

# UNIT 1

## Physical Science and You

**Chapter 1** *Studying Physics and Chemistry*

**Chapter 2** *Experiments and Variables*

**Chapter 3** *Key Concepts in Physical Science*



### TRY **THIS** AT HOME

Do your own metric scavenger hunt! Find a ruler that is marked off in centimeters. If you don't have a ruler you can print a paper ruler from the Internet. Find ten different objects. The first should have a length, width, or thickness of one centimeter. The second

should have a length, width, or thickness of two centimeters, and so on until you find an object that is ten centimeters long, wide, or thick. List and describe your ten objects.



## Chapter 1

# ***Studying Physics and Chemistry***

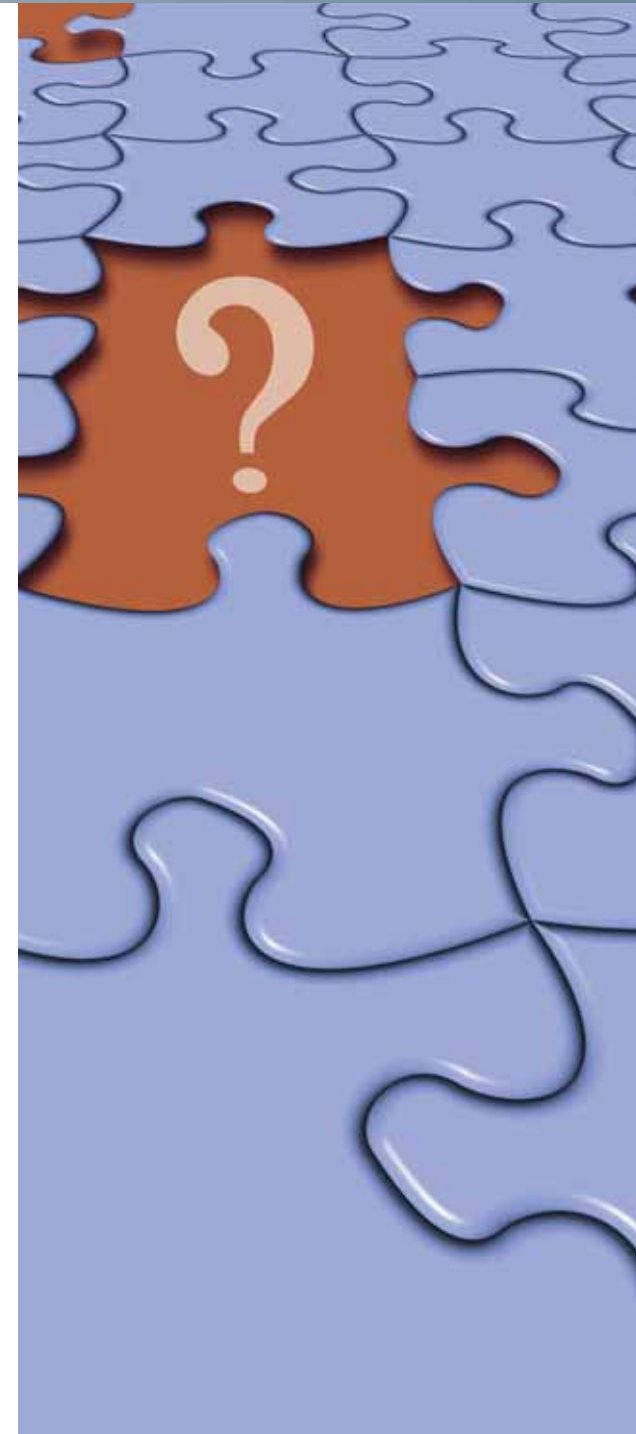
Imagine humans when they first had fire, when they first made wheels, when they first established where they were going by looking at the stars. Today, when you get off the school bus, go home and turn on the lights, put a CD on the player, you are in a way as far from your 19th-century ancestors — from your own relatives who lived like everyone, without electricity and automobiles, without radio and telephones — as you are from those ancient groups from early human history. How did the things we consider basic — heat, light, navigation, transportation, entertainment — and the things your great great-grandparents before you considered basic, ever come to be?

The answers all touch on physics and chemistry. Physical science, the subject of this book, includes physics and chemistry. Physics tells us how and why things move. Chemistry tells us how to make things and what things are made of. Even the most brilliant scientists, the most imaginative inventors, are born not knowing any science at all. Science has been *learned* over many thousands of years. This chapter is also about how scientists use inquiry to learn how the world works.



### **Key Questions**

1. *What is physical science and why is it important to learn?*
2. *How did people figure out the scientific knowledge that we know?*



## 1.1 The Physical Science in Your Life

In Unit One we will look at the 'big picture' of physical science. We will also review how people learned science in the first place. Each Unit after the first will then focus on one important area of physical science in more detail.

### The physics of a car

Cars changed the way people live



Few inventions have changed the world as much as the car. Before cars, it was a three-week, dangerous adventure to travel 500 miles between San Diego and San Francisco. Today, you might drive the same trip in a day to visit your relatives. Let's take a look at the physics and chemistry in an ordinary car.

**Forces are described by physics**

When you push on the gas pedal at a stoplight the car starts moving. The car starts moving because the engine causes a force that pushes the car forward. If there were no force, the car would not start moving. Forces are described by physics. Physics tells us how much force it takes to get the car moving. Physics also tells us how much force it takes to make the car turn or stop.

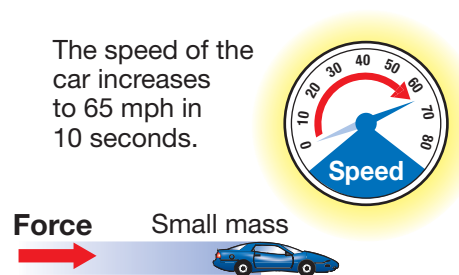
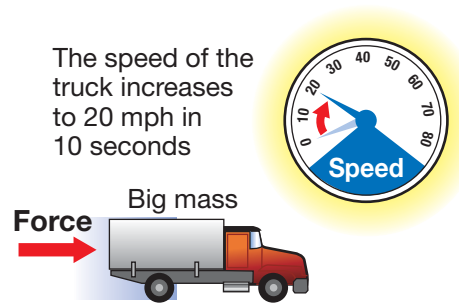
**Mass is also described by physics**

If you apply the same amount of force to a small sports car and to a big garbage truck, which one will start moving faster? Of course you know the answer (Figure 1.1). The sports car starts moving faster because a sports car has less **mass** than a garbage truck. The more mass you have, the more force it takes to get you moving. The reverse is also true. If you apply the same force to two objects, the one with less mass will start moving faster. The relationship between mass and motion is described by physics.

### VOCABULARY

**mass** - the amount of "stuff" (matter) an object contains. More about mass in chapter two.

**Objects with greater mass respond more slowly to the same force.**



**Figure 1.1:** When the same amount of force is applied to a sports car and a garbage truck, the sports car picks up speed much more rapidly because it has less mass.

