vectors.

Velocity vectors can be drawn on a motion diagram by connecting successive points with a vector.

Describing Motion

Position locates an object with respect to a chosen coordinate system. It is described by a coordinate.

The coordinate is the variable used to describe the position.

A change in position is called a displacement. For motion along a line, a displacement is a signed quantity. The displacement from \( x_i \) to \( x_f \) is \( \Delta x = x_f - x_i \).

Time is measured from a particular instant to which we assign \( t = 0 \). A time interval is the elapsed time between two specific instants \( t_i \) and \( t_f \). It is given by \( \Delta t = t_f - t_i \).

Velocity is the ratio of the displacement of an object to the time interval during which this displacement occurs:

\[
\text{Velocity} = \frac{\Delta x}{\Delta t}
\]

Units

Every measurement of a quantity must include a unit.

The standard system of units used in science is the SI system. Common SI units include:

- Length: meters (m)
- Time: seconds (s)
- Mass: kilograms (kg)

APPLICATIONS

Working with Numbers

In scientific notation, a number is expressed as a decimal number between 1 and 10 multiplied by a power of ten. In scientific notation, the diameter of the earth is \( 1.27 \times 10^7 \) m.

A prefix can be used before a unit to indicate a multiple of 10 or 1/10. Thus we can write the diameter of the earth as 12,700 km, where the k in km denotes 1000.

We can perform a unit conversion to convert the diameter of the earth to a different unit, such as miles. We do so by multiplying by a conversion factor equal to 1, such as \( 1 = \text{1 mi} / 1.61 \text{ km} \).

Significant figures are reliably known digits. The number of significant figures for:

- Multiplication, division, and powers is set by the value with the fewest significant figures.
- Addition and subtraction is set by the value with the smallest number of decimal places.

An order-of-magnitude estimate is an estimate that has an accuracy of about one significant figure. Such estimates are usually made using rough numbers from everyday experience.
Conceptual Questions

1. a. Write a paragraph describing the particle model. What is it, and why is it important?
   b. Give two examples of situations, different from those described in the text, for which the particle model is appropriate.
   c. Give an example of a situation, different from those described in the text, for which it would be inappropriate.
2. A softball player slides into second base. Use the particle model to draw a motion diagram of the player from the time he begins to slide until he reaches the base. Number the dots in order, starting with zero.
3. A car travels to the left at a steady speed for a few seconds, then brakes for a stop sign. Use the particle model to draw a motion diagram of the car for the entire motion described here. Number the dots in order, starting with zero.
4. A ball is dropped from the roof of a tall building and students in a physics class are asked to sketch a motion diagram for this situation. A student submits the diagram shown in Figure Q1.4. Is the diagram correct? Explain.

![Figure Q1.4](image)

5. Write a sentence or two describing the difference between position and displacement. Give an example of each.
6. Give an example of a trip you might take in your car for which the distance traveled as measured on your car's odometer is not equal to the displacement between your initial and final positions.
7. Write a sentence or two describing the difference between speed and velocity. Give one example of each.
8. The motion of a skateboard along a horizontal axis is observed for 5 s. The initial position of the skateboard is negative with respect to a chosen origin, and its velocity throughout the 5 s is also negative. At the end of the observation time, is the skateboard closer to or farther from the origin than initially? Explain.
9. Can the velocity of an object be positive during a time interval in which its position is always negative? Can its velocity be positive during a time interval in which its displacement is negative?
10. Two friends watch a jogger complete a 400 m lap around the track in 100 s. One of the friends states, “The jogger’s velocity was 4 m/s during this lap.” The second friend objects, saying, “No, the jogger’s speed was 4 m/s.” Who is correct? Justify your answer.
11. A softball player hits the ball and starts running toward first base. Draw a motion diagram, using the particle model, showing her velocity vectors during the first few seconds of her run.
12. A child is sledding on a smooth, level patch of snow. She encounters a rocky patch and slows to a stop. Draw a motion diagram, using the particle model, showing her velocity vectors.
13. A skydiver jumps out of an airplane. Her speed steadily increases until she deploys her parachute, at which point her speed quickly decreases. She subsequently falls to earth at a constant rate, stopping when she lands on the ground. Draw a motion diagram, using the particle model, that shows her position at successive times and includes velocity vectors.
14. Your roommate drops a tennis ball from a third-story balcony. It hits the sidewalk and bounces as high as the second story. Draw a motion diagram, using the particle model, showing the ball’s velocity vectors from the time it is released until it reaches the maximum height on its bounce.
15. A car is driving north at a steady speed. It makes a gradual 90° left turn without losing speed, then continues driving to the west. Draw a motion diagram, using the particle model, showing the car’s velocity vectors as seen from a helicopter hovering over the highway.
16. A toy car rolls down a ramp, then across a smooth, horizontal floor. Draw a motion diagram, using the particle model, showing the car’s velocity vectors.
17. Estimate the average speed with which you go from home to campus (or another trip you commonly make) via whatever mode of transportation you use most commonly. Give your answer in both mph and m/s. Describe how you arrived at this estimate.
18. Estimate the number of times you sneezed during the past year. Describe how you arrived at this estimate.
19. Density is the ratio of an object’s mass to its volume. Would you expect density to be a vector or a scalar quantity? Explain.

