SECTION 1

The Nature of Science

KEY TERMS
science
technology
scientific law
scientific theory

OBJECTIVES

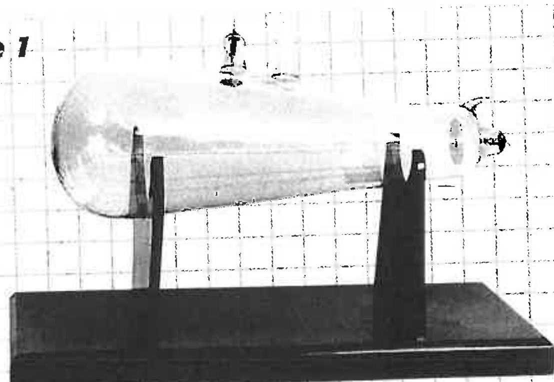
- **Describe** the main branches of natural science and relate them to each other.
- **Describe** the relationship between science and technology.
- **Distinguish** between scientific laws and scientific theories.
- **Explain** the roles of models and mathematics in scientific theories and laws.

Generally, scientists describe the universe using basic rules, which can be discovered by careful, methodical study. A scientist may perform experiments to find a new aspect of the natural world, to explain a known phenomenon, to check the results of other experiments, or to test the predictions of current theories.

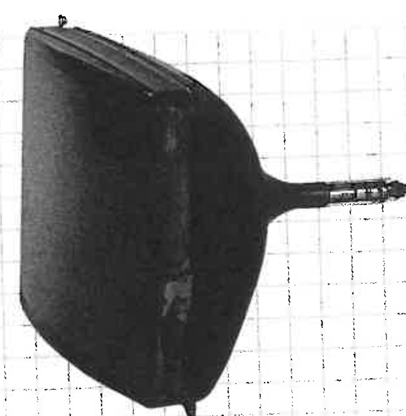
How Does Science Take Place?

Imagine that it is 1895 and you are experimenting with cathode rays. These mysterious rays were discovered almost 40 years before, but in 1895 no one knows what they are. To produce the rays, you create a vacuum by pumping the air out of a sealed glass tube that has two metal rods at a distance from each other, as shown in ***Figure 1A.*** When the rods are connected to an electrical source, electric charges flow through the empty space between the rods, and the rays are produced.

Figure 1



A The cathode ray tube used in 1895 looked like this.



B A television picture tube is a form of the same cathode ray tube.

Scientists investigate

You have learned from the work of other scientists and have conducted experiments of your own. From these, you know that when certain minerals are placed inside the tube, the cathode rays make them fluoresce (glow). Pieces of cardboard coated with powder made from these minerals are used to detect the rays. With a very high voltage, even the glass tube itself glows.

Other scientists have found that cathode rays can pass through thin metal foils, but they travel in our atmosphere for only 2 or 3 cm. You wonder if the rays could pass through the glass tube. Others have tried this experiment and have found that cathode rays don't go through glass. But you think that the glow from the glass tube might have outshined any weak glow from the mineral-coated cardboard. So, you decide to cover the glass tube with heavy black paper.

VOCABULARY Skills Tip

Cathode rays *got their name because they come from the cathode, the rod connected to the negative terminal of the electricity source. The positive terminal is called the* anode.

Scientists plan experiments

Before experimenting, you write your plan in your laboratory notebook and sketch the equipment you are using. You make a table in which you can write down the electric power used, the distance from the tube to the fluorescent detector, the air temperature, and anything you observe. You state the idea you are going to test: At a high voltage, cathode rays will be strong enough to be detected outside the tube by causing the mineral-coated cardboard to glow.

Scientists observe

Everything is ready. You want to be sure that the black-paper cover doesn't have any gaps, so you darken the room and turn on the tube. The black cover blocks the light from the tube. Just before you switch off the tube, you glimpse a light nearby. When you turn on the tube again, the light reappears.

Then you realize that this light is coming from the mineral-coated cardboard you planned to use to detect cathode rays. The detector is already glowing, and it is on a table almost 1 m away from the tube. You know that 1 m is too far for cathode rays to travel in air. You suspect that the tube must be giving off some new rays that no one has seen before. What do you do now?

This is the question Wilhelm Roentgen had to ponder in Würzburg, Germany, on November 8, 1895, when all this happened to him. Should he call the experiment a failure because it didn't give the results he expected? Should he ask reporters to cover this news story? Maybe he should send letters about his discovery to famous scientists and invite them to come and see it.

INTEGRATING

BIOLOGY

In 1928, the Scottish scientist Alexander Fleming was investigating disease-causing bacteria when he saw that one of his cultures contained an area where no bacteria were growing. Instead, an unknown organism was growing in that area. Rather than discarding the culture as a failure, Fleming investigated the unfamiliar organism and found that it was a type of mold. This mold produced a substance that prevented the growth of many disease bacteria. What he found by questioning the results of a "failed" experiment became the first modern antibiotic, penicillin. Major discoveries are often made by accident when trying to find something else.

Figure 2

Roentgen included this X ray of his wife's hand in one of the first papers he wrote on X rays.

Scientists always test results

Because Roentgen was a scientist, he first repeated his experiment to be sure of his observations. His results caused him to begin thinking of new questions and to design more experiments to find the answers.

He found that the rays passed through almost everything, although dense materials absorbed them somewhat. When he held his hand in the path of the rays, the bones were visible as shadows on the fluorescent detector, as shown in ***Figure 2.*** When Roentgen published his findings in December, he still did not know what the rays were. He called them *X rays* because *x* represents an unknown in a mathematical equation.

Within three months of Roentgen's discovery, a doctor in Massachusetts used X rays to help set properly the broken bones in a boy's arm. After a year, more than a thousand scientific articles about X rays had been published. In 1901, Roentgen received the first Nobel Prize in physics for his discovery.

Science has many branches

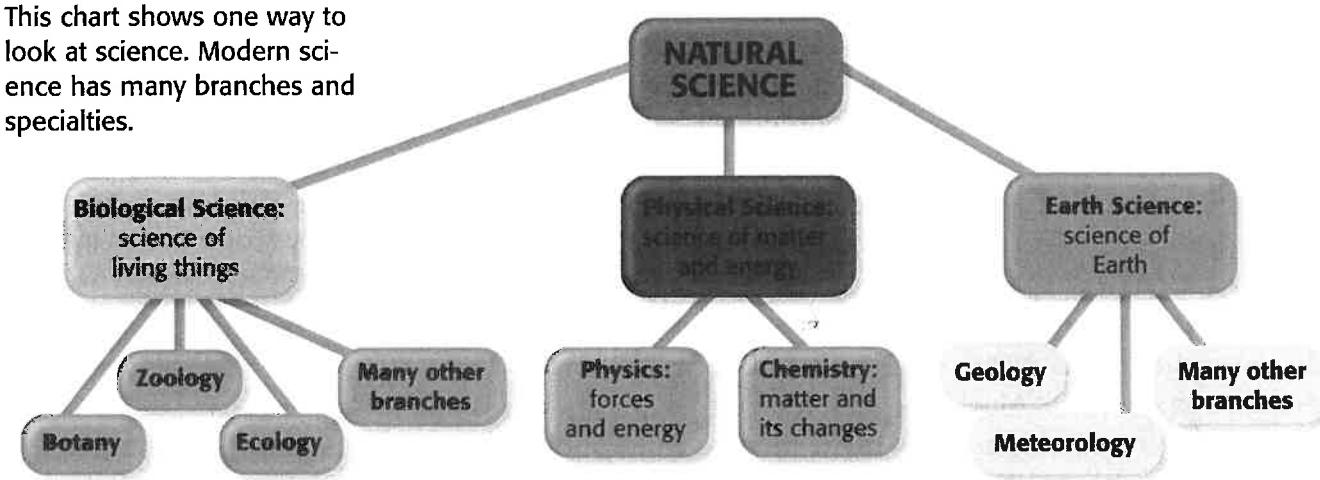
Roentgen's work with X rays illustrates how scientists work, but what is **science** about? Science is observing, studying, and experimenting to find the nature of things. You can think of science as having two main branches: social science, which deals with individual and group human behavior, and natural science. Natural science tries to understand how "nature," which really means "the whole universe," behaves. Natural science is usually divided into life science, physical science, and Earth science, as shown in ***Figure 3.***

■ **science** the knowledge obtained by observing natural events and conditions in order to discover facts and formulate laws or principles that can be verified or tested

Life science is *biology.* Biology has many branches, such as *botany,* the science of plants; *zoology,* the science of animals; and *ecology,* the science of balance in nature. Medicine and agriculture are branches of biology too.

Figure 3

This chart shows one way to look at science. Modern science has many branches and specialties.



Physical science has two main branches—*chemistry* and *physics.* Chemistry is the science of matter and its changes, and physics is the science of forces and energy. Both depend greatly on mathematics.

