PREFACE

Teaching higher order thinking skills is currently at the centre of educational attention. In general, measures of higher order thinking include all intellectual tasks that call for more than the retrieval of information. Six fundamental higher order thinking skills have been identified in the Chemistry Syllabus. They are problem solving skills, inquiring skills, reasoning skills, communicating skills, conceptualising skills and creative and innovative skills. These skills, together with intertwining ways of learning chemistry, thinking and using chemical knowledge are considered, important in chemistry education.

In this chemistry course, students will be working with their teacher and other students to develop the basic knowledge and skills which will help them understand chemistry more and to apply them in their daily life. They will learn how to show an interest in the creativity and innovation found in chemistry. In some lessons, students will participate in group activities to develop skills in scientific methods of investigation based on the concepts, theory, terms, facts, laws and principles related to main themes.

Skill Development

After learning this course, students will develop and practise higher order thinking skills: comprehension, analysis, synthesis and evaluation. They will be able to participate actively in all lessons through the **5 C's** as important **21st century skills for learning**:

- ✔ **Collaboration** – in lessons students will be working in groups, to share ideas with their classmates and to find the solution together.
- ✔ **Communication** – students will develop verbal and non-verbal communication skills in group works.
- ✔ **Critical Thinking and Problem Solving** – students will be given interesting problems to solve – finding and explaining solutions, looking for correcting errors.
- ✔ **Creativity and Innovation** – thinking 'outside the box' is an important 21st century skill. Students will be encouraged to explore new ideas and solve problems in new ways.
- ✔ **Citizenship** – students will join the school community and develop fairness and conflict resolution skills.

Important Features of This Textbook

- ♦ The High School Chemistry Curriculum covers **six main themes**: Particulate Nature of Substances, Periodicity, Chemical Calculations, Chemistry of Reactions, The Environment, and Organic Chemistry.
- ♦ There are **eight chapters** included in this Textbook:
  - Chapter 1 Chemistry : The Central Science;

- Chapter 2 Matter and Solutions;
- Chapter 3 The Electronic Structures of Atoms and Periodic Table;
- Chapter 4 The Quantities of Substances : Chemical Calculations;
- Chapter 5 Non-metals : Carbon, Oxygen and Halogens;
- Chapter 6 Acids, Bases and Salts;
- Chapter 7 Air, Water and Soil;
- Chapter 8 Fuels and Crude Oils.

♦ Each chapter starts with the ***introduction*** to the topic, containing an example of how the material covered in the chapter, followed by the **Learning Outcomes** of the chapter.

♦ In each section of the chapter, the text and illustrations describe and explain all of the facts and concepts that students need to know. **Review Questions** after each section give students a chance to check that they have understood the topic they have just read. There is a summary of **Key Terms** at the end of each section. Key Terms are highlighted in the text when they are first introduced. All end-of-chapter **Exercises** are designed to ensure that students have grasped major concepts, in addition to testing their understanding of the materials covered in the chapter. At the end of each chapter, the **Chapter Review** (a concept link) points out the summary and highlights of the chapter.

♦ In addition, the **"Chemistry in Society"** or **"Chemistry in Daily Life"** highlighted in colour, is introduced in each section of the chapter, reminding students that chemistry is so central and so intimately involved in almost every aspect of our material world. It introduces students to the important chemicals and substances that form the basis for the high standard of living and modern technology that they now enjoy. *It is suggested that teachers should not emphasise this section as exam-oriented teaching.*

♦ The key terms mentioned in all chapters are listed in the **Glossary** at the end of the Textbook.

Goals of Grade 10 Chemistry Textbook

The Grade 10 Chemistry Textbook has been written for two goals. The first goal is to teach the fundamental of chemical concepts, and the second goal is to teach basic critical thinking skills. Students will solve the problems and predict events. The overall goal is to produce a text that introduces the students to the relevance and excitement of chemistry. We hope that students will understand the benefits and hazards of the Material World through the knowledge they have learned.

CHAPTER 1 CHEMISTRY: THE CENTRAL SCIENCE

1.1 CHEMISTRY AS CENTRAL SCIENCE

Chemistry is an area of knowledge remarkable for its breadth and depth. Knowledge of chemistry is essential to improve the quality of our lives. For instance, faster electronic devices, stronger plastics, and more effective medicines and vaccines all rely on the innovations of chemists throughout the world. We cannot truly understand or even know very much about the world we live in or about our own bodies without knowing the fundamental concepts of chemistry.

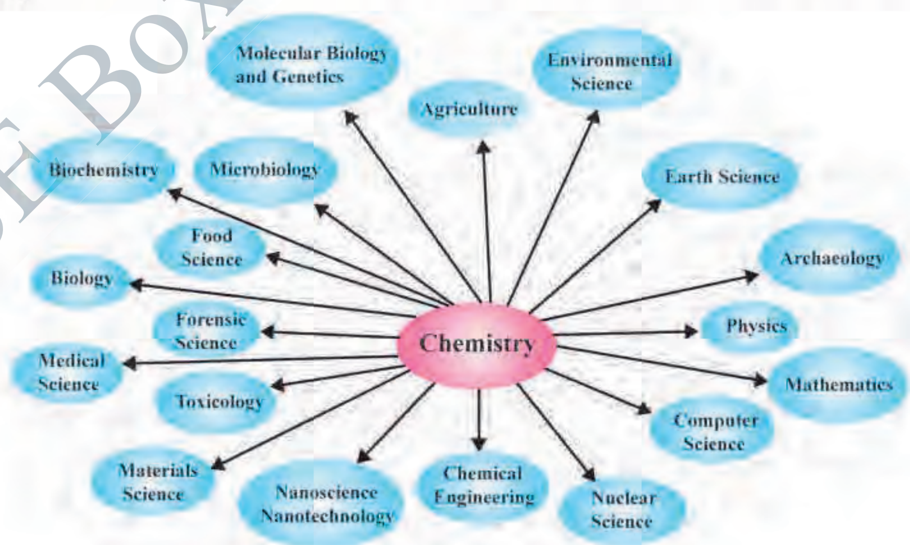
Climate change, water contamination, air pollution, food shortages and other societal issues are regularly featured in the media. However, did you know that chemistry plays a crucial role in addressing these challenges? As the 'Central Science', chemistry is woven into the fabric of practically every issue that our society faces today.

Learning Outcomes

After completing this chapter, students will be able to:

- describe the various branches of science and how society is impacted by them;
- recognise the role and impact of chemistry in daily life;
- discuss the importance of chemistry in daily life;
- distinguish and compare the branches of chemistry;
- develop and practice higher order thinking skills such as reasoning, analysis, synthesis, and evaluation.

Chemistry plays a central role in science and is often intertwined with other branches of science.



Just what is chemistry anyway? The usual definition is that chemistry is a study of matter and the changes it undergoes. What is matter? It is anything that has mass and occupies space. We change matter to make it more useful. Some matter we change to extract a part of its energy; for example, we burn gasoline to get energy to propel our automobiles. We practice chemistry everyday.

We practice chemistry when we cook in the kitchen, when we clean our house or paint our room, when we apply cosmetics, and when we take medicine or treat an injury. Our body takes oxygen from the air and combines it with part of the food we eat to provide us with energy for every activity we undertake. These are just a few of the ways in which chemistry impacts our daily lives.

So what is chemistry? It is a science that touches our life every moment. It deals with matter from the tiniest parts of atoms to the complex human body. It goes beyond the individual to affect society as a whole, shaping our civilisation.

1.2 MILESTONES IN THE HISTORY OF CHEMISTRY

Chemistry as a discipline has been around for a long time. The **history** of chemistry is an interesting and challenging one. In fact, chemistry is known to date back to as far as the prehistoric times. There are four categories that classified chemistry on the time line.

- Prehistoric time to the beginning of Christian era (about 300 BC) is classified as **black magic** period. The ancients believed the world made of 'four elements', which are earth, air, water and fire. The Greek philosophers were perhaps the first to formulate theories explaining the behaviour of matter without confirming their theories by experimentation. However, their philosophic point of view of nature, which can be attributed mainly to Aristotle, dominated the Greek culture. They used fire to bring about chemical changes. Examples include: extraction of metals from ores, making pottery and glazes, fermenting beer and wine, extracting chemicals from plants for medicine and perfume, making of fat into soap, manufacture of glass, and making of alloys like bronze and so on. These things and many others were accomplished without an understanding of the scientific principles involved.
- From about 300 BC to the end of 17^{th} century, the experimental roots of chemistry are planted in **alchemy**, a mystical chemistry that flourished in China and Europe. Alchemists made several attempts to turn cheaper metals to gold, using the substance called the Philosopher's Stone. They also wanted to find an elixir that would enable people to live longer and cure all ailments. Alchemists never achieved these goals, but they discovered many new chemical substances and techniques such as distillation and extraction that are still used today. In 1661, Robert Boyle (1627-1691) developed the basic ideas about the behaviour of gases. His research progress was made in putting chemistry on a basic foundation.
- The field of chemistry began to develop rapidly in the 1700's. **Traditional chemistry** period started by the end of 17^{th} century up to the middle of 19^{th} century. In 1774 Joseph Priestley discovered a gas, later named oxygen. The chemistry was introduced to the science in 1768 by French chemist Antoine Lavoisier (1743–1794), who explained the law of conservation of matter based on the experimentation method. From this onward, scientists use

the experimentation method, also known as scientific method, rather than logical and theoretical method of the ancients. In 1803 John Dalton postulated Atomic Theory, which states that all matter is composed of atoms, which are small and indivisible. Amedeo Avogadro (1776 - 1856) laid the groundwork for a more quantitative approach to chemistry by calculating the number of particles in a given amount of a gas, which we use today as Avogadro's constant.

- **Modern chemistry** starts from the middle of 19^{th} century to the present time. The beginnings of modern chemistry were coming with the emergence of the experimental method when the works of scientists were characterised by a reliance on experimentation. Scientific facts remain the same, no matter who does the measuring. These facts are verified by repeated testing.

Few of the areas that have emerged as being especially important in modern chemistry are Synthesis, Separation techniques, Identification and assay, Materials, Polymers, Nanochemistry, Biochemistry, Molecular biology, Green chemistry, and Combinatorial chemistry.

Much of 20^{th} century technology has grown out of scientific discoveries from radioactivity to artificial intelligence. Technological developments are used by scientists as tools for more discoveries. These developments in science and technology together with innovations are the basic current roots of the changing modern world.

1.3 IMPORTANCE OF CHEMISTRY

Chemistry is **important** because everything you do is **chemistry**. **Chemical** reactions occur when you breathe, eat, or just sit there reading. You are surrounded by materials and substances, all chemicals. Even your body is made of chemicals. The air you are breathing is a mixture of elements like oxygen and nitrogen. The book you are reading is made from wood pulp or cellulose which has been bleached and treated with various chemicals. The clothes you are wearing are probably made from synthetic chemicals called polymers, such as nylon or terylene. The seat you are sitting on is perhaps a plastic polymer, with polyurethane; foam seat padding and metal support. The room you are in is made from cement, plastics, concrete and glass, all of which are chemicals. Chemicals provide us with luxuries and improve our leisure time.

Some chemicals are toxic. Some causes cancer. Some chemicals are also beneficial. Some can save lives. Many are useful. All matter is made of chemicals, so the **importance** of chemistry is that it is the study of everything. **Chemistry deals with everything**. Perhaps a better understanding of chemistry would enable us to control the uses of chemicals so that we could maximise their benefits and minimise the risk involved in their use.

