# 8 Model of Matter – Atoms and Molecules

There are particles around us so small that we cannot see them with our naked eye. These particles can be either atoms or molecules. If they are so small, how do we then describe these particles? The atomic model will allow us to describe the structure of an atom so that we can understand the world around us better.

- Elements and Compounds (8.1)
- The Bohr Model (8.2)
- Atoms in Elements (8.3)
- Molecules (8.4)
- Ionic Compounds (8.5)
- Can Atoms and Molecules Mix Together? (8.6)

## 8.1 Elements and Compounds

Many substances around us can be either elements or compounds. How do we differentiate between an element and a compound? Do they have properties which are similar?

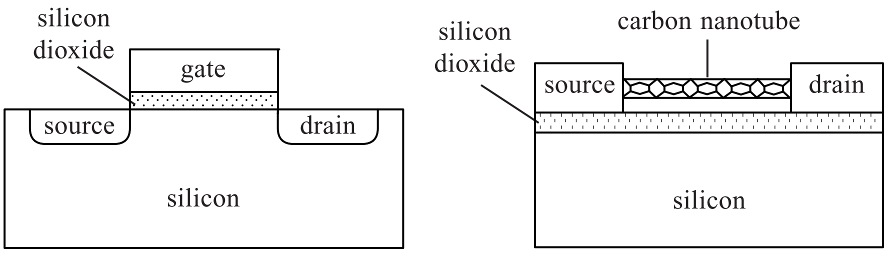



*Fig 8.1 Silicon (an element) and silicon dioxide $SiO_2$ (a compound we commonly call sand or silica) are used to make transistors, tiny devices (size of 14 nm) used to control the current flowing between two terminals (source and drain). In 2019, scientists created a microprocessor that consists of carbon nanotube (a form of the element, carbon) transistors. Such processors are energy efficient and can improve smartphone battery life.*

1. Elements and compounds are pure substances with fixed melting points and boiling points.

2. Elements are the simplest substances that cannot be broken down into two or more simpler substances.
3. Elements can be classified into metals (e.g. sodium Na and magnesium Mg) and non-metals (e.g. nitrogen $N_2$ and chlorine $Cl_2$).
4. Compounds are substances that are made up of two or more elements chemically combined together in a fixed percentage.
5. Some compounds such as water $H_2O$, carbon dioxide $CO_2$ and methane $CH_4$ have low melting and boiling points.
6. Some compounds such as sodium chloride NaC*l* and magnesium oxide MgO have very high melting and boiling points.

## **8.2** The Bohr Model

Presented by Niels Bohr and Ernest Rutherford in 1913, this model of the atom was widely accepted to explain the structure of an atom – something so small that we cannot even see with the naked eye.

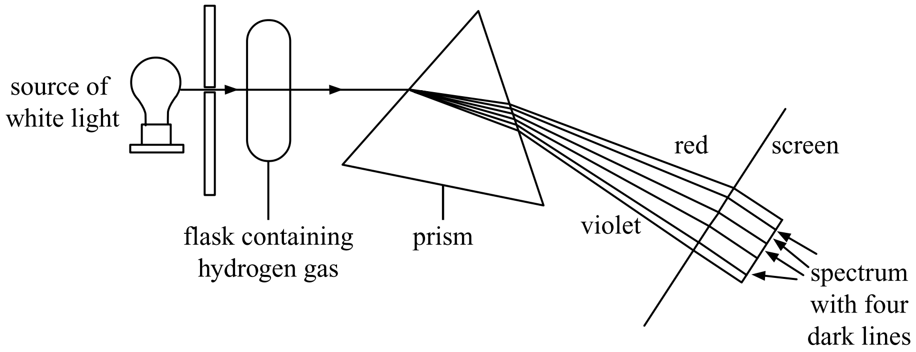


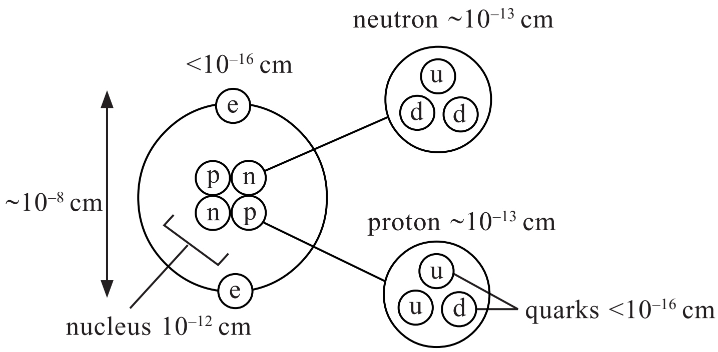

*Fig 8.2 We learned that white light can be dispersed to give a spectrum of colours. If the white light is passed through hydrogen gas, dark lines appear in the spectrum. These dark lines are due to electrons absorbing light energy and jumping from one energy level to another.*

1. All matter is made up of atoms. The model of the atom has undergone many changes throughout history. The Bohr model will be used to assist in the understanding of the atom.

2. In the Bohr model, the atom is an entity that is electrically neutral and is made up of a positively charged nucleus (protons and neutrons) with negatively charged electrons moving around the nucleus.
3. The small and dense nucleus comprises subatomic particles called **protons** which are positively charged and **neutrons** which are neutral.

**Extra**

Subatomic particles are made of elementary or fundamental particles which are not composed of other particles. A proton consists of two up quarks and one down quark, while a neutron consists of one up quark and two down quarks.