Multiple-Choice Questions

20. I A student walks 1.0 mi west and then 1.0 mi north. Afterward, how far is she from her starting point?
   A. 1.0 mi  
   B. 1.4 mi  
   C. 1.6 mi  
   D. 2.0 mi

21. I Which of the following motions is described by the motion diagram of Figure Q1.21?
   A. An ice skater gliding across the ice.
   B. An airplane braking to a stop after landing.
   C. A car pulling away from a stop sign.
   D. A pool ball bouncing off a cushion and reversing direction.

22. I A bird flies 3.0 km due west and then 2.0 km due north. What is the magnitude of the bird’s displacement?
   A. 2.0 km  
   B. 3.0 km  
   C. 3.6 km  
   D. 5.0 km
23. A bird flies 3.0 km due west and then 2.0 km due north. Another bird flies 2.0 km due west and 3.0 km due north. What is the angle between the net displacement vectors for the two birds?
   A. 23°  B. 34°  C. 56°  D. 90°

24. A woman walks briskly at 2.00 m/s. How much time will it take her to walk one mile?
   A. 830 min  B. 13.4 min  C. 21.7 min  D. 30.0 min

25. Compute $3.24 \text{ m} + 0.532 \text{ m}$ to the correct number of significant figures.
   A. 3.7 m  B. 3.77 m  C. 3.772 m  D. 3.7720 m

26. A rectangle has length 3.24 m and height 0.532 m. To the correct number of significant figures, what is its area?
   A. 1.72 m$^2$  B. 1.723 m$^2$  C. 1.7236 m$^2$  D. 1.72368 m$^2$

27. The earth formed $4.57 \times 10^9$ years ago. What is this time in seconds?
   A. $1.67 \times 10^3$ s  B. $4.01 \times 10^3$ s  C. $2.40 \times 10^4$ s  D. $1.44 \times 10^4$ s

28. An object’s average density $\rho$ is defined as the ratio of its mass to its volume: $\rho = \frac{M}{V}$. The earth’s mass is $5.94 \times 10^{24}$ kg, and its volume is $1.08 \times 10^{12}$ km$^3$. What is the earth’s average density?
   A. $5.50 \times 10^3$ kg/m$^3$  B. $5.50 \times 10^4$ kg/m$^3$  C. $5.50 \times 10^9$ kg/m$^3$  D. $5.50 \times 10^{12}$ kg/m$^3$

**Section 1.2 Position and Time: Putting Numbers on Nature**

4. Figure P1.4 shows Sue between her home and the cinema. What is Sue’s position $x$ if
   a. Her home is the origin?
   b. The cinema is the origin?

5. Keira starts at position $x = 23$ m along a coordinate axis. She then undergoes a displacement of $-45$ m. What is her final position?

6. A car travels along a straight east-west road. A coordinate system is established on the road, with $x$ increasing to the east. The car ends up 14 mi west of the intersection with Mulberry Road. If its displacement was $-23$ mi, how far from and on which side of Mulberry Road did it start?

7. Foraging bees often move in straight lines away from and toward their hives. Suppose a bee starts at its hive and flies 500 m due east, then flies 400 m west, then 700 m east. How far is the bee from the hive?

**PROBLEMS**

Section 1.1 Motion: A First Look

1. You’ve made a video of a car as it skids to a halt to avoid hitting an object in the road. Use the images from the video to draw a motion diagram of the car from the time the skid begins until the car is stopped.

2. A man rides a bike along a straight road for 5 min, then has a flat tire. He stops for 5 min to repair the flat, but then realizes he cannot fix it. He continues his journey by walking the rest of the way, which takes him another 10 min. Use the particle model to draw a motion diagram of the man for the entire motion described here. Number the dots in order, starting with zero.

