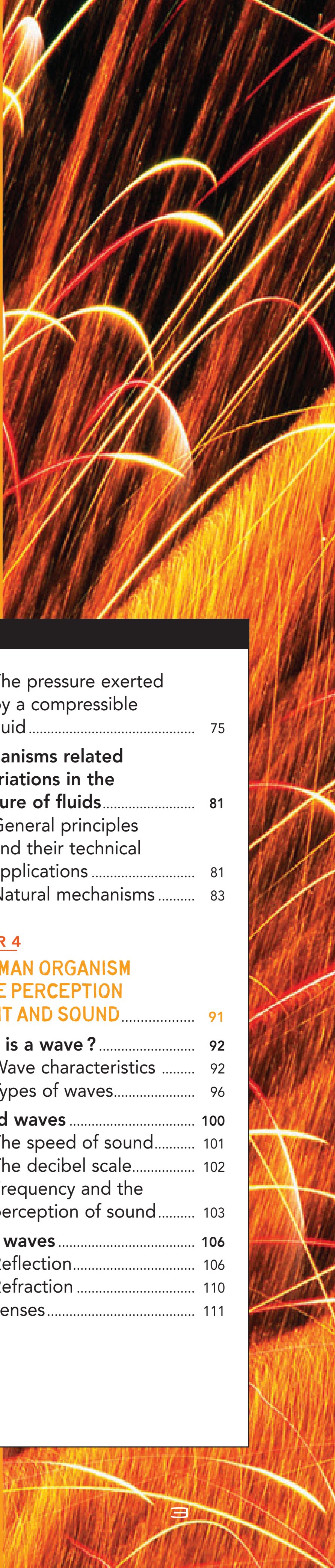
THE MATERIAL

WORLD

THE HUMAN ORGANISM IS COMPOSED OF PRECISELY STRUCTURED MATTER.

We need to exchange matter with our environment in order to survive. We also need to transform matter to be able to use it. These transformations give us the energy we need and help us to grow and maintain the health of our organs and systems.

Matter and energy are all around us. We are always interacting with them. In order to understand how the human organism works, we must think about the organization and transformation of matter and energy, as well as about their properties.



CONTENTS

1986 Discovery of fullerenes, a family of molecules shaped like soccerballs

1944 Development of paper chromatography

1898 Discovery of radium and polonium, the first radioactive elements

1869 Publication of first version of current periodic table

1860 Distinction made between atoms and molecules

1827 Brownian motion of particles observed

1807 Dalton's atomic theory

1781 Discovery that water is not an element

1754 Discovery of chemical composition of carbon dioxide

1661 Concept of chemical elements

1619 Discovery of carbon dioxide

CIRCA -400 Emergence of idea that matter is composed of atoms; at first rejected, only to reappear in the 19th century

CIRCA -450 Emergence of idea that all matter is composed of four elements: air, water, earth and fire

THE MATERIAL WORLD

THE HUMAN ORGANISM

AND THE ORGANIZATION OF MATTER

Everything that makes up the human body—skin, bones, muscles, blood—is matter, just as everything around us is matter, from the air we breathe to the food we eat and the objects we use. But how do we tell the difference between the air we breathe, the water we drink and the earth we walk on? How many different kinds of matter are there? What can we learn by studying them? Since we depend entirely on matter, we are better off learning how it is organized, so we can benefit from its properties.

1 WHAT IS MATTER?

The air we breathe, the water and food we consume and the materials we use are all made of matter. We ourselves are made of matter. Basically, anything that takes up space and has mass is matter.

MATTER is anything that has volume and mass.

CYCLE ONE
- Volume
- Mass
- States of matter
- Atom
- Molecule

1.1 THE PARTICLE MODEL

The particle model is a tool that can help us learn more about matter.

A model is a simplified version of reality. It helps us make an abstract or difficult-to-observe phenomenon, process or system more tangible. In science, a model also helps us understand observed behaviours by comparing how they relate to one another. It also helps us to predict new behaviours. Although every model has its limits, a good working model can always be modified and perfected.

The particle model is an example of a scientific model. It draws on the idea that matter is not continuous, but is instead made up of particles. More specifically, the model is based on the following statements:

Particle comes from the Latin word *particula*, meaning "little bit or part."

- Matter is made up of particles that are extremely small.
- These particles are in constant movement.
- When the temperature increases, the movement of these particles increases.
- The particles may be held together by forces of attraction.

The PARTICLE MODEL is a scientific model based on the idea that matter is made up of small particles.

In this student book, the particle model is used to explain different phenomena related to matter.

1773
1858

Robert Brown

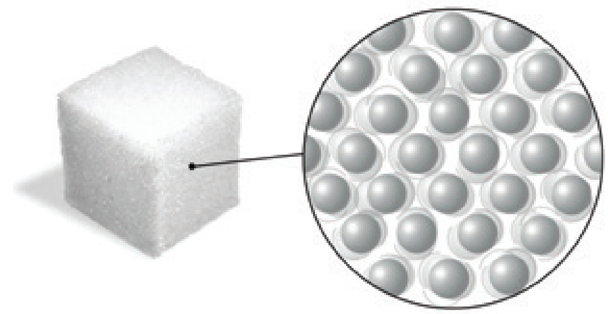
In 1827, this Scottish botanist discovered that particles of a material in suspension in a liquid or in a gas are in constant motion. Today, this is called *Brownian motion.*

PHASES OF MATTER

The particle model helps us examine three different types of matter: sugar, water and oxygen (Figures 1.1–1.3). The illustrations show the three phases that matter generally assumes: solid, liquid or gas. The model helps us understand how the particles in each of these phases are organized as well as how they behave.

Solid phase

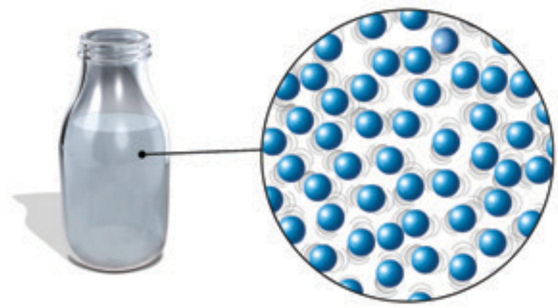
The particles in a solid are very close to each other because they are bound by strong forces of attraction. In Figure 1.1, we can see that the sugar particles appear to be very organized. The particles in a solid have very little freedom to move around. They can only vibrate in one spot. This gives the solid a definite structure and shape, which is why a solid generally does not need to be in a container in order to hold its shape and volume.



1.1 Particles of solid sugar

Liquid phase

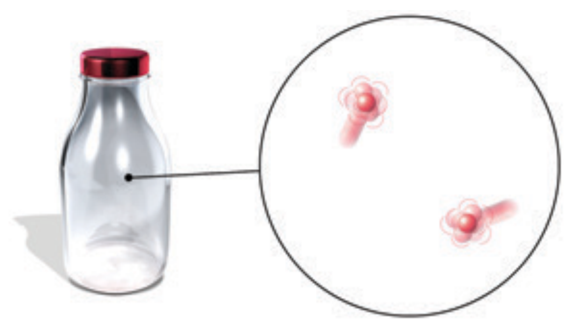
In a liquid, the particles are also very close together. They are, however, bound by forces that are weaker than those in solids. In Figure 1.2, we can see that the water particles are fairly disorganized. They have more freedom to move than in solids, and can slide over each other. Liquids have a definite volume but an indefinite form, which means they assume the shape of the container they are in, but lose their shape when they are poured out.



1.2 Particles of liquid water

Gaseous phase

The particles of a gas are very far apart; they are not bound by forces of attraction. In Figure 1.3, we can see that there is lots of space between the particles and thus ample freedom of movement. They take up all the space they are given. Gases do not have definite shape or volume. If we open a container of gas, some of the gas will naturally escape.



1.3 Particles of oxygen gas

1.2 MOLECULES AND ATOMS

The particle model stipulates that matter is made up of particles. To find out why the particles of different substances are not the same, and to learn more about the nature of the particles that make up matter, we need to use another scientific model, called the *atomic model* of matter.

The atomic model is based on experiments that were performed over the last century. Thanks to the knowledge gained from these experiments, we now know that the particles that make up matter are either molecules or atoms.

An atom is the smallest, indivisible unit of matter that exists. Take, for example, a piece of graphite (a pencil lead). If we grind it, we get carbon powder. If it was possible to separate the grains of powder until we had the smallest possible particles of carbon, we would have carbon atoms.

Atom comes from the Greek word *atomos*, meaning "indivisible."