Some of the branches of Earth science are *geology,* the science of the physical nature and history of the Earth, and *meteorology,* the science of the atmosphere and weather.

This classification of science appears very tidy, like stacks of boxes in a shoe store, but there's a problem with it. As science has progressed, the branches of science have grown out of their little boxes. For example, chemists have begun to explain the workings of chemicals that make up living things, such as DNA, shown in ***Figure 4.*** This science is *biochemistry,* the study of the matter of living things. It is both a life science and a physical science. In the same way, the study of the forces that affect the Earth is *geophysics,* which is both an Earth science and a physical science.

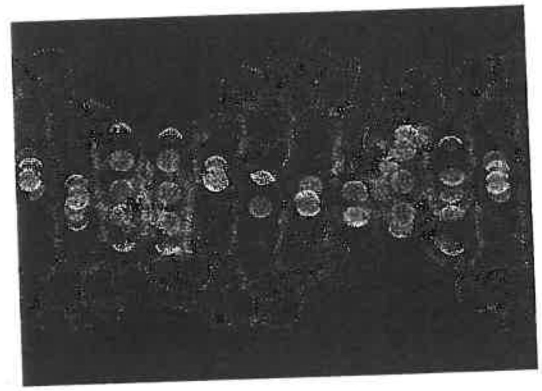


Figure 4
Our DNA (deoxyribonucleic acid) makes each of us unique.

■ **technology** the application of science for practical purposes

Science and technology work together

Scientists who do experiments to learn more about the world are practicing *pure science,* also defined as the continuing search for scientific knowledge. Engineers look for ways to use this knowledge for practical applications. This application of science is called **technology.** For example, scientists who practice pure science want to know how certain kinds of materials, called superconductors, conduct electricity with almost no loss in energy. Engineers focus on how that technology can be best used to build high-speed computers.

Technology and science depend on one another, as illustrated by some of Leonardo da Vinci's drawings in ***Figure 5.*** For instance, scientists did not know that tiny organisms such as bacteria even existed until the technology to make precision magnifying lenses developed in the late 1600s.

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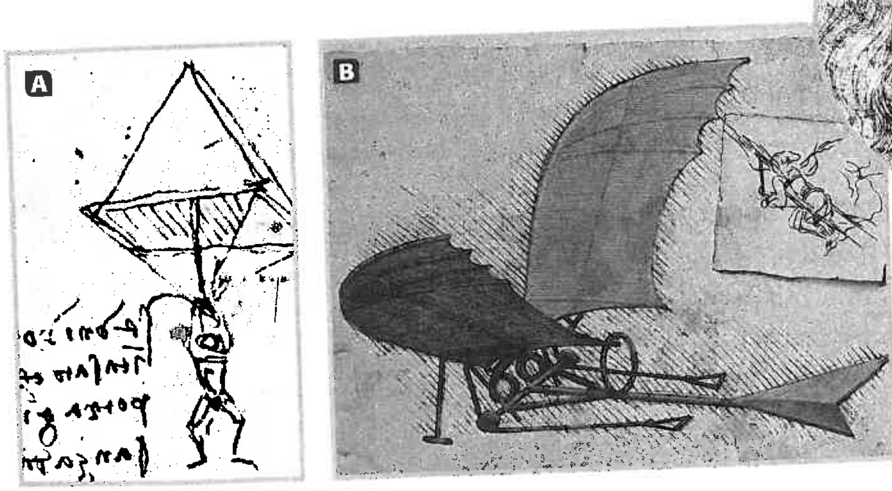


Figure 5
Some of Leonardo da Vinci's ideas could not be built until twentieth-century technology developed. Some examples are: **A** a design for a parachute and **B** a design for a glider.

Scientific Laws and Theories

People sometimes say things like, "My theory is that we'll see Jaime on the school bus," when they really mean, "I'm guessing that we'll find Jaime on the school bus." People use the word *theory* in everyday speech to refer to a guess about something. In science, a theory is much more than a guess.

scientific law a summary of many experimental results and observations; a law tells how things work

scientific theory an explanation for some phenomenon that is based on observation, experimentation, and reasoning

Laws and theories are supported by experimental results

When you place a hot cooking pot in a cooler place, does the pot become hotter as it stands? No, it will always get cooler. This illustrates a **scientific law** that states that warm objects always become cooler when they are placed in cooler surroundings. A scientific law describes a process in nature that can be tested by repeated experiments. A law allows predictions to be made about how a system will behave under a wide range of conditions.

However, a law does not *explain* how a process takes place. In the example of the hot cooking pot, nothing in the law tells why hot objects become cooler in cooler surroundings. Such an explanation of how a natural process works must be provided by a **scientific theory.**

Scientific theories are always being questioned and examined. To be valid, a theory must continue to pass several tests.

- A theory must explain observations clearly and consistently. The theory that heat is the energy of particles in motion explains how the far end of a metal tube gets hot when you hold the tip over a flame, as shown in ***Figure 6A.***
- Experiments that illustrate the theory must be repeatable. The far end of the tube always gets hot when the tip is held over a flame, whether it is done for the first time or the thirty-first time.
- You must be able to predict from the theory. You might predict that anything that makes particles move faster will make the object hotter. Sawing a piece of wood will make the metal particles in the saw move faster. If, as shown in ***Figure 6B,*** you saw rapidly, the saw will get hot to the touch.

A

B

Figure 6
The kinetic theory of heat explains many things that you can observe, such as why both the far end of the tube A and the saw blade B get hot.

Mathematics can describe physical events

How would you state the law of gravitation? You could say that something you hold will fall to Earth when you let go. This *qualitative* statement describes with words something you have seen many times. But many scientific laws and theories can be stated as mathematical equations, which are *quantitative* statements.

Rectangle Area Equation

$$A = l \times w$$

The rectangle area equation works for all rectangles, whether they are short, tall, wide, or thin.

Universal Gravitation Equation

$$F = G\frac{m_1 m_2}{d^2}$$

In the same way, the universal gravitation equation describes how big the force will be between two galaxies or between Earth and an apple dropped from your hand, as shown in ***Figure 7.*** Quantitative expressions of the laws of science make communicating about science easier. Scientists around the world speak and read many different languages, but mathematics, the language of science, is the same everywhere.

Theories and laws are always being tested

Sometimes theories have to be changed or replaced completely when new discoveries are made. Over 200 years ago, scientists used the *caloric theory* to explain how objects become hotter and cooler. Heat was thought to be an invisible fluid, called caloric, that could flow from a warm object to a cool one. People thought that fires were fountains of caloric, which flowed into surrounding objects, making them warmer. The caloric theory could explain everything that people knew about heat.

But the caloric theory couldn't explain why rubbing two rough surfaces together made them warmer. During the 1800s, after doing many experiments, some scientists suggested a new theory based on the idea that heat was a result of the motion of particles. The new theory was that heat is really a form of energy that is transferred when fast-moving particles hit others. Because this theory, the *kinetic theory,* explained the old observations as well as the new ones, it was kept and the caloric theory was discarded.

Models can represent physical events

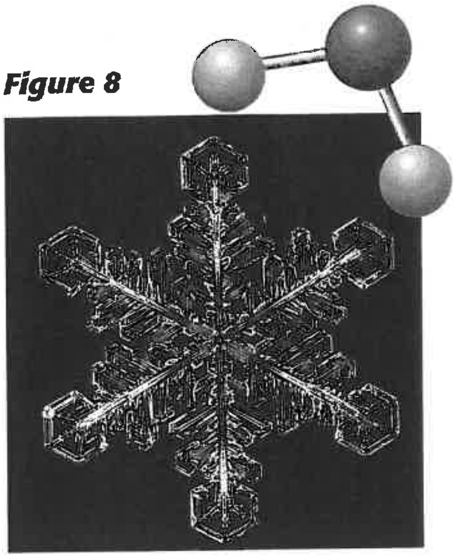
When you see the word *model,* you may think of a small copy of an airplane or a person who shows off clothing. Scientists use models too. A scientific model is a representation of an object or event that can be studied to understand the real object or event. Sometimes, like a model airplane, models represent things that are too big, too small, or too complex to study easily.

Figure 7
Gravitational attraction is described as a force that varies depending on the mass of the objects and the distance that separates them.

A model of water is shown in ***Figure 8A.*** Chemists use models to study how water forms an ice crystal, such as a snowflake. Models can be drawings on paper. The spring shown in ***Figure 8B*** serves as a model of a sound wave moving through matter. Also, a model can be a mental "picture" or a set of rules that describes what something does. After you have studied atoms in Chapter 3, you will be able to picture atoms in your mind and use models to predict what will happen in chemical reactions.

Scientists and engineers also use computer models. These can be drawings such as the one shown in ***Figure 9A;*** more often, they are mathematical models of complex systems. Computer models can save time and money because long calculations are done by a machine to predict what will happen.

