CHAPTER 8

Model of Matter – Atoms and Molecules

Introduction

This chapter is a continuation of Revision Guide 1A Chapter 3. In this chapter, we will learn how the atomic model is used to represent the simplest units of elements and compounds. We will learn how chemical formulas are used to represent molecules. This model helps us to understand atomic structure of matter, which cannot be observed with the naked eye.

Learning Map

This table shows the content covered in this chapter relating to the Primary Science (PS), Lower Secondary Science (LSS) and Upper Secondary Science (USS) syllabuses.

Content	PS	LSS	USS
Matter has mass and volume	✓	✓	✓
Structure of an atom – protons (positively charged) and neutrons (neutral) in the nucleus, and electrons (negatively charged) outside the nucleus		✓	✓
Structure of an atom – protons and neutrons in the nucleus and electrons arranged in shells			✓
Determining the numbers and types of atoms, given the chemical symbol of an element or the chemical formula of a compound		✓	✓
Unique number of protons in an atom of an element		✓	✓
Electrically neutral atom		✓	✓
Mass of an atom and the mass of the nucleus		✓	✓
Deducing the numbers of protons, neutrons and electrons in atoms and ions, given proton and nucleon numbers			✓
Isotopes			✓
Benefits and harmful effects of the applications of atomic technologies		✓	

Prior Knowledge

In Primary Science, you had learnt the following:

Topic: Matter

- Matter has mass and volume.

8.1 Simplest Unit of an Element and Its Structural Representation

Learning Outcomes

You should be able to:

- appreciate that an atom is the simplest unit of an element by comparing it with objects that are commonly found around us
- *understand and appreciate how models are constructed and revised as they are used to study new phenomena and to collect more data
- state that an atom is electrically neutral
- state that an atom is made up of protons and neutrons that are found in the positively charged nucleus, and negatively charged electrons that are moving around the nucleus
- understand that the mass of an atom is mainly contributed by the mass of the nucleus

Atoms Are Small

- Matter is made up of atoms of at least one or more elements.
- Elements are the basic building blocks of matter.
- If an element is repeatedly divided into smaller parts, we will get a part that can no longer be divided. This part is known as an atom, which is the simplest unit of an element.
- All the atoms of an element are identical. The atoms of one element differ from the atoms of another element.
- For example, iron is an element that is made up of one type of atoms, but steel is a mixture of iron and carbon. Hence, steel is made up of two types of atoms, as shown in the figure below.

iron (one type of atoms) steel (two types of atoms)

