



Term_1 2025/2026
Class Notebook

Class Teacher: Mr. MINA GERGES

G9/_____

Student Name:

1 A Physics Toolkit

ENCOUNTER THE PHENOMENON

Write the Encounter the Phenomenon question for this module.

Use the “What I Know” column to list the things you know about the Encounter the Phenomenon question. Then list the questions you have about the Encounter the Phenomenon question in the “What I Want to Find Out” column. As you read the module, fill in the “What I Learned” column.

K <i>What I Know</i>	W <i>What I Want to Find Out</i>	L <i>What I Learned</i>

A Physics Toolkit

1 Methods of Science

REVIEW VOCABULARY

science

Recall and write the definition of the Review Vocabulary term.

science

NEW VOCABULARY

physics

scientific methods

hypothesis

model

scientific theory

scientific law

Use your book to define each term.

physics

scientific methods

hypothesis

model

scientific theory

scientific law

1 Methods of Science (continued)

Student Edition, pp. 4–7

What is physics?

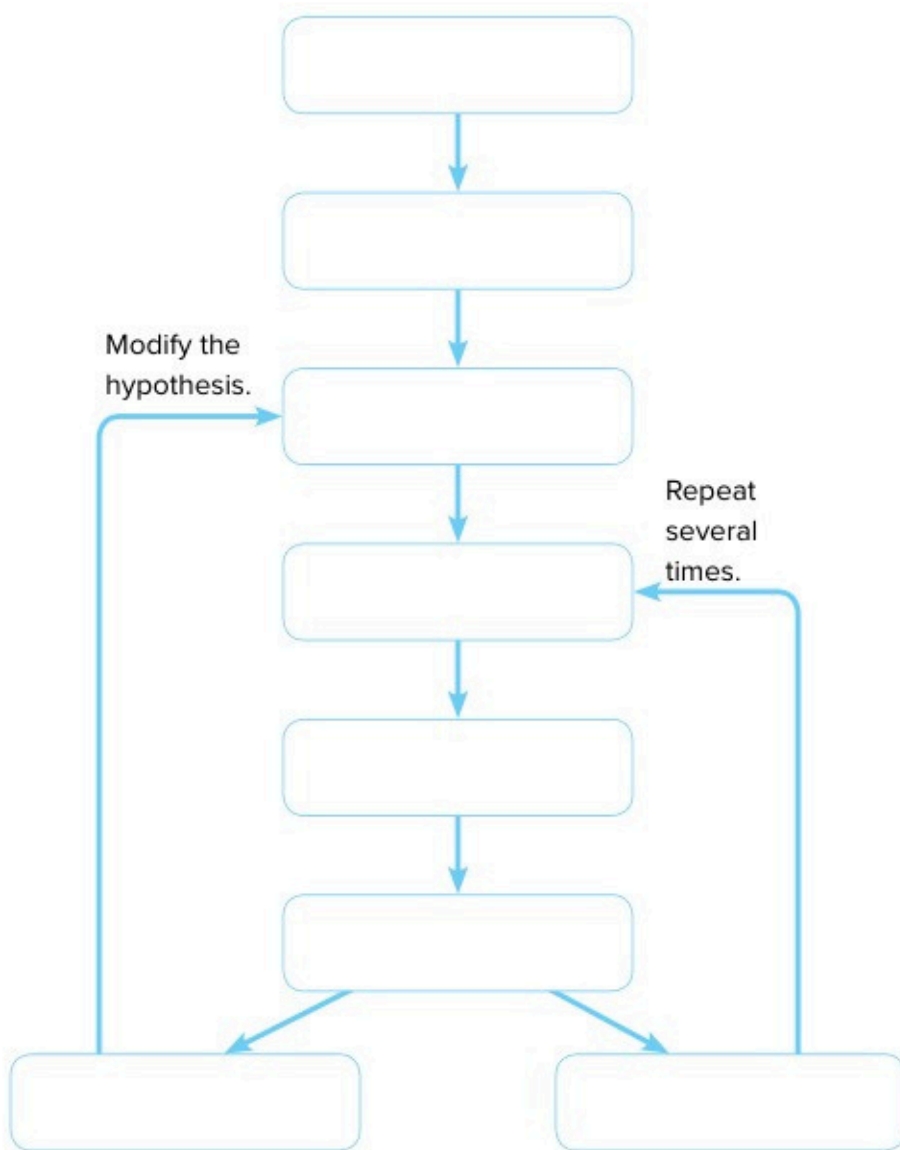
- Physics is a branch of science.
- Physics involves the study of matter and energy.

Scientific Methods

- Scientific methods are patterns of investigational procedures.
- There are several common steps in investigational procedures.

Write three sentences about physics and science.

Fill in the blanks of the flow chart below using information about scientific methods.



1 Methods of Science (continued)

Student Edition, pp. 7–9

Models

- A model is a representation of an idea, event, structure, or object that helps people understand it.
- Models change as new information is learned.

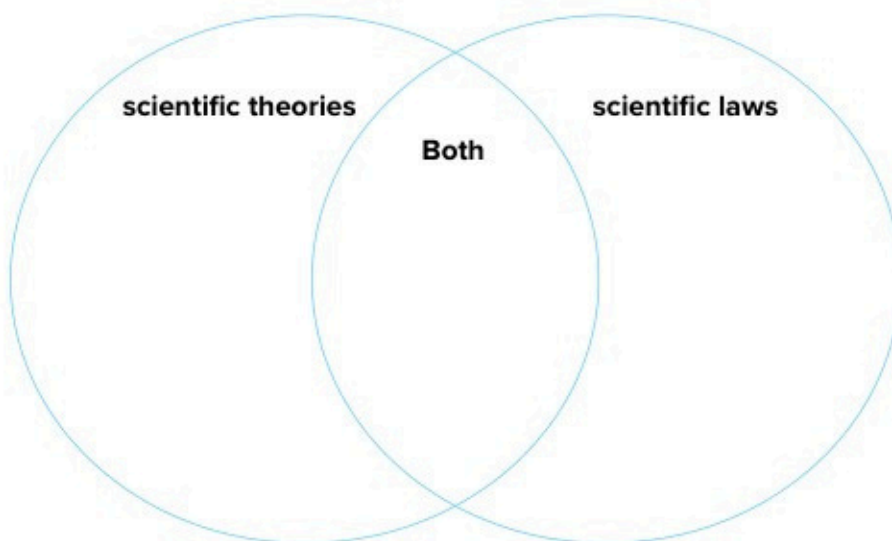
Scientific Theories and Laws

- A scientific theory is an explanation of things or events based on knowledge gained from many observations and investigations.
- A scientific law is a statement about what happens in nature and seems to be true all the time.

Identify three main ideas about models.

Get It? Discuss how computer simulations can help develop possible solutions to a problem.

Compare and contrast scientific theories and scientific laws by completing the Venn diagram.



1 Methods of Science (continued)

Student Edition, p. 9

The Limitations of Science

- Science can explain many things about the world.
- Science does not answer opinion, value, or emotion questions.

Write three true statements about the limitations of science.

CHECK YOUR PROGRESS

1. **Summarize** the steps you might use to carry out an investigation using scientific methods.

2. **Define** the term *hypothesis*. Identify three ways to test a hypothesis.

1 Methods of Science (continued)

3. **Describe** why it is important for scientists to avoid bias.

4. **Explain** why scientists use models. Give an example of a scientific model not mentioned in this lesson, and explain how that model is useful.

5. **Analyze** Your friend finds that 90 percent of students surveyed in the cafeteria like pizza. She says this scientifically proves that everyone likes pizza. How would you respond to her conclusion?

6. **Critical Thinking** An accepted value for free-fall acceleration is 9.8 m/s^2 . In an experiment with pendulums, you calculate that the value is 9.4 m/s^2 . Should the accepted value be tossed out to accommodate your new finding? Explain.

A Physics Toolkit

2 Mathematics and Physics

REVIEW VOCABULARY

SI

Recall and write the definition of the Review Vocabulary term.

SI

NEW VOCABULARY

Use your book to fill in the term that matches each definition.

method of treating units as algebraic quantities so they can be cancelled
valid digits in a measurement

Student Edition,
pp. 10–11

Mathematics in Physics

- Physicists use the language of mathematics.
- Equations represent relationships between measurements.

Explain why physicists use mathematics.

SI Units

- SI units are used by scientists worldwide.
- SI uses seven base units.

Fill in the blanks about SI Units.

The scientific notation for the prefix *femto*– is _____. SI units that are not base units are called _____ units. SI units are based on powers of _____.

2 Mathematics and Physics (continued)

Student Edition, pp.
11–13

Dimensional Analysis

- Dimensional analysis is a method of treating units as algebraic quantities.
- It can be used to check for errors in calculations.

Significant Figures

- Significant figures are valid digits in a measurement.
- Rules must be used to accurately determine the number of significant figures in a number.

Solving Problems

- Problems can be solved using a three-step process.

Use with Example
Problem 1.

Use this column for
scratch work and
sketches.

Get It? **Identify** the prefix that would be used to express 2,000,000,000 bytes of computer memory.

Demonstrate how to use dimensional analysis by using it to convert 35 km/h to m/s.

Write three bullet points about significant digits.

TRY IT!

Problem

DISTANCE, TIME, AND SPEED When a bus travels 253 km in 3.2 h, what is the bus's average speed?

1. ANALYZE AND SKETCH THE PROBLEM

KNOWN

UNKNOWN

distance = _____ = ?

time = _____

2 Mathematics and Physics (continued)

Student Edition, p. 13

Use this column for
scratch work and
sketches.

TRY IT! (CONTINUED)

2. SOLVE FOR THE UNKNOWN

Use the speed equation.

Solve the equation for speed.

Substitute the knowns.

Complete the calculation.

3. EVALUATE THE ANSWER

Use your answer to calculate the distance the car traveled.

_____ = speed $\times$ time = _____ $\times$ _____ = 253 km

The calculated distance matches the distance stated in the problem.

This means the average speed is correct.

CHECK YOUR PROGRESS

7. Modeling Why are concepts in physics described with formulas?

8. Significant Figures Solve the following problems, using the correct number of significant figures each time.

a. $10.8 \text{ g} - 8.264 \text{ g}$

d. $13.78 \text{ g} / 11.3 \text{ mL}$

b. $4.75 \text{ m} - 0.4168 \text{ m}$

e. $6.201 \text{ cm} + 7.4 \text{ cm} + 0.68 \text{ m} + 12.0 \text{ cm}$

c. $139 \text{ cm} \times 2.3 \text{ cm}$

f. $1.6 \text{ km} + 1.62 \text{ m} + 1200 \text{ cm}$

2 Mathematics and Physics (continued)

9. Dimensional Analysis How many seconds are in a leap year?

10. Solving Problems Rewrite $F = Bqv$ to find v in terms of F , q , and B .

11. Critical Thinking Using values given in a problem and the equation of distance = speed $\times$ time, you calculate a car's speed to be 290 km/h. Is this answer reasonable? Explain. Under what circumstances might this be a reasonable answer?