4. The relative charge of an electron is taken to be –1 and the relative charge of a proton is +1. The atom is effectively neutral because the number of electrons equals the number of protons.
5. The mass of an electron is negligible compared to the masses of the proton (taken to be 1 unit) and neutron (taken to be 1 unit). Therefore, the mass of the atom is concentrated in the nucleus.
6. Each element is made up of a unique number of protons. The Periodic Table arranges the elements in order of increasing proton number.
7. For example, the lithium atom contains three protons and four neutrons in its nucleus and three electrons outside the nucleus.

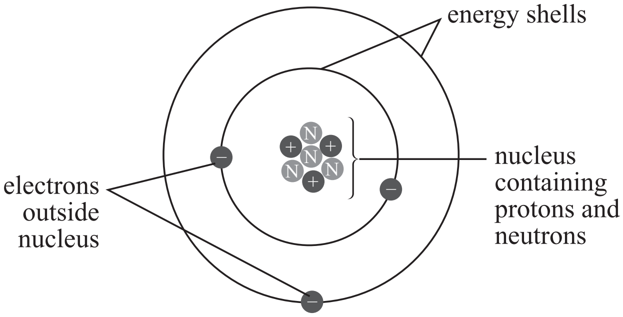



*Fig 8.3 The Bohr model*

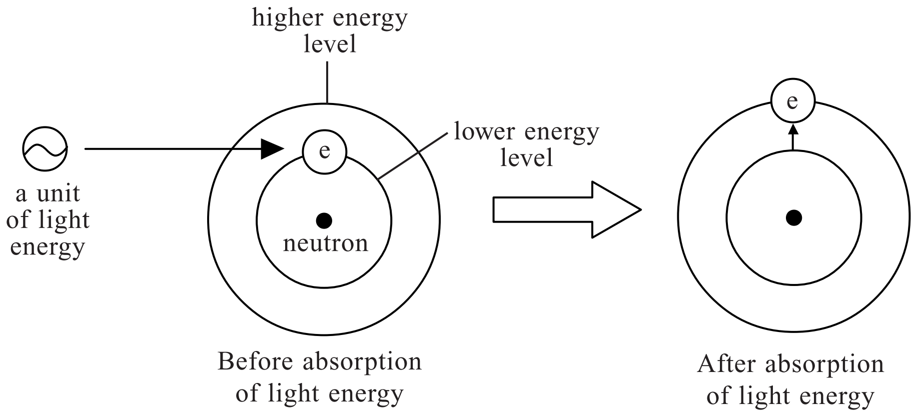
**Note**

For lower secondary science, the knowledge of the arrangement of electrons in the shells is not required.

8. In the Bohr model, the electrons move around the nucleus in orbits called energy shells or energy levels. The electrons in the outermost shell are referred to as the **valence electrons**. For example, the lithium atom has one valence electron.

**Note**

Ernest Rutherford discovered that an atom consists of electrons moving around a dense positively charged nucleus in the centre. However, the model does not explain why the electrons do not radiate energy and end up in the nucleus. Bohr modified Rutherford's atomic model by explaining that electrons move in orbits of fixed energy. An electron can absorb a unit of light energy and jump from a lower energy level to a higher energy level resulting in dark absorption lines shown in Figure 8.2.




9. The **atomic or proton number** of an element is the number of protons in each atom. Every element has a unique number of protons in its atoms.
10. **Optional** for N(A)

    The mass or nucleon number of an element is the sum of the numbers of protons and neutrons in each atom. For example, the atomic number of lithium is 3 while its mass number is (3 + 4 =) 7.
11. The **symbol** of lithium can be represented as $^{7}_{3}Li$.

12. Summary:

| Subatomic particle | Inside or outside the nucleus | Relative charge | Relative mass |
|---|---|---|---|
| Electron | Outside | −1 | $\frac{1}{1836}$ |
| Proton | Inside | +1 | 1 |
| Neutron | Inside | 0 | 1 |

*Table 8.1 Subatomic particles*

13. In Period 2 (second row) of the Periodic Table, from Li to Ne, the charge of the nucleus increases from +3 to +10 as the proton number increases from 3 to 10. Hence, the number of electrons increases from 3 to 10 to neutralise the positive charges.