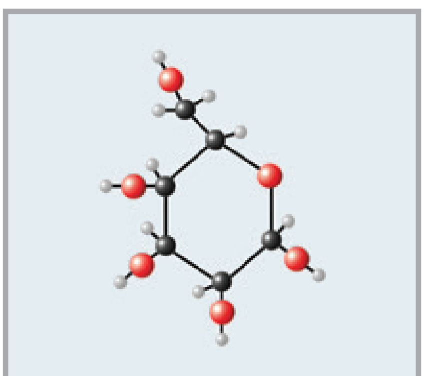
1.4 When we grind a piece of graphite, we get carbon powder. Each of the individual grains of powder contains billions of carbon atoms. An atom, therefore, is extremely small.

An ATOM is the smallest particle of matter. It cannot be divided by chemical means.

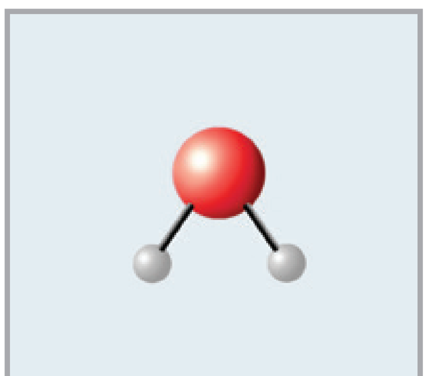
In nature, atoms are rarely all alone. Usually they are chemically bound to other atoms forming molecules. Most of the particles that make up the countless natural substances in our world are actually molecules, that is, groups of atoms held together by chemical bonds.

A MOLECULE is a group of two or more atoms held together by chemical bonds.

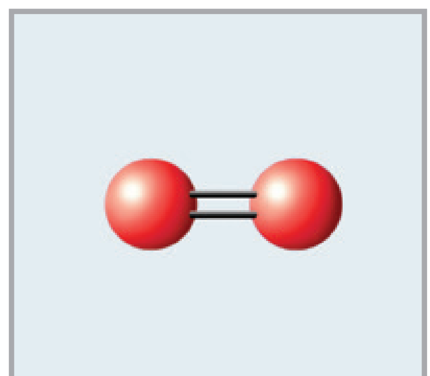
If we return to the three substances shown in Figures 1.1 to 1.3 (sugar, water and oxygen), we can see that their smallest particles are molecules and atoms.



1.5 A molecule of a simple sugar: glucose



1.6 A molecule of water



1.7 A molecule of gas: oxygen

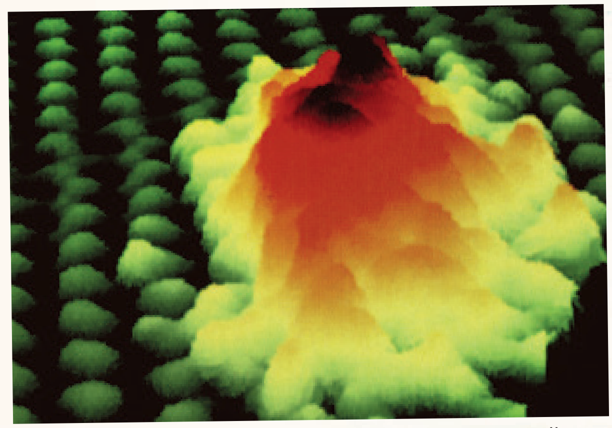
A glucose molecule is made up of three types of atoms: carbon (black), hydrogen (white) and oxygen (red). The black lines between the atoms represent the chemical bonds that hold the atoms together. The water molecule is made up of two hydrogen atoms and one oxygen atom. Lastly, the oxygen molecule contains only one kind of atom: oxygen.

All existing matter is formed with a relatively small number of different kinds of atoms (about one hundred). Basically, it works like a construction set: we just have to organize atoms in the right combinations and we can build all the molecules on Earth.

Now you can see them!

Just a few decades ago, a microscope powerful enough to allow us to see atoms would have been an impossibility. Now however, thanks to the work carried out in Zurich in 1981 by German engineer Gerd Binnig and his Swiss colleague Heinrich Rohrer, it is possible. Their secret? They use a scanning tunnelling microscope (stm), which makes use of a natural physical phenomenon called "quantum tunnelling."

The principle behind the instrument is relatively simple. Take the very fine conducting tip of an stm and place it extremely close to the object to be examined (at a distance of about 100 000 times less than the width of a hair). Then apply an electrical charge to the tip. Electrons move through the virtual "tunnel" thus established between the two surfaces, creating a low electrical current. The closer the tip gets to the surface of the sample, the stronger the current. By measuring the strength of the current, scientists are able to detect the bumps on the object's surface that are formed by the atoms.



This picture shows a pile of gold atoms (shown in yellow, orange and red) on the surface of carbon atoms (shown in green). The colours were added to make the atoms more visible.

This instrument earned its inventors the Nobel prize for physics in 1986.

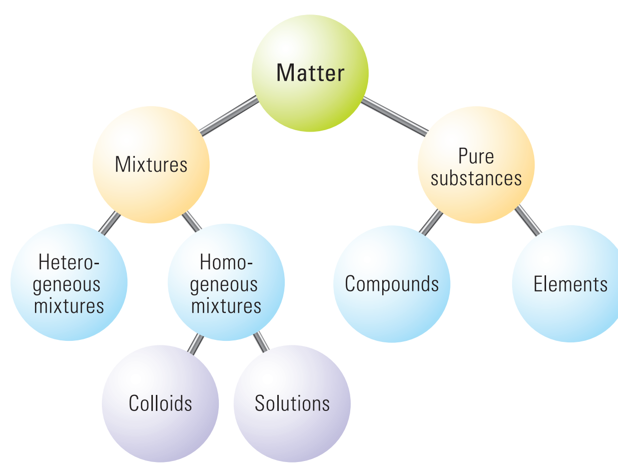
Adapted from Henri-Pierre Penel, "Le microscope à effet tunnel," *Science et vie*, December 2003, pp. 168-170. *[Translation]*

1.3 MIXTURES AND PURE SUBSTANCES

Atoms can bind chemically to other atoms to form molecules. Atoms and molecules can also be mixed together without forming chemical bonds. When a substance contains at least two types of particles (atoms or molecules), we call it a *mixture*. When all the particles in a substance are identical, we consider it a *pure substance*.

- **A MIXTURE consists of at least two different substances, that is, it contains at least two types of particles.**
- **A PURE SUBSTANCE consists of one substance, that is, it contains only one type of particle.**

Figure 1.8 provides an overview of the organization of matter. It is described in more detail in the following pages.



1.8 Organization of matter

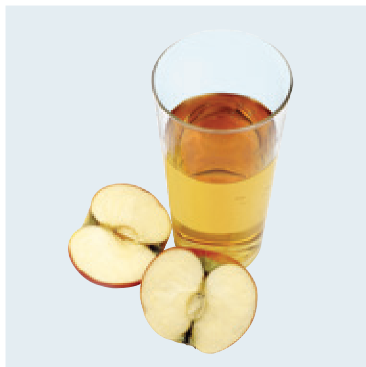
2 MIXTURES

Mixtures can be divided into two types: heterogeneous mixtures and homogeneous mixtures.

Take a look at Figure 1.9. Which mixtures are heterogeneous? Which ones are homogeneous?

CYCLE ONE
- The separation of mixtures
- Mixtures
- Solutions

SOUP



APPLE JUICE

MAYONNAISE

TEN-KARAT GOLD RING

GRANITE

MILK

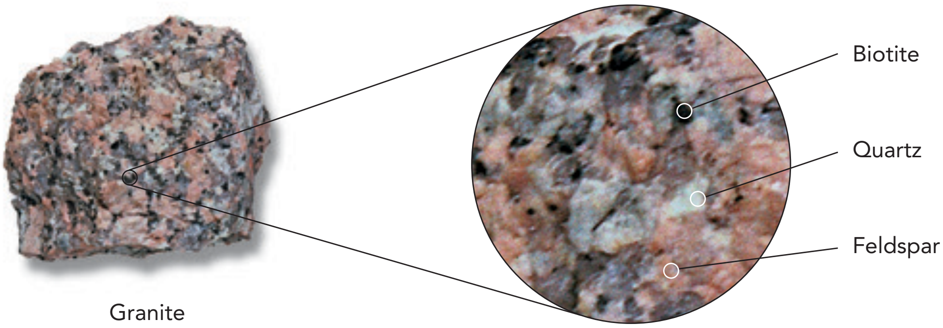
1.9 Examples of mixtures

2.1 HETEROGENEOUS MIXTURES

The soup and the granite in Figure 1.9 are obviously mixtures, because we can see their various constituents when they are not uniformly mixed. We call them heterogeneous mixtures.

Heterogeneous comes from the Greek words *heteros*, meaning "different," and *genos*, meaning "kind, gender, race."