1.4 BRANCHES OF CHEMISTRY

There are many branches of chemistry or chemistry disciplines. The different branches focus on different aspects of matter. The five main **branches** are considered to be **Organic chemistry, Inorganic chemistry, Physical chemistry, Analytical chemistry,** and **Biochemistry** (Table 1.1). In addition, Nuclear chemistry, Environmental chemistry, Industrial chemistry, Polymer chemistry, Materials chemistry, Nanochemistry, Green chemistry, Agricultural chemistry, Theoretical chemistry, etc., are other branches of chemistry.

Table 1.1 Branches of Chemistry

Branch	Areas of emphasis	Examples
organic chemistry	most carbon-containing chemicals which are hydrocarbons and their derivatives	pharmaceutical, plastics
inorganic chemistry	in general, matter that does not deal with hydrocarbons	minerals, metals and non-metals, semi-conductors
physical chemistry	the behaviour and changes of matter and the related energy changes	reaction rates, reaction mechanisms
analytical chemistry	components and compositions of substances	food nutrients, quality control (QC) and quality assurance (QA)
biochemistry	matter and processes of living organisms	metabolism, fermentation

1.5 UNDERSTANDING CHEMISTRY

By studying and understanding chemistry, you will become a global citizen in the twenty first century where you have to live and act more intellectually, mature and with greater understanding and satisfaction in an increasingly complex civilisation. To justify why we have to study chemistry, there are several reasons:

- Chemistry is clearly very broad. It is so important to the future of life on this planet that every educated citizen should have some knowledge of its scientific basis.
- The principles of chemistry are needed to understand the nature of every form of matter. For example, metals, drugs, gasoline, foods, the earth's crust, water, atmosphere, radioactive materials and the human brain cell, all have properties determined mainly by chemical principles.
- Furthermore, a course in chemistry can be a fascinating experience, because it helps you to understand yourselves and your surroundings in everyday living. Consumer aspects of chemistry and the chemistry of common things can also be known from the fundamental ideas of chemistry.
- Agriculture also uses chemistry in many areas. Chemistry is very important for the food and beverage industry and medical industry. Chemistry has helped in establishing industries which manufacture utility goods, such as acids, alkalis, soaps, detergents, dyes, polymers, metals, etc. These industries contribute in a big way to the economy of a nation and generate employment.

- Chemistry is also required for many fields of study. For example, courses in Pharmacy and Medicine require applicants to have knowledge of chemistry; cutting-edge of today's digital technology requires knowledge on the principles of chemistry.

It is for these reasons, the fact that chemistry is everywhere and does affect all aspects of our lives, that it is necessary to study it. Understanding basic chemistry and chemical terms will help to make your material world more meaningful.

Chemistry is considered as an experimental science. You should recognise that the principles and laws of nature are the results of extensive observations and speculative analyses refined over many investigations. Basic process skills such as observing, classifying, inferring, communicating (through diagram, graph, chart, etc.), measuring, predicting and using numbers will be developed if you study chemistry.

You are expected to enhance the development of these skills and use them to construct your chemical knowledge, and hence engage in life-long learning.

1.6 THE PRINCIPAL GOALS IN BASIC EDUCATION HIGH SCHOOL CHEMISTRY

Basic chemistry is the branch of science that studies the preparation, properties, structures and reactions of material substances. Chemistry contributes to a large extent in the development and growth of a nation. A developing country, like Myanmar, needs talented and creative chemists. To be a good chemist, one needs to understand the basic concepts of chemistry. On this context, there are **six main themes** in Basic Education High School Chemistry Course: **Particulate nature of substances, Periodicity, Chemical calculations, Chemistry of reactions, the Environment and Organic chemistry**. Knowledge of these chemistry principles will help you to better understand the benefits and hazards to mankind and enable you to make intelligent decisions in the future. The door 'Chemistry Grade 10' is open to you. In your career it will not be in vain, it will become a beneficial asset.

EXERCISES

1. Match each of the items given in List A with the appropriate correct item shown in List B.

List A	List B
(a) Aristotle	(i) discovered the gas, oxygen
(b) Robert Boyle	(ii) postulated the atomic theory
(c) Joseph Priestley	(iii) laid the background for a more quantitative approach to chemistry
(d) Antoine Lavoisier	(iv) very early chemist tried to turn cheaper metals to gold
(e) John Dalton	(v) explained the Law of Conservation of Matter
(f) Amedeo Avogadro	(vi) formulated the theories on the behaviour of matter
(g) Alchemist	(vii) developed the basic ideas about the behaviour of gases

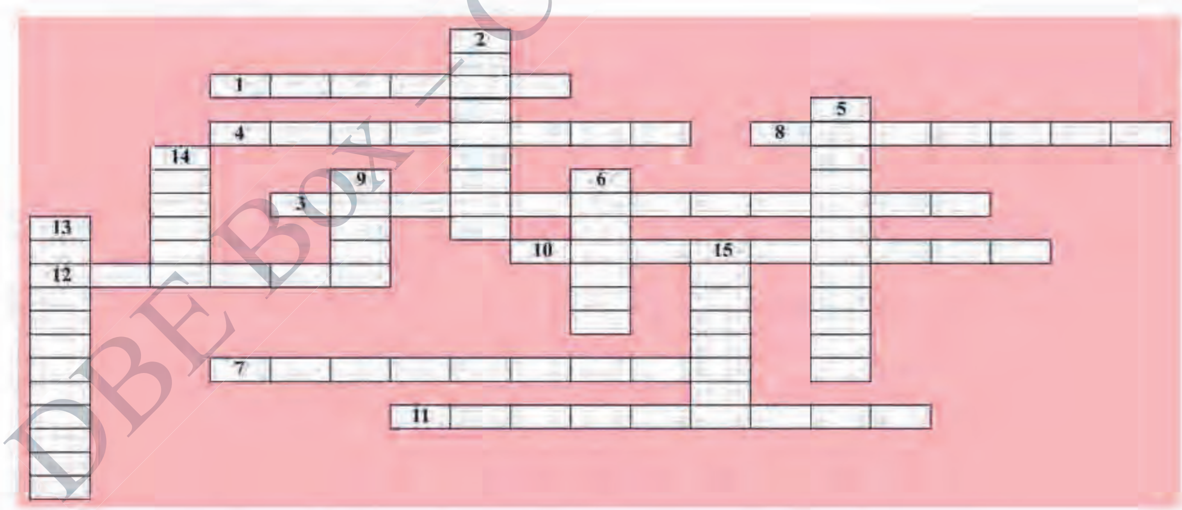
2. Fill in the blanks with suitable words and apply these words to solve the puzzle given below.

Across

(1) Chemistry is a study of _____ and their changes.
(3) Organic chemistry is an area of study on _____ and their derivatives.
(4) The behaviour and changes of matter and the related energy are studied in _____ chemistry.
(7) An area of study on matter not deal with hydrocarbons is _____ chemistry.
(8) Plastic is a synthetic _____ used to make a variety of products such as water plastic bottles.
(10) Chemical _____ occur when you breathe, eat, sit or read.
(11) Paper is made from _____.
(12) The air you breathe is a mixture of _____, nitrogen, etc.

Down

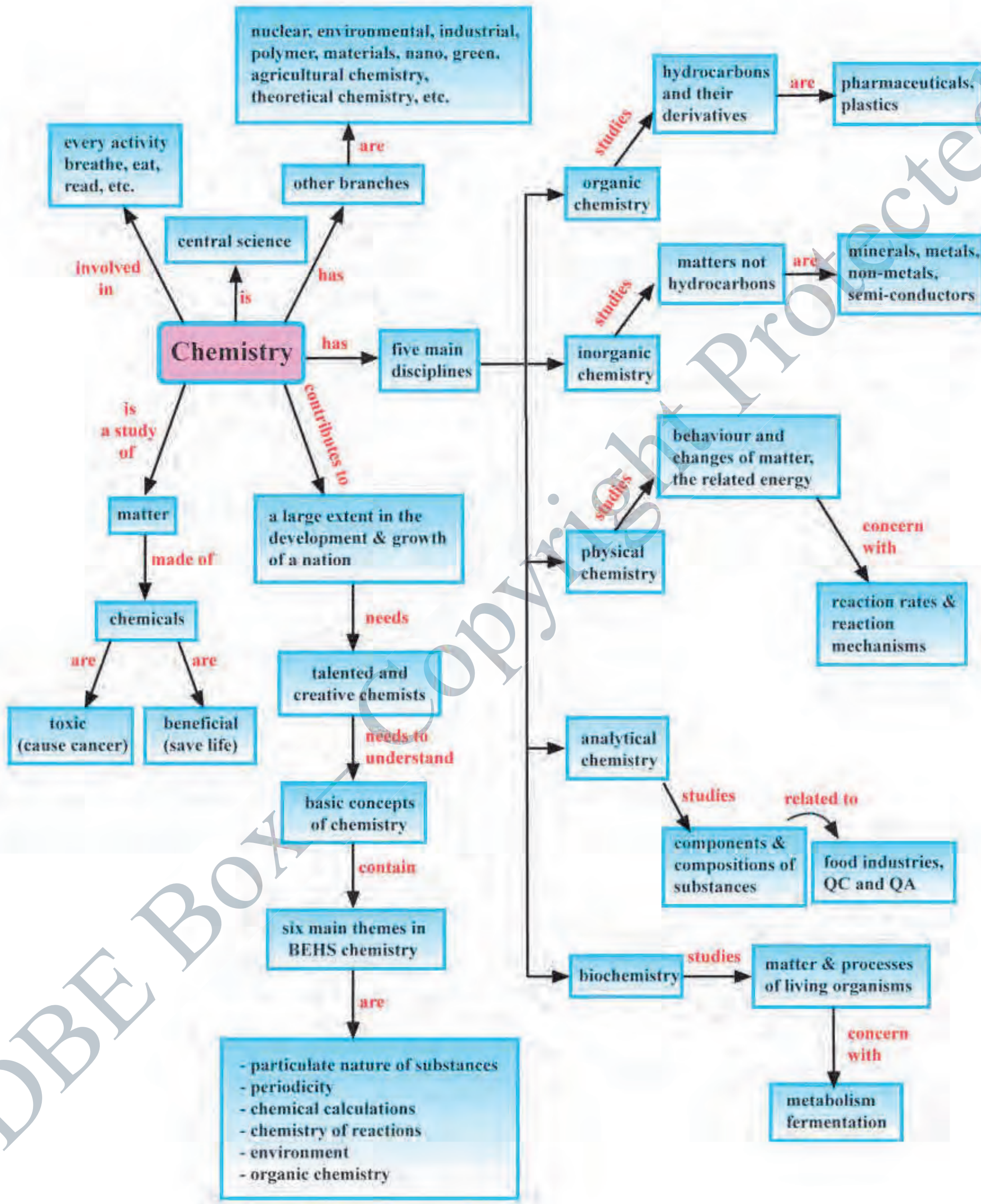
(2) Every activity, i.e., breathing, eating, reading, sitting, involves _____.
(5) Analytical chemistry is a study of components and _____ of substances.
(6) Chemistry is also considered as an experimental _____ since it is based on the results of observations and analyses through many investigations.
(9) A synthetic polymer, ____ is used for clothing.
(13) A study of matter and processes of living organisms is known as _____.
(14) Burning gasoline gives _____ to propel automobiles.
(15) Fermenting wine is _____ change.



