CHAPTER 1. WELCOME TO CHEMISTRY!

Enhanced Introductory College Chemistry

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Chapter Contents

Please visit the web version of Enhanced Introductory College Chemistry (https://ecampusontario.pressbooks.pub/enhancedchemistry/) to access the complete book, interactive activities and ancillary resources.

In this chapter, you will learn about

- The origins of chemistry
- The scientific method
- Matter and its classifications

To better support your learning, you should be familiar with the following concepts before starting this chapter:

- Understanding of driving scientific principles – Laws, theories and hypotheses

Your alarm goes off and, after hitting "snooze" once or twice, you pry yourself out of bed. You make a cup of coffee to help you get going, and then you shower, get dressed, eat breakfast, and check your phone for messages. On your way to school, you stop to fill your car's gas tank, almost making you late for the first day of chemistry class. As you find a seat in the classroom, you read the question projected on the screen: "Welcome to class! Why should we study chemistry?"

Do you have an answer? You may be studying chemistry because it fulfills an academic requirement, but if you consider your daily activities, you might find chemistry interesting for other reasons. Most everything you do and encounter during your day involves chemistry. Making coffee, cooking eggs, and toasting bread involve chemistry. The products you use—like soap and shampoo, the fabrics you wear, the electronics that keep you connected to your world, the gasoline that propels your car—all of these and more involve chemical substances and processes. Whether you are aware or not, chemistry is part of your everyday world. In this course, you will learn many of the essential principles underlying the chemistry of modern-day life.

Indigenous Perspective: Dawn Pratt, MSc.

Figure 1a shows a Tipi at the Toronto Zoo. (credit: Photo by Samantha Sullivan Sauer, CC BY 4.0)

"To me, [Indigenizing STEM] means bringing in land-based education, bringing in the culture, bringing in the language, bringing in the Elders and the Knowledge Keepers," — Dawn Pratt.

Belonging to the Muscowpetung Saulteaux Nation, Dawn Pratt is a chemist turned educator who is on a mission to Indigenize STEM. Her venture develops a curriculum to blend Indigenous knowledge and STEM lessons. Read more about this mission in *c&en: Chemical & Engineering News* [New Tab]. (https://cen.acs.org/education/science-communication/Dawn-Pratt-mission-increase-Indigenous/99/i37)

Source: (Harwitz, 2021)

Attributions & References

References

Harwitz, E. (2021, October 9). Dawn Pratt is on a mission to increase Indigenous representation in STEM, one fun science class at a time. *c&en: Chemical & Engineering News*. *99*(7). https://cen.acs.org/education/science-communication/Dawn-Pratt-mission-increase-Indigenous/99/i37

1.1 CHEMISTRY IN CONTEXT

Learning Objectives

By the end of this section, you will be able to:

- Outline the historical development of chemistry
- Provide examples of the importance of chemistry in everyday life
- Describe the scientific method
- Differentiate among hypotheses, theories, and laws
- Provide examples illustrating macroscopic, microscopic, and symbolic domains

Throughout human history, people have tried to convert matter into more useful forms. Our Stone Age ancestors chipped pieces of flint into useful tools and carved wood into statues and toys. These endeavours involved changing the shape of a substance without changing the substance itself. But as our knowledge increased, humans began to change the composition of the substances as well—clay was converted into pottery, hides were cured to make garments, copper ores were transformed into copper tools and weapons, and grain was made into bread.

Humans began to practice chemistry when they learned to control fire and use it to cook, make pottery, and smelt metals. Subsequently, they began to separate and use specific components of matter. A variety of drugs such as aloe, myrrh, and opium were isolated from plants. Dyes, such as indigo and Tyrian purple, were extracted from plant and animal matter. Metals were combined to form alloys—for example, copper and tin were mixed together to make bronze—and more elaborate smelting techniques produced iron. Alkalis were extracted from ashes, and soaps were prepared by combining these alkalis with fats. Alcohol was produced by fermentation and purified by distillation.

Attempts to understand the behaviour of matter extend back for more than 2500 years. As early as the sixth century BC, Greek philosophers discussed a system in which water was the basis of all things. You may have heard of the Greek postulate that matter consists of four elements: earth, air, fire, and water. Subsequently, an amalgamation of chemical technologies and philosophical speculations were spread from

Egypt, China, and the eastern Mediterranean by alchemists, who endeavoured to transform "base metals" such as lead into "noble metals" like gold, and to create elixirs to cure disease and extend life (Figure 1.1.a).

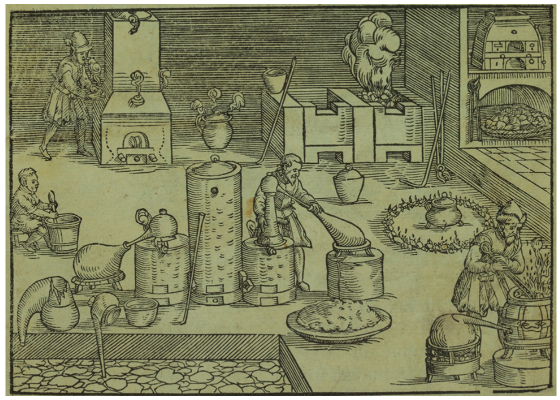

Figure 1.1a This portrayal shows an alchemist's workshop circa 1580. Although alchemy made some useful contributions to how to manipulate matter, it was not scientific by modern standards. (credit: Alchemist's workshop by Lazarus Ercker provided by the Science History Institute, PD)

From alchemy came the historical progressions that led to modern chemistry: the isolation of drugs from natural sources, metallurgy, and the dye industry. Today, chemistry continues to deepen our understanding and improve our ability to harness and control the behaviour of matter. This effort has been so successful that many people do not realize either the central position of chemistry among the sciences or the importance and universality of chemistry in daily life.

Chemistry: The Central Science

Chemistry is sometimes referred to as "the central science" due to its interconnectedness with a vast array of other STEM disciplines (STEM stands for areas of study in the science, technology, engineering, and math fields). Chemistry and the language of chemists play vital roles in biology, medicine, materials science, forensics, environmental science, and many other fields (Figure 1.1b). The basic principles of physics are essential for understanding many aspects of chemistry, and there is extensive overlap between many subdisciplines within the two fields, such as chemical physics and nuclear chemistry. Mathematics, computer science, and information theory provide important tools that help us calculate, interpret, describe, and generally make sense of the chemical world. Biology and chemistry converge in biochemistry, which is crucial to understanding the many complex factors and processes that keep living organisms (such as us) alive. Chemical engineering, materials science, and nanotechnology combine chemical principles and empirical findings to produce useful substances, ranging from gasoline to fabrics to electronics. Agriculture, food science, veterinary science, and brewing and wine making help provide sustenance in the form of food and drink to the world's population. Medicine, pharmacology, biotechnology, and botany identify and produce substances that help keep us healthy. Environmental science, geology, oceanography, and atmospheric science incorporate many chemical ideas to help us better understand and protect our physical world. Chemical ideas are used to help understand the universe in astronomy and cosmology.