A HETEROGENEOUS MIXTURE is made up of at least two substances that can be distinguished with the naked eye.



1.10 In a chunk of granite, we can see grains of biotite (black), quartz (white) and feldspar (pink). Thus, granite is a heterogeneous mixture.

2.2 HOMOGENEOUS MIXTURES

LAB 1

Let's look at Figure 1.9 again. The apple juice, mayonnaise, gold ring and milk are also mixtures, but it is less obvious. Their various constituents cannot be seen with the naked eye. Their constituents are uniformly combined and therefore they are called *homogeneous mixtures.*

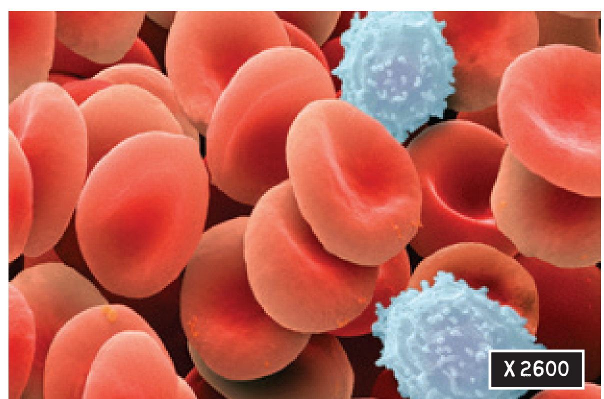
Homogeneous comes from the Greek words *homos,* meaning "same," and *genos,* meaning "kind, gender, race."

A HOMOGENEOUS MIXTURE is made up of at least two substances that cannot be distinguished with the naked eye.

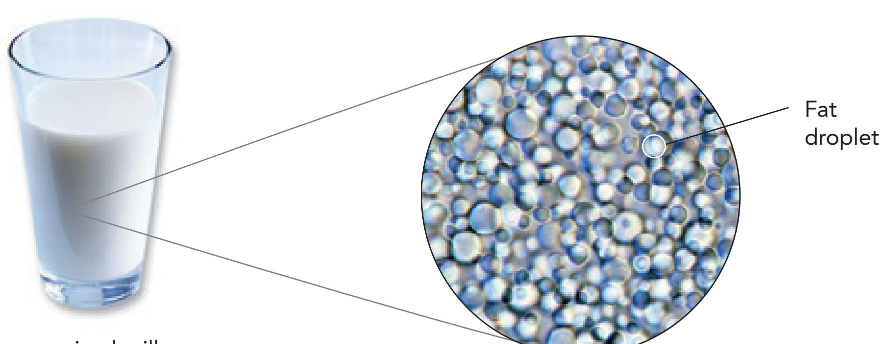
COLLOIDS

By using an optical instrument more precise than the human eye (for example, a magnifying glass or a microscope), we can see that milk (Figure 1.12) and mayonnaise are made up of drops of fat in suspension. These mixtures contain at least two different liquids (one being suspended fat and the other, a substance made up primarily of water). This type of mixture is called a *colloid*. A colloid is generally opaque.

A COLLOID is a homogeneous mixture in which at least two different substances can be distinguished under a magnifying instrument.



1.11 Blood is a colloid. When looked at through a microscope, we can distinguish red and white cells floating in a yellowish substance, which is called *plasma.*



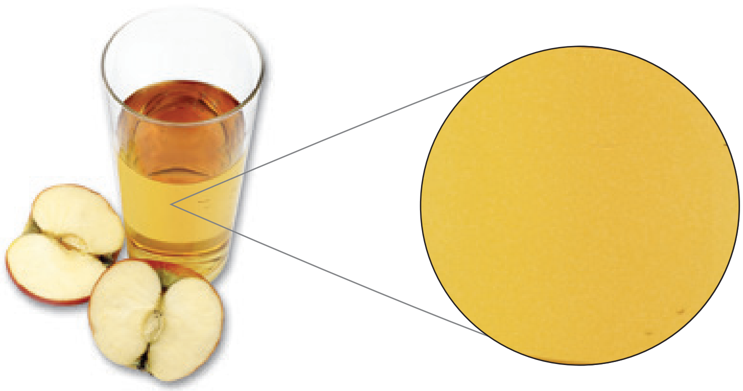
1.12 Homogenized milk is a colloid. When we look at it through a microscope, we can distinguish two types of substances: droplets of fat and skim milk.

SOLUTIONS

When it is impossible to distinguish the constituent parts of a mixture, even through a microscope, the mixture is called a *solution*. A solution is generally transparent.

A SOLUTION is a homogeneous mixture in which it is impossible to distinguish its constituent parts, even under a magnifying instrument.

In Figure 1.9, the apple juice is made up of sugar and other aromatic substances, which are dissolved in water, and the 10-karat gold ring is made up of copper and silver dissolved in gold. The apple juice and the gold ring are examples of solutions.



1.13 Apple juice is a solution. When we look at it through a microscope, we can't distinguish its constituent parts.

In a solution, the substance that seems to disappear into the other substance is called the *solute*. Usually there is less of this substance. The substance into which the solute has dissolved is called the *solvent*. There is generally more solvent than solute.

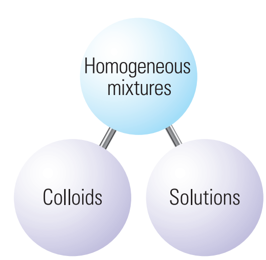
A SOLUTE is a substance that dissolves in another substance.

A SOLVENT is a substance that can dissolve a solute.

On the next page, Table 1.15 shows various examples of solutions grouped according to their phase, that is, according to whether they are a solid, liquid or gas. Note that it is the phase of the solvent that determines the phase of the solution.

When the solvent is a metal, the result is called an *alloy*. The 10-karat gold ring from Figure 1.9 is an example of an alloy.

There are many examples of solutions in the human body. Saliva, sweat, tears and urine are all common solutions in the body. They also share a common solvent: water.



1.14 Types of homogeneous mixtures

1.15 SOLID, LIQUID AND GASEOUS SOLUTIONS

Phases of solution components (Solute + solvent ⟶ solution)	Solutes	Solvent	Solution
Gas + gas ⟶ gas	Oxygen, carbon dioxide, water vapour, argon, etc.	Nitrogen	Air
Gas + liquid ⟶ liquid	Carbon dioxide	Water	Carbonated water
Liquid + liquid ⟶ liquid	Alcohol, aromatic substances	Water	Wine
Solid + liquid ⟶ liquid	Salt	Water	Salt water
Solid + solid ⟶ solid	Carbon	Iron	Steel

2.3 PROPERTIES OF SOLUTIONS

LABS 2–7

A solution's properties are what distinguish it from other solutions. Here we will take a look at three important properties: concentration, dilution and solubility.

CONCENTRATION

The proportions of solute and solvent are different from one solution to another. The quantity of solute in a volume of solution indicates the concentration of the solution.

The CONCENTRATION of a solution corresponds to the quantity of dissolved solute in a given quantity of solution.

A solution's concentration can be expressed in a variety of ways, such as:

- number of grams of solute per litre of solution (g/L)
- number of grams of solute per 100 mL of solution (percent mass/volume or %m/V)
- number of millilitres of solute per 100 mL of solution (percent volume/volume or %V/V)
- number of grams of solute per 100 g of solution (percent mass/mass or %m/m)

For example, a bottle of water contains 45 mg of calcium per litre of water (.045 g/L), and a bottle of vinegar, with a concentration of 5%V/V, contains 5 mL acetic acid for 100 mL vinegar.

We can calculate the concentration of a solution in g/L, using the following formula:

$$C = \frac{m}{V}$$

where C is the concentration (in g/L)
m is the mass of the solute (in g)
V is the volume of the solution (in L)

WHAT'S TRUE?

What's the difference between fruit juice, fruit drink, fruit cocktail, fruit punch and fruit nectar? Only containers labelled "fruit juice" contain 100 percent real juice. All the others contain juice diluted in water, and additives, of which sugar is the principal one.

HOW TO PREPARE A SOLUTION

HOW TO SOLVE A MATHEMATICAL PROBLEM

Let's take, for example, 2 L of a saltwater solution containing 5 g of salt. What is the concentration of this solution?

$$C = \frac{m}{V} = \frac{5\text{ g}}{2\text{ L}} = \frac{2.5\text{ g}}{1\text{ L}}$$

The concentration of the solution is 2.5 g/L.

It is often useful to know the concentration of a solution. For example, companies that make energy drinks study the concentration of various substances dissolved in the human body to create drinks that not only rehydrate the body, but also contain the quantity of salt and sugar that the body needs to recover quickly from an intense workout.