A Physics Toolkit

3 Measurement

REVIEW VOCABULARY

parallax

Recall and write the definition of the Review Vocabulary term.

parallax

NEW VOCABULARY

measurement

precision

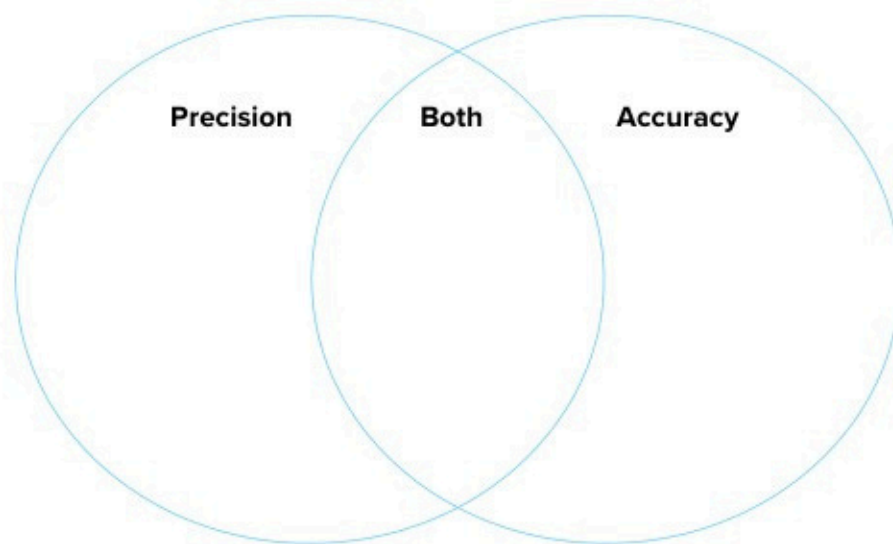
accuracy

Use your book to define the term below.

measurement

Student Edition, p. 15

Fill in the Venn diagram to compare and contrast precision and accuracy.



3 Measurement (continued)

Student Edition,
pp. 14–15

What is measurement?

- Measurement quantifies observations.
- Measurement is a comparison between an unknown quantity and a standard.

Comparing Results

- Measurements often are recorded with uncertainty.
- Measurements agree if they are within the margin of uncertainty.

Precision Versus Accuracy

- Precision is the degree of exactness.
- Accuracy is an agreement with the accepted value.

Describe a scenario in which you make an observation and record a measurement quantifying your observation.

Summarize the information about comparing results in three or four bullet points.

Explain how you can improve the accuracy of an electronic scale before measuring and how you can improve the precision of the measurement.

Get It? Compare and contrast precision and accuracy.

3 Measurement (continued)

Student Edition,
pp. 16–17

Techniques of Good Measurement

- Instruments must be used correctly.
- Measurements must be made correctly.

GPS

- GPS determines an object's latitude, longitude, and elevation.

Explain how parallax affects a measurement.

Fill in the blanks about predicting values and GPS.

Scientists use relationships in data to make _____. The Global Positioning System, or _____, consists of _____ satellites in orbit that transmit data to receivers. GPS uses the _____ for time data, because the atomic clock is more precise than standard household clocks.

CHECK YOUR PROGRESS

12. Precision and Accuracy You find a micrometer (a tool used to measure objects to the nearest 0.001 mm) that has been bent. How does it compare to a new, high-quality meterstick in its precision and accuracy?

13. Accuracy Some wooden rulers do not start with 0 at the edge, but have it set in a few millimeters. How could this improve the accuracy of the ruler?

14. Parallax Does parallax affect the precision of a measurement that you make? Explain.

3 Measurement (continued)

- 15. Uncertainty** Your friend tells you that his height is 182 cm. In your own words, explain the range of heights allowed by this statement.

- 16. Precision** A box has a length of 18.1 cm and a width of 19.2 cm, and it is 20.3 cm tall.

- | | |
|---|--|
| a. What is its volume? | c. How tall is a stack of 12 of these boxes? |
| b. How precise is the measurement of length? Of volume? | d. How precise is the measurement of the height of one box? Of 12 boxes? |

- 17. Critical Thinking** Your friend states in a report that the average time required for a car to circle a 1.5-mi track was 65.414 s. This was measured by timing 7 laps using a clock with a precision of 0.1 s. How much confidence do you have in the results of the report? Explain.

A Physics Toolkit

4 Graphing Data

REVIEW VOCABULARY

slope

Recall and write the definition of the Review Vocabulary term.

slope

NEW VOCABULARY

independent variable

dependent variable

line of best fit

linear relationship

quadratic relationship

inverse relationship

Use your book to define the terms below.

independent variable

dependent variable

line of best fit

linear relationship

quadratic relationship

inverse relationship

4 Graphing Data (continued)

Student Edition,
pp. 18–22

Identifying Variables

- An independent variable is the factor that is manipulated during an investigation.
- A dependent variable is the factor that depends on the independent variable.
- A line of best fit is drawn as close to all the data points as possible.

Linear Relationships

- In a linear relationship, one variable depends linearly on the other.
- The graph of a linear relationship is a straight line.
- The slope of a line equals the rise divided by the run.

Nonlinear Relationships

- In a quadratic relationship, one variable depends on the square of the other.
- The graph of a quadratic relationship is a parabola.
- In an inverse relationship, one variable depends on the inverse of the other.
- The graph of an inverse relationship is hyperbolic.

Describe the relationship between the independent variable and a dependent variable in an investigation.

Describe why drawing a line of best fit is useful.

Write the basic equation representing each relationship and draw a graph of each.

Linear	Quadratic	Inverse
$y =$	$y =$	$y =$

Get It? Explain how two variables are related to each other in a quadratic relationship.

Get It? Explain how two variables are related to each other in an inverse relationship.

4 Graphing Data (continued)

Student Edition, p. 23

Predicting Values

- Graphs can be used to make predictions.

Predict the speed of a car after 10.0 s when the car's speed follows the relationship $\text{speed} = (4.8 \text{ m/s}^2) \times (\text{time})$.

CHECK YOUR PROGRESS

19. Make a Graph Graph the following data. Time is the independent variable.

Time (s)	0	5	10	15	20	25	30	35
Speed (m/s)	12	10	8	6	4	2	2	2

20. Interpret a Graph What would be the meaning of a nonzero y-intercept in a graph of total mass versus volume?

4 Graphing Data (continued)

21. Predict Use the relationship illustrated in **Figure 16** to determine the mass required to stretch the spring 15 cm.

22. Predict Use the relationship shown in **Figure 18** to predict the travel time when speed is 110 km/h.

23. Critical Thinking Look again at the graph in **Figure 16**. In your own words, explain how the spring would be different if the line in the graph were shallower or had a smaller slope.

Lesson 1 Methods of Science

Mastering Concepts

- Describe a scientific method.
- Explain why scientists might use each of the models listed below.
 - physical model of the solar system
 - computer model of airplane aerodynamics
 - mathematical model of the force of attraction between two objects

Lesson 2 Mathematics and Physics

Mastering Concepts

- Why is mathematics important to science?
- What is the SI system?
- How are base units and derived units related?
- Suppose your lab partner recorded a measurement as 100 g.
 - Why is it difficult to tell the number of significant figures in this measurement?
 - How can the number of significant figures in such a number be made clear?
- Give the name for each of the following multiples of the meter.
 - $\frac{1}{100}$ m
 - $\frac{1}{1000}$ m
 - 1000
- To convert 1.8 h to minutes, by what conversion factor should you multiply?
- Solve each problem. Give the correct number of significant figures in the answers.
 - $4.667 \times 10^4 \text{ g} + 3.02 \times 10^5 \text{ g}$
 - $(1.70 \times 10^2 \text{ J}) \div (5.922 \times 10^{-4} \text{ cm}^3)$

Mastering Problems

- Convert each of the following measurements to meters.
 - 42.3 cm
 - 6.2 pm
 - 21 km
 - 0.023 mm
 - $214 \mu\text{m}$
 - 57 nm
- Add or subtract as indicated.
 - $5.80 \times 10^9 \text{ s} + 3.20 \times 10^8 \text{ s}$
 - $4.87 \times 10^{-6} \text{ m} - 1.93 \times 10^{-6} \text{ m}$
 - $3.14 \times 10^{-5} \text{ kg} + 9.36 \times 10^{-5} \text{ kg}$
 - $8.12 \times 10^7 \text{ g} - 6.20 \times 10^6 \text{ g}$
- Ranking Task** Rank the following numbers according to the number of significant figures they have, from most to least: 1.234, 0.13, 0.250, 7.603, 0.08. Specifically indicate any ties.
- State the number of significant figures in each of the following measurements.
 - 0.00003 m
 - 64.01 fm
 - 80.001 m
 - $0.720 \mu\text{g}$
 - $2.40 \times 10^6 \text{ kg}$
 - $6 \times 10^8 \text{ kg}$
 - $4.07 \times 10^{16} \text{ m}$
- Add or subtract as indicated.
 - $16.2 \text{ m} + 5.008 \text{ m} + 13.48 \text{ m}$
 - $5.006 \text{ m} + 12.0077 \text{ m} + 8.0084 \text{ m}$
 - $78.05 \text{ cm}^2 - 32.046 \text{ cm}^2$
 - $15.07 \text{ kg} - 12.0 \text{ kg}$

Module 1 continued

15. Multiply or divide as indicated.
- $(6.2 \times 10^{18} \text{ m})(4.7 \times 10^{-30} \text{ m})$
 - $(5.6 \times 10^{-7} \text{ m})/(2.8 \times 10^{-12} \text{ s})$
 - $(8.1 \times 10^{-4} \text{ km})(1.6 \times 10^{-3} \text{ km})$
 - $(6.5 \times 10^5 \text{ kg})/(3.4 \times 10^3 \text{ m}^3)$
16. **Gravity** The force due to gravity on Earth's surface is $F = mg$, where $g = 9.8 \text{ N/kg}$ on average.
- Find the force due to gravity on a 41.63-kg object.
 - The force due to gravity on an object is 632 N. What is its mass?
17. **Dimensional Analysis** Pressure is measured in pascals, where $1 \text{ Pa} = 1 \text{ kg/m} \cdot \text{s}^2$. Will the following expression give a pressure in the correct units?

$$\frac{(0.55 \text{ kg})(2.1 \text{ m/s})}{9.8 \text{ m/s}^2}$$

23. How precise a measurement could you make with the scale shown in the image?



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24. Give the measure shown on the meter in the image as precisely as you can. Include the uncertainty in your answer.