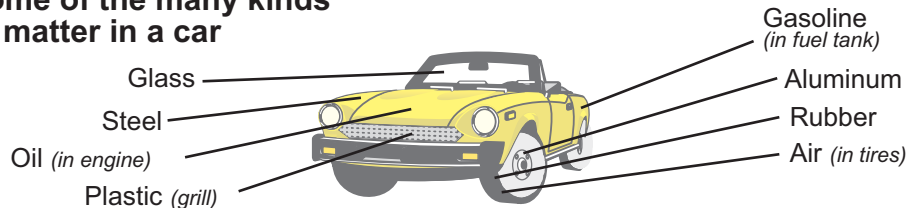


## The chemistry of a car

### Chemistry describes the different forms of matter

Look at a car and describe what the car is made of. At the most basic level a scientist might say a car is made of **matter**. Matter is everything that has mass and takes up space. This book is matter. You are matter. Even the air is matter. At the next level of detail, a car contains many different kinds of matter, such as steel, aluminum, plastic, and rubber. Chemistry is the science that concerns the different kinds of matter, how different kinds of matter are created and how matter can be changed from one kind to another.

#### Some of the many kinds of matter in a car



### Matter appears as solid, liquid, and gas

The matter in a car comes in three fundamental **phases**: called solid, liquid, and gas (Figure 1.2). Solid matter (like ice) is stiff, holds its shape, and may be strong. The frame of the car is made of solid steel. Liquid matter (like water) flows and does not hold its shape. Gasoline, oil, and windshield washer fluid are all liquids that are used in a car. Matter that is a gas (like air) can expand and contract. The air in the tires is a gas, as is the exhaust coming out the tailpipe.

### Burning gasoline is a chemical reaction

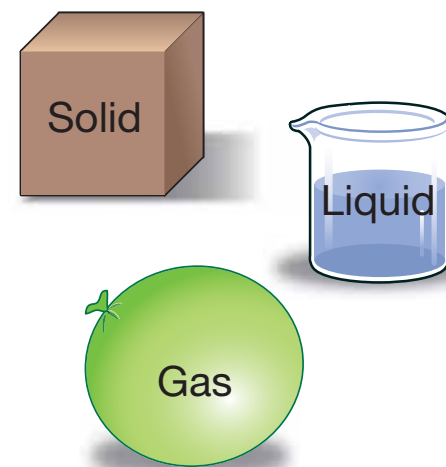
Virtually all of today's cars and trucks run on gasoline. You put gasoline in the tank and it is *burned* in the engine. The burning gasoline releases energy that makes the engine turn and makes the car work. Burning is a **chemical change** that turns gasoline and oxygen into carbon dioxide, water and other kinds of matter. Chemistry describes what gasoline is, and how gasoline combines with oxygen in a chemical reaction that releases energy.

## VOCABULARY

**matter** - everything that has mass and takes up space.

**phases of matter** - the different forms matter can take; commonly occur as solid, liquid, or gas.

**chemical change** - a chemical change transforms one kind of matter into another kind (or several) which may have different properties.



**Figure 1.2:** Matter appears in three different phases that we call solid, liquid, and gas.

## Physical science and sea otters

### Physical science and living things



A sea otter is a small furry mammal that spends all of its life in the water. Sea otters live in the giant kelp forests off the California coast. Like all living creatures, sea otters depend on physics and chemistry to exist.

### The force of water friction

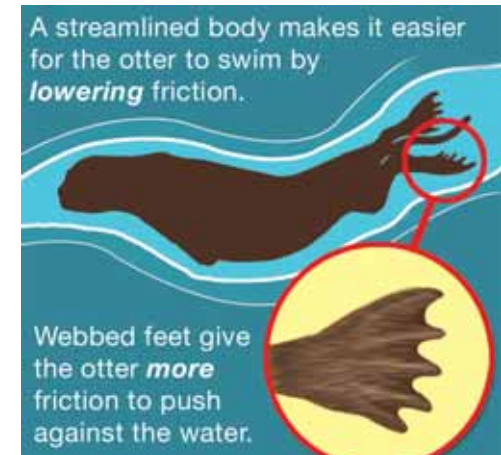
In order to swim, a sea otter has a streamlined body and webbed feet. The streamlined body shape reduces the friction of water against the sea otter's skin as it swims (Figure 1.3). The lower the force of water friction, the faster the sea otter can swim. The otter's webbed feet work in the opposite way. Having webs between its toes increases the force of water friction against the sea otter's outstretched feet. This makes the sea otter more effective in pushing against the water to swim. Friction and forces are described by physics.

### Why a sea otter floats instead of sinking

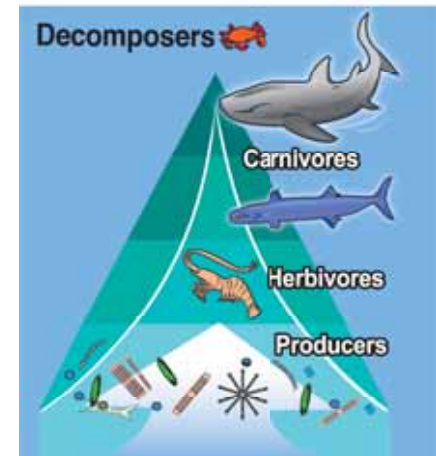
To find the shellfish they eat, sea otters dive down to the sea floor at the bottom of the kelp forest. Once they get a tasty clam or scallop, the otter swims back up to the surface and floats there to eat it. When it is floating, the sea otter is not swimming, yet it does not sink! A sea otter floats because its body is less *dense* than water. Density is a property of all matter, not just sea otters. Objects that are less dense (like the sea otter) float in liquids that are more dense (like water).

### Why living organisms need food to survive

Like most living organisms, a sea otter eats to survive. What is eating? Why do living organisms need food? The answer is provided by chemistry (Figure 1.4). Living organisms are made of special chemicals known as proteins, fats and carbohydrates. The sea otter needs these chemicals to provide energy to keep its body warm. The otter also needs these chemicals to grow. The otter gets the chemicals it needs by eating shellfish. *Biochemistry* is a branch of chemistry that explores exactly how plants and animals use chemicals and energy.



**Figure 1.3:** The otter's streamlined body reduces the force of water friction when it swims. The otter's webbed feet increase the force of water friction against its feet, making the otter more effective at pushing against the water.



**Figure 1.4:** Chemistry describes how living organisms use the food they eat.



## The sun is the source of energy for Earth

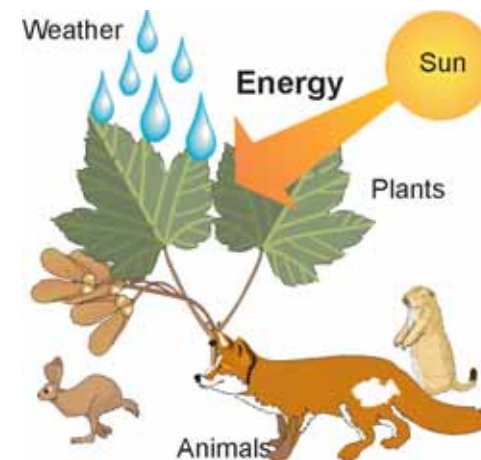
**The sun and energy** Both living creatures and human technology derive virtually all of their energy from the sun. Without the Sun's energy, Earth would be a cold icy place with a temperature of  $-273$  degrees Celsius. As well as warming the planet, the Sun's energy drives the entire food chain (Figure 1.5). Plants store the energy in carbohydrates, like sugar. Animals eat the plants to get energy. Other animals eat *those* animals for their energy. It all starts with the sun.