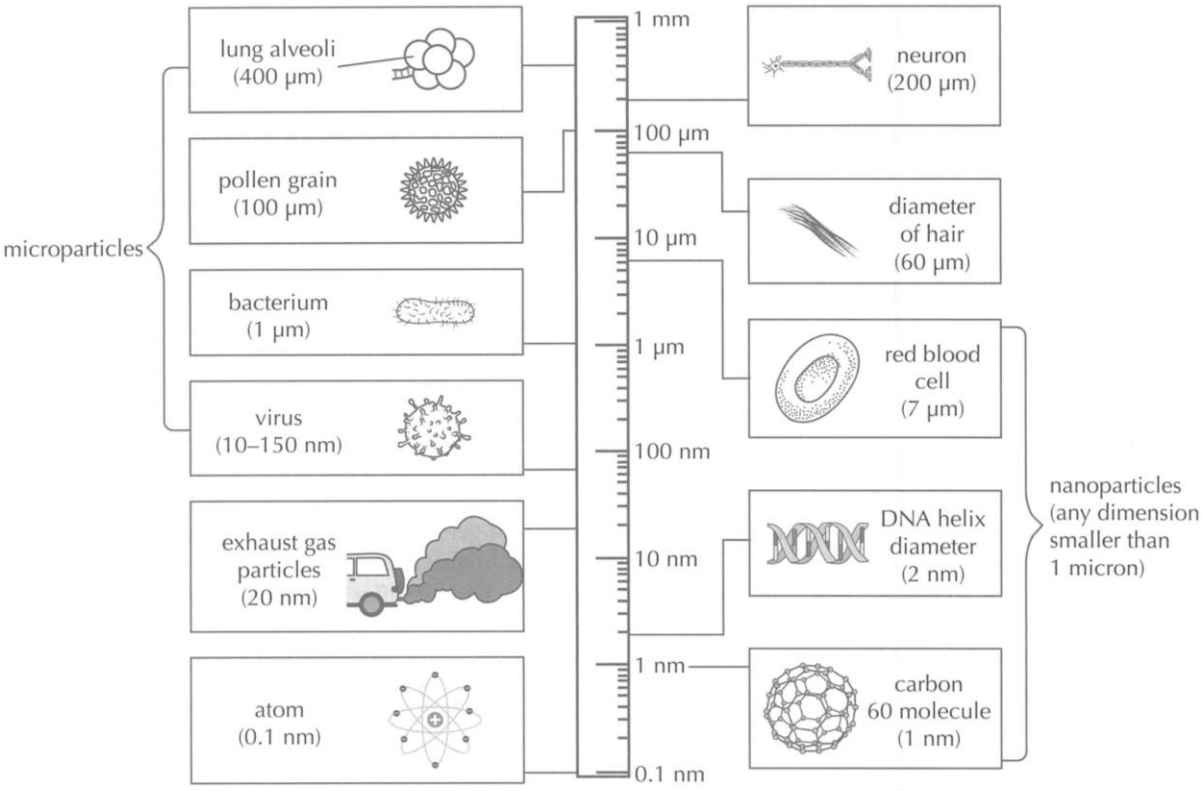
Tips

- An alloy is made up of a metal combined with one or more other elements.
- Steel, brass and bronze are examples of alloys.

- Cells are too small to be seen with the human eye. An atom is even smaller than a cell.

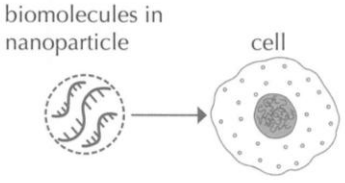
** denotes "Optional for N(A)"*

- The figure below compares the size of an atom with the size of other objects such as nanomaterials and biological structures.



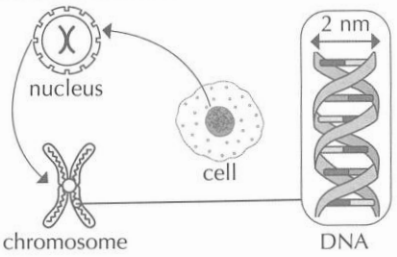
(***Note:*** *1 mm = 1000 μm; 1 μm = 1000 nm; 1 μm is also known as 1 micron.)*

- From the chart above, we can see that:
  - A red blood cell is around 7 μm (7000 nm) in diameter, whereas an atom is only around 0.1 nm. This means that a red blood cell is about 70 000 times larger than an atom; and
  - The thickness of a strand of hair is about 600 000 times larger than an atom.
- Particles of size between 1 nm and 1 μm are known as nanoparticles, while particles of size between 1 μm and several microns are known as microparticles.
- In general, the sizes of nanomaterials are comparable to those of viruses and DNA, while the sizes of microparticles are comparable to those of cells and cell structures.
- Since microparticles and nanoparticles are much smaller than human cells, they can be used for targeted drug delivery in the human body.
- For example, the new class of COVID-19 vaccines contains biomolecules that are packaged in nanoparticles to be delivered to cells. Thereafter, the human immune system would be stimulated to produce antibodies to fight against the virus that causes COVID-19.



Worked Example 1

DNA is found in the nucleus of a cell, as shown in the figure on the right. It is made up of phosphorus, carbon, oxygen, hydrogen and nitrogen.



(a) How many types of atoms can be found in DNA?

Answer
5

Tip
Each element consists of one type of atoms. Since DNA is made up of five elements, there are five types of atoms found in DNA.

(b) The diameter of a strand of DNA is 2 nm, as shown in the figure above.

Given that the size of an atom is 0.1 nm, how many atoms can make up the diameter of a strand of DNA?

