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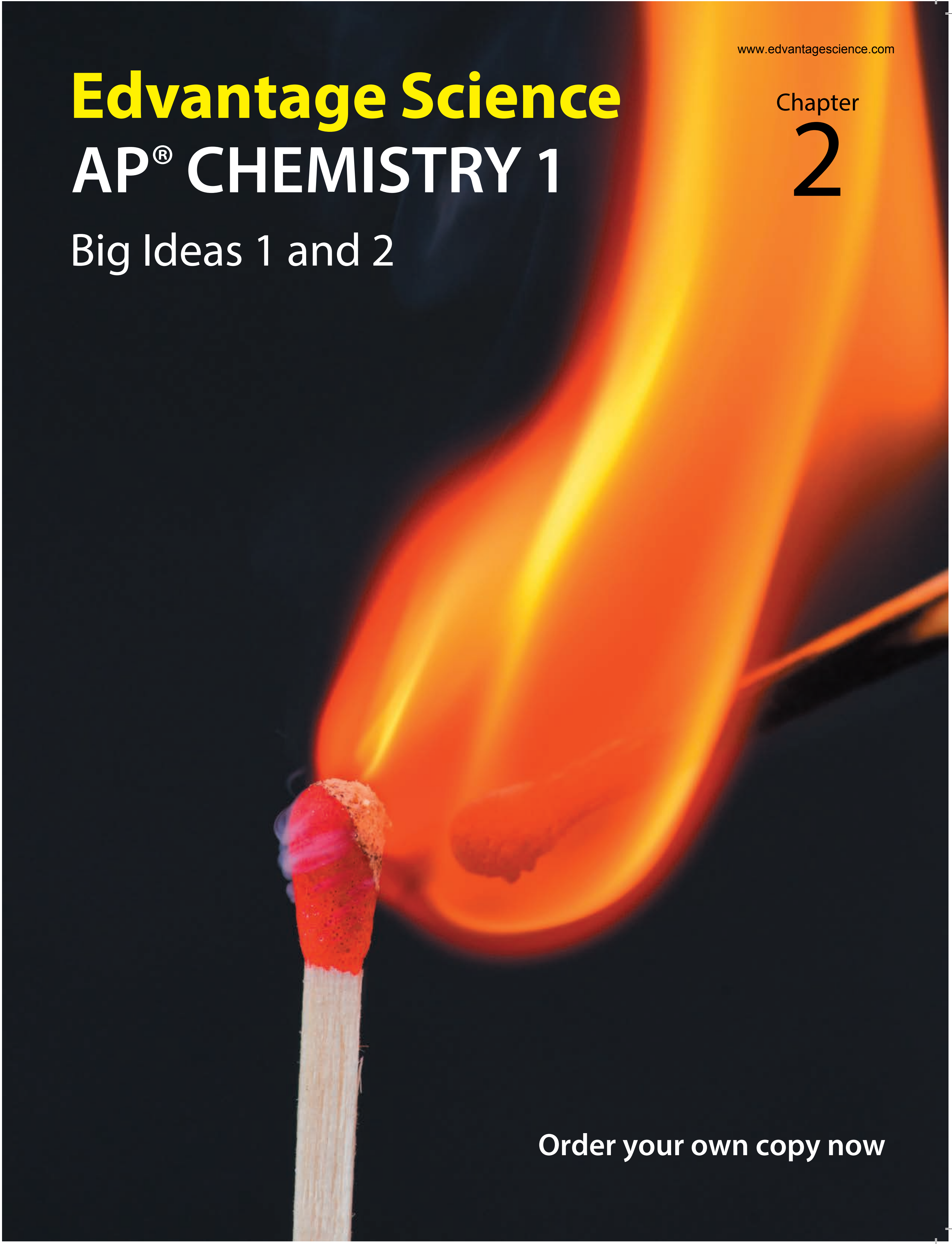
AP® CHEMISTRY 1

Big Ideas 1 and 2

Chapter 2



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AP Chemistry 1

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2 The Nature of Matter

This chapter focuses on the following AP Big Ideas from the College Board:

Big Idea 1: The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangements of atoms. These atoms retain their identify in chemical reactions.
Big Idea 2: Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.

By the end of this chapter, you should be able to do the following:

- Relate the observable properties and characteristics of elements, compounds, and mixtures to the concept of atoms and molecules
- Write the names and formulae for ionic and covalent compounds, given appropriate charts or data tables
- Describe the characteristics of matter
- Differentiate between physical and chemical changes
- Select an appropriate way of separating the components of a mixture

By the end of this chapter, you should know the meaning of these **key terms**:

- acid
- atom
- base
- boiling point
- chemical change
- chemical property
- chemical reactivity
- chromatography
- compound
- distillation
- element
- evaporation
- filtration
- freezing point
- gas
- ion charge
- ion/ionic
- kinetic molecular theory
- liquid
- mass
- matter
- melting point
- metal
- mixture
- molecular formula
- molecule
- monatomic ions
- non-metal
- physical change
- physical property
- pure substance
- salt
- solid

Your cellphone, your food, your books, your school, you — everything is made up of matter. How matter can be combined into compounds that form all the different parts of your cellphone depends on physical and chemical properties and physical and chemical changes. In this chapter, you'll learn about the nature of matter and its properties.

2.1 Properties of Matter

Warm Up

1. List four properties of snow.

   ______________________ ______________________

   ______________________ ______________________

2. Name or describe two different types of snow.

   ______________________ ______________________

3. Suggest why there are different types of snow. Hint: Think about why snow can have different properties.

   ____

Classifying Material Properties

Chemistry is the science concerned with the properties, composition, and behaviour of matter. **Matter** is anything that has mass and occupies space. **Mass** is the amount of matter contained in a thing. Usually the mass of common things is measured in grams (g) or kilograms (kg).

Properties are the qualities of a thing, especially those qualities common to a group of things. The relationship between matter and its properties is a very important aspect of chemistry. Properties are classified as being extensive or intensive.

Extensive properties are qualities that are or depend on the amount of the material. Examples of extensive properties are mass, volume, the electrical resistance of a copper wire (which depends on its diameter and length), and the flexibility of a metal sheet (which depends on its thickness).

Intensive properties are qualities that do not depend on the amount of the material. Melting point and density are examples of intensive properties. The gold in Figure 2.1.1 has a melting point of 1064°C and a density of 19.3 g/cm^3. Put another way, gold's melting point and density are the same for all samples of gold. These properties can therefore be used to identify that material. Other intensive properties such as temperature, concentration, and tension differ from sample to sample of the same material.

Figure 2.1.1 *Gold's melting point and density are two intensive properties that can be used to identify samples.*

Every material possesses a unique set of intensive properties that can be used to identify it.

You may be familiar from previous science courses with the alchemist's four elements of matter: earth, air, fire, and water. These elements were not equivalent to matter in modern chemistry. For the alchemists, earth, air, fire, and water represented four fundamental properties of matter. Alchemists believed that these properties existed independent of matter and could be added to matter or removed from matter to transform it. In other words, the alchemists had it backwards: they believed that a material depends on its properties rather that the properties depending on the material.

Physical Properties versus Chemical Properties

The properties of matter are also classified as being either physical properties or chemical properties. **Physical properties** describe physical changes, which are changes of state or form. Physical properties also describe the physical characteristics of a material. **Chemical properties** describe chemical changes. Chemical changes are those in which a new substance(s) or species is formed (Figure 2.1.2). Chemical properties also describe the tendency of a chemical to react. Chemical properties describe relationships or interactions between different forms of matter. They include a chemical's stability, its reactivity with other chemicals, its toxicity, and its flammability.

Most physical properties describe relationships or interactions between matter and energy. A material's electrical properties, magnetic properties, thermal properties, optical properties, acoustical properties, radiological properties, and mechanical properties (various indicators of strength) are all classified as physical properties. For example, a material can be classified as opaque, transparent, or translucent by how it interacts with light. Other physical properties you may have learned about include temperature, density, viscosity, and surface tension. In this section we'll focus on thermal properties (those related to thermal energy and heat).

Physical properties describe physical changes. Chemical properties describe interactions between different forms of matter.

Figure 2.1.2 *The wood that is burning to heat the pot is undergoing chemical changes. The boiling soup in the pot is undergoing a physical change.*

Particle Relationships

Matter is composed of basic units or particles that move independently. In some forms of matter, these particles are atoms while in others these particles are groups of atoms called molecules or polyatomic ions. Physical changes involve the rearrangement of a material's own particles. Chemical changes involve the reorganization of two or more substances' atoms in relation to each other.

Physical properties depend solely on the relationships between the material's own particles. Chemical properties depend on the difference between the atoms' current relationships with other atoms and new relationships with different atoms. For molecular substances, physical changes alter intermolecular relationships (those between the molecules) while chemical changes alter intramolecular relationships (those within molecules). Physical changes generally involve less energy than chemical changes. Changing the positions of molecules relative to one another involves less energy than changing the positions of atoms within molecules. Nature forms hierarchies or levels of organization. Subatomic particles (protons, neutrons and electrons) form atoms which in turn may form molecules which in turn form materials.

Quick Check

1. What is matter?

   ____

2. What is a property?

   ____

3. What is an extensive property?

   ____

4. What is a chemical property?

   ____

Kinetic Energy

Kinetic energy is any form of energy that cannot be stored. The greater an object's speed and mass, the greater its kinetic energy. The particles of matter possess a type of kinetic energy called **mechanical energy** because of their continuous motion. Independent atoms and molecules have three forms of mechanical energy or types of motion: translational (movement from place to place), rotational (movement about an axis), and vibrational (a repetitive "back and forth" motion).