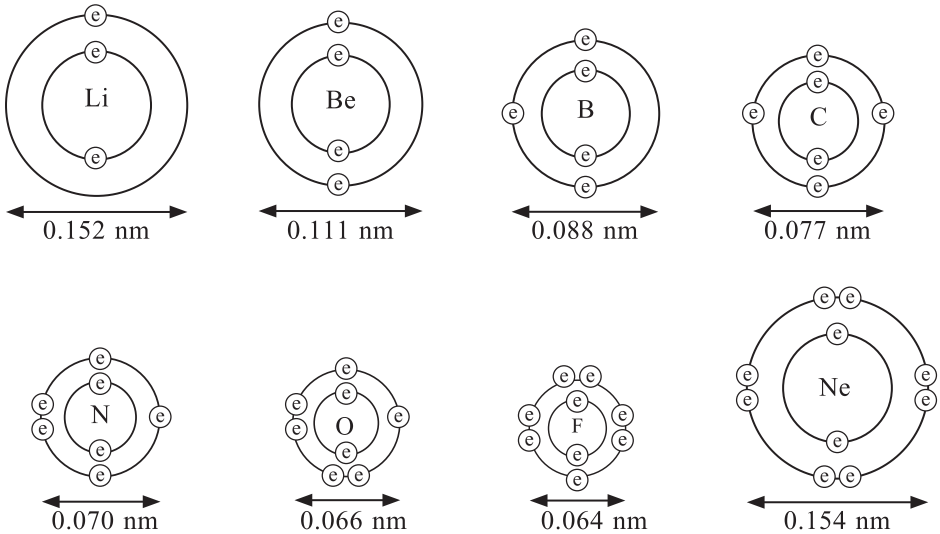


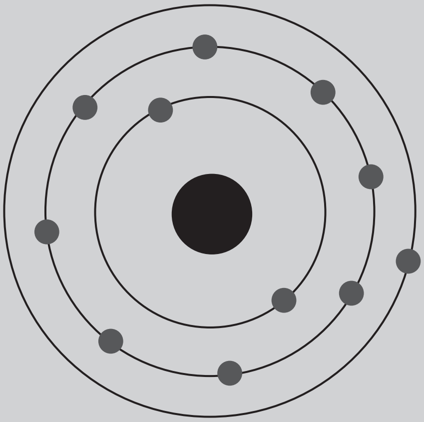

*Fig 8.4 Atoms in Period 2 of the Periodic Table*

**Size of Atoms**

1. Atoms are of the size ranging from 0.01 nm to 0.3 nm. (1 nm = $10^{-9}$ m)
2. Different atoms have different atomic size or atomic radius.
3. Down the Group (vertical column) of the Periodic Table, the atoms become larger.
4. Across the Period (horizontal row) from left to right, the atoms become smaller.

## SCIENCE AROUND US

In the study of the atoms, the following diagram was used to represent the electrons and nucleus in a neutral atom.



State what a 'neutral atom' means and, with the aid of the Periodic Table, identify the element. Explain how you deduce the number of each type of subatomic particles it has. [4]

**ANSWER**

*A neutral atom does not have an overall charge. There are 11 electrons in the above diagram of the atom. If it is neutral, the atom must also contain 11 protons in its nucleus.*

*In the Periodic Table, this element is sodium, symbol: ${}^{23}_{11}Na$, with an atomic number of 11 and a mass number of 23. Therefore, there are (23 – 11 =) 12 neutrons in the nucleus of the atom.*

## 8.3 Atoms in Elements

**Atoms in Metals**

1. In the Periodic Table, Groups I (e.g. sodium Na), II (e.g. magnesium Mg) and III (e.g. aluminium A*l*) are metals. There is also a block of elements between Groups II and III elements called **transition metals** (e.g. copper Cu and iron Fe).
2. At room temperature, metals are solids (except for mercury Hg). The atoms in pure metals are packed together closely in a regular arrangement.

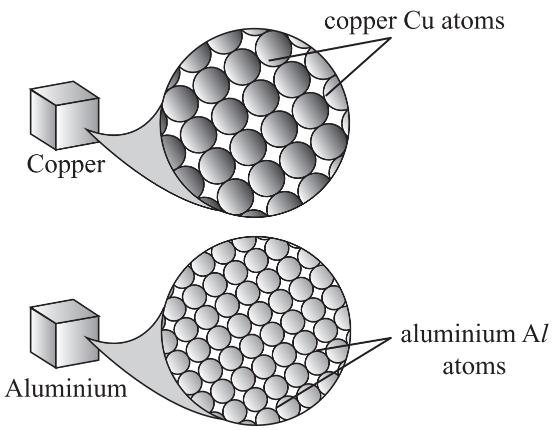



*Fig 8.5 Regularly arranged metal atoms*

3. In a metallic solid, **atoms** are **arranged** in a lattice-like 3D structure where there is a regular array of **metal** cations surrounded by a sea of delocalised electrons.

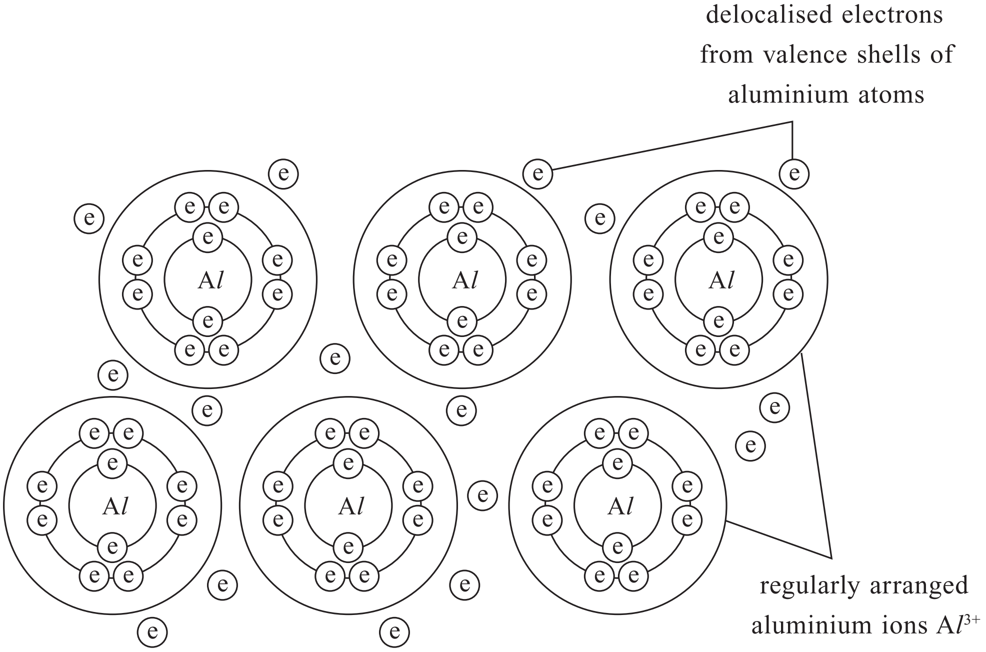



*Fig 8.6 In aluminium, the atoms have lost their three valence electrons to the surrounding sea of electrons.*