Answer
20

Tip
The diameter of DNA is 2 nm, so we divide the diameter by the size of an atom to get the number of atoms that can make up the diameter.
2 nm ÷ 0.1 nm = 20

Structure and Model of an Atom

- An atom is the simplest unit of an element. However, it is made up of even smaller particles known as sub-atomic particles.
- There are three types of sub-atomic particles:
  - protons
  - electrons
  - neutrons

Optional for N(A)

- To study the structure of an atom, scientists use models to represent atoms.
- Based on their new findings, scientists have constantly revised the models over the years.

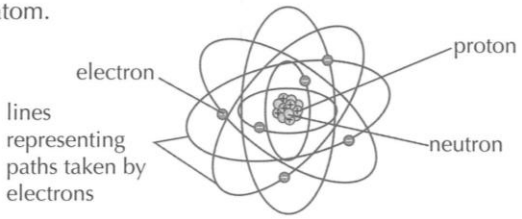
Optional for N(A)

- The figure below shows the history of the development of the model of atoms.

Year	1803	1904	1911	1913	1926
Model	Solid sphere model or billiard ball model	Plum pudding model 	**Enrichment** Nuclear model 	Planetary model 	**Enrichment** Quantum model 
Scientist	John Dalton	J.J. Thomson	Ernest Rutherford	Niels Bohr	Erwin Schrödinger
Discoveries	• An atom is indivisible. • An atom of one element differs from another element.	• Electrons are components of an atom. • They are scattered throughout a spherical cloud of positive charge.	• Positive charges are localised in the nucleus at the centre. • An atom is mostly empty space.	• Electrons move around in fixed paths around the nucleus. • Bohr postulated the existence of energy levels or shells of electrons.	• Electrons do not move in fixed paths. • The nucleus is surrounded by clouds of electron density with no exact location. • These regions of space are known as electron orbitals.

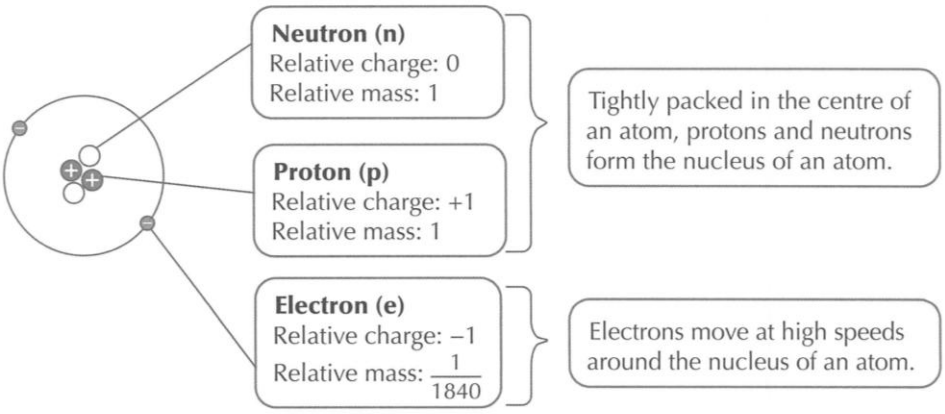
The Planetary Model of an Atom

- The planetary model is a simplified representation of the structure of an atom. It is useful in explaining chemical bonding and the reactivity of some groups of elements at a simple level.
- The figure on the right shows the planetary model of an atom.
- In this model, protons and neutrons are densely packed in the nucleus of the atom.
- Electrons move rapidly around the nucleus in fixed paths.
- An atom consists mostly of empty space.

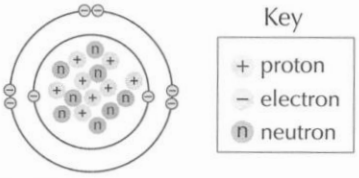


An Atom Is Electrically Neutral

- The sub-atomic particles in an atom have different relative charges and masses.



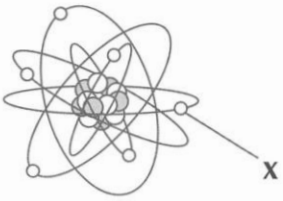
- A proton carries a positive charge (+1) while an electron carries a negative charge (–1).
- An atom is electrically neutral as it contains an equal number of protons and electrons, so the positive charge and negative charge balance each other out.
- For example, the overall charge of an oxygen atom is zero, as shown below.