Thermal Energy, Temperature, and Heat

Thermal energy is the total mechanical energy of an object's or a material's particles. It is an extensive property as it depends on the size of the object or the amount of the material. Within any substance there is a "normal" distribution of kinetic energy among its particles due to their random collisions. This is very similar to the "normal" distribution of marks among the members of a class. **Temperature** is the average mechanical energy of the particles that compose a material and is therefore an intensive property. An increase in a material's temperature indicates that the average speed of its particles has increased.

A bathtub full of cold water has more thermal energy than a cup of boiling water because the bathtub contains so many more molecules even though they are moving more slowly. Consider the following analogy. Which contains more money, a bathtub full of $5 bills or a cup full of $20 bills? Despite the greater denomination of the bills in the cup, the bathtub still contains more money because it contains so many more bills.

A physical property is largely defined by the instrument used to measure it. Thermometers are used to measure temperature. There are many kinds of thermometers. All thermometers work by correlating some other property of a material to its temperature. Some electronic thermometers contain a small semiconductor, the electric resistance of which correlates to its temperature. Some medical thermometers contain liquid crystals that change colour with varying temperature. Some thermometers correlate the temperature of a material to the infrared radiation it emits. Scientists can infer the temperature of luminous materials from the visible light the materials emit. The standard laboratory thermometer uses the expansion of a column of liquid, usually tinted alcohol or mercury, as an index of its temperature. As a natural consequence of moving faster, the thermometer's particles (atoms or molecules) strike each other harder and spread farther from each other. The expansion of the thermometer fluid is proportional to the average kinetic energy of its particles.

Figure 2.1.3 *Some different types of thermometers*

Most thermometers, including the standard laboratory thermometer, actually display the temperature of the thermometer itself rather than that of the fluid it is immersed in. The scientific definition of **heat** is the energy transferred from one body to another because of a difference in temperature. An object immersed in a fluid will transfer or exchange thermal energy with the fluid until both arrive at the same temperature thus the thermometer ultimately becomes the same temperature as the fluid it is immersed in. This however introduces a "Catch-22" into measuring temperature: the thermometer can't measure the temperature without altering it. When a cold thermometer is placed into hot water, the thermometer heats up and the water cools down until they are at the same temperature. For this reason, chemists include thermometers in their apparatus at the beginning of experiments so they will not have to introduce them into the fluid later.

Quick Check

1. What is temperature? ____

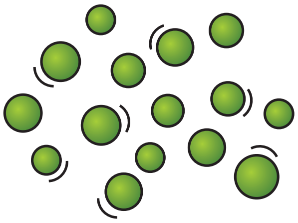
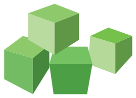
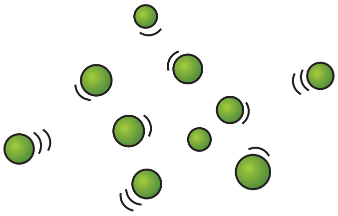
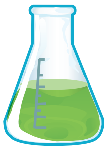
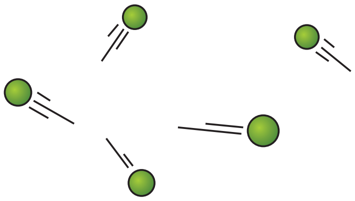
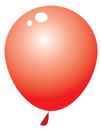
2. What is thermal energy? ____

3. What is heat? ____

The States of Matter

Under normal conditions, matter exists in three states: solid, liquid, or gas. The three states can be defined using both an operational definition and a conceptual definition as in Table 2.1.1. An **operational definition** consists of observable characteristics that help us classify things as belonging or not belonging to the defined group. **Conceptual definitions** explain what operational definitions describe.

Table 2.1.1 *The States of Matter*

State	Operational Definition		Conceptual Definition
	Shape	Volume	
solid	fixed	fixed	Each particle bounces around pushing the ones surrounding it outward. The particles have not spread far enough apart for any particle to fit through a gap between the particles surrounding it so the structure remains intact. 
			
liquid	adopts its container's	fixed	The particles are travelling faster and striking each other harder. As a result they have spread apart to an extent where they can slip by one another. 
			
gas	adopts its container's	adopts its container's	The particles have been struck with enough force to escape their attractions to the other particles in the liquid. They are now either too far apart or moving too fast for their attractions to affect their movement. 
			

The Kinetic Molecular Theory

The **kinetic molecular theory** explains what happens to matter when the kinetic energy of particles changes. The key points of the kinetic molecular theory are:

1. All matter is made up of tiny particles.
2. There is empty space between particles.
3. Particles are always moving. Their freedom to move depends on whether they are in a solid, liquid, or gas, as described in Table 2.1.1 above.
4. The particles move because of energy. The amount of energy the particles have determine how fast the particles move and how much or far they move.

Figure 2.1.4 identifies the three states of matter and the terms for each phase change. These phase changes depend on temperature. The following terms describe changes from one state to another.

- **freezing:** liquid to solid
- **melting**: solid to liquid
- **evaporation** (also known as vaporization): liquid to gas
- **condensation**: gas to liquid
- **sublimation**: solid to gas
- **deposition**: gas to solid

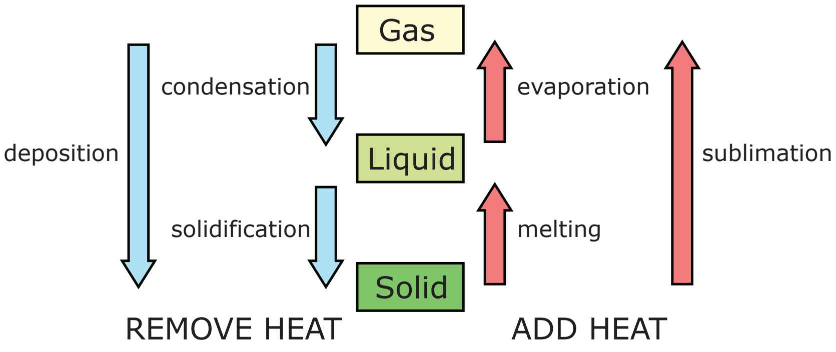


Figure 2.1.4 *Changes of state*

Quick Check

1. Explain the difference between the operational and conceptual definition of a liquid.

____

2. Describe the differences in kinetic energy between the particles in a cube of ice and a glass of water.

____

3. How does heat contribute to a phase change?

____

Some Physical Properties of Pure Substances

Melting Point

A material's **melting point** is the temperature of its solid as it changes to a liquid. Melting occurs because the independent particles (atoms, molecules, or ions) have spread far enough apart so that they can just slip through the gaps between the atoms surrounding them. The melting point of a substance depends on the strength of the attractive forces (bond strength) between its independent particles as well as the mass and symmetry of the particles. The freezing point and melting point of most substances are the same. Thus, the melting point may also be described as the temperature at which a solid can be immersed indefinitely in its own liquid because its rate of melting equals its rate of freezing.

Figure 2.1.5 *At the melting point, a substance can exist in both the solid and liquid states.*

Boiling Point

Boiling is a special case of evaporation. Any particle in the liquid state may evaporate. The puddles on your street evaporate but you've never seen a puddle boil. The gas formed by a substance that boils above room temperature is called **vapour**.

Boiling is the vigorous bubbling that occurs within the body of a liquid as it vaporizes internally. A bubble is a quantity of gas or vapour surrounded by liquid. Imagine a pot of water being heated (Figure 2.1.6). Some molecules at the bottom of the pot are receiving so much heat and consequently moving so fast that they bounce around pushing other water molecules away from them. This produces a bubble. The vapour pressure inside the bubble acts to inflate the bubble while the weight of the water and air above the bubble creates an opposing pressure that acts to collapse the bubble. As the bubble rises, the water vapour molecules transfer energy to the water molecules around the bubble. This causes the vapour molecules to lose energy so the bubble shrinks and collapses before it reaches the surface.

Figure 2.1.6 *Vigorously boiling water. The bubbles are rising to the surface without collapsing.*

The entire pot of water is not yet boiling because it has not yet reached the boiling point. This process continues, transferring energy from the bottom of the pot to the top until all of the water molecules are moving as fast as possible without entering the gas phase. Only at this point, when the bubbles rise to the surface of the water without collapsing is the entire pot of water boiling. Just before breaking through the water's surface the bubble is only opposed by the atmospheric pressure above the liquid. One definition of boiling point is the temperature at which the substance's vapour pressure (the pressure inside that bubble) equals the surrounding air pressure. The air pressure above the sample could be lowered by placing the sample in a vacuum chamber or by taking it to a higher elevation. This would lower the substance's boiling point because the bubbles would have less opposing pressure.

Boiling point is also defined as a substance's highest possible temperature in the liquid state at any given atmospheric pressure. It therefore represents the highest kinetic energy the substance's particles can possess in the liquid state. As the temperature of the water approaches 100°C, more and more of the molecules have their maximum kinetic energy in the liquid state until at 100°C all the molecules are moving at the same maximum speed in the liquid state.

Boiling point, vapour pressure, and volatility are three closely related properties that are all relevant to boiling. **Volatile** substances are substances that readily evaporate or evaporate at high rates. They have high vapour pressures and low boiling points.

Heat of Fusion (H_f)

The **heat of fusion** is the amount of heat required to melt a specified amount of a substance at its melting point. It represents the difference of potential energy between the solid and liquid states since only the substance's state, not its temperature, is changing. **Potential energy** is stored energy. Objects have stored energy by virtue of their position or shape. The heat of fusion is released when the specified quantity of the substance freezes. Heat of fusion is measured in joules per gram.

Heat of Vaporization (H_v)

The **heat of vaporization** is the amount of heat required to evaporate a specified amount of a substance at its boiling point. It represents the difference of potential energy between the liquid and gas states since only the substance's state, not its temperature, is changing. The heat of vaporization is released when the specified quantity of the substance condenses. The heat of vaporization indicates the strength of the force holding the liquid particles together in the liquid state. Heat of vaporization is measured in units such as joules per gram.