**Atoms in Noble Gases**

1. The elements in Group 0 (e.g. helium He and argon Ar), which is the last Group of the Periodic Table, are known as **noble gases**.
2. The atoms in noble gases are far apart. They move about randomly and freely in all directions at high speeds.
3. Noble gases are commonly used in lighting because of their lack of chemical reactivity. For example, argon is used in light bulbs as it will not react with the tungsten used to make the filaments of the bulbs.

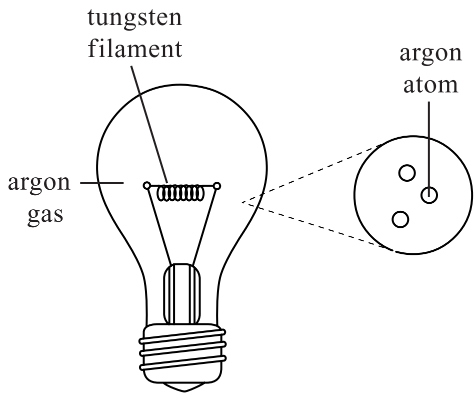



*Fig 8.7 The filament light bulb is filled with argon to prevent the filament from being oxidised.*

## 8.4 Molecules

Aspirin, a molecular compound, is used to reduce fever and relieve mild to moderate pain from conditions such as muscle aches, toothaches, common cold, and headaches. It is solid at room temperature but has a low solubility in water.

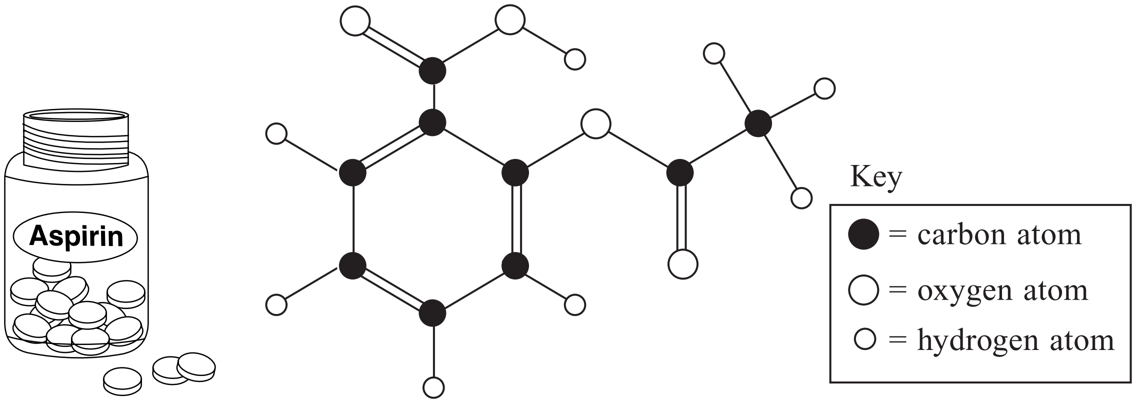



*Fig 8.8 When you get injured, the damaged tissue releases chemicals that intensify electrical signals coming from the nerves, increasing the pain felt. Aspirin ($C_9H_8O_4$) reduces pain by blocking the effects of certain enzymes that create these chemicals.*

**Molecules of Non-metallic Elements**

1. Groups IV (e.g. carbon C), V (e.g. nitrogen $N_2$), VI (e.g. oxygen $O_2$) and VII (e.g. chlorine $Cl_2$) elements are non-metals. Other than the noble gases, non-metallic elements often exist as molecules.
2. Molecules are groups of two or more atoms that are chemically combined.
3. **Molecules of elements** consist of the same atoms joined together chemically.
4. Each chlorine molecule consists of two chlorine atoms joined together chemically
5. In chlorine gas, the molecules are far apart. They move about randomly and freely in all directions at high speeds.
6. We write the chemical formula of chlorine as '$Cl_2$' instead of '$Cl$'. We say that chlorine is a diatomic molecule.

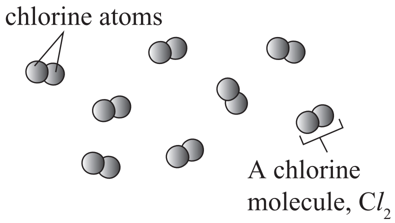



*Fig 8.9 The arrangement of chlorine molecules in chorine gas*

7. Diatomic molecules are molecules containing two atoms. Elements that exist as diatomic molecules include hydrogen $H_2$, oxygen $O_2$, nitrogen $N_2$, bromine $Br_2$ and iodine $I_2$.
8. Both oxygen gas ($O_2$) and ozone ($O_3$) are molecules of the same element, oxygen. Oxygen molecule is diatomic but ozone molecule is triatomic.