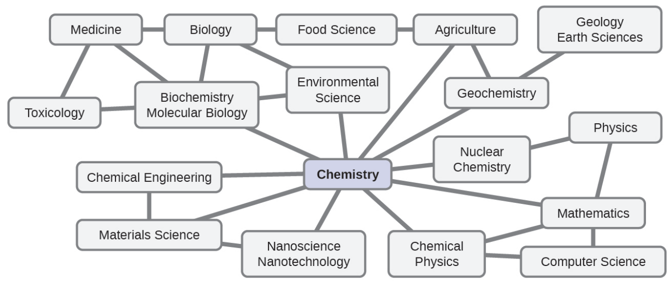

Figure 1.1b Knowledge of chemistry is central to understanding a wide range of scientific disciplines. This diagram shows just some of the interrelationships between chemistry and other fields. (credit: Chemistry (OpenStax), CC BY 4.0).

What are some changes in matter that are essential to daily life? Digesting and assimilating food, synthesizing polymers that are used to make clothing, containers, cookware, and credit cards, and refining crude oil into gasoline and other products are just a few examples. As you proceed through this course, you will discover many different examples of changes in the composition and structure of matter, how to classify these changes and how they occurred, their causes, the changes in energy that accompany them, and the principles and laws involved. As you learn about these things, you will be learning **chemistry**, the study of the composition, properties, and interactions of matter. The practice of chemistry is not limited to chemistry books or laboratories: It happens whenever someone is involved in changes in matter or in conditions that may lead to such changes.

The Scientific Method

Chemistry is a science based on observation and experimentation. Doing chemistry involves attempting to answer questions and explain observations in terms of the laws and theories of chemistry, using procedures that are accepted by the scientific community. There is no single route to answering a question or explaining an observation, but there is an aspect common to every approach: Each uses knowledge based on experiments that can be reproduced to verify the results. Some routes involve a **hypothesis**, a tentative explanation of observations that acts as a guide for gathering and checking information. We test a hypothesis by experimentation, calculation, and/or comparison with the experiments of others and then refine it as needed.

Some hypotheses are attempts to explain the behaviour that is summarized in laws. The **laws** of science summarize a vast number of experimental observations, and describe or predict some facet of the natural world. If such a hypothesis turns out to be capable of explaining a large body of experimental data, it can reach the status of a theory. Scientific **theories** are well-substantiated, comprehensive, testable explanations of particular aspects of nature. Theories are accepted because they provide satisfactory explanations, but they can be modified if new data become available. The path of discovery that leads from question and observation to law or hypothesis to theory, combined with experimental verification of the hypothesis and any necessary modification of the theory, is called the **scientific method** (Figure 1.1c).

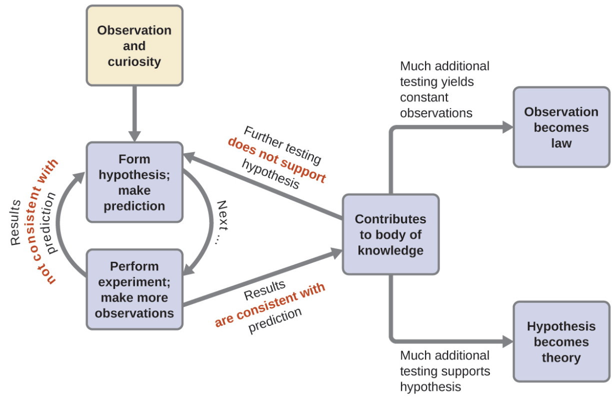

Figure 1.1c The scientific method follows a process similar to the one shown in this diagram. All the key components are shown, in roughly the right order. Scientific progress is seldom neat and clean: It requires open inquiry and the reworking of questions and ideas in response to findings (credit: Chemistry (OpenStax), CC BY 4.0).

The Domains of Chemistry

Chemists study and describe the behaviour of matter and energy in three different domains: macroscopic, microscopic, and symbolic. These domains provide different ways of considering and describing chemical behaviour.

Macro is a Greek word that means "large." The **macroscopic domain** is familiar to us: It is the realm of everyday things that are large enough to be sensed directly by human sight or touch. In daily life, this includes the food you eat and the breeze you feel on your face. The macroscopic domain includes every day and laboratory chemistry, where we observe and measure physical and chemical properties, or changes such as density, solubility, and flammability.

The **microscopic domain** of chemistry is almost always visited in the imagination. *Micro* also comes from Greek and means "small." Some aspects of the microscopic domains are visible through a microscope, such as a magnified image of graphite or bacteria. Viruses, for instance, are too small to be seen with the naked eye, but when we're suffering from a cold, we're reminded of how real they are.

However, most of the subjects in the microscopic domain of chemistry—such as atoms and molecules—are too small to be seen even with standard microscopes and often must be pictured in the mind. Other components of the microscopic domain include ions and electrons, protons and neutrons, and chemical bonds, each of which is far too small to see. This domain includes the individual metal atoms in a wire, the ions that compose a salt crystal, the changes in individual molecules that result in a colour change, the conversion of nutrient molecules into tissue and energy, and the evolution of heat as bonds that hold atoms together are created.

The **symbolic domain** contains the specialized language used to represent components of the macroscopic and microscopic domains. Chemical symbols (such as those used in the periodic table), chemical formulas, and chemical equations are part of the symbolic domain, as are graphs and drawings. We can also consider calculations as part of the symbolic domain. These symbols play an important role in chemistry because they help interpret the behaviour of the macroscopic domain in terms of the components of the microscopic domain. One of the challenges for students learning chemistry is recognizing that the same symbols can represent different things in the macroscopic and microscopic domains, and one of the features that makes chemistry fascinating is the use of a domain that must be imagined to explain behaviour in a domain that can be observed.

A helpful way to understand the three domains is via the essential and ubiquitous substance of water. That water is a liquid at moderate temperatures, will freeze to form a solid at lower temperatures, and boil to form a gas at higher temperatures (Figure 1.1d) are macroscopic observations. But some properties of water fall into the microscopic domain—what we cannot observe with the naked eye. The description of water as comprised of two hydrogen atoms and one oxygen atom, and the explanation of freezing and boiling in terms of attractions between these molecules, is within the microscopic arena. The formula H_2O, which can describe water at either the macroscopic or microscopic levels, is an example of the symbolic domain. The abbreviations (*g*) for gas, (*s*) for solid, and (*l*) for liquid are also symbolic.

