Chapter 2
What is Matter?

Everything around us consists of matter. To understand chemistry, we need to understand the classification of matter and the terminology that we use.

2.1 Background

For at least two thousand years, people have contemplated matter. Why are there different types of matter? What is matter made of? The Greek philosopher, Aristotle, in about 350 B.C. contended that all matter comprised different proportions of the four substances: fire, air, water, and earth. In China, about the same period, Dzou Yen proposed that there were five elements: earth, wood, fire, metal, and water. It was not until the 1600s and 1700s that these speculative ideas were replaced by scientific experimentation. Science advances from the cumulative knowledge and ideas from many individuals. But to show that chemistry is a human endeavour, we have chosen to mention one pair of individuals from the time of the Scientific Revolution, Antoine Lavoisier and his wife and colleague, Anne-Marie Paulze Lavoisier. Between 1770 and 1790, the most important chemical research was being performed in France and the Lavoisiers were at the forefront of the movement. It was in their laboratory where many of the modern ideas of chemistry originated.

Figure 2.1 Anne-Marie Paulze Lavoisier and Antoine Lavoisier in their laboratory

2.2 Properties of Matter

Matter has two fundamental properties: it occupies space – that is, it has volume – and it has mass. We can define ***volume*** as the space occupied by a substance.

The definition of ***mass*** is more difficult. People often confuse mass and weight, but weight is very different. Weight is the result of the pull of gravity on an object. For example, if your weight is 50 kg on Earth, it would be 19 kg on the small planet Mars, 120 kg on the large planet Jupiter, and only 8 kg on the Moon.

Mass is the measure of the quantity of matter in a substance and this is constant everywhere. To do this, we compare the mass of any object with the mass of a cylinder of an alloy of the two metals, iridium and platinum. The mass of that cylinder is defined as exactly one kilogram. The original is in Paris, but there are copies in other countries, for example, the United States has four copies. Though scientists attempt to make each cylinder as close as possible in mass to the original, there are very slight differences.

Figure 2.2 One of the copies of the platinum-iridium standard kilogram underneath two glass covers.

From mass and volume, we can define a third property of matter: density. ***Density*** is a measure of the compactness of matter. For example, solid water – what we call ice – is less dense than liquid water. So the solid floats on the liquid. Water is the only common substance for which this is true. For all others, the solid is denser and sinks to the bottom. This unique property of water is crucial – it enables the colder regions of the Earth to be habitable. In the next Chapter, you will see how density can be defined in numerical terms.

2.3 Phases of Matter

Matter can be found in three different common forms and also in two rarer forms.

Common Phases of Matter

A ***solid*** substance has a definite shape and definite volume. The most perfect example of a solid is called a ***crystal***.

Figure 2.3 An ice crystal (snowflake) seen through a microscope

A ***liquid*** has definite volume but indefinite shape. That is, a liquid will change its shape according to the container that it is placed in.
A ***gas*** has indefinite volume and indefinite shape. That is, a gas will fill whatever container it is placed in. A gas is compressible, that is, it can be 'squished' into a smaller volume – or allowed to expand into a larger volume.

UNUSUAL PHASES OF MATTER

A ***liquid crystal*** is a liquid which has an ordered structure. Thus, in a way, a liquid crystal has properties between those of a solid and a liquid. Liquid crystals now play a major role in our lives for they are the basis of most of our visual displays (LCDs) such as computer, TV, and cell phone screens. They are also used in temperature measurement. Cholesterol, an important substance in our body, is also a liquid crystal.

Figure 2.4 (a) the liquid crystal display (LCD) of a computer screen (b) a liquid crystal display for body temperature measurement.

A ***plasma*** is a gas in which the particles are broken down into charged components. About 149 million kilometres from Earth, there is a giant ball of plasma which we call the Sun.

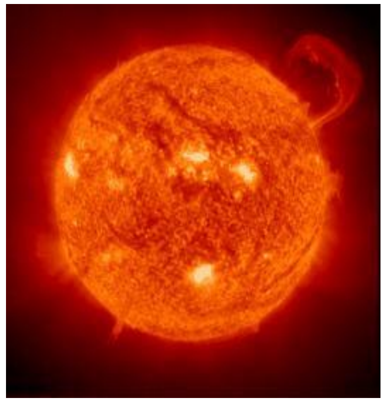

Figure 2.5 The Sun is an enormous ball of plasma

PHASE CHANGES

By altering the temperature, any substance can be changed from one phase to another. For each phase change, there is a specific name and these are as follows:

Melting is the change from solid to liquid. The melting of ice is a good example.