Figure 8

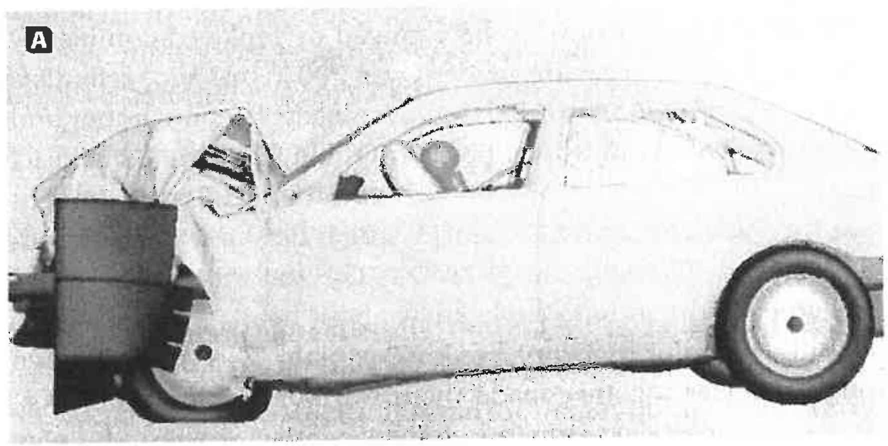


A Models can be used to describe a water molecule (top right) and to study how water molecules are arranged in a snowflake.

B Experiments show that this model depicts how a sound wave moves through matter.

Figure 9

Crash tests give information that is used to make cars safer. Now, models **A** can replace some real-world crash tests **B**.



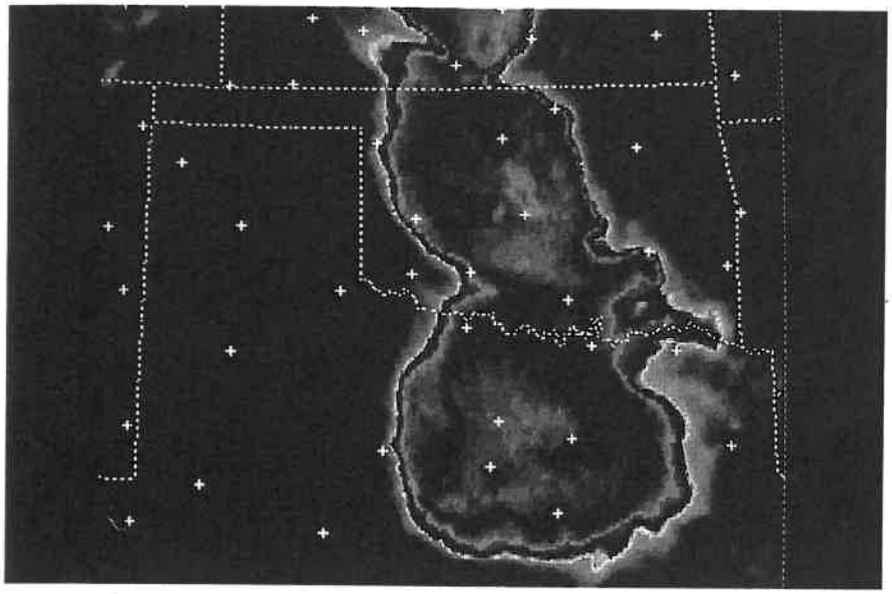


Figure 10
Models help forecast the weather and, in cases of dangerous storms, can help save lives.

Computer models have a variety of applications. For example, they can be used instead of expensive crash tests to study the effects of motion and forces in car crashes, as shown in ***Figure 9.*** Engineers use the predictions from the models to improve the design of cars. *Meteorologists* have computer models such as the one shown in ***Figure 10,*** which uses information about wind speed and direction, air temperature, moisture levels, and ground shape to help forecast the weather.

SECTION 1 REVIEW

SUMMARY

- A scientist makes objective observations.
- A scientist confirms results by repeating experiments and learns more by designing and conducting new experiments.
- Scientific laws and theories are supported by repeated experiments but may be changed when results are not consistent with predictions.
- Models are used to represent real situations and to make predictions.

1. **Compare and Contrast** the two main branches of physical science.
2. **Explain** how science and technology depend on each other.
3. **Explain** how a scientific theory differs from a guess or an opinion.
4. **Define** *scientific law* and give an example.
5. **Compare and Contrast** a scientific law and a scientific theory.
6. **Compare** quantitative and qualitative descriptions.
7. **Describe** how a scientific model is used, and give an example of a scientific model.
8. **Creative Thinking** How do you think Roentgen's training as a scientist affected the way he responded to his discovery?
9. **Creative Thinking** Pick a common happening, develop an explanation for it, and describe an experiment you could perform to test your explanation.

SECTION 2

The Way Science Works

KEY TERMS
critical thinking
scientific method
variable
length
mass
volume
weight

OBJECTIVES

- **Understand** how to use critical thinking skills to solve problems.
- **Describe** the steps of the scientific method.
- **Know** some of the tools scientists use to investigate nature.
- **Explain** the objective of a consistent system of units, and identify the SI units for length, mass, and time.
- **Identify** what each common SI prefix represents, and convert measurements.

critical thinking the ability and willingness to assess claims critically and to make judgments on the basis of objective and supported reasons

Throwing a spear accurately to kill animals for food or to ward off intruders was probably a survival skill people used for thousands of years. In our society, throwing a javelin is an athletic skill, and riding a bicycle or driving a car is considered almost a survival skill. The skills that we place importance on change over time, as society and technology change.

Science Skills

Although pouring liquid into a test tube without spilling is a skill that is useful in science, other skills are more important. Identifying problems, planning experiments, recording observations, and correctly reporting data are some of these more important skills. The most important skill is learning to think critically.

Critical thinking

If you were doing your homework and the lights went out, what would you do? Would you call the electric company immediately? A person who thinks like a scientist might first ask questions and make observations. Are lights on anywhere in the house? If so, what would you conclude? Suppose everything electrical in the house is off. Can you see lights in the neighbors' windows? If their lights are on, what does that mean? What if everyone's lights are off?

If you approach the problem this way, you are thinking logically. This kind of thinking is very much like **critical thinking.** You do this kind of thinking when you consider if the giant economy-sized jar of peanut butter is really less expensive than the regular size, as shown in ***Figure 11,*** or consider if a specific brand of soap makes you more attractive.

Figure 11
Making thoughtful decisions is important in scientific processes as well as in everyday life.

The Scientific Method

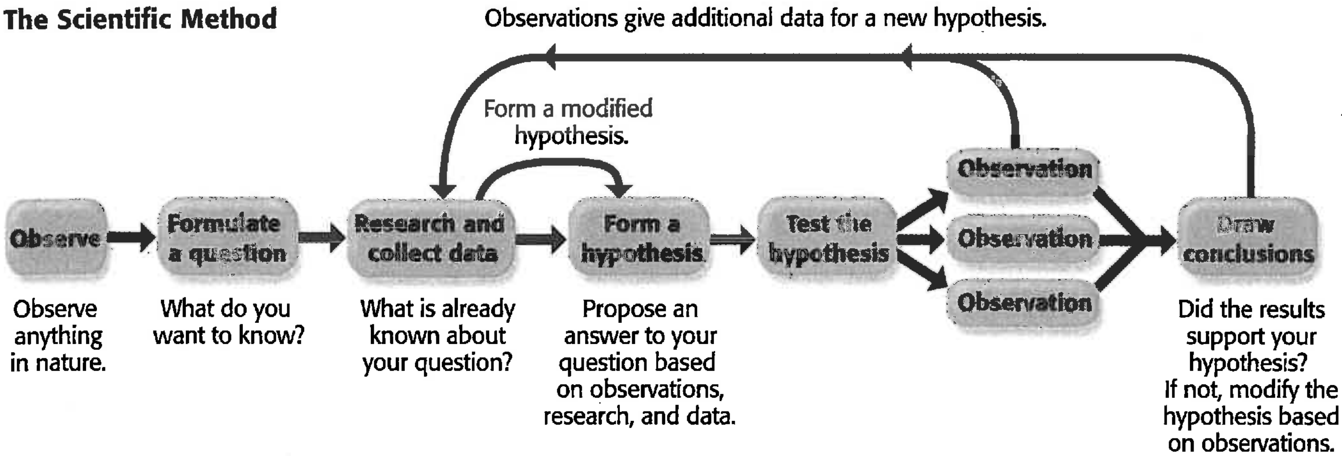


Figure 12
The scientific method is a general description of scientific thinking rather than an exact path for scientists to follow.

When the lights go out, if you get more facts before you call the power company, you're thinking critically. You're not making a reasonable conclusion if you immediately assume there is a citywide power failure. You can make observations and use logic.