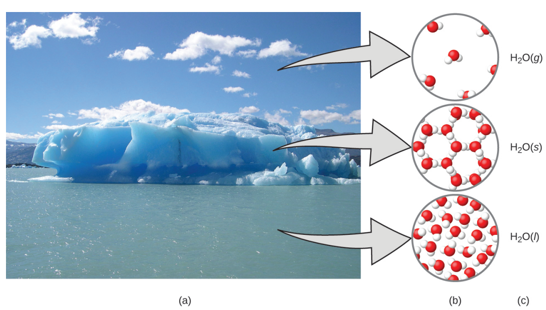

Figure 1.1d (a) Moisture in the air, icebergs and the ocean represent water in the macroscopic domain. (b) At the molecular level (microscopic domain), gas molecules are far apart and disorganized, solid water molecules are close together and organized, and liquid molecules are close together and disorganized. (c) The formula H_2O symbolizes water, and (g), (s), and (l) symbolize its phases. Note that clouds are actually comprised of either very small liquid water droplets or solid water crystals; gaseous water in our atmosphere is not visible to the naked eye, although it may be sensed as humidity. (credit: modification of work by Gorkaazk, CC BY 3.0; in *Chemistry (OpenStax),* CC BY 4.0).

Exercise 1.1a

Check Your Learning Exercise (Text Version)
Matter consists of tiny particles that can combine in specific ratios to form substances with specific properties. Identify this statement as being most similar to a hypothesis, a law, or a theory. Explain your reasoning.

Check Your Answer[1]

Source: "Exercise 1.1a" is adapted from "Exercise 1.1-3b" in General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Exercise 1.1b

Check Your Learning Exercise (Text Version)
At a higher temperature, solids (such as salt or sugar) will dissolve better in water. Identify this statement as being most similar to a hypothesis, a law, or a theory. Explain your reasoning.

Check Your Answer[2]

Source: "Exercise 1.1b" is adapted from "Exercise 1.1-3c" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Exercise 1.1c

Check Your Learning Exercise (Text Version)
Identify the item in bold (also marked with an *) as a part of either the macroscopic domain, the

microscopic domain, or the symbolic domain of chemistry. For those in the symbolic domain, indicate whether they are symbols for a macroscopic or a microscopic feature.

a. A certain molecule contains one ***H** atom and one Cl atom.
b. ***Copper *wire** has a density of about 8 g/cm3
c. The bottle contains 15 grams of ***Ni *powder**.
d. A ***sulfur *molecule** is composed of eight sulfur atoms.

Check Your Answer[3]

Source: "Exercise 1.1c" is adapted from "Exercise 1.1-5c" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

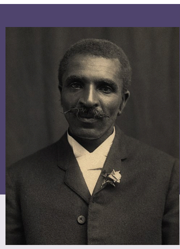

Figure 1.1e George Washington Carver (credit: Photo by Unknown, restored by Adam Cuerden, PD)

Scientists in Action: George Washington Carver, PhD.

George Washington Carver was born into slavery in Missouri. His interest in science started with taking care of plants at a young age. He is most famous for his contributions to agricultural chemistry, and he is credited with developing over 100 uses for the peanut. He was the first African American to have a national monument dedicated to him. The American Chemical Society dedicated his work as a National Historic Chemical Landmark in 2005.Learn more about Dr. George Washington Carver in this American Chemical Society Commemorative booklet [New Tab][PDF] (https://www.acs.org/content/dam/acsorg/education/whatischemistry/landmarks/carver/george-washington-carver-commemorative-booklet.pdf)He was dedicated to the continuing education of poor farmers and took his Jessup wagon (think of it as a traveling lab) around to rural communities to share what he had learned. His epitaph reads "He could have added fortune to fame, but caring for neither, he found happiness and honour in being helpful to the world." If you'd like to, listen to an old audio recording of George Washington Carver [New Tab] (https://www.youtube.com/watch?v=2s9CK22ajSI&t=).

Attribution & References

Notes

1. hypothesis (a tentative explanation, can be investigated by experimentation)
2. theory (a widely accepted explanation of the behaviour of matter);
3. (a) Symbolic, Microscopic; (b) Macroscopic; (c) Symbolic, Macroscopic; (d) Microscopic

1.2 PHASES AND CLASSIFICATION OF MATTER

Learning Objectives

By the end of this section, you will be able to:

- Describe the basic properties of each physical state of matter: solid, liquid, and gas
- Define and give examples of atoms and molecules
- Classify matter as an element, compound, homogeneous mixture, or heterogeneous mixture with regard to its physical state and composition
- Distinguish between mass and weight
- Apply the law of conservation of matter

Matter is defined as anything that occupies space and has mass, and it is all around us. Solids and liquids are more obviously matter: We can see that they take up space, and their weight tells us that they have mass. Gases are also matter; if gases did not take up space, a balloon would stay collapsed rather than inflate when filled with gas.

Solids, liquids, and gases are the three states of matter commonly found on earth (Figure 1.2a, Table 1.2a). A **solid** is rigid and possesses a definite shape. A **liquid** flows and takes the shape of a container, except that it forms a flat or slightly curved upper surface when acted upon by gravity. (In zero gravity, liquids assume a spherical shape.) Both liquid and solid samples have volumes that are very nearly independent of pressure. A **gas** takes both the shape and volume of its container.

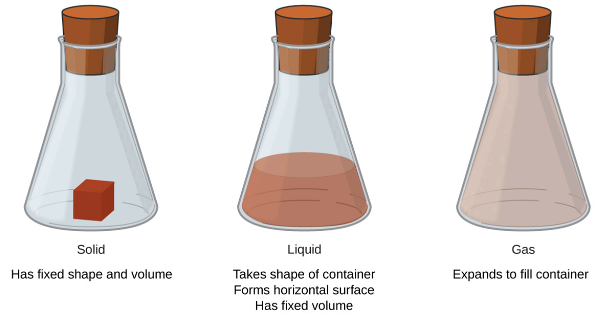

Figure 1.2a The three most common states or phases of matter are solid, liquid, and gas. (credit: Chemistry (OpenStax), CC BY 4.0).

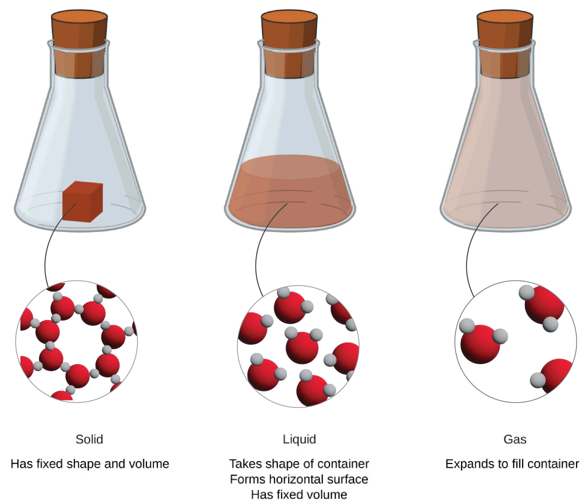

Figure 1.2b States of matter illustrated with the molecular structure of each. (credit: *Chemistry (Open Stax)*, Adapted by Revathi Mahadevan, CC BY 4.0)

Table 1.2a Summary characteristics of the states of matter

Characteristic	**Solid**	**Liquid**	**Gas**
Shape	definite shape	Takes the shape of the container	Takes the shape of the container
Volume	Has a definite volume	Has a definite volume	Fills the volume of the container
Particle Arrangement	Very close, fixed positions	Close, random motion	Far apart, random motion
Particle Interaction	Very strong	Strong	Essentially none
Particle Movement	Very slow	Moderate	Very fast
Examples	Ice, sugar, copper	Water, mercury, ethanol	Water vapour, hydrogen, air

Exercise 1.2a

Check Your Learning Exercise (Text Version)
For each statement, determine whether it is describing a property of a solid, liquid, or gas.

a. cannot be compressed or poured.
b. can be compressed and flow when poured.
c. cannot be compressed, but can be poured.