**Understanding what energy really is** If energy is so important, what is it? The answer is slippery but essential to physics and chemistry. Energy measures the ability for things to change. Energy is exchanged when *anything* changes. Nothing changes when no energy is exchanged. For example, when you press its accelerator, the speed of a car changes. The change comes from the exchange of energy between the gasoline in the engine and the motion of the whole car. The sea otter's body is warmer inside than the surrounding ocean water. Because the otter is warmer, heat energy flows from the otter into the ocean water. The otter needs a constant supply of energy from its food to replenish the energy exchanged with the water. Energy is such an important idea that you will find examples of energy in every single Unit of this book!

### Life on Mars and other planets



A very important question in science today is whether there is life on other planets, such as Mars. Mars is farther from the sun than Earth. For this reason, Mars receives less energy from the sun than does Earth. In fact, the average temperature on Mars is well below the freezing point of water. Can life exist on Mars? Recent research suggests that can. Scientists have found living bacteria in the Antarctic ice living at a temperature colder than the average temperature of Mars.



**Figure 1.5:** The flow of energy from the sun supports all living things on Earth.



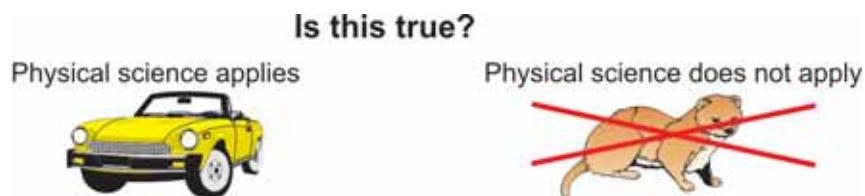
### CHALLENGE

The planet Venus is closer to the sun than Earth. Should this make Venus warmer or colder than Earth? Research your answer to see what scientists think Venus is like on the planet surface.

## 1.1 Section Review

Based on what you learned in this section, decide which of the following statements are *true* and which are *false*.

1. Understanding force and mass are part of the subject of physical science.
2. Physical science applies to mechanical inventions such as a car but not to living creatures.



3. Steel is matter because it is solid but water is not matter because water can flow and change its shape.
4. Matter can take the form of solid, liquid, or gas.
5. A sea otter floats because it eats a special kind of shellfish that it gets from the ocean floor.
6. The Earth receives a significant amount of its energy from the Moon and the other planets.
7. A car increases its speed primarily because energy is exchanged between the tires and the road. (careful, this is tricky to answer!)
8. Mars is warmer than Earth because it receives more energy from the sun than Earth does.
9. Proteins, fats, and carbohydrates are the three phases of matter in living creatures.
10. Gasoline is necessary for most cars because it is used in a chemical reaction inside the engine.



### STUDY SKILLS

#### Using new words

Write two sentences about something you know using each new glossary word. Using a new word helps you to remember what it means and how it is used. In fact, if you do not use a new word right away you are very likely to forget it within a few hours!

#### Science assigns precise meanings to many common words

Many words in science are words you already know, like “force” or “energy”. However, science defines these words in very precise ways that may be different from how they are used in everyday conversation. When you see a common word used in science, do not assume it means the same thing as it would in casual conversation.



## 1.2 Time and Length

In science we often want to know what happens next based on what happened before. The concepts of *next* and *before* involve time. Time plays an essential role in science. We also need a way to describe the size of things from the tiniest bacteria to the entire solar system. In physical science, size is described by length. This section is about the way scientists measure and communicate information about time and length.

### Two meanings for time

**What time is it?** Time has two important meanings (Figure 1.6). One meaning is to identify a particular moment in the past or in the future. For example, saying your 18th birthday party will be on January 1st, 2010 at 2:00 p.m. identifies a particular moment in the future for your party to start. This is the way “time” is usually used in everyday conversation. You may think of this meaning as *historical time*. If you ask, “What time is it?” you usually want to identify a moment in historical time. To answer the question, you would look at a calendar, clock or your watch.

**How much time?** The second meaning is to describe a *quantity* of time. For example, saying that a class lasts for 45 minutes is identifying a quantity of time; 45 minutes. If you ask, “How much time?” (did something take to occur, for instance), you are looking for a quantity of time. To answer, you need to measure an interval of time that has both a beginning and an end. For example, you might measure how much time has passed between the start of a race and when the first runner crosses the finish line. A quantity of time is often called a time interval. A microwave oven with a built-in clock (Figure 1.7) displays both kinds of time: historical time and time intervals. In physical science, the word “time” will usually mean a time interval instead of historical time.



**Figure 1.6:** There are two different ways to understand time.



**Figure 1.7:** A microwave oven can understand time in either mixed units (minutes and seconds) or in a single unit (seconds). Both 1:30 and 0:90 will result in the same cooking time.



## Units for Time

### Units for measuring time

You are probably familiar with the units for measuring time: seconds, minutes, hours, days, and years. But you may not know how they relate to each other. The table below gives some useful relationships between units of time.

Time unit	... in seconds ..	... and in days
1 second	1	0.0001157
1 minute	60	0.00694
1 hour	3,600	0.0417
1 day	86,400	1
1 year	31,557,600	365.25

### One second

The second (s) is the basic unit of time in both the English and metric systems. One second is about the time it takes to say “thousand.” There are 60 seconds in a minute and 3,600 seconds in an hour. The second was originally defined in terms of one day: There are 86,400 seconds in an average day of 24 hours ( $86,400 = 3,600 \times 24$ ).

### Mixed units

In everyday life, time is often expressed in mixed units. For example, the timer in Figure 1.8 shows the time for a race as 2 hours, 30 minutes and 45 seconds. This time is in mixed units (hours, minutes, and seconds). People are used to hearing time this way. However, to do scientific calculations, you must convert the time into a single unit.

### Converting time to seconds

For most physical science problems, you will need to express time in seconds. When converting to seconds the first thing you do is convert each quantity of hours and minutes to seconds. Then you add up all the seconds to get the total.

For example, 2 hours = 7,200 seconds. 30 minutes = 1,800 seconds. Therefore, 2:30:45 = 7,200 + 1,800 + 45 = 9,045 seconds.



**Figure 1.8:** Digital timers have displays that show time in mixed units.



### SOLVE IT!

Suppose you won a contest that gave you two choices. You could have either:

- a) 1 million dollars, or
- b) \$1 per second for a month.

Which choice is worth more money?

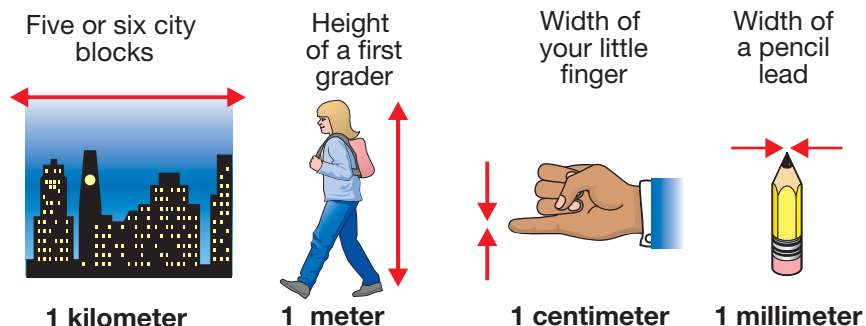


## Length and Distance

**What is distance?** You can think of distance as the amount of space between two points, like the points of a pencil that has been sharpened on both ends. You probably have a good understanding of distance from everyday experiences, like the distance from one house to another, or the distance between Los Angeles and San Francisco. The concept of distance in science is the same, but the actual distances may be much larger and much smaller than anything you normally think about in your everyday life.

