1.2: What is chemistry?

Learning Objectives

- Define chemistry, physical properties, physical process, intensive and extensive properties, chemical properties, chemical process, and the law of multiple proportions.
- Be able to write and interpret chemical equations.
- Understand the scientific method and its steps, including observation, hypothesis, experiment, conclusion, law, theory, and how theory evolves knowledge.

Chemistry is the study of matter. More specifically, chemistry studies matter's composition, properties, and transformations.

The properties of matter are of two types, physical properties, and chemical properties, as illustrated in Fig. 1.3.1.

Figure 1.2.1: Chemical property relates to elemental composition and its changes. Physical property relates to appearance and its change. Source: https://www.hiclipart.com/free-trans...mnxsm/download

Physical property and physical process

Physical property

Physical property is the property that, when observed, does not change the elemental composition of the matter.

Examples include color, mass, volume, electrical conductivity, and heat conductivities.

Intensive properties

Physical properties that do not depend on the amount of matter are called intensive properties, e.g., color, density, and heat conductivity.

Extensive properties

Physical properties that depend on the amount of the substance, like, mass and volume, are called extensive properties.

Physical process

Any process that changes the matter somehow but does not change the elemental composition is called a physical process.

For example, melting solid to liquid or boiling liquid to a gas state are physical processes.

Mixtures can be separated using physical processes based on the differences in the physical properties of the constituents. Fig. 1.3.2 demonstrates that a magnetic material like iron can be separated from a nonmagnetic material like sulfur using a magnet.

The filtration process can separate a heterogeneous mixture of liquid and solid, like sand in water. Water passes through the filter paper leaving behind the sand particles on the filter.

The distillation process can separate homogeneous mixtures of solids in liquids or liquids in liquids based on the difference in the boiling points of the components. For example, salt dissolved in water separates by distilling off the water, leaving behind the solid salt. Distillation can also separate a mixture of two or more liquids if their boiling points differ; e.g., a distillation of crude oil separates the components based on their boiling points.

Chromatography is another technique often used to separate mixtures. For example, a mixture of inks is adsorbed on a porous paper and separated by ascending through the capillaries in the paper. The component of the ink mixture separate because some components have more ability to stay adsorbed in the solid phase and less ability to solubilize in the liquid phase than the other components. Fig. 1.3.2 Illustrates the physical separation processes described.

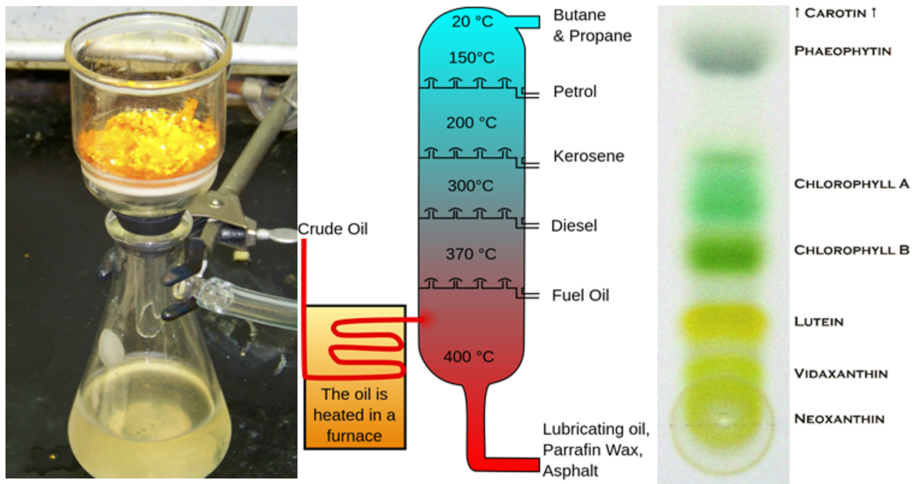

Figure 1.2.1: Filtration (left), a distillation of crude oil (middle), and chromatography of chlorophyll and other pigments of a leaf extract (right). Source: a) Smokefoot / Public domain, b) Crude_Oil_Distillation-fr.svg: Image originale:Psarianos, Theresa knott ; image vectorielle:Rogilbertderivative work: Utain () / CC BY-SA (http://creativecommons.org/licenses/by-sa/3.0/), c) No machine-readable author provided. Flo~commonswiki assumed (based on copyright claims). / CC BY-SA (https://creativecommons.org/licenses/by-sa/2.5)

Chemical property and chemical process

Chemical property

> Chemical properties relate to the change in the elemental composition of the matter.