Element	oxygen
Chemical Symbol	O
Atomic Structure	
Number of Protons	8 (+)
Number of Electrons	8 (–)
Number of Neutrons	8 (0)
Overall Charge	0

- The numbers of neutrons and protons may not be equal in some atoms.

Worked Example 2

The figure below shows the planetary model of atom **P**.



Complete the sentences below.

(a) The planetary model is proposed by Niels Bohr. In this model, there are three types of _____ particles in an atom.

(b) **X** represents the _____ of atom **P**, with a _____ charge.

(c) **X** moves in _____ paths around the nucleus.

(d) There are _____ protons in atom **P**.

Answer

(a) sub-atomic **(b)** electron; negative **(c)** fixed **(d)** six

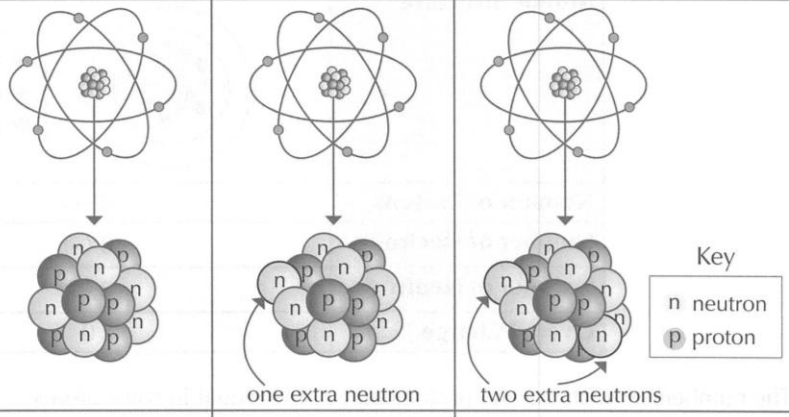
Tips

- Scientists use models to study the structure of an atom that cannot be seen with the naked eye.
- Niels Bohr proposed the planetary model.
- In this model, electrons are the negative charges that move around the nucleus in fixed paths.
- Atom **P** is electrically neutral when the number of protons is equal to the number of electrons. Since there are six electrons in atom **P**, there are six protons.

Enrichment

Isotopes

- Isotopes are atoms of the same element that have the same number of protons, but different number of neutrons.
- For example, carbon occurs naturally in three isotopes: carbon-12, carbon-13 and carbon-14. The table below compares these three isotopes.

Isotope	carbon-12	carbon-13	carbon-14
Atomic Structure			
Number of Protons	6	6	6
Number of Electrons	6	6	6
Number of Neutrons	6	7	8

- The properties of the isotopes can be different due to the different numbers of neutrons. For example, carbon-14 is radioactive, but carbon-12 and carbon-13 are not.

Optional for N(A)

The Mass of an Atom

- The mass of an atom is mainly contributed by the mass of the nucleus, which consists of protons and neutrons.
- The table below shows the relative masses of the three sub-atomic particles.

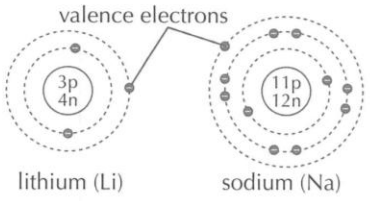
Sub-atomic Particles	Relative Mass
proton	1
neutron	1
electron	$\frac{1}{1840}$

- Since the relative masses of protons and neutrons are much larger compared to electrons, the mass of the nucleus contributes to most of the mass of an atom.

Worked Example 3

The figure on the right shows the atomic structures of lithium and sodium. Both elements are found in Group 1 of the Periodic Table of Elements as each of them has one electron in their outermost shells. This electron is known as valence electron.

In this question, "p" represents proton and "n" represents neutron.



Optional for N(A)

(a) Given that the mass of one proton and one neutron is one unit (1u) each, complete the table below.

Element	lithium (Li)	sodium (Na)
Number of Electrons		
Number of Protons		
Mass of the Atom		

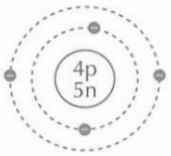
Tip

The mass of an atom is given by its total number of protons and neutrons.

Answer

Element	lithium (Li)	sodium (Na)
Number of Electrons	3	11
Number of Protons	3	11
Mass of the Atom	7u	23u

(b) The figure on the right shows an atom of element **W**.