Solidifying is the change from liquid to solid. The freezing of the surface of a lake is one such case. In science, solidifying is preferable to freezing, as ***freezing*** is usually used specifically for water.

Boiling is the change from liquid to gas. For boiling to occur, the liquid must be at its boiling point. For example, when water is boiling in a kettle, if you observe the region just above the spout, it is colourless. This portion contains water as a gas. A different word, ***evaporating***, is used if the liquid is vaporizing at a temperature below its boiling temperature.

Condensing is the change from a gas to a liquid. Again using the example of boiling water in a kettle, further from the spout, a cloud is typically seen. These are tiny liquid water droplets, the water having changed back from gas to liquid in contact with the cool surrounding air.

These common phase changes are summarized in Figure 2.6.

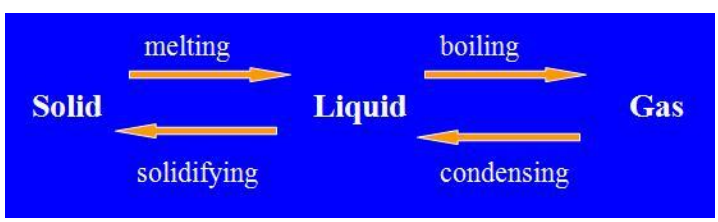

Figure 2.6 A summary of the common terms used for phase changes.

For certain substances, under certain conditions, there is a direct transformation between solid and gas. There are two specific terms for these:

Sublimation is the change directly from solid to gas. As an example, if wet clothes are put outside on a cold day (below 0°C), the water first solidifies (freezes), then, over time the clothes dry. The water has been transformed directly from the solid to gaseous phase. Freeze-dried foods are prepared by freezing them, then removing the water by sublimation.

Deposition, sometimes called dry deposition, the change directly from gas to solid. An example is the formation of frost after a cold night. The water present in the air has changed directly from gas to solid.

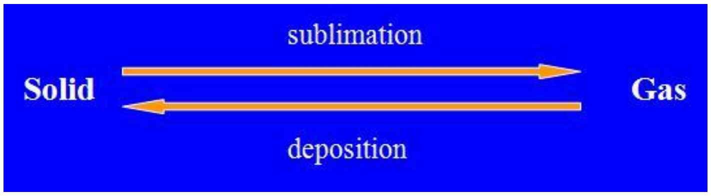

Figure 2.7 A summary of other terms used for phase changes.

2.4 The Kinetic-Molecular Model of Matter

A major purpose of science is to find explanations for things that we observe. For chemistry, we explain our observations by considering everything in the universe consisting of incredibly tiny particles. In subsequent chapters, we will discuss more about the nature of the particles, but for now, we can consider them as very tiny spheres. We can explain the reason why there are three common phases and that substances convert between the phases by means of the **kinetic-molecular model of matter**. This used to be called a theory, but we now have enough evidence that it is a good representation as to why different phases of matter exist. As a result, it is better called a **model** – a way that scientists can picture something that we cannot actually "see."

According to the Kinetic-Molecular Model, particles are in constant motion and therefore possess kinetic energy. At the same time, there are attractive forces between the particles. It is currently accepted that the phase of a substance is determined by the balance between the kinetic energy of the particles and the attractive forces. For a particular substance, the attractive forces between particles are constant. However, the kinetic energy of the particles depends upon the temperature: the higher the temperature, the greater the kinetic energy. Thus phase changes are a result of changes in the balance between the two factors.

THE SOLID PHASE

In the solid phase, the particles are packed together in a three-dimensional array. The kinetic energy of the particles is much less than the energy of attraction between the particles. As a result, the kinetic energy causes the particles to vibrate about fixed positions. As the temperature increases, the heat energy causes the vibrations to become greater.

