2.2 The Classification of Matter

Warm Up

Most sentences or paragraphs in your textbooks could be classified as a definition, a description, an explanation, a comparison, a sequence, an example, or a classification.

1. Give an example of a sport. ______________________
2. Name a class of sports. ______________________
3. What is the difference between an example of something and a class of something?

____

Classifying Matter

We currently classify everything in the physical world as either a form of energy or a form of matter. Early chemists failed to distinguish between forms of energy and forms of matter. They identified light, heat, electricity, and magnetism as substances. Any solid, liquid, or gas is a form of matter. Matter can be further classified as shown in Figure 2.1.1.

Recall from section 2.1 that there are different types of definitions that describe concepts. An operational definition is more descriptive, providing an operation that helps us classify things as belonging or not belonging to the defined group. Conceptual definitions explain what operational definitions describe. Table 2.2.1 shows operational and conceptual definitions that distinguish between a pure substance and a mixture.

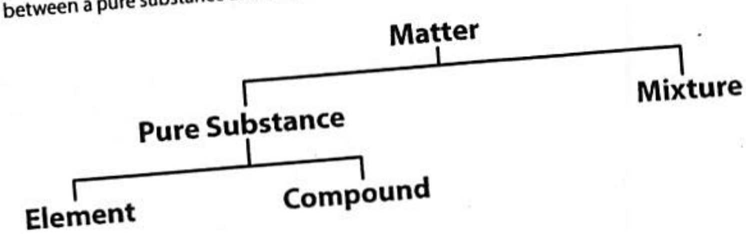

Figure 2.2.1 *Classification of matter*

Table 2.2.1 *Distinguishing Between a Pure Substance and a Mixture*

Material	Operational Definition	Conceptual Definition
pure substance	• all samples have the same proportions of components • a material with only one set of properties	• a material with atoms that are chemically combined in a fixed ratio • a material which in the solid phase has only one pattern and/or grouping of atoms throughout
mixture	• a material with components that retain their own individual identities and can thus be separated • the same components may be mixed in different proportions	• a material composed of more than one substance
element	• a pure substance that cannot be decomposed	• a pure substance composed of only one type of atom
compound	• a pure substance that can be decomposed	• a pure substance composed of more than one type of atom

The particles that make up materials are also forms of matter. Chemists refer to all the particles of matter collectively as **chemical species**. Just as materials are classified, so are chemical species. Chemical species can be classified as neutral atoms, molecules, or ions. These in turn can be further classified as types of atoms, molecules, and ions. Atoms are composed of particles that can be classified as well. The initial classification of chemical species will be discussed later in this section and the rest will be left to later sections and later courses.

...nce and *element* in a sentence that describes how the two terms are related.

____

...ance and *mixture* in a sentence that describes how the two terms are related.

____

...n element, a compound, and a mixture.

____

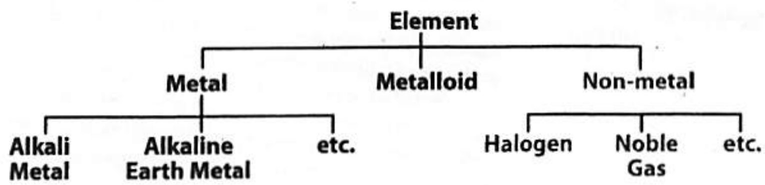

Figure 2.2.2 *Classification of elements*

The elements are further classified as metals, non-metals, and metalloids (Figure 2.2.2). About 80% of the elements are metals. The metals are separated from the non-metals on the periodic table of the elements by a staircase beginning between boron and aluminum as shown in Figure 2.2.3. The elements shaded in grey are generally considered to be metalloids because they are intermediate in properties between the metals and the non-metals. Hydrogen also has properties that are in-between those of the metals and the non-metals. Although it has some chemical properties of metals, it has more in common with non-metals and is classified as a non-metal for most purposes. Hydrogen is such a unique element that it is usually considered to be in a group of its own.