Using the scientific method

In the **scientific method,** critical thinking is used to solve scientific problems. The scientific method is a general way to help organize your thinking about questions that you might think of as scientific. Using the scientific method helps you find and evaluate possible answers. The scientific method is often followed as a series of steps like those in ***Figure 12.***

scientific method a series of steps followed to solve problems including collecting data, formulating a hypothesis, testing the hypothesis, and stating conclusions

Most scientific questions begin with observations—simple things you notice. For example, you might notice that when you open a door, you hear a squeak. You ask the question: Why does this door make noise? You may gather data by checking other doors and find that the other doors don't make noise. So you form a *hypothesis,* a possible answer that you can test in some way. For instance, you may think that if the door makes a noise, the source of the noise is the doorknob.

Testing hypotheses

Scientists test a hypothesis by doing a *controlled experiment.* In a controlled experiment, all **variables** that can affect the outcome of the experiment are kept constant, or controlled, except for one. Only the results of changing one given variable are observed.

variable a factor that changes in an experiment in order to test a hypothesis

When you change more than one thing at a time, it's harder to make reasonable conclusions. If you remove the knob, sand the frame, and put oil on the hinges, you may stop the squeak, but you won't know what was causing the squeak. Even if you test one thing at a time, you may not find the answer on the first try. If you take the knob off the door and the door still makes noise, was your experiment a failure?

Quick ACTIVITY

Making Observations

1. Get an ordinary candle of any shape and color.
2. Record all the observations you can make about the candle.
3. Light the candle, and watch it burn for 1 minute.
4. Record as many observations about the burning candle as you can.
5. Share your results with your class, and find out how many different things were observed.

Conducting experiments

In truth, no experiment is a failure. Experiments may not give the results you expected, but they are all observations of events in the natural world. These results are used to revise a hypothesis and to plan tests of a different variable. For example, once you know that the doorknob did not cause the squeak, you can revise your hypothesis to see if oiling the hinges stops the noise.

Scientists often do "what if" experiments to see what happens in a certain situation. These experiments are a form of data collection. Often, as with Roentgen's X rays, experimental results are surprising and lead scientists in new directions.

Scientists always have the question to be tested in mind. You can find out if ice is more dense than water just by thinking whether ice floats or sinks in water. The thinking that led to the law of gravitation began in 1666 when, according to legend, Isaac Newton saw an apple fall. He wondered why objects fall toward the center of Earth rather than in another direction.

Some questions, such as how Earth's continents have moved over millions of years, cannot be answered with experimental data. Instead of doing experiments, geologists make observations all over Earth. They also use models, such as the one shown in ***Figure 13,*** based on the laws of physics.

Using scientific tools

Of course, logical thinking isn't the only skill used in science. Scientists must make careful observations. Sometimes only the senses are needed for observations, as in the case of field botanists using their eyes to identify plants. At other times, special tools are provided through developments in technology. Scientists must know how to use these tools, what the limits of the tools are, and how to interpret data from them.

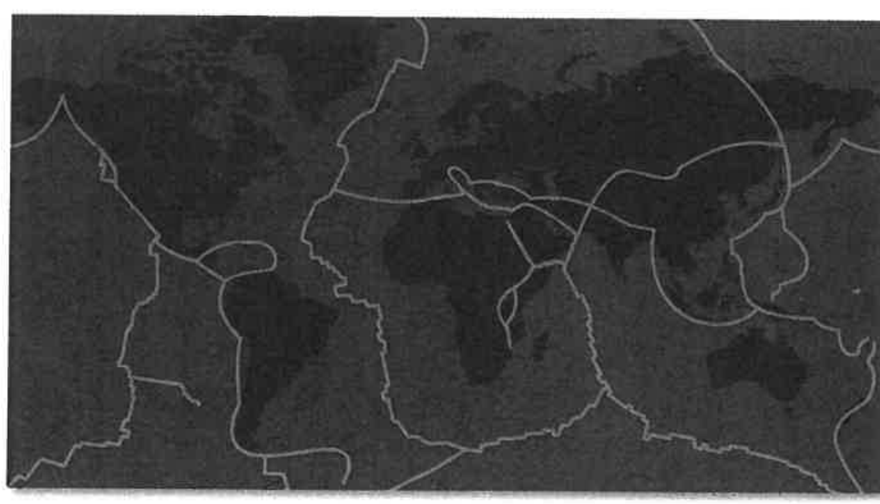
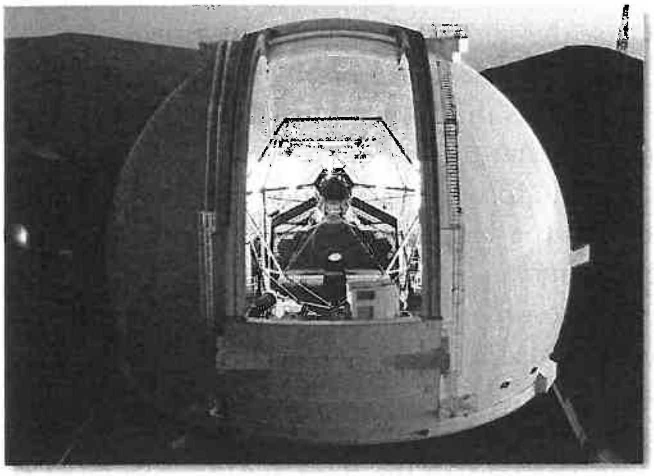


Figure 13

Computer models of Earth's crust help geologists understand how the continental plates (outlined in red) moved in the past and how they may move in the future.

Figure 14



A The Gemini North observatory in Hawaii is a new tool for scientists. Its 8.1 m mirror is used to view distant galaxies.

B The Whirlpool galaxy (M51) and its companion NGC5195 are linked by a trail of gas and dust, which NGC5195 has pulled from M51 by gravitational attraction.

Astronomers, for example, use *telescopes* with lenses and mirrors such as the one shown in ***Figure 14A*** to magnify objects that appear small because they are far away, such as the distant galaxies shown in ***Figure 14B.*** Other kinds of telescopes do not form images from visible light. *Radio telescopes* detect the radio signals emitted by distant objects. Some of the oldest, most distant objects in the universe have been found with radio telescopes. Radio waves from those objects were emitted almost 15 billion years ago.

Several different types of *spectroscopes* break light into a rainbowlike *spectrum.* A chemist can learn a great deal about a substance from the light it absorbs or emits. Physicists use *particle accelerators* to make fragments of atoms move extremely fast and then let them smash into atoms or parts of other atoms. Data from these collisions give us information about the structure of atoms.

Units of Measurement

As you learned in Section 1, mathematics is the language of science, and mathematical models rely on accurate observations. But if your scientific measurements are in inches and gallons, some scientists may not understand because they do not use these units. For this reason scientists use the International System of Units, abbreviated SI, which stands for the French phrase *le Système Internationale d'Unités.*

Connection to LANGUAGE ARTS

The word *scope* comes from the Greek word *skopein,* meaning "to see." Science and technology use many different scopes to see things that can't be seen with unaided eyes. For example, the telescope gets its name from the Greek prefix *tele-* meaning "distant" or "far." So a telescope is a tool for seeing far.

Making the Connection

Use a dictionary to find out what is seen by a microscope, a retinoscope, a kaleidoscope, and a hygroscope.

Did You Know?

SI started with the metric system in France in 1795. The meter was originally defined as 1/10 000 000 of the distance between the North Pole and the Equator.

SI units are used for consistency

When all scientists use the same system of measurement, sharing data and results is easier. SI is based on the metric system and uses the seven SI base units that you see listed in ***Table 1.***

Perhaps you noticed that the base units do not include area, volume, pressure, weight, force, speed, and other familiar quantities. Combinations of the base units, called *derived units*, are used for these measurements.

Suppose you want to order carpet for a floor that measures 8.0 m long and 6.0 m wide. You know that the area of a rectangle is its length times its width.

$$A = l \times w$$

The area of the floor can be calculated as shown below.

$$A = 8.0 \text{ m} \times 6.0 \text{ m} = 48 \text{ m}^2$$

(or 48 square meters)

The SI unit of area, m^2, is a derived unit.

Table 1 **SI Base Units**

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

Table 2 **Prefixes Used for Large Measurements**

Prefix	Symbol	Meaning	Multiple of base unit
kilo-	k	thousand	1000
mega-	M	million	1 000 000
giga-	G	billion	1 000 000 000

Table 3 **Prefixes Used for Small Measurements**

Prefix	Symbol	Meaning	Multiple of base unit
deci-	d	tenth	0.1
centi-	c	hundredth	0.01
milli-	m	thousandth	0.001
micro-	μ	millionth	0.000 001
nano-	n	billionth	0.000 000 001

SI prefixes are for very large and very small measurements

Look at a meterstick. How would you express the length of a bird's egg in meters? How about the distance you traveled on a trip? The bird's egg might be 1/100 m, or 0.01 m, wide. Your trip could have been 800 000 m in distance. To avoid writing a lot of decimal places and zeros, SI uses prefixes to express very small or very large numbers. These prefixes, shown in ***Table 2*** and ***Table 3,*** are all *multiples* of 10.