**Distance is measured in units of length**

**Distance** is measured in units of length. Some of the commonly used units of length include inches, feet, miles, centimeters, kilometers, and meters. The metric (or SI) system uses millimeters (mm), centimeters (cm), meters (m), and kilometers (km). There are 10 millimeters in a centimeter, 100 centimeters in a meter, and 1,000 meters in a kilometer. The names of units in the metric system are based on multiplying by ten (Table 1.1). Almost all fields of science use metric units because they are easier to work with.



**Always include units**

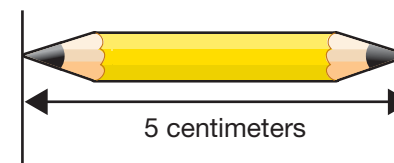
It is important to always specify which length unit you are using for a measurement. All measurements must have units. Without a unit, a measurement cannot be understood. For example, if you asked someone to walk 10, she would not know how far to go: 10 feet, 10 meters, 10 miles, 10 kilometers are all 10, but the units are different and therefore the distances are also different.

### VOCABULARY

**distance** - the amount of space between two points.

### Distance

Distance is the amount of space between two points.



**Figure 1.9:** *The definition of distance.*

**Table 1.1:** *Metric prefixes*

Prefix	Meaning	
giga (G)	1 billion	1,000,000,000
mega (M)	1 million	1,000,000
kilo (k)	1 thousand	1,000
centi (c)	1 one-hundredth	0.01
milli (m)	1 one-thousandth	0.001
micro ( $\mu$ )	1 one-millionth	0.000001

## Measuring length

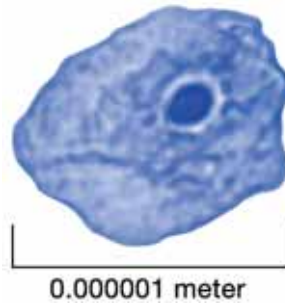
### VOCABULARY

**astronomical unit (AU)** - the distance between Earth and the Sun (1 AU).

**light year** - the distance light travels in one year (9.5 trillion km).

**The meter stick** For ordinary lengths you must measure in the laboratory a meter stick is the most convenient tool to use. A meter stick is one meter long and has divisions of millimeters and centimeters. The diagram in Figure 1.10 shows a meter stick along with several different length objects. Can you see how the meter stick is used to measure the length shown for each object?

### Microscopic lengths

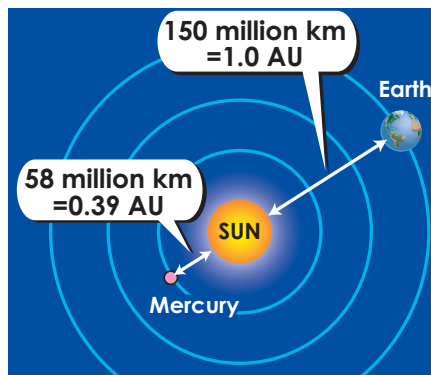


For very small lengths, such as the size of a bacteria, scientists use measuring instruments that fit into a microscope. The micron ( $\mu$ ) is a very tiny unit of length, appropriate to measuring tiny living creatures like bacteria. There are one million microns in a meter. The picture shows a single cell with a micron scale. Can you determine the length of the cell?

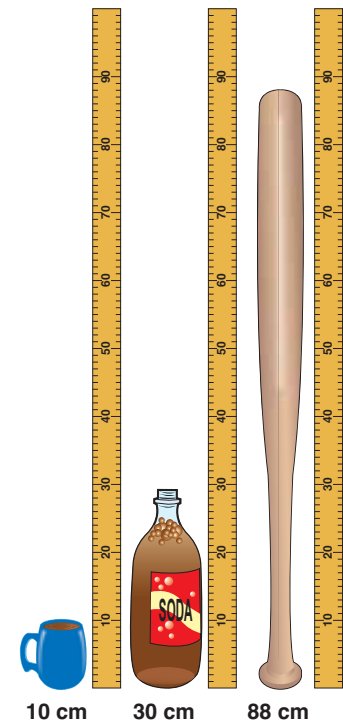
### Geographic lengths

For geographical lengths the most common metric unit is the kilometer. One kilometer is equal to one thousand meters (1 km = 1,000 m). A mile is longer than a kilometer. In fact, one mile is a bit more than one and a half kilometers (1 mile = 1.6 km).

### Astronomical lengths



Science also considers very large lengths, such as the distance between planets and stars. One **astronomical unit (AU)** is the distance between Earth and the sun, about 150 million kilometers. One **light year** is the distance light travels in one year, which is 9.5 trillion kilometers. The nearest star is 4.3 light years away from us.



**Figure 1.10:** How to read a meter stick.



## Converting between units of length

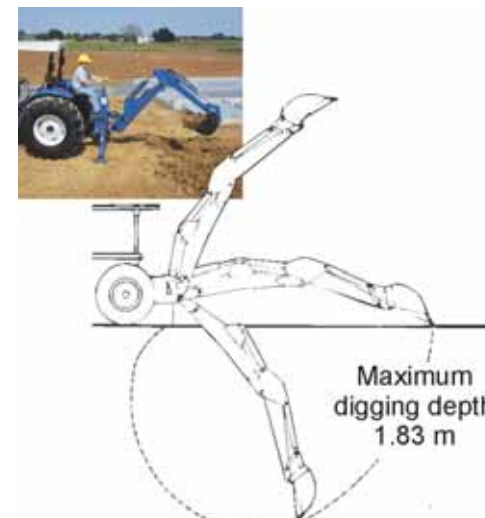
**The problem of multiple units** It would be best (for science) if everyone always used the same unit for length, like the meter. Unfortunately, many different units of length are used for different things, and in different places. In California, you will find inches, feet and miles used more commonly than centimeters, meters and kilometers. In many problems you will need to translate a measurement in one unit into another unit.

**Comparing feet and meters** For example, a backhoe on one tractor gives the maximum depth the tractor can dig as 1.83 meters (Figure 1.11). The contractor using the backhoe needs to dig a foundation for a house that is 8 feet deep. Can the backhoe do the job?

**Doing units conversions** To answer the question you need to convert from feet to meters and then compare the distances in the same units. To do the conversion you multiply by *conversion factors*. A conversion factor is a ratio that has the value of one. That means the same length is on the top and bottom of the fraction. The trick is that the top and bottom are in different units. For example to convert 1.83 meters into feet you need a conversion factor that relates meters and feet. The table in Figure 1.12 gives two related conversion factors between feet and meters: 1 m / 3.28 ft and 1 foot / 0.305 m. The diagram below shows you what happens when you multiply 1.83 meters by both conversion factors. the correct answer is 6 feet. Can you tell why this answer is correct and the other one is not?

<p><b>The wrong way</b></p> $1.83 \text{ m} \times \left( \frac{1 \text{ m}}{3.28 \text{ ft}} \right) = 0.56 \frac{\text{m}^2}{\text{ft}}$ <p style="text-align: center;">conversion factor</p>	<p><b>The right way</b></p> $1.83 \text{ m} \times \left( \frac{1 \text{ ft}}{0.305 \text{ m}} \right) = 6 \text{ feet}$ <p style="text-align: center;">conversion factor</p>
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Answer: This backhoe can only dig 6 feet deep so a larger machine is needed.