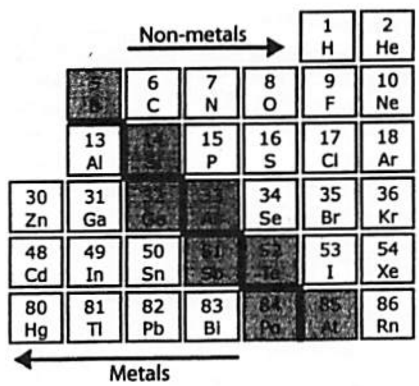

Figure 2.2.3 *The location of metals, non-metals, and metalloids in the periodic table of the elements*

Metals are good conductors of both heat and electricity. They are also malleable (can be pounded into thin sheets), ductile (can be drawn into wires), and lustrous. Many people have the misconception that metals are hard. It is actually **alloys**, mixtures containing metals, which are hard. Metal oxides react with water to form bases (hydroxides). For example:

$Na_2O + H_2O \rightarrow 2\ NaOH$

Non-metals are poor conductors of both heat and electricity. Many are gases at room temperature but in the solid phase their crystals are brittle and shatter easily. Non-metal oxides react with water to form acids. For example:

$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$ (carbonic acid)

An element is described as being more or less metallic according to the extent that it possesses these properties. Moving up and to the right in the periodic table, there is a general trend toward decreasing metallic character from one element to the next. As a consequence, there is no sharp demarcation between the metals and non-metals. Instead, there is a group of elements called metalloids that exhibit some metallic properties (although weakly) and some non-metallic properties. For example, silicon is a semiconductor meaning that it conducts electricity but poorly. Some elements have different **allotropes** meaning different groupings or arrangements of the same atoms. Some elements bordering on the metalloids have one allotrope that could be considered a metalloid and another or others that are metallic or non-metallic. For example, one allotrope of carbon called diamond is non-metallic whereas another allotrope called graphite is semi-metallic.

Both the metals and the non-metals are further classified according to more selective criteria regarding their chemical and physical properties. These different groups are easily identified and associated with a column or columns in the periodic table. For example, the elements in the first column of the periodic table are called the alkali metals.

Compounds

A compound word is one word that is made from more than one word, e.g. daycare. A compound of matter is a pure substance composed of more than one type of atom. A compound can be decompounded (we say decomposed). Decomposition is a type of chemical reaction in which a single compound reacts to produce two or more new substances. The process requires assemblages of chemically combined atoms to be disassembled and then reassembled in a different manner. Specifically, they reassemble into two or more new groupings or patterns of the atoms. For example:

$2NaCl \rightarrow 2Na + Cl_2$
$K_2CO_3 \rightarrow K_2O + CO_2$
$2H_2O \rightarrow 2H_2 + O_2$

Compounds are classified in several ways. A few of the more common ways in which a compound can be classified are as an organic or inorganic compound, as a molecular or an ionic compound, as an electrolyte or a non-electrolyte, and as a binary or non-binary compound. Some compounds are also classified as acids, bases, or salts.

Organic Compounds versus Inorganic Compounds

An **organic compound** is any compound that has carbon and hydrogen atoms. It may have other types of atoms as well. All other compounds are inorganic, meaning not organic. Organic chemistry is essentially the chemistry of carbon compounds, and inorganic chemistry is the chemistry of all the other elements' compounds. This must surely seem like an unbalanced division of the science. However, because of carbon's unique ability to form extended chain structures, there are countless billions of carbon compounds, while there are less than a thousand inorganic compounds. Living things contain many inorganic compounds but for the most part they are built out of organic compounds. Organic compounds will be covered in chapter 8.

Binary Compounds versus Non-binary Compounds

A **binary compound** is composed of only two elements. Hydrocarbons (compounds consisting of only carbon and hydrogen atoms) are thus binary compounds whereas carbohydrates are non-binary compounds because they contain carbon, hydrogen, and oxygen atoms.

Ionic Compounds versus Molecular Compounds

An **ion** is a charged atom or group of atoms. Because ions are more stable than their corresponding neutral atoms, the atoms of many elements exist almost exclusively in nature as ions. **Ionic compounds** consist of positively and negatively charged ions held together by their opposite electrical charges into long range, symmetrical packing arrangements called **ionic crystal lattices** (Figure 2.2.4). The bond or attraction between oppositely charged ions is appropriately called an **ionic bond**.