3. How does the study of chemistry relate to other areas of study in science?

4. In what ways does chemistry affect your life?

CHAPTER REVIEW
(Concept Map)



CHAPTER 2 MATTER AND SOLUTIONS

Chemistry is after all the study of all matter, its composition, its properties, and its transformation from one form to another. **What is matter?** This word is used to cover all the substances and materials from which the physical universe is composed. There are many millions of different substances known and all of them can be categorised as solids, liquids or gases. Nowadays, there is a fourth state known as 'plasma' which is a hot ionised gas containing charged particles.

Learning Outcomes

After completing this chapter, students will be able to:
- explain the theory of matter;
- identify the states of matter based on the arrangement and movement of atoms and molecules;
- analyse the changes of state based on changes in the arrangement and movement of atoms and molecules and the level of energy;
- discuss the characteristics of and the distinctions between elements, compounds and mixtures;
- differentiate between physical and chemical changes;
- compare the characteristics of, behaviours of and connections between a solute, solvent and solution;
- solve the solubility of substances and the effect of temperature on it;
- describe separation techniques as applied to mixtures.

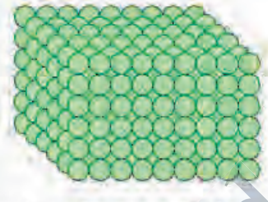
All substances are **matter**. Matter is made up of tiny particles. These can be atoms or molecules (groups of atoms), and elements or compounds. This includes the air, the sea, the Earth, all living creatures and even the galaxies.

The air (gas), the sea water (liquid), and alloys (solid) are not pure substances; they are mixtures. Many mixtures contain useful substance mixed with unwanted material. In order to obtain these useful substances, chemists often have to separate them from impurities. Different methods of separation depend on whether the substances to be separated are solids, liquids or gases. Adding sugar to tea or coffee is a solid-liquid mixture. This type of process involves solute, solvent and solution. What other examples can you think of where this type of process takes place?

2.1 STATES OF MATTER AND ARRANGEMENT OF PARTICLES IN MATTER

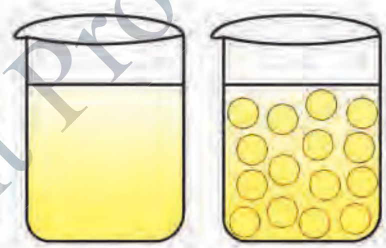
The most common states of matter are solid, liquid and gas. Water is a substance, which exists in all three states of matter: ice (solid), water (liquid) and steam (gas). The properties of each state of matter depend on the forces of attraction between the particles which can be weak or strong.

(a) Solids



The particles in a solid are packed very tightly together with strong forces between one another. Therefore, they have little freedom of movement and can vibrate about a fixed position. Solids have a definite shape and volume. They have different colours and different properties. Some solids are hard while others are soft. Some are dense while others are light. However, all solids have common properties, i.e., unlike gases they cannot be compressed and do not flow. Solids do expand slightly when heated.

(b) Liquids

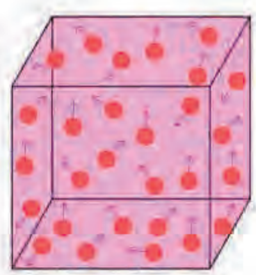


Liquids are composed of particles which are not fixed in any definite positions as in the solids. The particles are able to move freely throughout the liquids but not as independently as the gases so that the liquid can take up the shape of the container. Liquids can have a definite volume, because the particles in liquid are held together more strongly than those in gases. Some liquids have colours. However, unlike gases they cannot be compressed but they can flow easily.

(c) Gases

The particles in a gas are in constant and rapid motion because of weak attractive forces between gaseous particles. They move freely in all directions until they hit the walls of the container. The gas in a container spreads out to occupy the whole space of the container taking its shape and volume. Hence, gases do not have a definite volume and shape of their own.

Gases can have different properties. Some gases have a smell while others are odourless. Some gases have colours while others are colourless. However, all gases can easily be compressed and spread in all directions. It can be clearly visible in particles of smoke suspended in a gas. It is because of the effect known as **Brownian motion.**



(d) Particles of Matter: Diffusion Process

Diffusion can be explained by the Brownian motion.

The particles of matter are too small to be seen directly. It can be explained by indirect ways to show that matter consists of particles. One method is by a process called diffusion.

In diffusion, the particles of one substance mix with and move through the particles of another substance. Diffusion is mainly seen in liquids and gases. Some examples are given below:

A drop of food colouring matter diffuses throughout the water in a glass so that, eventually, the entire content of the glass will be coloured.

When a few drops of perfume are released into a room, the particles of perfume move through the air and spread the room. Anyone in the room would be able to smell the perfume eventually.

The speed of diffusion of particles is affected by the mass of particles and by the temperature.

- The bigger the mass, the slower the particles diffuse. The smaller the mass, the faster the particles diffuse.
- The higher the temperature, it enables the particles to diffuse faster.

Chemistry in Daily Life

- Matter is everything that we come across in our lives, like the air you breathe, the clothes you wear and the water you drink.
- The most common states of matter are solid, liquid and gas. Some are in solid (ice, sugar, salt, iron, copper, etc.), some are in liquid (water, oil, juice, etc.), some are in gaseous (air, oxygen, carbon dioxide, etc.) states.
- Diffusion of particles can occur in many ways. Preparing tea using tea bag in hot water, smelling perfume, aroma of foods, aroma therapies etc. are some examples of diffusion.

Review Questions

(1) Distinguish among the solid, liquid and gas.

(2) Which states can you see the following matter in our environment as solid or liquid or gas?

(a) iron (b) water (c) mercury (d) argon (e) gold (f) copper (g) vinegar

Key Terms

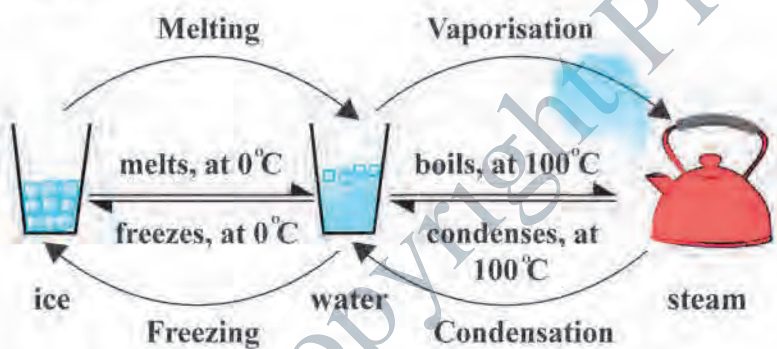
- **Matter** is made up of tiny particles, and has mass and takes up space. Three common states of matter are solid, liquid and gas.
- **Brownian motion** is the continuous random movement of small particles suspended in a gas or liquid, which arises from collisions with the gas or liquid particles, e.g., the motion of pollen grains on still water, movement of invisible dust in a room.

2.2 CHANGES IN MATTER

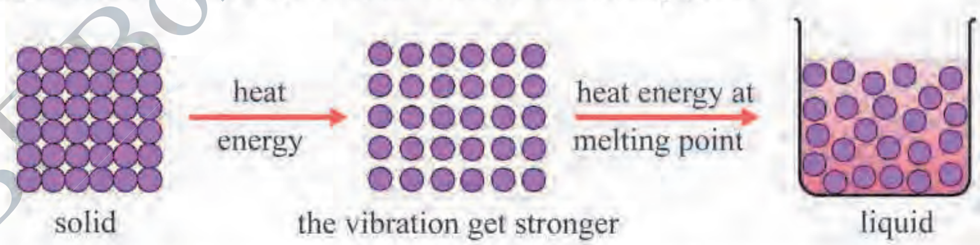
The materials around us are subject to constant change. Plants and animal materials decay, metals corrode, and land areas erode. Moreover, every substance – for example, water, sugar, salt, gold or silver – has a set characteristics or properties that distinguish it from all other substances and gives it a unique identity. One way to classify properties is based on whether or not chemical composition of an object is changed by the act of observing the property. Changes in substances can be classified as either physical or chemical.

(a) Physical Changes

A physical change is a change in which no new substances are formed. For example, when ice melts from solid to liquid, or when sand is ground to a fine powder, no new substance is formed. Melting, boiling, freezing, evaporation, vaporisation, condensation and sublimation are considered as physical changes.



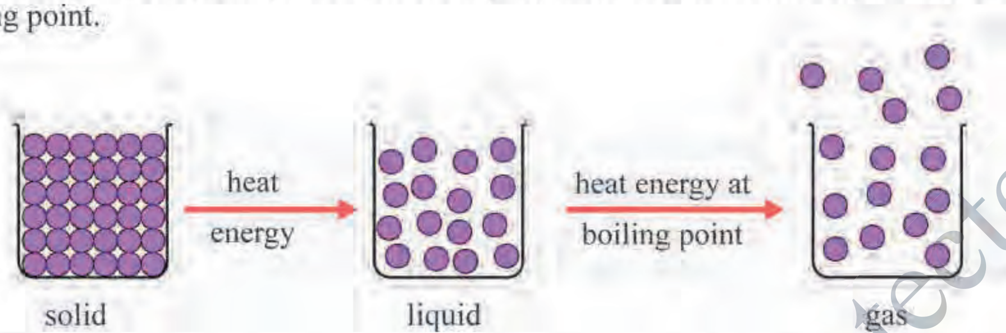
In a solid the particles attract one another. There are attractive forces between the particles which hold them close together. The particles have little freedom of movement and can only vibrate about a fixed position. When a solid substance is heated, the particles of the solid vibrate more strongly. Finally, these particles are able to overcome the forces that hold the particles in their fixed position. The solid then turns into a liquid. This is called melting. The temperature at which a solid melts is called the melting point.



When heating is continued, the particles of the liquid gain more energy and move more quickly as the temperature is increased. Eventually, the particles have enough energy to completely break the forces holding them together. Then the liquid particles escape from the surface to the space above the liquid. The particles are now able to move freely and get farther. A gas is formed. This is called vaporisation. **Vaporisation** is the process that occurs when a chemical or element is converted from a liquid to a vapour.

Evaporation is the process of a substance in a liquid state changing to a gaseous state due to an increase in temperature and / or pressure.

Boiling is the rapid vaporisation of a liquid, which occurs when a liquid is heated to its boiling point.



An unusual change of state can also occur, i.e., change of solid state to gaseous state and vice versa. For example, iodine solid changes to iodine vapour, where heat is absorbed. This is known as **sublimation**. Water vapour turns to frost is an example of **deposition**.

You can readily see that there is no new chemical substance formed in these changes. It is known as physical change; for example, sugar being dissolved in water, moulding silver and gold, passing electricity in electric bulb.

(b) Chemical Changes

A chemical change is a change in which one or more new substances are formed. Examples of chemical changes are cooking of rice from rice grains, green mangoes ripening, burning of a match, and burning of candle.

Chemical changes occur via chemical reactions such as dissociation, neutralisation, precipitation, etc. For example,

- Heating of limestone or marble (dissociation or decomposition)
- Use of magnesia to treat gastric patient (neutralisation)
- Passing carbon dioxide into limewater (precipitation)

Chemistry in Daily Life

- Freezing, melting, boiling and dissolving, cutting and moulding of the substances, etc. are physical changes.
- Mothballs sublime into vapour of deodorant for toilets and bathrooms. It is also a physical change.
- In our daily life, cooking the foods, burning the candle, iron rusting, vegetables rotting, building a fire, photosynthesis reaction, making soaps and detergents, etc. are chemical changes.

Review Questions

(1) Is squeezing juice from lime a physical change or chemical change?
Give reason for your answer.