For example, methane (CH_4) in natural gas is combustible -this is a chemical property. It means methane (\ce{CH4}\)) and oxygen (\ce{O2}\)) change their elemental composition to become carbon dioxide (\ce{CO2}\))and water (\ce{H2O}\)) and release heat after ignition.

Chemical process

> A process that changes the elemental composition is called a chemical process or chemical reaction.

For example, photosynthesis is a chemical process that converts carbon dioxide and water to glucose using energy from sunlight.

Chemical equation

> A chemical equation represents a chemical reaction in the form of symbols of elements and compounds involved.

Substances consumed in a chemical reaction are **reactants;** the substances formed are **products**. The reactants are written on the left side, separated by a plus sign, followed by an arrow, and products are on the right side of the arrow, as illustrated in Fig. 1.3.3. For example, the following chemical equation represents the combustion of methane.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Note that the chemical formula without any preceding number, e.g., O_2 and CO_2, represents one molecule or a unit amount of the chemical. The number preceding the formula is called the **coefficient**, and it represents the number of particles or the number of units involved. For example, the coefficient of 2 in $2H_2O$ in the above chemical equation represents two molecules of water formed or two moles of water formed, where the mole is the unit amount. Note that the chemical composition has changed in the chemical reaction. Before, one substance was carbon and hydrogen atoms in a 1:4 ratio, and the other substance was oxygen atoms. After the reaction, one substance is carbon and oxygen atoms in a 1:2 ratio, and the other is hydrogen and oxygen in a 2:1 proportion.

The physical state of matter is sometimes shown in a chemical equation by the following symbols: (s) for solid, (l) for liquid, (g) for gas, and (aq) for a substance dissolved in water, as illustrated in Fig. 1.3.3.

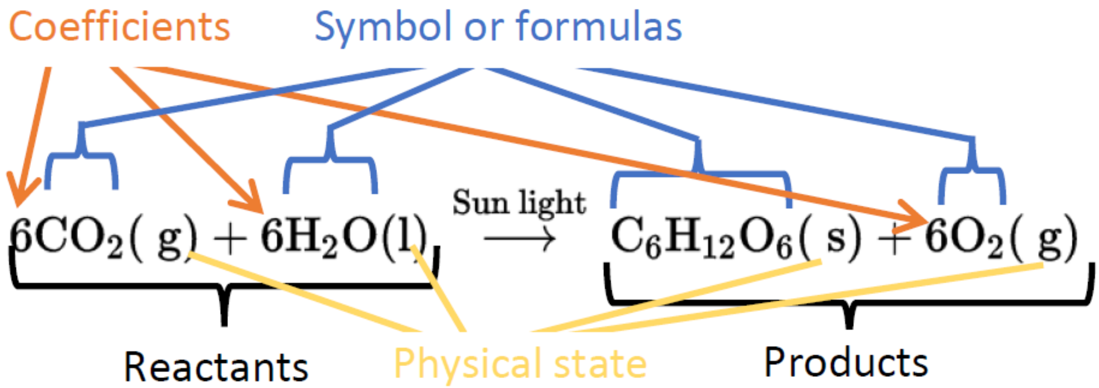

Figure 1.2.3: Components of a chemical equation (Copyright: Public domain).

Scientific method -how does science make progress?

Chemistry is one branch of science. Science knowledge is gathered systematically from generation to generation through the scientific method.

> The scientific method starts with making observations, giving a tentative explanation, i.e., hypotheses, testing the hypothesis, i.e., experiment, and deducing a conclusion from the investigation. A truth found through repeated experiments becomes a law, and a comprehensive explanation of related findings gathered over time becomes a theory.

Figure 1.2.4 illustrates these scientific method steps and is described below.

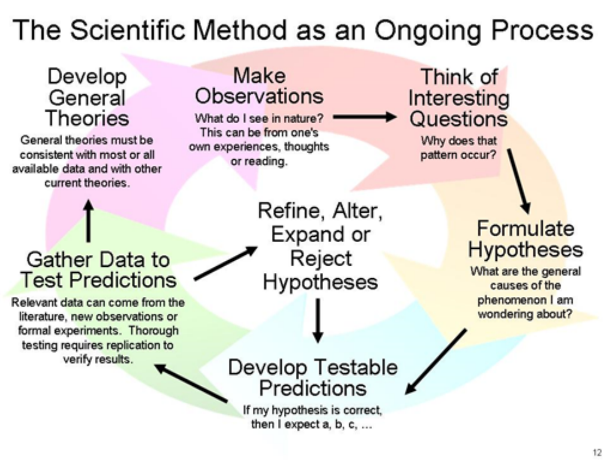

Figure 1.2.4: Illustration of the scientific method. Source: Whatiguana / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)

Observation

Observation is the active acquisition of information from a primary source. For example, you fill the air in a car tire and notice that the pressure reading on the gauge increases. This is an observation.