Lesson 3 Measurement

Mastering Concepts

- What determines the precision of a measurement?
- How does the last digit differ from the other digits in a measurement?

Mastering Problems

- A water tank has a mass of 3.64 kg when it is empty and a mass of 51.8 kg when it is filled to a certain level. What is the mass of the water in the tank?
- The length of a room is 16.40 m, its width is 4.5 m, and its height is 3.26 m. What volume does the room enclose?
- The sides of a quadrangular plot of land are 132.68 m, 48.3 m, 132.736 m, and 48.37 m. What is the perimeter of the plot?

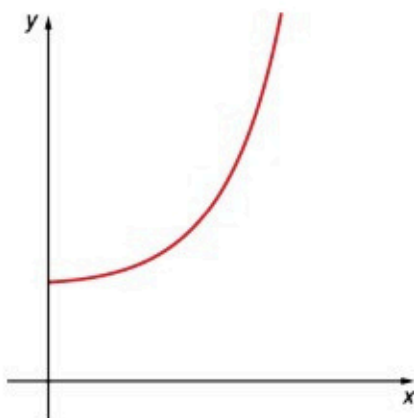
- Estimate the height of the nearest door frame in centimeters. Then measure it. How accurate was your estimate? How precise was your estimate? How precise was your measurement? Why are the two precisions different?
- Temperature** The temperature drops linearly from 24°C to 10°C in 12 hours.
 - Find the average temperature change per hour.
 - Predict the temperature in 2 more hours if the trend continues.
 - Could you accurately predict the temperature in 24 hours? Explain why or why not.

Module 1 continued

Lesson 4 Graphing Data

Mastering Concepts

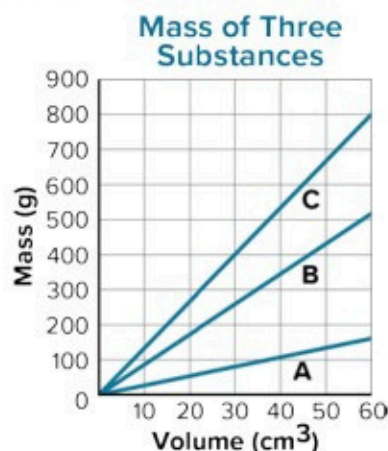
27. How do you find the slope of a linear graph?
28. When driving, the distance traveled between seeing a stoplight and stepping on the brakes is called the reaction distance. Reaction distance for a given driver and vehicle depends linearly on speed.
- Would the graph of reaction distance versus speed have a positive or a negative slope?
 - A driver who is distracted takes a longer time to step on the brake than a driver who is not. Would the graph of reaction distance versus speed for a distracted driver have a larger or smaller slope than for a normal driver? Explain.
29. During a laboratory experiment, the temperature of the gas in a balloon is varied and the volume of the balloon is measured. Identify the independent variable and the dependent variable.
30. What type of relationship is shown in the graph? Give the general equation for this type of relation.



31. Given the equation $F = mv^2/R$, what relationship exists between each of the following?
- F and R
 - F and m
 - F and v

Mastering Problems

32. The graph shows the masses of three substances for volumes between 0 and 60 cm³.



- What is the mass of 30 cm³ of each substance?
- If you had 100 g of each substance, what would be its volume?
- In one or two sentences, describe the meaning of the slopes of the lines in this graph.
- Explain the meaning of each line's y-intercept.

Module 1 continued

33. Suppose a mass is placed on a horizontal table that is nearly frictionless. Various horizontal forces are applied to the mass. The distance the mass traveled in 5 seconds for each force applied is measured. The results of the experiment are shown in **Table 1**.

Table 1	
Distance Traveled with Different Forces	
Force (N)	Distance (cm)
5.0	24
10.0	49
15.0	75
20.0	99
25.0	120
30.0	145

- Plot the values given in the table and draw the curve that best fits all points.
- Describe the resulting curve.
- Use the graph to write an equation relating the distance to the force.
- What is the constant in the equation? Find its units.
- Predict the distance traveled when a 22.0-N force is exerted on the object for 5 s.

34. Suppose the procedure from the previous problem changed. The mass was varied while the force was kept constant. Time and distance were measured, and the acceleration of each mass was calculated. The results of the experiment are shown in **Table 2**.

Table 2	
Acceleration of Different Masses	
Mass (kg)	Acceleration (m/s^2)
1.0	12.0
2.0	5.9
3.0	4.1
4.0	3.0
5.0	2.5
6.0	2.0

- Plot the values given in the table and draw the curve that best fits all points.
- Describe the resulting curve.
- Write the equation relating acceleration to mass given by the data in the graph.
- Find the units of the constant in the equation.
- Predict the acceleration of an 8.0-kg mass.

Module 1 continued

35. During an experiment, a student measured the mass of 10.0 cm^3 of alcohol. The student then measured the mass of 20.0 cm^3 of alcohol. In this way, the data in **Table 3** were collected.

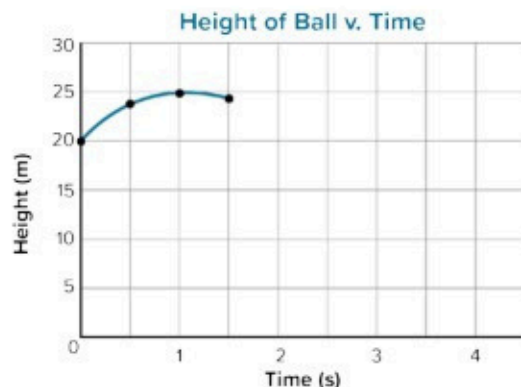
Table 3	
The Mass Values of Specific Volumes of Alcohol	
Volume (cm^3)	Mass (g)
10.0	7.9
20.0	15.8
30.0	23.7
40.0	31.6
50.0	39.6

- Plot the values given in the table and draw the curve that best fits all the points.
- Describe the resulting curve.
- Use the graph to write an equation relating the volume to the mass of the alcohol.
- Find the units of the slope of the graph. What is the name given to this quantity?
- What is the mass of 32.5 cm^3 of alcohol?

Applying Concepts

- Is a scientific method one set of clearly defined steps? Support your answer.
- Explain the difference between a scientific theory and a scientific law.

38. The graph shows the height above the ground of a ball that is thrown upward from the roof of a building, for the first 1.5 s of its trajectory. What is the ball's height at $t = 0$? Predict the ball's height at $t = 2 \text{ s}$ and at $t = 5 \text{ s}$.



- Density** The density of a substance is its mass divided by its volume.
 - Give the metric units for density.
 - Is the unit for density a base unit or a derived unit?
- What metric unit would you use to measure each of the following?
 - the width of your hand
 - the thickness of a book cover
 - the height of your classroom
 - the distance from your home to your classroom
- Size** Make a chart of sizes of objects. Lengths should range from less than 1 mm to several kilometers. Samples might include the size of a cell, the distance light travels in 1 s, and the height of a room.
- Time** Make a chart of time intervals. Sample intervals might include the time between heartbeats, the time between presidential elections, the average lifetime of a human, and the age of the United States. In your chart, include several examples of very short and very long time intervals.

Module 1 continued

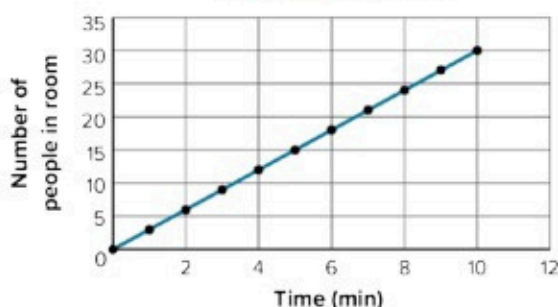
- 43. Speed of Light** Two scientists measure the speed of light. One obtains $(3.001 \pm 0.001) \times 10^8$ m/s; the other obtains $(2.999 \pm 0.006) \times 10^8$ m/s.
- Which is more precise?
 - Which is more accurate?
- 44.** You measure the dimensions of a desk as 132 cm, 83 cm, and 76 cm. The sum of these measures is 291 cm, while the product is 8.3×10^5 cm³. Explain how the significant figures were determined in each case.
- 45. Money** Suppose you receive \$15.00 at the beginning of a week and spend \$2.50 each day for lunch. You prepare a graph of the amount you have left at the end of each day for one week. Would the slope of this graph be positive, zero, or negative? Why?
- 46.** Data are plotted on a graph, and the value on the y-axis is the same for each value of the independent variable. What is the slope? Why? How does y depend on x ?
- 47. Driving** The graph of braking distance versus car speed is part of a parabola. Thus, the equation is written $d = av^2 + bv + c$. The distance (d) has units in meters, and velocity (v) has units in meters/second. How could you find the units of a , b , and c ? What would they be?
- 48.** How long is the leaf in the image? Include the uncertainty in your measurement.



- 49.** Explain the difference between a hypothesis and a scientific theory.
- 50.** Give an example of a scientific law.

- 51.** What reason might the ancient Greeks have had not to question the hypothesis that heavier objects fall faster than lighter objects? *Hint: Did you ever question which falls faster?*
- 52.** A graduated cylinder is marked every mL. How precise a measurement can you make with this instrument?
- 53. Reverse Problem** Write a problem with real-life objects for which the graph could be part of the solution.

Number of People in a Room over Time



Mixed Review

- 54.** Arrange the following numbers from most precise to least precise
0.0034 m 45.6 m 1234 m
- 55.** You are cracking a code and have discovered the following conversion factors: 1.23 longs = 23.0 mediums, and 74.5 mediums = 645 shorts. How many shorts are equal to one long?
- 56.** You are given the following measurements of a rectangular bar: length = 2.347 m, thickness = 3.452 cm, height = 2.31 mm, mass = 1659 g. Determine the volume, in cubic meters, and density, in g/cm³, of the beam.

Module 1 continued

57. A drop of water contains 1.7×10^{21} molecules. If the water evaporated at the rate of one million molecules per second, how many years would it take for the drop to completely evaporate?
58. A 17.6-gram sample of metal is placed in a graduated cylinder containing 10.0 cm^3 of water. If the water level rises to 12.20 cm^3 , what is the density of the metal?

Thinking Critically

59. **Apply Concepts** It has been said that fools can ask more questions than the wise can answer. In science, it is frequently the case that one wise person is needed to ask the right question rather than to answer it. Explain.
60. **Apply Concepts** Find the approximate mass of water in kilograms needed to fill a container that is 1.40 m long and 0.600 m wide to a depth of 34.0 cm. Report your result to one significant figure. (Use a reference source to find the density of water.)
61. **Analyze and Conclude** A container of gas with a pressure of 101 kPa has a volume of 324 cm^3 and a mass of 4.00 g. If the pressure is increased to 404 kPa, what is the density of the gas? Pressure and volume are inversely proportional.
62. **Design an Experiment** How high can you throw a ball? What variables might affect the answer to this question?
63. **Problem Posing** Complete this problem so that the final answer will have 3 significant digits: "A home remedy used to prevent swimmer's ear calls for equal parts vinegar and rubbing alcohol. You measure 45.62 mL of vinegar...."