Check Your Answer[1]

Source: "Exercise 1.2a" by Daryl Shaun Aranha is adapted from "1.2 Phases and Classification of Matter" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

The fourth state of matter, plasma, occurs naturally in the interiors of stars. A **plasma** is a gaseous state of matter that contains appreciable numbers of electrically charged particles (Figure 1.2c). The presence of these charged particles imparts unique properties to plasmas that justify their classification as a state of matter distinct from gases. In addition to stars, plasmas are found in some other high-temperature environments (both natural and man-made), such as lightning strikes, certain television screens, and specialized analytical instruments used to detect trace amounts of metals.

Figure 1.2c A plasma torch can be used to cut metal. (credit: work by Hypertherm, undeclared license)

Watch The Chemistry of Light (2006): Silver Chloride Photography (2 mins)
(https://www.youtube.com/watch?v=ZLEYyzW427I)

Some samples of matter appear to have properties of solids, liquids, and/or gases at the same time. This can occur when the sample is composed of many small pieces. For example, we can pour sand as if it were a liquid because it is composed of many small grains of solid sand. Matter can also have properties of more than one state when it is a mixture, such as with clouds. Clouds appear to behave somewhat like gases, but they are actually mixtures of air (gas) and tiny particles of water (liquid or solid).

The **mass** of an object is a measure of the amount of matter in it. One way to measure an object's mass is to measure the force it takes to accelerate the object. It takes much more force to accelerate a car than a bicycle because the car has much more mass. A more common way to determine the mass of an object is to use a balance to compare its mass with a standard mass.

Although weight is related to mass, it is not the same thing. **Weight** refers to the force that gravity exerts on an object. This force is directly proportional to the mass of the object. The weight of an object changes as the force of gravity changes, but its mass does not. An astronaut's mass does not change just because she goes to the moon. But her weight on the moon is only one-sixth her earth-bound weight because the moon's gravity is only one-sixth that of the earth's. She may feel "weightless" during her trip when she experiences negligible external forces (gravitational or any other), although she is, of course, never "massless."

The **law of conservation of matter** summarizes many scientific observations about matter: It states that *there is no detectable change in the total quantity of matter present when matter converts from one type to another (a chemical change) or changes among solid, liquid, or gaseous states (a physical change)*. Brewing beer and the operation of batteries provide examples of the conservation of matter (Figure 1.2d). During the brewing of beer, the ingredients (water, yeast, grains, malt, hops, and sugar) are converted into beer (water, alcohol, carbonation, and flavouring substances) with no actual loss of substance. This is most clearly seen during the bottling process, when glucose turns into ethanol and carbon dioxide, and the total mass of the substances does not change. This can also be seen in a lead-acid car battery: The original substances (lead, lead oxide, and sulfuric acid), which are capable of producing electricity, are changed into other substances (lead sulfate and water) that do not produce electricity, with no change in the actual amount of matter.

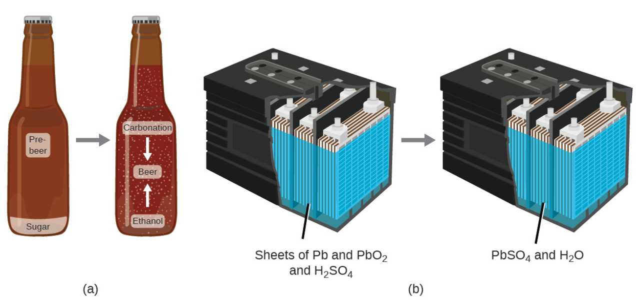

Figure 1.2d (a) The mass of beer precursor materials is the same as the mass of beer produced: Sugar has become alcohol and carbonation. (b) The mass of the lead, lead oxide plates, and sulfuric acid that goes into the production of electricity is exactly equal to the mass of lead sulfate and water that is formed (credit: *Chemistry (OpenStax)*, CC BY 4.0).

Although this conservation law holds true for all conversions of matter, convincing examples are few and far between because, outside of the controlled conditions in a laboratory, we seldom collect all of the material that is produced during a particular conversion. For example, when you eat, digest, and assimilate food, all of the matter in the original food is preserved. But because some of the matter is incorporated into your body, and much is excreted as various types of waste, it is challenging to verify by measurement.

Exercise 1.2b

Check Your Learning Exercise (Text Version)
The pressure of a sample of gas is directly proportional to the temperature of the gas. Identify this statement as being most similar to a hypothesis, a law, or a theory. Explain your reasoning.

Check Your Answer[2]

Source: "Exercise 1.2b" is adapted from "Exercise 1.1-3a" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Atoms and Molecules

An **atom** is the smallest particle of an element that has the properties of that element and can enter into a chemical combination. Consider the element gold, for example. Imagine cutting a gold nugget in half, then cutting one of the halves in half, and repeating this process until a piece of gold remained that was so small that it could not be cut in half (regardless of how tiny your knife may be). This minimally sized piece of gold is an atom (from the Greek *atomos*, meaning "indivisible") (Figure 1.2e). This atom would no longer be gold if it were divided any further.

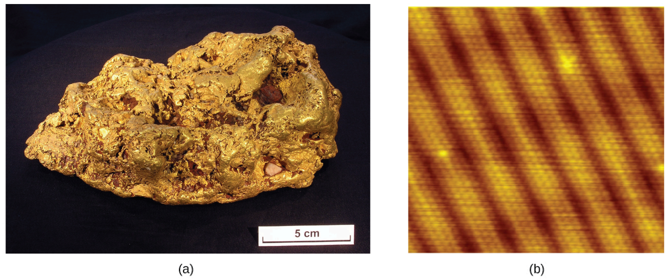

Figure 1.2e (a) This photograph shows a gold nugget. (b) A scanning-tunneling microscope (STM) can generate views of the surfaces of solids, such as this image of a gold crystal. Each sphere represents one gold atom. (credit a: modification of work by CSIRO, CC BY 3.0; credit b: modification of work by Erwinrossen, PD.)