**Figure 1.11:** This backhoe specification gives the maximum depth the machine can dig in meters.

$\frac{1 \text{ cm}}{0.01 \text{ m}}$	$\frac{1 \text{ cm}}{0.394 \text{ in}}$	$\frac{1 \text{ cm}}{10 \text{ mm}}$
$\frac{1 \text{ inch}}{0.0254 \text{ m}}$	$\frac{1 \text{ inch}}{2.54 \text{ cm}}$	$\frac{1 \text{ inch}}{25.4 \text{ mm}}$
$\frac{1 \text{ foot}}{0.305 \text{ m}}$	$\frac{1 \text{ foot}}{12 \text{ in}}$	$\frac{1 \text{ foot}}{30.5 \text{ cm}}$
$\frac{1 \text{ m}}{3.28 \text{ ft}}$	$\frac{1 \text{ m}}{39.4 \text{ in}}$	$\frac{1 \text{ m}}{100 \text{ cm}}$
$\frac{1 \text{ km}}{0.622 \text{ mi}}$	$\frac{1 \text{ km}}{1,000 \text{ m}}$	$\frac{1 \text{ km}}{3,280 \text{ ft}}$
$\frac{1 \text{ mile}}{1.61 \text{ km}}$	$\frac{1 \text{ mile}}{1,609 \text{ m}}$	$\frac{1 \text{ mile}}{5,280 \text{ ft}}$

**Figure 1.12:** Length conversion factors. Each fraction is equal to 1.

## 1.2 Section Review

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1. There are two ways to view time in science: as historical time and as time interval.
  - a. Give an example in which the two meanings are similar.
  - b. Give an example in which the two meanings are different.
2. Arrange the following intervals of time from shortest to longest.
  - a. 160 seconds
  - b. 2 minutes
  - c. 2 minutes 50 seconds
3. A bicyclist completes a race in one hour, five minutes, and 27 seconds (Figure 1.13). How many seconds did it take for the bicyclist to finish the race?
4. The length of a sheet of standard (letter size) paper is closest to:
  - a. 0.11 meters
  - b. 11 centimeters
  - c. 29 centimeters
  - d. 279 millimeters
5. The height of an average person is closest to:
  - a. 1.0 meters
  - b. 1.8 meters
  - c. 5.6 meters
  - d. 10 meters
6. Someone who sells rope offers you 200 of rope for \$10. What is wrong with this offer?
7. Which is longer, one kilometer or one mile?
8. Many home improvement stores sell plywood with a thickness of seven millimeters. How does this compare to standard plywood which has thicknesses of  $\frac{1}{4}$ ",  $\frac{3}{8}$ ",  $\frac{1}{2}$ " and  $\frac{3}{4}$ "? Which one of these thicknesses could be replaced with seven millimeter plywood?



**Figure 1.13:** *The bicyclist for question 3.*



## 1.3 Inquiry and the Scientific Method

We believe that the universe obeys a set of rules that we call **natural laws**. We believe that everything that happens everywhere obeys the same natural laws. Unfortunately, the natural laws are not written down nor are we born knowing them. *The primary goal of science is to discover what the natural laws are.* Over time, we have found the most reliable way to discover the natural laws is called *scientific inquiry*.

### What inquiry means

- Inquiry is learning through questions** Learning by asking questions is called **inquiry**. An inquiry is like a crime investigation in that there is a mystery to solve. With a crime, something illegal happened and the detective must figure out what it was. Solving the mystery means accurately describing what actually happened.
- Deduction** One problem always is that the detective did not see what happened. The detective must **deduce** what happened in the past from information collected in the present.
- Theories** In the process of inquiry, the detective asks lots of questions related to the mystery. The detective searches for evidence and clues that help answer the questions. Eventually, the detective comes up with a theory about what happened that is a description of the crime and what occurred down to the smallest details.
- How you know you have learned the truth** At first, the detective's theory is only one explanation among several of what *might have happened*. The detective must have proof that a theory describes what *did happen*. To be proven, a theory must pass three demanding tests. First, it must be supported by significant evidence. Second, there cannot be even a *single* piece of evidence that proves the theory is false. Third, the theory must be unique. If two theories both fit the facts equally well, you cannot tell which is correct. When the detective arrives at a theory that passes all three tests, he or she believes they have learned from their inquiry what happened.

### VOCABULARY

**natural laws** - the set of rules that are obeyed by every detail of everything that occurs in the universe, including living creatures and human technology.

**inquiry** - a process of learning that starts with questions and proceeds by seeking the answers to the questions.

**deduce** - to figure something out from known facts using logical thinking. For example, "this is what happened ... because ...".



**Figure 1.14:** The steps in learning through inquiry.

## Scientific Theories and Natural Laws

### How theories are related to natural laws

A scientific theory is a human attempt to describe a natural law. For example, if you leave a hot cup of coffee on the table eventually it will cool down. Why? There must be some natural law that explains what causes the coffee to cool. A good place to start looking for the answer is by asking what it is about the coffee that makes it hot. Whatever quality creates “hot” must go away or weaken as the coffee gets cool (Figure 1.15). The question of what heat is — not how to create it or what it feels like but what it is — puzzled people for a long time.

### The theory of caloric

Before 1843, scientists believed (a theory) that heat was a kind of fluid (like water) that flowed from hotter objects to colder objects. They called this fluid *caloric*. Hot objects had more caloric than cold objects. When you put a hot object in contact with a cold object, the caloric flowed between the two until the temperature was equal.

### Testing the theory

This theory was at first supported by the evidence. However, problems with the theory came up as soon as people learned to measure weight accurately. If caloric flowed from a hot object to a cold object, a hot object should weigh slightly more than the same object when it was cold. Experiments showed that this was *not true*. To the most precise measurements that could be made, an object had the same weight, hot or cold. The theory had to be changed because new evidence proved it could not be correct.

### How theories are tested against evidence

Scientists continually test theories against new evidence.

1. The current theory correctly explains the new evidence. This gives us more confidence that the current theory is the right one.
2. The current theory does *not* explain the new evidence. This means scientists must revise the theory or come up with a completely new one that explains the new evidence as well as all the previous evidence, too.



**Figure 1.15:** A question that might begin an inquiry into what “heat” really is.

### CHALLENGE

Many things in science were unknown 1,000 years ago. That doesn't mean people didn't know about qualities like temperature! Ancient people certainly knew the difference between hot and cold. What they did not know is the explanation for qualities such as hot or cold. People believed different things about these qualities than they do today.

Research a theory about something in science that was believed in the past and is no longer believed today. What evidence convinced people to change their minds?



## Theories and hypotheses

**The hypothesis** In a criminal investigation, a good detective often proposes many possible but different theories for what might have happened. Each different theory is then compared with the evidence. The same is true in science, except that the word **theory** is reserved for a single explanation supported by lots of evidence collected over a long period of time. Instead of “theory” scientists use the word **hypothesis** to describe a possible explanation for a scientific mystery.

**Theories in science are hypotheses that correctly explain every bit of evidence**

Theories in science start out as hypotheses. The explanation of heat in terms of caloric is an incorrect hypothesis, one of many leading up to the modern theory of heat. The first hypothesis that heat was a form of energy was made by the German doctor, Julius Mayer in 1842, and confirmed by experiments done by James Joule in 1843. Energy has no weight so Mayer’s hypothesis explained why an object’s weight remained unchanged whether hot or cold. After many experiments, Mayer’s hypothesis (that heat was a form of energy) became the accepted *theory* of heat we believe today.