(2) Classify the following changes into physical change and chemical change:

(a) boiling an egg (b) mixing sand and water (c) making jelly
(d) evaporating alcohol (e) souring of milk (f) baking a cake
(g) digesting food (h) crushing a can (i) breaking a glass
(j) mixing green and red marbles

(3) State the change of each of the following processes:

(a) When iodine, a solid, is gently heated it forms directly into a purple gas.
(b) Frost is formed when water vapour is cooled.
(c) Lime water becomes cloudy when carbon dioxide gas is passed into it.

Key Terms

- The temperature at which a solid changes to a liquid state at one atmospheric pressure is called **melting point** of that solid.
- The temperature at which the vapour pressure of the liquid is equal to the atmospheric pressure of the surrounding is called the **boiling point**.
- **Vaporisation** is the process that occurs when a chemical or element is converted from a liquid to a vapour.
- **Evaporation** is the process of a substance in a liquid state changing to a gaseous state due to an increase in temperature and / or pressure.
- **Freezing** is the process in which a liquid becomes sufficiently cold to change into a solid. **Freezing point** is the temperature at which a liquid becomes a solid.
- **Condensation** is the change from a gaseous state to its liquid state.
- **Sublimation** is the change of solid state directly into gaseous state without melting.
- **Deposition** is the direct solidification of a vapour by cooling; the reverse of sublimation.
- A **physical change** is a change in which no new substances are formed. There may be a temporary change in colour, temperature and state of the substances but no new substances are formed in the physical change.
- A **chemical change** is a change in which one or more new substances are formed. The substances change in colour, temperature and state but they also change into a new substance or substances in the chemical change.

2.3 ELEMENTS, COMPOUNDS AND MIXTURES

All samples of matter can be divided into two categories: pure substances and mixtures. A pure substance is a form of matter that always has a definite and constant composition. Pure substances are classified as either elements or compounds. At the beginning of the 19^{th} century, John Dalton proposed the theory of matter: that all matter was composed of atoms, which were invisible and indivisible. Today, the atom is still considered as the basic unit of any element. An atom may combine chemically to form molecules; the molecules become the smallest unit of any substances that possesses the properties of that substance. Modern experimental evidence has shown that atoms are divisible to create either lighter or heavier atoms.

(a) Elements

Elements are substances consisting of one type of atom, e.g., carbon element is made up of carbon atoms. Atoms are the smallest particles into which an element can be divided.

There are 92 known elements which occur naturally, either in the free or combined state. Some elements are solids such as copper, iron, zinc, silver, gold, carbon and phosphorus. Some elements are liquids. They are mercury and bromine. Some elements are gases such as oxygen, nitrogen, hydrogen and chlorine. Substances like these, which cannot be broken down into a simpler substance by chemical means, are called elements.

On the basis of their properties, elements may be classified into two groups, metals and non-metals (Table 2.1).

Table 2.1 General Properties of Metals and Non-metals

Metals	Non-metals
Metals show metallic luster.	Non-metals do not show metallic luster.
Metals have high density.	Non-metals have low density.
Most of the metals are malleable and ductile.	Non-metals are usually brittle.
Metals are good conductors of heat and electricity.	Most of the non-metals are poor conductors of heat and electricity.

(b) Compounds

The atoms of some elements are joined together in small groups. These small groups of atoms are called molecules.

Molecules exist in elements as well as compounds. A molecule of an element (molecular element) consists of atoms of the same kind. A molecule of a compound (molecular compound) consists more than one kind of atoms. The atoms of different elements in the molecule of a compound are combined in a definite ratio.

Most substances on Earth occur as compounds, e.g. carbon dioxide (CO_2), water (H_2O), marble ($CaCO_3$), glucose ($C_6H_{12}O_6$), ethanol (C_2H_5OH) and ammonia (NH_3). Although there is only small number of elements, there are millions of compounds.

Formulae and types of some compounds are described in Table 2.2.

Two or more different elements may combine together to form compounds. Some compounds occur naturally but some are made in laboratories, e.g., water occurs in nature and ethanol is a man-made compound.

The compounds can be classified in various ways. They can also be classified based on the combination of the number of atoms or the number of different elements. Hydrogen molecule is formed by two atoms of hydrogen. So, it is a diatomic molecule. Water is formed by combining two different elements: H and O. So, it is a triatomic molecule (binary compound).

Carbon dioxide is formed by the combination of two different elements, C and O. So it is a triatomic molecule (binary compound). In ammonia, there are more than three atoms from two different elements: N and H. So, it is a polyatomic molecule (binary compound). In ethanol, there are more than three atoms from three different elements: C, H, O. Therefore, it is a polyatomic molecule (ternary compound) (Table 2.2).

The most obvious difference is that an element cannot be broken down into other substances by chemical means whereas a compound can be broken down into other substances by chemical means.

Table 2.2 Name, Formula and Type of Compounds

Name	Element	How the atoms are joined	Formula	Type of compound (based on number of atoms)	Occurrence
water	hydrogen and oxygen		H_2O	triatomic molecule (binary compound)	natural
carbon dioxide	carbon and oxygen		CO_2	triatomic molecule (binary compound)	natural
ammonia	nitrogen and hydrogen		NH_3	polyatomic molecule (binary compound)	man-made
ethanol	carbon, hydrogen and oxygen		C_2H_5OH	polyatomic molecule (ternary compound)	man-made

(c) Mixtures

Mixtures consist of two or more different substances that are mixed physically but not chemically combined. They do not have well defined specific properties and the substances are not in fixed ratios.

The substances in a mixture may be solids, liquids or gases. For example, brass, a solid, is a mixture of the elements copper and zinc; sea water is a mixture of compounds including mainly water and sodium chloride; air is a mixture of gases containing nitrogen, oxygen, argon, carbon dioxide and water vapour. The mixtures may also be heterogeneous or homogeneous (Table 2.3). Therefore, the mixtures can be classified as two main categories: homogeneous and heterogeneous mixtures.

Table 2.3 Different Types of Mixtures

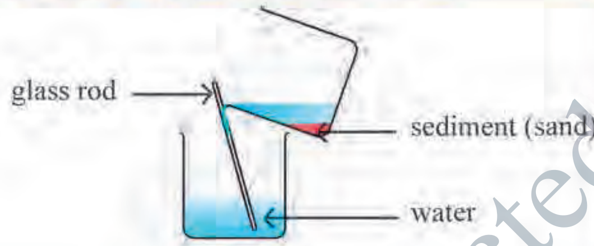
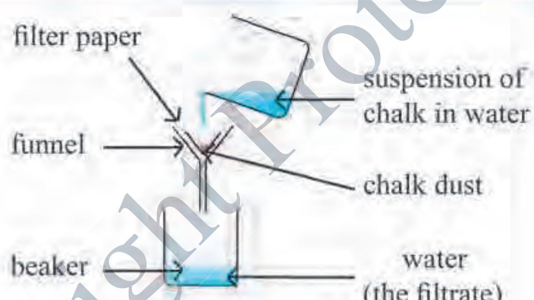
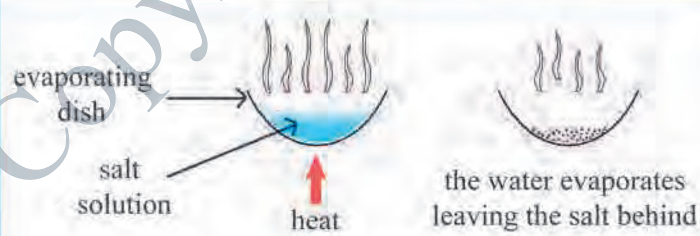
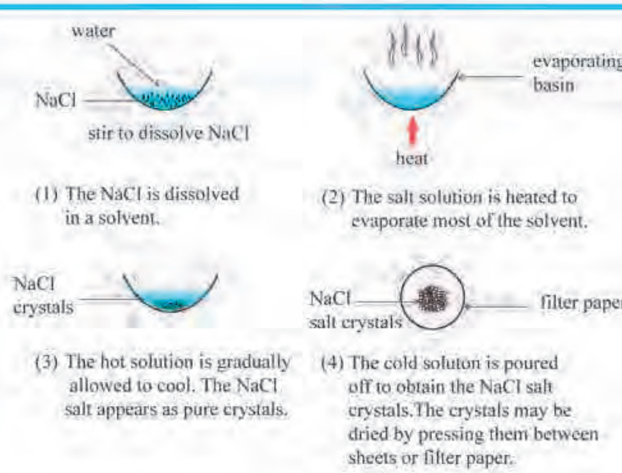
Physical state	Type of mixture	Example
solid-solid	homogeneous	stainless steel (mixture of iron and chromium)
solid-solid	heterogeneous	flour and rice powder
solid-liquid	homogeneous	sugar solution (sugar and water)
solid-liquid	heterogeneous	salt and oil
solid-gas	heterogeneous	dust in air
liquid-liquid	homogeneous	vinegar (mixture of acetic acid and water)
liquid-liquid	heterogeneous	oil and water
liquid-gas	homogeneous	soft drink (carbon dioxide gas dissolved in sterilised water at high pressure)
liquid-gas	heterogeneous	fossil fuel (mixture of crude oil and natural gas)
gas-gas	homogeneous	air (mixture of different gases)

Apart from **alloys** containing two metals, solid-solid mixtures are heterogeneous. Some heterogeneous mixtures cannot be recognised by the naked eyes, such as a mixture of magnesium oxide and calcium oxide. However, solid-solid mixtures can be recognised by microscopic examination, whereas we cannot do so with homogeneous solutions. Therefore, we are able to differentiate between a homogeneous mixture and a heterogeneous mixture by visual examination.

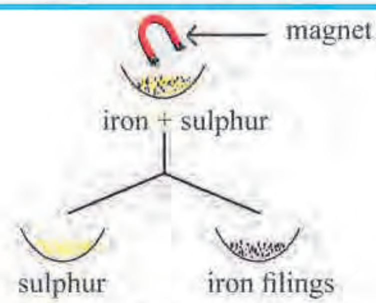
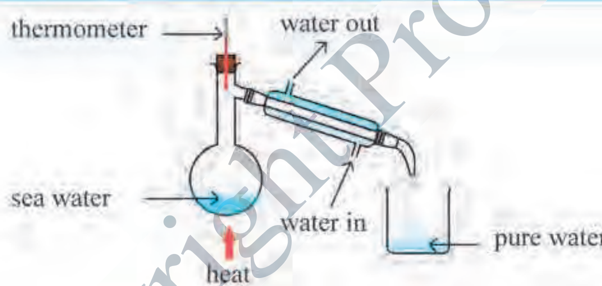
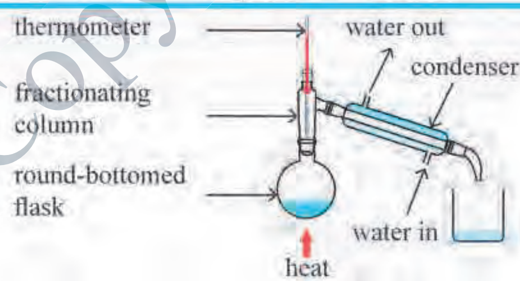
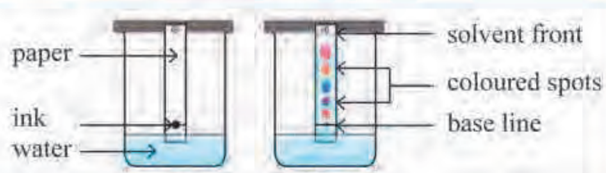
(d) Separation of Mixtures

Most substances are naturally found as mixtures; therefore the separation methods shown in Table 2.4 indicate how the physical states of components in the mixture can be separated into pure substances.

