Chapter 1

A Physics Toolkit

What You'll Learn

- You will use mathematical tools to measure and predict.
- You will apply accuracy and precision when measuring.
- You will display and evaluate data graphically.

Why It's Important

The measurement and mathematics tools presented here will help you to analyze data and make predictions.

Satellites Accurate and precise measurements are important when constructing and launching a satellite—errors are not easy to correct later. Satellites, such as the *Hubble Space Telescope* shown here, have revolutionized scientific research, as well as communications.

Think About This ▶

Physics research has led to many new technologies, such as satellite-based telescopes and communications. What are some other examples of tools developed from physics research in the last 50 years?

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LAUNCH Lab

Do all objects fall at the same rate?

Question

How does weight affect the rate at which an object falls?

Procedure

The writings of the Greek philosopher Aristotle included works on physical science theories. These were a major influence in the late Middle Ages. Aristotle reasoned that weight is a factor governing the speed of fall of a dropped object, and that the rate of fall must increase in proportion to the weight of the object.

1. Tape four pennies together in a stack.
2. Place the stack of pennies on your hand and place a single penny beside them.
3. **Observe** Which is heaviest and pushes down on your hand the most?
4. **Observe** Drop the two at the same time and observe their motions.

Analysis

According to Aristotle, what should be the rate of fall of the single penny compared to the stack? What did you observe?

Critical Thinking Explain which of the following properties might affect the rate of fall of an object: size, mass, weight, color, shape.

1.1 Mathematics and Physics

What do you think of when you see the word *physics?* Many people picture a chalkboard covered with formulas and mathematics: $E = mc^2$, $I = V/R$, $d = \frac{1}{2}at^2 + v_0t + d_0$. Perhaps you picture scientists in white lab coats, or well-known figures such as Marie Curie and Albert Einstein. Or, you might think of the many modern technologies created with physics, such as weather satellites, laptop computers, or lasers.

► **Objectives**

- **Demonstrate** scientific methods.
- **Use** the metric system.
- **Evaluate** answers using dimensional analysis.
- **Perform** arithmetic operations using scientific notation.

► **Vocabulary**

physics
dimensional analysis
significant digits
scientific method
hypothesis
scientific law
scientific theory

What is Physics?

Physics is a branch of science that involves the study of the physical world: energy, matter, and how they are related. Physicists investigate the motions of electrons and rockets, the energy in sound waves and electric circuits, the structure of the proton and of the universe. The goal of this course is to help you understand the physical world.

People who study physics go on to many different careers. Some become scientists at universities and colleges, at industries, or in research institutes. Others go into related fields, such as astronomy, engineering, computer science, teaching, or medicine. Still others use the problem-solving skills of physics to work in business, finance, or other very different disciplines.

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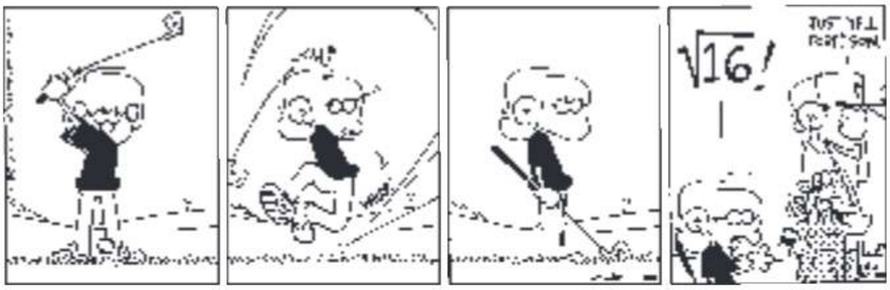
Figure 1-1 Physicists use mathematics to represent many different phenomena—a trait sometimes spoofed in cartoons.



Mathematics in Physics

Physics uses mathematics as a powerful language. As illustrated in **Figure 1-1,** this use of mathematics often is spoofed in cartoons. In physics, equations are important tools for modeling observations and for making predictions. Physicists rely on theories and experiments with numerical results to support their conclusions. For example, think back to the Launch Lab. You can predict that if you drop a penny, it will fall. But how fast? Different models of falling objects give different answers to how the speed of the object changes, or on what the speed depends, or which objects will fall. By measuring how an object falls, you can compare the experimental data with the results predicted by different models. This tests the models, allowing you to pick the best one, or to develop a new model.

▶ EXAMPLE **Problem 1**

Electric Current The potential difference, or voltage, across a circuit equals the current multiplied by the resistance in the circuit. That is, V (volts) = I (amperes) × R (ohms). What is the resistance of a lightbulb that has a 0.75 amperes current when plugged into a 120-volt outlet?

1 Analyze the Problem

- Rewrite the equation.
- Substitute values.

Known:	Unknown:
$I = 0.75$ amperes	$R = ?$
$V = 120$ volts	

2 Solve for the Unknown

Rewrite the equation so the unknown is alone on the left.

$$V = IR$$

$$IR = V \quad \text{Reflexive property of equality}$$

$$R = \frac{V}{I} \quad \text{Divide both sides by } I.$$

$$= \frac{120 \text{ volts}}{0.75 \text{ amperes}} \quad \text{Substitute 120 volts for } V \text{, 0.75 amperes for } I.$$

$$= 160 \text{ ohms} \quad \text{Resistance will be measured in ohms.}$$

Math Handbook
Isolating a Variable
page 845

3 Evaluate the Answer

- **Are the units correct?** 1 volt = 1 ampere-ohm, so the answer in volts/ampere is in ohms, as expected.
- **Does the answer make sense?** 120 is divided by a number a little less than 1, so the answer should be a little more than 120.

CONTENTS

PRACTICE Problems

Additional Problems, Appendix B

For each problem, give the rewritten equation you would use and the answer.

1. A lightbulb with a resistance of 50.0 ohms is used in a circuit with a 9.0-volt battery. What is the current through the bulb?
2. An object with uniform acceleration *a*, starting from rest, will reach a speed of *v* in time *t* according to the formula $v = at$. What is the acceleration of a bicyclist who accelerates from rest to 7 m/s in 4 s?
3. How long will it take a scooter accelerating at 0.400 m/s^2 to go from rest to a speed of 4.00 m/s?
4. The pressure on a surface is equal to the force divided by the area: $P = F/A$. A 53-kg woman exerts a force (weight) of 520 Newtons. If the pressure exerted on the floor is 32,500 N/m^2, what is the area of the soles of her shoes?

Does it make sense? Sometimes you will work with unfamiliar units, as in Example Problem 1, and you will need to use estimation to check that your answer makes sense mathematically. At other times you can check that an answer matches your experience, as shown in **Figure 1-2.** When you work with falling objects, for example, check that the time you calculate an object will take to fall matches your experience—a copper ball dropping 5 m in 0.002 s, or in 17 s, doesn't make sense.

The Math Handbook in the back of this book contains many useful explanations and examples. Refer to it as needed.

Figure 1-2 What is a reasonable range of values for the speed of an automobile?

SI Units

To communicate results, it is helpful to use units that everyone understands. The worldwide scientific community and most countries currently use an adaptation of the metric system to state measurements. The Système International d'Unités, or SI, uses seven base quantities, which are shown in **Table 1-1.** These base quantities were originally defined in terms of direct measurements. Other units, called derived units, are created by combining the base units in various ways. For example, energy is measured in joules, where 1 joule equals one kilogram-meter squared per second squared, or $1\ J = 1\ kg \cdot m^2/s^2$. Electric charge is measured in coulombs, where $1\ C = 1\ A \cdot s$.

Table 1-1
SI Base Units

Base Quantity	Base Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of a substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	cd

Mark E. Gibson

■ **Figure 1-3** The standards for the kilogram and meter are shown. The International Prototype Meter originally was measured as the distance between two marks on a platinum-iridium bar, but as methods of measuring time became more precise than those for measuring length, the meter came to be defined as the distance traveled by light in a vacuum in 1/299 792 458 s.

Scientific institutions have been created to define and regulate measures. The SI system is regulated by the International Bureau of Weights and Measures in Sèvres, France. This bureau and the National Institute of Science and Technology (NIST) in Gaithersburg, Maryland keep the standards of length, time, and mass against which our metersticks, clocks, and balances are calibrated. Examples of two standards are shown in **Figure 1-3.** NIST works on many problems of measurement, including industrial and research applications.

You probably learned in math class that it is much easier to convert meters to kilometers than feet to miles. The ease of switching between units is another feature of the metric system. To convert between SI units, multiply or divide by the appropriate power of 10. Prefixes are used to change SI units by powers of 10, as shown in **Table 1-2.** You often will encounter these prefixes in daily life, as in, for example, milligrams, nanoseconds, and gigabytes.