3. A jogger running east at a steady pace suddenly develops a cramp. He is lucky: A westbound bus is sitting at a bus stop just ahead. He gets on the bus and enjoys a quick ride home. Use the particle model to draw a motion diagram of the jogger for the entire motion described here. Number the dots in order, starting with zero.

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**Section 1.3 Velocity**

8. A security guard walks 110 m in one trip around the perimeter of the building. It takes him 240 s to make this trip. What is his speed?

9. List the following items in order of decreasing speed, from greatest to least: (i) A wind-up toy car that moves 0.15 m in 2.5 s. (ii) A soccer ball that rolls 2.3 m in 0.55 s. (iii) A bicycle that travels 0.60 m in 0.075 s. (iv) A cat that runs 8.0 m in 2.0 s.

10. Figure P1.10 shows the motion diagram for a horse galloping in one direction along a straight path. Not every dot is labeled, but the dots are at equally spaced instants of time. What is the horse’s velocity
   a. During the first ten seconds of its gallop?
   b. During the interval from 30 s to 40 s?
   c. During the interval from 50 s to 70 s?

**FIGURE P1.10**

11. It takes Harry 35 s to walk from $x = -12$ m to $x = -47$ m. What is his velocity?

12. A dog trots from $x = -12$ m to $x = 3$ m in 10 s. What is its velocity?

13. A ball rolling along a straight line with velocity 0.35 m/s goes from $x = 2.1$ m to $x = 7.3$ m. How much time does this take?

**Section 1.4 A Sense of Scale: Significant Figures, Scientific Notation, and Units**

14. Convert the following to SI units:
   a. 9.12 $\mu$s  b. 3.42 km  c. 44 cm/ms  d. 80 km/hour

15. Convert the following to SI units:
   a. 8.0 in  b. 66 ft/s  c. 60 mph

16. Convert the following to SI units:
   a. 1.0 hour  b. 1.0 day  c. 1.0 year

17. List the following three speeds in order, from smallest to largest: 1 mm per $\mu$s, 1 km per ks, 1 cm per ms.
18. a. 6.21  b. 62.1  c. 0.620  d. 0.062
19. a. 0.621  b. 0.006200  c. 1.0621  d. 6.21 \times 10^3
20. a. 33.3 \times 25.4  b. 33.3 - 25.4  c. \sqrt{33.3}  d. 33.3 + 25.4
21. The Empire State Building has a height of 1250 ft. Express this height in meters, giving your result in scientific notation with three significant figures.
22. Estimate (don’t measure!) the length of a typical car. Give your answer in both feet and meters. Briefly describe how you arrived at this estimate.
23. Blades of grass grow from the bottom, so, as growth occurs, the top of the blade moves upward. During the summer, when your lawn is growing quickly, estimate this speed in m/s. Explain how you made this estimate, and express your result in scientific notation.
24. Estimate the average speed with which the hair on your head grows. Give your answer in both m/s and \( \mu \text{m}/\text{h} \). Briefly describe how you arrived at this estimate.
25. Estimate the average speed at which your fingernails grow, in both m/s and \( \mu \text{m}/\text{h} \). Briefly describe how you arrived at this estimate.

### Section 1.5 Vectors and Motion: A First Look

26. Carol and Robin share a house. To get to work, Carol walks north 2.0 km while Robin drives west 7.5 km. How far apart are their workplaces?
27. Joe and Max shake hands and say goodbye. Joe walks east 0.55 km to a coffee shop, and Max flags a cab and rides north 3.25 km to a bookstore. How far apart are their destinations?
28. A city has streets laid out in a square grid, with each block 135 m long. If you drive north for three blocks, then west for two blocks, how far are you from your starting point?
29. A butterfly flies from the top of a tree in the center of a garden to rest on top of a red flower at the garden’s edge. The tree is 8.0 m taller than the flower, and the garden is 12 m wide. Determine the magnitude of the butterfly’s displacement.
30. A garden has a circular path of radius 50 m. John starts at the easternmost point on this path, then walks counterclockwise around the path until he is at its southernmost point. What is John’s displacement? Use the (magnitude, direction) notation for your answer.
31. Migrating geese tend to travel in straight-line paths at approximately constant speed. A goose flies 32 km south, then turns to fly 20 km west. How far is the goose from its original position?
32. A ball on a porch rolls 60 cm to the porch’s edge, drops 40 cm, continues rolling on the grass, and eventually stops 80 cm from the porch’s edge. What is the magnitude of the ball’s net displacement, in centimeters?
33. A kicker punts a football from the very center of the field to the sideline 43 yards downfield. What is the net displacement of the ball? (A football field is 53 yards wide.)