Writing in Physics

64. Research and describe a topic in the history of physics. Explain how ideas about the topic changed over time. Be sure to include the contributions of scientists and to evaluate the impact of the contributions on scientific thought and the world outside the laboratory.
65. Explain how improved precision in measuring time would have led to more accurate predictions about how an object falls.

2 Representing Motion

ENCOUNTER THE PHENOMENON

Write the Encounter the Phenomenon question for this module.

Use the “What I Know” column to list the things you know about the Encounter the Phenomenon question. Then list the questions you have about the Encounter the Phenomenon question in the “What I Want to Find Out” column. As you read the module, fill in the “What I Learned” column.

K <i>What I Know</i>	W <i>What I Want to Find Out</i>	L <i>What I Learned</i>

Representing Motion

1 Picturing Motion

REVIEW VOCABULARY

model

Recall and write the definition of the Review Vocabulary term.

model

NEW VOCABULARY

motion diagram

particle model

Use your book to define each term.

motion diagram

particle model

1 Picturing Motion (continued)

Get It? Describe how the picture in **Figure 1** would be different if the train were sitting still.

Summarize information about the many kinds of motion in three or four statements.

All Kinds of Motion

Get It? Identify two factors you must know in order to describe the motion of an object along a straight line.

Motion Diagrams

Describe a scenario that is not in the textbook in which photographs can be used to describe the motion of an object.

Describe what a motion diagram is in your own words.

1 Picturing Motion (continued)

Particle Models

Compare and contrast a motion diagram and a particle model.

Get It? Describe how you would model the motion of the hiker at the beginning of this module.

CHECK YOUR PROGRESS

1. Representing Motion How does a motion diagram represent an object's motion?

2. Bike Motion Diagram Draw a particle model motion diagram for a bike rider moving at a constant pace along a straight path.



1 Picturing Motion (continued)

3. **Car Motion Diagram** Draw a particle model motion diagram corresponding to the motion diagram in **Figure 4** for a car coming to a stop at a stop sign. What point on the car did you use to represent the car?



Figure 4

4. **Bird Motion Diagram** Draw a particle model motion diagram corresponding to the motion diagram in **Figure 5** for a flying bird. What point on the bird did you choose to represent the bird?



Figure 5

5. **Critical Thinking** Draw particle model motion diagrams for two runners during a race in which the first runner crosses the finish line as the other runner is three-fourths of the way to the finish line.

Representing Motion

2 Where and When?

REVIEW VOCABULARY

dimension

Recall and write the definition of the Review Vocabulary term.

dimension

NEW VOCABULARY

Use your book to fill in the term that matches each definition.

change in position having both magnitude and direction

difference between two times

distance and direction from the origin to the object

entire length of an object's path

a system used to describe motion that gives the location of the zero point of the variable and the direction in which the values of the variables increase

point at which all variables in a coordinate system have the value zero

quantity that has both magnitude and direction

quantity that is just a number without any direction

the size of a quantity

vector that represents the sum of two other vectors

2 Where and When? (continued)

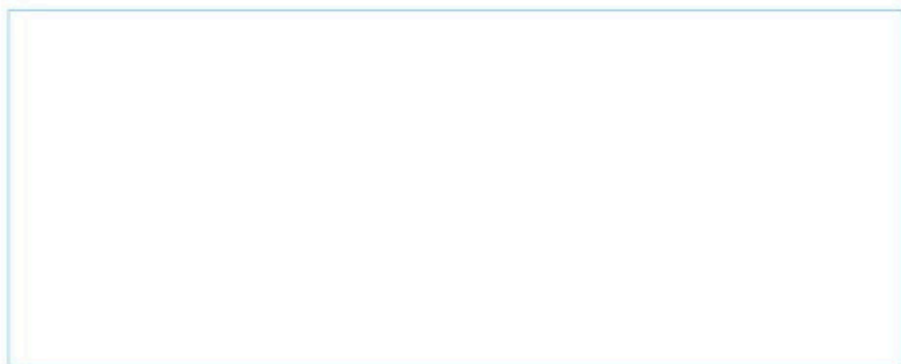
Coordinate Systems

Summarize how a coordinate system is used to diagram motion.

Fill in the blanks.

You can indicate how far an object is from the origin of a coordinate system by drawing an _____ from the _____ to the point that represents the object. This arrow represents the object's _____. In general, the _____ is the entire length of an object's path, even if the object moves in many directions.

Draw a motion diagram for an object. Add the particle model diagram below the motion diagram. Add a coordinate system for the motion diagram below the particle model diagram. The starting point of the object should be the zero point.



Explain how an object can have a negative position in a coordinate system.

2 Where and When? (continued)

Vectors and Scalars

Get It? Explain how positive and negative positions are determined.

Fill in the blanks about vectors and scalars.

A quantity that has both magnitude and direction is called a _____. You can represent a _____ with an arrow. The _____ of the arrow represents the magnitude. The _____ of the arrow represents the _____ of the vector. A quantity that is a number without direction is a _____.

Get It? Describe the difference between a vector and a scalar.

Describe what the direction and length of a displacement arrow indicate.

CHECK YOUR PROGRESS

6. Coordinate System Identify a coordinate system you could use to describe the motion of a girl swimming across a rectangular pool.

2 Where and When? (continued)

7. **Displacement** The motion diagram for a car traveling on an interstate highway is shown below. The starting and ending points are indicated. Make a copy of the diagram. Draw a vector to represent the car's displacement from the starting time to the end of the third time interval.

Start End

8. **Position** Two students added a vector for a moving object's position at $t = 2$ s to a motion diagram. When they compared their diagrams, they found that their vectors did not point in the same direction. Explain.

9. **Displacement** The motion diagram for a boy walking to school is shown below. Make a copy of this motion diagram, and draw vectors to represent the displacement between each pair of dots.

Home School

Representing Motion

3 Position-Time Graphs

REVIEW VOCABULARY

intersection

Recall and write the definition of the Review Vocabulary term.

intersection

NEW VOCABULARY

position-time graph

instantaneous position

Use your book to define each term.

position-time graph

instantaneous position

Finding Positions

Summarize the information about finding positions.

3 Position-Time Graphs (continued)

Multiple Objects on a Position-Time Graph

List five methods you can use to describe motion.

Describe in a few short sentences how plotting the motion of multiple objects on a position-time graph can be useful.

Get It? **Explain** what the intersection of two lines on a position-time graph means.

Use with Example Problem 2.

Use this column for scratch work and sketches.

TRY IT!

Problem

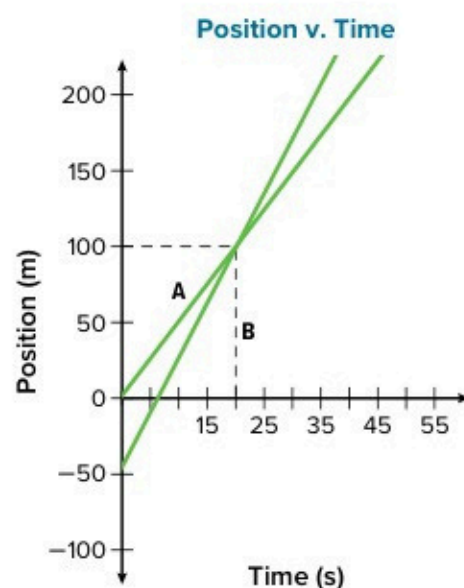
The lines on the graph represent the motions of two runners along a straight path. When and where does runner B pass runner A?

1. ANALYZE THE PROBLEM

Restate the questions.

Question 1: At what time are the runners at the same position?

Question 2: What is the position of the runners at this time?



3 Position-Time Graphs (continued)

TRY IT! (CONTINUED)

2. SOLVE FOR THE UNKNOWN

Question 1: Examine the graph to find the intersection of the lines representing the motions of the two runners.

Question 2: Examine the graph to determine the position when the lines representing the motion of the runners intersect.

CHECK YOUR PROGRESS

- 20. Particle Diagram** Using the particle model motion diagram in **Figure 16** of a baby crawling across a kitchen floor, plot a position-time graph to represent the baby's motion. The time interval between successive dots on the diagram is 1 s.

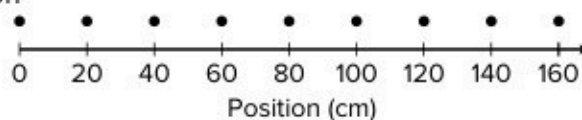


Figure 16

3 Position-Time Graphs (continued)

For problems 21–24, refer to **Figure 17**.

- 21. Particle Model** Create a particle model motion diagram from the position-time graph of a hockey puck gliding across the ice.



Figure 17

Time (s)					
Position (m)					

- 22. Time** Use the hockey puck's position-time graph to determine the time when the puck was 10.0 m beyond the origin. _____
- 23. Distance** Use the position-time graph to determine how far the hockey puck moved between 0.0 s and 5.0 s. _____
- 24. Time Interval** Use the position-time graph for the hockey puck to determine how much time it took for the puck to go from 40 m beyond the origin to 80 m beyond the origin. _____
- 25. Critical Thinking** Look at the diagram and graph shown in **Figure 18**. Do they describe the same motion? Explain. The time intervals in the particle model diagram are 2 s.

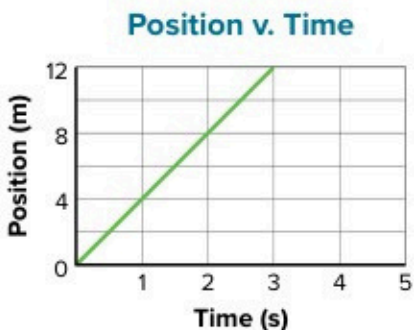
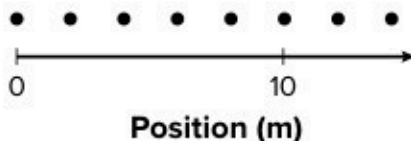


Figure 18

Representing Motion

4 How Fast?

REVIEW VOCABULARY

absolute value

NEW VOCABULARY

average velocity

average speed

instantaneous velocity

Velocity and Speed

Recall and write the definition of the Review Vocabulary term.

absolute value

Use your book to answer the questions below.

1. What is the difference between average velocity and instantaneous velocity?

2. Define the term *average speed*.

Summarize the information about velocity and speed using a few sentences.

Get It? Explain In the graph in **Figure 19**, the graph for both joggers starts at the coordinates (0,0). Explain what this means in terms of position.