Quick Check

1. What is melting? ____

2. What is boiling? ____

3. What is the heat of fusion? ____

Reading a Heating Curve

As energy is added to a solid, the temperature changes. These changes in temperature can be illustrated in a graph called a heating curve. Figure 2.1.7 illustrates an ideal heating curve for water. Note the first plateau in the graph. As a solid melts slowly in its own liquid, the temperature of the liquid will not rise if the melting converts kinetic energy into potential energy as fast as the heat is being added. As the amount of solid decreases, it becomes less able to remove the heat as fast as it is being added. This usually causes the melting segment on the graph to curve upward on the right, rather than remaining horizontal as shown on the ideal heating curve (Figure 2.1.7). The amount of heat needed to melt the ice is the heat of fusion. Once all the ice has melted the water's temperature will begin to increase.

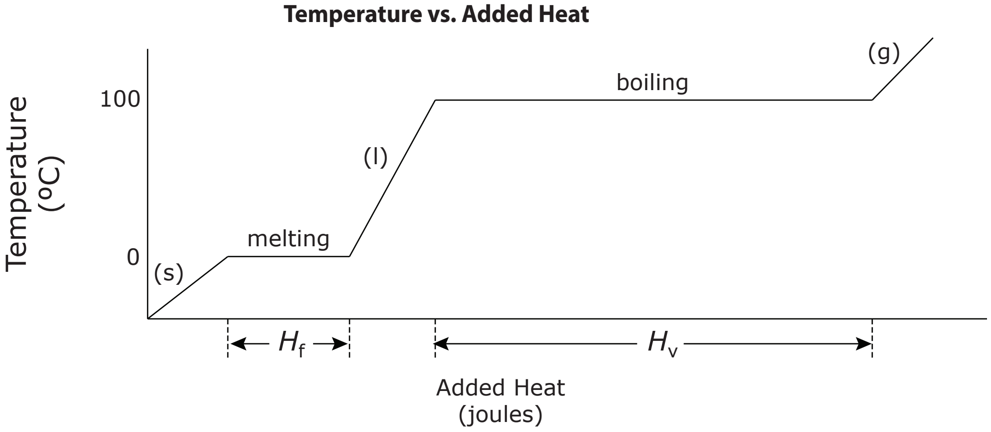


Figure 2.1.7 *Ideal heating curve of water (not to scale)*

Some Chemical Properties of Substances

Reactivity

Reactivity refers to whether a substance reacts or to its reaction rate. Both of these properties are temperature dependent but otherwise depend on different underlying factors. Reaction rates depend on the path from reactants to products, particularly which reactant bonds require breaking. Reaction rates also depend on properties such as reactant concentration. On the other hand, whether or not a reaction will occur depends only on the beginning and end states. Chemical reactions occur because the organization and potential energy of the atoms in the products are favoured over those in the reactants.

Heat of Formation

The **heat of formation** is the heat released when a substance is formed from its elements. The heat of formation is measured in joules per gram.

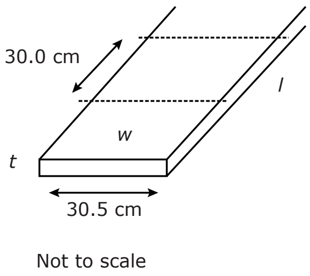
Heat of Combustion

The **heat of combustion** is the heat released when a specified amount of a substance undergoes complete combustion with oxygen. It is usually measured in units such as joules or kilojoules per gram.

Table 2.1.2 *Some Thermal Properties of Selected Substances*

Substance	Melting Point (°C)	Boiling Point (°C)	Heat of Fusion (J/g)	Heat of Vaporization (J/g)	Heat of Combustion (J/g)	Heat of Formation (J/g)
methane	–182.5	–161.6	69	511	54 000	4 679
ammonia	–77.7	–33.3	333	1 374	22 471	2 710
water	0.0	100.0	334	2 259	—	13 400
magnesium	650	1091	349	5 268	12 372	—

2.1 Activity: The Thickness of Aluminum Foil



Question

What is the thickness of a sheet of aluminum foil?

Background

The thickness of a sheet of aluminum foil is an extensive property that is difficult to measure directly with reasonable precision and accuracy. The thickness of the foil can however be derived by dividing its volume by the surface area of one side as proven below:

$$\frac{\text{volume}}{\text{surface area}} = \frac{\cancel{\text{length} \times \text{width}} \times \text{thickness}}{\cancel{\text{length} \times \text{width}}} = \text{thickness}$$

Obviously you can't calculate the volume of the sheet using the formula $V = lwt$ because you don't know the foil's thickness. You will have to calculate its volume by dividing its mass (another extensive property) by its density (an intensive property).

Procedure

1. Mark two points 30 cm apart on one edge of a piece of aluminum foil (see diagram).
2. Repeat step 1 on the parallel edge.
3. Draw a straight line between adjacent points on the opposite edges.
4. Use a razor blade or scissors to carefully cut out your marked section of foil.
5. Scrunch up your piece of foil and weigh it on a milligram scale.

Results and Discussion

Length (cm)	Width (cm)	S. Area (cm^2)	Mass (g)	Density (g/cm^3)	Volume (cm^3)	Thickness (cm)
30.0	30.5			2.702		

1. Calculate the surface area of one side of the foil (length × width). The standard width of a roll of aluminum foil is 30.5 cm, as indicated on the box.

2. Calculate the volume of the piece of foil.

$$\text{volume} = \underline{\qquad\qquad} \text{ g Al} \times \frac{1 \text{ cm}^3 \text{ Al}}{2.702 \text{ g Al}} = \underline{\qquad\qquad} \text{cm}^3$$

3. Calculate the thickness of the sheet of foil.

$$\text{thickness} = \frac{\text{volume}}{\text{surface area}} = \frac{\underline{\qquad\qquad} \text{cm}^3}{\underline{\qquad\qquad} \text{cm}^2} = \underline{\qquad\qquad\qquad} \text{ cm}$$

4. Aluminum atoms have a diameter of 0.286 nm. If aluminum atoms were stacked linearly, one on top of the other, how many atoms thick would this sheet of Al foil be?

5. This technique is remarkably reliable. Compare your results to those of the other groups.

2.1 Review Questions

1. In each pair of items below, which is a form of matter and which is a property?
   (a) vapour, vapour pressure

   (b) freezing point, solid

2. What are two properties shared by all matter?

3. How was the alchemists' view of matter and its properties different from ours today?

4. Describe three general properties that would be desirable for a material(s) being used for the outer sole of tennis shoes.

5. You sometimes choose one brand over another because it has properties that you prefer. List three properties of paper towels that might influence your choice of which brand to purchase.

6. Whether a property is intensive or extensive often depends on how it is expressed. State whether each of the following physical properties is intensive or extensive.
   (a) temperature

   (b) thermal energy

   (c) thermal expansion (the change in volume in response to a change in temperature)

   (d) coefficient of thermal expansion (the fractional change in volume per degree Celsius change in temperature)

   (e) specific heat capacity (the joules of heat required to raise 1 g of the material by 1°C)

   (f) heat capacity (the joules of heat required to raise the temperature of the object 1°C)

7. State whether each phrase refers to a physical or a chemical property.
   (a) changes of state or form

   (b) relationships or interactions between matter and energy

   (c) only evident through a chemical reaction or a lack thereof

   (d) dependent solely on the relationships between the material's own particles

   (e) relationships or interactions between different forms of matter

8. State whether each of the following properties is physical or chemical.
   (a) heat of vaporization
   (b) heat of formation
   (c) corrosion resistance
   (d) electrical resistance
   (e) flammability (how easily something will burn or ignite)
   (f) speed of sound through the material

9. Composite materials (or just composites) consist of two or more constituent materials that adhere to each other but remain separate and distinct (e.g. the materials could be layered on each other). Why do you think manufacturers sometimes use composite materials in their products?

10. What two properties of particles affect the temperature of the material they compose?

11. Density is mass per unit volume, commonly the amount of matter in one cubic centimetre of the material. What two properties of particles affect the density of the material they compose?

12. Briefly explain what causes materials to expand at the particle level when heated.

13. List the defining physical properties of each phase of matter; solids, liquids, and gases.

14. Does an individual atom or molecule have a melting point? Explain.

15. Describe what is occurring at the molecular level when a material melts.

16. Why doesn't the temperature of an ice water bath (a mixture of ice and water) increase as it absorbs heat from a classroom?

17. Under what condition do all the particles of a liquid have the same kinetic energy?

18. Provide an operational (what to look for) and a conceptual (an explanation) definition of boiling point.

19. (a) Which is greater, a substance's heat of fusion or its heat of vaporization?

    (b) Explain in terms of relationships why this would be expected.

20. (a) Which is greater, a substance's heat of vaporization or its heat of combustion?

    (b) Explain in terms of relationships why this would be expected.

21. Sensorial properties describe our senses of a material. Rather than being the properties of something, they are actually the properties of our interaction with that thing. Are sensorial properties such as taste and odour physical properties or are they chemical properties?

22. Label and describe briefly a physical change and a chemical change on the drawing of the lit candle.

23. Students change classes at designated times throughout the day in most secondary schools. How is this event like a chemical change or reaction?

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.

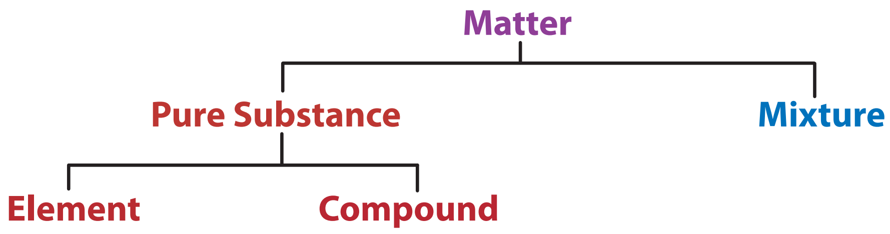


Figure 2.2.1 *Classification of matter*

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.

