1. The Elements

Figure 1.1: Styrofoam boxes are commonly used in Singapore to package food

When we buy takeaway food, do you notice the packaging that our food comes in? At times, the stall owner will put our food in a styrofoam box (Figure 1.1); other times, it could be in a plastic container or even wrapped in a plastic-coated paper sheet.

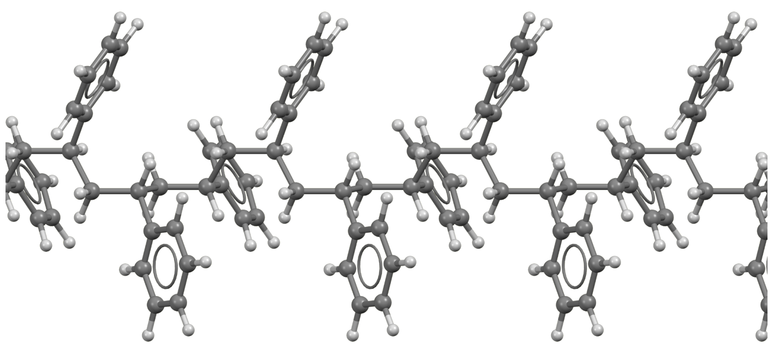

Figure 1.2: A molecular model of polystyrene, commonly known as styrofoam

However, research has shown that the chemicals used in our food packaging come with health risks, including cancer and cardiovascular diseases. For example, polystyrene (Figure 1.2), also known as styrofoam, is a type of carcinogenic plastic that is associated with an increased risk of cancer. As such, many researchers are trying to find suitable packaging alternatives that are both cheap to produce and safe for food.

In order to analyse the materials used to manufacture food packaging, scientists must first understand the **chemical composition** of a substance. What exactly is polystyrene made of?

What causes the carcinogenic nature of polystyrene? These questions will then guide the scientist to find possible solutions to tackle the issue at hand — that is, finding a suitable, alternative packaging material.

1.1 Chemical Composition of Materials

Figures 1.3 – 1.5: Water, table salt, iron nails with rust

The world around us is made of different materials with different properties and purposes.

For example, water (Figure 1.3) is a liquid at room temperature and is essential to our daily lives. We consume water to survive, and we use water in the chores we do, from showering to washing the dishes. Sometimes, we may hear water being referred to as H_2O.

What do the H and O represent? H stands for hydrogen, and O stands for oxygen, both of which are **elements**. Elements are the basic building blocks that make up all forms of matter, and they cannot be split into simpler substances. All elements come in the form of **atoms**, meaning each element has its own unique atom that interacts with other atoms to form different substances.

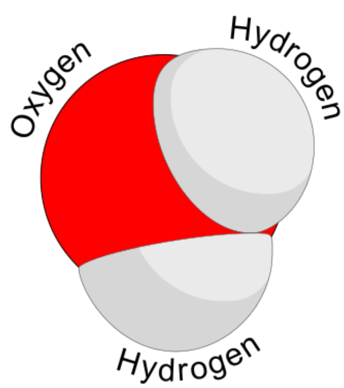

Figure 1.6: A water molecule

Therefore, when we state that water is H_2O, we are referring to the fact that every water particle, called a **molecule**, consists of two hydrogen atoms and one oxygen atom (Figure 1.6). In a single drop of water, there are over 1.5 sextillion (1,500,000,000,000,000,000,000) molecules of H_2O.

Currently, there are 118 elements that have been identified by researchers, which can be seen in the **Periodic Table of Elements** (Figure 1.7). The table arranges the elements by atomic size, and groups elements that exhibit similar properties by column.

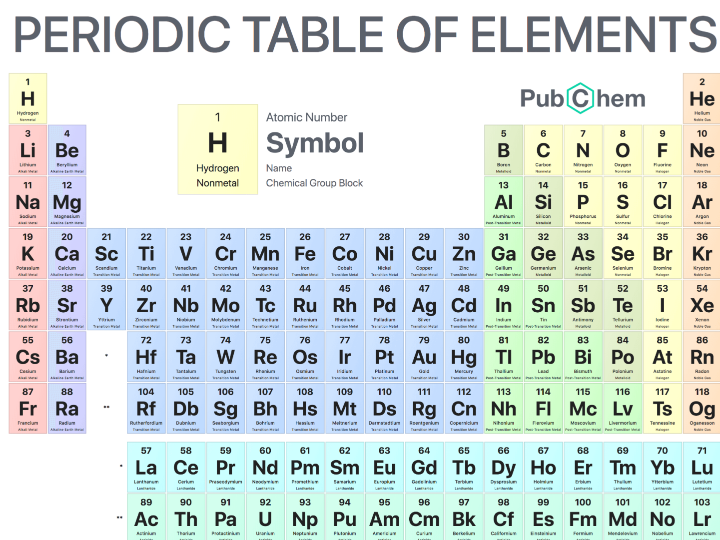

Figure 1.7: The Periodic Table of Elements

Every element is represented by a unique **symbol** of one to two letters, as seen with H for hydrogen and O for oxygen. In addition, every element is assigned a unique **atomic number**, such as 1 for hydrogen and 8 for oxygen.