Table 1-2
Prefixes Used with SI Units

Prefix	Symbol	Multiplier	Scientific Notation	Example
femto-	f	0.000000000000001	10^{-15}	femtosecond (fs)
pico-	p	0.000000000001	10^{-12}	picometer (pm)
nano-	n	0.000000001	10^{-9}	nanometer (nm)
micro-	μ	0.000001	10^{-6}	microgram (μg)
milli-	m	0.001	10^{-3}	milliamps (mA)
centi-	c	0.01	10^{-2}	centimeter (cm)
deci-	d	0.1	10^{-1}	deciliter (dL)
kilo-	k	1000	10^{3}	kilometer (km)
mega-	M	1,000,000	10^{6}	megagram (Mg)
giga-	G	1,000,000,000	10^{9}	gigameter (Gm)
tera-	T	1,000,000,000,000	10^{12}	terahertz (THz)

Dimensional Analysis

Math Handbook
Dimensional Analysis
page 847

You can use units to check your work. You often will need to use different versions of a formula, or use a string of formulas, to solve a physics problem. To check that you have set up a problem correctly, write out the equation or set of equations you plan to use. Before performing calculations, check that the answer will be in the expected units, as shown in step 3 of Example Problem 1. For example, if you are finding a speed and you see that your answer will be measured in s/m or m/s^2, you know you have made an error in setting up the problem. This method of treating the units as algebraic quantities, which can be cancelled, is called **dimensional analysis.**

Dimensional analysis also is used in choosing conversion factors. A conversion factor is a multiplier equal to 1. For example, because 1 kg = 1000 g, you can construct the following conversion factors:

$$1 = \frac{1\ \text{kg}}{1000\ \text{g}} \qquad\qquad 1 = \frac{1000\ \text{g}}{1\ \text{kg}}$$

Choose a conversion factor that will make the units cancel, leaving the answer in the correct units. For example, to convert 1.34 kg of iron ore to grams, do as shown below.

$$1.34\ \cancel{\text{kg}}\left(\frac{1000\ \text{g}}{1\ \cancel{\text{kg}}}\right) = 1340\ \text{g}$$

You also might need to do a series of conversions. To convert 43 km/h to m/s, do the following:

$$\left(\frac{43\ \cancel{\text{km}}}{1\ \cancel{\text{h}}}\right)\left(\frac{1000\ \text{m}}{1\ \cancel{\text{km}}}\right)\left(\frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}}\right)\left(\frac{1\ \cancel{\text{min}}}{60\ \text{s}}\right) = 12\ \text{m/s}$$

PRACTICE Problems | **Additional Problems, Appendix B**

Use dimensional analysis to check your equation before multiplying.

5. How many megahertz is 750 kilohertz?

6. Convert 5021 centimeters to kilometers.

7. How many seconds are in a leap year?

8. Convert the speed 5.30 m/s to km/h.

Significant Digits

Suppose you use a meterstick to measure a pen, and you find that the end of the pen is just past 14.3 cm. This measurement has three valid digits: two you are sure of, and one you estimated. The valid digits in a measurement are called **significant digits.** The last digit given for any measurement is the uncertain digit. All nonzero digits in a measurement are significant.

Are all zeros significant? No. For example, in the measurement 0.0860 m, the first two zeros serve only to locate the decimal point and are not significant. The last zero, however, is the estimated digit and is significant. The measurement 172,000 m could have 3, 4, 5, or 6 significant digits. This ambiguity is one reason to use scientific notation: it is clear that the measurement 1.7200×10^{5} m has five significant digits.

Math Handbook
Significant Digits
pages 833–836

Arithmetic with significant digits When you perform any arithmetic operation, it is important to remember that the result never can be more precise than the least-precise measurement.

To add or subtract measurements, first perform the operation, then round off the result to correspond to the least-precise value involved. For example, 3.86 m + 2.4 m = 6.3 m because the least-precise measure is to one-tenth of a meter.

To multiply or divide measurements, perform the calculation and then round to the same number of significant digits as the least-precise measurement. For example, 409.2 km/11.4 L = 35.9 km/L, because the least-precise measure has three significant digits.

Some calculators display several additional digits, as shown in **Figure 1-4,** while others round at different points. Be sure to record your answers with the correct number of digits. Note that significant digits are considered only when calculating with measurements. There is no uncertainty associated with counting (4 washers) or exact conversion factors (24 hours in 1 day).

Figure 1-4 This answer to 3.9 ÷ 7.2 should be rounded to two significant digits.

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PRACTICE Problems

Additional Problems, Appendix B

Solve the following problems.

9. a. 6.201 cm + 7.4 cm + 0.68 cm + 12.0 cm

b. 1.6 km + 1.62 m + 1200 cm

10. a. 10.8 g − 8.264 g

b. 4.75 m − 0.4168 m

11. a. 139 cm × 2.3 cm

b. 3.2145 km × 4.23 km

12. a. 13.78 g ÷ 11.3 mL

b. 18.21 g ÷ 4.4 cm^3

MINI LAB

Measuring Change

Collect five identical washers and a spring that will stretch measurably when one washer is suspended from it.

1. **Measure** the length of the spring with zero, one, two, and three washers suspended from it.
2. **Graph** the length of the spring versus the mass.
3. **Predict** the length of the spring with four and five washers.
4. **Test** your prediction.

Analyze and Conclude

5. **Describe** the shape of the graph. How did you use it to predict the two new lengths?

Scientific Methods

In physics class, you will make observations, do experiments, and create models or theories to try to explain your results or predict new answers, as shown in **Figure 1-5.** This is the essence of a **scientific method.** All scientists, including physicists, obtain data, make predictions, and create compelling explanations that quantitatively describe many different phenomena. The experiments and results must be reproducible; that is, other scientists must be able to recreate the experiment and obtain similar data. Written, oral, and mathematical communication skills are vital to every scientist.

A scientist often works with an idea that can be worded as a **hypothesis,** which is an educated guess about how variables are related. How can the hypothesis be tested? Scientists conduct experiments, take measurements, and identify what variables are important and how they are related. For example, you might find that the speed of sound depends on the medium through which sound travels, but not on the loudness of the sound. You can then predict the speed of sound in a new medium and test your results.

a

b

■ **Figure 1-5** These students are conducting an experiment to determine how much power they produce climbing the stairs **(a).** They use their data to predict how long it would take an engine with the same power to lift a different load **(b).**

Laura Sifferlin

CONTENTS

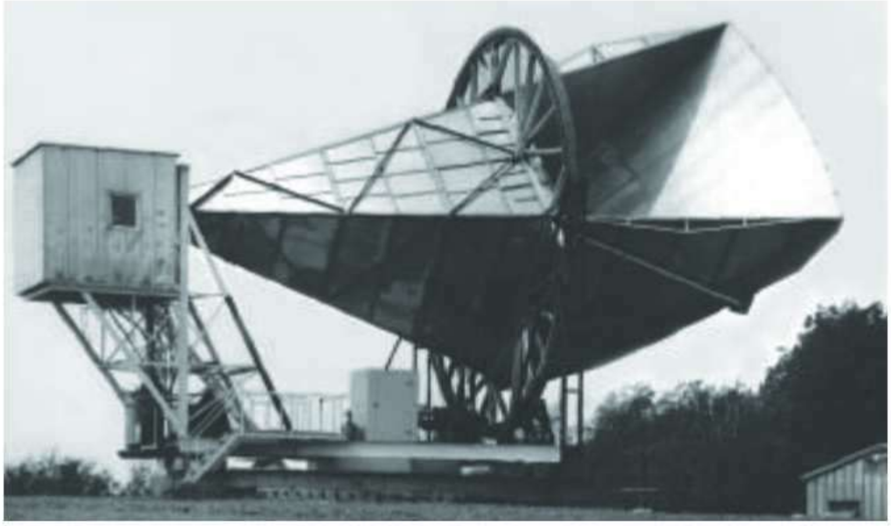

Figure 1-6 In the mid-1960s, Arno Penzias and Robert Wilson were trying to eliminate the constant background noise in an antenna to be used for radio astronomy. They tested systems, duct-taped seams, and cleared out pigeon manure, but the noise persisted. This noise is now understood to be the cosmic microwave background radiation, and is experimental support for the Big Bang theory.

Models, laws, and theories An idea, equation, structure, or system can model the phenomenon you are trying to explain. Scientific models are based on experimentation. Recall from chemistry class the different models of the atom that were in use over time—new models were developed to explain new observations and measurements.

If new data do not fit a model, both are re-examined. **Figure 1-6** shows a historical example. If a very well-established model is questioned, physicists might first look at the new data: can anyone reproduce the results? Were there other variables at work? If the new data are born out by subsequent experiments, the theories have to change to reflect the new findings. For example, in the nineteenth century it was believed that linear markings on Mars showed channels, as shown in **Figure 1-7a.** As telescopes improved, scientists realized that there were no such markings, as shown in **Figure 1-7b.** In recent times, again with better instruments, scientists have found features that suggest Mars once had running and standing water on its surface, as shown in **Figure 1-7c.** Each new discovery has raised new questions and areas for exploration.