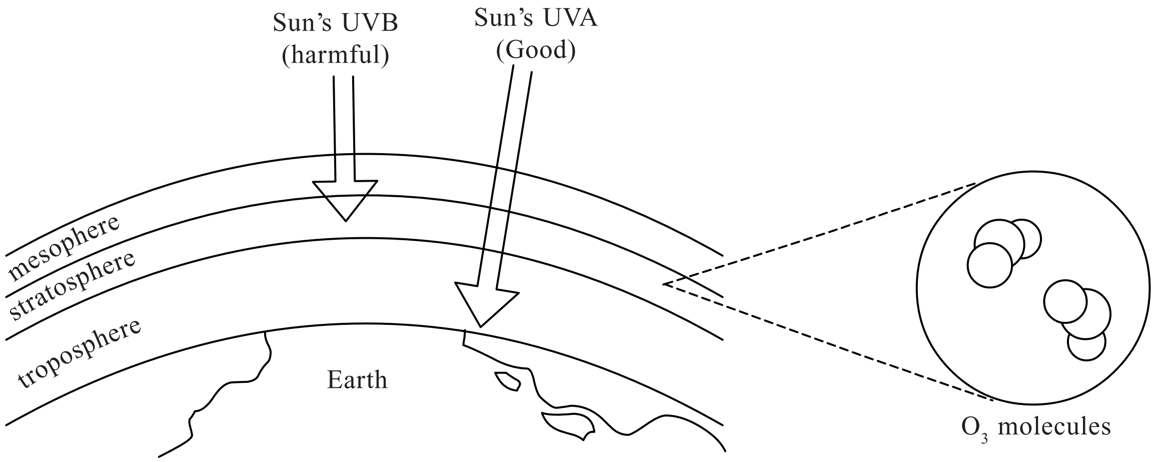



*Fig 8.10 Oxygen $O_2$ occurs in our troposphere while ozone $O_3$ occurs in the stratosphere. This ozone layer absorbs harmful UVB from the Sun. UV is harmful as it can cause skin cancer and eye diseases.*

9. Iodine is a solid at room temperature and pressure. The molecules are arranged regularly in fixed positions.

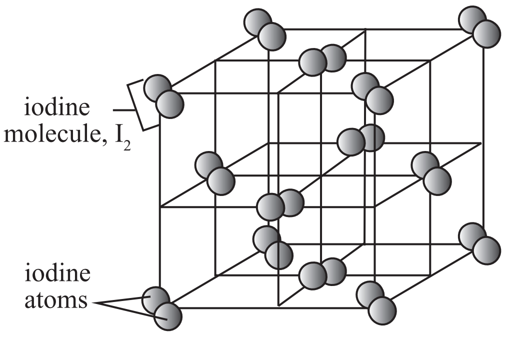



*Fig 8.11 The arrangement of iodine molecules in solid iodine*

**Note**

The $I_2$ molecules in solid iodine should be closely packed together. Here, they are drawn further apart to clearly show their arrangement.

10. Other non-metallic elements such as phosphorus $P_4$ and sulfur $S_8$ consist of more than two atoms in their molecules. They exist as polyatomic molecules. There are also huge molecules such as molecules of Buckyball which are each made up of 60 carbon atoms joined together.
11. Carbon in solid state exists as different giant molecules in diamond, graphene (2D material), graphite and nanotubes.

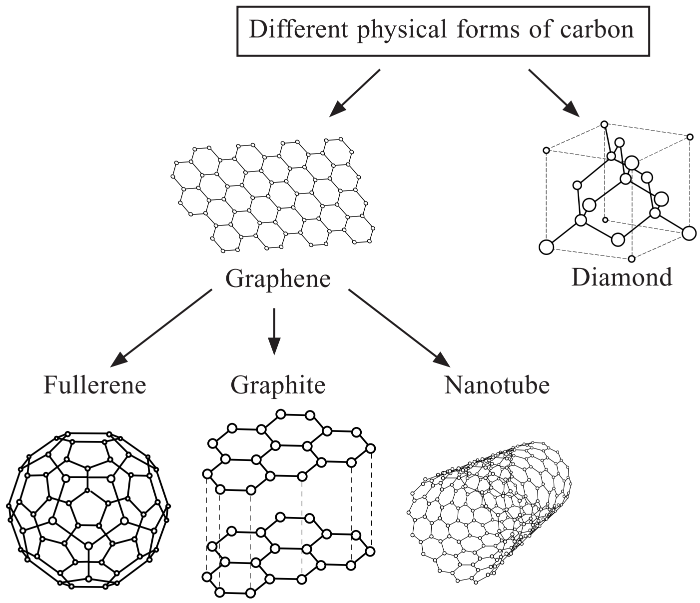
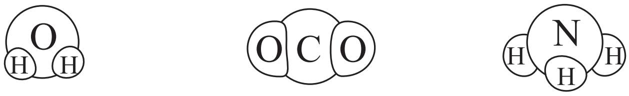



*Fig 8.12 Different forms of the element carbon*

**Molecules of Compounds**

1. Different non-metallic atoms can join together through chemical reactions to give molecules of compounds.
2. **Molecules of compounds** consist of different atoms joined together chemically.
3. One water molecule contains an oxygen atom chemically joined together with two hydrogen atoms.
4. One carbon dioxide molecule contains a carbon atom chemically joined to two oxygen atoms.