### General Problems

Problems 34 through 40 are motion problems similar to those you will learn to solve in Chapter 2. For now, simply interpret the problem by drawing a motion diagram showing the object’s position and its velocity vectors. Do not solve these problems or do any mathematics.

34. In a typical greyhound race, a dog accelerates to a speed of 20 m/s over a distance of 30 m. It then maintains this speed. What would be a greyhound’s time in the 100 m dash?
35. Billy drops a watermelon from the top of a three-story building, 10 m above the sidewalk. How fast is the watermelon going when it hits?
36. Sam is recklessly driving 60 mph in a 30 mph speed zone when he suddenly sees the police. He steps on the brakes and slows to 30 mph in three seconds, looking nonchalant as he passes the officer. How far does he travel while braking?
37. A speed skater moving across frictionless ice at 8.0 m/s hits a 5.0-m-wide patch of rough ice. She slows steadily, then continues on at 6.0 m/s. What is her acceleration on the rough ice?
38. The giant eland, an African antelope, is an exceptional jumper, able to leap 1.5 m off the ground. To jump this high, with what speed must the eland leave the ground?
39. A ball rolls along a smooth horizontal floor at 10 m/s, then starts up a 30° ramp. How high does it go before rolling back down?
40. A motorist is traveling at 20 m/s. He is 60 m from a stop light when he sees it turn yellow. His reaction time, before stepping on the brake, is 0.50 s. What steady deceleration while braking will bring him to a stop right at the light?

Problems 41 through 46 show a motion diagram. For each of these problems, write a one or two sentence “story” about a real object that has this motion diagram. Your stories should talk about people or objects by name and say what they are doing. Problems 34 through 40 are examples of motion short stories.

41. 

![FIGURE P1.41](image)

42. 

![FIGURE P1.42](image)

43. 

![FIGURE P1.43](image)
44. \( \begin{align*}
\text{Start} & \quad \vec{v} \\
\text{Stop} & \quad \text{Same point}
\end{align*} \)

The two parts of the motion diagram are displaced for clarity, but the motion actually occurs along a single line.

**FIGURE P1.44**

45. \( \begin{align*}
\text{Side view of motion} & \quad \text{in a vertical plane} \\
\text{Circular arc} & \quad \vec{v}
\end{align*} \)

**FIGURE P1.45**

46. \( \begin{align*}
\vec{v} & \quad \vec{v}
\end{align*} \)

**FIGURE P1.46**

47. III How many inches does light travel in one nanosecond? The speed of light is \(3.0 \times 10^8 \text{ m/s} \).

48. I Joseph watches the roadside mile markers during a long car trip on an interstate highway. He notices that at 10:45 A.M. they are passing a marker labeled 101, and at 11:00 A.M. the car reaches marker 119. What is the car’s speed, in mph?

49. I Alberta is going to have dinner at her grandmother’s house, but she is running a bit behind schedule. As she gets onto the highway, she knows that she must exit the highway within 45 min if she is not going to arrive late. Her exit is 32 mi away. What is the slowest speed at which she could drive and still arrive on time? Express your answer in miles per hour.

50. II The end of Hubbard Glacier in Alaska advances by an average of 105 feet per year. What is the speed of advance of the glacier in m/s?

51. I The earth completes a circular orbit around the sun in one year. The orbit has a radius of 93,000,000 miles. What is the speed of the earth around the sun in m/s? Report your result using scientific notation.

52. III Shannon decides to check the accuracy of her speedometer. She adjusts her speed to read exactly 70 mph on her speedometer and holds this steady, measuring the time between successive mile markers separated by exactly 1.00 mile. If she measures a time of 54 s, is her speedometer accurate? If not, is the speed it shows too high or too low?

53. III Motor neurons in mammals transmit signals from the brain to skeletal muscles at approximately 25 m/s. Estimate how much time in ms \((10^{-3} \text{ s})\) it will take for a signal to get from your brain to your hand.

54. III Satellite data taken several times per hour on a particular albatross showed travel of 1200 km over a time of 1.4 days.

a. Given these data, what was the bird’s average speed in mph?

b. Data on the bird’s position were recorded only intermittently. Explain how this means that the bird’s actual average speed was higher than what you calculated in part a.