The first suggestion that matter is composed of atoms is attributed to the Greek philosophers Leucippus and Democritus, who developed their ideas in the 5th century BCE. However, it was not until the early nineteenth century that John Dalton (1766–1844), a British schoolteacher with a keen interest in science, supported this hypothesis with quantitative measurements. Since that time, repeated experiments have confirmed many aspects of this hypothesis, and it has become one of the central theories of chemistry. Other aspects of Dalton's atomic theory are still used but with minor revisions (details of Dalton's theory are provided in the chapter on atoms and molecules).

An atom is so small that its size is difficult to imagine. One of the smallest things we can see with our unaided eye is a single thread of a spider web: These strands are about 1/10,000 of a centimetre (0.0001 cm) in diameter. Although the cross-section of one strand is almost impossible to see without a microscope, it is huge on an atomic scale. A single carbon atom in the web has a diameter of about 0.000000015 centimetre, and it would take about 7000 carbon atoms to span the diameter of the strand. To put this in perspective, if a carbon atom were the size of a dime, the cross-section of one strand would be larger than a football field, which would require about 150 million carbon atom "dimes" to cover it. Figure 1.2f shows increasingly close microscopic and atomic-level views of ordinary cotton.

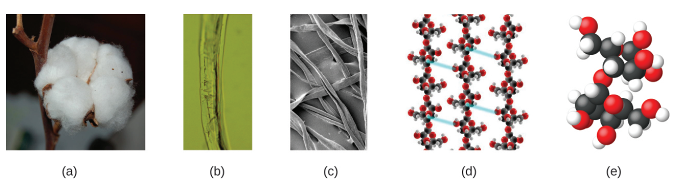

Figure 1.2f These images provide an increasingly closer view: (a) a cotton boll, (b) a single cotton fibre viewed under an optical microscope (magnified 40 times), (c) an image of a cotton fibre obtained with an electron microscope (much higher magnification than with the optical microscope); and (d and e) atomic-level models of the fibre (spheres of different colours represent atoms of different elements). (credit a: work by KoS, PD; credit c: modification of work by Featheredtar, CC BY 3.0)

An atom is so light that its mass is also difficult to imagine. A billion lead atoms (1,000,000,000 atoms) weigh about 3×10^{-13} grams, a mass that is far too light to be weighed on even the world's most sensitive balances.

It would require over 300,000,000,000,000 lead atoms (300 trillion, or 3×10^{14}) to be weighed, and they would weigh only 0.0000001 gram.

It is rare to find collections of individual atoms. Only a few elements, such as the gases helium, neon, and argon, consist of a collection of individual atoms that move about independently of one another. Other elements, such as the gases hydrogen, nitrogen, oxygen, and chlorine, are composed of units that consist of pairs of atoms (Figure 1.2g). One form of the element phosphorus consists of units composed of four phosphorus atoms. The element sulfur exists in various forms, one of which consists of units composed of eight sulfur atoms. These units are called molecules. A **molecule** consists of two or more atoms joined by strong forces called chemical bonds. The atoms in a molecule move around as a unit, much like the cans of soda in a six-pack or a bunch of keys joined together on a single key ring. A molecule may consist of two or more identical atoms, as in the molecules found in the elements hydrogen, oxygen, and sulfur, or it may consist of two or more different atoms, as in the molecules found in water. Each water molecule is a unit that contains two hydrogen atoms and one oxygen atom. Each glucose molecule is a unit that contains 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms. Like atoms, molecules are incredibly small and light. If an ordinary glass of water were enlarged to the size of the earth, the water molecules inside it would be about the size of golf balls.

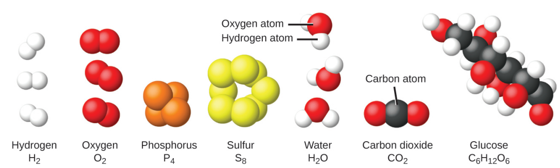

Figure 1.2g The elements hydrogen, oxygen, phosphorus, and sulfur form molecules consisting of two or more atoms of the same element. The compounds water, carbon dioxide, and glucose consist of combinations of atoms of different elements (credit: *Chemistry (OpenStax)*, CC BY 4.0).

Exercise 1.2c

Check Your Learning Exercise (Text Version)

Fill in the blanks with either "one" or "two or more" to make the statement correct.

a. Molecules of elements contains [BLANK] type(s) of atom(s)?
b. Molecules of compounds contains [BLANK] type(s) of atom(s)?
c. Molecules of elements and molecules of compounds are similar in that both are comprised of [BLANK] atom(s) chemically bonded together.

Check Your Answer[3]

Source: "Exercise 1.2c" by Daryl Shaun Aranha is adapted from "1.2 Phases and Classification of Matter" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Exercise 1.2d

Practice using the following PhET simulation: States of Matter (https://phet.colorado.edu/sims/html/states-of-matter/latest/states-of-matter_en.html)

Classifying Matter

We can classify matter into several categories. Two broad categories are mixtures and pure substances. A **pure substance** has a constant composition. All specimens of a pure substance have exactly the same makeup and properties. Any sample of sucrose (table sugar) consists of 42.1% carbon, 6.5% hydrogen, and 51.4% oxygen by mass. Any sample of sucrose also has the same physical properties, such as melting point, colour, and sweetness, regardless of the source from which it is isolated.

We can divide pure substances into two classes: elements and compounds. Pure substances that cannot be broken down into simpler substances by chemical changes are called **elements**. Iron, silver, gold, aluminum, sulfur, oxygen, and copper are familiar examples of the more than 100 known elements, of which about 90 occur naturally on the earth, and two dozen or so have been created in laboratories.

Pure substances that can be broken down by chemical changes are called **compounds**. This breakdown may produce either elements or other compounds, or both. Mercury(II) oxide, an orange, crystalline solid, can be broken down by heat into the elements mercury and oxygen (Figure 1.2h). When heated in the absence of air, the compound sucrose is broken down into the element carbon and the compound water. (The initial stage of this process, when the sugar is turning brown, is known as caramelization—this is what imparts the characteristic sweet and nutty flavor to caramel apples, caramelized onions, and caramel). Silver(I) chloride is a white solid that can be broken down into its elements, silver and chlorine, by absorption of light. This property is the basis for the use of this compound in photographic films and photochromic eyeglasses (those with lenses that darken when exposed to light).

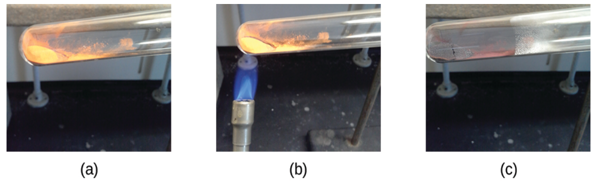

Figure 1.2h (a) The compound mercury(II) oxide, (b) when heated, (c) decomposes into silvery droplets of liquid mercury and invisible oxygen gas. (credit: modification of work by Paul Flowers in *Chemistry (OpenStax)*, CC BY 4.0).