4 How Fast? (continued)

Get It? Explain the meaning of a position-time graph slope that is upward or downward, and above or below the x-axis.

Get It? Explain how average velocity is different from velocity.

Get It? Identify what the lengths of velocity vectors mean.

Equation of Motion

Complete the table showing how general variables compare to specific motion variables.

General Variable	Specific Motion Variable
y	
m	
x	
b	

4 How Fast? (continued)

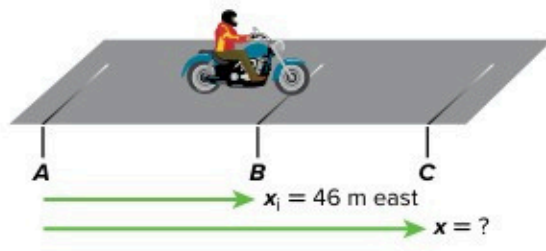
Use with Example Problem 4.

Use this column for scratch work and sketches.

TRY IT!

Problem

Position The figure shows a motorcyclist traveling east along a straight road. After passing point **B**, the cyclist continues to travel at an average velocity of 18 m/s east and arrives at point **C** 2.8 s later. What is the position of point **C**?



1. ANALYZE AND SKETCH THE PROBLEM

Choose a coordinate system with the origin at A.

KNOWNs

UNKNOWN

$\bar{v} =$ _____ $t =$ _____ _____ = ?

$x_i =$ _____

2. SOLVE FOR THE UNKNOWN

Use the equation for position.

3. EVALUATE THE ANSWER

- Are the units correct?

- Does the direction make sense?

4 How Fast? (continued)

CHECK YOUR PROGRESS

36. Velocity and Position How is an object's velocity related to its position?

For problems 37–39, refer to **Figure 25**.

37. Ranking Task Rank the position-time graphs according to the average speed, from greatest average speed to least average speed. Specifically indicate any ties.

38. Contrast Average Velocities Describe differences in the average velocities shown on the graph for objects A and B. Describe differences in the average velocities shown on the graph for objects C and D.

39. Ranking Task Rank the graphs in **Figure 25** according to each object's initial position, from most positive position to most negative position. Specifically indicate any ties. Would your ranking be different if you ranked according to initial distance from the origin?

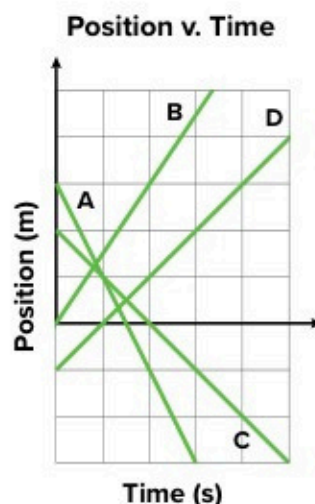


Figure 25

4 How Fast? (continued)

- 40. Average Speed and Average Velocity** Explain how average speed and average velocity are related to each other for an object in uniform motion.

- 41. Position** Two cars are traveling along a straight road, as shown in **Figure 26**. They pass each other at point B and then continue in opposite directions. The orange car travels for 0.25 h from point B to point C at a constant velocity of 32 km/h east. The blue car travels for 0.25 h from point B to point D at a constant velocity of 48 km/h west. How far has each car traveled from point B? What is the position of each car relative to the origin, point A?

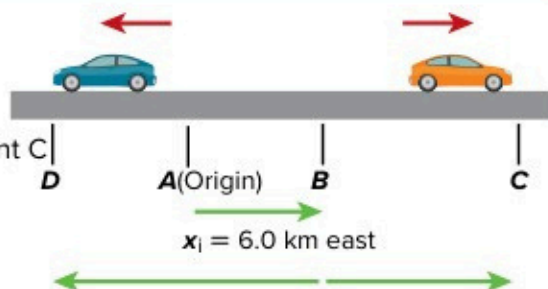


Figure 26

- 42. Position** A car travels north along a straight highway at an average speed of 85 km/h. After driving 2.0 km, the car passes a gas station and continues along the highway. What is the car's position relative to the start of its trip 0.25 h after it passes the gas station?
- 43. Critical Thinking** In solving a physics problem, why is it important to create pictorial and physical models before trying to solve an equation?

Lesson 1 Picturing Motion

Mastering Concepts

1. What is the purpose of drawing a motion diagram?
2. Under what circumstances is it legitimate to treat an object as a particle when solving motion problems?

Lesson 2 Where and When?

Mastering Concepts

3. The following quantities describe location or its change: position, distance, and displacement. Briefly describe the differences among them.
4. How can you use a clock to find a time interval?

Lesson 3 Position-Time Graphs

Mastering Concepts

5. **In-line Skating** How can you use the position-time graphs for two in-line skaters to determine if and when one in-line skater will pass the other one?

Lesson 4 How Fast?

Mastering Concepts

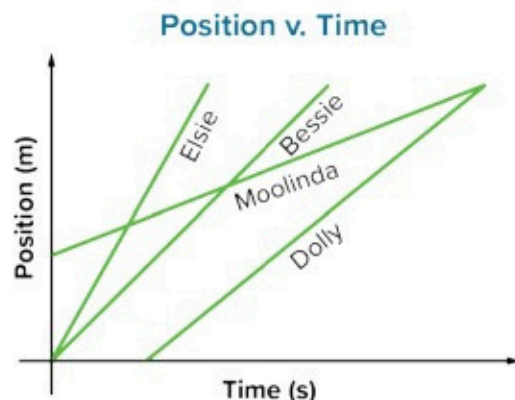
6. Which equation describes how the average velocity of a moving object relates to its displacement?
7. **Walking Versus Running** A walker and a runner leave your front door at the same time. They move in the same direction at different constant velocities. Describe the position-time graphs of each.
8. What does the slope of a position-time graph measure?
9. If you know the time it took an object to travel between two points and the positions of the object at the points, can you determine the object's instantaneous velocity? Its average velocity? Explain.

Mastering Problems

10. You ride a bike at a constant speed of 4.0 m/s for 5.0 s. How far do you travel?
11. **Astronomy** Light from the Sun reaches Earth in about 8.3 min. The speed of light is 3.00×10^8 m/s. What is the distance from the Sun to Earth?
12. **Problem Posing** Complete this problem so that someone must solve it using the concept of average speed: "A butterfly travels 15 m from one flower to another...."
13. Nora jogs several times a week and always keeps track of how much time she runs each time she goes out. One day she forgets to take her stopwatch with her and wonders if there is a way she can still have some idea of her time. As she passes a particular bank building, she remembers that it is 4.3 km from her house. She knows from her previous training that she has a consistent pace of 4.0 m/s. How long has Nora been jogging when she reaches the bank?
14. **Driving** You and a friend each drive 50.0 km. You travel at 90.0 km/h; your friend travels at 95.0 km/h. How much sooner will your friend finish the trip?

Applying Concepts

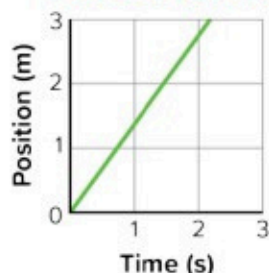
15. **Ranking Task** The position-time graph represents the motion of four cows walking from the pasture back to the barn. Rank the cows according to their average velocity, from slowest to fastest.



Module 2 continued

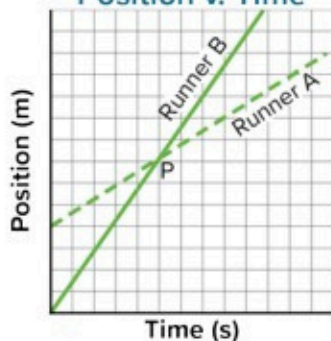
16. The position-time graph represents a rabbit running away from a dog. How would the graph differ if the rabbit ran twice as fast? How would it differ if the rabbit ran in the opposite direction?

Position v. Time



17. Test the following combinations and explain why each does not have the properties needed to describe the concept of velocity: $\Delta x + \Delta t$, $\Delta x - \Delta t$, $\Delta x \times \Delta t$, $\Delta t/\Delta x$.
18. **Football** When solving physics problems, what must be true about the motion of a football in order for you to treat the football as if it were a particle?
19. This graph represents two people running.

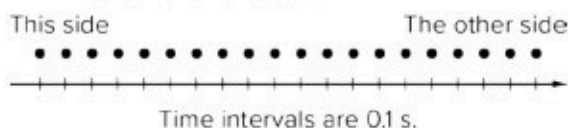
Position v. Time



- Describe the position of runner A relative to runner B at the y-intercept.
- Which runner is faster?
- What occurs at point P and beyond?

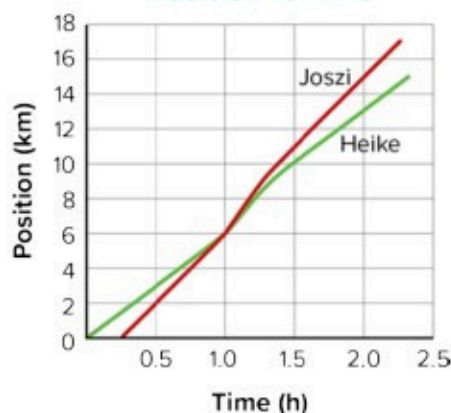
Mixed Review

20. **Cycling** A cyclist traveling along a straight path maintains a constant velocity of 5.0 m/s west. At time $t = 0.0$ s, the cyclist is 250 m west of point A.
- Plot a position-time graph of the cyclist's location from point A at 10.0-s intervals for a total time of 60.0 s.
 - What is the cyclist's position from point A at 60.0 s?
 - What is the displacement from the starting position at 60.0 s?
21. The particle model diagram represents a chicken casually walking across a road. Time intervals in the model are every 0.1 s. Draw the corresponding position-time graph, and write an equation to describe the chicken's motion.



22. The position-time graph represents Joszi and Heike paddling canoes in a local river.

Position v. Time



- At what time(s) are Joszi and Heike in the same place?
- How long is Joszi paddling before passing Heike?
- Where on the river does it appear that there might be a swift current?

Module 2 continued

- 23. Driving** Both car A and car B leave school when a stopwatch reads zero. Car A travels at a constant 75 km/h, and car B travels at a constant 85 km/h.

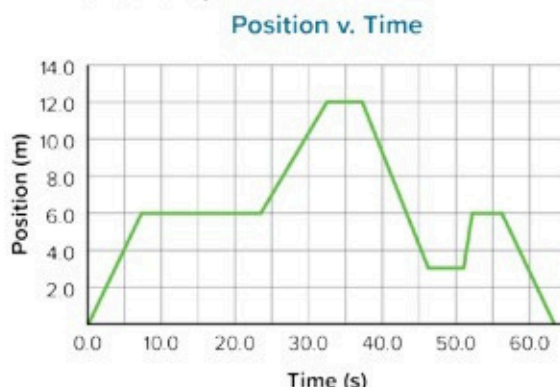
- Draw a position-time graph showing the motion of both cars over 3 hours. How far are the two cars from school when the stopwatch reads 2.0 h? Calculate the distances and show them on your graph.
- Both cars passed a gas station 120 km from the school. When did each car pass the gas station? Calculate the times and show them on your graph.