Quick Check

1. Use the words, *substance* and *element* in a sentence that describes how the two terms are related.

   ____

2. Use the words, *substance* and *mixture* in a sentence that describes how the two terms are related.

   ____

3. Give an example of an element, a compound, and a mixture.

   ____

Elements

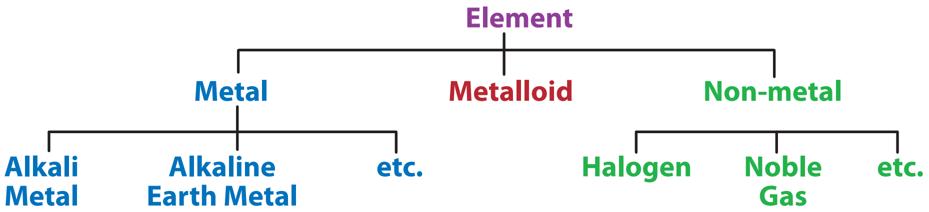


Figure 2.2.2 *Classification of elements*

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.

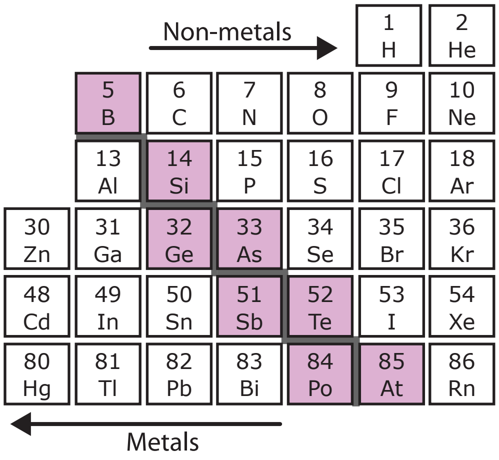


Figure 2.2.3 *The location of metals, non-metals, and metalloids in the periodic table of the elements*

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**.

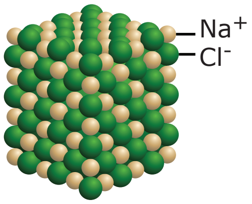


Figure 2.2.4 *An ionic crystal lattice*

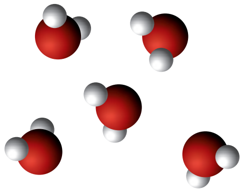


Figure 2.2.5 *A molecular compound*

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 ______________________

(b) CaF_2 ______________________

(c) C_3H_8 ______________________

(d) $Mg_3(PO_4)_2$ ______________________

(e) $Li_2Cr_2O_7$ ______________________

(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

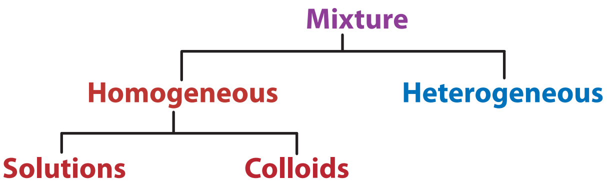


Figure 2.2.6 *Classification of mixtures*

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*

	Dispersed Phase		
Medium	**Solid** (grains)	**Liquid** (droplets)	**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***			**Conceptual Definition****
	Tyndall Effect	**Sediments if left undisturbed**	**Separates by Centrifugation**	
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?

   ____

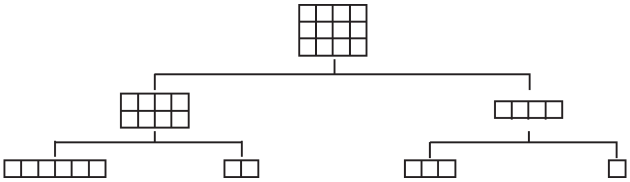
3. What are the two components of a colloid called?

   ____

2.2 Activity: Classifying Chemical Glassware

Question

Can things be classified according to a variety of schemes?



Background

In section 1.1 you were asked to classify items of safety equipment. People have a compulsion to mentally organize the world around them. Knowledge is essentially recognizing relationships. Organizing our world helps us to cope with it and allows us to think about it. The way we conceptualize or organize the world reflects both the world itself and the ways we perceive it. You are classifying something every time you call something by a name that isn't specific to that individual thing.

Procedure

1. Your teacher will display a variety of chemical glassware.
2. Divide the items into two groups based on any criterion you choose.
3. Subdivide the items in each of the two groups into two smaller groups again based on any criteria you choose.

Results and Discussion

1. Display your groupings on a piece of poster paper using a classification chart like that shown at the top of the page. Include your criteria on the chart.
2. Compare your classification scheme with those of other groups.

3. Were some classification schemes more valid than others? Explain in the space below.

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 compound, 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.

8. Complete the following table by classifying each of the compounds.

Compound	Organic or Inorganic	Binary or Non-Binary	Molecular or Ionic	Acid, Base, Salt or None of these
$CaCl_2$				
CH_3CH_2OH				
NH_4ClO_3				
KOH				
C_3H_8				
H_3PO_4				
$Ba(NO_3)_2$				
CO_2				
$Al(OH)_3$				

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

10. 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.

2.3 Separating the Substances of a Mixture

Warm Up

A student scoops up a pail full of water and mud from the bottom of a pond. The mixture in the pail is a suspension of mud particles and algal cells and a solution of salts. Outline a method for separating these three components.

____

____

____

Separating Mixed Substances

Most naturally occurring objects and materials are mixtures. Our atmosphere, our natural water systems, and the ores and petroleum products (such as crude oil and natural gas) that we extract from the ground are mixtures. Just as a compound can be decompounded (decomposed), a mixture can be unmixed. Since the ingredients of a mixture are not chemically combined, they retain their individual identities. The trick to separating the substances in a mixture is to pick a property that clearly differentiates the substances.

Consider a mixture of marbles and beads. Because the marbles and beads do not form any aggregates, they can easily be separated by pouring the mixture into a colander (a bowl full of holes). It would capture the marbles but allow the beads to pass through. Laboratory technicians perform a tremendous number of separations daily in medical, forensic, and analytical chemistry laboratories to allow the substances in the mixtures to be identified. Large industrial-scale separations are performed around the world in commercial refineries (for sugar, oil, metal, etc.) to obtain the target substances for their useful properties, their intrinsic values, or more commonly to use the substances to produce useful mixtures of our own design.

Mechanical Means of Separation

In Chemistry 12, you'll examine a chemical separation technique called selective precipitation. In this course we restrict our studies to **physical separations**: those not involving chemical reaction. Physical separation techniques include centrifugation, chromatography, recrystallization, decantation, density separation, distillation, electrophoresis, evaporation, extraction, flotation, filtration, freezing, magnetic separation, reverse osmosis, and sedimentation. Physical separations may be classified as mechanical or non-mechanical. Non-mechanical means of separation include techniques that use heat, electricity, magnetism, dissolving, or sticking to separate a mixture's components. **Mechanical means of separation** use gravity, contact forces, or motion to sort the components of a mixture. Terms such as picking, sifting, filtering, shaking, spinning, pouring, and skimming, describe the type of actions involved in mechanical separations. We'll just describe some of the more common techniques in this section.

Density Separation

To **sediment** (verb) means to fall or sink to the bottom of a liquid. **Sediment** (noun) is matter that has fallen or sunk to the bottom of a liquid. As Isaac Newton deduced, an object doesn't just fall of its own accord. A force is required to change an object's state of motion. A falling object is acting under the influence of gravity. The difference between falling through a vacuum (which is essentially empty space) and falling through a medium is the medium. A medium exerts an upward force called **buoyancy** on all objects immersed in it. As an object enters a fluid, it lifts the fluid it displaces. A buoyant force equal to the weight of this displaced fluid is redirected upward on the immersed object.

Every object surrounded by a fluid (air, water, etc.) has at least some of its weight supported by buoyancy.

If the object is less dense than the fluid, then the object will float because it will displace a weight of fluid greater than its own weight. Therefore, the force of buoyancy acting on it will be greater than the force of gravity acting on it. Density separation can be used to separate solids with different densities. By adding a liquid that is more dense than one of the solids in the mixture, only that solid floats while the others sink. Conversely, by adding a liquid that is less dense than one of the solids in the mixture, only that solid sinks while the others float. The solids must be insoluble in the liquid media used to selectively float or sink them. This technique is used to separate plastics of different densities.

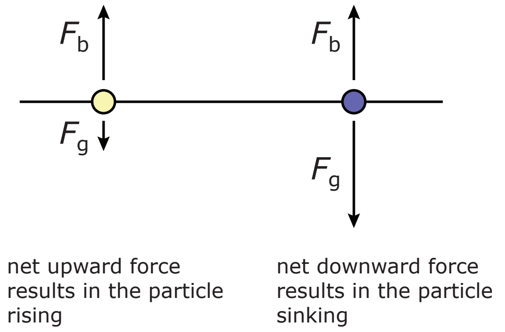


Figure 2.3.1 *Forces acting on particles suspended in a heterogeneous mixture*

Although density separation separates the solid particles from each other, they are now mixed with the liquid(s) used to separate them. The particles that float can be skimmed off the top of the liquid and dried. The particles that sediment can be separated from the liquid by decanting off the liquid or by filtering out the sediment. **Decanting** is carefully pouring off the liquid and leaving the sediment in the bottom of the original container. A small amount of liquid is usually left in the container and care must be taken to prevent a small amount of sediment from flowing with the liquid out of the container.