Table 2.4 Some Separation Methods of Mixtures

Types of mixtures	Separation method
a liquid and a solid mixture such as a suspension (sand/water)	 **decantation**
a solid from a liquid (chalk dust from water)	 **filtration**
solute from its solution (sodium chloride, NaCl salt from its solution)	 **evaporation**
a solute crystal from its solution (sodium chloride, NaCl salt from its solution)	 **crystallisation**

Continued from **Table 2.4**

Types of mixtures	Separation method
to attract magnetically susceptible materials (sulphur and iron mixture)	 **magnetic separation**
a solvent from a solution (pure water from sea water)	 **simple distillation**
liquids from each other (separation of petroleum)	 **fractional distillation**
a solid from a liquid (milk, blood)	 **centrifugation**
different substances from a solution (separation of ink by paper chromatography)	 **chromatography**

Chemistry in Daily Life

- Gold, silver and copper have been used to make ornamental objects and jewellery for thousands of years. Special properties of gold make it perfect for manufacturing jewellery.
- Mercury is used in thermometers and traditional blood pressure monitors. Mercury is a very toxic substance. When it accumulates in the body, it causes damage to the brain, kidney and lungs.
- Calcium carbonate is a compound made up of three elements-calcium, carbon and oxygen. Chalk is one form of calcium carbonate.
- Examples of homogeneous mixtures include sugar solution, which is the mixture of sucrose and water, and gasoline which is a mixture of dozens of hydrocarbon compounds.
- Colloidal mixtures (heterogeneous) have components that tend not to settle out. Milk is a colloid of fat globules suspended in water.
- The mixture of gasoline / kerosene and water is an example often cited as a safety hazard. Decanting a mixture containing flammable solvents can be dangerous as the flammable material evaporates and forms dangerous fumes.
- When rain touches the ground it mixes with dirt, rocks and so on, i.e., it could become a mixture.
- Sediment from the fermentation process of wine can produce an undesirable taste. Wine is separated from the sediments by decantation.
- Plasma can be removed from blood by decantation after centrifugation.

Review Questions

(1) When attempts are made to break down substance **A** by chemical methods, the same original substance is always formed. Is substance **A** an element or a compound?

(2) When a substance is broken down by chemical means, two substances with different properties are formed. Is the original substance an element or a compound?

Key Terms

- An **element** is a substance that cannot be broken down into other simpler substances through chemical means. Every element is made up of its own type of atoms. Therefore, it has a unique position in the Periodic Table.
- A **compound** is a substance containing two or more different elements chemically joined together in a fixed ratio.
- A **molecule** is the simplest unit of the chemical substance, usually a group of two or more atoms.
- **Molecules** exist in elements as well as compounds. A molecule of an element (molecular element) consists of atoms of the same kind. A molecule of a compound (molecular compound) consists of more than one kind of atoms. The atoms of different elements in the molecule of a compound are combined in a definite ratio.

- **Diatomic molecules** are molecules composed of only two atoms of same or different elements.
- **Triatomic molecules** are molecules composed of only three atoms of same or different elements.
- **Polyatomic molecules** are molecules composed of three or more atoms of same or different elements.
- The compounds formed by the combination of two elements are called **binary compounds**.
- The compounds formed by the combination of three elements are called **ternary compounds**.
- A **mixture** is a combination of more than one substance, where these substances are not bonded to each other. It consists of two or more substances which may be present in any proportion by weight. The constituents of the mixture do not combine chemically.
- A **heterogeneous mixture** is one that is non-uniform, and where the different components of the mixture can be seen. The components separate, and the composition varies.
- A **homogeneous mixture** is one in which the composition of its components are uniformly mixed throughout. The components cannot be seen separately on visual or microscopic examination.
- **Alloy** is a substance made by combining two or more metallic elements, especially to give greater strength or resistance to corrosion.
- **Filtration** is a method for separating an insoluble solid from a liquid. When a mixture of sand and water is filtered, the sand remains as residue on the filter paper and the water, which is also called filtrate, passes through the filter paper.
- **Crystallisation** is defined as a process by which a chemical is converted from a liquid solution into a solid crystalline state.
- **Decantation** is a process to separate mixtures. Decanting is just allowing a mixture of solid and liquid or two immiscible liquids to settle and separate by gravity.
- **Magnetic separation** is used to separate the components of a mixture when at least one of them is magnetic in nature.
- **Simple distillation** is a procedure by which two liquids with different boiling points can be separated. It is used to separate solvent from a solution.
- **Fractional distillation** is a method for separation of a liquid mixture into fractions with different boiling points (and hence chemical composition) by means of distillation, typically using a fractionating column.
- **Centrifugation** is a technique used for the separation of particles from a solution according to their size, shape, density, viscosity of the medium and rotor speed.
- **Chromatography** is a separation method of the mixed substances that depends on the speed at which they move through special media, or chemical substances. It consists of a stationary phase (a solid) and a mobile phase (a liquid or a gas).

2.4 SOLUTIONS AND SOLUBILITY

A solution is a homogeneous (uniform) mixture of two or more substances. The ocean is a vast water solution containing different compounds extracted from the minerals of the Earth's crust. Nutrients are carried in water solution to all parts of a plant.The production of many useful materials by the chemical industry involves chemical reactions in which the reacting substances are dissolved in water, ethanol (ethyl alcohol), etc. Solutions play an important part in many processes that go on about us.

(a) Solutions

Some solids such as copper(II) sulphate, sugar and common salt are soluble in water but some solids such as sand, charcoal and chalk are insoluble in water. Some solids such as iodine are slightly soluble in water. When you mix sugar with water, it seems to disappear. That is because its particles spread all through the water particles. The sugar has dissolved in the water, giving the mixture called as a **solution**. Sugar is the **solute**, and water is the **solvent**.

Some liquids can mix with one another in all proportions (miscible liquids), while some liquids do not mix (immiscible liquids). Thus for example, ethanol, acetic acid and sulphuric acid are soluble in water but petrol and oils are insoluble in water.

Some gases such as hydrogen chloride and ammonia are very soluble in water. Some gases such as oxygen, nitrogen and hydrogen are not very soluble in water.

Solutions may be gaseous, solid, or liquid in nature. Dry air is a familiar example of a gaseous solution. Brass (copper and zinc) is an example of a solid solution. Liquid solutions may contain solid, liquid, or gaseous solutes. Salt water is a familiar example of a solid dissolved within a liquid. Vinegar is a solution containing two liquids, acetic acid and water. Carbonated water contains carbon dioxide gas molecules existing between molecules of water.

Solutions having water as the solvent are referred to as aqueous solutions. Many reactions including those vital for life processes occur in aqueous solutions. Blood and saliva are some of the more familiar solutions of biological importance.

(b) Solubility

Some solid is added to a certain volume of water in a beaker with stirring until all of it dissolved. If some more solid added can dissolve with stirring, this solution is known as an **unsaturated solution**. A **saturated** solution forms when no more solute can be dissolved in the given amount of solvent at that temperature even if it is stirred. The amount (in grams) of the solute in 100 g of water to give a saturated solution at that experimental temperature is known as the **solubility** of that solute. If the solution contains more solute than it should have at room temperature, it is a **supersaturated** solution.

Effect of temperature on solubility

Solubility of the solute depends, in part, on the temperature of the solvent. When the temperature of the solution is increased the solubility of the solute increases (Table 2.5 and Figure 2.1).

Table 2.5 The Solubility of Potassium Nitrate in Water at Different Temperatures

Temperature (°C)	10	20	30	40	50	60	70	80	90	100
Solubility (g / 100 g water)	21.2	31.6	45.3	61.4	83.5	106	135	167	203	245

From the solubility data of the potassium nitrate in the above table, a graph is drawn with temperature on the horizontal axis and solubility on the vertical axis as shown in Figure 2.1.

There are some exceptions. The solubility of all gases and some solids such as calcium hydroxide and calcium sulphate decreases when temperature of the solution is increased. It is, therefore, necessary to specify the temperature at which the solution is saturated. A good example is opening two cans of soda, one cold one and one warm one. Comparing the reactions will demonstrate that more gas is released from the warm pop than from the cold pop.

When a saturated solution at a higher temperature is cooled, the solubility decreases. So the excess solute, i.e., the difference in the solubility of the two temperatures, will come out as solid.

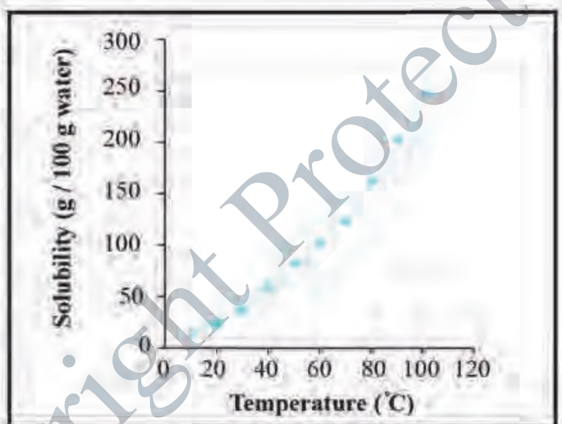


Figure 2.1 The Solubility of Potassium Nitrate in Water at Different Temperatures

Chemistry in Daily Life

- Solution can be found almost everywhere on the earth, from the oceans to the sky. Every ocean and every lake on earth is a solution, because the water has mixed with dirt, salt and various substances.
- When you stir sugar in a cup of coffee, you are making a solution.
- Solubility has many practical applications in our lives such as purifying water and making drinks.

Review Questions

(1) Give two examples for each of the following:
(a) solids that dissolve in water (b) insoluble solids in water
(c) solvents other than water

(2) 20 g of a soluble substance is dissolved in water to form 100 g of the solution. 25 g of the solution is taken and evaporated to dryness. How many grams of the solid will be obtained?

(3) The solubility of copper(II) sulphate at 60 °C is 40 g / 100 g, and at 90 °C is 67.5 g / 100 g.

A saturated solution of copper(II) sulphate in 100 g of water at 90 °C is cooled to 60 °C. Calculate the amount of copper(II) sulphate which would come out of the solution.

Key Terms

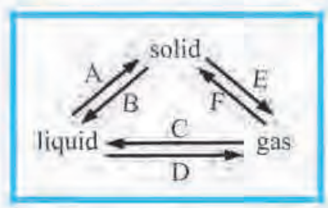
- A **solute** is a substance which dissolves in a solvent to give a solution.
- A **solvent** is a substance, mostly liquid, in which another substance dissolves to give a homogeneous mixture.
- A **solution** is a clear homogeneous mixture obtained when a substance dissolves in a solvent. In a solution the solute is uniformly distributed throughout the solution.
- **Solubility** of a substance at a given temperature is the mass in grams of the substance which will saturate 100 g of water, at that temperature.
- A **saturated solution** is one in which no more solute will dissolve at the given temperature, in the presence of excess solute. A solution in which more of the solute can dissolve at the given temperature is called **unsaturated solution**.
- The solution that retains more solute than that required to saturate the solution at room temperature is called a **supersaturated solution**.

EXERCISES

1. This question is about ways to separate and purify substances. Match each term from List A with the correct description from List B.