- 24.** Draw a position-time graph for two cars traveling to a beach that is 50 km from school. At noon, Car A leaves a store that is 10 km closer to the beach than the school is and moves at 40 km/h. Car B starts from school at 12:30 P.M. and moves at 100 km/h. When does each car get to the beach?

- 25.** Two cars travel along a straight road. When a stopwatch reads $t = 0.00$ h, car A is at $x_A = 48.0$ km moving at a constant speed of 36.0 km/h. Later, when the watch reads $t = 0.50$ h, car B is at $x_B = 0.00$ km moving at 48.0 km/h. Answer the following questions, first graphically by creating a position-time graph, and then algebraically by writing equations for the positions x_A and x_B as a function of the stopwatch time, t .

- What will the watch read when car B passes car A?
- At what position will car B pass car A?
- When the cars pass, how long will it have been since car A was at the reference point?

- 26.** The graph represents Jim's movement along a straight path. The origin is at one end of the path.



- Reverse Problem** Write a story describing Jim's movements along the path that would correspond to the motion represented by the graph.
- When is Jim 6.0 m from the origin?
- How much time passes between when Jim starts moving and when he is 12.0 m from the origin?
- What is Jim's average velocity between 37.0 s and 46.0 s?

Thinking Critically

- 27. Apply Calculators** Members of a physics class stood 25 m apart and used stopwatches to measure the time at which a car traveling on the highway passed each person. **Table 2** shows their data.

Time (s)	Position (m)
0.0	0.0
1.3	25.0
2.7	50.0
3.6	75.0
5.1	100.0
5.9	125.0
7.0	150.0
8.6	175.0
10.3	200.0

Use a graphing calculator to fit a line to a position-time graph of the data and to plot this line. Be sure to set the display range of the graph so that all the data fit on it. Find the line's slope. What was the car's speed?

Module 2 continued

- 28. Apply Concepts** You want to average 90 km/h on a car trip. You cover the first half of the distance at an average speed of 48 km/h. What average speed must you have for the second half of the trip to meet your goal? Is this reasonable? Note that the velocities are based on half the distance, not half the time.
- 29. Design an Experiment** Every time someone drives a particular red motorcycle past your friend's home, his father becomes angry. He thinks the motorcycle is going too fast for the posted 25 mph (40 km/h) speed limit. Describe a simple experiment you could do to determine whether the motorcycle is speeding the next time it passes your friend's house.
- 30. Interpret Graphs** Is it possible for an object's position-time graph to be a horizontal line? A vertical line? If you answer yes to either situation, describe the associated motion in words.

Writing in Physics

- 31.** Physicists have determined that the speed of light is 3.00×10^8 m/s. How did they arrive at this number? Read about some of the series of experiments that scientists have performed to determine light's speed. Describe how the experimental techniques improved to make the experiments' results more accurate.
- 32.** Some species of animals have good endurance, while others have the ability to move very quickly, but for only a short amount of time. Use reference sources to find two examples of each quality, and describe how it is helpful to that animal.

3 Accelerated Motion

ENCOUNTER THE PHENOMENON

Write the Encounter the Phenomenon question for this module.

Use the “What I Know” column to list the things you know about the Encounter the Phenomenon question. Then list the questions you have about the Encounter the Phenomenon question in the “What I Want to Find Out” column. As you read the module, fill in the “What I Learned” column.

K <i>What I Know</i>	W <i>What I Want to Find Out</i>	L <i>What I Learned</i>

Accelerated Motion

1 Acceleration

REVIEW VOCABULARY

vector

Recall and write the definition of the Review Vocabulary term.

vector

NEW VOCABULARY

acceleration

velocity-time graph

average acceleration

instantaneous acceleration

Use your book to define each term.

acceleration

velocity-time graph

average acceleration

instantaneous acceleration

1 Acceleration (continued)

Draw particle model diagrams with vectors to represent the indicated motion.

A person speeding up

A person slowing down

Get It? Analyze What do increasing and decreasing lengths of velocity vectors indicate on a motion diagram?

Identify two main ideas about the direction of acceleration.

Get It? Describe the motion of an object if its velocity and acceleration vectors have opposite signs.

1 Acceleration (continued)

Summarize What information can be determined using a velocity-time graph?

Get It? Identify What can you conclude about the acceleration of an object if the graph of its motion is a straight line on a velocity-time graph?

Get It? Describe the meaning of a line crossing the x-axis in a velocity-time graph.

Describe how you determine the instantaneous acceleration of an object from a velocity-time graph.

Get It? Contrast How is instantaneous acceleration different from average acceleration?

Identify the equation that you use to calculate the average acceleration of an object.

1 Acceleration (continued)

Use with Example
Problem 2.

Use this column for
scratch work and
sketches.

TRY IT!

Problem

ACCELERATION Describe a ball's motion as it rolls up a slanted driveway. It starts with an initial velocity of 1.25 m/s up the ramp. It travels upward, while slowing down, for 4.22 s, stops for an instant, and then rolls back down. What are the direction and the magnitude of the ball's acceleration as it rolls up the driveway?

1. ANALYZE AND SKETCH THE PROBLEM

Set up the coordinate system Choose the positive direction to be up the driveway. Place the origin where the motion begins.

KNOWN

$$v_i = \underline{\hspace{2cm}}$$

$$v_f = \underline{\hspace{2cm}} \text{ at } t = \underline{\hspace{2cm}}$$

UNKNOWN

$$\underline{\hspace{2cm}} = ?$$

2. SOLVE FOR THE UNKNOWN

Solve for the change in velocity and the time taken to make that change.

Use the definition of acceleration.

3. EVALUATE THE ANSWER

- Are the units correct? $\underline{\hspace{2cm}}$
- Do the directions make sense? $\underline{\hspace{2cm}}$

Get It? Describe the evidence that the planes at the beginning of this module are accelerating even if they are traveling at a constant speed.

1 Acceleration (continued)

CHECK YOUR PROGRESS

11. Describing Motion What are three ways an object can accelerate?

12. Position-Time and Velocity-Time Graphs Two joggers run at a constant velocity of 7.5 m/s east. **Figure 10** shows the positions of both joggers at time $t = 0$.



Figure 10

a. What would be the difference(s) in the position-time graphs of their motion?

b. What would be the difference(s) in their velocity-time graphs?

13. Velocity-Time Graph Sketch a velocity-time graph for a car that goes east at 25 m/s for 100 s, then west at 25 m/s for another 100 s.

1 Acceleration (continued)

14. Average Velocity and Average Acceleration A canoeist paddles upstream at a velocity of 2.0 m/s for 4.0 s and then floats downstream at 4.0 m/s for 4.0 s .

- a. What is the average velocity of the canoe during the 8.0-s time interval?
- b. What is the average acceleration of the canoe during the 8.0-s time interval?

15. Critical Thinking A police officer clocked a driver going 32 km/h over the speed limit just as the driver passed a slower car. When the officer stopped the car, the driver argued that the other driver should get a ticket as well. The driver said that the cars must have been going the same speed because they were observed next to each other. Is the driver correct? Explain with a sketch and a motion diagram.

Accelerated Motion

2 Motion with Constant Acceleration

REVIEW VOCABULARY

displacement

Recall and write the definition of the Review Vocabulary term.

displacement

Explain why the slope of a velocity-time graph is the average acceleration of the object.

Get It? Identify What is the shape of a position-time graph of an object traveling with constant acceleration?

Get It? Identify What is the shape of a velocity-time graph of an object traveling with constant acceleration?

2 Motion with Constant Acceleration (continued)

Write the equation that relates final velocity and average acceleration below. Explain what each variable means.

$v_f =$ $+ \overline{a}$

Use with Example Problem 3.

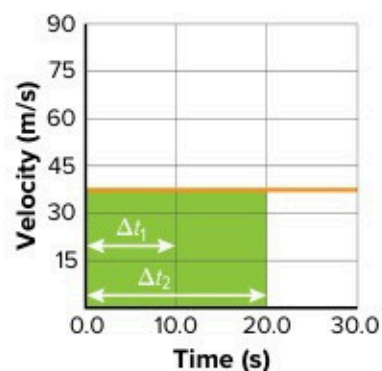
Use this column for scratch work and sketches.

TRY IT!

Problem

FINDING DISPLACEMENT FROM A VELOCITY-TIME GRAPH

The velocity-time graph shows the motion of a car traveling at a constant velocity of + 37.6 m/s (forward is the positive direction). Find the displacement of the car for $\Delta t_1 = 10.0$ s and for $\Delta t_2 = 20.0$ s.



1. ANALYZE AND SKETCH THE PROBLEM

KNOWNs

$$v = \underline{\hspace{2cm}}$$

$$\Delta t_1 = \underline{\hspace{2cm}}$$

$$\Delta t_2 = \underline{\hspace{2cm}}$$

UNKNOWNs

$$\underline{\hspace{2cm}} = ?$$

$$\underline{\hspace{2cm}} = ?$$

2 Motion with Constant Acceleration (continued)

TRY IT! (CONTINUED)

2. SOLVE FOR THE UNKNOWN

Use the relationship among displacement, velocity, and time interval to find Δx_1 during $\Delta t_1 = 10.0$ s.

Use the same relationship to find Δx_2 during $\Delta t_2 = 20.0$ s.

3. EVALUATE THE ANSWER

- Do the signs make sense? _____
- Is the magnitude realistic? _____

Write the equation that relates position, velocity, and constant acceleration without including time. Then, explain in words what the equation means.

2 Motion with Constant Acceleration (continued)

CHECK YOUR PROGRESS

33. Displacement Given initial and final velocities and the constant acceleration of an object, what mathematical relationship would you use to find the displacement?

34. Acceleration A woman driving west along a straight road at a speed of 23 m/s sees a deer on the road ahead. She applies the brakes when she is 210 m from the deer. If the deer does not move and the car stops right before it hits the deer, what is the acceleration provided by the car's brakes?

35. Distance The airplane in **Figure 18** starts from rest and accelerates east at a constant 3.00 m/s^2 for 30.0 s before leaving the ground.



Figure 18

- What was the plane's displacement (Δx)?
- How fast was the airplane going when it took off?