Based on the information given in the question and the Periodic Table of Elements, in which group can element **W** be found?

Answer

Group 2

Tip

Lithium and sodium are both in Group 1, where each atom contains one valence electron. Since element **W** has two valence electrons, it is found in Group 2.

8.2 Using the Proton Number of an Atom to Identify an Element

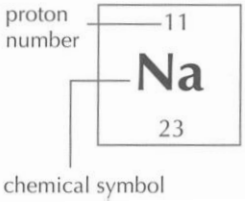
Learning Outcomes

You should be able to:

- understand that each element in the Periodic Table of Elements has a unique number of protons (proton number)
- identify an unknown element based on its proton number

Proton Number

- Elements in the Periodic Table are arranged in order of an increasing number of protons in their atoms.
- Each element in the Periodic Table has a unique proton number, which is also known as the atomic number.
- Hence, we can identify an unknown element using the proton number.
- The figure shows the sodium element in the Periodic Table.
  - Each sodium atom contains 11 protons.
  - Since there is an equal number of protons and electrons in an atom, each sodium atom also contains 11 electrons.



- The physical and chemical properties of elements are affected by the number of protons in their atoms.
- The table below shows two elements that are arranged consecutively in the Periodic Table.

Element	6 C carbon 12	7 N nitrogen 14
Physical Property	• Solid at room temperature • Dull grey or black in colour	• Gas at room temperature • Colourless gas
Chemical Property	Can react with oxygen to form carbon monoxide gas that is colourless, odourless and toxic	Can react with oxygen to form nitrogen dioxide gas that is brown and pungent

  - The proton number of carbon is 6 and the proton number of nitrogen is 7. This means that there are six protons in a carbon atom and there are seven protons in a nitrogen atom.
  - Although there is a difference of only one proton between carbon and nitrogen, both elements have very different physical and chemical properties, as shown in the table above.

Worked Example 4

Refer to the Periodic Table of Elements to complete the table below.

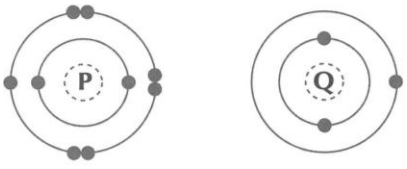
Element	Number of Protons	Number of Electrons	Group Number
Magnesium		12	
	6		14
		29	11

Answer

Element	Number of Protons	Number of Electrons	Group Number
Magnesium	12	12	2
Carbon	6	6	14
Copper	29	29	11

Worked Example 5

The figure below shows two atoms, **P** and **Q**.



(a) State the number of protons found in atoms **P** and **Q** respectively.

Number of protons in atom **P**: _____
Number of protons in atom **Q**: _____

Answer
Number of protons in atom **P**: 9
Number of protons in atom **Q**: 3

Tips
- An atom is electrically neutral, so the number of protons is equal to the number of electrons.
- Since there are nine electrons in atom **P**, the atom should have nine protons.
- Atom **Q** contains three electrons, so it should have three protons.

(b) Using the Periodic Table, identify the elements with atoms **P** and **Q**.

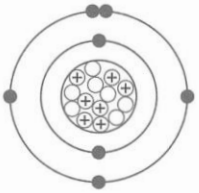
Element with atom **P**: _____
Element with atom **Q**: _____

Answer
Element with atom **P**: Fluorine
Element with atom **Q**: Lithium

Tip
Based on the number of protons, we can identify the element using the Periodic Table.

Worked Example 6

The figure on the right tells us the numbers of sub-atomic particles found in atom **X**.



(a) State the number of each sub-atomic particle present in atom **X**.

Number of protons: _____
Number of neutrons: _____
Number of electrons: _____

Answer
Number of protons: 7
Number of neutrons: 7
Number of electrons: 7

(b) Given that the number of electron shells tell us the period number of an atom in the Periodic Table, state the period number of the element that has atom **X**.

Answer
Period 2

Tip
The number of electron shells of an atom tells us the period number of the atom. There are two electron shells shown in the figure.

(c) Using the figure above, explain why atom **X** is electrically neutral.