The sediment can also be separated from the liquid by filtration. In the simplest form of **filtration**, the liquid containing the sediment is poured into a folded piece of filter paper in a funnel. The material filtered out of the mixture is called the **residue**. The liquid that passes through the filter paper is called the **filtrate**. Dissolved substances and colloids are too small to be filtered out by regular filter paper but some colloids can be removed by ultra-filtration which uses filter paper with extremely small pores.

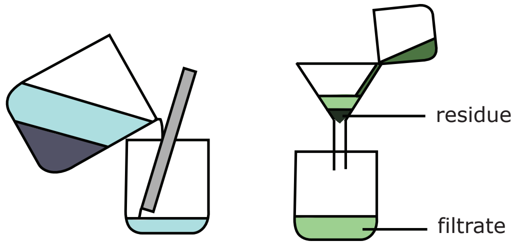


Figure 2.3.2 *Decanting (left) and filtering*

Centrifugation

Another mechanical means of separation is centrifugation or spinning. Centrifugation enhances density separation. Particles that would normally sink or rise still do so, just more rapidly.

When you are in a car that turns a sharp corner you may be "thrown" sideways. It might seem as though a force pushed you against the door. To explain this and similar phenomena, people have invented an imaginary or nonexistent force known as a centrifugal force, which is said to cause the outward motion. In fact, no force was necessary for you to keep travelling at a constant speed in a straight line. When the car turned, you didn't. Your body attempted to keep going in your original direction. All objects have a resistance to change in motion. This property is called **inertia**. The suspended particles in a mixture behave similarly in a centrifuge. As the tube changes its direction, the suspended particles initially maintain their linear motion. This process occurs continuously as the tube spins, directing the suspended particles to the bottom of the tube (Figure 2.3.3).

Figure 2.3.3 *The particle in the centrifuge tube continues to travel in a straight line while the tube turns. The spinning forces it to the bottom of the tube, as shown on the right.*

Quick Check

1. What force causes objects to float? ______________________________
2. What is decanting?

   ____
3. How does centrifugation work? ____

   ____

Non-Mechanical Means of Separation

Chromatography

Chromatography is one of the most widely used techniques in scientific research today. The processes involved in the separation are generally mild ones. Chromatography has been successfully employed to separate some of the most fragile and elusive substances. Researchers have been able to devise a chromatographic method for separating all but a few mixtures.

Chromatography separates the substances in a solution by having a flowing liquid or gas carry them at different rates through a *stationary phase*. The flowing liquid or gas is called the *mobile phase*. Each substance travels through the stationary phase at its own characteristic rate, according to its relative affinities for the two phases. A substance that adheres strongly to the stationary phase but isn't very soluble in the mobile phase travels slowly through the chromatogram. Conversely, a substance that adheres weakly to the stationary phase but is very soluble in the mobile phase travels quickly through the chromatogram.

There are many forms of chromatography. These include gas chromatography, column chromatography, thin layer chromatography, and paper chromatography. In thin layer chromatography (TLC), the stationary phase is a thin layer of silica gel dried onto a glass plate. In paper chromatography, the stationary phase is a strip or sheet of paper. The mobile phase in both forms of chromatography could be water, an organic solvent such as alcohol, or a mixture of solvents. A drop of the solution to be separated is placed near the bottom of the sheet or plate and allowed to dry. Another drop of the solution is then placed on top of the first and also allowed to dry.

This process is repeated many times until there is a sufficient amount of each solute to produce a clear chromatogram. The bottom of the chromatogram is lowered into a pool of the solvent. **Capillary action** is the tendency of a liquid to rise in narrow tubes or to be drawn into small openings. Capillary action results from the adhesive forces between the solvent molecules and those of the wicking material in combination with the cohesive forces between the solvent molecules themselves. Capillary action causes the solvent to rise up the stationary medium, between the paper fibres or the grains of the gel, past the deposit of solutes, and up the remainder of the paper or glass plate.

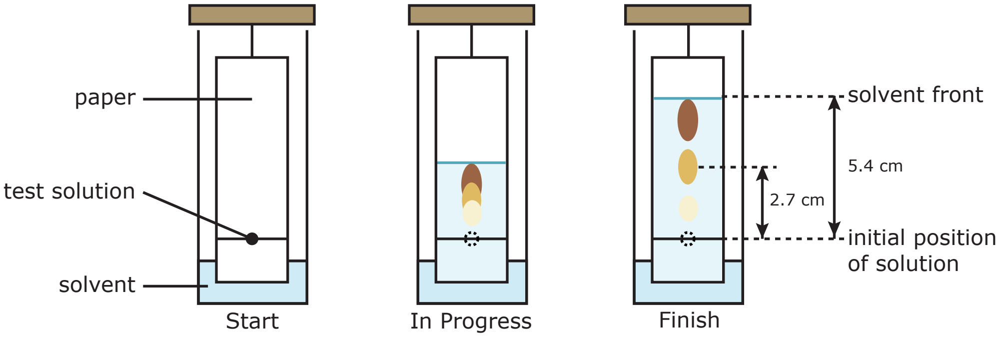


Figure 2.3.4 *Thin layer or paper chromatography*

A substance's $\boldsymbol{R_f}$ (retention factor) for any particular system is defined as its flow speed relative to that of the mobile phase. Here is an example calculation:

$$R_f = \frac{\text{distance the substance flows}}{\text{distance the solvent flows}} \quad \text{(in a given time period)}$$

$$= \frac{2.7\text{ cm}}{5.4\text{ cm}} = 0.50$$

A substance's R_f may help identify it or at least support its identification by more definitive means.

"Developing a chromatogram" is the spraying of chemicals on a chromatogram to form coloured complexes with the separated substances so they reveal their location. *Elution* is the process of rinsing the separated substances off the chromatogram. Their recovery is usually necessary so that they can be identified through further analysis. Chemists commonly run at least two chromatograms under identical conditions. One is developed to determine the location of the separated substances. The substances are then eluted from the same locations on the undeveloped chromatogram.

In column chromatography, the stationary phase is a glass tube packed with specially treated resin beads. The mobile phase is sometimes just the solution itself but another solvent may be needed to wash the solutes through. Column chromatography is an "open-ended" form of chromatography in which the separated substances flow out the bottom end of the column at different times. Periodic chemical tests or constant electronic monitoring indicates the presence of substances as they leave the column. For column chromatography, the substances' R_f values are calculated as:

$$R_f = \frac{\text{substance time}}{\text{solvent time}} \quad \text{(to travel through the column)}$$

Electrophoresis is similar to chromatography except that the stationary phase is a gel-coated slide or gel-filled dish with oppositely charged electrodes at either end. Species are separated according to their charge or polarity, mass, and size. Other separation methods that involve solubility include solvent extraction and recrystallization. In solvent extraction, one or more compounds are soluble in a particular solvent while the others are not. In recrystallization, trace amounts of impurities stay in solution as the solution is cooled

Distillation

Distillation is any process that separates a mixture of substances by using their different vapour pressures or boiling points. Distillations require a heating device, a flask containing the original mixture, a condenser to cool and condense the vapours, and something to collect the condensed substances as they leave the condenser one after the other (Figure 2.3.5). Distilled water is produced by boiling tap water, cooling its vapours, and then collecting the condensate or **distillate**. The impurities that were dissolved in the water remain as **residue** in the original flask.

Such *simple distillations* are suitable for separating dissolved solids from a solvent but there is a fundamental problem using this technique to separate two liquids. Liquids can evaporate long before boiling occurs as evidenced by the puddles on our street that come and go without ever boiling. Because of this, the initial distillate is still a mixture although it is now richer in the liquid with the lower boiling point. If you took this distillate and repeated the distillation process, the next distillate would be richer still in this liquid. If you repeated this process many times, each time the distillate would become increasingly richer in the substance with the lower boiling point but this would be a tedious process. A mixture that cannot be completely separated by simple distillation is called an azeotropic mixture.

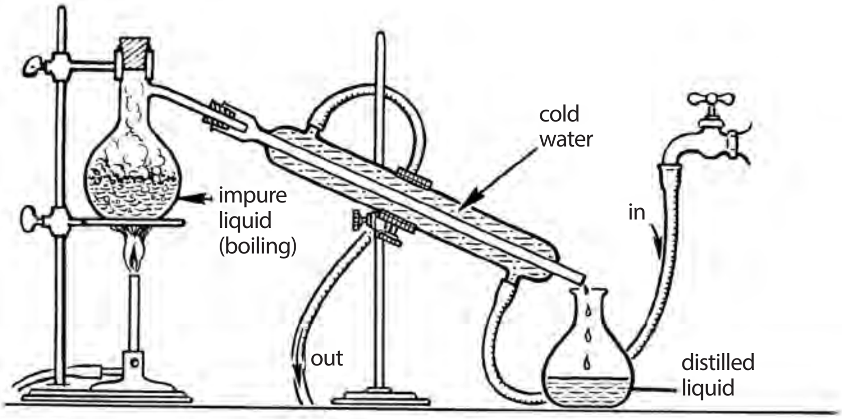


Figure 2.3.5 *Laboratory distillation apparatus*

Scientists have therefore devised a method called **fractional distillation** in which the simple distillation (vaporizing and condensing) is repeated many times within the one device. After evaporating, the vapour enters a *fractionating column*. This may be a tube packed with glass fibres, a tube containing overlapping glass lips or plates, or simply coiled tubing as popularized by backwoods stills. The idea is to provide surfaces on which the vapours can condense. As the hot vapours from below reheat the distillate, some compounds revapourize and travel farther up the column. At the same time, others with higher boiling points drip back in the opposite direction. This process is called *reflux*. The plates become progressively cooler as you move up the column. Each time the process is repeated, the distillate becomes richer in the liquid with the lower boiling point. The component liquids thus proceed at different rates up the fractionating column so as you move higher up, the mixture becomes increasing richer in the liquid with the lower boiling point. If the column is long enough, the liquid components may separate completely and enter the condenser one after the other. There are of course several variations on this same technique.