Watch Decomposition Mercury (II) Oxide and Oxygen (2 mins)
(https://www.youtube.com/watch?v=_Y1alDuXm6A)

The properties of combined elements are different from those in the free, or uncombined, state. For example, white crystalline sugar (sucrose) is a compound resulting from the chemical combination of the element carbon, which is a black solid in one of its uncombined forms, and the two elements hydrogen and oxygen, which are colourless gases when uncombined. Free sodium, an element that is a soft, shiny, metallic solid, and free chlorine, an element that is a yellow-green gas, combine to form sodium chloride (table salt), a compound that is a white, crystalline solid.

A **mixture** is composed of two or more types of matter that can be present in varying amounts and can be separated by physical changes, such as evaporation (you will learn more about this later). A mixture with a composition that varies from point to point is called a **heterogeneous mixture**. Italian dressing is an example of a heterogeneous mixture (Figure 1.2i). Its composition can vary because we can make it from varying amounts of oil, vinegar, and herbs. It is not the same from point to point throughout the mixture—one drop may be mostly vinegar, whereas a different drop may be mostly oil or herbs because the oil and vinegar separate and the herbs settle. Other examples of heterogeneous mixtures are chocolate chip cookies (we can see the separate bits of chocolate, nuts, and cookie dough) and granite (we can see the quartz, mica, feldspar, and more).

A **homogeneous mixture**, also called a **solution**, exhibits a uniform composition and appears visually the same throughout. An example of a solution is a sports drink, consisting of water, sugar, colouring, flavouring, and electrolytes mixed together uniformly (Figure 1.2i). Each drop of a sports drink tastes the same because each drop contains the same amounts of water, sugar, and other components. Note that the composition of a sports drink can vary—it could be made with somewhat more or less sugar, flavouring, or other components, and still be a sports drink. Other examples of homogeneous mixtures include air, maple syrup, gasoline, and a solution of salt in water.

Figure 1.2i (a) Oil and vinegar salad dressing is a heterogeneous mixture because its composition is not uniform throughout. (b) A commercial sports drink is a homogeneous mixture because its composition is uniform throughout. (credit a "left": modification of work by John Mayer, CC BY 2.0; credit a "right": modification of work by Umberto Salvagnin, CC BY 2.0; credit b: left: modification of work by Jeff Bedford in *Chemistry (OpenStax)*, CC BY 4.0).

Although there are just over 100 elements, tens of millions of chemical compounds result from different combinations of these elements. Each compound has a specific composition and possesses definite chemical and physical properties by which we can distinguish it from all other compounds. And, of course, there are innumerable ways to combine elements and compounds to form different mixtures. A summary of how to distinguish between the various major classifications of matter is shown in (Figure 1.2j).

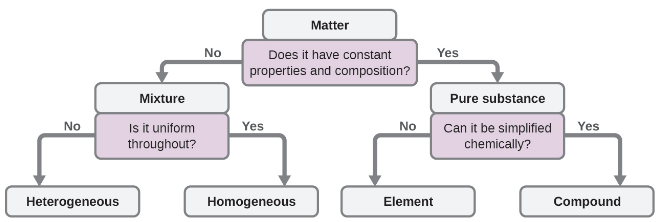

Figure 1.2j Depending on its properties, a given substance can be classified as a homogeneous mixture, a heterogeneous mixture, a compound, or an element (credit: *Chemistry (OpenStax)*, CC BY 4.0).

Eleven elements make up about 99% of the earth's crust and atmosphere (Table 1.2b). Oxygen constitutes nearly one-half and silicon about one-quarter of the total quantity of these elements. A majority of elements on earth are found in chemical combinations with other elements; about one-quarter of the elements are also found in the free state.

Table 1.2b Elemental Composition of Earth

Element	Symbol	Percent Mass
oxygen	O	49.20
silicon	Si	25.67
aluminum	Al	7.50
iron	Fe	4.71
calcium	Ca	3.39
sodium	Na	2.63
potassium	K	2.40
magnesium	Mg	1.93
hydrogen	H	0.87
titanium	Ti	0.58
chlorine	Cl	0.19
phosphorus	P	0.11
manganese	Mn	0.09
carbon	C	0.08
sulfur	S	0.06
barium	Ba	0.04
nitrogen	N	0.03
fluorine	F	0.03
strontium	Sr	0.02
all others	–	0.47

Exercise 1.2e

Check Your Learning Exercise (Text Version)
Classify each of the following as an element, a compound, or a mixture:

a. iron

b. oxygen
c. mercury oxide
d. pancake syrup
e. carbon dioxide
f. a substance composed of molecules each of which contains one hydrogen atom and one chlorine atom
g. baking soda
h. baking powder

Check Your Answer[4]

Source: "Exercise 1.2e" is adapted from "Exercise 1.2-10" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Decomposition of Water / Production of Hydrogen

Water consists of the elements hydrogen and oxygen combined in a 2 to 1 ratio. Water can be broken down into hydrogen and oxygen gases by the addition of energy. One way to do this is with a battery or power supply, as shown in (Figure 1.2k).

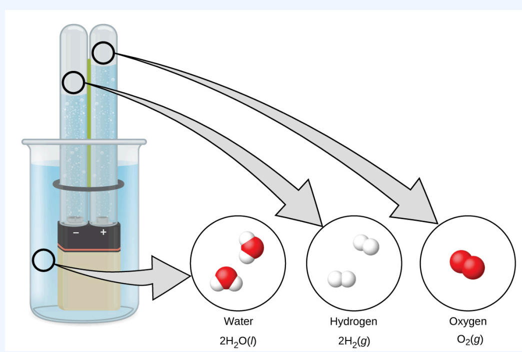

Figure 1.2k The decomposition of water is shown at the macroscopic, microscopic, and symbolic levels. The battery provides an electric current (microscopic) that decomposes water. At the macroscopic level, the liquid separates into the gases hydrogen (on the left) and oxygen (on the right). Symbolically, this change is presented by showing how liquid H_2O separates into H_2 and O_2 gases (credit: *Chemistry (OpenStax)*, CC BY 4.0).

The breakdown of water involves a rearrangement of the atoms in water molecules into different molecules, each composed of two hydrogen atoms and two oxygen atoms, respectively. Two water molecules form one oxygen molecule and two hydrogen molecules. The representation for what occurs, $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$, will be explored in more depth in later chapters.

The two gases produced have distinctly different properties. Oxygen is not flammable but is required for combustion of a fuel, and hydrogen is highly flammable and a potent energy source. How might this knowledge be applied in our world? One application involves research into more fuel-efficient transportation. Fuel-cell vehicles (FCV) run on hydrogen instead of gasoline (Figure 1.2l). They are more efficient than vehicles with internal combustion engines, are nonpolluting, and reduce greenhouse gas emissions, making us less dependent on fossil fuels. FCVs are not yet economically viable, however, and current hydrogen production depends on natural gas. If we can develop a process to economically decompose water, or produce hydrogen in another environmentally sound way, FCVs may be the way of the future.