Depending on the combination of atoms, we are able to synthesise many different substances called **compounds**, which have vastly different properties. For example, the table salt (Figure 1.4) that we use to season our food is actually only made up of two elements, sodium and chlorine! This is why it is also known as sodium chloride. Unlike water which has distinct molecules formed by hydrogen and oxygen atoms, sodium chloride has a crystalline structure with strong bonds between sodium and chlorine atoms.

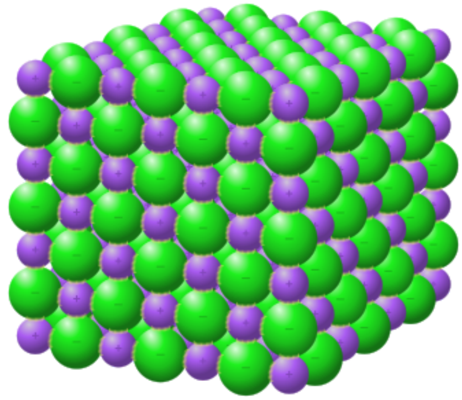

Figure 1.8: The crystalline structure of sodium chloride, where sodium atoms are in purple and chlorine atoms are in green

The strong bonds between these atoms are what causes this compound to be solid at room temperature.

1.2 Chemical Interactions & Changes

When we take a teaspoon of table salt, however, and stir it into a glass of water, we realise that the solid crystals of sodium chloride (NaCl) seemingly disappear. The salt has **dissolved** in the water, and the salt solution is now in an **aqueous** state instead.

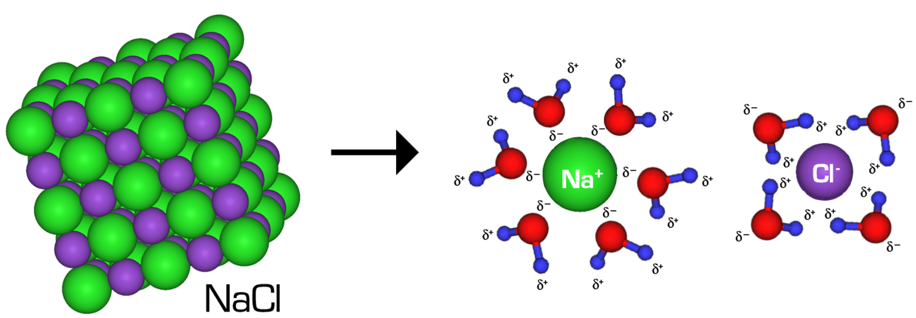

Figure 1.9: NaCl dissolving in water

When NaCl dissolves in water, the salt dissociates into **ions**, a form of charged particles that are strongly attracted to water molecules. NaCl dissociates into two ions: Na^+ and Cl^-. Surrounding both of these ions are H_2O molecules (Figure 1.9), and the strong attraction between the ions and the water molecules is what makes the salt crystal able to dissolve in water.

This is a form of **chemical interaction**. Chemical interactions happen all around us. Ever wonder why liquid water freezes into solid ice, or why certain cold countries sprinkle salt on the icy roads? Different substances have vastly different qualities and characteristics, and these differences are what make **chemical changes** possible.

Another form of chemical change is the formation of new substances that arise from a chemical reaction. One such example in our daily lives is the **corrosion** of certain metallic items, such as iron nails (Figure 1.5), also known as rust. The reddish-brown substance that coats the iron nail may be a hindrance when trying to hammer it into a wall, but have we ever stopped to wonder why an iron nail rusts in the first place?

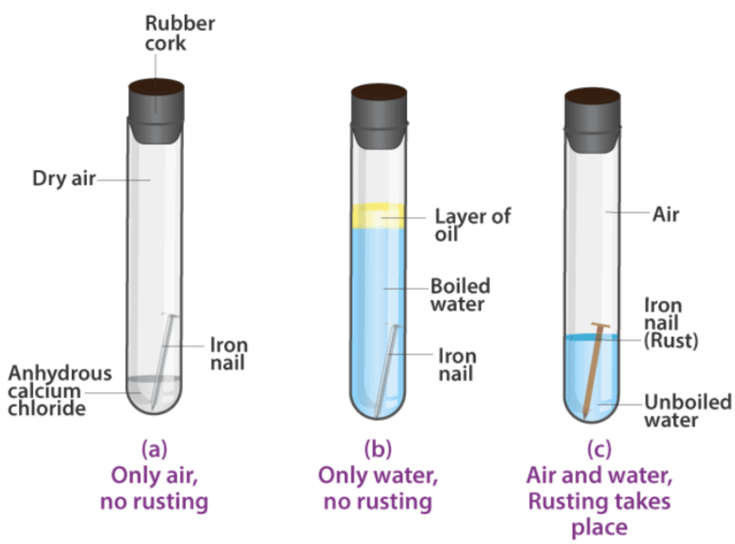

Figure 1.10: An experiment concluding that both air and water are needed for rust to form on an iron nail.