Using the prefixes, you can now say that the bird's egg is 1 cm (1 *centi*meter is 0.01 m) wide and your trip was 800 km (800 *kilo*meters are 800 000 m) long. Note that the base unit of mass is the *kilo*gram, which is already a multiple of the gram.

It is easy to convert SI units to smaller or larger units. Remember that to make a measurement, it takes more of a small unit or less of a large unit. A person's height could be 1.85 m, a fairly small number. In centimeters, the same height would be 185 cm, a larger number.

So, if you are converting to a smaller unit, multiply the measurement to get a bigger number. To write 1.85 m as *centi*meters, you multiply by 100, as shown below.

$$1.85\ \cancel{m} \times \frac{100\ cm}{1\ \cancel{m}} = 185\ cm$$

If you are converting to a larger unit, divide the measurement to get a smaller number. To change 185 cm to meters, divide by 100, as shown in the following.

$$185\ \cancel{cm} \times \frac{1\ m}{100\ \cancel{cm}} = 1.85\ m$$

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Math Skills

Conversions A roll of copper wire contains 15 m of wire. What is the length of the wire in centimeters?

1 List the given and unknown values.

Given: *length in meters*, l = 15 m

Unknown: *length in centimeters* = ? cm

2 Determine the relationship between units.

Looking at **Table 1-3,** you can find that 1 cm = 0.01 m.
This also means that 1 m = 100 cm.
You will multiply because you are converting from a larger unit (meters) to a smaller unit (centimeters).

3 Write the equation for the conversion.

$$\textit{length in cm} = m \times \frac{100\ cm}{1\ m}$$

4 Insert the known values into the equation, and solve.

$$\textit{length in cm} = 15\ \cancel{m} \times \frac{100\ cm}{1\ \cancel{m}}$$

$$\textit{length in cm} = 1500\ cm$$

Practice HINT

If you have done the conversions properly, all the units above and below the fraction will cancel except the units you need.

Practice

Conversions

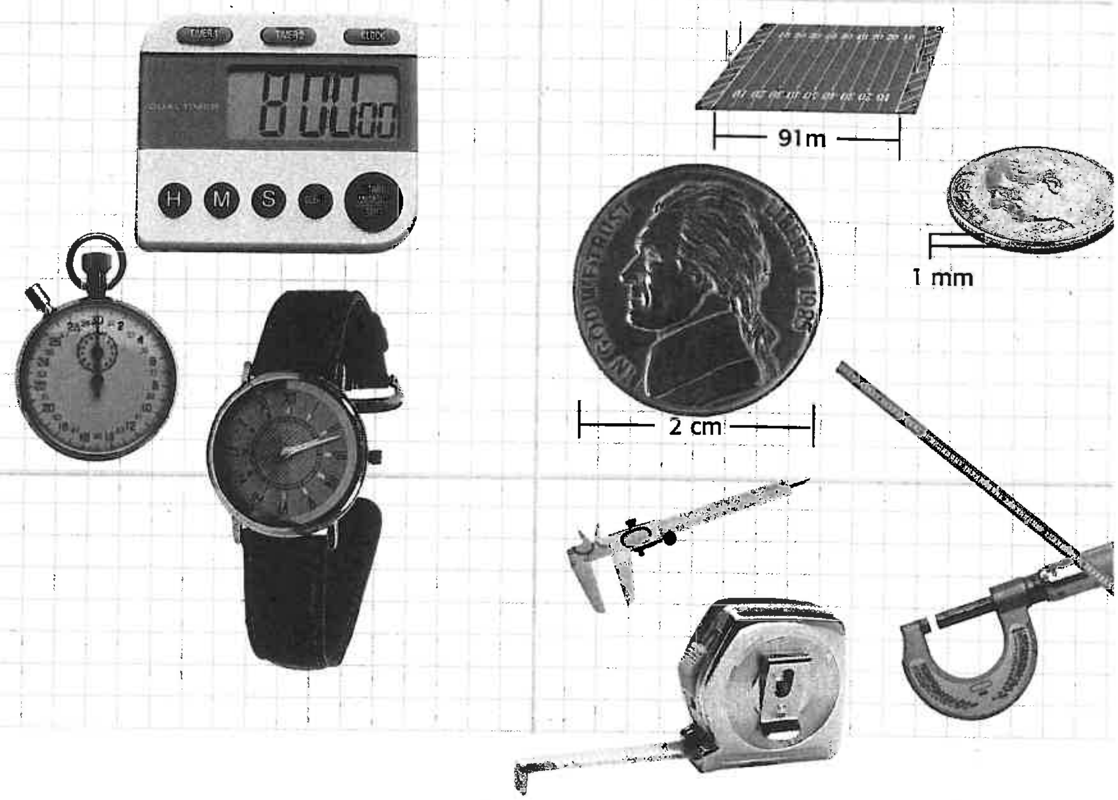
1. Write 550 *milli*meters as meters.
2. Write 3.5 seconds as *milli*seconds.
3. Convert 1.6 *kilo*grams to grams.
4. Convert 2500 *milli*grams to *kilo*grams.
5. Convert 4 *centi*meters to *micro*meters.
6. Change 2800 *milli*moles to moles.
7. Change 6.1 amperes to *milli*amperes.
8. Write 3 *micro*grams as *nano*grams.

Did You Know?

A unit used for measuring the mass of precious metals and gems is the carat. The word *carat* comes from the word *carob.* Originally, the carat was the mass of one seed from the carob plant. It is now defined as 200 mg.

Figure 15 **Quantitative Measurements**

	Time	Length
SI unit	second, s	meter, m
Other units	milliseconds, ms minutes, min hours, h	millimeter, mm centimeter, cm kilometer, km
Examples		
Tools		



Making measurements

length a measure of the straight-line distance between two points

mass a measure of the amount of matter in an object

volume a measure of the size of a body or region in three-dimensional space

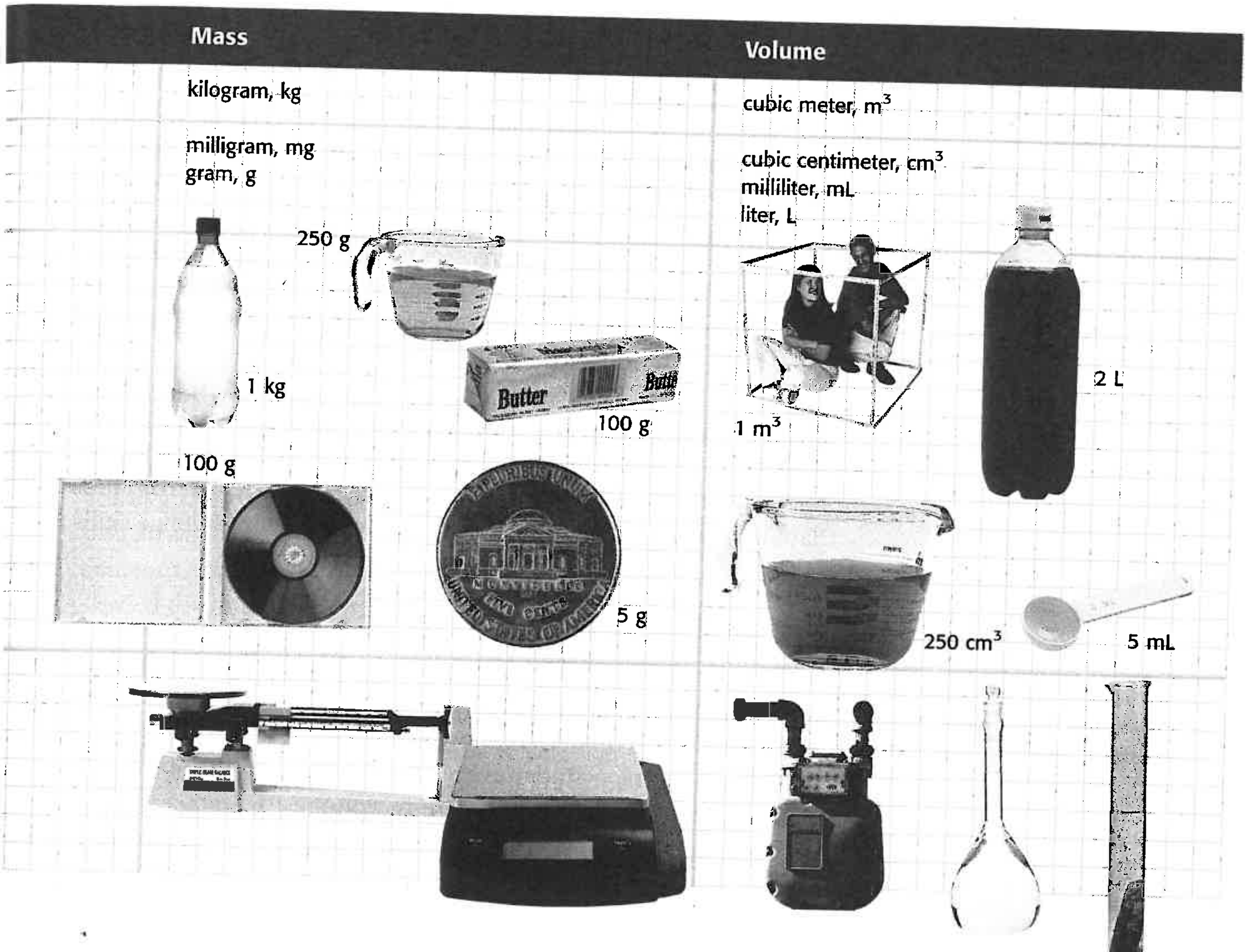
weight a measure of the gravitational force exerted on an object