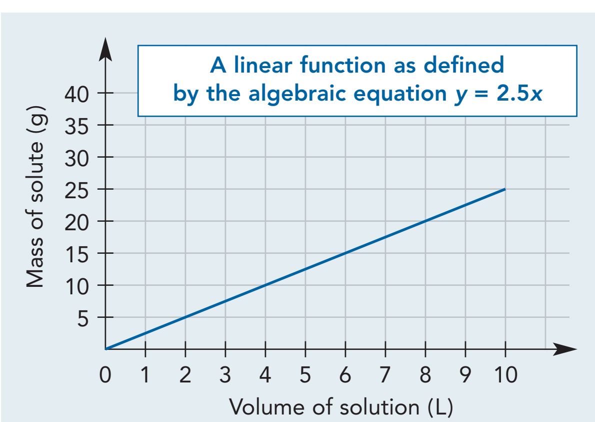
1.16 If the police suspect a driver of drinking and driving, they administer a Breathalyzer test to measure the level of alcohol in his or her blood.

CONNECTIONS MATHEMATICS

Linear functions and proportions

A linear function is an algebraic relationship defined in the set of real numbers. It can be defined by an equation, such as $y = ax$ where a is the constant.

As with all functions in the set of real numbers, the linear function can be represented on a Cartesian graph. The result is a straight line, which begins at the starting point of the two axes, (0, 0). The straight line is made up of all the points whose coordinates (x, y) make up the function.



This line shows the mass of solute present in different volumes of a solution with a concentration of 2.5 g/L.

The slope of the line is equal to the value of the constant. When the constant is positive, as in the diagram on the left, the line has a positive slope. When the constant equals zero, the line is horizontal and parallels the x axis. When the constant is negative, the line has a negative slope.

To find a in the algebraic equation that defines the linear function, we get $a = y / x$. The relationship between the value of y and the corresponding value of x is always equal to the constant. As a result, all y / x relationships are equal: they are proportional.

If we use the data from the diagram, we find that:

$$a = \frac{2.5}{1} = \frac{5}{2} = \frac{7.5}{3} = \ldots = 2.5\text{ g/L}$$

This proportion can be used to calculate the concentration of a solution, among other things. It would then be expressed as $C = \frac{m}{V}$.

THE DEMISE OF THE PENNY?

Adapted from Gabrielle Duchaine-Baillargeon, "La fin des 'cennes noires'?" *L'Actualité* 31, 13, September 1, 2006, p.16. *[Translation]*

In the United States, the future of both the penny and the nickel looks grim: the cost to produce these coins is more than their worth on the market. The U.S. government spends 1.23 ¢ to make each penny and 5.73 ¢ to make each nickel. These high costs are due to increases in the price of zinc and copper, two precious metals used in the production of coins.

In Canada, we have decreased the concentration of precious metals in our coins. Our penny, which was once made almost entirely of copper, is now a steel coin plated with copper. In the five-cent coin, steel has replaced nickel. Because Canada is one of the world's leading producers of iron, the main ingredient in steel, the use of this alloy is cost-effective. Today, it costs just 0.008 ¢ to produce a penny on this side of the border.

Canada has lowered the concentration of precious metals in its coins.

DILUTION

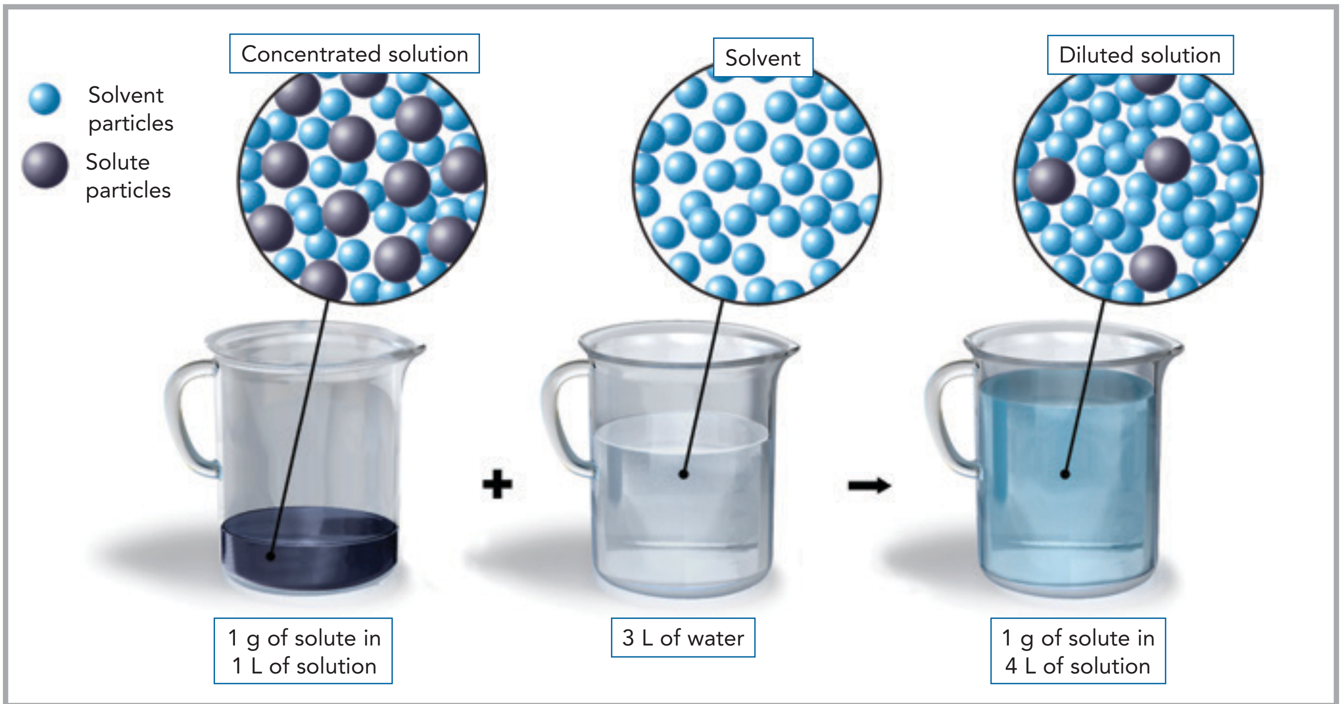
In our everyday lives, we often have to change the concentration of a solution. To increase the concentration of a solution, it is simpler to add solute than to remove solvent. On the other hand, if we want to decrease the concentration of a solution—that is, to dilute it—we add more solvent (as it is generally not possible to remove the solute).

Let's look at a few examples where we need to change the concentration of a solution. To make juice from frozen concentrate, we need to add water. In other words, we dilute the frozen concentrate. When our soup is not salty enough, we add salt, thus increasing the soup's concentration of salt.

In a laboratory, when preparing a solution with a precise concentration, we can use either pure substances or concentrated mixtures. In the first case, the technique is called *dissolution* (Chapter 2, page 46) and in the second case, the technique is called *dilution*.

DILUTION is a laboratory technique that involves decreasing the concentration of a solution by adding solvent.

1.17 When preparing medication, pharmacists often have to dilute the medication in order to obtain the exact dosage indicated on the prescription.



1.18 The addition of a solvent to a solution decreases its concentration, that is, it dilutes the solution.

Let's look at how dilution changes the concentration of a solution. Imagine that we have 1 L of a solution with a concentration of 1 g/L. How will the concentration change if we add 3 L of water?

After the dilution, the quantity of the solute does not change: there is still 1 g of solute. However, the quantity of solution has changed: there is now 4 L of solution instead of 1 L. The concentration is now 1 g/4 L, or 0.25 g/L.

The particle model can help us visualize the dilution of a solution (Figure 1.18).

Mathematically, we can also use the following reasoning:

Since $C = \frac{m}{V}$, we can also write m = C V. Because the mass *(m)* of the solute stays the same before (m_1) and after (m_2) the dilution, therefore $m_1 = m_2$. Therefore:

$C_1V_1 = C_2V_2$, where C_1 is the solution's initial concentration (in g/L)
V_1 is the solution's initial volume (in L)
C_2 is the solution's final concentration (in g/L)
V_2 is the solution's final volume (in L)

To find the concentration of the diluted solution find C_2:

$$C_2 = \frac{C_1V_1}{V_2} = \frac{1\ \text{g/L} \times 1\ \text{L}}{4\ \text{L}} = 0.25\ \text{g/L}$$

Therefore, the final concentration of the diluted solution is 0.25 g/L.

HOW TO PREPARE A SOLUTION

HOW TO SOLVE A MATHEMATICAL PROBLEM

SOLUBILITY

There is a limit to the amount of solute you can add to a solvent. The maximum amount of solute in a solvent corresponds to its solubility.