5. One ammonia molecule contains a nitrogen atom chemically bonded to three hydrogen atoms.




Water molecule, $H_2O$ | Carbon dioxide molecule, $CO_2$ | Ammonia molecule, $NH_3$

*Fig 8.13 Some simple molecules of compounds*

6. At room temperature, water is a liquid. The water molecules are close together. They slide past one another randomly.
7. At room temperature, carbon dioxide is a gas. The carbon dioxide molecules are far apart. They move randomly and freely in all directions at high speeds.
8. More examples of molecular compounds:

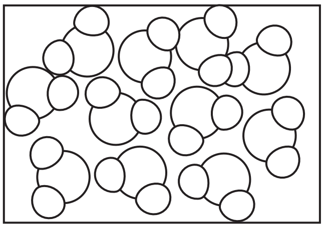


*Fig 8.14 The arrangement of water molecules in liquid water*

| | **Molecular gaseous compounds** | **Molecular liquid compounds** | **Molecular solid compounds** |
|---|---|---|---|
| **Examples** | Carbon dioxide $CO_2$, ammonia $NH_3$, hydrogen chloride $HCl$ and methane $CH_4$ | Water $H_2O$, ethanol $C_2H_5OH$ and ethanoic acid $CH_3CO_2H$ | Sugar $C_6H_{12}O_6$ and naphthalene $C_{10}H_8$ |

9. **Optional** for N(A)

There are also giant molecular compounds. Silicon dioxide $SiO_2$ (common name: sand, silica) is a giant molecule made up of two different elements, silicon and oxygen atoms which are linked to each other in a regular arrangement. Carbon dioxide $CO_2$ on the other hand, is made up of carbon and oxygen atoms but exists as simple molecules.

**Note**

The lower secondary science syllabus does not expect you to recall formulas of compounds. However, check with your school teacher what he/she expects of you.

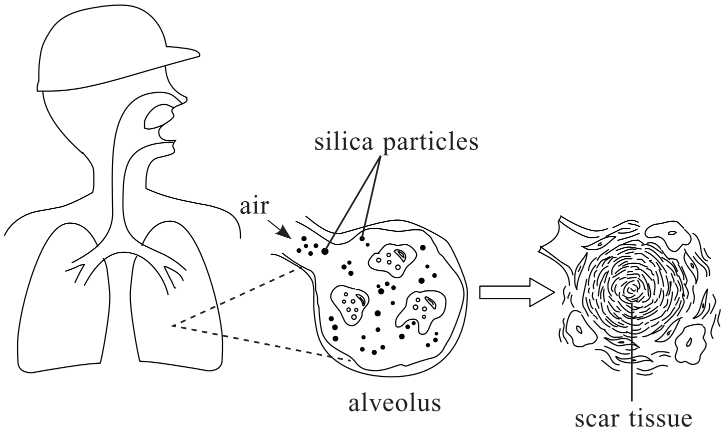



*Fig 8.15 Even though silica $SiO_2$ has a giant molecular structure and is insoluble, fine particles of silica can cause breathing problems. As the lungs are unable to get rid of the silica particles, they become scarred and the ability of the lungs to absorb oxygen from the air decreases.*

## Properties of Molecular Compounds

**Extension Knowledge**

1. Molecular compounds often have low melting and boiling points.
2. Molecular compounds are often insoluble in water. Exceptions are ammonia, hydrogen chloride, ethanol, ethanoic acid and sugar.
3. Molecular compounds are poor conductors of electricity.

## 8.5 Ionic Compounds

**Extension Knowledge**

Calcium oxide CaO (common name: quicklime) and calcium carbonate $CaCO_3$ (common name: limestone) are ionic compounds which have high melting points. Like a typical ionic compound, calcium oxide is soluble in water forming limewater $Ca(OH)_2$. Calcium carbonate, however, is insoluble in water.

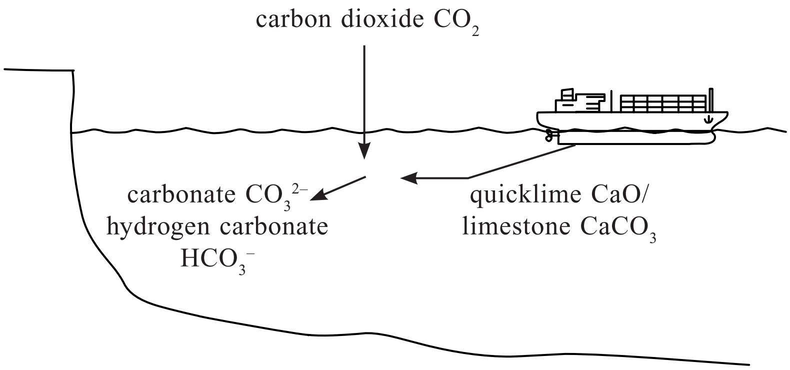



*Fig 8.16 One idea of reducing carbon dioxide in the atmosphere is by having ships to add quicklime or limestone into the sea. These compounds react with excess carbon dioxide in seawater and air.*

1. In chemical reactions between a metal and a non-metal, atoms form ions.
2. **Ions** are atoms (or molecules) that have either gained or lost electrons.
3. **Metal atoms** often lose electrons to **form positive ions** (e.g. sodium ion $Na^+$, calcium ion $Ca^{2+}$ and aluminium ion $Al^{3+}$).
4. **Non-metal atoms** often gain electrons to **form negative ions** (e.g. nitride ion $N^{3-}$, oxide ion $O^{2-}$ and chloride ion $Cl^-$).
5. Compounds such as sodium chloride $NaCl$ (common name: table salt) and calcium oxide CaO (common name: quicklime) consist of ions.

| Name and chemical formula of compound | Positive ion | Negative ion |
|---|---|---|
| Sodium chloride $NaCl$ | $Na^+$ | $Cl^-$ |
| Magnesium oxide MgO | $Mg^{2+}$ | $O^{2-}$ |
| Calcium chloride $CaCl_2$ | $Ca^{2+}$ | $Cl^-$ |
| Calcium oxide CaO | $Ca^{2+}$ | $O^{2-}$ |
| Potassium bromide KBr | $K^+$ | $Br^-$ |

*Table 8.2 Some ionic compounds and their ions*

**Extra**

Some ions such as ammonium $NH_4^+$, carbonate $CO_3^{2-}$, nitrate $NO_3^-$ and sulfate $SO_4^{2-}$ consist of more than one atom chemically bonded together. Ammonium nitrate $NH_4NO_3$ used as fertilisers as well as explosives, is a compound consisting of $NH_4^+$ and $NO_3^-$.