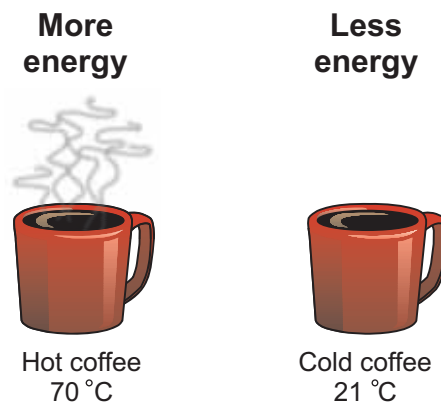
**Hypotheses must be testable to be scientific**

A scientific hypothesis must be testable. That means it must be possible to collect evidence that proves whether the hypothesis is true or false. This requirement means *not all hypotheses* can be considered by science. For instance, it has been believed at times that creatures are alive because of an undetectable “life force.” This is not a scientific hypothesis because there is no way to test it. If the “life force” is undetectable that means no evidence can be collected that would prove whether it existed or not. Science restricts itself only to those ideas which may be proved or disproved by actual evidence.

### VOCABULARY

**hypothesis** - an unproved or preliminary explanation that can be tested by comparison with scientific evidence. Early hypotheses are rarely correct and are often modified as new evidence becomes available.

**theory** - a scientific explanation supported by much evidence collected over a long period of time.



**Figure 1.16:** Eventually, scientists were able to deduce that heat is a form of energy. A hot cup of coffee has more heat energy than a cold cup of coffee. As coffee cools, its heat energy is transferred to the room. As a result, air in the room is warmed.



## The Scientific Method

**Learning by chance** At first, humans learned about the world by trial and error, trying one thing at a time, like a small child attempting to open a jar. She will try what she knows: biting the lid, pulling on it, shaking the jar, dropping it ... until, by chance, she twists the lid. It comes off. She puts it back and tries twisting it again — and the lid comes off again. The child learns by trying many things and *remembering what works*.

**Learning by the scientific method** It takes a long time to learn by randomly trying everything. What is worse, you can never be sure you tried *everything*. The **scientific method** is a much more dependable way to learn.

### *The Scientific Method*

1. Scientists observe nature, then invent or revise hypotheses about how things work.
2. The hypotheses are tested against evidence collected from observations and experiments.
3. Any hypothesis which correctly accounts for all of the evidence from the experiments is a potentially correct theory.
4. A theory is continually tested by collecting new and different evidence. Even a single piece of evidence that does not agree with a theory causes scientists to return to step one.

**Why the scientific method works** The scientific method is the underlying logic of science. It is basically a careful and cautious way to build a supportable, evidence-based understanding of our natural world. Each theory is continually tested against the results of observations and experiments. Such testing leads to continued development and refinement of theories to explain more and more different things. The way people learned about many things great and small, to the solar system and beyond, can be traced through many hypotheses (Figure 1.17).

## VOCABULARY

**scientific method** - a process of learning that begins with a hypothesis and proceeds to prove or change the hypothesis by comparing it with scientific evidence.



Early civilizations believed the Earth was covered by a dome on which the Sun, stars, and planets moved.



In the middle ages people thought the Sun, stars, and planets circled the Earth which sat in the center.



Today we know the Earth and planets orbit around the Sun and the stars are very far away.

**Figure 1.17:** Three different models for Earth and the solar system that were believed at different times in history.



## Scientific evidence

- What counts as scientific evidence?** The scientific method tells us the only sure way to know you are right is to compare what you think against evidence. However, what types of evidence qualify as *scientific* evidence? Do feelings or opinions count as scientific evidence? Does what other people think qualify as scientific evidence? The answer is no. Because evidence is so important in science, there are careful rules defining what counts as scientific evidence.
- An example of scientific evidence** Scientific evidence may be measurements, data tables, graphs, observations, pictures, sound recordings, or any other information that describes what happens in the real world (Figure 1.18). Scientific evidence may be collected even without doing experiments in a laboratory. For example, Galileo used his telescope to observe the moon and recorded his observations by sketching what he saw. Galileo's sketches are considered scientific evidence.
- When is evidence considered scientific?** The two most important characteristics of scientific evidence are that it be **objective** and **repeatable**. “Objective” means the evidence should describe *only what actually happened* as exactly as possible. “Repeatable” means that others who repeat the same experiment the same way observe the same results. Scientific evidence must pass the tests of both objectivity and repeatability. Galileo's sketches describe in detail what he actually saw through the telescope, therefore they pass the test of objectivity. Others who looked through his telescope saw the same thing, therefore the sketches pass the test of repeatability. Galileo's sketches convinced people that the Moon was actually a world like the Earth with mountains and valleys. This was not what people believed prior to Galileo's time.
- Communicating scientific evidence** It is important that scientific evidence be communicated clearly, with no room for misunderstanding. For this reason, in science we must define concepts like “force” and “weight” very clearly. Usually, the scientific definition is similar to the way you already use the word, but more exact. For example, your “weight” in science means the force of gravity pulling on the mass of your body.

## VOCABULARY

**objective** - describes evidence that documents only what actually happened as exactly as possible.

**repeatable** - describes evidence that can be seen independently by others if they repeat the same experiment or observation in the same way.

### Examples of scientific evidence



Pictures or sketches that show actual observations

time (sec)	speed (m/sec)	position (m)
0.0	0.00	0.00
0.2	0.83	0.08
0.4	1.66	0.33
0.6	2.50	0.75
0.8	3.33	1.33
1.0	4.16	2.08

Measurements and data

**Figure 1.18:** Some examples of scientific evidence.

## Learning science through inquiry

### What learning through inquiry means

The goal of this book is to help you learn science through inquiry. This means you will be asked questions instead of being given answers. You will be asked to propose explanations (hypotheses) for things that you see. And like your most ancient ancestors and the most modern detectives, and almost everyone in between, *not all your explanations will be correct*. In inquiry, getting the right answer immediately *is not important*. What is important is having a possible answer that can be tested to see whether it is right or not. You will be given ways (investigations) to collect evidence so you can decide which hypotheses are correct and which are not.

### Why not just tell you the answers?

Of course, you could just read the answers in the book and skip all the thinking and testing. There are two major reasons why learning through inquiry is a better way. For one, just reading the answers in a book is boring and you are unlikely to remember them anyway.

### Inquiry teaches you how to use science

The most important reason to learn through inquiry is that someday, maybe tomorrow, you will be stumped by something that does not work in your life outside the classroom. It is very unlikely this book or any book will have taught you to fix the exact thing that has you stumped. Inquiry teaches you how to learn how almost anything works. Once you know how something works, you can often figure out how to make it work for *you*. This is called problem-solving and it is an extraordinarily useful skill. In fact, *problem-solving is the most important thing you will learn in this course*. Simple answers, like the temperature of Mars can always be looked up in a book. Inquiry teaches you how to *use* the answers to solve *your problems* and become successful.



### MY JOURNAL

You use inquiry and the scientific method every day, only you probably do not realize it. Write down three things you have learned in your life by being curious and testing your ideas for yourself.



### SOLVE IT!

Problem-solving in the real world often involves things that are not written down. For example, suppose you have a flashlight. You turn on the switch, and nothing happens. There is no light.

List two potential reasons why the flashlight might not work. These are your hypotheses.