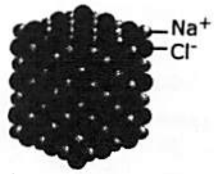

Figure 2.2.4 *An ionic crystal lattice*

Figure 2.2.5 *A molecular compound*

Non-metal atoms can also become more stable by sharing valence (outer) electrons with each other. A shared pair of valence electrons that holds two atoms together is appropriately called a **covalent bond.** A neutral group of covalently bonded atoms is called a **molecule** and compounds consisting of molecules are called **molecular compounds.**

Non-metals form molecular compounds with other non-metals but form ionic compounds with metals.

Any compound containing a metal is an ionic compound.

Any compound containing only non-metals is a molecular compound, except compounds containing the ammonium ion (NH_4^+) which are ionic.

Sample Problem — Classifying a Compound as Ionic or Molecular

State whether each of the following is an ionic compound or a molecular compound:

(a) NaCl (b) $Cu(NO_3)_2$ (c) P_2O_5

What to Think about	How to Do It
If the compound contains a metal or the ammonium ion then it is ionic, otherwise it is molecular.	
(a) Na is a metal	(a) NaCl is an ionic compound.
(b) Cu is a metal	(b) $Cu(NO_3)_2$ is an ionic compound.
(c) P and O are both non-metals	(c) P_2O_5 is a molecular compound.

Practice Problems — Classifying a Compound as Ionic or Molecular

1. State whether each of the following is an ionic compound or a molecular compound:

(a) CO_2 ______________ (d) $Mg_3(PO_4)_2$ ______________

(b) CaF_2 ______________ (e) $Li_2Cr_2O_7$ ______________

(c) C_3H_8 ______________ (f) NH_4Cl ______________

Acids versus Bases versus Salts

Some compounds are also classified as acids, bases, or salts. There are both organic and inorganic acids, bases, and salts.

From its formula, an **acid** appears to be a compound having one or more H^+ ions bonded to an anion (e.g., HCl, H_2SO_4, H_3PO_4). In reality, acids are a special type of molecular compound that can be induced to form these ions. This is a complex affair you'll learn about in Chemistry 12.

Chemists actually have three different conceptual definitions of acids and bases, which they use interchangeably depending on the circumstance. The most common definition of a **base** is a hydroxide. This is any compound containing the hydroxide (OH^-) ion. Examples include $NaOH$, $Ca(OH)_2$, and $Al(OH)_3$.

A **salt** is any ionic compound other than a hydroxide. A salt is thus one type of ionic compound, the only other type being a base. Acids and bases react to produce a salt and water. This type of reaction is called a neutralization reaction. For example:

$$HCl + NaOH \rightarrow NaCl + H_2O$$

Quick Check

Circle the correct response.

1. Salts are (ionic or molecular).
2. $Mg(OH)_2$ is a(n) (acid, base, or salt).
3. AgBr is a(n) (acid, base, or salt).

Classification of Mixtures

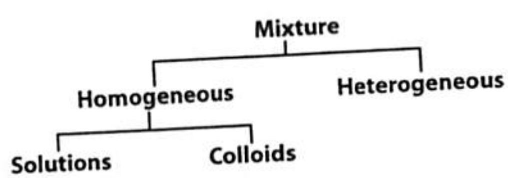

Figure 2.2.6 *Classification of mixtures*

Table 2.2.2 *Distinguishing Between Homogeneous and Heterogeneous Mixtures*

Material	Operational Definition	Conceptual Definition
Homogeneous mixture	a mixture that appears the same throughout	The individual particles are smaller than 1 μm (a micrometre).
Heterogeneous mixture	a mixture that doesn't appear the same throughout	At least some particles are larger than 1 μm (a micrometre).

There are many instances where the scientific meaning of a word conflicts with its general usage or even its literal meaning. As an example, the components of a material do not need to be mixed for it to be a chemical mixture. Any material having atoms that are not chemically combined in a fixed ratio is a chemical mixture and would be so even if those atoms were organized in a uniform pattern. Conversely, any material having atoms that have been chemically forced into a fixed ratio is a pure substance and would be so even if those atoms were mixed. As an example, molten (melted) sodium chloride is a pure substance. Even though its ions are mixed, they coexist in a chemically determined ratio and cannot be separated.