THE TRANSITION TO THE LIQUID PHASE

At the melting point of the substance, the particle vibrations become of about the same energy as the energy of attraction between the particles. The particles then have enough energy to escape from their fixed positions and move over one another while remaining in contact. This is what we call the liquid phase.

THE TRANSITION TO THE GASEOUS PHASE

At a certain temperature, known as the boiling point, enough energy has been added that the kinetic energy of the particles significantly exceeds the energy of attraction between the particles. The particles can then escape the surface and move independently. This is what we call the gaseous phase.

The kinetic-molecular model of matter enables us to explain differences in melting and boiling points between substances. It does so in terms of differences in the energy of attraction between the particles. Thus, the stronger the energy of attraction between particles, the higher the melting and boiling points; the weaker the energy of attraction, the lower the melting and boiling points.

We can also use the model to explain other observations, such as evaporation. If you have an open container of water, over time, the water will 'disappear.' The water has not boiled as it has not reached its boiling temperature – the water has evaporated. In the kinetic-molecular model, at a particular temperature, we must picture different particles as having different energies. There will be a mean value of particle energy, but some particles will have less and others more, than the mean. Some particles will have a much higher energy and these will be able to escape the surface of the liquid – the process of evaporation. The remaining liquid will therefore be slightly cooler as the mean kinetic energy will be very slightly less. In practice, the liquid will absorb energy from the surrounding air, enough to generate some more high energy particles and the evaporation process will continue.

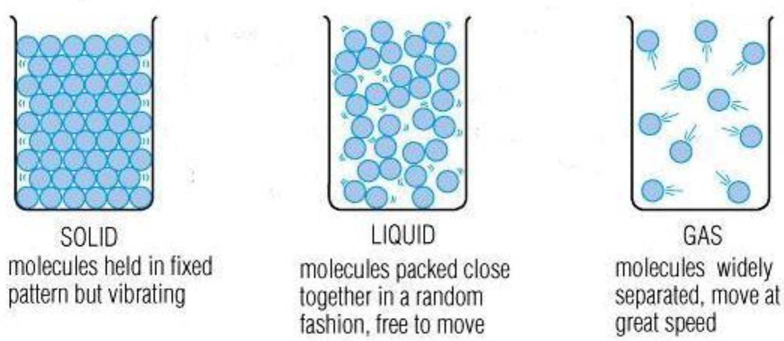

Figure 2.8 The interpretation of phases in terms of the kinetic-molecular model.

2.5 Properties of a Substance

In the preceding sections, we have seen how substances can exist in different phases and that they can change from one phase to another. We have noted that each substance has a characteristic melting point and boiling point. The melting and boiling points are examples of ***physical properties*** of a substance.

PHYSICAL PROPERTIES

A physical property is something that can be measured without changing the nature of the substance. For example, we can cool water until it freezes (a ***physical change***), determine the temperature at which it happens (0°C), then allow the substance to warm back to the liquid phase. The water is still water. Other physical properties are colour, texture of a solid (powder or crystals), viscosity of a liquid, or odour of a gas.

CHEMICAL PROPERTIES

A ***chemical property*** is something that can be observed only when the substance has been transformed into other substances. An example is the chemical property of barbeque charcoal (chemical name, carbon), that it burns in air. As a result of this ***chemical change***, the carbon is no longer a black solid but it has been transformed into a different substance, a colourless gas, called carbon dioxide. The carbon dioxide gas cannot be easily converted back to the solid carbon.

2.6 Classification of Matter

So far, we have been discussing substances as if they were pure but this is not always the case. Thus we are now going to show how to classify substances into different categories. We will start by taking a sample which we can generically call 'matter.' Matter is anything that has mass and occupies space and it can be divided into three types: pure substance, homogeneous mixture (also called a solution), and heterogeneous mixture (Figure 2.9).

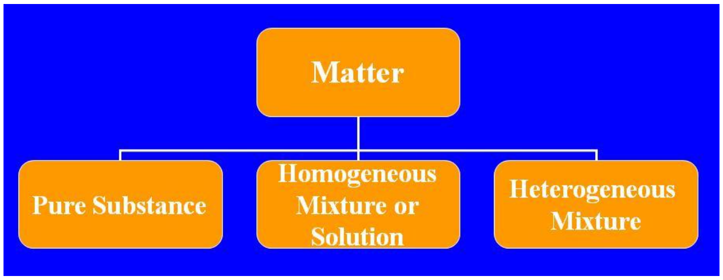

Figure 2.9 The primary classification of matter.