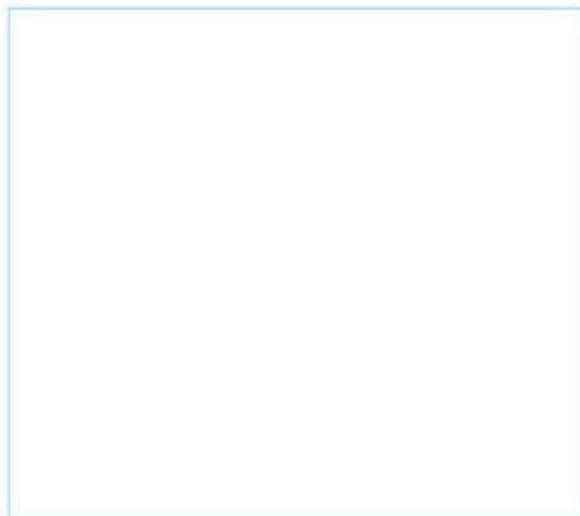
2 Motion with Constant Acceleration (continued)

36. Distance An in-line skater first accelerates from 0.0 m/s to 5.0 m/s in 4.5 s, then continues at this constant speed for another 4.5 s. What is the total distance traveled by the in-line skater?

37. Final Velocity A plane travels a distance of 5.0×10^2 m north while being accelerated uniformly from rest at the rate of 5.0 m/s^2 . What final velocity does it attain?

38. Final Velocity An airplane accelerated uniformly from rest at the rate of 5.0 m/s^2 south for 14 s. What final velocity did it attain?

39. Graphs A sprinter walks up to the starting blocks at a constant speed and positions herself for the start of the race. She waits until she hears the starting pistol go off and then accelerates rapidly until she attains a constant velocity. She maintains this velocity until she crosses the finish line, and then she slows to a walk, taking more time to slow down than she did to speed up at the beginning of the race. Sketch a velocity-time and a position-time graph to represent her motion. Draw them one above the other using the same time scale. Indicate on your position-time graph where the starting blocks and finish line are.



Accelerated Motion

3 Free Fall

REVIEW VOCABULARY

origin

Recall and write the definition of the Review Vocabulary term.

origin

NEW VOCABULARY

Use your book to fill in the term that matches each definition.

acceleration of an object due only to the effect of gravity

motion of an object when gravity is the only significant force acting on it

Complete the following statements about free-fall acceleration.

- Free fall is the motion of an object when _____
- Galileo discovered that, neglecting the effect of air, all objects in free fall _____
- Galileo's results were verified _____
- Near Earth's surface, free-fall acceleration is _____

3 Free Fall (continued)

Describe the acceleration experiment by astronaut David Scott in 1971.

Get It? Identify Why is it important to clearly define the coordinate system you want to use when analyzing objects in free fall?

Get It? Analyze During which second does the rising ball stop and reverse direction? How can you tell?

Get It? Describe If you throw a ball straight up, what would the shape of its position-time graph look like?

Get It? Analyze If you throw a ball straight up, what are its velocity and acceleration at the uppermost point of its path?

3 Free Fall (continued)

Derive simplified equations that you could use to calculate an object's displacement and final velocity when it starts at rest a height (h) above the ground and then goes into free fall at constant acceleration. Begin with the generic equations for displacement ($x_f = x_i + v_i t_f + \left(\frac{1}{2}\right) \bar{a} t_f^2$) and velocity ($v_f = v_i + \bar{a} t_f$). Assume the positive axis is upward and that this scenario occurs near Earth's surface where $g = 9.8 \text{ m/s}^2$ downward.

Displacement

Velocity

Use the equations you just derived to find the velocity and position of a ball that was dropped from a height of 10.0 m after it has fallen for 1.0 s.

Identify three main ideas about variations in free fall.

3 Free Fall (continued)

CHECK YOUR PROGRESS

- 46. Free Fall** Suppose you hold a book in one hand and a flat sheet of paper in another hand. You drop them both, and they fall to the ground. Explain why the falling book is a good example of free fall, but the paper is not.

- 47. Final Velocity** Your sister drops your house keys down to you from the second-floor window, as shown in **Figure 25**. What is the velocity of the keys when you catch them?

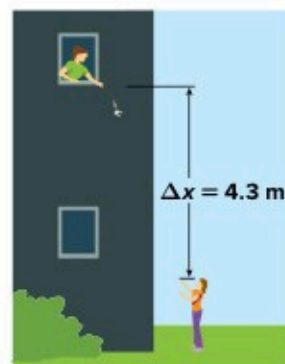


Figure 25

- 48. Free-Fall Ride** Suppose a free-fall ride at an amusement park starts at rest and is in free fall. What is the velocity of the ride after 2.3 s? How far do people on the ride fall during the 2.3-s time period?

3 Free Fall (continued)

49. Maximum Height and Flight Time The free-fall acceleration on Mars is about one-third that on Earth. Suppose you throw a ball upward with the same velocity on Mars as on Earth.

a. How would the ball's maximum height compare to that on Earth?

b. How would its flight time compare?

50. Velocity and Acceleration Suppose you throw a ball straight up into the air. Describe the changes in the velocity of the ball. Describe the changes in the acceleration of the ball.

51. Critical Thinking A ball thrown vertically upward continues upward until it reaches a certain position, and then falls downward. The ball's velocity is instantaneously zero at that highest point. Is the ball accelerating at that point? Devise an experiment to prove or disprove your answer.

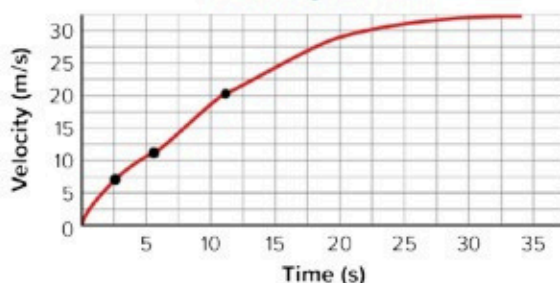
Lesson 1 Acceleration

Mastering Concepts

- How are velocity and acceleration related?
- Give an example of each of the following:
 - an object that is slowing down, but has a positive acceleration
 - an object that is speeding up but has a negative acceleration
 - an object that is moving at a constant speed but has an acceleration

- The velocity-time graph represents an automobile on a test track. Describe how the velocity changes with time.

Velocity v. Time



- If an object's velocity-time graph is a straight line parallel to the horizontal axis, what can you conclude about the object's acceleration?

Mastering Problems

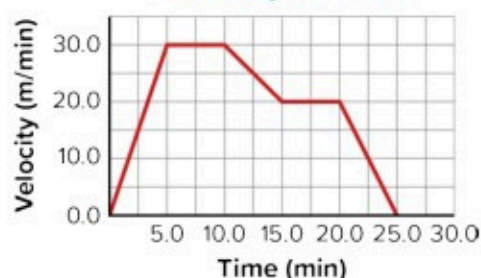
- Ranking Task** Rank the following objects according to the magnitude of the acceleration, from least to greatest. Specifically indicate any ties.
 - A falling acorn accelerates from 0.50 m/s to 10.3 m/s in 1.0 s.
 - A car accelerates from 20 m/s to rest in 1.0 s.
 - A centipede accelerates from 0.40 cm/s to 2.0 cm/s in 0.50 s.
 - While being hit, a golf ball accelerates from rest to 4.3 m/s in 0.40 s.
 - A jogger accelerates from 2.0 m/s to 1.0 m/s in 8.3 s.

- Problem Posing** Complete this problem so that it can be solved using the concept listed: "Angela is playing basketball ..."

- acceleration
- speed

- The graph describes the motion of an object moving east along a straight path. Find the acceleration of the object at each of the times.

Velocity v. Time



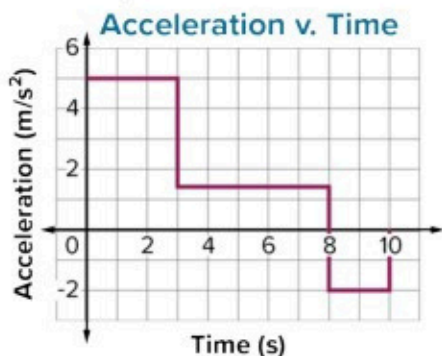
- during the first 5.0 min of travel
 - between 5.0 min and 10.0 min
 - between 10.0 min and 15.0 min
 - between 20.0 min and 25.0 min
- Plot a velocity-time graph using the information in **Table 1**, and answer the following questions:
 - During what time interval is the object speeding up? Slowing down?
 - At what time does the object reverse direction?
 - How does the average acceleration of the object between 0.0 s and 2.0 s differ from the average acceleration between 7.0 s and 12.0 s?
 - Determine the final velocity of a proton that has an initial forward velocity of 2.35×10^5 m/s and then is accelerated uniformly in an electric field at the rate of -1.10×10^{12} m/s² for 1.50×10^{-7} s.
 - Sports Cars** Marco wants to buy a used sports car with the greatest acceleration. Car A can go from 0 m/s to 17.9 m/s in 4.0 s. Car B can accelerate from 0 m/s to 22.4 m/s in 3.5 s. Car C can go from 0 to 26.8 m/s in 6.0 s. Rank the three cars from greatest acceleration to least. Indicate if any are the same.

Module 3 continued

Lesson 2 Motion with Constant Acceleration

Mastering Concepts

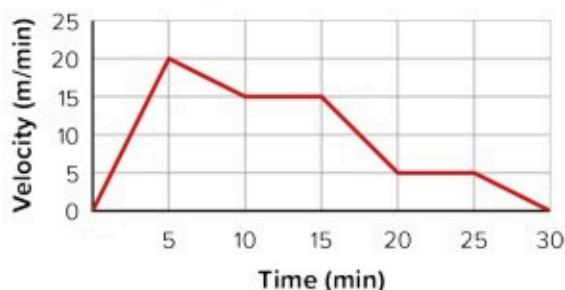
11. What quantity does the area under a velocity-time graph represent?
12. **Reverse Problem** Write a physics problem with real-life objects for which the graph would be part of the solution.



Mastering Problems

13. A car moves forward up a hill at 12 m/s with a uniform backward acceleration of 1.6 m/s^2 .
 - a. What is its displacement after 6.0 s?
 - b. What is its displacement after 9.0 s?
14. **Airplane** Determine the displacement of a plane that experiences uniform acceleration from 66 m/s north to 88 m/s north in 12 s.
15. **Race Car** A race car is slowed with a constant acceleration of 11 m/s^2 , opposite the direction of motion.
 - a. If the car is going 55 m/s, how many meters will it travel before it stops?
 - b. How many meters will it take to stop a car going twice as fast?
16. Refer to the graph to find the magnitude of the displacement during the following time intervals. Round answers to the nearest meter.