A simple experiment (Figure 1.10) utilises three closed test tubes with iron nails inside each of them. Table 1.11 summarises the setup shown in Figure 1.10.

Test tube	**Independent variable**	**Setup**
(a)	The nail is only exposed to air	The nail is placed in the test tube with anhydrous calcium chloride, which removes the moisture in the air of the test tube, keeping the air “dry”.

(b)	The nail is only exposed to water	The nail is submerged in water which has been boiled to remove the dissolved air. A layer of oil is also added to the top to prevent the air in the test tube from dissolving into the water.
(c)	The nail is exposed to both air and water	The nail is partially submerged in water and is exposed to air. There is no layer of oil on the water, which allows the air in the test tube to dissolve into the water.

Table 1.11: The setup for the experiment shown in Figure 1.10

The experiment shows that exposure to both air and water is needed for the iron nail to rust. This is indeed the case — the rust on the iron nail is a substance called iron oxide. Iron oxide is formed when the iron molecules on the surface of the nail react with oxygen molecules, but only in the presence of water molecules.

Chemical reactions and the formation of substances play a huge role in the world today. Certain processes, such as manufacturing medicines, require factories that carry out hundreds of different chemical reactions which form different substances, in a field known as **organic chemistry**. Our bodies also utilise chemical reactions to form proteins and other physiological substances, in a field known as **biochemistry**. Researchers also need to assess and analyse different materials to find the most suitable materials for building different things, in a field known as **material chemistry**. There are so many more fields of chemistry, and even more fields of science that rely on chemistry for their research, all of which are important to our world and society. This makes it fitting for chemistry to be known as the **central science**.

1.3 Analysing the Properties of Materials

When researchers analyse the chemical composition of materials, they are often able to hypothesise a certain property of a material from the atoms or groups of atoms in the molecular structure of the material. For example, research has shown that all salt compounds with sodium are able to dissolve in water. Therefore, when we are presented with an unknown salt sample, knowing that Na is one of the elements that the salt is composed of, we are able to make an educated guess that the salt is dissolvable.

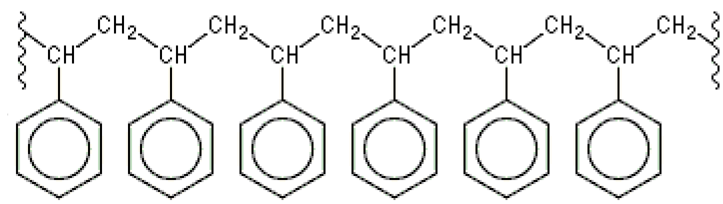

Figure 1.12: Skeletal structure of polystyrene (compare this with Figure 1.2!)

Figure 1.12 shows the skeletal molecular structure of polystyrene, which is a polymer (an extremely long molecule chain of repeating segments called monomers) consisting of carbon and hydrogen. The molecule also contains hexagonal rings of carbon atoms known as benzene rings.

Compounds that contain a benzene ring, which is also known as an arene functional group, are called "aromatic compounds". Benzene may also exist as a molecule of its own (Figure 1.13).

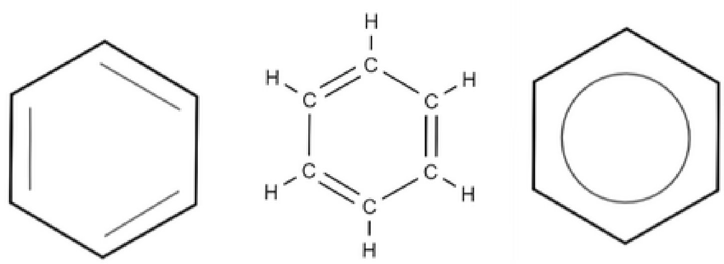

Figure 1.13: Different depictions of the same molecule, benzene

Through research, benzene is known to be carcinogenic, where long-term exposure to benzene in the air greatly increases the risk of cancers such as leukemia. It is also known that aromatic compounds and other benzene derivatives are similarly carcinogenic, although with varying degrees.

Polystyrene contains the arene functional group, which caused scientists to hypothesise that the compound could also be carcinogenic. Indeed, with further research, polystyrene is now considered to be a highly probable carcinogen, noting the carcinogenic nature of its monomer, styrene. While many food authorities still consider it safe for its uses in food packaging due to its low carcinogenicity, many consumers are starting to consider other alternatives for their takeaway meals.

This is a prime example of how researchers can utilise the chemical composition of materials to hypothesise important properties that affect how a material can be used for different purposes.

1.4 Further Reading: The History of the Periodic Table