The difference between the classes of mixtures is really a matter of degree, rather than of kind. It can't be overemphasized that there is no sharp demarcation between the classes of mixtures but rather a general trend from smaller particles to larger particles in moving from solutions to colloids to heterogeneous mixtures.

A **homogeneous mixture** is one that appears the same throughout. A homogeneous mixture is not actually perfectly homogeneous. Atoms are not homogeneous and therefore nothing composed of atoms is truly homogeneous. A homogeneous mixture doesn't even have the same proportions of atoms throughout because every sample has a slightly different composition due to the random motion and mixing of the particles. It can be difficult to distinguish between a homogeneous mixture and a compound since both appear to be the same throughout. Whether or not the constituents of air for example are chemically combined was still a point of contention in the early 1800s. The French chemists, Proust and Berthollet, had an ongoing debate over this issue. What Berthollet perceived as a compound that could vary in proportion, Proust perceived as a physical mixture. As a prerequisite to his development of atomic theory, John Dalton resolved the issue in 1808 by simply declaring that any process in which elements do not combine in a fixed proportion is not a chemical process. Thus any material having constituents that do not combine in a fixed proportion became a mixture. This scheme proved to be so fruitful in advancing chemistry that it quickly found general acceptance.

Solutions

A **solution** is a type of homogeneous mixture in which the constituent chemical species do not aggregate to form any particles greater than 1 nm (nanometre). A **solute** is a minor component of the mixture, generally what has been dissolved. The **solvent** is the major component of the mixture, generally what the solute was dissolved in. Many chemicals are in **aqueous** solution (dissolved in water). Our lakes and rivers, our oceans, our drinks, our bodily fluids, and the bottles on the shelves of your laboratory are all aqueous solutions. Chemists denote that a chemical is in aqueous solution with "*aq*" in brackets after the formula (e.g., NaCl(*aq*)).

Solutions can be produced from materials in different phases (e.g., a solid can dissolve in a liquid). Regardless of the constituents' phases when undissolved, a solution is a single phase, usually that of the solvent. If the solvent is a solid, it is melted to allow for mixing and then cooled to solidify the mixture.

Table 2.2.3 *Examples of Solutions*

	Solute		
Solvent	**Solid**	**Liquid**	**Gas**
Solid	steel, bronze	mercury in gold	hydrogen in palladium
Liquid	salt water	gasoline	oxygen in water
Gas	–	–	air

Colloids

A colloidal system consists of particles between 1 nm and 1 μm dispersed throughout a continuous medium (Table 2.2.5). The particles of the dispersed phase are large molecules (macromolecules) or aggregates of molecules that are invisible to the naked eye. Unlike a solution, the colloid particles can be in a different phase than the dispersion medium in which they are suspended. Any mixture of solid particles in a liquid, regardless of how small the solid particles are, is a colloid or a mechanical mixture.

If a liquid is translucent (cloudy) then it is a colloid or a heterogeneous mixture. A bright beam of light is not visible when shone through a solution because the particles of a solution are too small to reflect or scatter the light. A bright beam of light is visible however when shone through a colloid because the particles of the dispersed phase are large enough to scatter and reflect the light. This is called the **Tyndall effect**.

Table 2.2.4 *Names and (Examples) of Colloids*

Medium	Dispersed Phase: Solid (grains)	Dispersed Phase: Liquid (droplets)	Dispersed Phase: Gas (bubbles)
Solid	solid sol (some stained glass)	gel (jelly, butter)	solid foam (styrofoam)
Liquid	sol (blood)	emulsion (milk, mayonnaise)	foam (whipped cream)
Gas	solid aerosol (smoke)	liquid aerosol (fog)	–

Heterogeneous Mixtures

If one or more of the components of a mixture is visible then it is a **heterogeneous mixture**. The term, "mechanical mixture" is often misused as an intended synonym for "heterogeneous mixture." A mechanical mixture is a mixture of components that can be separated by mechanical means, i.e. by picking, sifting, shaking, spinning, pouring, skimming, etc. This definition includes at least some mixtures of every class. For example, the components of colloids can be separated by mechanical means such as centrifugation (spinning) and ultra-filtration. Even isotopes of the same element (atoms of the same element with different masses) can be separated by centrifugation. If the heterogeneous mixture has a dispersed phase and a continuous medium then, it is a **coarse suspension** or just a suspension.