55. I Your brain communicates with your body using nerve impulses, electrical signals propagated along axons. Axons come in two varieties: insulated axons with a sheath made of myelin, and uninsulated axons with no such sheath. Myelinated (sheathed) axons conduct nerve impulses much faster than unmyelinated (unsheathed) axons. The impulse speed depends on the diameter of the axons and the sheath, but a typical myelinated axon transmits nerve impulses at a speed of about 25 m/s, much faster than the typical 2.0 m/s for an unmyelinated axon. Figure P1.55 shows three equal-length nerve fibers consisting of eight axons in a row. Nerve impulses enter at the left side simultaneously and travel to the right.

a. Draw motion diagrams for the nerve impulses traveling along fibers A, B, and C.

b. Which nerve impulse arrives at the right side first?

c. Which will be last?

56. I The bacterium *Escherichia coli* (or *E. coli*) is a single-celled organism that lives in the gut of healthy humans and animals. Its body shape can be modeled as a 2-μm-long cylinder with a 1-μm diameter, and it has a mass of \(1 \times 10^{-12} \text{ g}\). Its chromosome consists of a single double-stranded chain of DNA 700 times longer than its body length. The bacterium moves at a constant speed of 20 μm/s, though not always in the same direction. Answer the following questions about *E. coli* using SI units (unless specifically requested otherwise) and correct significant figures.

a. What is its length?

b. Diameter?

c. Mass?

d. What is the length of its DNA, in millimeters?

e. If the organism were to move along a straight path, how many meters would it travel in one day?

57. I The bacterium *Escherichia coli* (or *E. coli*) is a single-celled organism that lives in the gut of healthy humans and animals. When grown in a uniform medium rich in salts and amino acids, it swims along zig-zag paths at a constant speed. Figure P1.57 shows the positions of an *E. coli* as it moves from point A to point J. Each segment of the motion can be identified by two letters, such as segment BC. During which segments, if any, does the bacterium have the same

58. In 2003, the population of the United States was 291 million people. The per-capita income was $31,459. What was the total income of everyone in the United States? Express your answer in scientific notation, with the correct number of significant figures.

59. The sun is 30° above the horizon. It makes a 52-m-long shadow of a tall tree. How high is the tree?

60. A large passenger aircraft accelerates down the runway for a distance of 3000 m before leaving the ground. It then climbs at a steady 3.0° angle. After the plane has traveled 3000 m along this new trajectory, (a) how high is it, and (b) how far horizontally is it, from its initial position?

61. Starting from its nest, an eagle flies at constant speed for 3.0 min due east, then 4.0 min due north. From there the eagle flies directly to its nest at the same speed. How long is the eagle in the air?

62. John walks 1.00 km north, then turns right and walks 1.00 km east. His speed is 1.50 m/s during the entire stroll.
   a. What is the magnitude of his displacement, from beginning to end?
   b. If Jane starts at the same time and place as John, but walks in a straight line to the endpoint of John’s stroll, at what speed should she walk to arrive at the endpoint just when John does?

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**Passage Problems**

**Growth Speed**

The images of trees in Figure P1.63 come from a catalog advertising fast-growing trees. If we mark the position of the top of the tree in the successive years, as shown in the graph in the figure, we obtain a motion diagram much like ones we have seen for other kinds of motion. The motion isn’t steady, of course. In some months the tree grows rapidly; in other months, quite slowly. We can see, though, that the average speed of growth is fairly constant for the first few years.

![Figure P1.63](image)

**Problems**

63. What is the tree’s speed of growth, in feet per year, from \( t = 1 \) yr to \( t = 3 \) yr?
   A. 12 ft/yr  
   B. 9 ft/yr  
   C. 6 ft/yr  
   D. 3 ft/yr

64. What is this speed in m/s?
   A. \( 9 \times 10^{-8} \) m/s  
   B. \( 3 \times 10^{-8} \) m/s  
   C. \( 5 \times 10^{-6} \) m/s  
   D. \( 2 \times 10^{-6} \) m/s

65. At the end of year 3, a rope is tied to the very top of the tree to steady it. This rope is staked into the ground 15 feet away from the tree. What angle does the rope make with the ground?
   A. 63°  
   B. 60°  
   C. 30°  
   D. 27°

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**STOP TO THINK ANSWERS**

**Stop to Think 1.1:** B. The images of B are farther apart, so B travels a greater distance than does A during the same intervals of time.

**Stop to Think 1.2:** A. Dropped ball. B. Dust particle. C. Descending rocket.

**Stop to Think 1.3:** C. Depending on her initial positive position and how far she moves in the negative direction, she could end up on either side of the origin.

**Stop to Think 1.4:** D > C > B = A.

**Stop to Think 1.5:** B. The vector sum is found by placing the tail of one vector at the head of the other.