Distillation is an important laboratory and industrial process (Figure 2.3.6). Oil refineries employ distillation to separate the hundreds of different hydrocarbons in crude oil into smaller groups of hydrocarbons with similar boiling points. Chevron has an oil refinery in Burnaby and Husky has an oil refinery in Prince George. When distilling a single batch, as described and illustrated above, the temperatures within the column continuously change as the chemicals travel through the column much like solutes travelling up a piece of chromatography paper. By contrast, oil refineries continuously feed the vaporized crude oil mixture into large steel fractionating towers that electronically monitor and maintain a steady range of temperatures from 400°C at the bottom to 40°C at the top. Each compound rises until it reaches a section of the column that is cool enough for it to condense and be withdrawn from the column. For example, the gasoline fraction (meaning the fraction containing gasoline, itself a mixture) exits near the top of the tower at the 40°C to 110°C level.

Figure 2.3.6 *Industrial distillation*

Froth Flotation

BC is one of the world's major mining regions, and mining is a key contributor to the province's economy. Precious metals such as gold and silver are very stable or unreactive and are found in nature in their "native" or elemental form. This property is central to their value in jewellery. Other metal atoms such as copper are mostly found in nature in ionic compounds. Naturally occurring compounds are called **minerals**.

Rock containing a desired mineral is called **ore**. The first stage of mining is to extract the ore via blasting or drilling, depending on the kind of mine. The second stage is to mill or crush the ore into a fine powder. The third stage is to separate the target mineral(s) from the rest of the ore, called gangue. Copper compounds are separated by a technique called **froth flotation**. The powdered rock is mixed with water and then a small amount of pine oil is added that adheres to the mineral grains but not to the gangue. Oil and water don't mix so the grains are rendered **hydrophobic** or water repelling. Air is bubbled through the mixture and the hydrophobic grains of mineral escape the water by attaching to the air bubbles, which float them to the surface. The target mineral is then skimmed off, washed, dried, and shipped to a refinery where it is decomposed to recover the metal. Froth flotation is also used in wastewater treatment and paper recycling.

Quick Check

1. What is chromatography?

____

____

2. What is distillation?

____

____

3. Name three areas that use froth flotation.

______________________________________ ______________________________________

____

2.3 Activity: Separating Stuff

Question

Can you separate a variety of objects using methods that don't rely on their appearance?

Background

Chemists separate the substances in a mixture by picking on properties that clearly distinguish the substances from one another.

Procedure

1. Design and perform a procedure to separate a mixture of marbles, paper clips, pennies and small wooden discs.
2. Record your results in the table below.

Procedure		Items Separated from Mixture
1.		
2.		
3.		

Results and Discussion

1. What property of each item allowed you to separate it from the mixture?
2. Was the order of the procedures important in your separation scheme?
3. Discuss any complications that arose during your procedures.
4. Compare your methods with those of other groups.

2.3 Review Questions

1. What is the difference between decomposing compounds and separating mixtures?

2. Give three reasons for separating the substances in a mixture.

3. Oil floats on top of water because it is less dense. However, oil pours more slowly than water because it is more viscous. Is the ability of a fluid to suspend particles more closely correlated to its density or its viscosity?

4. Inertia plays an integral role in most mechanical separations.
   (i) What is inertia?

   (ii) Describe the role inertia plays in centrifugation.

5. Rewrite the underlined part of the following statement to correct it.
   Heavier particles centrifuge more rapidly because <u>of the greater centrifugal force exerted on them.</u>

6. Devise a simple scheme for separating a mixture of sand, sugar, and iron filings. Each material must be recovered in its original solid form.

7. Briefly describe the role of a furnace filter.

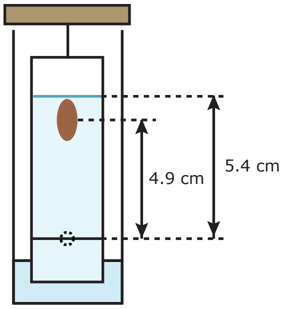
8. Briefly describe how chromatography separates the substances in a mixture.

9. What does the phrase "developing a chromatogram" refer to?

10. What is elution and what is its usual purpose?

11. Why should you mark the starting position of the deposited solution on the chromatography paper with pencil rather than pen?

12. What is the R_f of the compound shown in the diagram ?



13. What is the basic problem with simple distillation?

14. Identify two factors that affect how completely the components of a solution are separated by fractional distillation.

15. Air is approximately 78% nitrogen (boiling point: –196°C) and 21% oxygen (boiling point: –183°C). Briefly describe how you would separate nitrogen and oxygen from air.

16. Which process requires more energy: chromatography or distillation? Explain.

17. Both density separations and froth flotations involve some materials floating and others sinking, yet density separations are considered a mechanical means of separation while froth flotations are not. What is the main difference between these two techniques?

2.4 Names and Formulae of Inorganic Compounds

Warm Up

Ions are charged atoms or charged groups of atoms. Ions always associate (bond) together in the ratio that results in their charges cancelling to form neutral compounds. Complete the table by providing the formulas of the compounds formed by the ions specified.

	Br^-	O^{2-}	N^{3-}	OH^-	SO_4^{2-}	PO_4^{3-}
Na^+	NaBr		Na_3N			
Ca^{2+}						$Ca_3(PO_4)_2$
Al^{3+}				$Al(OH)_3$		
NH_4^+		$(NH_4)_2O$				
Sn^{4+}					$Sn(SO_4)_2$	

Binary Ionic Compounds

Recall from section 2.2 that non-metals form molecular compounds with other non-metals but they form ionic compounds with metals. The names and formulas of these two types of compounds are handled differently.

A **binary compound** contains the atoms of only two elements, and binary ionic compounds contain only two types of **monatomic ions** (charged individual atoms).

The name of any ionic compound is simply the name of its constituent metal ion followed by the name of its constituent non-metal ion.

For example, a compound containing sodium ions and chloride ions is called sodium chloride.

The ratio of the ions formed when a particular metal and non-metal react can be predicted through the charge of their common ions, which can be found in the table of common ions at the back of this book. Positively charged ions are called **cations** (think of the letter 't" as a + sign). Negatively charged ions are called **anions.** Note that the sign of the ion charge (+ or –) is written after the numeral. For example, the aluminum ion is denoted as Al^{3+} rather than as Al^{+3}. Scientists felt that placing the plus or minus charge before the numeral might mislead people into believing that it meant greater than or less than zero. In fact, these plus and minus signs designate the type of electrical charge. The different types of electrical charge are called opposite charges because they have opposing effects. They can cancel each other. Note that there is a difference between cancelling two things and two things cancelling. Cancelling two things (e.g., magazine subscriptions) means eliminating them. By contrast, two things cancelling means they negate each other's effects. This is what happens with positive and negative ion charges. When particles with equal but opposite charges bond together, the charges cancel to yield a product with a net charge of zero.

The concept of a net property means that the property of the whole is equal to the sum of the still existing properties of its parts. Ions always associate together in a ratio that results in their charges cancelling to form neutral compounds. For example:

$$\overbrace{2Al^{3+}(aq) \quad + \quad 3S^{2-}(aq)}^{\text{separate}} \quad \rightarrow \quad \overset{\text{combined}}{Al_2S_3\,(s)}$$

$$6+ \qquad + \quad 6- \qquad = \quad 0$$

All compounds are neutral. There is no such thing as a charged compound.

The formula Al_2S_3 means that there are $2Al^{3+}$ ions for every $3S^{2-}$ ions. Chemists know the charges but don't show the charges in the formulas of ionic compounds. The ionic nature of the compound is implicit in the combination of a metal and a non-metal. The formula of an ionic compound shows that the compound as a whole is neutral even though it contains both positively and negatively charged ions. Remember that a neutral atom also contains positively and negatively charged particles (protons and electrons) that are not evident in its symbol.

Look at the formula of aluminum sulphide shown below on the left. The number of aluminum ions equals the numerical value of the sulphide ion's charge and vice versa. This simple shortcut for determining the formula of ionic compounds is sometimes called the cross-over method. The cross-over method matches up the opposite charges so that they cancel and will always work if you reduce the formula to its simplest ratio.

$Al^{\textcircled{3}+}\ S^{\textcircled{2}-}$ Al_2S_3 $Pb^{\textcircled{4}+}\ S^{\textcircled{2}-}$ Pb_2S_4 which reduces to PbS_2

$2(3+) = 3(2-)$ $2(4+) = 4(2-)$

Multivalent Ions

Some elements have two or more possible valence shell electron configurations (ways of arranging its electrons). These **multivalent** elements have more than one form of stable ion. Many of the transition metals (groups 3 to 12 in the periodic table) are multivalent. For example, iron has two stable ions, Fe^{2+} and Fe^{3+}. Rather than Fe^{2+} being called the iron two plus ion, it is simply called the iron two ion, but it is written as iron(II), bracketing the roman numeral for the numerical value of the ion's charge after the name. Likewise Fe^{3+} is called the iron(III) ion. The roman numerals only appear in the compound's name, never in its formula.

A different method for naming the ions of multivalent elements was used in the not too distant past, and you may encounter it occasionally. In that method, an *–ous* or *–ic* suffix was added to the root of the element's name from which the symbol was derived. The *–ous* suffix denoted the lesser ion charge and the *–ic* suffix denoted the greater ion charge. For example, the iron(II) ion, Fe^{2+}, was called the ferrous ion, and the iron(III) ion, Fe^{3+}, was called the ferric ion.