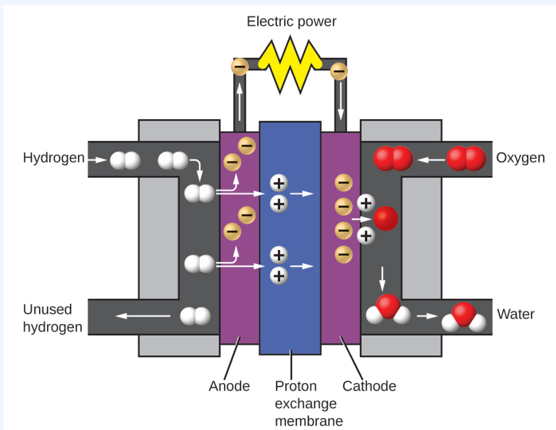

Figure 1.2l A fuel cell generates electrical energy from hydrogen and oxygen via an electrochemical process and produces only water as the waste product (credit: *Chemistry (OpenStax)*, CC BY 4.0).

Exercise 1.2f

Check Your Learning Exercise (Text Version)
Guess the answer:

a. Anything that occupies space
b. A measure of the amount of matter contained in an object
c. A measure of the force of gravity acting upon an object

d. The smallest piece of matter that naturally exist
e. Loss of electrons resulting in a positive charge
f. Gain of electrons resulting in a negative charge
g. Are the combination of 2 or more atoms
h. The atoms in a molecule are held together by a

Check Your Answer[5]

Source: "Exercise 1.2f" by Daryl Shaun Aranha is adapted from "1.2 Phases and Classification of Matter (https://boisestate.pressbooks.pub/chemistry/chapter/1-2-phases-and-classification-of-matter/)" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Chemistry of Cell Phones

Imagine how different your life would be without cell phones (Figure 1.2m) and other smart devices. Cell phones are made from numerous chemical substances, which are extracted, refined, purified, and assembled using an extensive and in-depth understanding of chemical principles. About 30% of the elements that are found in nature are found within a typical smart phone. The case/body/frame consists of a combination of sturdy, durable polymers comprised primarily of carbon, hydrogen, oxygen, and nitrogen [acrylonitrile butadiene styrene (ABS) and polycarbonate thermoplastics], and light, strong, structural metals, such as aluminum, magnesium, and iron. The display screen is made from a specially toughened glass (silica glass strengthened by the addition of aluminum, sodium, and potassium) and coated with a material to make it conductive (such as indium tin oxide). The circuit board uses a semiconductor material (usually silicon); commonly used metals like copper, tin, silver, and gold; and more unfamiliar elements such as yttrium, praseodymium, and gadolinium. The battery relies upon lithium ions and a variety of other materials, including iron, cobalt, copper, polyethylene oxide, and polyacrylonitrile.

Figure 1.2m Almost one-third of naturally occurring elements are used to make a cell phone. (credit: modification of work by John Taylor, CC BY 2.0; in *Chemistry (OpenStax)*, CC BY 4.0).

Links to Interactive Learning Tools

Explore the Classification of Matter (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Classifications-of-Matter) from the Physics Classroom (https://www.physicsclassroom.com/).

Explore Classifying Matter (https://h5pstudio.ecampusontario.ca/content/44300) from eCampusOntario H5P Studio (https://h5pstudio.ecampusontario.ca/).

Attribution & References

Notes

1. a) solid; b) gas; c) liquid
2. law (states a consistently observed phenomenon, can be used for prediction)
3. (a) one; (b) two or more; (c) two or more

4. (a) element; (b) element; (c) compound; (d) mixture; (e) compound; (f) compound; (g) compound; (h) mixture
5. (a) Matter; (b) Mass; (c) Weight; (d) Atoms; (e) Cation; (f) Anion; (g) Molecules; (h) Chemical Bond

CHAPTER 1 - SUMMARY

1.1 Chemistry in Context

Chemistry deals with the composition, structure, and properties of matter, and the ways by which various forms of matter may be interconverted. Thus, it occupies a central place in the study and practice of science and technology. Chemists use the scientific method to perform experiments, pose hypotheses, and formulate laws and develop theories, so that they can better understand the behaviour of the natural world. To do so, they operate in the macroscopic, microscopic, and symbolic domains. Chemists measure, analyze, purify, and synthesize a wide variety of substances that are important to our lives.

1.2 Phases and Classification of Matter

Matter is anything that occupies space and has mass. The basic building block of matter is the atom, the smallest unit of an element that can enter into combinations with atoms of the same or other elements. In many substances, atoms are combined into molecules. On earth, matter commonly exists in three states: solids, of fixed shape and volume; liquids, of variable shape but fixed volume; and gases, of variable shape and volume. Under high-temperature conditions, matter also can exist as a plasma. Most matter is a mixture: It is composed of two or more types of matter that can be present in varying amounts and can be separated by physical means. Heterogeneous mixtures vary in composition from point to point; homogeneous mixtures have the same composition from point to point. Pure substances consist of only one type of matter. A pure substance can be an element, which consists of only one type of atom and cannot be broken down by a chemical change, or a compound, which consists of two or more types of atoms.

Attributions & References

CHAPTER 1 - REVIEW

1.1 Chemistry in Context

1. Explain how you could experimentally determine whether the outside temperature is higher or lower than 0 °C (32 °F) without using a thermometer. **Check Answer:** [1]
2. Identify each of the following statements as being most similar to a hypothesis, a law, or a theory. Explain your reasoning.
   a. Falling barometric pressure precedes the onset of bad weather.
   b. All life on earth has evolved from a common, primitive organism through the process of natural selection.
   c. My truck's gas mileage has dropped significantly, probably because it's due for a tune-up.
3. Identify each of the following statements as being most similar to a hypothesis, a law, or a theory. Explain your reasoning.
   a. The pressure of a sample of gas is directly proportional to the temperature of the gas.
   b. Matter consists of tiny particles that can combine in specific ratios to form substances with specific properties.
   c. At a higher temperature, solids (such as salt or sugar) will dissolve better in water.
   Check Answer: [2]
4. Identify each of the following bolded items (also preceded by *) as a part of either the macroscopic domain, the microscopic domain, or the symbolic domain of chemistry. For any in the symbolic domain, indicate whether they are symbols for a macroscopic or a microscopic feature.
   a. The mass of a ***lead pipe** is 14 lb.
   b. The mass of a certain ***chlorine atom** is 35 amu.
   c. A bottle with a label that reads ***Al** contains aluminum metal.
   d. ***Al** is the symbol for an aluminum atom.
5. Identify each of the following bolded items (also preceded by *) as a part of either the macroscopic domain, the microscopic domain, or the symbolic domain of chemistry. For those in the symbolic domain, indicate whether they are symbols for a macroscopic or a microscopic feature.
   a. A certain molecule contains one ***H** atom and one Cl atom.
   b. ***Copper wire** has a density of about 8 g/cm^3.
   c. The bottle contains 15 grams of ***Ni powder**.
   d. A ***sulfur molecule** is composed of eight sulfur atoms.
   Check Answer: [3]