Answer
There are seven protons and seven electrons in atom **X**. Hence, the positive charges and negative charges balance each other out.

Tip
An atom is electrically neutral as the numbers of electrons and protons in the atom are the same.

8.3 Representations of Atoms and Molecules in Elements and Compounds

Learning Outcomes

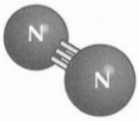
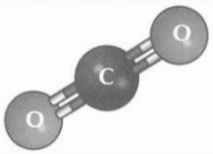
You should be able to:

- compare between atoms and molecules
- understand that a molecule is made up of a group of two or more atoms that are chemically combined
- derive the numbers and types of atoms present in an element or a compound based on the given chemical symbol (for an element) or chemical formula (for a compound)

Representing Atoms and Molecules

- An element consists of one type of atoms, while a compound consists of more than one type of atoms, depending on how many elements are chemically combined to form that compound.
- A molecule is formed when two or more atoms of the same element or different elements are chemically combined.
- Atoms of elements and compounds are usually represented by circles, spheres and molecular models.
- Different elements are represented by circles of different sizes, colours, shades and/or patterns.

Substance	Atom of element	Molecule of element	Molecule of compound
How to Represent Using Circles	• A single circle is used to represent an atom. • The chemical symbol of the element is labelled in the circle. • Different sizes of circles represent different types of atoms.	• Atoms of the same element are chemically combined to form a molecule of an element. • There is only one type of atoms. • Circles of the same type are touching each other, representing that the atoms are chemically combined.	• Atoms of different elements are chemically combined to form a molecule of a compound. • There are two or more types of atoms. • Circles of different types are touching each other, representing that the atoms are chemically combined.
Representation Using Circles	11 **Na** sodium 23	7 **N** nitrogen 14	6 **C** carbon 12 8 **O** oxygen 16
	 • A sodium atom can be represented by one circle labelled Na.	 • A nitrogen molecule is made up of two nitrogen atoms. • It can be represented by two identical circles labelled N.	 • A carbon dioxide molecule is made up of two elements and three atoms. • It has one carbon atom and two oxygen atoms. • It can be represented by two identical circles labelled with O and one smaller circle labelled C.

Substance	Atom of element	Molecule of element	Molecule of compound
Representation Using Molecular Model			

Worked Example 7

Study the figures below. Hence, state the elements and the total number of atoms found in each molecule.

Representation of Molecules			
Element(s) Present			
Total Number of Atoms			

Answer

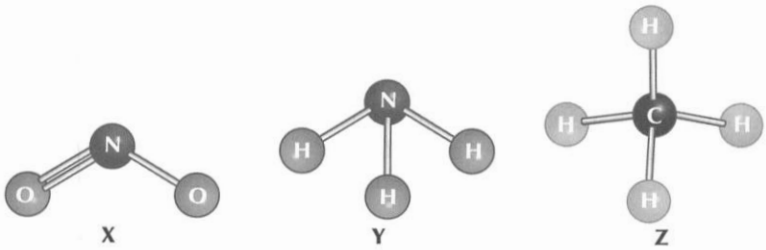
Representation of Molecules			
Element(s) Present	oxygen	carbon and hydrogen	nitrogen and oxygen
Total Number of Atoms	2	5	3

Tips

- Using the chemical symbols, you can find the names of the elements in the Periodic Table.
- The number of circles represents the total number of atoms present in the molecule.

Worked Example 8

The figure below shows the molecular models of three substances **X**, **Y** and **Z**.



Are these three substances elements or compounds? Explain.

Answer

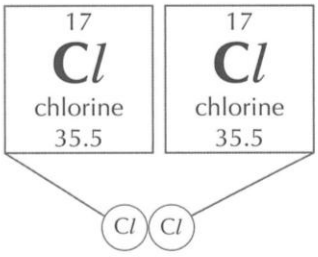
They are compounds. Substances **X**, **Y** and **Z** each contain two types of atoms that are chemically combined.