Hypothesis

A hypothesis is a tentative explanation of the observation or a law based on available scientific knowledge. For example, John visits a friend and starts sneezing. The friend says I have a cat, and you might be allergic to cats. This tentative explanation of

John's sneezing is a hypothesis.

Experiment

Experiments test the hypothesis. For example, John visits another friend with a cat to determine whether he is allergic to cats. If he sneezes in this experiment, it supports the hypothesis. If he does not sneeze, the experiment disproves the hypothesis.

Conclusion

A hypothesis proven true becomes a conclusion. The hypothesis is rejected or revised if the experiment results do not support it. For example, scientists worldwide and in different periods attempted to convert other metals to gold and failed every time. It concluded that elements do not transform into the more simple matter by any physical or chemical reaction.

Law

It becomes law if an observation is universally true in repeated experiments. Examples of law are the following.

1. The pressure of any gas is directly proportional to the amount of gas if temperature and volume are kept constant, is Avogadro's law.
2. The proportion of atoms of different elements in a compound is always the same, a **law of constant proportion**.
3. Mass before any chemical reaction is the same as after the chemical reaction, i.e., mass is conserved in any chemical reaction or process, a **law of conservation of mass.**

Theory

A theory is a comprehensive explanation based on scientific principles to explain several laws and conclusions on a related topic. For example, the knowledge gathered over time on the properties of matter led Dalton to put forward Dalton's atomic theory.

Dalton's atomic theory

Postulates of Dalton's atomic theory are:

1. elements are composed of tiny indivisible particles called atoms;
2. atoms of any one element are identical to each other but different from atoms of any other element;
3. Atoms of different elements react with each other in a constant whole-number ratio to produce a compound;
4. atoms in a compound separate and recombine to give new material. Still, the atoms are neither created nor destroyed in the reaction.

These postulates explain the properties of the matter described in the previous sections. For example, elements can not convert to simpler substances by any physical or chemical process because they are composed of one type of atom, and atoms are indivisible according to the first postulate. Compounds can convert to elements by the chemical reaction because the atoms in the compounds can separate and recombine according to the fourth postulate.

What happens after a theory is accepted?

The theory goes through the test of time. If it keeps explaining the results of future experiments, it remains valid. It is either rejected or revised if it is disproved or cannot explain some observations of future investigations. For example, "atoms are not divisible" is no more considered valid. According to current knowledge, atoms can divide into **subatomic particles** like electrons, protons, and neutrons. However, the subatomic particles do not represent the element anymore.

"Atoms of the same element are the same" has been revised because isotopes are atoms of the same element that are different in some respects. The statement "atoms are neither created nor destroyed" is still valid for chemical reactions but does not hold in nuclear reactions where atoms of one element can convert to atoms of other elements. Similarly, matter can be converted into energy and vice versa in nuclear reactions, following Einstein's famous equation: $E = mc^2$, where E is energy, m is mass, and c is the speed of light. It means the law of conservation of mass and the law of conservation of energy are not valid individually in a nuclear reaction. Still, the mass and energy together are conserved in nuclear reactions. These are examples of revisions made in theory over time.

The theory is a basic knowledge that allows the prediction of new laws and leads to new ideas on related concepts. For example, Dalton predicted the law of multiple proportions, also known as Dalton's law, i.e., if atoms of two elements can combine in one whole number ratio to give a specific compound, they may also mix in another whole number ratio to give another compound.

Law of multiple proportions

When two elements form more than one compound, the proportions of the atoms of elements in those chemical compounds can be expressed in small whole-number ratios, or the ratio of the masses of the second element in the two compounds that combines with a fixed mass of the first, is a small whole number ratio.

For example, hydrogen and oxygen atoms can mix in a 2:1 ratio to provide water (H_2O). Still, they can also combine in a 2:2 ratio to give hydrogen peroxide (H_2O_2), a different compound. Similarly, carbon and hydrogen combine in a 1:4 ratio to make methane (CH_4); they can combine in a 2:6 ratio to make another ethane compound (C_2H_6).