6. Ionic compounds have **high melting points**, are hard and are often soluble in water.

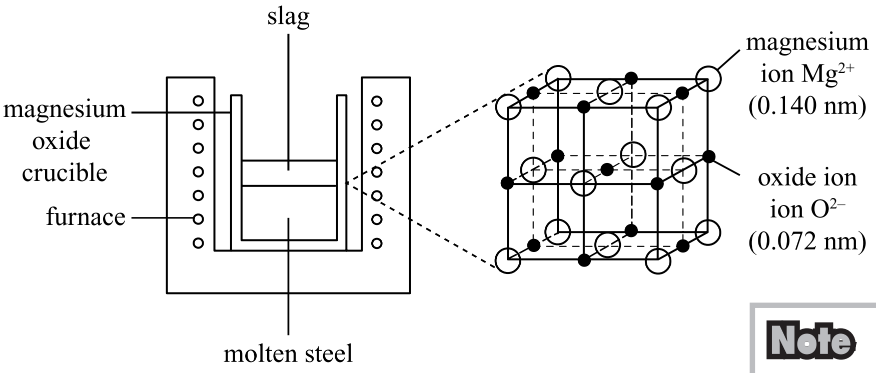



*Fig 8.17 Magnesium oxide, an ionic compound, is often used in blast furnaces as a refractory material due to its high melting point. Magnesium oxide has a high melting point (2852 °C) and so can resist the high temperatures in a furnace. Its melting point is high because of the strong ionic bonds between the small $Mg^{2+}$ and $O^{2-}$ ions.*

**Note**

The $Mg^{2+}$ and $O^{2-}$ ions are closely packed together. Here, they are drawn further apart to show the arrangement in 3D space.

7. In solid sodium chloride, the $Na^+$ and $Cl^-$ ions are closely packed in a fixed and regular arrangement.
8. In liquid/molten sodium chloride, the $Na^+$ and $Cl^-$ ions slide past one another randomly.

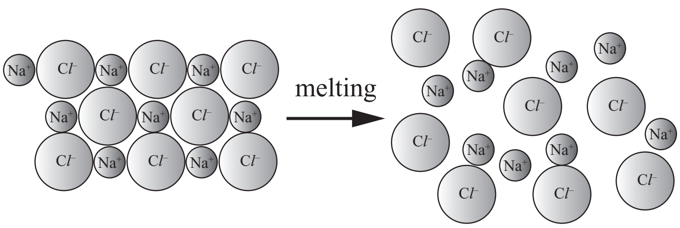



*Fig 8.18 At 801 ºC, sodium chloride melts and the regular arrangement of the sodium ions and chloride ions breaks down to become a random arrangement of the ions.*

9. Sodium chloride does not conduct electricity in solid state but conducts electricity in liquid state.

10. The types of particles are summarised below:

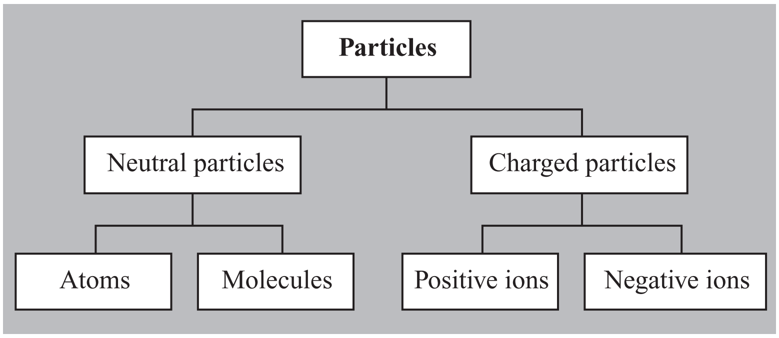



*Fig 8.19 Summary chart of particles in elements and compounds*

## 8.6 Can Atoms and Molecules Mix Together?

Mixtures around us can be made up of atoms and/or molecules. A mixture is composed of different types of atoms and/or molecules that are not chemically bonded.