Give at least one way to test each hypothesis to see if it is the correct one. Each test is an experiment that produces scientific evidence that allows you to evaluate the hypothesis.

It is not hard to fix a flashlight by doing the things you just wrote down. This is the scientific method as applied to every day problem-solving.



## 1.3 Section Review

- Which of the following is an example of deduction?
  - Hector calls the weather service to find out if the temperature outside is below freezing.
  - Caroline looks out the window and concludes the temperature is below freezing because she sees that the puddles in her neighbor's driveway are frozen.
- Describe the relationship between a hypothesis, a theory, and a natural law.
- To be correct, a scientific theory must be everything **except**
  - supported by every part of a large collection of evidence,
  - believed by a large number of reputable people,
  - testable by comparison with scientific evidence,
  - an explanation of something that actually occurs in the natural world or human technology
- Julie, a third grade student, believes that the moon disappears on certain days every month. Explain why the following information is or is not scientific evidence which can be used to evaluate Julie's hypothesis.
  - Julie sometimes cannot see the moon all night even though the sky is clear.
  - Anne, Julie's older sister, thinks the phases of the moon are caused by the moon's position in its orbit around the Earth.
- When describing scientific evidence, what is the meaning of the word "repeatable"?
- Which of the following is an example of learning through inquiry?
  - Miguel is told that hot objects, like a cup of coffee, cool off when left on the table in a cooler room.
  - Enrique wonders what happens to hot objects if you remove them from the stove. He puts a thermometer in a cup of hot coffee and observes that the coffee cools off.



### STUDY SKILLS

#### Keep your eyes and ears open to the world

A great many discoveries were made almost by accident! For example, paper used to be made of cotton or linen. Both of these are plant fibers and are very expensive. Many inventors searched for a better and less expensive way to make paper. In 1719 French scientist and inventor Rene de Reaumer was walking in the woods when he noticed that wasp nests were made from something a lot like paper! How did the wasps do it? Reaumer discovered that the wasps used wood fibers to make paper. Reaumer began experimenting with a way to make paper from wood, like the wasps. It was trickier than he realized and it was not until 1840 that Friedrich Keller made the first all wood paper. However, Reaumer's curiosity and alert eyes lead directly to the modern, wood-based paper we use today.



## The Art and Sole of Scientific Thinking

When you are playing a sport, how often do you think about your shoes? If they are “working” properly, you shouldn’t think about them at all. This is no accident, either. Your athletic shoes have been scientifically designed and engineered.

Not that long ago, athletic shoes were relatively crude. They were made of leather or canvas. They had cleats if they were used on grass and rubber soles if they were used on hard surfaces. What they did not have was much cushioning to protect athletes’ feet and legs and knees and hips from the impact of running and jumping, starting and stopping.

### Using the scientific method

Today’s athletic shoes are high-tech. Scientists and engineers are constantly studying the forces that act on the feet and legs of athletes in various sports and using those studies to redesign and improve footwear.



Photo - courtesy of Orthopaedic Biomechanics Laboratory of Michigan State University

So how do scientists and engineers work together to study and improve running shoes - or any other product? They use the scientific method. The scientific method helps ensure that new shoe designs actually improve performance.

Remember, the scientific method begins with observations that lead to questions. For example: “how can a shoe reduce the impact force on a runner’s foot?” A design engineer proposes answers to the questions, such as “this new shape of wedge should lessen impact force”. The designer’s proposed answer is a testable hypothesis because it includes a prediction that can be tested by actual measurements. In the instance of a running shoe, the engineer does experiments that measure the impact forces with the new wedge shape. The measurements can then be compared to other shapes.

This process of scientific thinking is applied to all aspects of the research and testing of athletic shoes at the Orthopaedic Biomechanics Laboratories (OBL) at Michigan State University, in East Lansing, Mich. The OBL is a unique facility that has won recognition for its excellence in science research.

### Building a better running shoe

Modern athletic shoes are specialized for various sports, and the running shoe may be the most specialized and highly engineered of all. Running puts great stress on the feet and legs because of the repeated motion and impact. Many runners develop stress injuries. As running has become more popular both as a way to exercise and in competition, millions of people are relying on - and investing in - shoes that will keep them going.

Is there a connection between the shoes runners wear and the injuries they develop? The OBL conducts experiments on athletic shoes in order to study their durability, comfort, and the protection they provide from injury. In terms of the

scientific method, this is an observable fact. Researchers can hypothesize whether shoes can reduce the natural stresses of running on the feet and legs. By observing runners, they see that a runner's heel hits the ground first, then the foot rolls forward, and lastly the runner pushes off on the forefoot.

Early experiments measured the forces of these actions. It was calculated that the heel strikes the ground with a force equal to two or three times the body weight of the runner. Scientists hypothesized that the materials in a running shoe's sole would affect how a runner pushes off on the forefoot. Testing this prediction with different variables, they discovered that the forefoot pushed off with more spring when the sole of the shoe was flexible.

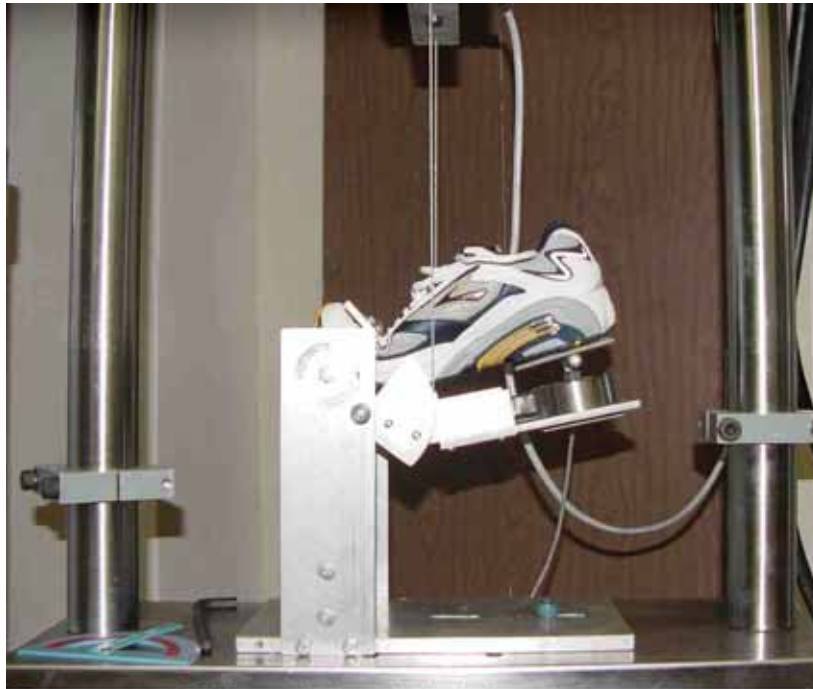


Photo - courtesy of Orthopaedic Biomechanics Laboratory of Michigan State University

Scientists predicted that if a shoe allowed a person to run more efficiently, stress-related injuries would be less probable. This led to the general hypothesis that shoes with

well-cushioned heels and flexible soles would reduce injuries in runners.

### From running shoes to turkey bones?

Because of their special expertise, the biologists, engineers, and clinicians at the OBL work on many projects involving the musculo-skeletal system of both humans and animals.