Many observations rely on quantitative measurements. The most basic scientific measurements generally answer questions such as how much time did it take and how big is it?

Often, you will measure time, **length, mass,** and **volume.** The SI units for these quantities, examples of each quantity, and the tools you may use to measure them are shown in ***Figure 15.***

Although you may hear someone say that he or she is "weighing" an object with a balance, **weight** is not the same as mass. Mass is the quantity of matter and weight is the force with which Earth's gravity pulls on that quantity of matter.

In your lab activities, you will use a graduated cylinder to measure the volume of liquids. The volume of a solid that has a specific geometric shape can be calculated from the measured lengths of its surfaces. Small volumes are usually expressed in cubic centimeters, cm^3. One cubic centimeter is equal to 1 mL.



SECTION 2 REVIEW

SUMMARY

- In the scientific method, a person asks a question, collects data about the question, forms a hypothesis, tests the hypothesis, draws conclusions, and if necessary, modifies the hypothesis based on results.
- In an ideal experiment, only one factor, the variable, is tested.
- SI has seven base units.

1. **List** three examples each of things that are commonly measured by mass, by volume, and by length.
2. **Explain** why the scientific method is said to involve critical thinking.
3. **Describe** a hypothesis and how it is used. Give an example of a hypothesis.
4. **Explain** why no experiment should be called a failure.
5. **Relate** the discussion of scientists' tools to how science and technology depend on each other.
6. **Explain** the difference between SI base units and derived units. Give an example of each.
7. **Critical Thinking** Why do you think it is wise to limit an experiment to test only one factor at a time?

SECTION 3

Organizing Data

KEY TERMS

scientific notation
precision
significant figures
accuracy

OBJECTIVES

- **Interpret** line graphs, bar graphs, and pie charts.
- **Use** scientific notation and significant figures in problem solving.
- **Identify** the significant figures in calculations.
- **Understand** the difference between precision and accuracy.

One thing that helped Roentgen discover X rays was that he could read about the experiments other scientists had performed with the cathode ray tube. He was able to learn from their data. Organizing and presenting data are important science skills.

Presenting Scientific Data

Suppose you are trying to determine the speed of a chemical reaction that produces a gas. You can let the gas displace water in a graduated cylinder, as shown in ***Figure 16.*** You read the volume of gas in the cylinder every 10 seconds from the start of the reaction until there is no change in volume for four successive readings. ***Table 4*** shows the data you collect in the experiment.

Because you did the experiment, you saw how the volume changed over time. But how can someone who reads your report see it? To show the results, you can make a graph.

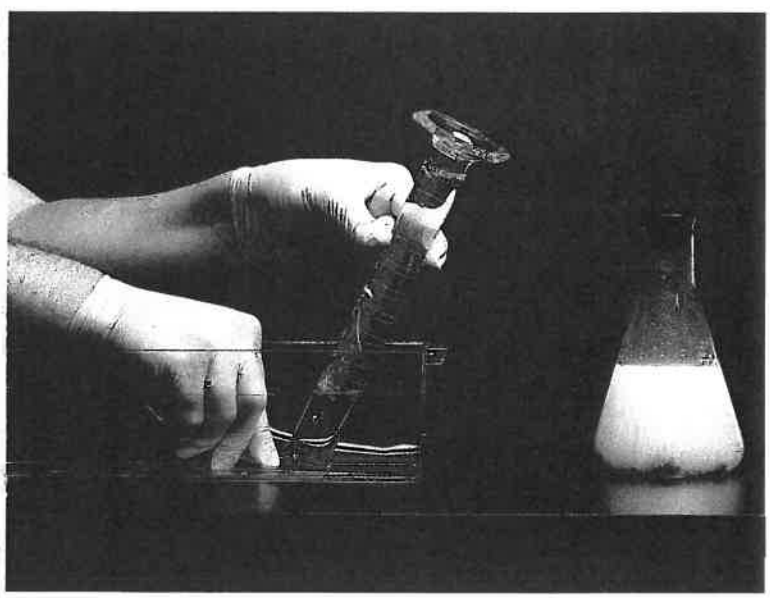


Figure 16
The volume of gas produced by a reaction can be determined by measuring the volume of water the gas displaces in a graduated cylinder.

Table 4 **Experimental Data**

Time (s)	Volume of gas (mL)	Time (s)	Volume of gas (mL)
0	0	90	116
10	3	100	140
20	6	110	147
30	12	120	152
40	25	130	154
50	43	140	156
60	58	150	156
70	72	160	156
80	100	170	156

Line graphs are best for continuous changes

Many types of graphs can be drawn, but which one should you use? A *line graph* is best for displaying data that change. Our example experiment has two variables, time and volume. Time is the *independent variable* because you chose the time intervals to take the measurements. The volume of gas is the *dependent variable* because its value depends on what happens in the experiment.

Line graphs are usually made with the x-axis showing the independent variable and the y-axis showing the dependent variable. ***Figure 17*** is a graph of the data that is in ***Table 4.***

A person who never saw your experiment can look at this graph and know what took place. The graph shows that gas was produced slowly for the first 20 s and that the rate increased until it became constant from about 40 s to 100 s. The reaction slowed down and stopped after about 140 s.

Volumes Measured over Time

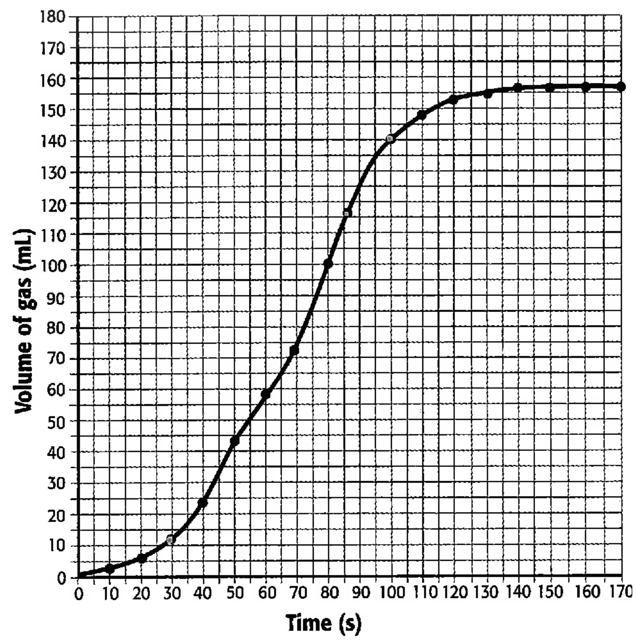


Figure 17

Data that change over a range are best represented by a line graph. Notice that many in-between volumes can be estimated.

Bar graphs compare items

A *bar graph* is useful when you want to compare similar data for several individual items or events. If you measured the melting temperatures of some metals, your data could be presented in a way similar to that in ***Table 5. Figure 18*** shows the same values as a bar graph. A bar graph often makes clearer how large or small the differences in individual values are.