Sample Problem — Determining the Formula of a Binary Ionic Compound from Its Name

What is the formula of tin(IV) sulphide?

What to Think about	How to Do It
1. Write the symbols of the ions named. 2. Combine the ions in the simplest ratio that results in their charges cancelling.	$Sn^{4+}\ \ S^{2-}$ $1\,Sn^{4+} + 2\,S^{2-} \rightarrow SnS_2$ $4+ \quad + \quad 4- \quad = \quad 0$

Sample Problem — Determining the Name of a Binary Ionic Compound from Its Formula

What is the name of Fe_2S_3?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Write the formulas of the possible compounds to see which one has the correct formula.	iron(II) or iron(III), sulphide iron(II) sulphide $Fe^{2}+ + S^{2-} \rightarrow FeS$ × iron(III) sulphide $2\,Fe^{3+} + 3\,S^{2-} \rightarrow Fe_2S_3$ ✓

Practice Problems — Determining the Names and Formulas of Binary Ionic Compounds

1. Write the formula of each of the following binary ionic compounds:

(a) lithium sulphide
(b) chromium(III) oxide
(c) aluminum chloride
(d) lead(II) sulphide
(e) tin(II) iodide
(f) zinc bromide

2. Name each of the following binary ionic compounds:

(a) ZnO ________________________________
(b) $PbCl_4$ ________________________________
(c) $CuCl_2$ ________________________________
(d) NaI ________________________________
(e) K_2S ________________________________
(f) CrO ________________________________

Polyatomic Ions

Recall that a molecule is a *neutral* group of covalently bonded atoms. A **polyatomic ion** is a *charged* group of covalently bonded atoms so it's like a molecule except that it has a charge. Polyatomic ions play an extremely important role in the environment, the laboratory, and industry. They are relatively stable species that often remain intact in chemical reactions. Many polyatomic ions are **oxyanions**, consisting of an atom of a given element and some number of oxygen atoms. Typically the element forms polyatomic ions with different numbers of oxygen atoms. When the element forms two such ions, the one with the lesser number of oxygen atoms takes an –*ite* suffix, while the one with the greater number of oxygen atoms takes an –*ate* suffix. For example:

nitrite	NO_2^-	nitrate	NO_3^-
sulphite	SO_3^{2-}	sulphate	SO_4^{2-}

When there are more than two oxyanions in a series, the prefixes *hypo*- (less than) and *per*- (more than) are used to indicate polyatomic ions with still less or still more oxygen atoms. For example:

hypochlorite	ClO^-
chlorite	ClO_2^-
chlorate	ClO_3^-
perchlorate	ClO_4^-

The prefix bi- before the name of a polyatomic ion adds an H^+ to it. For example:

carbonate	CO_3^{2-}	hydrogen carbonate or bicarbonate	HCO_3^- $(H^+ + CO_3^{2-})$
sulphate	SO_4^{2-}	hydrogen sulphate or bisulphate	HSO_4^- $(H^+ + SO_4^{2-})$

Note that there are some exceptions to these naming conventions. The hydroxide ion is the only polyatomic ion to have an –*ide* suffix. The dichromate ion has the formula $Cr_2O_7^{2-}$ and despite its prefix does not refer to two chromate ions.

Because they are charged, polyatomic ions associate with oppositely charged ions to form ionic compounds. Polyatomic ions are bracketed in formulas. For example, the formula of calcium nitrate is $Ca(NO_3)_2$. This means that the atoms within the brackets are bonded covalently to each other and as a group they are bonded ionically to the atom or atoms outside the brackets. The brackets are necessary to show that the formula ratio applies to the entire polyatomic ion, not just to its last atom. For example, the formula of calcium hydroxide is $Ca(OH)_2$ meaning that there are two hydroxide (OH^-) ions for each calcium ion. If the brackets were omitted, the formula would look like this: $CaOH_2$. In that case, the subscript 2 would apply only to the hydrogen atom. By convention, chemists omit the brackets if no subscript is required. For example, Na(OH) is written as just NaOH.

The ionic compounds that you'll encounter in this course will each have only two types of ions unless otherwise specified. Therefore, the first element in the formula will represent the cation and the remainder will represent the anion. The one exception is in ammonium compounds; the only polyatomic cation you'll encounter is the ammonium ion, NH_4^+. For example:

$ZnCr_2O_7$ must consist of Zn^{2+} ions and $Cr_2O_7^{2-}$ ions (to cancel the 2+).
$Cr_2O_7^{2-}$ is the dichromate ion so this compound is called zinc dichromate.

$NaClO_2$ must consist of Na^+ ions and ClO_2^- ions (to cancel the 1+).
ClO_2^- is the chlorite ion so this compound is called sodium chlorite.

Sample Problem — Determining the Formula of any Ionic Compound from Its Name

What is the formula of potassium sulphite?

What to Think about	How to Do It
1. Write the symbols of the ions named. 2. Combine the ions in the simplest ratio that results in their charges cancelling.	$K^+ \quad SO_3^{2-}$ $2\,K^+ + SO_3^{2-} \rightarrow K_2SO_3$ $2+ \quad + \quad 2- \quad = \quad 0$

Sample Problem — Determining the Name of any Ionic Compound from Its Formula

What is the name of $Cr(HSO_4)_2$?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Write the formulas of the possible compounds to see which one has the correct formula.	chromium(II) or chromium(III), bisulphate chromium(II) bisulphate $Cr^{2+} + 2\,HSO_4^- \rightarrow Cr(HSO_4)_2$ ✓ chromium(III) bisulphate $Cr^{3+} + 3\,HSO_4^- \rightarrow Cr(HSO_4)_3$ ×

Practice Problems — Determining the Names and Formulas of Ionic Compounds

1. Write the formula of each of the following ionic compounds:
   (a) barium sulphate
   (b) silver nitrate
   (c) mercury(II) bromide
   (d) tin(IV) oxalate
   (e) aluminum dichromate
   (f) potassium fluoride

2. Name each of the following ionic compounds:
   (a) $Zn(OH)_2$ ____________________
   (b) SnO ____________________
   (c) $Cu(ClO)_2$ ____________________
   (d) $NaCH_3COO$ ____________________
   (e) MgI_2 ____________________
   (f) $FeCr_2O_7$ ____________________

Names and Formulas of Binary Molecular Compounds

Any cation and anion combine in a single ratio that is easily predictable from their charges. This is why ionic compounds' names do not need to explicitly contain their formulas. On the other hand, two non-metal atoms may share electrons and combine in several ratios. Therefore, the name of the molecular compound must reveal its formula to distinguish it from the other compounds of the same two elements. The name of a molecular compound uses a prefix code to provide its formula. The prefixes used are shown in Table 2.4.1.

The names of all binary compounds have an –*ide* suffix. N_2O_4 is therefore dinitrogen tetroxide. Note that the number of atoms comes before the *name* of the element but after the *symbol* of the element. The prefix *mono-* is understood for the first element named if no prefix is stated. For example, carbon dioxide is CO_2.

Table 2.4. *Prefixes for Molecular Compounds*

Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Sample Problem — Determining the Formula of a Molecular Compound from Its Name

What is the formula of xenon tetrafluoride?

What to Think about	How to Do It
1. Write the symbols of each element and the number of atoms of each.	1 Xe and 4 F
2. Rewrite this information as a formula.	XeF_4

Sample Problem — Determining the Name of a Molecular Compound from Its Formula

What is the name of P_4S_{10}?

What to Think about	How to Do It
1. Write the names of each element and the number of atoms of each.	4 phosphorus and 10 sulphur
2. Rewrite this information using the prefix code.	tetraphosphorus decasulphide

Practice Problems — Determining the Names and Formulas of Molecular Compounds

1. Write the formula of each of the following molecular compounds:

(a) nitrogen monoxide

(b) nitrogen dioxide

(c) dinitrogen tetroxide

(d) dinitrogen trioxide

2. Name each of the following molecular compounds:

(a) PCl_5 ______________________________

(b) SO_2 ______________________________

(c) CO ______________________________

(d) P_2O_5 ______________________________

Hydrates

When many salts crystallize out of aqueous solution they incorporate water molecules in a fixed ratio and pattern into their ionic crystal lattice. These salts are called **hydrates.** Many salts are supplied as hydrates. The water in the crystal doesn't usually present a problem as most salts are destined for aqueous solutions anyway. Water is an integral part of hydrates and thus must be accounted for in both their names and their formulas. The same prefixes used for naming molecules precede the term *-hydrate* to denote the number of water molecules in the formula. This tells you the ratio of water molecules to ions.

Gently warming a hydrated salt will usually remove the water from the crystal. The term "**anhydrous**" refers to the form of the salt without ("an") water ("hydrous"). Some anhydrous salts are *hygroscopic* which means that they can absorb water from the air to form hydrates. Hygroscopic salts that are being used to keep the air dry in a container are called **desiccants**. Pouches containing silicate salts are sometimes used as desiccants in boxes or cases containing binoculars, guitars, shoes, etc. Most labs have a special airtight glass container designed to store containers of hygroscopic salts. This container is called a **desiccator**. One of the salts is poured onto the bottom of the desiccator to keep its air dry so the others are not exposed to water vapour.

Sample Problem — Determining the Formula of a Hydrate from Its Name

What is the formula of copper(II) sulphate heptahydrate?