CATEGORIES OF MATTER

A ***pure substance*** is defined as matter that is uniform throughout and has a definite set of physical and chemical properties.

A ***homogeneous mixture***, more commonly called a ***solution***, has a uniform composition but a variable set of physical and chemical properties. For example, a mixture of alcohol (chemical name, ethanol) and water will boil at neither the boiling point of alcohol (78°C) nor the boiling point of water (100°C). Instead, it will boil at some intermediate temperature determined by the proportion of the two (or more) component pure substances, the higher the proportion of alcohol, the closer the value will be to 78°C and the higher the proportion of water, the closer the value will be to 100°C.

A ***heterogeneous mixture*** does not have a uniform composition throughout. Sometimes we can see this visually. For example, the common rock, granite, is a heterogeneous mixture of several different pure substances. There are at least three components which can be seen under a microscope as pink, colourless, and black crystals (Figure 2.10(a)). Milk is also a heterogeneous mixture, the main components being globules (spheres) of fat in water (Figure 2.10(b)).

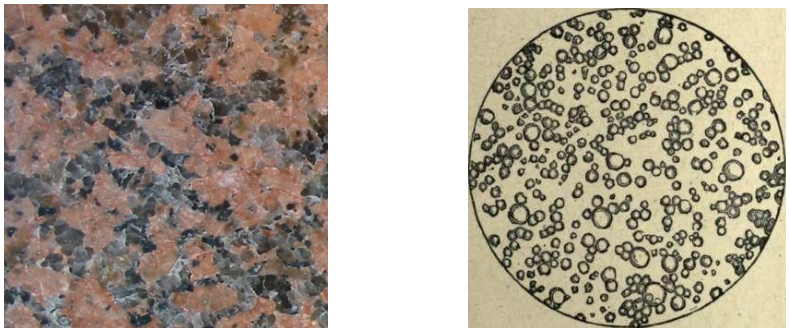

Figure 2.10 A microscope view shows that (a) a sample of granite and (b) a droplet of milk, are both heterogeneous mixtures.

Fat is less dense than water and will normally float on the surface of the water. However, if the fat particles are very small – as in the case of homogenized milk – they will stay suspended. Very small particles of one component suspended in another are called **colloids**. Table 2.1 lists the categories of colloids with their specific names and examples of each.

Table 2.1 Classification of Colloids

		MINOR (DISPERSED) PHASE		
		gas	*liquid*	*solid*
MAJOR PHASE	*gas*	**none**	**liquid aerosol** cloud, mist	**solid aerosol** smoke
	liquid	**foam** whipped cream	**emulsion** milk, hand cream	**sol** blood
	solid	**solid foam** styrofoam	**gel** jelly, cheese	**solid sol** pearl

If you see a cloudy liquid, then it is an indication it is a heterogeneous mixture. A clear liquid usually indicates a homogeneous mixture (solution) but sometimes in a heterogeneous mixture, the dispersed particles are so small, the liquid also looks transparent. Blood is one such example. We can distinguish a true solution from a finely-dispersed emulsion or sol by using the **Tyndall effect**. If an intense beam of light is passed through a true solution, it will be invisible. However, through a fine colloid, the light will reflect off the individual particles and the beam will be visible (Figure 2.11).

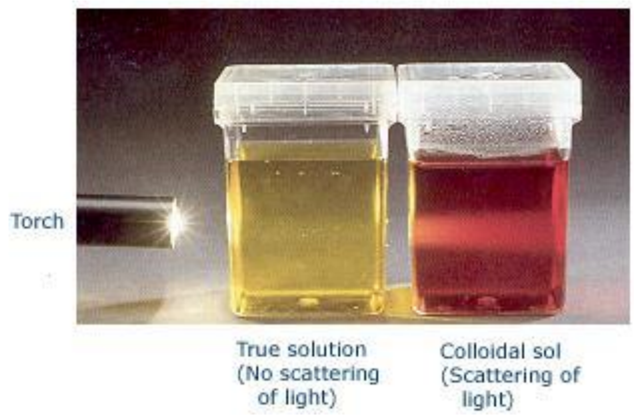

Figure 2.11 Using the Tyndall effect to differentiate a true solution from a colloidal sol.