> **SOLUBILITY is the maximum amount of solute that can be dissolved in a given amount of solvent.**

Just like concentration, solubility can be expressed in a variety of ways, such as:

- g/L
- percent mass/volume (%m/V)
- percent volume/volume (%V/V)
- percent mass/mass (%m/m)

If a solution contains less than the maximum amount of solute, it is called *unsaturated*. If it contains exactly the maximum amount of solute, it is called a *saturated* solution. If it contains more than the maximum amount of solute, it is called *supersaturated*. In most cases, the surplus solute will appear as a **PRECIPITATE**.

1.19 When there is too much solute, the excess falls to the bottom of the solution in the form of a precipitate. The result is a saturated solution with a solid precipitate.

> **A SATURATED SOLUTION is one which contains exactly the maximum amount of solute that can be dissolved in it.**

Solubility depends on many factors, such as the nature of the solute and the solvent plus temperature and pressure. We will examine two of these factors: the nature of the solvent and temperature.

The nature of the solvent

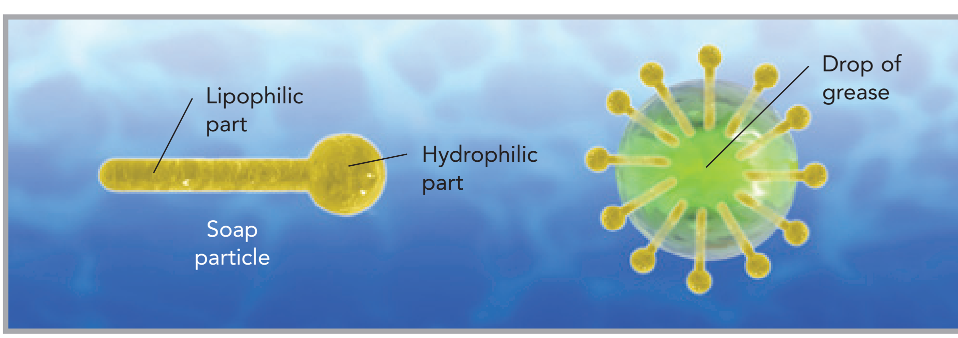
The solubility of a given substance will vary depending on the solvent. For example, table salt is very soluble in water, but not in oil. Therefore, we say that salt is hydrophilic.

Hydrophilic comes from the Greek words *hudor*, meaning "water," and *philos*, meaning "friend."

On the other hand, a lipophilic substance is very soluble in oil. For example, many aromatic substances are soluble in oil. In cooking, we often add oil or another fatty substance to food to enhance its flavour.

Lipophilic comes from the Greek words *lipos*, meaning "fat," and *philos*, meaning "friend."

Soap has a special structure that allows it to be both hydrophilic and lipophilic. This is the reason that it can dissolve greasy stains that are otherwise not soluble in water.



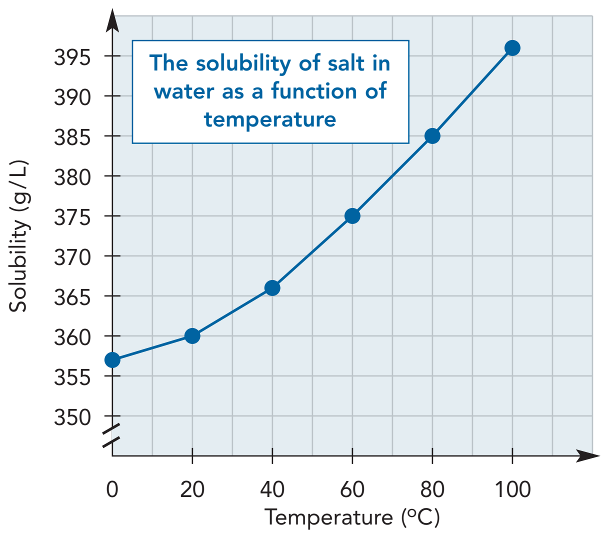
1.20 The lipophilic part of soap attaches itself to a drop of grease, while the hydrophilic part dissolves in the water. This is how soap "traps" the grease, which is then easily rinsed away with water.

It is often useful to know the solubility of a solute in a solvent; for example, when we want to remove stains from clothing. The best way to do this is to find out what caused the stain, and then choose the best solvent for its removal. Some substances (like mud) are easy to clean with water, others (like grease and oil) need soap. As for ink stains, they are best removed with an alcohol-based stain remover.

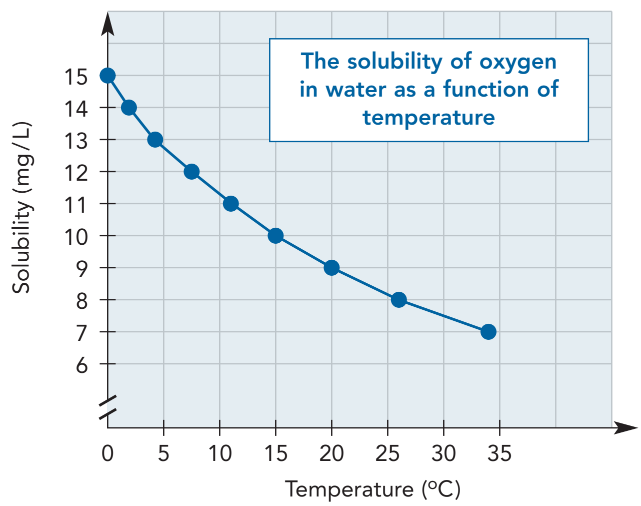
Temperature

Solubility also depends on temperature. The solubility of many solids increases with temperature (this is true, for example, with salt and sugar whose solubility in water increases with temperature) (Figure 1.21).

On the other hand, the solubility of many gases decreases with temperature (for example, the solubility of oxygen and carbon dioxide in water) (Figure 1.22). This is one of the reasons why, during summer heat waves, the level of oxygen in lakes decreases, leading to the death of some fish.



1.21 The rising slope on the graph shows that the solubility of solid salt in water increases with temperature.



1.22 The descending slope on the graph shows that the solubility of oxygen gas in water decreases with temperature.

In summary

Table 1.23 shows how the solubility of a solute—in this case, sugar—can vary depending on the temperature and solvent in which it has been dissolved.

1.23 SOLUBILITY OF SUGAR AT DIFFERENT TEMPERATURES AND IN DIFFERENT SOLVENTS (in g/L)

Temperature (°C)	Solvent		
	Water	Oil (soya oil)	Alcohol (methanol)
0	1783.7	Does not dissolve	Imperceptible
40	2345.0	Does not dissolve	0.55
60	2885.7	Does not dissolve	1.34
80	3690.1	Does not dissolve	Does not apply: methanol boils at 65°C.

1.24 In order to get these jeans really clean, we need to choose a solvent in which the stains are the most soluble.

1.25 Sugar dissolves faster and in larger amounts in hot cocoa than in cold milk. The solubility of sugar increases as its temperature increases.

1.26 An open bottle of soda pop releases increasing amounts of carbon dioxide as its temperature increases.

2.4 SEPARATING MIXTURES

Mixtures exist everywhere in nature; in fact, there are practically no pure substances in nature. We have to apply purification techniques to obtain pure substances. Many techniques are physical separations, that is, they separate the constituents of a mixture without changing their nature (Figure 1.27, next page). When it is impossible to physically separate a substance any further, then we have a pure substance.

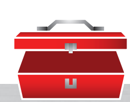
Here are a few examples of cases where we commonly separate the constituents of a mixture:

- to make water safe for drinking, we remove any impurities and **PATHOGENS** that may be present.
- to obtain gas, diesel fuel, tar, furnace oil and so on, we process oil, separating it into its various constituents.
- to obtain many of the metals that we use in manufacturing (such as gold, silver and copper), we purify their ore, that is, remove the rock that makes up part of the various minerals.

Sometimes, we need to use more than one separation technique in order to obtain the substance(s) we want. For example, in a water filtration plant, we use the processes of both decantation and filtration (next page) to make water safe for drinking. In spite of this, the water is still not 100 percent pure. If we wanted to purify the water completely, we would need to use a distillation process.

WHAT TO CHOOSE?

In Canada, bottled water, like tap water, is strictly regulated. According to Health Canada guidelines, neither variety poses a health risk and the choice of one or the other is a matter of personal preference.



HOW TO SEPARATE A MIXTURE

Decantation

A separation funnel

DESCRIPTION

When a mixture's constituents have different densities, they separate into different layers. Each layer can then be poured out individually.

Centrifugation

A centrifuge

DESCRIPTION

This technique accelerates and accentuates the decantation process using a centrifuge, which is an instrument that can spin a mixture at high speeds.