What to Think about	How to Do It
1. Write the symbols of the ions named. 2. Combine the ions in the simplest ratio that results in their charges cancelling. 3. Tack on the appropriate number of water molecules to complete the formula.	Cu^{2+} SO_4^{2-} $Cu^{2+} + SO_4^{2-} \rightarrow CuSO_4$ heptahydrate means $7H_2O$ $CuSO_4 \bullet 7H_2O$

Sample Problem — Determining the Name of a Hydrate from its Formula

What is the name of $NaCH_3COO \bullet 3H_2O$?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Tack on the appropriate number of water molecules using the prefix code (–hydrate).	sodium, acetate sodium acetate trihydrate

Practice Problems — Determining the Names and Formulas of Hydrates

1. Write the formula of each of the following hydrates:
   (a) barium chloride dihydrate
   (b) sodium carbonate monohydrate
   (c) iron(III) nitrate nonahydrate
   (d) barium hydroxide octahydrate

2. Name each of the following hydrates:
   (a) $CoCl_2 \bullet 6H_2O$ ____________________
   b) $FeCl_3 \bullet 4H_2O$ ____________________
   (c) $Na_2Cr_2O_7 \bullet 2H_2O$ ____________________
   (d) $MgSO_4 \bullet 7H_2O$ ____________________

Acids

Acids have a number of interesting and unique properties. An acid can be thought of as one or more H^+ ions bonded to an anion. Remember that in ionic compounds the charges cancel (negate each other) without being cancelled (eliminated). In acids however, these ion charges are actually cancelled as the ions convert into neutral atoms and the group of atoms into a molecule. **Acids** are a special type of molecular compound that can be induced to form ions. The names of acids are based on the name of the anion formed.

The rules for naming acids depend on whether the anion contains oxygen. If the *anion doesn't contain oxygen*, the prefix *hydro-* precedes the name of the anion and the suffix *–ic* replaces the *–ide* in the anion's name. Hydrogen fluoride (HF) is hydrofluoric acid; hydrogen chloride (HCl) is hydrochloric acid; hydrogen cyanide (HCN) is hydrocyanic acid, etc. There are of course some exceptions. S^{2-} is the sulphide ion, not the sulphuride ion yet hydrogen sulphide (H_2S) is hydrosulphuric acid.

If the *anion does contain oxygen* then the suffix –*ic* replaces –*ate* in the anion's name or the suffix –*ous* replaces –*ite* in the anion's name. Hydrogen sulphate (H_2SO_4) is sulphuric acid and hydrogen sulphite (H_2SO_3) is sulphurous acid.

It bears mentioning that the term "acid" is sometimes ambiguous in that it may refer either to the compound or to its solution. For example, $H_2SO_4(l)$ and $H_2SO_4(aq)$ are both called sulphuric acid. Although the latter might be referred to as a solution of sulphuric acid, it is commonly referred to simply as sulphuric acid. Hydrogen chloride is a gas that condenses into a liquid at –85°C. Because neither the gas nor the liquid is commonly encountered, the term "hydrochloric acid" virtually always refers to an aqueous solution of hydrogen chloride.

Sample Problem — Determining the Formula of an Acid from Its Name

What is the formula of hydrobromic acid?

What to Think about	**How to Do It**
1. Decode the suffix to determine possible anions: bromic denotes bromide or bromate.	Br^- or BrO_3^-
2. Decode the prefix (if any) to select the anion: *hydro*- indicates that the anion doesn't contain oxygen.	Br^-
3. Determine the formula from the ion charges.	$H^+ + Br^- \rightarrow HBr$

Sample Problem — Determining the Name of an Acid from Its Formula

What acid has the formula HNO_2?

What to Think about	**How to Do It**
1. Write the names of the two constituent ions.	hydrogen nitrite
2. Use the code for naming acids. The anion contains oxygen so the suffix –*ous* replaces –*ite* in the anion's name.	nitrous acid

Practice Problems — Determining the Names and Formulas of Acids

1. Write the formula of each of the following acids:

(a) hydrofluoric acid

(b) hypochlorous acid

(c) phosphoric acid

(d) hydrosulphuric acid

2. Name each of the following (as) acids:

(a) HCH_3COO ____________________________

(b) H_2SO_3 ____________________________

(c) H_2CO_3 ____________________________

(d) HI ____________________________

2.4 Activity: The Ionic Compound Card Game

Question

Are students more likely to study or practise if it's fun?

Background

The basic premise of fun theory is that the easiest way to change people's behaviour is to make the desired behaviour more fun than the other options. Learning is sometimes defined as changing behaviour. From that perspective, we are testing the theory that people are more likely to learn if it's fun than simply virtuous or to our advantage. Learn more about fun theory by searching for "The Fun Theory" online.

Procedure

1. Your teacher will have made some special cards for this fun activity. Thank your teacher. (Teachers: go to bcscienceinteractions.com for stickers and instructions.)
2. Deal seven cards to each player.
3. The player to the left of the dealer flips one card face up from the deck. The player then attempts to make a compound by combining one or more cards from his or her hand with the card that is face up on the table. Each compound may only consist of two types of ions.
   If the player makes a compound then the player must correctly state the formula or name of the compound. Those cards are then removed from the game. If the player cannot make a compound or correctly state the formula or name of the compound, the player leaves the card face up on the table.
4. Play rotates clockwise around the table. A player always begins a turn by flipping over a card from the deck so there is always at least one card to combine with. A player may make only one formula per turn. Cards flipped over from the deck remain there until combined with a card or cards from a player's hand. Every time a player is unable to form a compound, the number of cards face up on the table increases by one.
5. The game continues until someone wins by having no cards remaining in his or her hand. The first player to win two hands wins the game.

Results and Discussion

1. Did you enjoy this card game? Why or why not?

2. Did it help you learn how to write chemical formulas or remember the names of ions? Why or why not?

3. Feel free to devise an ionic formula card game of your own: ionic formula rummy, ionic formula "Go Fish," etc.

2.4 Review Questions

1. In each case below, write out the chemical equation for the association of the ions that form the given binary ionic compound.
Example: magnesium phosphide
$3\ Mg^{2+} + 2\ P^{3-} \rightarrow Mg_3P_2$
(a) sodium fluoride

(b) iron(II) bromide

(c) tin(IV) chloride

(d) chromium(III) sulphide

2. Write the formulas of the following binary ionic compounds:
(a) chromium(III) chloride

(b) aluminum fluoride

(c) magnesium iodide

(d) tin(IV) oxide

3. Write the names of the following binary ionic compounds:
(a) K_2O

(b) $ZnBr_2$

(c) PbO_2

(d) $HgCl_2$

4. Write the name and formula of the binary ionic compound formed by:
(a) potassium and chlorine

(b) manganese(IV) and oxygen

(c) iron(III) and sulphur

(d) copper(II) and iodine

5. In each case below, write out the chemical equation for the association of the ions that form the given ionic compound,
Example: magnesium nitrate
$Mg^{2+} + 2\ NO_3^{-} \rightarrow Mg(NO_3)_2$
(a) sodium nitrite

(b) silver phosphate

(c) lithium ethanoate (lithium acetate)

(d) chromium(III) oxalate

6. Write the formulas of the following ionic compounds:
(a) copper(I) perchlorate

(b) calcium bisulphide

(c) aluminum monohydrogen phosphate
(d) magnesium hydroxide

7. Write the names of the following ionic compounds:

(a) $Ba_3(PO_4)_2$

(b) $Fe(HSO_3)_2$

(c) $Pb(HC_2O_4)_4$

(d) CuH_2PO_4

8. Many minerals contain three types of ions. In BC, we mine several minerals of copper including two forms of copper(II) carbonate hydroxide.
malachite
$2\ Cu^{2+} + CO_3^{2-} + 2\ OH^{-} \rightarrow Cu_2(CO_3)(OH)_2$
$4+ \ + \ 2- \ + \ 2- \ = \ 0$
azurite
$3\ Cu^{2+} + 2\ CO_3^{2-} + 2\ OH^{-} \rightarrow Cu_3(CO_3)_2(OH)_2$
$6+ \ + \ 4- \ + \ 2- \ = \ 0$
Notice that more than one ratio of the ions results in their charges cancelling. Thus there is more than one possible compound of three ion combinations. Write a possible formula for:
(a) iron(III) sodium chromate

(b) zinc sulphate nitrate

9. Write the formulas of the following molecular compounds:

   (a) chlorine monoxide

   (b) tetraphosphorus hexaoxide

   (c) arsenic pentafluoride

   (d) nitrogen tri-iodide

10. Write the names of the following molecular compounds:

    (a) P_3Br_5

    (b) B_2H_6

    (c) SO_3

    (d) CF_4

11. Write the formulas of the following hydrated salts:

    (a) sodium sulphate decahydrate

    (b) calcium chloride dihydrate

    (c) copper(II) acetate monohydrate

    (d) chromium(III) chloride hexahydrate

12. Write the names of the following hydrated salts:

    (a) $Cd(NO_3)_2 \cdot 4H_2O$

    (b) $Na_2HPO_4 \cdot 7H_2O$

    (c) $CuSO_4 \cdot 5H_2O$

    (d) $Fe(NO_3)_3 \cdot 9H_2O$

13. Why is a hydrate not a mixture of salt and water?

14. Suggest why hydrate formulas are written in the manner they are, rather than bracketing the number of water molecules in the formula (e.g., $SrCl_2 \cdot 6H_2O$ rather than $SrCl_2(H_2O)_6$).

15. Write the formulas of the following acids:

    (a) hydrobromic acid

    (b) chromic acid

    (c) chloric acid

    (d) hypochlorous acid

16. Write the names of the following acids:

    (a) H_2S

    (b) $HClO_4$

    (c) HNO_2

    (d) HSCN

17. Write the formulas of the following variety of compounds:

    (a) potassium oxide

    (b) permanganic acid

    (c) sulphur dioxide

    (d) ammonium carbonate

    (e) iron(II) sulphate heptahydrate

    (f) hydrocyanic acid

    (g) sulphur hexafluoride

    (h) calcium acetate monohydrate

    (i) chromium(III) bisulphite

    (j) magnesium hydroxide