A **scientific law** is a rule of nature that sums up related observations to describe a pattern in nature. For example, the law of conservation of charge states that in the various changes matter can undergo, the electric charge before and after stays the same. The law of reflection states that the angle of incidence for a light beam on a reflective surface equals the angle of reflection. Notice that the laws do not explain why these phenomena happen, they simply describe them.

Figure 1-7 Drawings of early telescope observations **(a)** showed channels on Mars; recent photos taken with improved telescopes do not **(b).** In this photo of Mars' surface from the *Mars Global Surveyor* spacecraft **(c),** these layered sedimentary rocks suggest that sedimentary deposits might have formed in standing water.

(t)Tom Pantages, (bc)NASA, (others)Photo Researchers

Figure 1-8 Theories are changed and modified as new experiments provide insight and new observations are made. The theory of falling objects has undergone many revisions.

Greek philosophers proposed that objects fall because they seek their natural places. The more massive the object, the faster it falls.

↓ **Revision**

Galileo showed that the speed at which an object falls depends on the amount of time it falls, not on its mass.

↓ **Revision**

Galileo's statement is true, but Newton revised the reason why objects fall. Newton proposed that objects fall because the object and Earth are attracted by a force. Newton also stated that there is a force of attraction between any two objects with mass.

↓ **Revision**

Galileo's and Newton's statements still hold true. However, Einstein suggested that the force of attraction between two objects is due to mass causing the space around it to curve.

A **scientific theory** is an explanation based on many observations supported by experimental results. Theories may serve as explanations for laws. A theory is the best available explanation of why things work as they do. For example, the theory of universal gravitation states that all the mass in the universe is attracted to other mass. Laws and theories may be revised or discarded over time, as shown in **Figure 1-8.** Notice that this use of the word *theory* is different from the common use, as in "I have a theory about why it takes longer to get to school on Fridays." In scientific use, only a very well-supported explanation is called a theory.

1.1 Section Review

13. Math Why are concepts in physics described with formulas?

14. Magnetism The force of a magnetic field on a charged, moving particle is given by $F = Bqv$, where F is the force in kg·m/s^2, q is the charge in A·s, and v is the speed in m/s. B is the strength of the magnetic field, measured in teslas, T. What is 1 tesla described in base units?

15. Magnetism A proton with charge 1.60×10^{-19} A·s is moving at 2.4×10^5 m/s through a magnetic field of 4.5 T. You want to find the force on the proton.

a. Substitute the values into the equation you will use. Are the units correct?

b. The values are written in scientific notation, $m\times10^n$. Calculate the 10^n part of the equation to estimate the size of the answer.

c. Calculate your answer. Check it against your estimate from part b.

d. Justify the number of significant digits in your answer.

16. Magnetism Rewrite $F = Bqv$ to find v in terms of F, q, and B.

17. Critical Thinking An accepted value for the acceleration due to gravity is 9.801 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.

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CONTENTS

1.2 Measurement

When you visit the doctor for a checkup, many measurements are taken: your height, weight, blood pressure, and heart rate. Even your vision is measured and assigned a number. Blood might be drawn so measurements can be made of lead or cholesterol levels. Measurements quantify our observations: a person's blood pressure isn't just "pretty good," it's 110/60, the low end of the good range.

What is a measurement? A **measurement** is a comparison between an unknown quantity and a standard. For example, if you measure the mass of a rolling cart used in an experiment, the unknown quantity is the mass of the cart and the standard is the gram, as defined by the balance or spring scale you use. In the Mini Lab in Section 1.1, the length of the spring was the unknown and the centimeter was the standard.

▶ **Objectives**

- **Distinguish** between accuracy and precision.
- **Determine** the precision of measured quantities.

▶ **Vocabulary**

measurement
precision
accuracy

Comparing Results

As you learned in Section 1.1, scientists share their results. Before new data are fully accepted, other scientists examine the experiment, looking for possible sources of error, and try to reproduce the results. Results often are reported with an uncertainty. A new measurement that is within the margin of uncertainty confirms the old measurement.

For example, archaeologists use radiocarbon dating to find the age of cave paintings, such as those from the Lascaux cave, in **Figure 1-9,** and the Chauvet cave. Radiocarbon dates are reported with an uncertainty. Three radiocarbon ages from a panel in the Chauvet cave are 30,940 ± 610 years, 30,790 ± 600 years, and 30,230 ± 530 years. While none of the measurements exactly match, the uncertainties in all three overlap, and the measurements confirm each other.

Figure 1-9 Drawings of animals from the Lascaux cave in France. By dating organic material in the cave, such as pigments and torch marks, scientists are able to suggest dates at which these cave paintings were made. Each date is reported with an uncertainty to show how precise the measurement is.

CONTENTS

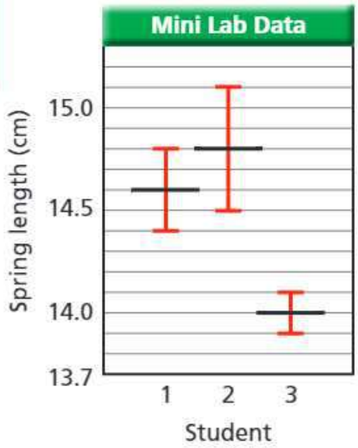

Figure 1-10 Three students took multiple measurements. Are the measurements in agreement? Is student 1's result reproducible?

Suppose three students performed the Mini Lab from Section 1.1 several times, starting with springs of the same length. With two washers on the spring, student 1 made repeated measurements, which ranged from 14.4 cm to 14.8 cm. The average of student 1's measurements was 14.6 cm, as shown in **Figure 1-10.** This result was reported as (14.6 ± 0.2) cm. Student 2 reported finding the spring's length to be (14.8 ± 0.3) cm. Student 3 reported a length of (14.0 ± 0.1) cm.

Could you conclude that the three measurements are in agreement? Is student 1's result reproducible? The results of students 1 and 2 overlap; that is, they have the lengths 14.5 cm to 14.8 cm in common. However, there is no overlap and, therefore, no agreement, between their results and the result of student 3.

Precision Versus Accuracy

Both precision and accuracy are characteristics of measured values. How precise and accurate are the measurements of the three students? The degree of exactness of a measurement is called its **precision.** Student 3's measurements are the most precise, within ± 0.1 cm. The measurements of the other two students are less precise because they have a larger uncertainty.

Precision depends on the instrument and technique used to make the measurement. Generally, the device that has the finest division on its scale produces the most precise measurement. The precision of a measurement is one-half the smallest division of the instrument. For example, the graduated cylinder in **Figure 1-11a** has divisions of 1 mL. You can measure an object to within 0.5 mL with this device. However, the smallest division on the beaker in **Figure 1-11b** is 50 mL. How precise were your measurements in the MiniLab?

The significant digits in an answer show its precision. A measure of 67.100 g is precise to the nearest thousandth of a gram. Recall from Section 1.1 the rules for performing operations with measurements given to different levels of precision. If you add 1.2 mL of acid to a beaker containing 2.4×10^{2} mL of water, you cannot say you now have 2.412×10^{2} mL of fluid, because the volume of water was not measured to the nearest tenth of a milliliter, but to 100 times that.

Figure 1-11 The graduated cylinder contains 41 ± 0.5 mL **(a).** The flask contains 325 mL ± 25 mL **(b)**.

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CONTENTS

Accuracy describes how well the results of a measurement agree with the "real" value; that is, the accepted value as measured by competent experimenters. If the length of the spring that the three students measured had been 14.8 cm, then student 2 would have been most accurate and student 3 least accurate. How accurate do you think your measurements in the Mini Lab on page 8 were? What might have led someone to make inaccurate measurements? How could you check the accuracy of measurements?

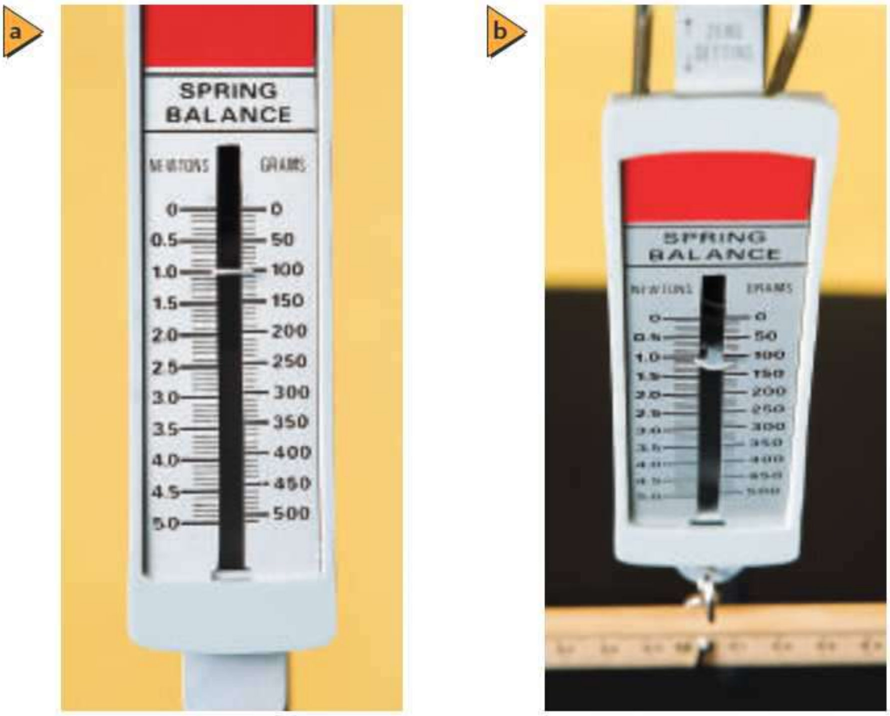
A common method for checking the accuracy of an instrument is called the two-point calibration. First, does the instrument read zero when it should? Second, does it give the correct reading when it is measuring an accepted standard, as shown in **Figure 1-12?** Regular checks for accuracy are performed on critical measuring instruments, such as the radiation output of the machines used to treat cancer.