Graph of the Melting Points of Some Common Metals

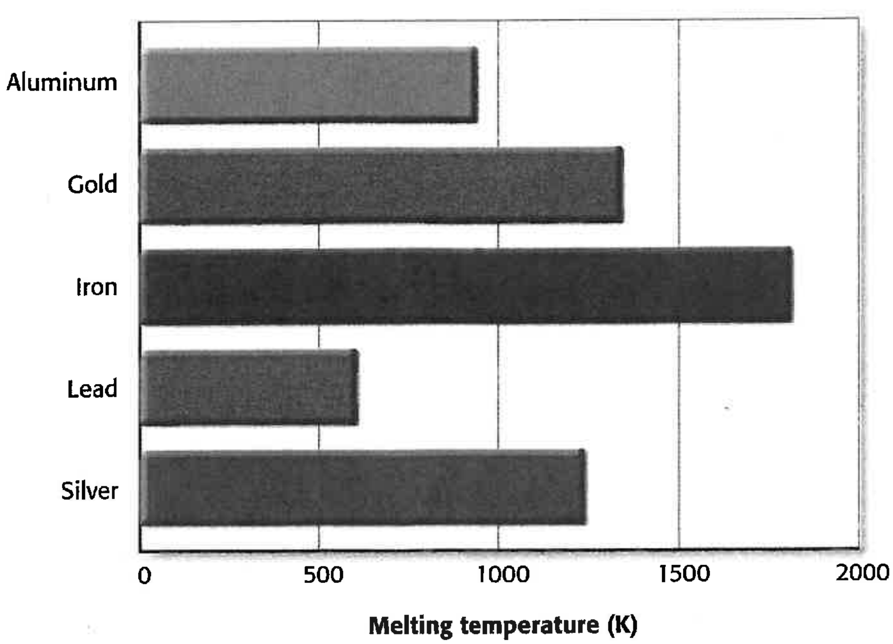


Table 5 **Melting Points of Some Metals**

Element	Melting temp. (K)
Aluminum	933
Gold	1337
Iron	1808
Lead	601
Silver	1235

Figure 18

A bar graph is best for data that have specific values for different events or things.

Composition of Calcite

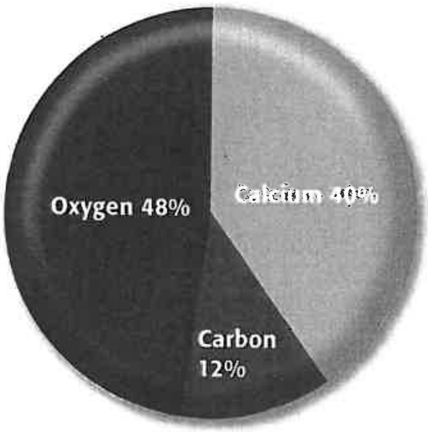


Figure 19

A pie chart is best for data that represent parts of a whole, such as the percentage of each element in the mineral calcite.

Pie charts show the parts of a whole

A *pie chart* is ideal for displaying data that are parts of a whole. Suppose you have analyzed a compound to find the percentage of each element it contains. Your analysis shows that the compound consists of 40 percent calcium, 12 percent carbon, and 48 percent oxygen. You can draw a pie chart that shows these percentages as a portion of the whole pie, the compound, as shown in ***Figure 19.*** To construct a pie chart, refer to the Graphing Skills Refresher in Appendix A and the skills page at the end of this chapter.

Writing Numbers in Scientific Notation

Scientists sometimes need to express measurements using numbers that are very large or very small. For example, the speed of light through space is about 300 000 000 m/s. Suppose you want to calculate the time required for light to travel from Neptune to Earth when Earth and Neptune are 4 500 000 000 000 m apart. To find out how long it takes, you would divide the distance between Earth and Neptune by the distance light travels in 1 s.

$$t = \frac{\text{distance from Earth to Neptune (m)}}{\text{distance light travels in 1 s (m/s)}}$$

$$t = \frac{4\,500\,000\,000\,000 \text{ m}}{300\,000\,000 \text{ m/s}}$$

This is a lot of zeros to keep track of when performing a calculation.

To reduce the number of zeros, you can express values as a simple number multiplied by a power of 10. This is called **scientific notation.** Some powers of 10 and their decimal equivalents are shown below.

■ **scientific notation** a method of expressing a quantity as a number multiplied by 10 to the appropriate power

$$10^4 = 10\,000$$
$$10^3 = 1000$$
$$10^2 = 100$$
$$10^1 = 10$$
$$10^0 = 1$$
$$10^{-1} = 0.1$$
$$10^{-2} = 0.01$$
$$10^{-3} = 0.001$$

In scientific notation, 4 500 000 000 000 m can be written as 4.5×10^{12} m. The speed of light in space is 3.0×10^8 m/s. Refer to the Math Skills Refresher in Appendix A for more information on scientific notation.

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Using scientific notation

When you use scientific notation in calculations, you follow the math rules for powers of 10. When you multiply two values in scientific notation, you add the powers of 10. When you divide, you subtract the powers of 10.

So the problem about Earth and Neptune can be solved more easily as shown below.

$$t = \frac{4.5 \times 10^{12}\ \text{m}}{3.0 \times 10^{8}\ \text{m/s}}$$

$$t = \left(\frac{4.5}{3.0} \times \frac{10^{12}}{10^{8}}\right) \frac{\text{m}}{\text{m/s}}$$

$$t = (1.5 \times 10^{(12-8)})\text{s}$$

$$t = 1.5 \times 10^{4}\ \text{s}$$

Math Skills

Writing Scientific Notation The adult human heart pumps about 18 000 L of blood each day. Write this value in scientific notation.

1 List the given and unknown values.

Given: *volume,* $V = 18\ 000$ L

Unknown: *volume,* $V = ? \times 10^{?}$ L

2 Write the form for scientific notation.

$V = ? \times 10^{?}$ L

3 Insert the known values into the form, and solve.

First find the largest power of 10 that will divide into the known value and leave one digit before the decimal point. You get 1.8 if you divide 10 000 into 18 000 L. So, 18 000 L can be written as (1.8 × 10 000) L.

Then write 10 000 as a power of 10. Because $10\ 000 = 10^4$, you can write 18 000 L as 1.8×10^4 L.

$V = 1.8 \times 10^4$ L

Practice HINT

- A shortcut for scientific notation involves moving the decimal point and counting the number of places it is moved. To change 18 000 to 1.8, the decimal point is moved four places to the left. The number of places the decimal is moved is the correct power of 10.

  18 000 L = 1.8×10^4 L

- When a quantity smaller than 1 is converted to scientific notation, the decimal moves to the right and the power of 10 is *negative.* For example, suppose an *E. coli* bacterium is measured to be 0.000 0021 m long. To express this measurement in scientific notation, move the decimal point to the right.

  0.000 0021 m = 2.1×10^{-6} m

Practice

Writing Scientific Notation

1. Write the following measurements in scientific notation:

a. 800 000 000 m **d.** 0.000 95 m

b. 0.0015 kg **e.** 8 002 000 km

c. 60 200 L **f.** 0.000 000 000 06 kg

2. Write the following measurements in long form:

a. 4.5×10^3 g **c.** 3.115×10^6 km

b. 6.05×10^{-3} m **d.** 1.99×10^{-8} cm

Math Skills

Using Scientific Notation Your state plans to buy a rectangular tract of land measuring 5.36×10^3 m by 1.38×10^4 m to establish a nature preserve. What is the area of this tract in square meters?

1 List the given and unknown values.

Given: *length,* $l = 1.38 \times 10^4$ m

width, $w = 5.36 \times 10^3$ m

Unknown: *area,* $A = ?$ m^2

2 Write the equation for area.

$A = l \times w$

3 Insert the known values into the equation, and solve.

$A = (1.38 \times 10^4 \text{ m})(5.36 \times 10^3 \text{ m})$

Regroup the values and units as follows.

$A = (1.38 \times 5.36)(10^4 \times 10^3)(\text{m} \times \text{m})$

When multiplying, add the powers of 10.

$A = (1.38 \times 5.36)(10^{4+3})(\text{m} \times \text{m})$

$A = 7.3968 \times 10^7 \text{ m}^2$

$A = 7.40 \times 10^7 \text{ m}^2$

Practice HINT

Because not all devices can display superscript numbers, scientific calculators and some math software for computers display numbers in scientific notation using E values. That is, 3.12×10^4 may be shown as 3.12 E4. Very small numbers are shown with negative values. For example, 2.637×10^{-5} may be shown as 2.637 E–5. The letter E signifies exponential notation. The E value is the exponent (power) of 10. The rules for using powers of 10 are the same whether the exponent is displayed as a superscript or as an E value.