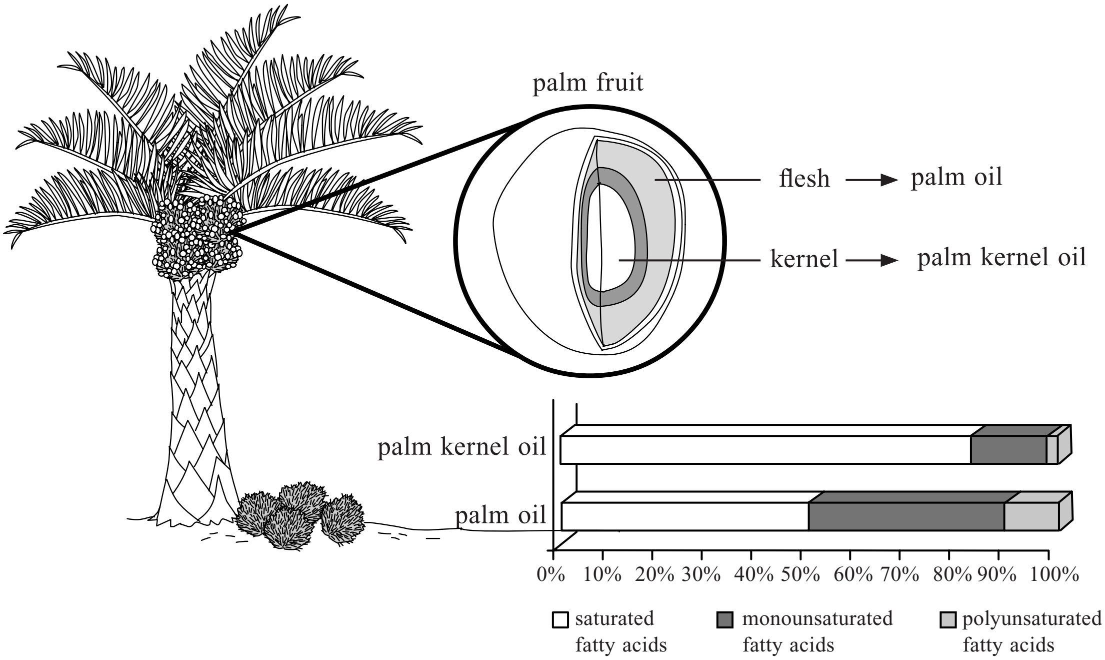



*Fig 8.20 Palm oil and palm kernel oil are mixtures of long molecules called saturated fatty acids and unsaturated fatty acids present in different porportions. They are used in cooking, frying and formulation of soaps, cosmetics and detergents. However, deforestation by slash and burn to make way for oil palm plantations brings about devastating impacts on the environment and wildlife.*

1. Air consists of atoms (e.g. argon Ar), elemental molecules (e.g. oxygen $O_2$, nitrogen $N_2$) and compound molecules (e.g. carbon dioxide $CO_2$ and water molecules $H_2O$).
2. An alloy consists of different types of atoms. The regular arrangement of atoms in the pure metal has been disrupted by the impurity atoms.
3. A solution of sodium chloride consists of positive sodium ions $Na^+$ surrounded by water molecules and negative chloride ions $Cl^-$ surrounded by water molecules.

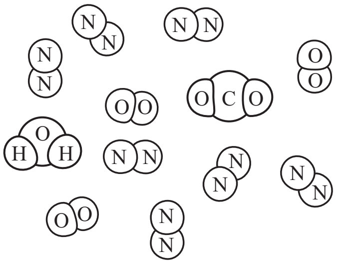



*Fig 8.21 Air is a mixture of different gases.*

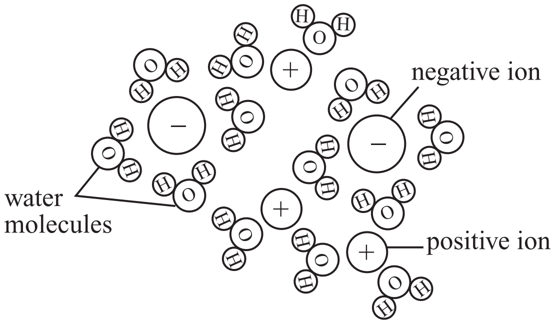



*Fig 8.23 Sodium chloride solution*

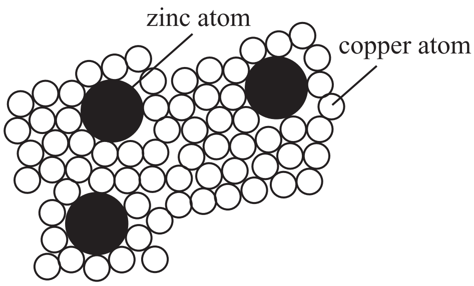



*Fig 8.22 Brass is an alloy of copper atoms and some zinc atoms.*

4. Nanoparticles (1 nm to 100 nm in size) are made up of about 100 atoms. Nanotechnology is the manipulation of matter on an atomic, molecular, and supramolecular scale. The use of nanotechnology to help treat diseases and prevent health issues in the medical field is termed as nano-medicine.

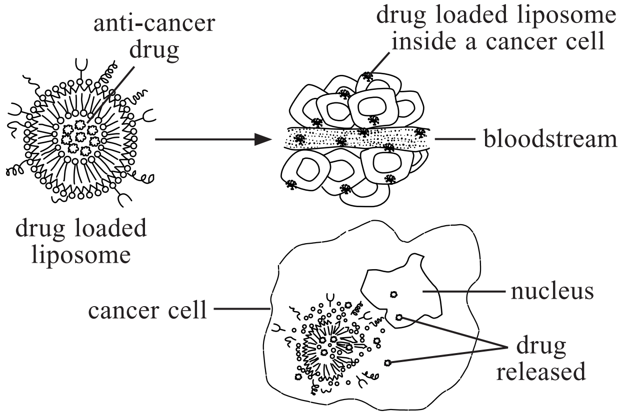



*Fig 8.24 Nanoparticles (e.g. dendrimers, liposomes, fullerene as shown in Fig 8.12) can carry specific drugs that can attach to molecules on tumour cells. Once attached, the nanoparticles deliver the drug to the specific tumour site. This prevents the drug from causing harm to healthy tissues and so reduce side effects.*