Figure 1-12 Accuracy is checked by measuring a known value.

Techniques of Good Measurement

To assure accuracy and precision, instruments also have to be used correctly. Measurements have to be made carefully if they are to be as precise as the instrument allows. One common source of error comes from the angle at which an instrument is read. Scales should be read with one's eye directly above the measure, as shown in **Figure 1-13a.** If the scale is read from an angle, as shown in **Figure 1-13b,** you will get a different, and less accurate, value. The difference in the readings is caused by *parallax,* which is the apparent shift in the position of an object when it is viewed from different angles. To experiment with parallax, place your pen on a ruler and read the scale with your eye directly over the tip, then read the scale with your head shifted far to one side.

Figure 1-13 By positioning the scale head on **(a),** your results will be more accurate than if you read your measurements at an angle **(b).** How far did parallax shift the measurement in b?



APPLYING PHYSICS

Distance to the Moon For over 25 years, scientists have been accurately measuring the distance to the Moon by shining lasers through telescopes. The laser beam reflects off reflectors placed on the surface of the Moon by Apollo astronauts. They have determined that the average distance between the centers of Earth and the Moon is 385,000 km, and it is known with an accuracy of better than one part in 10 billion. Using this laser technique, scientists also have discovered that the Moon is receding from Earth at about 3.8 cm/yr.

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■ **Figure 1-14** A series of expeditions succeeded in placing a GPS receiver on top of Mount Everest. This improved the accuracy of the altitude measurement: Everest's peak is 8850 m, not 8848 m, above sea level.

The Global Positioning System, or GPS, offers an illustration of accuracy and precision in measurement. The GPS consists of 24 satellites with transmitters in orbit and numerous receivers on Earth. The satellites send signals with the time, measured by highly accurate atomic clocks. The receiver uses the information from at least four satellites to determine latitude, longitude, and elevation. (The clocks in the receivers are not as accurate as those on the satellites.)

Receivers have different levels of precision. A device in an automobile might give your position to within a few meters. Devices used by geophysicists, as in **Figure 1-14,** can measure movements of millimeters in Earth's crust.

The GPS was developed by the United States Department of Defense. It uses atomic clocks, developed to test Einstein's theories of relativity and gravity. The GPS eventually was made available for civilian use. GPS signals now are provided worldwide free of charge and are used in navigation on land, at sea, and in the air, for mapping and surveying, by telecommunications and satellite networks, and for scientific research into earthquakes and plate tectonics.

1.2 Section Review

18. 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?

19. Tools You find a micrometer (a tool used to measure objects to the nearest 0.01 mm) that has been badly bent. How would it compare to a new, high-quality meterstick in terms of its precision? Its accuracy?

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

21. Error Your friend tells you that his height is 182 cm. In your own words, explain the range of heights implied by this statement.

22. 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?

b. How precise is the measure of length? Of volume?

c. How tall is a stack of 12 of these boxes?

d. How precise is the measure of the height of one box? of 12 boxes?

23. Critical Thinking Your friend states in a report that the average time required 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.

Bill Crouse

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1.3 Graphing Data

A well-designed graph can convey information quickly and simply. Patterns that are not immediately evident in a list of numbers take shape when the data are graphed. In this section, you will develop graphing techniques that will enable you to display, analyze, and model data.

▶ **Objectives**
- **Graph** the relationship between independent and dependent variables.
- **Interpret** graphs.
- **Recognize** common relationships in graphs.

▶ **Vocabulary**

independent variable
dependent variable
line of best fit
linear relationship
quadratic relationship
inverse relationship

Identifying Variables

When you perform an experiment, it is important to change only one factor at a time. For example, **Table 1-3** gives the length of a spring with different masses attached, as measured in the Mini Lab. Only the mass varies; if different masses were hung from different types of springs, you wouldn't know how much of the difference between two data pairs was due to the different masses and how much to the different springs.

Table 1-3

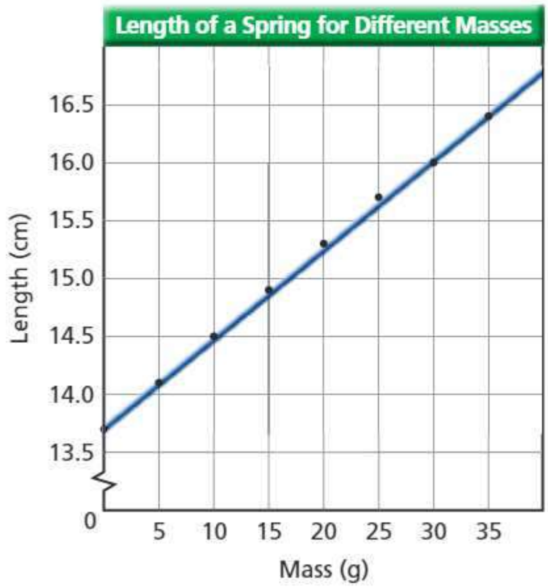
Length of a Spring for Different Masses

Mass Attached to Spring (g)	Length of Spring (cm)
0	13.7
5	14.1
10	14.5
15	14.9
20	15.3
25	15.7
30	16.0
35	16.4

A *variable* is any factor that might affect the behavior of an experimental setup. The **independent variable** is the factor that is changed or manipulated during the experiment. In this experiment, the mass was the independent variable. The **dependent variable** is the factor that depends on the independent variable. In this experiment, the amount that the spring stretched depended on the mass. An experiment might look at how radioactivity varies with time, how friction changes with weight, or how the strength of a magnetic field depends on the distance from a magnet.

One way to analyze data is to make a line graph. This shows how the dependent variable changes with the independent variable. The data from Table 1-3 are graphed in black in **Figure 1-15.** The line in blue, drawn as close to all the data points as possible, is called a **line of best fit.** The line of best fit is a better model for predictions than any one point that helps determine the line. The problem-solving strategy on the next page gives detailed instructions for graphing data and sketching a line of best fit.

Figure 1-15 The independent variable, mass, is on the horizontal axis. The graph shows that the length of the spring increases as the mass suspended from the spring increases.



▶ PROBLEM-SOLVING Strategies

Plotting Line Graphs

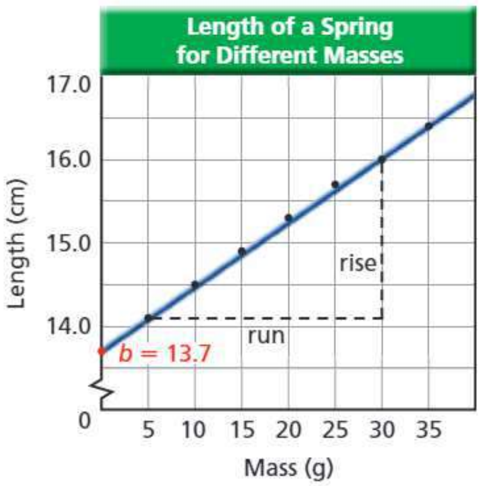
▶ Connecting **Math to Physics**

Use the following steps to plot line graphs from data tables.

1. Identify the independent and dependent variables in your data. The independent variable is plotted on the horizontal axis, the *x*-axis. The dependent variable is plotted on the vertical axis, the *y*-axis.
2. Determine the range of the independent variable to be plotted.
3. Decide whether the origin (0, 0) is a valid data point.
4. Spread the data out as much as possible. Let each division on the graph paper stand for a convenient unit. This usually means units that are multiples of 2, 5, or 10.
5. Number and label the horizontal axis. The label should include the units, such as *Mass (grams)*.
6. Repeat steps 2–5 for the dependent variable.
7. Plot the data points on the graph.
8. Draw the best-fit straight line or smooth curve that passes through as many data points as possible. This is sometimes called *eyeballing*. Do not use a series of straight line segments that connect the dots. The line that looks like the best fit to you may not be exactly the same as someone else's. There is a formal procedure, which many graphing calculators use, called the least-squares technique, that produces a unique best-fit line, but that is beyond the scope of this textbook.
9. Give the graph a title that clearly tells what the graph represents.