CATEGORIES OF PURE SUBSTANCE

If we know that we have a pure substance, then that in turn can be categorized as an element or a compound (Figure 2.12).

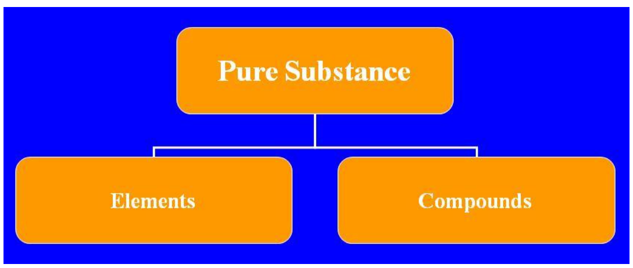

Figure 2.12 The classification of pure substances.

An ***element*** is a substance that cannot be broken down into simpler substances by chemical methods.

A ***compound*** is a substance that can be broken down into two or more simpler substances (often elements) by chemical means.

CATEGORIES OF COMPOUNDS

Compounds can be sub-divided. There are several different ways of categorizing a compound, but the most useful one at this point is to identify whether it is an acid, a base, or a neutral substance (Figure 2.13).

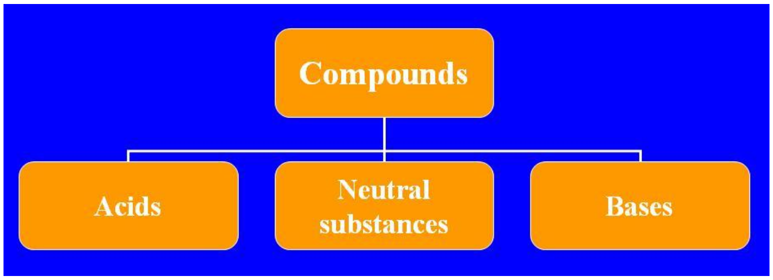

Figure 2.13 A common classification of compounds.

There are many definitions of an ***acid***. To get you started, we will use a very simplistic definition that an acid is a sharp-tasting, corrosive substance.

Again, there are several definitions of a ***base***, and at this point, we'll use the simple definition that a base is bitter-tasting, usually has a slippery feel, and can be corrosive.

A ***neutral substance*** is one that is neither an acid nor a base.

Obviously, we should not in practice use taste as a guide. In the laboratory, we use a substance called an ***indicator*** to identify an acid or a base. An indicator is a substance that has a different colour in acid or base. The traditional indicator is litmus, a compound extracted from lichens that grow on rocks. Litmus turns red in acid and blue in base. The most convenient way of testing for an acid or base is to use strips of paper (litmus paper) which has been impregnated with the litmus dye. There is both red and blue litmus paper.
If a strip of each is placed in an acid, the blue will change to red and the red will remain red.
If a strip of each is placed in a base, the red will change to blue and the blue will remain blue.
If a strip of each is placed in a neutral substance, the red will remain red and the blue will remain blue.

There are many other indicators. Some, like litmus, are found in plants, another example being red cabbage juice. However, the 'natural' indicators tend to be pale colours. Chemists have synthesized a wide variety of indicators which have intense colours and which provide much better results in the laboratory.

Categories of Elements

As elements are the fundamental building-blocks of matter, we will discuss them again in Section 2.8 and in more detail in later chapters. Elements, too, can be categorized, and here we will identify them as either a metal or a nonmetal. (Figure 2.14).

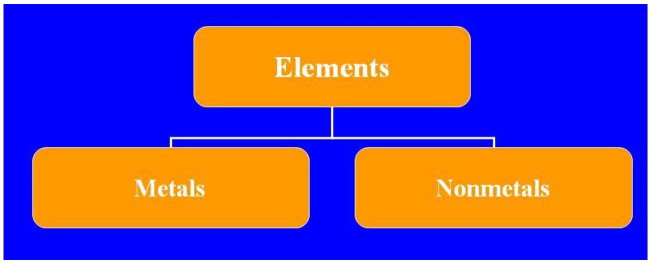

Figure 2.14 A common classification of elements.