List A	List B
(a) evaporation	(i) a solid appears as the solution cools
(b) condensing	(ii) used to separate a mixture of two liquids
(c) filtering	(iii) the solvent is removed as a gas
(d) crystallising	(iv) this method allows you to recycle a solvent
(e) distillation	(v) a gas changes to a liquid, on cooling
(f) fractional distillation	(vi) separates an insoluble substance from a liquid

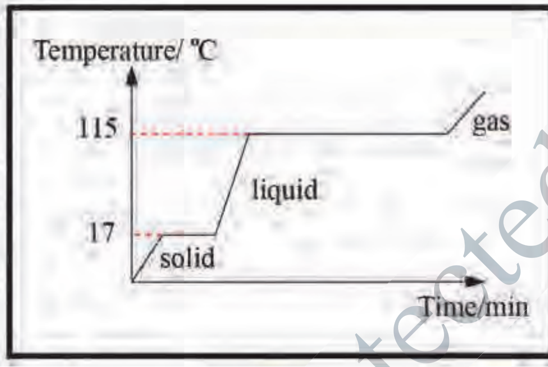
2. The following diagram shows the three states of matter and how they can be interchanged.
   (a) Name the changes of A to F.
   (b) Name a substance which will undergo changes from solid to liquid to gas between 0 °C and 100 °C.
   (c) Describe what happens to the particles of the solid during change E.
   (d) Name a substance which will undergo change E.



3. (a) Why solids do not undergo diffusion? Explain why diffusion of gases is faster than liquids.
   (b) Give two examples for diffusion of gases and liquids found at home.

4. When a jar of coffee is opened, people in all parts of the room soon notice the smell. Explain how this happens.

5. The heating curve for a pure substance is given. It shows how the temperature rises over time, when the substance is heated until it melts, then boils.
   (a) What is the melting point of the substance?
   (b) What happens to the temperature while the substance changes state?
   (c) The graph shows that the substance takes longer to boil than to melt. Suggest a reason for this.
   (d) How can you tell that the substance is not water?
   (e) Sketch a rough heating curve for pure water.



6. The solubility (g / 100 g water) of three substances at different temperatures are given below.

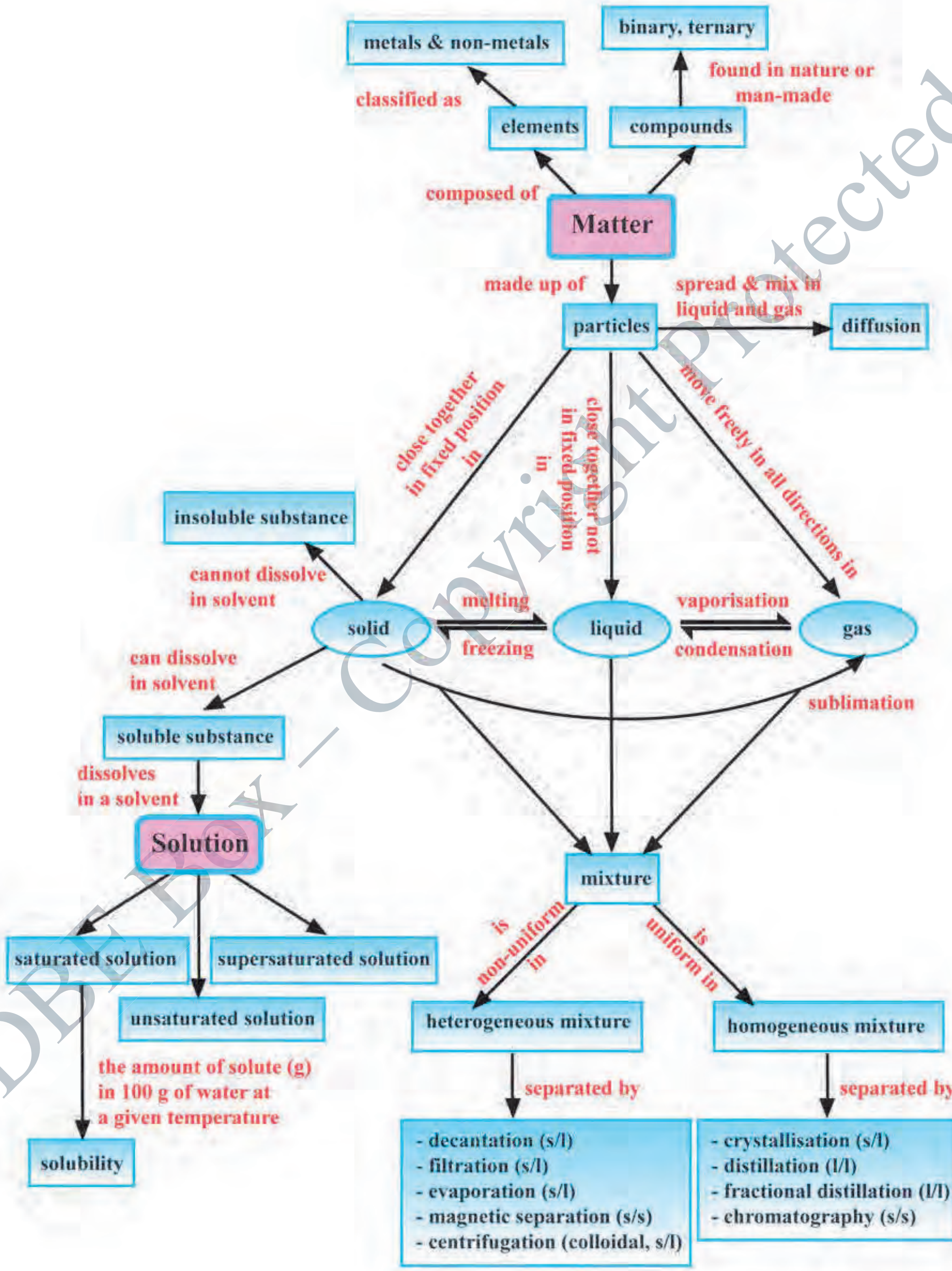
Temperature °C	0	10	20	30	40	50	60	70	80
Potassium chlorate	3.3	5.0	7.3	10.0	14.0	18.5	24.0	30.2	37.5
Calcium hydroxide	0.13	0.13	0.12	0.11	0.10	0.00	0.08	0.06	-
Sodium sulphate	5.0	9.0	20.5	41.0	48.0	47.0	45.0	44.0	43.0

   (a) Plot the solubility curve of each substance.
   (b) Describe the change in solubility with the temperature for each substance.
   (c) What is the solubility of each substance at 25 °C?
   (d) What happens when each solution at 70 °C is cooled down to 30 °C?

7. The solubility of sodium nitrate at 40 °C is 104 g / 100 g water.
   (a) How much sodium nitrate will be obtained if 25.5 g of saturated solution at 40 °C is evaporated to dryness?
   (b) What is the maximum amount of solid that can be dissolved in 250 g of water at 40 °C?

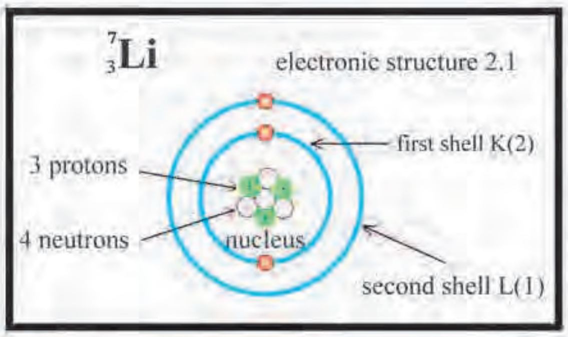
8. The solubility of solid **A** at 60 °C is 24 g / 100 g water.
   (a) What is the amount of solid required to saturate 30 g of water at 60 °C?
   (b) What will be the amount of saturated solution obtained at 60 °C when 12 g of the solid **A** is used to prepare a saturated solution?

CHAPTER REVIEW
(Concept Map)



CHAPTER 3 THE ELECTRONIC STRUCTURES OF ATOMS AND PERIODIC TABLE

In Chapter 2, we have seen the word 'atom', which is the smallest particle of an element. In this chapter we will learn that the arrangement of atoms in the element can be explained by the new model. Atoms very rarely exist by themselves. They are usually joined together in groups by chemical bonds. Two types of chemical bonding: ionic and covalent, will be explained in this chapter.



We know that chemical elements play a vital role in our daily lives and are crucial for humankind, our planet, and our industries. The development of the Periodic Table of the elements is one of the most significant achievements in science. The Periodic Table gives insights into the elements and helps us to understand the characteristics of elements.

Learning Outcomes

After completing this chapter, students will be able to:
- describe the properties of electrons, protons and neutrons;
- define isotopes and isobars, and explain them with respect to atomic number and mass number;
- explain the electronic structure of atoms;
- explain how the Periodic Table is organised based on atomic structure;
- classify elements based on electron configurations;
- describe the periodic properties of common elements;
- discuss the general trends in metallic and non-metallic character, electronegativity, sizes, ionisation energy and electron affinity of elements within the periods and groups of the Periodic Table;
- compare the different types of bonds that form between atoms when molecules are formed.

3.1 STRUCTURE OF ATOM

All matter is made up of atoms. Atoms are so tiny that it was not realised that atoms were in fact made up of charged particles until about 1900 AD. The old model of the atom was published by Dalton in 1803. However, based on the experimental evidence, Dalton's atomic model has been replaced by the new model.

(a) Arrangement of Sub-atomic Particles in Atom

Atoms consist of three sub-atomic particles called proton, neutron and electron. They are also known as fundamental particles. The properties of fundamental particles of an atom are summarised in Table 3.1.

Table 3.1 Properties of Fundamental Particles

Particle	Symbol	Relative mass	Relative charge
proton	p	1	positive (+1)
neutron	n	1	neutral (0)
electron	e	1/1837	negative (–1)

A **proton** is a particle carrying a positive charge. A **neutron** is a particle carrying no charge and having a mass similar to proton. An **electron** is a particle carrying a negative charge and having a very small mass. The mass of an electron is approximately 1/1837 times the mass of a proton.

In a neutral atom, the number of protons is equal to the number of electrons. Atoms are identified by the number of protons in it. The **proton number** is referred to the number of protons in the atom and is often referred to as the **atomic number (Z)** of the element. Different elements have a different proton number or atomic number from each other.

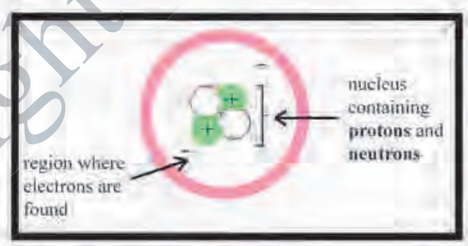


Figure 3.1 Atomic Structure of an Atom

The atom has a small, dense, positively charged center called **nucleus**. It contains proton(s) and neutron(s). The total number of these two particles is also known as the **nucleon number** or **mass number (A)**. Outside and around the nucleus, electrons rapidly move in circular or near circular orbits. It can be represented in Figure 3.1.

We can describe any elements in a short way like this:

$$^{\text{mass number}}_{\text{atomic number}}\text{X} \quad \textbf{symbol of element}$$

For example, $^{12}_{6}C$, $^{16}_{8}O$ and $^{35}_{17}Cl$

(b) Isotopes

Not all atoms of an element are necessarily the same. All atoms of the same element have the same number of protons. However, some atoms of an element have different number of neutrons. For example, although all carbon atoms have six protons, not all carbon atoms are identical. Some have more neutrons than others.

Most of carbon atoms have 6 neutrons but some carbon atoms are found with 7 neutrons or 8 neutrons as shown in the diagram (Figure 3.2). These three different carbon atoms are called **isotopes** of carbon.

Figure 3.2 Isotopes of Carbon

Isotopes are atoms with the same number of protons but different number of neutrons. In other words, isotopes are the atoms of the same element with different masses.