Math Handbook
Graphs of Relations
pages 848–852

■ **Figure 1-16** To find an equation of the line of best fit for a linear relationship, find the slope and *y*-intercept.



Linear Relationships

Scatter plots of data may take many different shapes, suggesting different relationships. (The line of best fit may be called a curve of best fit for nonlinear graphs.) Three of the most common relationships will be shown in this section. You probably are familiar with them from math class.

When the line of best fit is a straight line, as in Figure 1-15, the dependent variable varies linearly with the independent variable. There is a **linear relationship** between the two variables. The relationship can be written as an equation.

Linear Relationship Between Two Variables $y = mx + b$

Find the *y*-intercept, *b*, and the slope, *m*, as illustrated in **Figure 1-16.** Use points on the line—they may or may not be data points.

The slope is the ratio of the vertical change to the horizontal change. To find the slope, select two points, *A* and *B*, far apart on the line. The vertical change, or rise, Δy, is the difference between the vertical values of *A* and *B*. The horizontal change, or run, Δx, is the difference between the horizontal values of *A* and *B*.

Slope $m = \frac{rise}{run} = \frac{\Delta y}{\Delta x}$

The slope of a line is equal to the rise divided by the run, which also can be expressed as the change in *y* divided by the change in *x*.

$$\text{In Figure 1-16: } m = \frac{(16.0 \text{ cm} - 14.1 \text{ cm})}{(30 \text{ g} - 5 \text{ g})} = 0.08 \text{ cm/g}$$

If *y* gets smaller as *x* gets larger, then $\Delta y/\Delta x$ is negative, and the line slopes downward.

The *y*-intercept, *b*, is the point at which the line crosses the *y*-axis, and it is the *y*-value when the value of *x* is zero. In this example, $b = 13.7$ cm. When $b = 0$, or $y = mx$, the quantity *y* is said to vary directly with *x*.

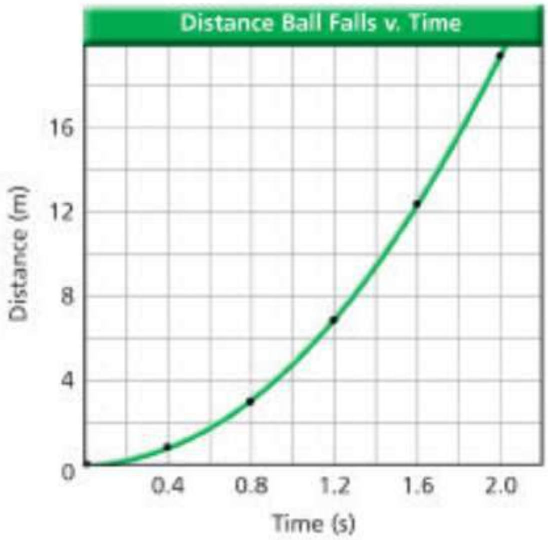


Figure 1-17 This graph indicates a quadratic, or parabolic, relationship.

Nonlinear Relationships

Figure 1-17 shows the distance a brass ball falls versus time. Note that the graph is not a straight line, meaning the relationship is not linear. There are many types of nonlinear relationships in science. Two of the most common are the quadratic and inverse relationships. The graph in Figure 1-17 is a **quadratic relationship,** represented by the following equation.

Quadratic Relationship Between Two Variables

$y = ax^2 + bx + c$

A quadratic relationship exists when one variable depends on the square of another.

Math Handbook

Quadratic Graphs page 852
Quadratic Equations page 846

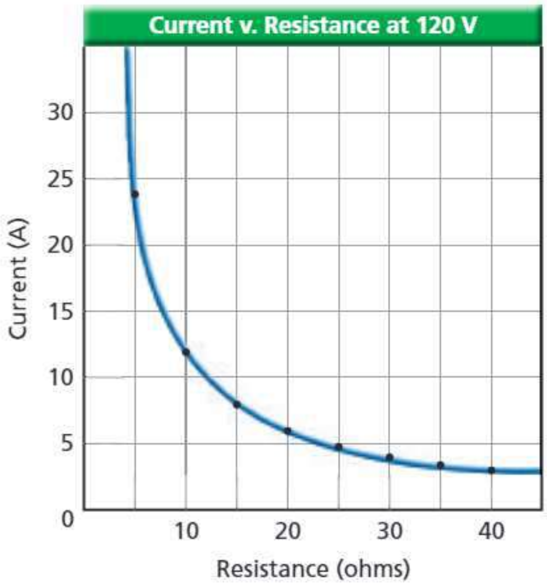
A computer program or graphing calculator easily can find the values of the constants *a*, *b*, and *c* in this equation. In this case, the equation is $d = 5t^2$. See the Math Handbook in the back of the book for more on making and using line graphs.

CHALLENGE PROBLEM

An object is suspended from spring 1, and the spring's elongation (the distance it stretches) is X_1. Then the same object is removed from the first spring and suspended from a second spring. The elongation of spring 2 is X_2. X_2 is greater than X_1.

1. On the same axes, sketch the graphs of the mass versus elongation for both springs.
2. Is the origin included in the graph? Why or why not?
3. Which slope is steeper?
4. At a given mass, $X_2 = 1.6\,X_1$. If $X_2 = 5.3$ cm, what is X_1?

■ **Figure 1-18** This graph shows the inverse relationship between resistance and current. As resistance increases, current decreases.



The graph in **Figure 1-18** shows how the current in an electric circuit varies as the resistance is increased. This is an example of an **inverse relationship,** represented by the following equation.

Inverse Relationship $y = \frac{a}{x}$

A hyperbola results when one variable depends on the inverse of the other.

The three relationships you have learned about are a sample of the simple relations you will most likely try to derive in this course. Many other mathematical models are used. Important examples include sinusoids, used to model cyclical phenomena, and exponential growth and decay, used to study radioactivity. Combinations of different mathematical models represent even more complex phenomena.

PRACTICE Problems

Additional Problems, Appendix B

24. The mass values of specified volumes of pure gold nuggets are given in **Table 1-4.**

a. Plot mass versus volume from the values given in the table and draw the curve that best fits all points.

b. Describe the resulting curve.

c. According to the graph, what type of relationship exists between the mass of the pure gold nuggets and their volume?

d. What is the value of the slope of this graph? Include the proper units.

e. Write the equation showing mass as a function of volume for gold.

f. Write a word interpretation for the slope of the line.

Table 1-4
Mass of Pure Gold Nuggets

Volume (cm^3)	Mass (g)
1.0	19.4
2.0	38.6
3.0	58.1
4.0	77.4
5.0	96.5

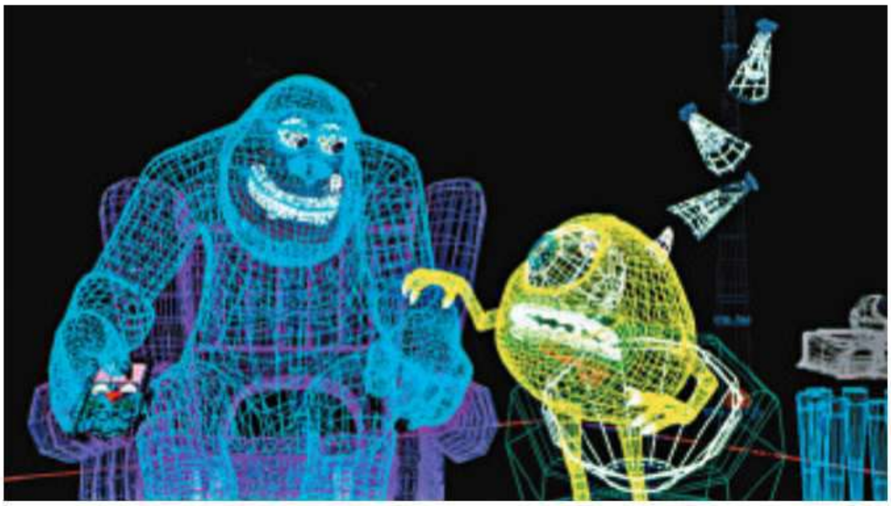


Figure 1-19 Computer animators use mathematical models of the real world to create a convincing fictional world. They need to accurately portray how beings of different sizes move, how hair or clothing move with a character, and how light and shadows fall, among other physics topics.

Predicting Values

When scientists discover relations like the ones shown in the graphs in this section, they use them to make predictions. For example, the equation for the linear graph in **Figure 1-16** is as follows:

$$y = (0.08\ \text{cm/g})x + 13.7\ \text{cm}$$

Relations, either learned as formulas or developed from graphs, can be used to predict values you haven't measured directly. How far would the spring in Table 1-3 stretch with 49 g of mass?

$$y = (0.08\ \text{cm/g})(49\ \text{g}) + 13.7\ \text{cm}$$
$$= 18\ \text{cm}$$

It is important to decide how far you can extrapolate from the data you have. For example, 49 kg is a value far outside the ones measured, and the spring might break rather than stretch that far.