For example, Dr. Roger Haut, the labs' director, worked on turkeys! Turkeys raised on big farms develop so fast that they actually outgrow their bone structure. In an average week, 1% of farm turkeys break their



Photo - courtesy of Orthopaedic Biomechanics Laboratory of Michigan State University

femurs. Farmers can lose almost 20% of their flock as a result of this problem. Dr. Haut and his staff at OBL conducted a series of experiments to determine the strength of turkey femurs. They are researching ways to improve the turkeys' bone strength.

Whether it be research on a runner's bones or a turkey's, the scientific method is the foundation. Now you know there is more to your athletic shoe than just good looks.

#### Questions:

1. What is the first step in the scientific method?
2. What are the main qualities of a good hypothesis?
3. What general hypothesis did scientists make about running shoes?
4. How do scientists and engineers test running shoes in the lab?



## CHAPTER ACTIVITY

# Make a Water Clock

A clock is a tool used to measure time. Inside a clock are parts that move with a constant repetition. We can record a quantity of time by counting how many “movements” of our clock occur during an interval of time that has a beginning and an end. The number of movements gives us our time measurement. In this activity, you and a partner will make your own clock and measure time with it.

### Materials

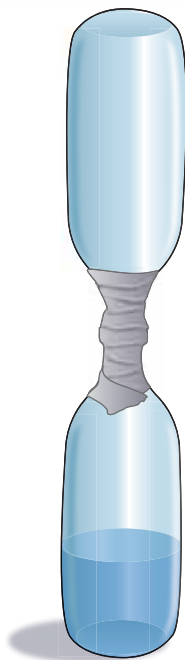
Two empty 2-liter soda bottles  
400 mL beaker  
Water  
Duct tape  
Stopwatch

### Making your clock

1. Put three beakers of water (1200 mL) into one of the empty soda bottles.
2. Attach the mouths of the two soda bottles together and seal them with duct tape.
3. Turn the two attached soda bottles upside down so that the water runs from one soda bottle to the other.
4. Seal your bottles with more duct tape if you have any leaks.

### Measuring time with your clock

5. One partner should hold the stopwatch, while the other partner holds the soda bottle clock.



6. One partner turns the soda bottle clock upside down at the same time the other partner starts the stopwatch.
7. Stop the stopwatch as soon as all the water has emptied from the top bottle to the bottom bottle. Record your data in the table.
8. Repeat the procedure two more times, and record your data in the table.
9. Switch roles and repeat the activity three more times. Record your data in the table.

Trial	Time (seconds)
1	
2	
3	
4	
5	
6	
Average	

### Discussion Questions

- a. Clocks are described as tools that measure time using moving parts. What is the moving part of your soda bottle clock?
- b. The new unit of time you created was the time it took the water to run from one bottle completely into the other. Give this unit of time a name.
- c. Using the data from your six trials, find the average number of seconds in your new unit of time and record it in the table.
- d. Maurice Green can run 100 meters in about 9.8 seconds. How many of your new units did it take?
- e. What are some problems with the clock you made today? Why isn't this type of design used in many of our current clocks?

# Chapter 1 Assessment

## Vocabulary

Select the correct term to complete the sentences.

phases of matter	mass	energy
natural laws	chemical change	scientific method
theory	hypothesis	inquiry
objective		

### Section 1.1

1. Solids, liquids and gases are three fundamental \_\_\_\_.
2. Changes in matter are caused by an exchange of \_\_\_\_.
3. The amount of matter an object contains is called \_\_\_\_.
4. When one kind of matter is changed into another kind of matter a(n) \_\_\_\_ has taken place.

### Section 1.2

No vocabulary words in this section

### Section 1.3

5. When evidence used in an investigation contains only factual information, the evidence is called \_\_\_\_.
6. Problem solving by moving from hypothesis to conclusion using information collected through inquiry, experimentation, and comparison is called the \_\_\_\_.
7. An unproven or preliminary idea that can be tested by scientific inquiry is a(n) \_\_\_\_.
8. A process of learning that starts with questions and arrives at answers to the questions is known as \_\_\_\_.
9. Rules that explain how all things in the entire universe always behave are called \_\_\_\_.
10. When an explanation of something in nature is verified by all known facts it may be called a(n) \_\_\_\_.

## Concepts

### Section 1.1

1. Describe one effect of chemistry and one effect of physics in each of the following actions.
  - a. A birthday cake is made by heating a mixture of salt, flour, baking powder, sugar, eggs and oil.
  - b. Iron, not silver, is used to build the frame of a car.
  - c. A small wagon accelerates faster than a large pickup truck when the same force is applied to both.
  - d. Sea otters can float in water on their backs while feeding.
2. Write the letters **L** (liquid), **S** (solid), or **G** (gas) to indicate the phase of matter of each of the following examples.
  - a. \_\_\_\_ Helium in a balloon
  - b. \_\_\_\_ A piece of bread
  - c. \_\_\_\_ Steam
  - d. \_\_\_\_ Cooking oil
3. The source of virtually all of the energy on Earth is:
  - a. green plants.
  - b. gasoline and oil.
  - c. the sun.

### Section 1.2

4. Explain the difference between historical time and a quantity of time. Give one example of each.
5. Most people in the United States use inches, yards, and miles while scientists and people in most other countries, including Canada, Mexico, Japan, Germany, China and England use the SI units of centimeters, meters, and kilometers. What would be the advantage of having people in the United States use SI units of length?



6. What unit would be most convenient for measuring each of the following lengths?
  - a. The height of a door
  - b. The distance between planets
  - c. The length of tiny bacteria
  - d. The distance between stars
  - e. The distance between cities

### Section 1.3

7. Write the letters **H** (hypothesis), **T** (theory), or **L** (law) to describe the following statements. Letters will be used more than once.
  - a. \_\_\_ Complex animal life evolved from simpler forms of life.
  - b. \_\_\_ An attractive force exists between two bodies. Its strength is determined by the mass of the bodies and the distance between them.
  - c. \_\_\_ Atoms are the smallest particles of matter.
  - d. \_\_\_ It is possible for a race car to jump across the Grand Canyon.
8. What three tests must a scientific theory pass to be accepted as the correct theory for a natural event?

## Problems

### Section 1.1

1. Describe a common substance that you have experienced in all three phases of matter (solid, liquid, and gas).
2. The same force is applied to a ping-pong ball and a bowling ball. Both balls are free to roll along a level floor. Describe the differences between the motion of the two balls.

3. Select the correct description and examples for each phase of matter to fill in the table:

expands freely	wood, rock, ice
maintains shape	air, oxygen, helium
flows; has no definite shape	milk, water, gasoline

Phase	Description	Examples
Solid		
Liquid		
Gas		

### Section 1.2

4. Convert 36,000 seconds to the units shown:
  - a. \_\_\_ years
  - b. \_\_\_ days
  - c. \_\_\_ minutes
5. Convert the following distances to the units shown:
  - a. 3.0 miles is equal to \_\_\_\_\_ kilometers
  - b. 1.23 miles is equal to \_\_\_\_\_ meters
  - c. 8.2 feet is equal to \_\_\_\_\_ meters

### Section 1.3

6. A student notices that some plants in her class have grown faster than others and wants to know why. Unscramble the steps of the scientific method she might use to investigate. Place them in a logical order from the first step to the last.
  - a. She thinks it might be light (a hypothesis).
  - b. She wonders why (a question).
  - c. She concludes that it is not light (a conclusion).
  - d. She grows similar plants under different amounts of light (an experiment).
  - e. She compares the plants growth (analyzes data).