A ***metal*** is shiny and conducts heat and electricity. Most metals are solids at room temperature.

Nonmetals have few properties in common. At room temperature, they can be solid, liquid, or gaseous. They are poor conductors of heat and, with one exception, are non-conductors of electricity.

2.7 Separation of Mixtures

In the previous section, we saw that matter often consists of mixtures, either heterogeneous mixtures or homogeneous mixtures (solutions). One task of chemists is to find ways of separating the components of a mixture. There are many circumstances were this is necessary, for example, chemists have devised ways to take seawater or contaminated well water and make the water drinkable. Here, we will see two simple ways of separating mixtures.

PURIFYING WATER

Pure water is an increasingly rare commodity on our planet. In Canada, we are fortunate to have ample quantities, but most countries are not so fortunate. In some countries, such as Bangladesh, the well water is contaminated with poisonous arsenic compounds, while in others, salt water has seeped into the groundwater. There are several ways of purifying the water, but a traditional and effective one of separating the components of a solution (a homogeneous mixture) is by ***distillation***.

In the laboratory version of this procedure, the salt water is placed in a distillation flask (Figure 2.15). The flask is then gently heated. The water boils and the gaseous water passes through a water-cooled condenser, causing it to revert to the liquid phase. The pure liquid water is then collected in a flask. The salt remains behind as it will not vapourise.

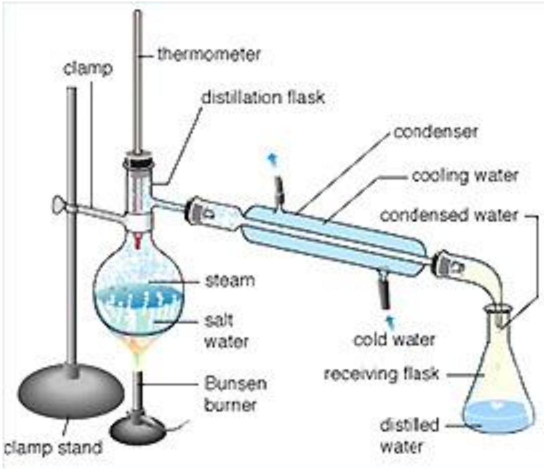

Figure 2.15 The process of distillation can be used to purify water

Distillation can also be used to separate two liquids, among the most widely-used example being the production of strong alcoholic beverages. Thus brandy is produced by taking wine which has a low alcohol content, and distilling it. Alcohol, and some of the flavourings, have a lower boiling point than water, thus the liquid that distills over has a much higher alcohol content.

SEPARATING SALT AND SAND

There are different ways of separating the components of heterogeneous mixtures. A common mixture used for practicing laboratory techniques is a salt-sand mixture.

The mixture can be placed in a beaker and water added. Salt dissolves in water. Thus stirring will result in all the salt crystals dissolving in the water. To separate the solution of salt in water and the solid sand, we can use the technique of ***filtration***. The simplest form of filtration involves a porous paper, called filter paper, and a filter funnel to hold the paper. These are placed in the mouth of a collection flask (Figure 2.16a) and the mixture poured in. The sand is retained on the paper, while the salt solution flows through and collects in the bottom of the flask.
The filter paper holding the sand can be placed in an oven and allowed to dry.

We have separated one of the components of the heterogeneous mixture, but the other component is now part of a homogeneous mixture – a solution of salt in water. To separate the salt, we can place the solution in an evaporating basin and heat the mixture. The water will evaporate, leaving pure dry salt (Figure 2.16b).