6. According to one theory, the pressure of a gas increases as its volume decreases because the molecules in the gas have to move a shorter distance to hit the walls of the container. Does this theory follow a macroscopic or microscopic description of chemical behaviour? Explain your answer.
7. The amount of heat required to melt 2 lbs of ice is twice the amount of heat required to melt 1 lb of ice. Is this observation a macroscopic or microscopic description of chemical behaviour? Explain your answer. **Check Answer:** [4]

1.2 Phases and Classification of Matter

1. Why do we use an object's mass, rather than its weight, to indicate the amount of matter it contains?
2. What properties distinguish solids from liquids? Liquids from gases? Solids from gases? **Check Answer:** [5]
3. How does a heterogeneous mixture differ from a homogeneous mixture? How are they similar?
4. How does a homogeneous mixture differ from a pure substance? How are they similar? **Check Answer:** [6]
5. How does an element differ from a compound? How are they similar?
6. How do molecules of elements and molecules of compounds differ? In what ways are they similar? **Check Answer:** [7]
7. How does an atom differ from a molecule? In what ways are they similar?
8. Many of the items you purchase are mixtures of pure compounds. Select three of these commercial products and prepare a list of the ingredients that are pure compounds. **Check Answer:** [8]
9. Classify each of the following as an element, a compound, or a mixture:
    a. copper
    b. water
    c. nitrogen
    d. sulfur
    e. air
    f. sucrose
    g. a substance composed of molecules each of which contains two iodine atoms
    h. gasoline
10. Classify each of the following as an element, a compound, or a mixture:
    a. iron
    b. oxygen
    c. mercury oxide
    d. pancake syrup
    e. carbon dioxide
    f. a substance composed of molecules each of which contains one hydrogen atom and one chlorine

atom

g. baking soda
h. baking powder

Check Answer: [9]

11. A sulfur atom and a sulfur molecule are not identical. What is the difference?
12. How are the molecules in oxygen gas, the molecules in hydrogen gas, and water molecules similar? How do they differ? **Check Answer:** [10]
13. We refer to astronauts in space as weightless, but not without mass. Why?
14. As we drive an automobile, we don't think about the chemicals consumed and produced. Prepare a list of the principal chemicals consumed and produced during the operation of an automobile. **Check Answer:** [11]
15. Matter is everywhere around us. Make a list by name of fifteen different kinds of matter that you encounter every day. Your list should include (and label at least one example of each) the following: a solid, a liquid, a gas, an element, a compound, a homogenous mixture, a heterogeneous mixture, and a pure substance.
16. When elemental iron corrodes it combines with oxygen in the air to ultimately form red brown iron(III) oxide which we call rust.
    a. If a shiny iron nail with an initial mass of 23.2 g is weighed after being coated in a layer of rust, would you expect the mass to have increased, decreased, or remained the same? Explain.
    b. If the mass of the iron nail increases to 24.1 g, what mass of oxygen combined with the iron? **Check Answer:** [12]
17. As stated in the text, convincing examples that demonstrate the law of conservation of matter outside of the laboratory are few and far between. Indicate whether the mass would increase, decrease, or stay the same for the following scenarios where chemical reactions take place:
    a. Exactly one pound of bread dough is placed in a baking tin. The dough is cooked in an oven at 350 °F releasing a wonderful aroma of freshly baked bread during the cooking process. Is the mass of the baked loaf less than, greater than, or the same as the one pound of original dough? Explain.
    b. When magnesium burns in air a white flaky ash of magnesium oxide is produced. Is the mass of magnesium oxide less than, greater than, or the same as the original piece of magnesium? Explain.
    c. Antoine Lavoisier, the French scientist credited with first stating the law of conservation of matter, heated a mixture of tin and air in a sealed flask to produce tin oxide. Did the mass of the sealed flask and contents decrease, increase, or remain the same after the heating?
18. Yeast converts glucose to ethanol and carbon dioxide during anaerobic fermentation as depicted in the simple chemical equation here:

$$\text{glucose} \rightarrow \text{ethanol} + \text{carbon dioxide}$$

a. If 200.0 g of glucose is fully converted, what will be the total mass of ethanol and carbon dioxide produced?

b. If the fermentation is carried out in an open container, would you expect the mass of the container and contents after fermentation to be less than, greater than, or the same as the mass of the container and contents before fermentation? Explain.

c. If 97.7 g of carbon dioxide is produced, what mass of ethanol is produced?
Check Answer: [13]

Attributions & References

Except where otherwise noted, this page is adapted by JR van Haarlem from "1.1 Chemistry in Context (https://boisestate.pressbooks.pub/chemistry/chapter/1-1-chemistry-in-context/)" and "1.2 Phases and Classification of Matter" In *General Chemistry 1 & 2* by Rice University, a derivative of *Chemistry (Open Stax)* by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson and is licensed under CC BY 4.0. Access for free at *Chemistry (OpenStax) (https://openstax.org/books/chemistry/pages/1-introduction)* / Summary and exercises from the two sections combined into review for our version.

Notes

1. Place a glass of water outside. It will freeze if the temperature is below 0 °C.
2. (a) law (states a consistently observed phenomenon, can be used for prediction); (b) theory (a widely accepted explanation of the behaviour of matter); (c) hypothesis (a tentative explanation, can be investigated by experimentation)
3. (a) symbolic, microscopic; (b) macroscopic; (c) symbolic, macroscopic; (d) microscopic
4. Macroscopic. The heat required is determined from macroscopic properties.
5. Liquids can change their shape (flow); solids can't. Gases can undergo large volume changes as pressure changes; liquids do not. Gases flow and change volume; solids do not.
6. The mixture can have a variety of compositions; a pure substance has a definite composition. Both have the same composition from point to point.
7. Molecules of elements contain only one type of atom; molecules of compounds contain two or more types of atoms. They are similar in that both are comprised of two or more atoms chemically bonded together.
8. Answers will vary. Sample answer: Gatorade contains water, sugar, dextrose, citric acid, salt, sodium chloride, monopotassium phosphate, and sucrose acetate isobutyrate.
9. (a) element; (b) element; (c) compound; (d) mixture, (e) compound; (f) compound; (g) compound; (h) mixture
10. In each case, a molecule consists of two or more combined atoms. They differ in that the types of atoms change from one substance to the next.
11. Gasoline (a mixture of compounds), oxygen, and to a lesser extent, nitrogen are consumed. Carbon dioxide and water are the principal products. Carbon monoxide and nitrogen oxides are produced in lesser amounts.

12. (a) Increased as it would have combined with oxygen in the air thus increasing the amount of matter and therefore the mass. (b) 0.9 g
13. (a) 200.0 g; (b) The mass of the container and contents would decrease as carbon dioxide is a gaseous product and would leave the container. (c) 102.3 g