Tips

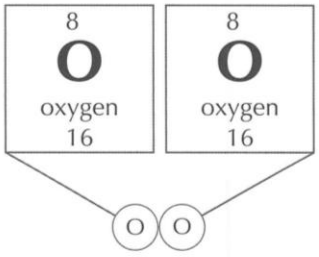
- An element contains only one type of atoms that are chemically combined, while a compound contains more than one type of atoms that are chemically combined.
- Substance **X** is made up of nitrogen and oxygen atoms. Substance **Y** is made up of nitrogen and hydrogen atoms, while substance **Z** is made up of carbon and hydrogen atoms.

Chemical Formula

- Chemical formulae can also be used to represent molecules.
- Each constituent element is represented by its chemical symbol found in the Periodic Table.
- For example, below are the representations of the molecules of two elements.

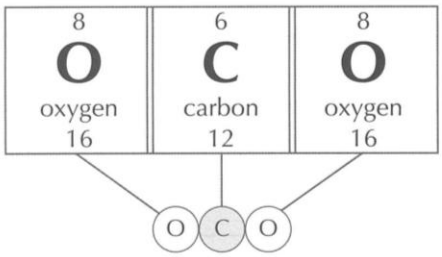


Name: chlorine
Chemical formula: Cl_2

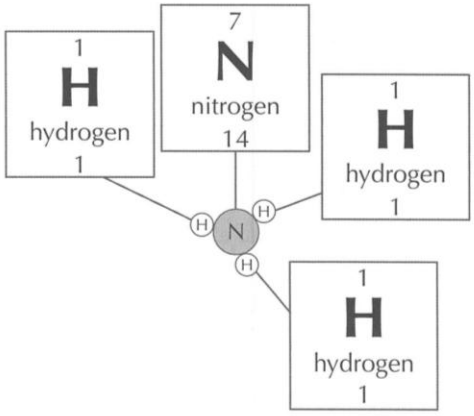


Name: oxygen
Chemical formula: O_2

- For example, below are the representations of the molecules of two compounds.

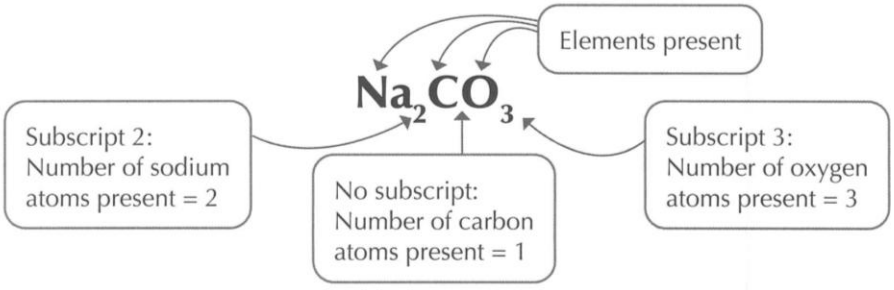


Name: carbon dioxide
Chemical formula: CO_2
Elements present: carbon, oxygen



Name: ammonia
Chemical formula: NH_3
Elements present: nitrogen, hydrogen

- The number of atoms of each element is also shown in the chemical formula.
- The subscript gives the number of atoms of each element present in the compound.
- When there is no numerical number present as a subscript, this means that only one atom of that element is present.
- For example, below is the chemical formula for the compound sodium carbonate.



Tip

Some elements such as helium and neon exist as individual atoms. They are found in Group 18 of the Periodic Table and do not chemically combine to form molecules.

Worked Example 9

Study the chemical formula of a substance below.

$$MgSO_4$$

(a) Name the elements that are present in this substance.

Answer

Magnesium, sulfur and oxygen

Tip

Refer to the Periodic Table of Elements, use the chemical symbols to identify the names of the elements present in the substance.

(b) How many atoms are present in this substance?

Answer

Six

Tip

The subscript gives the number of atoms of each element present in the compound. When there is no numerical number present in the subscript, this means that only one atom of that element is present.

Worked Example 10

The chemical formulae of the following substances contain elements found in Group 17 of the Periodic Table.

Cl_2 NaCl I_2 KI

(a) Identify the elements. Then, state the number of atoms present in each element.

Answer

Cl_2 and I_2 are elements. There are two atoms in each element.

Tip

Cl_2 and I_2 are molecules of elements. A molecule of an element contains only one type of atoms.

(b) Name another element that is also found in Group 17 of the Periodic Table.