Physicists use models to accurately predict how systems will behave: what circumstances might lead to a solar flare, how changes to a circuit will change the performance of a device, or how electromagnetic fields will affect a medical instrument. People in all walks of life use models in many ways. One example is shown in **Figure 1-19.** With the tools you have learned in this chapter, you can answer questions and produce models for the physics questions you will encounter in the rest of this textbook.

1.3 Section Review

25. 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

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

27. Predict Use the relation illustrated in Figure 1-16 to determine the mass required to stretch the spring 15 cm.

28. Predict Use the relation in Figure 1-18 to predict the current when the resistance is 16 ohms.

29. Critical Thinking In your own words, explain the meaning of a shallower line, or a smaller slope than the one in Figure 1-16, in the graph of stretch versus total mass for a different spring.

Physics Online physicspp.com/self_check_quiz

PHYSICS LAB • Internet

Exploring Objects in Motion

Physics is a science that is based upon experimental observations. Many of the basic principles used to describe and understand mechanical systems, such as objects in linear motion, can be applied later to describe more complex natural phenomena. How can you measure the speed of the vehicles in a video clip?

QUESTION

What types of measurements could be made to find the speed of a vehicle?

Objectives

- **Observe** the motion of the vehicles seen in the video.
- **Describe** the motion of the vehicles.
- **Collect and organize data** on the vehicle's motion.
- **Calculate** a vehicle's speed.

Safety Precautions

Materials

Internet access is required.
watch or other timer

Procedure

1. Visit physicspp.com/internet_lab to view the Chapter 1 lab video clip.
2. The video footage was taken in the midwestern United States at approximately noon. Along the right shoulder of the road are large, white, painted rectangles. These types of markings are used in many states for aerial observation of traffic. They are placed at 0.322-km (0.2-mi) intervals.
3. **Observe** What type of measurements might be taken? Prepare a data table, such as the one shown on the next page. Record your observations of the surroundings, other vehicles, and markings. On what color vehicle is the camera located, and what color is the pickup truck in the lane to the left?
4. **Measure and Estimate** View the video again and look for more details. Is the road smooth? In what direction are the vehicles heading? How long does it take each vehicle to travel two intervals marked by the white blocks? Record your observations and data.

Benjamin Coifman

CONTENTS

Data Table

Marker	Distance (km)	White Vehicle Time (s)	Gray Pickup Time (s)

Analyze

1. Summarize your qualitative observations.
2. Summarize your quantitative observations.
3. **Make and Use Graphs** Graph both sets of data on one pair of axes.
4. **Estimate** What is the speed of the vehicles in km/s and km/h?
5. **Predict** How far will each vehicle travel in 5 min?

Conclude and Apply

1. **Measure** What is the precision of the distance and time measurements?
2. **Measure** What is the precision of your speed measurement? On what does it depend?
3. **Use Variables, Constants, and Controls** Describe the independent and the dependent variables in this experiment.
4. **Compare and Contrast** Which vehicle's graph has a steeper slope? What is the slope equal to?
5. **Infer** What would a horizontal line mean on the graph? A line with a steeper slope?

Going Further

Speed is distance traveled divided by the amount of time to travel that distance. Explain how you could design your own experiment to measure speed in the classroom using remote-controlled cars. What would you use for markers? How precisely could you measure distance and time? Would the angle at which you measured the cars passing the markers affect the results? How much? How could you improve your measurements? What units make sense for speed? How far into the future could you predict the cars' positions? If possible, carry out the experiment and summarize your results.

Real-World Physics

When the speedometer is observed by a front-seat passenger, the driver, and a passenger in the rear driver's-side seat, readings of 90 km/h, 100 km/h, and 110 km/h, respectively, are observed. Explain the differences.

Share Your Data

Design an Experiment Visit physicspp.com/internet_lab to post your experiment for measuring speed in the classroom using remote-controlled cars. Include your list of materials, your procedure, and your predictions for the accuracy of your lab. If you actually perform your lab, post your data and results as well.

Physics Online

To find out more about measurement, visit the Web site: physicspp.com

Computer History and Growth

Each pixel of the animations or movies you watch, and each letter of the instant messages you send presents your computer with several hundred equations. Each equation must be solved in a few billionths of a second—if it takes a bit longer, you might complain that your computer is slow.

Early Computers The earliest computers could solve very complex arrays of equations, just as yours can, but it took them a lot longer to do so. There were several reasons for this. First, the mathematics of algorithms (problem-solving strategies) still was new. Computer scientists were only beginning to learn how to arrange a particular problem, such as the conversion of a picture into an easily-transmittable form, so that it could be solved by a machine.

UNIVAC 1, an early computer, filled an entire room.

Machine Size Second, the machines were physically large. Computers work by switching patterns of electric currents that represent binary numbers. A 16-bit machine works with binary numbers that are 16 bits long. If a 64-bit number must be dealt with, the machine must repeat the same operation four times. A 32-bit machine would have to repeat the operation only twice, thus making it that much faster. But a 32-bit machine is four times the size of a 16-bit machine; that is, it has four times as many wires and transistor switches, and even 8-bit machines were the size of the old UNIVAC shown above.

Moreover, current travels along wires at speeds no greater than about two-thirds the speed of light. This is a long time if the computer wires are 15 m long and must move information in less than 10^{-9} s.

Memory Third, electronic memories were extremely expensive. You may know that a larger memory lets your computer work faster. When one byte of memory required eight circuit boards, 1024 bytes (or 1 K) of memory was enormous. Because memory was so precious, computer programs had to be written with great cleverness. Astronants got to the Moon with 64 K of memory in *Apollo's* on-board computers.

Processor chips used in today's computers are tiny compared to the old computer systems.

When Gordon Moore and others invented the integrated circuit around 1960, the size and cost of computer circuitry dropped drastically. Physically smaller, and thus faster, machines could be built and very large memories became possible. Today, the transistors on a chip are now smaller than bacteria.

The cost and size of computers have dropped so much that your cell phone has far more computing power than most big office machines of the 1970s.

Going Further

1. **Research** A compression protocol makes a computer file smaller and less prone to transmission errors. Look up the terms *.jpg*, *.mp3*, *.mpeg*, and *.midi* and see how they apply to the activities you do on your computer.
2. **Calculate** Using the example here, how long does it take for a binary number to travel 15 m? How many such operations could there be each second?

Chapter 1 Study Guide

1.1 Mathematics and Physics

Vocabulary

- physics (p. 3)
- dimensional analysis (p. 6)
- significant digits (p. 7)
- scientific method (p. 8)
- hypothesis (p. 8)
- scientific law (p. 9)
- scientific theory (p. 10)

Key Concepts

- Physics is the study of matter and energy and their relationships.
- Dimensional analysis is used to check that an answer will be in the correct units.
- The result of any mathematical operation with measurements never can be more precise than the least-precise measurement involved in the operation.
- The scientific method is a systematic method of observing, experimenting, and analyzing to answer questions about the natural world.
- Scientific ideas change in response to new data.
- Scientific laws and theories are well-established descriptions and explanations of nature.

1.2 Measurement

Vocabulary

- measurement (p. 11)
- precision (p. 12)
- accuracy (p. 13)

Key Concepts

- New scientific findings must be reproducible; that is, others must be able to measure and find the same results.
- All measurements are subject to some uncertainty.
- Precision is the degree of exactness with which a quantity is measured. Scientific notation shows how precise a measurement is.
- Accuracy is the extent to which a measurement matches the true value.

1.3 Graphing Data

Vocabulary

- independent variable (p. 15)
- dependent variable (p. 15)
- line of best fit (p. 15)
- linear relationship (p. 16)
- quadratic relationship (p. 17)
- inverse relationship (p. 18)

Key Concepts

- Data are plotted in graphical form to show the relationship between two variables.
- The line that best passes through or near graphed data is called the line of best fit. It is used to describe the data and to predict where new data would lie on the graph.
- A graph in which data points lie on a straight line is a graph of a linear relationship. In the equation, m and b are constants.

$$y = mx + b$$

- The slope of a straight-line graph is the vertical change (rise) divided by the horizontal change (run) and often has a physical meaning.

$$m = \frac{rise}{run} = \frac{\Delta y}{\Delta x}$$

- The graph of a quadratic relationship is a parabolic curve. It is represented by the equation below. The constants a, b, and c can be found with a computer or a graphing calculator; simpler ones can be found using algebra.