Colloids are distinguished from suspensions by their longevity or stability. Colloids remain suspended indefinitely but the larger mass of the suspended particles in suspensions causes them to settle out or **sediment** upon standing. The dispersed phase in a suspension is usually a solid. Common examples of suspensions include silt in water, dust in air, and paint (pigments in a solvent). The component particles are all visible solid particles in some heterogeneous mixtures such as gravel.

Table 2.2.5 provides operational and conceptual definitions of solutions, colloids, and suspensions.

Table 2.2.5 *Distinguishing Solutions, Colloids, and Suspensions*

Type of Mixture	Operational Definition*: Tyndall Effect	Operational Definition*: Sediments if left undisturbed	Operational Definition*: Separates by Centrifugation	Conceptual Definition**
Solution	no	no	no	All particles are < 1 nm.
Colloid	yes	no	yes	Dispersed particles are between 1 nm and 1 um. Particles comprising the medium are < 1 nm.
Suspension	yes	yes	yes	Dispersed particles are > 1 μm.

* The operational definitions only provide methods of differentiating mixtures that have a liquid continuous medium.

** The sizes cited for the particles are only rough guidelines, not steadfast rules.

Quick Check

1. What is a homogeneous mixture?

2. What are the two components of a solution called?

3. What are the two components of a colloid called?

2.2 Review Questions

1. Name an element, a compound, and a mixture found in your home.

2. Is it easier to prove that an unknown substance is an element or a compound? Explain.

3. Elements, compounds and mixtures are each classified into types of elements, compounds, and mixtures. Use "properties" or "composition" to correctly complete each of the following sentences:
   (a) Elements are classified on the basis of their ________________.
   (b) Compounds are classified on the basis of their ________________.
   (c) Mixtures are classified on the basis of their ________________.

4. Using only white circles (○) and black circles (●) to represent different types of atoms, draw an element, a molecular compou an ionic compound, a mixture of elements, and a mixture of compounds using at least 10 circles in each drawing.

5. Classify each of the following as an element (E), a compound (C), or a mixture (M).
   (a) potassium fluoride
   (b) eggnog
   (c) can be decomposed
   (d) can vary in proportions
   (e) carbon
   (f) seawater
   (g) substance containing only one type of atom
   (h) contains more than one substance

6. Classify each of the following elements as a metal, metalloid, or a non-metal.
   (a) germanium (b) calcium (c) iodine (d) xenon

7. Give four examples of physical properties of metals.

the following table by classifying each of the compounds.

	Organic or Inorganic	Binary or Non-Binary	Molecular or Ionic	Acid, Base, Salt or None of these
H_2OH				
O_3				
O_4				
$(NO_3)_2$				
O_2				
$(OH)_3$				

ppose that chemists used nanotechnology to produce a material with two different types of metal atoms organized into ternating rows. Would this material be a substance or would it be a mixture? Explain.

Why is no material truly homogeneous at the atomic level?

11. Is a mixture of O_2 and O_3 (two different allotropes of the element oxygen) a chemical mixture? Explain.

12. Identify each of the following species as a neutral atom, an ion, or a molecule.

(a) N_2 (b) O (c) NO_2^- (d) H (e) NH_3 (f) K^+

13. Complete the following table by checking (✓) the type(s) of mixture each statement describes.

	Solution	Colloid	Heterogeneous Mixture
All particles are less than 1 nm in size			
Gravel			
Does not appear the same throughout			
Forms a sediment if left undisturbed			
Has a solute and a solvent			
Milk			
Exhibits the Tyndall effect			
Homogeneous mixture			
Coarse suspension			
Orange juice with pulp			
May be separated by centrifugation			

14. To diagnose an ulcer, a doctor may have the patient drink a suspension of barium sulphate which coats the patient's gastrointestinal tract allowing it to be imaged by X-rays. What is the difference between a suspension and a colloid?

15. Is dust a colloid or is it a suspension? Explain.

16. Correct each of the following sentences by replacing the underlined word.

(a) Salt water is a denser <u>substance</u> than fresh water.

(b) The colloid particles were <u>dissolved</u> in water.