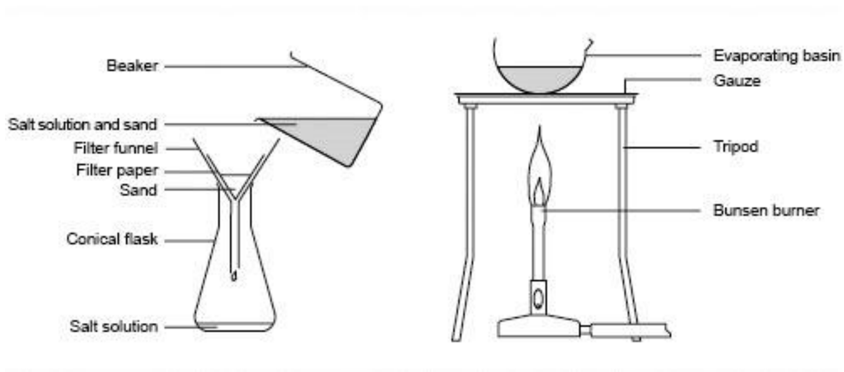

Figure 2.16 Separating a sand-salt mixture (a) the process of filtration and (b) the process of evaporation.

Salt is a vital part of our diet, even if in developed countries we are over-addicted to the compound. One of the traditional means of obtaining salt is through the construction of large shallow ponds which are filled with seawater. Using the Sun's heat (instead of a gas burner), the water evaporates and the salt crystals can be harvested (Figure 2.17).

Figure 2.17 Harvesting salt crystals from evaporation ponds in Indonesia.

2.8 Names and Symbols of some Chemical Elements

In Section 2.6, we saw that the simplest category of matter is the chemical element. About 120 chemical elements are known but only about 30 are of significance in this course. Scientists like to use abbreviations, and it was hundreds of years ago when only a few chemical elements were known, that chemists started to use symbols to represent the chemical elements. Some of the names and corresponding symbols are shown in Figure 2.18.

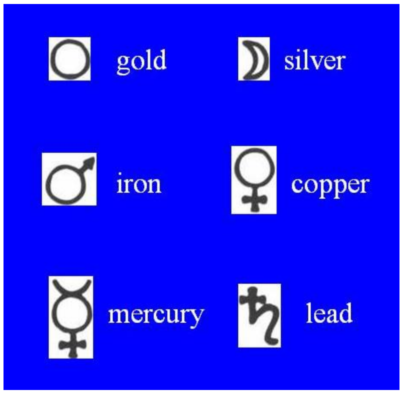

Figure 2.18 The names and early corresponding symbols used for some of the chemical elements.

As more elements were discovered, it became apparent that creating a different shaped symbol for each newly-discovered element was not practicable. In the early 1800s, the Swedish chemist, J.J. Berzelius, proposed that each element be represented by either a single letter or a two-letter combination and that is the system used ever since. In Table 2.2, the common elements are listed for which the first letter of their English name is used as the symbol. These symbols are common to every country which utilizes the Roman alphabet. There is one exception, in countries using Germanic languages, iodine is given the symbol J. Sulfur is correctly spelt with an "f" but "ph" is commonly used in Britain and often used in Canada.

Table 2.2 Common elements symbolized by the first letter of their name

Element	Symbol
Carbon	C
Fluorine	F
Hydrogen	H
Iodine	I
Nitrogen	N
Oxygen	O
Phosphorus	P
Sulfur	S
Uranium	U

A high proportion of elements have symbols derived from the first two letters of their name in English (Table 2.3)

Table 2.3 Common elements symbolized by the first two letters of their name

Element	Symbol
Aluminum	Al
Barium	Ba
Bromine	Br
Calcium	Ca
Helium	He

Lithium	**Li**
Neon	**Ne**
Silicon	**Si**

There are a few pairs of elements which have the first and second letter of their names in common. In these cases, the first and third letters of the name are chosen (Table 2.4).

Table 2.4 Common elements symbolized by the first and third letters of their name

Element	**Symbol**
Chlorine	**Cl**
Chromium	**Cr**
Magnesium	**Mg**
Manganese	**Mn**
Zinc	**Zn**

Finally, some elements have been known for hundreds or even thousands of years, and their symbols are derived from their Latin, Greek, or Arabic name (Table 2.5).

Table 2.5 Common elements symbolized by their historic name

Element	**Symbol**
Copper	**Cu**
Gold	**Au**
Iron	**Fe**
Lead	**Pb**
Mercury	**Hg**
Potassium	**K**
Silver	**Ag**
Sodium	**Na**
Tin	**Sn**

2.9 Where Next?

The study of chemistry involves making measurements. In the next chapter, the fundamental units of chemical measurements will be discussed.