Practice

Using Scientific Notation

1. Perform the following calculations.

a. $(5.5 \times 10^4 \text{ cm}) \times (1.4 \times 10^4 \text{ cm})$

b. $(2.77 \times 10^{-5} \text{ m}) \times (3.29 \times 10^{-4} \text{ m})$

c. $(4.34 \text{ g/mL}) \times (8.22 \times 10^6 \text{ mL})$

d. $(3.8 \times 10^{-2} \text{ cm}) \times (4.4 \times 10^{-2} \text{ cm}) \times (7.5 \times 10^{-2} \text{ cm})$

2. Perform the following calculations.

a. $\dfrac{3.0 \times 10^4 \text{ L}}{62 \text{ s}}$

b. $\dfrac{6.05 \times 10^7 \text{ g}}{8.8 \times 10^6 \text{ cm}^3}$

c. $\dfrac{5.2 \times 10^8 \text{ cm}^3}{9.5 \times 10^2 \text{ cm}}$

d. $\dfrac{3.8 \times 10^{-5} \text{ kg}}{4.6 \times 10^{-5} \text{ kg/cm}^3}$

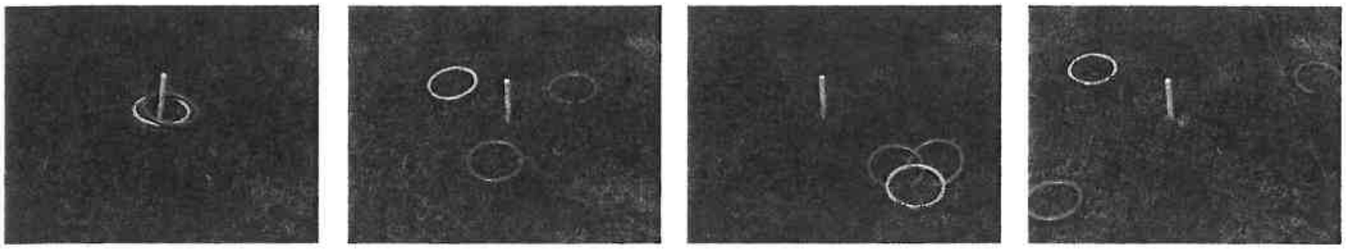
Using Significant Figures

Suppose you measure a length of wire with two tape measures. One tape is marked every 0.001 m, and the other is marked every 0.1 m. The tape marked every 0.001 m gives you more **precision,** because with it you can report a length of 1.638 m. The other tape is only precise to 1.6 m.

To show the precision of a measured quantity, scientists use **significant figures.** The length of 1.638 m has four significant figures because the digits 1638 are known for sure. The measurement of 1.6 m has two significant figures.

precision the exactness of a measurement

significant figure a prescribed decimal place that determines the amount of rounding off to be done based on the precision of the measurement



A Good accuracy (near post) and good precision (close together)

B Good accuracy (near post) and poor precision (spread apart)

C Poor accuracy (far from post) and good precision (close together)

D Poor accuracy (far from post) and poor precision (spread apart)

Figure 20

A ring toss is a game of skill, but it is also a good way to visualize accuracy and precision in measurements.

If the tip of your tape measure has broken off, you can read 1.638 m precisely, but that number is not **accurate.** A measured quantity is only as accurate as the tool used to make the measurement. One way to think about the accuracy and precision of measurements is shown in ***Figure 20.***

accuracy a description of how close a measurement is to the true value of the quantity measured

Math Skills

Significant Figures Calculate the volume of a room that is 3.125 m high, 4.25 m wide, and 5.75 m long. Write the answer with the correct number of significant figures.

1 List the given and unknown values.

Given: *length*, $l = 5.75$ m

width, $w = 4.25$ m

height, $h = 3.125$ m

Unknown: *Volume*, $V = ?$ m^3

2 Write the equation for volume.

Volume, $V = l \times w \times h$

3 Insert the known values into the equation, and solve.

$V = 5.75 \text{ m} \times 4.25 \text{ m} \times 3.125 \text{ m}$

$V = 76.367\ 1875 \text{ m}^3$

The answer should have three significant figures because the value with the smallest number of significant figures has three significant figures.

$V = 76.4 \text{ m}^3$

Practice

Significant Figures

Perform the following calculations, and write the answer with the correct number of significant figures.

1. 12.65 m × 42.1 m
2. 3.02 cm × 6.3 cm × 8.225 cm
3. 3.7 g ÷ 1.083 cm^3
4. 3.244 m ÷ 1.4 s

Practice HINT

When rounding to get the correct number of significant figures, do you round up or down if the last digit is a 5? Your teacher may have other ways to round, but one very common way is to round to get an even number. For example, 3.25 is rounded to 3.2, and 3.35 is rounded to 3.4. Using this simple rule, half the time you will round up and half the time you will round down. See the Math Skills Refresher in Appendix A for more about significant figures and rounding.

When you use measurements in calculations, the answer is only as precise as the least precise measurement used in the calculation—the measurement with the fewest significant figures. Suppose, for example, that the floor of a rectangular room is measured to the nearest 0.01 m (1 cm). The measured dimensions are reported to be 5.871 m by 8.14 m.

If you use a calculator to multiply 5.871 by 8.14, the display may show 47.789 94 as an answer. But you don't really know the area of the room to the nearest 0.000 01 m^2, as the calculator showed. To have the correct number of significant figures, you must round off your results. In this case the correct rounded result is $A = 47.8\ m^2$, because the least precise value in the calculation had three significant figures.

When adding or subtracting, use this rule: the answer cannot be more precise than the values in the calculation. A calculator will add 6.3421 s and 12.1 s to give 18.4421 as a result. But the least precise value was known to 0.1 s, so round to 18.4 s.

SECTION 3 REVIEW

SUMMARY

- Representing scientific data with graphs helps you and others understand experimental results.
- Scientific notation is useful for writing very large and very small measurements because it uses powers of 10 instead of strings of zeros.
- Accuracy is the extent to which a value approaches the true value.
- Precision is the degree of exactness of a measurement.
- Expressing data with significant figures tells others how precisely a measurement was made.

1. **Describe** the kind of data that is best displayed as a line graph.
2. **Describe** the kind of data that is best displayed as a pie chart. Give an example of data from everyday experiences that could be placed on a pie chart.
3. **Explain** in your own words the difference between accuracy and precision.
4. **Critical Thinking** An old riddle asks, "Which weighs more, a pound of feathers or a pound of lead?" Answer the question, and explain why you think people sometimes answer incorrectly.

WRITING SKILL

Math Skills

5. **Convert** the following measurements to scientific notation:
   - **a.** 15 400 mm^3
   - **b.** 0.000 33 kg
   - **c.** 2050 mL
   - **d.** 0.000 015 mol
6. **Calculate** the following:
   - **a.** $3.16 \times 10^3\ m \times 2.91 \times 10^4\ m$
   - **b.** $1.85 \times 10^{-3}\ cm \times 5.22 \times 10^{-2}\ cm$
   - **c.** $9.04 \times 10^5\ g \div 1.35 \times 10^5\ cm^3$
7. **Calculate** the following, and round the answer to the correct number of significant figures.
   - **a.** $54.2\ cm^2 \times 22\ cm$
   - **b.** $23\ 500\ m \div 89\ s$

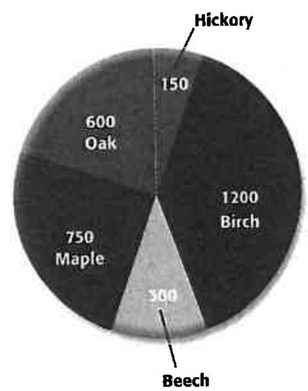
Graphing Skills

Constructing a Pie Chart

Unlike line or bar graphs, pie charts require special calculations to accurately display data. The steps below show how to construct a pie chart from this data.

Wisconsin Hardwood Trees

Type of tree	Number found
Oak	600
Maple	750
Beech	300
Birch	1200
Hickory	150
Total	3000



1 First, find the percentage of each type of tree. To do this, divide the number of each type of tree by the total number of trees and multiply by 100.

$$\frac{600\ oak}{3000\ trees} \times 100 = 20\%\ oak \qquad \frac{750\ maple}{3000\ trees} \times 100 = 25\%\ maple$$

Continuing these calculations for the rest of the trees, you find that 10% of the trees are beech, 40% are birch, and 5% are hickory. Check to make sure the sum is 100.

2 Now determine the size of the pie shapes that will make up the chart. Use the conversion factor 360°/100% to convert from percentage to degrees of a circle.

$$20\%\ oak \times \frac{360°}{100\%} = 72°\ oak \qquad 25\%\ maple \times \frac{360°}{100\%} = 90°\ maple$$

$$10\%\ beech \times \frac{360°}{100\%} = 36°\ beech \qquad 40\%\ birch \times \frac{360°}{100\%} = 144°\ birch$$

$$5\%\ hickory \times \frac{360°}{100\%} = 18°\ hickory$$

Check to make sure that the sum of all angles is 360°.

3 Use a compass to draw a circle and mark the circle's center. Then use a protractor to draw an angle of 144°. Mark this angle. From this mark, measure an angle of 90°. Continue marking angles from largest to smallest until all the angles have been marked. Finally, label each part of the chart, and choose an appropriate title for the graph.

Practice

1. A recipe for a loaf of bread calls for 474 g water, 9.6 g yeast, 28.3 g butter, 10 g salt, 10 g honey, and 907 g flour. Make a pie chart showing what percentage of the bread each of these ingredients is.