Filtration

A filter

DESCRIPTION

This process involves passing a solid-liquid or a solid-gas (e.g. smoke) mixture through a filter. The solids stay on the surface of the filter.

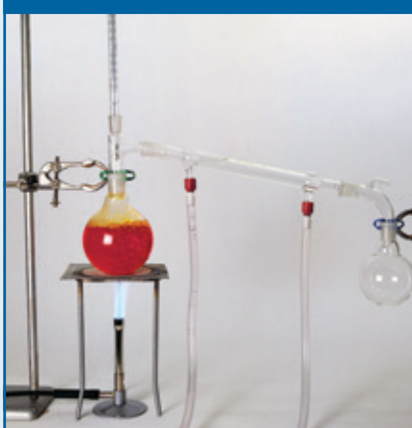
Evaporation

A desiccator

DESCRIPTION

This technique makes it possible to collect a solid that has dissolved. The liquid in the solid-liquid mixture evaporates.

Distillation



A laboratory setup for fractional distillation

DESCRIPTION

This technique is based on the different boiling points of a mixture's constituents. When heated, they boil off and condense at different temperatures.

Chromatography

A laboratory setup for paper chromatography

DESCRIPTION

This technique separates a mixture into its various constituents using porous paper and a solvent. The differences in the rates with which the constituents travel along the paper lead to their separation.

1.27 Different physical techniques for separating mixtures

3 PURE SUBSTANCES

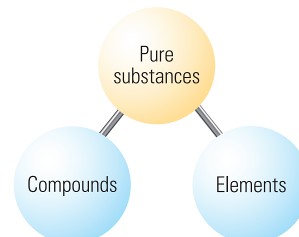
A pure substance contains only one substance, one constituent. Distilled water, sugar, iron, copper and diamonds are examples of pure substances.

CYCLE ONE

- Elements
- Periodic table
- Characteristic properties
- Physical change
- Temperature
- Acidity and alkalinity
- Chemical change

3.1 COMPOUNDS AND ELEMENTS

We have learned about the different physical separation techniques that can be used to separate the constituents of a mixture in order to obtain pure substances (preceding page). Some pure substances, however, are made up of at least two different elements, and are therefore called *compounds.* These pure substances can be separated by chemical techniques, such as electrolysis.



1.28 Types of pure substances

- **An ELEMENT is a pure substance that contains only one type of atom; it is impossible to separate an element into other substances, using chemical separation techniques.**

- **A COMPOUND is a pure substance that contains at least two types of atoms that have chemically combined; it can be separated into its constituent elements, using chemical separation techniques.**

It took a long time before scientists realized that some pure substances were, in fact, compounds. In 1781, the British physician and chemist, Henry Cavendish, demonstrated that water was composed of two different constituents. He applied electrolysis to water in its liquid state, and obtained gaseous oxygen and hydrogen. Until then, it was believed that water was indivisible, that is, it was an element in itself.

1867
1934

Marie Curie

In 1898, this Polish physician, along with husband Pierre Curie (1859-1906), discovered two elements that had been previously unknown: polonium and radium. Polonium was named in honour of Marie Curie's national origin.

THE PERIODIC TABLE OF THE ELEMENTS

Elements are the building blocks of matter. There are more than 100 kinds of elements. All existing substances are formed by these elements.

Scientists classify the elements in a chart called the *periodic table of the elements* (located on the inside back cover of this textbook). This table is very useful because it groups elements with similar properties together. For example, all of the elements in the last column are inert gases, often called *noble gases.* These gases do not normally react with other substances.

The first version of the periodic table was developed by a Russian chemist named Dimitri Mendeleev in the late 1860s. The table has since evolved with the arrival of new scientific discoveries and technological procedures. Today, there are more than 100 elements in the table, and most are found naturally on Earth. The rest can be produced artificially in a laboratory.

Each element is represented by a symbol that is the same in every language and country. For example, the symbol for carbon is C, while silver is represented by Ag. The first letter is always a capital, and it is sometimes followed by one or two lower-case letters.

There are 25 elements that are essential to life, and four of them are particularly important: carbon, oxygen, hydrogen and nitrogen. These four alone make up 96 percent of the matter on Earth. They make up nearly all the molecules that form living organisms, from bacteria to humans, and include plants, mushrooms and all the animals in the world.

THE ELEMENTREE

The Québec chemist Fernando Dufour has developed a three-dimensional representation of the periodic table. His model looks like a tree. It has a central stem surrounded by a widening spiral. On this spiral, the elements are represented by discs, and placed in order of their atomic number.

3.2 PROPERTIES OF PURE SUBSTANCES

We can describe pure substances by describing their characteristic and non-characteristic properties.

A non-characteristic property cannot help us to tell one pure substance from another. While we can distinguish one clear plastic cup from another by its size and its shape, for example, these characteristics do not tell us what makes this clear plastic different from another transparent substance, such as glass, crystal, Pyrex, ice or another clear substance.

A characteristic property helps us to identify precisely a pure substance. Melting point and density are examples of characteristic properties. Certain plastics, glass and ice are all examples of transparent solids. Their melting points and their density, however, are very different.

There are some characteristic properties that help us classify substances by groups. For example, a litmus test helps us to determine if a substance is acidic, basic or neutral. Other characteristic properties, such as electrical conductivity, help us distinguish metals from nonmetals.

1.29 Size and shape help us to tell objects apart, but cannot help us distinguish one substance from another. Size and shape are non-characteristic properties.

A CHARACTERISTIC PROPERTY is one that helps us identify a pure substance or the group to which the pure substance belongs.

Characteristic properties can be divided into two categories: characteristic physical properties and characteristic chemical properties.

CHARACTERISTIC PHYSICAL PROPERTIES

LABS 8–13

Characteristic physical properties help us to identify a pure substance without changing the nature of the substance in the process. For example, to find the boiling point of water, we need to change the phase of water. We need to heat it until it moves from a liquid to a gaseous phase (or cool it down so that it passes from a gaseous phase to a liquid). This change of phase, however, does not change the nature of water.

HOW TO DETERMINE THE CHARACTERISTIC PROPERTIES OF A SUBSTANCE

Table 1.30, below, contains some common physical properties of matter that are characteristic. There are many more, including electrical conductivity, heat conductivity, hardness, malleability and magnetism.

1.30 CHARACTERISTIC PHYSICAL PROPERTIES OF MATTER

Physical properties	Description	Examples
Melting point	• The temperature at which a solid becomes a liquid (or a liquid becomes a solid). • Can be expressed in °C.	• Water: 0°C • Ethanol: -117°C • Table salt: 801°C
Boiling point	• The temperature at which a liquid becomes a gas (or a gas becomes a liquid). • Can be expressed in °C.	• Water: 100°C • Ethanol: 79°C • Table salt: 1465°C
Density	• Mass per unit of volume • We often use the following formula: $\rho = \frac{m}{V}$ where p = density m = mass V = volume • Can be expressed in g/mL.	• Water: 1.0 g/mL • Ethanol: 0.79 g/mL • Gold: 19.3 g/mL
Solubility	• The maximum amount of solute that can be dissolved in a given volume of solvent. • Can be expressed in g/L or in % (% m/V, % m/m, % V/V).	• Table salt in water: 357 g/L • Carbon dioxide in water: 3.48 g/L • Sugar in water: 1792 g/L

Characteristic physical properties must be measured at a specific temperature and specific **PRESSURE**. A higher or lower temperature or pressure can change the physical properties of a substance. For example, water boils at 100°C at sea level, that is, when atmospheric pressure measures 101.3 kilopascals (kPa). If we go up to an altitude of 1600 m, atmospheric pressure decreases and the boiling point of water goes down to 94°C.

When we talk about data obtained under Normal Temperature and Pressure (NTP), we mean that the temperature was 0°C and the pressure was 101.3 kPa when the data were taken. When we say the data were obtained under Standard Ambient Temperature and Pressure (SATP), we mean that the temperature was between 20°C and 25°C and the pressure was 101.3 kPa.

CHARACTERISTIC CHEMICAL PROPERTIES

LAB 14

Chemical properties help us identify a substance, but in the course of making the identification, the nature of the substance may be changed. For example, to find the acidity of a substance, we need to use a pH indicator. This tool reacts with the substance being tested, giving rise to another substance whose colour indicates the pH of the original substance. Many characteristic chemical properties are reactions to **INDICATORS**.

Table 1.31 below lists some characteristic chemical properties often used in chemistry. In the fields of medicine and nutrition, we often use other indicators, such as Fehling's solution to detect the level of glucose, or an iodine solution to test for starch.