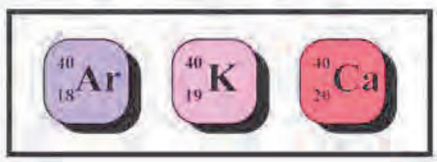
With the help of the mass spectrometer, some of the elements were found to consist of a mixture of the atoms having different masses. Mass spectrometer is a device used to find out the masses of isotopes and their relative abundance. It becomes a mean of measuring the ionisation energy of all elements.

Isotopes of the same element have the same chemical properties but there are some small differences in physical properties. For example, the three hydrogen isotopes, ${}^{1}_{1}H$, ${}^{2}_{1}H$ and ${}^{3}_{1}H$ have slightly different boiling points.

Some isotopes are **radioactive** whereas some are **non-radioactive**. A carbon-14 atom is radioactive but carbon-12 and carbon-13 are not radioactive. Radioactive isotopes produce radiation. Some radiations are harmful but some can be used for good. Most isotopes in the air and ground are not radioactive.

(c) Isobars

Some of the different elements have same nucleon number. That is, different elements with different proton number and same nucleon number. An example of a series of isobars would be ${}^{40}Ar$, ${}^{40}K$ and ${}^{40}Ca$.



Chemistry in Society

Up to the early 20th century, uranium was used in making an attractive yellow glaze for pottery. This was ended when people realised that uranium is radioactive, making the pots radioactive too. When nuclear reactors were invented, scientists were able to make nuclear bombs from radioactive plutonium.

There are many radioisotopes which are mainly used in the treatment of hazardous diseases. Cobalt-60 (Co-60) is used in radiotherapy and in food preservation. P-32 and Sr-90 are used to treat skin cancer. Na-24 is used to detect tumors and blood clots and also detect the leakage from underground pipes. Similarly, I-131 is used to investigate the thyroid glands. C-14 is widely used in estimation of the age of ancient artifacts by radiocarbon dating method.

Review Questions

(1) How many electrons, protons and neutrons are present in the following atoms?

$${}^{16}_{8}O \quad , \quad {}^{39}_{19}K \quad \text{and} \quad {}^{207}_{82}Pb$$

(2) Select isotopes and isobars from the following atoms. Give reasons.

$${}^{39}_{19}K \; , \; {}^{238}_{92}U \; , \; {}^{27}_{13}Al \; , \; {}^{16}_{8}O \; , \; {}^{235}_{92}U \; , \; {}^{39}_{17}Cl$$

Key Terms

- **Atoms** are the smallest particles into which an element can be divided.
- The number of protons in the nucleus of an atom is known as **atomic number (Z)** of an element. The atomic number never changes.
- The **mass number (A)** of the element is the sum of the number of protons and neutrons or the total number of nucleons in the nucleus of an atom of that element.
- The **nucleon number** of an element is total number of protons and neutrons in the nucleus of its atom.
- Atoms of the same element that have the same number of protons but different number of neutrons are called **isotopes.** They are the atoms of the same element with different masses.
- **Isobars** are the atoms with same mass number but different atomic number.

3.2 ELECTRONIC STRUCTURES (ELECTRON CONFIGURATIONS)

The way in which electrons are arranged around the nucleus of an atom is very important because the electron arrangement determines the chemical properties of the atom. The arrangement of electrons in an atom was suggested in 1913 by Niels Bohr.

(a) Main Shells

Electrons move round the nucleus in definite **shells** or **orbits.** Each shell is numbered 1, 2, 3, 4, and so on, going outwards from the nucleus. They are also known as K shell, L shell, M shell, N shell, and so on, as shown in Figure 3.3. Each shell has different energy levels and can contain a limited number of electrons. In general, the closer the shell is to the nucleus, the lower is its energy. The maximum number of electrons in each shell which could contain can be calculated by the formula $2n^2$, where n is the shell number.

shell number	1	2	3	4
main shell	K	L	M	N
maximum number of electrons	2	8	18	32

Figure 3.3 Diagrammatic Representation of the Nucleus and the Electron Shells in an Atom (not to scale)

(b) Sub-shells

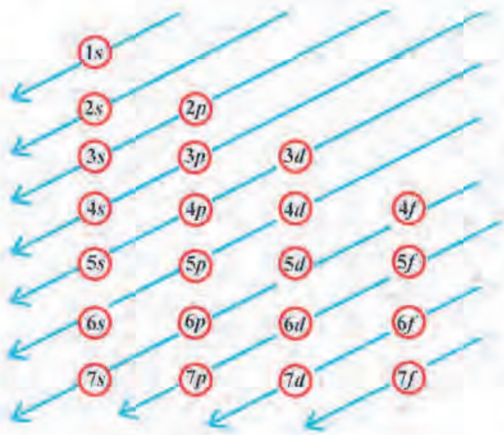


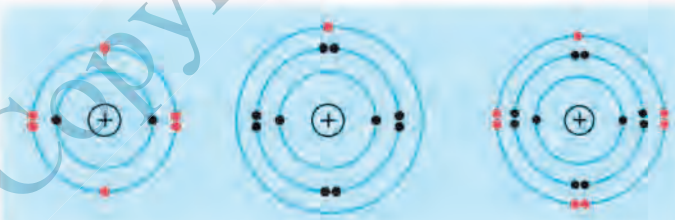
Figure 3.4 Order of Occupancy of Sub-shells

Each main shell is again divided into a number of **sub-shells (orbitals)**, *s*, *p*, *d* and *f*. The letters used for sub-shells notations: *s* stands for sharp; *p* for principal; *d* for diffuse and *f* for fundamental. The maximum number of electrons in *s*, *p*, *d* and *f* sub-shells is 2, 6, 10 and 14, respectively. The shell number 1 (K shell), has only *s* sub-shell, the shell number 2 (L shell) has *s* and *p* sub-shells, the shell number 3 (M shell) *s*, *p* and *d* sub-shells and the shell number 4 (N shell) *s*, *p*, *d* and *f* sub-shells and so on. Therefore, the order of filling the sublevels is given as: $\mathbf{1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^2\ 4f^{14}\ 5d^{10}\ 6p^6}$**...** .

The order in which the sub-shells fill is shown in the Figure 3.4, which is arranged so that it is easily remembered. One simply lists the sub-shells in order, starting each shell with a new line. The order of filling them is found by crossing them with diagonal arrows.

(c) Arrangement of Electrons

The electronic structures of some elements (arrangement of electrons in an atom of O, Na and Cl) described as integer as well as complete and essential electron configurations are shown in Figure 3.5.



integer form:	O (2.6)	Na (2.8.1)	Cl (2.8.7)
complete electronic structure:	$1s^2\ 2s^2\ 2p^4$	$1s^2\ 2s^2\ 2p^6\ 3s^1$	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$
essential electronic structure:	$2s^2\ 2p^4$	$3s^1$	$3s^2\ 3p^5$

Figure 3.5 Electronic Structures of Oxygen, Sodium and Chlorine

This is the arrangement of electrons in shells around the nucleus. Each shell can hold a certain maximum number of electrons. The electrons always go into the shell nearest to the nucleus which has lowest energy. Once the shell is filled up, the electrons go into next available shell and so on. Hence, the first shell (K) can hold up two electrons which fill up in *s* sub-shell, subsequent shell (L) up to eight electrons in which two in *s* sub-shell and six in *p* sub-shell and so on.

(d) Valence of the Elements (Combining Capacity)

The shell which is furthest from the nucleus is called the **outer shell**. It is also called the **valence shell**. The electrons in this shell are known as **outer electrons** (or) **valence electrons**. These electrons are involved in chemical reactions.

The number of outermost shell electron ≤ 4, Valence = number of outermost shell electrons

The number of outermost shell electron > 4, Valence = 8 − number of outermost shell electrons

For example,

The complete electronic structure of sodium is $1s^2\ 2s^2\ 2p^6\ 3s^1$.

The essential electronic structure of sodium is $3s^1$.

The outermost shell electron is 1 and valence is 1.

In the case of fluorine, the essential electronic structure is $2s^2\ 2p^5$, the outermost shell electron is 7 and its valence is therefore 1, i.e., $8 - 7 = 1$.

Review Question

Use Periodic Table to complete the following table:

Element	Integer electronic structure	Complete electronic structure	Essential electronic structure	Valence
Li		$1s^2\ 2s^1$	$2s^1$	
B		$1s^2\ 2s^2\ 2p^1$		3
Na	2.8.1		$3s^1$	
Al	2.8.3	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$		
	2.8.8.1		$4s^1$	
	2.8.7		$3s^2\ 3p^5$	

Key Terms

- The distribution of electrons in an atom of an element is called the **electronic structure**.
- The arrangement of all the electrons of an atom of the element in appropriate sub-shells is known as the **complete electronic structure**.
- The representation of the arrangement of valence electrons of an atom of the element in appropriate sub-shells is called the **essential electronic structure**.
- **Valence** is the number of electrons in the outermost shell when the number of electrons in the outermost shell is 4 or less . On the other hand, valence is equal to 8 minus number of electrons in the outermost shell when the number of electrons in the outermost shell is greater than 4.

3.3 THE PERIODIC TABLE

The Periodic Table was devised in 1869 by the Russian chemist Dmitri Mendeleev (1834-1907). His Periodic Table was based on the chemical and physical properties of the 63 elements that had been discovered at that time.

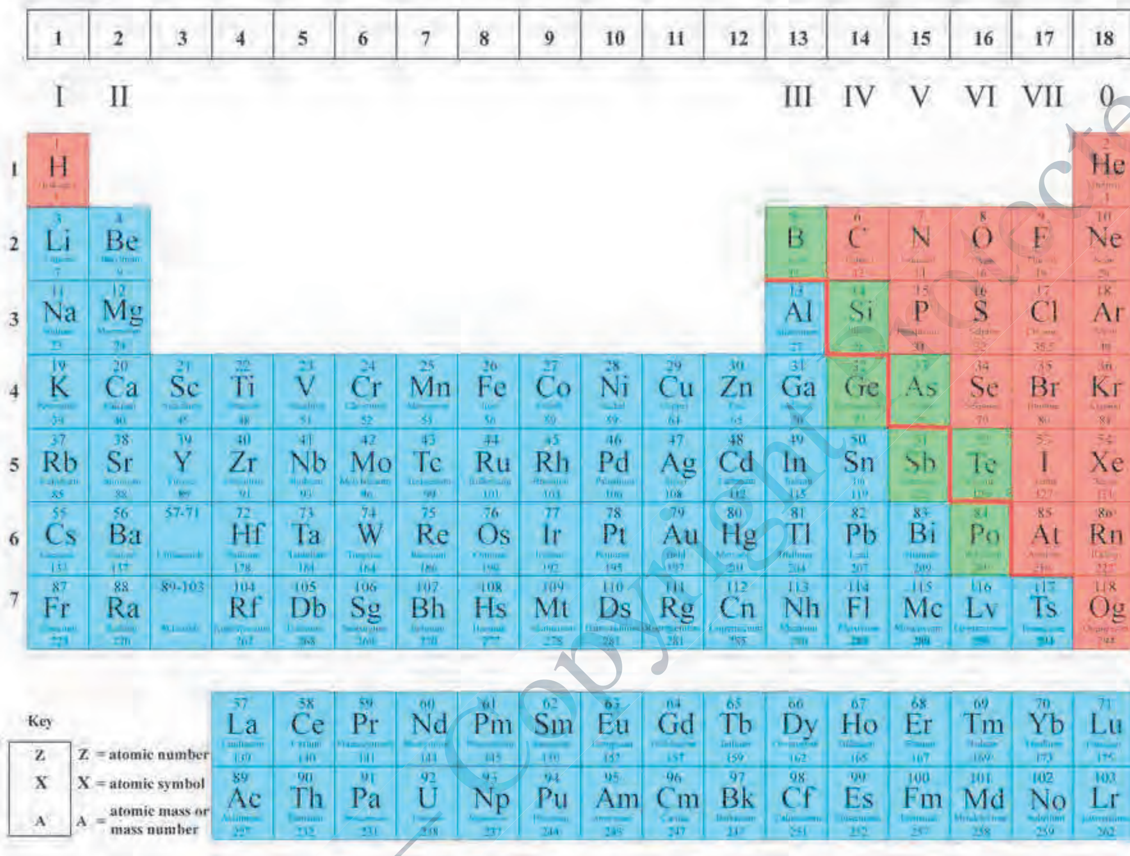


Figure 3.6 The Periodic Table

In the modern Periodic Table the 118 known elements are arranged in order of increasing atomic number (Figure 3.6). This table helps chemists to understand the elements better and to predict properties of elements.