$$y = ax^2 + bx + c$$

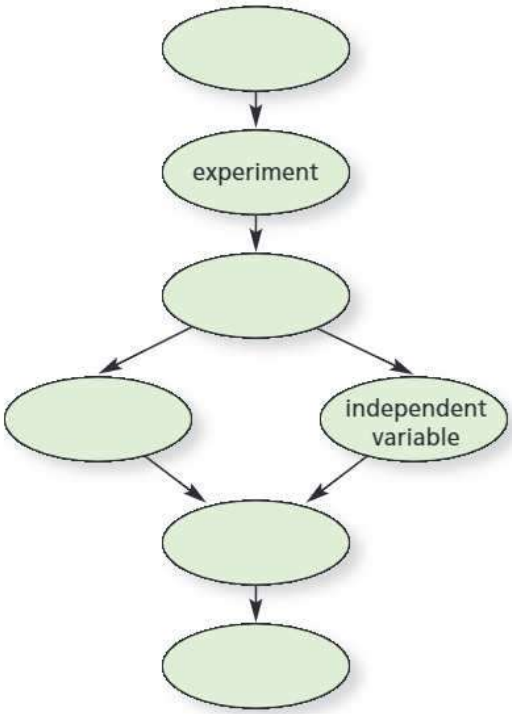
- The graph of an inverse relationship between x and y is a hyperbolic curve. It is represented by the equation below, where a is a constant.

$$y = \frac{a}{x}$$

Assessment

Concept Mapping

30. Complete the following concept map using the following terms: *hypothesis, graph, mathematical model, dependent variable, measurement.*



Mastering Concepts

31. Describe a scientific method. (1.1)

32. Why is mathematics important to science? (1.1)

33. What is the SI system? (1.1)

34. How are base units and derived units related? (1.1)

35. Suppose your lab partner recorded a measurement as 100 g. (1.1)

a. Why is it difficult to tell the number of significant digits in this measurement?

b. How can the number of significant digits in such a number be made clear?

36. Give the name for each of the following multiples of the meter. (1.1)

a. $\frac{1}{100}$ m **b.** $\frac{1}{1000}$ m **c.** 1000 m

37. To convert 1.8 h to minutes, by what conversion factor should you multiply? (1.1)

38. Solve each problem. Give the correct number of significant digits in the answers. (1.1)

a. 4.667×10^4 g + 3.02×10^5 g

b. $(1.70\times10^2$ J$) \div (5.922\times10^{-4}$ cm$^3)$

39. What determines the precision of a measurement? (1.2)

40. How does the last digit differ from the other digits in a measurement? (1.2)

41. A car's odometer measures the distance from home to school as 3.9 km. Using string on a map, you find the distance to be 4.2 km. Which answer do you think is more accurate? What does *accurate* mean? (1.2)

42. How do you find the slope of a linear graph? (1.3)

43. For a driver, the time between seeing a stoplight and stepping on the brakes is called reaction time. The distance traveled during this time is the reaction distance. Reaction distance for a given driver and vehicle depends linearly on speed. (1.3)

a. Would the graph of reaction distance versus speed have a positive or a negative slope?

b. A driver who is distracted has a longer reaction time 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.

44. During a laboratory experiment, the temperature of the gas in a balloon is varied and the volume of the balloon is measured. Which quantity is the independent variable? Which quantity is the dependent variable? (1.3)

45. What type of relationship is shown in **Figure 1-20?** Give the general equation for this type of relation. (1.3)

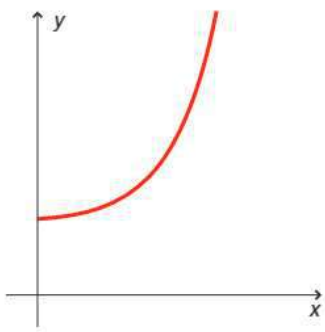


Figure 1-20

46. Given the equation $F = mv^2/R$, what relationship exists between each of the following? (1.3)

a. F and R

b. F and m

c. F and v

Applying Concepts

47. Figure 1-21 gives 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 $t = 2$ s and at $t = 5$ s.

■ Figure 1-21

48. Is a scientific method one set of clearly defined steps? Support your answer.

49. Explain the difference between a scientific theory and a scientific law.

50. Density The density of a substance is its mass per unit volume.
- **a.** Give a possible metric unit for density.
- **b.** Is the unit for density a base unit or a derived unit?

51. What metric unit would you use to measure each of the following?
- **a.** the width of your hand
- **b.** the thickness of a book cover
- **c.** the height of your classroom
- **d.** the distance from your home to your classroom

52. 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.

53. 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. Find as many very short and very long examples as you can.

54. Speed of Light Two students measure the speed of light. One obtains $(3.001 \pm 0.001)\times10^8$ m/s; the other obtains $(2.999 \pm 0.006)\times10^8$ m/s.
- **a.** Which is more precise?
- **b.** Which is more accurate? (You can find the speed of light in the back of this textbook.)

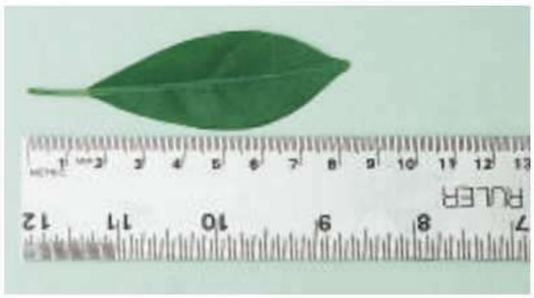
55. You measure the dimensions of a desk as 132 cm, 83 cm, and 76 cm. The sum of these measures is 291 cm, while the product is 8.3×10^5 cm^3. Explain how the significant digits were determined in each case.

56. Money Suppose you receive $5.00 at the beginning of a week and spend $1.00 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?

57. 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?

58. 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?

59. How long is the leaf in **Figure 1-22?** Include the uncertainty in your measurement.



■ Figure 1-22

60. The masses of two metal blocks are measured. Block A has a mass of 8.45 g and block B has a mass of 45.87 g.
- **a.** How many significant digits are expressed in these measurements?
- **b.** What is the total mass of block A plus block B?
- **c.** What is the number of significant digits for the total mass?
- **d.** Why is the number of significant digits different for the total mass and the individual masses?

61. History Aristotle said that the speed of a falling object varies inversely with the density of the medium through which it falls.
- **a.** According to Aristotle, would a rock fall faster in water (density 1000 kg/m^3), or in air (density 1 kg/m^3)?
- **b.** How fast would a rock fall in a vacuum? Based on this, why would Aristotle say that there could be no such thing as a vacuum?

62. Explain the difference between a hypothesis and a scientific theory.

63. Give an example of a scientific law.

64. 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?*

65. **Mars** Explain what observations led to changes in scientists' ideas about the surface of Mars.

66. A graduated cylinder is marked every mL. How precise a measurement can you make with this instrument?

Mastering Problems

1.1 Mathematics and Physics

67. Convert each of the following measurements to meters.
- **a.** 42.3 cm
- **b.** 6.2 pm
- **c.** 21 km
- **d.** 0.023 mm
- **e.** 214 μm
- **f.** 57 nm

68. Add or subtract as indicated.
- **a.** 5.80×10^{9} s + 3.20×10^{8} s
- **b.** 4.87×10^{-6} m − 1.93×10^{-6} m
- **c.** 3.14×10^{-5} kg + 9.36×10^{-5} kg
- **d.** 8.12×10^{7} g − 6.20×10^{6} g

69. Rank the following mass measurements from least to greatest: 11.6 mg, 1021 μg, 0.000006 kg, 0.31 mg.

70. State the number of significant digits in each of the following measurements.
- **a.** 0.00003 m
- **b.** 64.01 fm
- **c.** 80.001 m
- **d.** 0.720 μg
- **e.** 2.40×10^{6} kg
- **f.** 6×10^{8} kg
- **g.** 4.07×10^{16} m

71. Add or subtract as indicated.
- **a.** 16.2 m + 5.008 m + 13.48 m
- **b.** 5.006 m + 12.0077 m + 8.0084 m
- **c.** 78.05 cm^2 − 32.046 cm^2
- **d.** 15.07 kg − 12.0 kg

72. Multiply or divide as indicated.
- **a.** $(6.2\times10^{18}\ \text{m})(4.7\times10^{-10}\ \text{m})$
- **b.** $(5.6\times10^{-7}\ \text{m})/(2.8\times10^{-12}\ \text{s})$
- **c.** $(8.1\times10^{-4}\ \text{km})(1.6\times10^{-3}\ \text{km})$
- **d.** $(6.5\times10^{5}\ \text{kg})/(3.4\times10^{3}\ \text{m}^3)$

73. **Gravity** The force due to gravity is $F = mg$ where $g = 9.80\ \text{m/s}^2$.
- **a.** Find the force due to gravity on a 41.63-kg object.
- **b.** The force due to gravity on an object is 632 kg·m/s^2. What is its mass?

74. **Dimensional Analysis** Pressure is measured in pascals, where 1 Pa = 1 kg/m·s^2. Will the following expression give a pressure in the correct units?

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

1.2 Measurement

75. 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?

76. 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?

77. 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?

78. How precise a measurement could you make with the scale shown in **Figure 1-23?**

Figure 1-23

79. Give the measure shown on the meter in **Figure 1-24** as precisely as you can. Include the uncertainty in your answer.