HOW TO DETERMINE THE CHARACTERISTIC PROPERTIES OF A SUBSTANCE

1.31 CHARACTERISTIC CHEMICAL PROPERTIES OF MATTER

Chemical properties	Description	Examples
Reaction of litmus paper	The colour of the litmus paper indicates whether the test substance is an acid, a base or neutral.	• If the paper turns red, the test substance is acidic ($pH < 7$). • If the paper turns blue, the test substance is basic ($pH > 7$). • If the paper turns purple, the test substance is neutral ($pH = 7$).
Reaction of cobalt chloride paper	The colour of the cobalt chloride paper indicates the presence or absence of water.	• If the paper turns pink or a different shade of blue, the test substance contains water.
Reaction of limewater	The reaction to the limewater indicates the presence or absence of gaseous carbon dioxide.	• If the limewater becomes milky (that is, if a precipitate forms), the test substance contains carbon dioxide gas.
Reaction of a glowing wood splint	The reaction of the test substance with the wood splint indicates the presence or absence of a substance that could cause combustion.	• If the splint reignites, the test substance contains a substance that can cause combustion, such as oxygen gas.
Reaction of a burning wood splint	The reaction indicates the probable presence or absence of an explosive gas.	• If an explosion occurs, the test substance probably contains an explosive gas, such as hydrogen gas.
Reaction to an open flame	The colour of the flame may indicate the presence of certain substances.	• If the flame turns purple, the test substance probably contains the element potassium. • If the flame turns green, the test substance probably contains the element barium. • If the flame turns red, the test substance probably contains the element strontium.

3.3 IDENTIFYING UNKNOWN SUBSTANCES

LAB 15

We can use the characteristic properties of matter to identify many pure substances. Imagine a liquid that is colourless and odourless. To find out if it is water or something else, we could perform a series of tests: if the unknown liquid boils at 100°C, freezes at 0°C, has a density of 1.0 g/mL and turns a strip of cobalt chloride paper pink, it's probably water.

We can identify a substance by comparing its characteristic properties with the data in a table that lists the properties of different substances. For an example of such a table, see Appendix 1, Properties of common substances on page 416. Table 1.32 on page 26 contains excerpts from this table. In it we can see, for example, that while water and glycerine are both colourless, odourless liquids, we can tell them apart by their characteristic properties.

The table of properties on page 26 can also help us to avoid using dangerous substances. For example, it indicates that placing hydrogen close to a flame is dangerous, because hydrogen explodes when exposed to fire.

We can also use a table of properties to choose the best material to build an object or a machine. Table 1.32 shows that tungsten is a good material to use for a light bulb's filament: its melting point is very high, it is a good electrical conductor and it does not oxidize easily.

1748
1822

Claude-Louis Berthollet

In 1789, this French chemist discovered the decolourizing properties of sodium hypochlorite. He named the substance *eau de Javel* [Javel water] in honour of a city renowned for its laundry industry. The name and the liquid are still in use today.

INDESTRUCTIBLE BLACK BOXES

At the scene of a plane crash, the black box is found among the plane debris and wreckage. This box contains precious information about the events of the flight. It is damaged, but still in one piece. What is its secret?

Black boxes are designed to withstand almost any type of impact.

Its secret is a stainless steel alloy, reinforced with titanium or aluminum and high-temperature silicone insulation, designed to withstand temperatures higher than 1500°C for more than one hour, immersion in salt water for 30 days, as well as immersion in a variety of other liquids from airplane fuel to oil. These black boxes—which are, in fact, orange—can also tolerate extremely high pressure.

Could we build a plane from the same metal as the black box? Yes, but the plane would certainly be too heavy to fly.

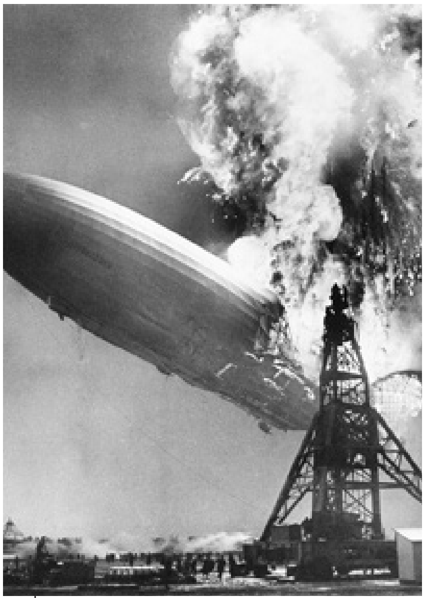
Adapted from Agence Science-Presse, "Indestructibles boîtes noires," September 18, 2001. *[Translation]*

I.32 **EXCERPTS FROM THE TABLE OF PROPERTIES OF COMMON SUBSTANCES**
(see Appendix 1 in this textbook)

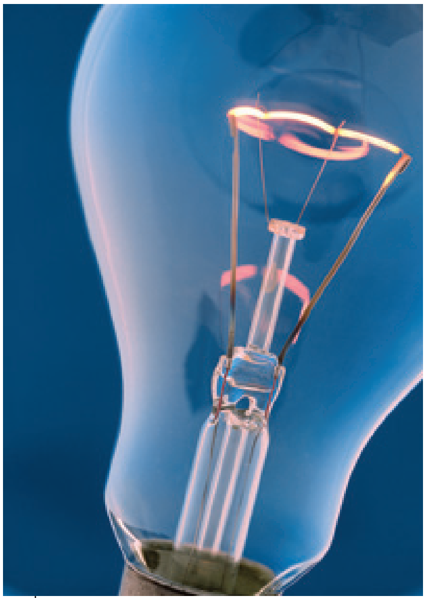
Substances (chemical formulas)	Description	Dangers and precautions	Physical properties					Chemical properties
			FP (°C)	BP (°C)	ρ (g/mL)	EC	S	
Hydrogen (H_2)	• Colourless • Odourless	Explosive when exposed to an open flame	–259	–253	0.000 09	No	• 0.002 g/L of water	• Explodes when exposed to an open flame.
Water (H_2O)	• Colourless • Odourless	None	0	100	1.00	No	• N/A	• Cobalt chloride paper turns pink. • Neutral litmus paper turns violet.
Glycerine or glycerol ($C_3H_8O_3$)	• Colourless • Odourless • Viscous • Sweet taste	Explosive in certain conditions	18	290	1.26	No	• Soluble in water	• Explodes when exposed to certain substances.
Tungsten (W)	• Grey • Odourless • Shiny	Can irritate respiratory tract	3410	5900	19.35	Good conductor	• Not soluble in water	• Does not easily oxidize. • Reacts with nitric acid.

FP: freezing point
BP: boiling point
ρ: density
EC: electrical conductivity
S: solubility

I.33 The gas in this test tube is probably carbon dioxide because it turns the limewater milky and has a density of 0.002 g/L.



I.34 Following the explosion of the Hindenburg in 1937, the use of hydrogen for hot-air balloons and dirigibles was banned because it is too dangerous.



I.35 We use tungsten to make the filaments for electric light bulbs because this metal is very resistant to high temperatures.

CHECKUP

1 WHAT IS MATTER? (pp. 6–9)

1. How do we define matter?
2. What holds the particles of a solid together?
3. Using the particle model, describe two differences between a solid, a liquid and a gas.
4. The particles in a sample of matter are very close together.
   a) Using only this information, can you confirm that this sample is a solid? Explain your answer.
   b) What other information could you use to be certain that the sample is a solid?
5. What is the name of the smallest particle of matter that can be chemically divided?

2 MIXTURES (pp. 10–20)

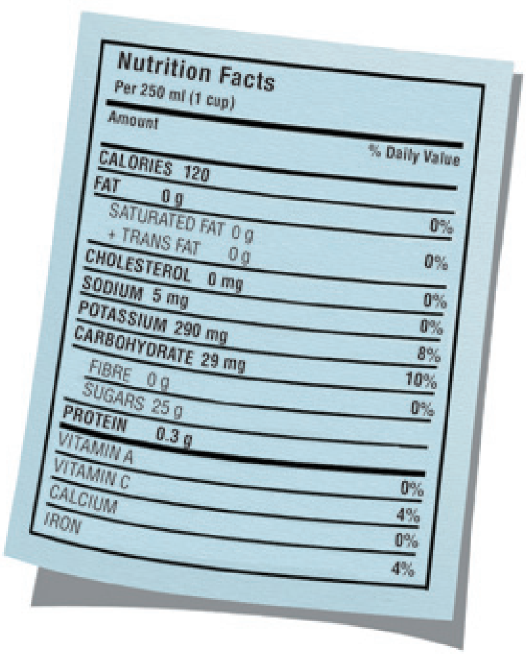
6. Look at the photo below. What type of mixture is each of the items in the photo?