Answer

Fluorine
Bromine
Astatine
(Any one acceptable answer)

8.4 Applications of Atomic Technologies

Learning Outcomes

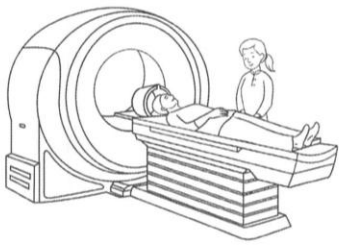
You should be able to:

- understand that atomic technologies, resulting from the knowledge of atoms, bring us benefits
- understand the risks, costs, and social and ethical issues that arise from atomic technologies

Benefits Brought About by the Knowledge of Atoms in Everyday Life

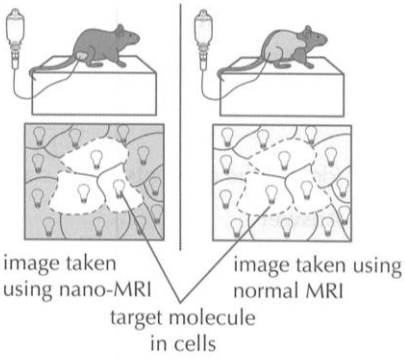
- The knowledge of atoms has brought about new materials and technologies in healthcare, food and power plants.

1. Magnetic resonance imaging (MRI)
   - MRI is a type of scan that uses strong magnetic fields and radio waves to produce detailed images of the inside of the body. The figure on the right shows a simplified diagram of an MRI scanner.
   - MRI sensors are able to detect the energy released as the protons in the atoms of human cells realign with the magnetic field.
   - MRI can be used to detect brain tumors, infection, and the causes of headache.



2. Molecular gastronomy
   - Molecular gastronomy involves the study of physical and chemical changes that occur during cooking.
   - This allows chefs to create new dishes with better appearance and taste.
   - For example, liquid nitrogen could flash freeze almost anything and is used to make sherbets, a type of desserts.

3. Nanotechnology
   - Nanotechnology is the use of matter on an atomic or molecular scale for industrial purposes.
   - Examples include air purification with ions, wastewater purification with nanobubbles, nanofiltration systems for heavy metals and the invention of smart fabrics that do not stain or wrinkle.
   - Another example is the nanoscale-magnetic resonance imaging (nano-MRI). Nano-MRI is a new technique that could improve the resolution of MRI measurements from the usual tens of micrometres to the nanometric scale.
   - This makes the differentiation between diseased areas and surrounding tissues easier. The figure on the right shows that the image taken using nano-MRI shows the diseased area more easily.



Issues Arising From Atomic Technologies

- Social and ethical issues could arise from atomic technologies.
- Large amounts of energy can be obtained from atoms used in nuclear power plants.
- However, accidents in these power plants and the usage of atomic bombs can result in deaths, pollution and other harmful effects such as the release of radioactive materials.
- Nanotechnology allows weapons to be made and may increase the likelihood of nano-enabled terrorism.
- Workers involved in industries using nanotechnology are exposed to the potential hazards of a new technology.

Worked Example 11

Titanium dioxide (TiO_2) nanoparticles are used to make sunblock in cosmetics. When these potentially toxic nanoparticles are released into the environment, they may have indirect effects on the ecosystems and the surrounding living organisms.

(a) State if titanium dioxide is an element or a compound.

Answer
Compound

Tip
Titanium dioxide is made up of two elements, which are titanium and oxygen, that are chemically combined.

(b) The concentration of titanium dioxide nanoparticles found in seawater increases with the number of people visiting the beach during holiday seasons. Titanium dioxide nanoparticles have shown to suppress the immune system of fish, which helps fish fight against diseases.

Explain how the release of these nanoparticles into seawater affects the marine ecosystem.

Answer
When titanium dioxide nanoparticles are ingested by aquatic organisms, they will be passed down the food chain. When fish ingest these nanoparticles and die, other organisms in the same food chain are affected, hence affecting the marine ecosystem.

Tip
The titanium dioxide nanoparticles ingested by aquatic organisms will accumulate in animals further up the food chain. This can lead to toxicity of the fish and other organisms in the food chain. The unusual increase/decrease in the number of organisms will upset the balance in the marine ecosystem.