Velocity v. Time



- a. $t = 5.0 \text{ min}$ and $t = 10.0 \text{ min}$
- b. $t = 10.0 \text{ min}$ and $t = 15.0 \text{ min}$
- c. $t = 25.0 \text{ min}$ and $t = 30.0 \text{ min}$
- d. $t = 0.0 \text{ min}$ and $t = 25.0 \text{ min}$

Section 3 Free Fall

Mastering Concepts

17. Explain why an aluminum ball and a steel ball of similar size and shape, dropped from the same height, reach the ground at the same time.
18. Give some examples of falling objects for which air resistance can and cannot be ignored.

Mastering Problems

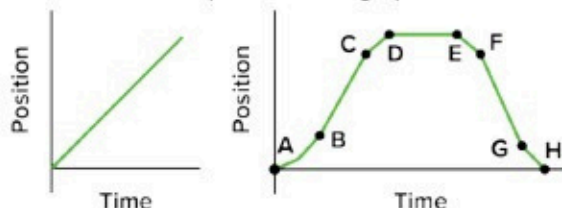
19. Suppose an astronaut drops a feather from a height of 1.2 m above the surface of the Moon. If the free-fall acceleration on the Moon is 1.62 m/s^2 downward, how long does it take the feather to hit the Moon's surface?
20. A stone that starts at rest is in free fall for 8.0 s.
 - a. Calculate the stone's velocity after 8.0 s.
 - b. What is the stone's displacement during this time?
21. A bag is dropped from a hovering helicopter. The bag has fallen for 2.0 s. What is the bag's velocity? How far has the bag fallen? Ignore air resistance.

Module 3 continued

22. You throw a ball downward from a window at a speed of 2.0 m/s. How fast will it be moving when it hits the sidewalk 2.5 m below?
23. If you throw the ball in the previous problem up instead of down, how fast will it be moving when it hits the sidewalk?
24. **Beanbag** You throw a beanbag in the air and catch it 2.2 s later at the same place at which you threw it.
- How high did it go?
 - What was its initial velocity?

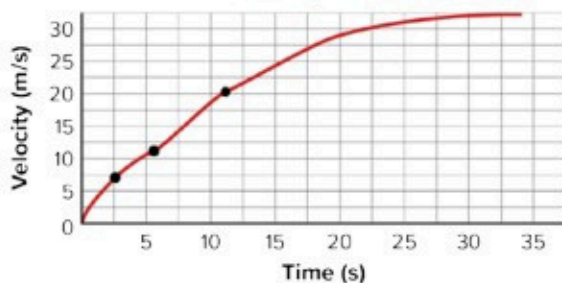
Applying Concepts

25. **Croquet** A croquet ball, after being hit by a mallet, slows down and stops. Do the velocity and the acceleration of the ball have the same signs?
26. Explain how you would walk to produce each of the position-time graphs.

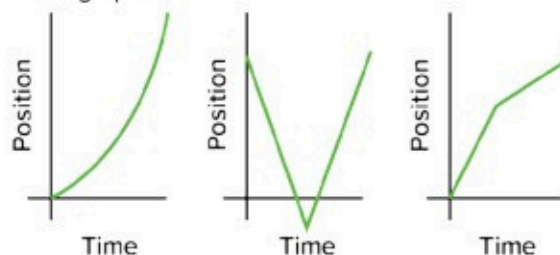


27. If you were given a table of velocities of an object at various times, how would you determine whether the acceleration was constant?
28. The three notches in the graph occur where the driver changed gears. Describe the changes in velocity and acceleration of the car while in first gear. Is the acceleration just before a gear change larger or smaller than the acceleration just after the change? Explain your answer.

Velocity v. Time



29. An object shot straight up rises for 7.0 s before it reaches its maximum height. A second object falling from rest takes 7.0 s to reach the ground. Compare the displacements of the two objects during this time interval.
30. Draw a velocity-time graph for each of the graphs.



31. **The Moon** The value of free-fall acceleration on the Moon is about one-sixth of its value on Earth.
- Would a ball dropped by an astronaut hit the surface of the Moon with a greater, equal, or lesser speed than that of a ball dropped from the same height to Earth?
 - Would it take the ball more, less, or equal time to fall?
32. **Jupiter** An object on the planet Jupiter has about three times the free-fall acceleration as on Earth. Suppose a ball could be thrown vertically upward with the same initial velocity on Earth and on Jupiter. Neglect the effects of Jupiter's atmospheric resistance and assume that gravity is the only force on the ball.
- How would the maximum height reached by the ball on Jupiter compare to the maximum height reached on Earth?
 - If the ball on Jupiter were thrown with an initial velocity that is three times greater, how would this affect your answer to part a?
33. Rock A is dropped from a cliff, and rock B is thrown upward from the same position.
- When they reach the ground at the bottom of the cliff, which rock has a greater velocity?
 - Which has a greater acceleration?
 - Which arrives first?

Module 3 continued

Mixed Review

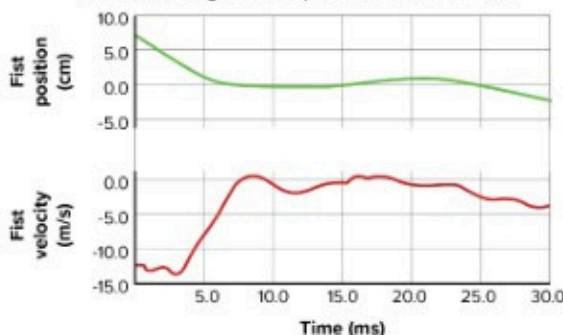
- 34.** Suppose a spaceship far from any star or planet uniformly accelerates from 65.0 m/s to 162.0 m/s in 10.0 s. How far would the spaceship move?
- 35. Bicycle** A bicycle accelerates from 0.0 m/s to 4.0 m/s in 4.0 s. What distance does it travel?
- 36.** A weather balloon is floating at a constant height above Earth when it releases a pack of instruments.
- If the pack hits the ground with a downward velocity of -73.5 m/s, how far did the pack fall?
 - How long did it take for the pack to fall?
- 37.** The total distance a steel ball rolls down an incline at various times is given in **Table 2**.
- Draw a position-time graph of the motion of the ball. When setting up the axes, use five divisions for each 10 m of travel on the x -axis. Use five divisions for 1 s of time on the t -axis.
 - Calculate the distance the ball has rolled at the end of 2.2 s.
- 38.** Engineers are developing new types of guns that might someday be used to launch satellites as if they were bullets. One such gun can give a small object a forward velocity of 3.5 km/s while moving it through a distance of only 2.0 cm.
- What acceleration does the gun give this object?
 - Over what time interval does the acceleration take place?
- 39. Baseball** A baseball pitcher throws a fastball at a speed of 44 m/s. The ball has constant acceleration as the pitcher holds it in his hand and moves it through an almost straight-line distance of 3.5 m. Calculate the acceleration. Compare this acceleration to the free-fall acceleration on Earth.
- 40. Sleds** Rocket-powered sleds are used to test the responses of humans to acceleration. Starting from rest, one sled can reach a speed of 444 m/s in 1.80 s and can be brought to a stop again in 2.15 s.
- Calculate the acceleration of the sled when starting, and compare it to the magnitude of free-fall acceleration, 9.8 m/s².
 - Find the acceleration of the sled as it is braking, and compare it to the magnitude of free-fall acceleration.
- 41.** The forward velocity of a car changes over an 8.0-s time period, as shown in the table.

Table	
Velocity v. Time	
Time (s)	Velocity (m/s)
0.0	0.0
1.0	4.0
2.0	8.0
3.0	12.0
4.0	16.0
5.0	20.0
6.0	20.0
7.0	20.0
8.0	20.0

- Plot the velocity-time graph of the motion.
 - Determine the displacement of the car during the first 2.0 s.
 - What displacement does the car have during the first 4.0 s?
 - What is the displacement of the car during the entire 8.0 s?
 - Find the slope of the line between $t = 0.0$ s and $t = 4.0$ s. What does this slope represent?
 - Find the slope of the line between $t = 5.0$ s and $t = 7.0$ s. What does this slope indicate?
- 42.** A truck is stopped at a stoplight. When the light turns green, the truck accelerates at 2.5 m/s². At the same instant, a car passes the truck going at a constant 15 m/s. Where and when does the truck catch up with the car?

Module 3 continued

- 43. Karate** The position-time and velocity-time graphs of George's fist breaking a wooden board during karate practice are shown.



- Use the velocity-time graph to describe the motion of George's fist during the first 10 ms.
 - Estimate the slope of the velocity-time graph to determine the acceleration of his fist when it suddenly stops.
 - Express the acceleration as a multiple of the magnitude of free-fall acceleration, 9.8 m/s^2 .
 - Determine the area under the velocity-time curve to find the displacement of the fist in the first 6 ms. Compare this with the position-time graph.
- 44. Cargo** A helicopter is rising at 5.0 m/s when a bag of its cargo is dropped. The bag falls for 2.0 s .
- What is the bag's velocity?
 - How far has the bag fallen?
 - How far below the helicopter is the bag?

Thinking Critically

- 45. Apply CBLs** Design a lab to measure the distance an accelerated object moves over time. Use equal time intervals so that you can plot velocity over time as well as distance. A pulley at the edge of a table with a mass attached is a good way to achieve uniform acceleration. Suggested materials include a motion detector, CBL, lab cart, string, pulley, C-clamp, and masses. Generate position-time and velocity-time graphs using different masses on the pulley. How does the change in mass affect your graphs?

- 46. Analyze and Conclude** Which (if either) has the greater acceleration: a car that increases its speed from 50 km/h to 60 km/h or a bike that goes from 0 km/h to 10 km/h in the same time? Explain.

- 47. Analyze and Conclude** An express train traveling at 36.0 m/s is accidentally sidetracked onto a local train track. The express engineer spots a local train exactly $1.00 \times 10^2 \text{ m}$ ahead on the same track and traveling in the same direction. The local engineer is unaware of the situation. The express engineer jams on the brakes and slows the express train at a constant rate of 3.00 m/s^2 . If the speed of the local train is 11.0 m/s , will the express train be able to stop in time, or will there be a collision? To solve this problem, take the position of the express train when the engineer first sights the local train as a point of origin. Next, keeping in mind that the local train has exactly a $1.00 \times 10^2 \text{ m}$ lead, calculate how far each train is from the origin at the end of the 12.0 s it would take the express train to stop (accelerate at 23.00 m/s^2 from 36 m/s to 0 m/s).

- On the basis of your calculations, would you conclude that a collision will occur?
- To check the calculations from part **a**, and to verify your conclusion, take the position of the express train when the engineer first sights the local train as the point of origin and calculate the position of each train at the end of each second after the sighting. Make a table showing the distance of each train from the origin at the end of each second. Plot these positions on the same graph and draw two lines. Compare your graph to your answer to part **a**.

Writing in Physics

- 48.** Research and describe Galileo's contributions to physics.
- 49.** Research the maximum acceleration a human body can withstand without blacking out. Discuss how this impacts the design of three common entertainment or transportation devices.