7. What type of mixture is each of the following?
   a) a handful of earth
   b) air
   c) smog
   d) a stainless steel fork
   e) seawater
   f) whipping cream
   g) a raisin muffin
8. Give the term for each of the following definitions.
   a) a substance that can dissolve another substance
   b) a substance that can dissolve into another substance
   c) a homogeneous mixture made up of one substance dissolved in another substance
9. What determines the concentration of a solution?
10. A patient receives a prescription from the doctor for a medication that needs to be dissolved in water, at a concentration of 2 g/L. The dosage is the following: one teaspoon (5 mL) three times a day for 10 days.
    a) What is the minimum volume of the medication in solution that the patient will need?
    b) If you were the pharmacist, how would you prepare the medication from a powder? Describe what you would do and show all of the calculations you need to prepare the right quantity of medication for the patient.

11. A woman wants to dye her hair lighter than her natural colour. Her hairdresser uses a hydrogen peroxide solution at three percent V/V to lighten her hair. He needs to prepare 100 mL of this solution by diluting a concentrate to 30 percent. How should he do it? Describe how you reached your answer, showing all your calculations.

12. The label on a bottle of wine indicates that the wine contains 12 percent alcohol V/V. How much alcohol does a 750 mL bottle of wine contain? Show all the steps leading to your answer.

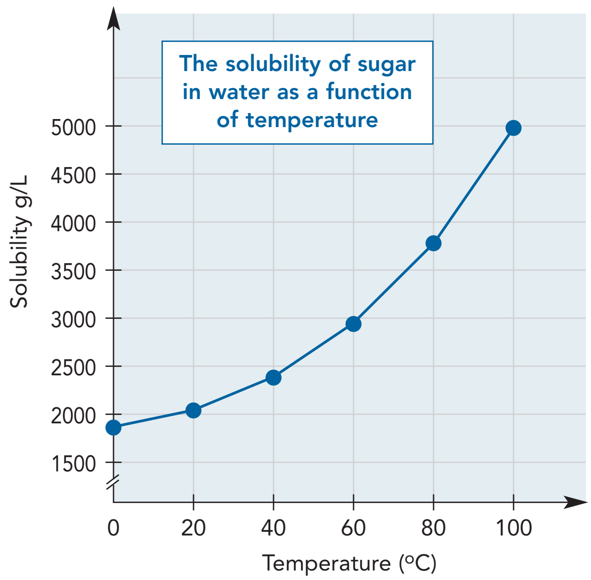
13. The Nutrition Facts label on a container of apple juice, indicates that 250 mL of juice contains 25 g of sugar. Calculate the concentration of sugar in the juice in g/L. Show all the steps leading to your answer.



14. Name four factors that can affect the solubility of a substance.

15. How does the solubility of table salt in water change with temperature?

16. Look at the following graph. What is the solubility, in g/L, of this solid at a temperature of 60°C?



17. Some industries dump hot water into the environment. How is this practice harmful to fish?

18. How can we obtain pure substances from a mixture?

19. Indicate which separation technique you think would be the most appropriate for each of the following mixtures?
   a) a saltwater solution
   b) water mixed with sand
   c) a blood sample
   d) an oil-and-vinegar dressing
   e) water mixed with alcohol
   f) black ink
   g) toxic smoke
   h) oil

3 PURE SUBSTANCES (pp. 21–26)

20. Give two examples of non-characteristic properties.

21. We can identify a substance by observing its characteristic properties.
    - a) What is the difference between a characteristic physical property and a characteristic chemical property?
    - b) Give an example of a characteristic physical property.
    - c) Give an example of a characteristic chemical property.

22. Why is density a characteristic physical property, but not mass or volume?

23. You are given three solid substances, all in the form of a white powder. How can solubility help you to identify each of the three substances?

24. A technician is given a gas sample to identify. She performs a series of tests and compiles her results as follows:

Properties	Results
Freezing point	–259°C
Density	0.000 09 g/mL
Colour	Colourless
Odour	Odourless
Reaction to limewater	No change
Reaction to open flame	An explosion

   - a) Study the results in the table. Which tests can be used to identify the gas?
   - b) What is the gas in the sample?

CONCEPT MAPS

HOW TO BUILD A CONCEPT MAP

Prepare your own summary of Chapter 1 by building a concept map based on the following terms:

- Atoms
- Boiling point
- Characteristic chemical properties
- Characteristic physical properties
- Colloids
- Compounds
- Concentration
- Density
- Dilution
- Elements
- Heterogeneous mixtures
- Homogeneous mixtures
- Matter
- Melting point
- Mixtures
- Molecules
- Properties of pure substances
- Properties of solutions
- Pure substances
- Reactions to indicators
- Solubility
- Solutions

FOLLOW-UP

ELEMENTS ON OUR DINNER PLATE

Many elements, in their mineral form, are essential to the maintenance and the healthy functioning of the human organism. Our bodies are incapable of producing these elements, so we need to get them in our food. Nutritional deficiency, or a lack of certain elements in our diet, can lead to health problems. Table 1.36 contains several elements, as well as the roles they play in the human body.

1.36 ELEMENTS AND THEIR ROLES IN THE HUMAN BODY

Elements	Major roles	Signs of deficiencies
Calcium (Ca)	• Formation of teeth and bones • Coagulation of blood • Transmission in the nervous system	• Slow growth (rickets) • Fragile bones (osteoporosis)
Iron (Fe)	• Composition of hemoglobin • Function of the immune system	• Fatigue, weakness, pallor (anemia) • Immune deficiency (cold, influenza, infection)
Iodine (I)	• Composition of the hormones in the thyroid gland • Production of energy	• Enlargement of the thyroid gland (goitre)
Fluoride (F)	• Maintenance of healthy teeth	• Dental cavities
Sodium (Na)	• Maintenance of water balance • Regulation of blood pressure	• Muscle cramps • Loss of appetite • Low blood pressure

Many of these elements also act together. What is more, some elements are better assimilated when combined with others. For example, vitamin D boosts the body's absorption of calcium and phosphorous, while vitamin C boosts iron absorption.

1.37

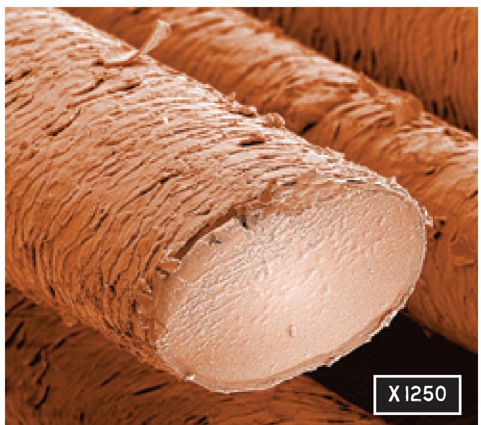
The labels on bottles of water generally list the elements they contain, such as sodium, potassium, calcium, magnesium, chlorine, fluoride, copper, arsenic, lead and zinc.

1. Name at least one food that is a good source of each of the elements listed in Table 1.36.
2. Table 1.36 gives only a few examples of the elements that are indispensable to the body. Name at least two more.

CAROLE PÉCLET

Technological progress has helped us to develop instruments for analysis that are more and more sensitive and precise. Carole Péclet has devised a technique to detect certain substances, such as drugs and medicine, in the hair of crime suspects or victims. Hair keeps traces of such substances over long periods of time, well after they have already been eliminated from other parts of the body, rendering blood and urine tests useless. Péclet's technique can detect very small concentrations of the test substances in the hair of both dead and living bodies.

Human hair grows at a rate of about one centimetre every month. The position of the substance on the hair shaft helps to approximate the date the substance was absorbed. The longer the hair, the farther in the past one can look, building a more complete history of the person in question. But a word of caution: you have to really know the physiology of hair and possible contaminants to be able to interpret the test results correctly.



1.38 Traces of different substances ingested by the body remain in hair for a long time.

NAME

Carole Péclet

JOB

Chemist in a forensic science and forensic pathology laboratory

AREA WHERE SHE WORKS

Montréal

EDUCATION

Bachelor's degree in biochemistry
Master's degree in biochemistry

PROUDEST ACHIEVEMENTS

Developed a technique that helps to detect very small concentrations of certain substances in human hair

1.39 **OCCUPATIONS CONNECTED TO PÉCLET'S WORK**

Occupation	Education required	Length of study	Main tasks
Medical secretary	AVS* in medical secretarial work	450 hours	• Provide secretarial services in a doctor's office or clinic • Produce medical reports using basic medical terminology
Biochemistry laboratory technologist	DCS in laboratory techniques	3 years	• Use and maintain laboratory equipment
Biologist	Bachelor's degree in biology (with a concentration in medical biology)	3 years	• Develop new laboratory techniques • Conduct scientific research

* Attestation of Vocational Specialization