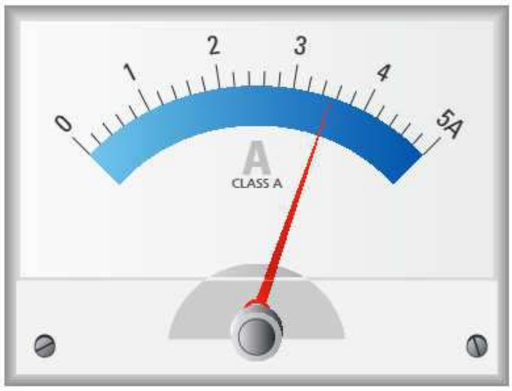


Figure 1-24

 For more problems, go to Additional Problems, Appendix B.

Horizons Companies

CONTENTS

80. 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?

81. Base Units Give six examples of quantities you might measure in a physics lab. Include the units you would use.

82. Temperature The temperature drops from 24°C to 10°C in 12 hours.

a. Find the average temperature change per hour.

b. Predict the temperature in 2 more hours if the trend continues.

c. Could you accurately predict the temperature in 24 hours?

1.3 Graphing Data

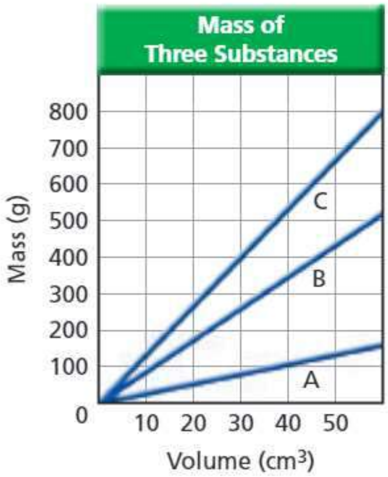
83. Figure 1-25 shows the masses of three substances for volumes between 0 and 60 cm^3.

a. What is the mass of 30 cm^3 of each substance?

b. If you had 100 g of each substance, what would be their volumes?

c. In one or two sentences, describe the meaning of the slopes of the lines in this graph.

d. What is the *y*-intercept of each line? What does it mean?



■ **Figure 1-25**

84. During a class demonstration, a physics instructor placed a mass on a horizontal table that was nearly frictionless. The instructor then applied various horizontal forces to the mass and measured the distance it traveled in 5 seconds for each force applied. The results of the experiment are shown in **Table 1-5.**

Table 1-5 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

a. Plot the values given in the table and draw the curve that best fits all points.

b. Describe the resulting curve.

c. Use the graph to write an equation relating the distance to the force.

d. What is the constant in the equation? Find its units.

e. Predict the distance traveled when a 22.0-N force is exerted on the object for 5 s.

85. The physics instructor from the previous problem changed the procedure. 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 1-6.**

Table 1-6 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

a. Plot the values given in the table and draw the curve that best fits all points.

b. Describe the resulting curve.

c. According to the graph, what is the relationship between mass and the acceleration produced by a constant force?

d. Write the equation relating acceleration to mass given by the data in the graph.

e. Find the units of the constant in the equation.

f. Predict the acceleration of an 8.0-kg mass.

86. 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 1-7** were collected.

Table 1-7
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

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

Mixed Review

87. Arrange the following numbers from most precise to least precise

0.0034 m   45.6 m   1234 m

88. **Figure 1-26** shows the toroidal (doughnut-shaped) interior of the now-dismantled Tokamak Fusion Test Reactor. Explain why a width of 80 m would be an unreasonable value for the width of the toroid. What would be a reasonable value?

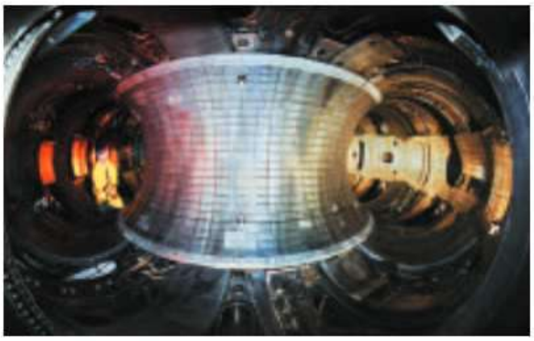


Figure 1-26

89. 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?

90. 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/cm^3, of the beam. Express your results in proper form.

91. 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?

92. 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

93. **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.

94. **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 digit. (Use a reference source to find the density of water.)

95. **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.

96. **Design an Experiment** How high can you throw a ball? What variables might affect the answer to this question?

97. **Calculate** If the Sun suddenly ceased to shine, how long would it take Earth to become dark? (You will have to look up the speed of light in a vacuum and the distance from the Sun to Earth.) How long would it take the surface of Jupiter to become dark?

Writing in Physics

98. 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 their contributions on scientific thought and the world outside the laboratory.

99. Explain how improved precision in measuring time would have led to more accurate predictions about how an object falls.

 For more problems, go to Additional Problems, Appendix B.

Standardized Test Practice

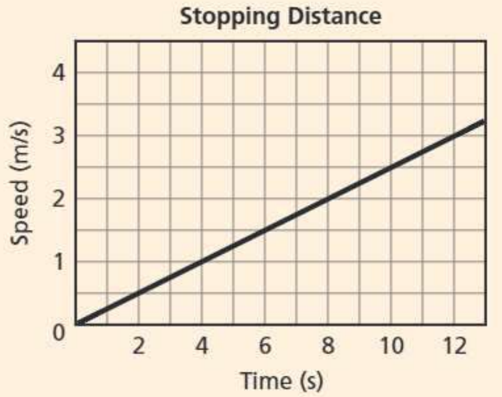
Multiple Choice

1. Two laboratories use radiocarbon dating to measure the age of two wooden spear handles found in the same grave. Lab A finds an age of 2250 ± 40 years for the first object; lab B finds an age of 2215 ± 50 years for the second object. Which of the following is true?
   - (A) Lab A's reading is more accurate than lab B's.
   - (B) Lab A's reading is less accurate than lab B's.
   - (C) Lab A's reading is more precise than lab B's.
   - (D) Lab A's reading is less precise than lab B's.

2. Which of the following is equal to 86.2 cm?
   - (A) 8.62 m
   - (B) 0.862 mm
   - (C) 8.62×10^{-4} km
   - (D) 862 dm

3. Jario has a problem to do involving time, distance, and velocity, but he has forgotten the formula. The question asks him for a measurement in seconds, and the numbers that are given have units of m/s and km. What could Jario do to get the answer in seconds?
   - (A) Multiply the km by the m/s, then multiply by 1000.
   - (B) Divide the km by the m/s, then multiply by 1000.
   - (C) Divide the km by the m/s, then divide by 1000.
   - (D) Multiply the km by the m/s, then divide by 1000.

4. What is the slope of the graph?
   - (A) $0.25\ m/s^2$
   - (B) $0.4\ m/s^2$
   - (C) $2.5\ m/s^2$
   - (D) $4.0\ m/s^2$

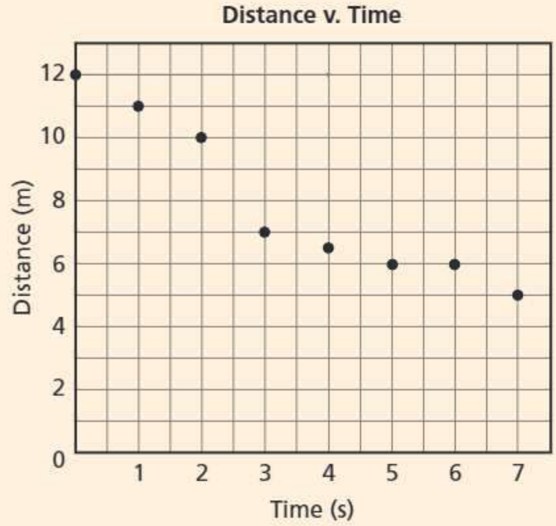


5. Which formula is equivalent to $D = \frac{m}{V}$?
   - (A) $V = \frac{m}{D}$
   - (B) $V = Dm$
   - (C) $V = \frac{mD}{V}$
   - (D) $V = \frac{D}{m}$

Extended Answer

6. You want to calculate an acceleration, in units of m/s^2, given a force, in N, and the mass, in g, on which the force acts. ($1\ N = 1\ kg\cdot m/s^2$)
   - **a.** Rewrite the equation $F = ma$ so a is in terms of m and F.
   - **b.** What conversion factor will you need to multiply by to convert grams to kilograms?
   - **c.** A force of 2.7 N acts on a 350-g mass. Write the equation you will use, including the conversion factor, to find the acceleration.

7. Find an equation for a line of best fit for the data shown below.



✓ Test-Taking TIP

Skip Around if You Can

You may want to skip over difficult questions and come back to them later, after you've answered the easier questions. This will guarantee more points toward your final score. In fact, other questions may help you answer the ones you skipped. Just be sure you fill in the correct ovals on your answer sheet.