There are 18 vertical columns and 7 horizontal rows in the Periodic Table. The vertical columns are called **groups**. The horizontal rows are called **periods**. Those elements with similar chemical properties are found in the same columns or groups.

Group I elements (except hydrogen) are called the **alkali metals**.
Group II elements are called the **alkaline earth metals**.
Group VII elements are called the **halogens**.
Group 0 elements are known as the **noble gases** or **inert gases**.
Groups I and II consist of *s*-block elements. Groups III, IV, V, VI,VII and group 0 consist of ***p*-block elements**. **Transition elements** are ***d*-block elements**. **Inner transition elements** (lanthanides and actinides series), also known as **rare earth elements** are the ***f* -block elements**.

Chemistry in Society

- Lithium is used to make batteries that power electronic devices like digital cameras.
- Sodium vapour lamps give off yellow-orange light and are often used in street lamps.
- The halogens have many varied uses: fluoride in toothpaste to help reduce dental decay; chlorine in household bleach to kill bacteria, to whiten clothes, and to clean swimming pool; bromine as a fire retardant; and iodine in photographic reproduction.
- The metalloid silicon is used to make silicon chips.
- Helium is used for filling weather or advertisement balloons and airships.
- Neon is used in making light and advertising signs.
- Argon is used to fill tungsten bulbs to provide an inert (unreactive) atmosphere that prevents oxidation of the filament.

Review Question

You are given the following elements: A to G represent unknown elements.

$_{10}A$, $_{17}B$, $_{3}C$, $_{9}D$, $_{11}E$, $_{18}F$, $_{19}G$.

(a) Write down the electronic structures of these elements.
(b) Which elements are alkali metals?
(c) Which elements are noble gases?
(d) Which elements are halogens?
(e) Which elements are *s*-block elements?

Key Terms

- The **Periodic Table** is a list of chemical elements arranged in order of atomic number in rows, so that elements with similar electronic structures (and hence, similar chemical properties) appear in vertical columns. There are 18 vertical columns and 7 horizontal rows in the Periodic Table.
- The elements are classified as alkali metals (group I), alkaline earth metals (group II), halogens (group VII) and noble gases or inert gases (group 0).

3.4 PERIODIC PROPERTIES

The Periodic Table can be used to predict the properties of elements. Different elements have different periodic properties, such as metallic and non-metallic character, electronegativity, size, ionisation energy and electron affinity of the elements.

(a) Metallic and Non-metallic Character

As we go from left to right across the Periodic Table, the elements change in properties from metals to non-metals. The Periodic Table can be divided into two as shown by the dark line that starts beneath boron (Figure 3.7).

Figure 3.7 Metals, Non-metals and Metalloids

All elements to the left of the red line are metals.

The elements to the right of the red line are non-metals.

For along each side of the red line are elements that have the properties of both metals and non-metals. These elements except Al are called **metalloids**. Hydrogen is also a non-metal.

(b) Electronegativity

Electronegativity is a measure of the tendency of an atom to attract a bonding pair of electron; the higher the electronegativity, the greater is an atom's attraction for electrons. In the Periodic Table, in general, electronegativity of elements increases from left to right across a period, and the bottom of a group to the top (although this does not apply to the transition metals).

Atoms with high electronegativity tend to form negative ions (e.g., fluorine, oxygen). Atoms with low electronegativity, which is highly **electropositive elements** (e.g., caesium, potassium) tend to form positive ions. In general, metals are the electropositive elements and non-metals are the **electronegative elements**. The most electronegative element is fluorine, and the least electronegative (most electropositive) element is caesium.

The noble gases or inert gases are neither electropositive nor electronegative. It is because they have very stable electronic structures and have little tendency to gain or lose electrons.

(c) Sizes

Atomic sizes (Atomic radii)

Atomic size is generally described by the radius of an atom. Atomic radii decrease from left to right across a period. This is because ongoing from left to right across a period, the nuclear charge (atomic number) increases while the added electrons enter the outermost shell. The increased nuclear charge attracts the electrons in the outermost shell closer to the nucleus. Hence, the shell contracts resulting in smaller atoms.

The atomic radii increase from top to bottom down a group in the Periodic Table. This is because as the number of electrons increases, these additional electrons are in the larger electron shells make farther and farther from the nucleus. Hence, the shell expands resulting in larger atoms.

Ionic sizes

When one or more electrons are removed from a metal atom, a positive ion (a cation) is formed. Both a positive ion and the parent neutral atom have same nuclear charges. There is a lesser number of electrons in the positive ion. Hence, the repulsion between electrons is reduced in the positive ion. Thus, a positive ion is always smaller than its parent atoms.

When one or more electrons are added to a neutral atom, a negative ion (an anion) is formed. Both a negative ion and the parent neutral atom have same nuclear charges. There are a greater number of electrons in the negative ion. Hence, the repulsion between electrons is increased in the negative ion. Thus, a negative ion is always larger than its parent atom.

(d) Ionisation Energy

The amount of energy required to remove an electron from a gaseous atom to form a gaseous ion is called the **ionisation energy.** These electrons are held strongly within the atom by the attraction of the nucleus. Thus, ionisation process can be expressed in an equation.

$$\text{element(g)} + \text{ionisation energy} \longrightarrow \text{cation(g)} + \text{electron}$$

$$M(g) + \text{energy} \longrightarrow M^+(g) + \bar{e}$$

Ionisation energies measure how tightly electrons are bound to atoms. Low ionisation energies indicate ease of removal of electrons. As ionisation energy (I) increases, atoms are harder to ionise. Successive ionisation for electrons are represented by I_i (i = 1, 2, 3,….).

$$I_1 < I_2 < I_3 < \ldots$$

This is because, the nuclear charge increases across a period and the electrons are more strongly held by the force of attraction between the nucleus and the electrons.

In general, ionisation energies increase from left to right across a period. This is because, the nuclear charge increases across a period and the electrons are more strongly held by the force of attraction between the nucleus and the electrons. Therefore, more energy is required to remove an electron from the element.

In general, ionisation energies decrease down a group. This is because the atomic size increases and the outermost electron is farther from the nucleus making it easier to remove it. Therefore, less energy is required to remove an electron from the element.

The noble gases have the highest ionisation energies. This is because the noble gases are known to have the closed electronic structures (the octet) which resist the removal of electrons.

(e) Electron Affinity

The **electron affinity** of an element is the energy released when an electron is added to a gaseous atom to form a gaseous ion.

$$\text{element(g)} + \text{electron} \longrightarrow \text{anion(g)} + \text{energy}$$

$$X(g) + \bar{e} \longrightarrow X^-(g) + \text{energy}$$

The electron affinities generally increase from left to right across a period.

The electron affinity decreases on moving down a group. This is because the size of the atom increases and the electron being added goes to higher shells.

Review Questions

(1) From the following groups, select the one which has the largest radius. Give reasons.
(a) Fe^{2+}, Fe^{3+} (b) Cl, Cl^- (c) Li, Na, K (d) C, N, O

(2) Explain which of the following elements has the highest ionisation energy:
(a) 2.8.1 (b) 2.8.5 (c) 2.8.8

(3) Arrange the following elements in order of their increasing electronegativity: oxygen, carbon, fluorine, nitrogen.

Key Terms

- **Metalloids** are the elements that have the properties of both metals and non-metals.
- Metals are the **electropositive elements**. They tend to lose electrons and form positive ions.
- Non-metals are the **electronegative elements**. They tend to gain electrons and form negative ions.
- The amount of energy required to remove an electron from a gaseous atom to form a gaseous ion is called the **ionisation energy**.
- The **electron affinity** of an element is the energy released when an electron is added to a gaseous atom to form a gaseous ion.

3.5 BONDS BETWEEN ATOMS

Since atoms exist by themselves, they are usually joined together in groups by chemical bonds. There are two main ways of forming chemical bonds between atoms: ionic bonding and covalent bonding. There is another important type of chemical bonding, called metallic bonding. This is only found in metals.

(a) Formation of Bonds

The electronic structures of noble gases are very stable and unreactive, so they do not need to lose or gain any extra electrons to fill up their outermost shells. They do not usually react with other elements to form compounds.

Atoms of most other elements are reactive. They combine with other atom to form molecules or compounds. In forming a chemical bond, atoms gain, lose or share electrons in such a way to attain the stable electronic structures of the noble gases, i.e., to have eight electrons in the outermost shell, which is known as **octet** electron configuration **(Octet Rule)**. Exception is that helium has only two outer electrons. Helium has a **duplet** electron configuration.

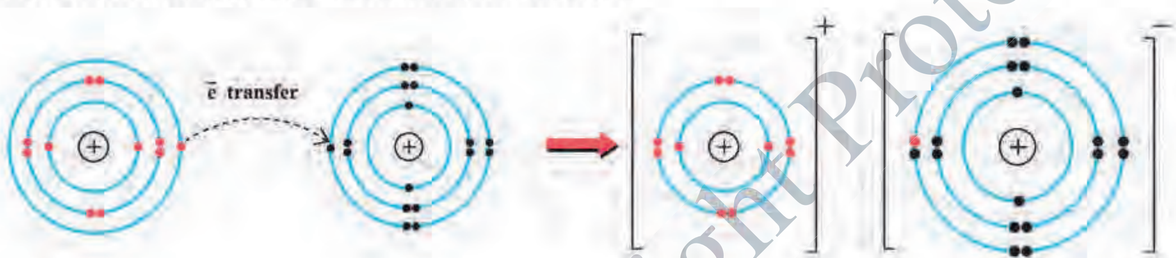
(b) Ions Formation

An ion is formed when an atom loses or gains electrons, so that it has a charge on it. Metals tend to lose electrons to form positively charged ions (cations). Non-metals tend to gain electrons to form negatively charged ions (anions).

(c) Ionic Bond

An ionic bond is formed when there is complete transfer of an electron or electrons from one atom to another resulting in the formation of cations and anions. These oppositely charged ions are held together by a force of electrostatic attraction known as **ionic bond**. This kind of bond occurs mainly between a metal and a non-metal. Compounds that contain ionic bonds are called ionic compounds.

For example, sodium reacts with chlorine to form sodium chloride. In this reaction, the sodium atom loses an electron to become a sodium ion, Na^+. The electron is taken by a chlorine atom to become a chloride ion, Cl^- (Figure 3.8). There is a transfer of an electron from sodium atom to the chlorine atom. In this way, sodium ion and chloride ion achieve the electron configuration of the stable noble gas.



sodium atom (2.8.1) | chlorine atom (2.8.7) | sodium ion (2.8) | chloride ion (2.8.8)

Figure 3.8 Formation of an Ionic Bond in Sodium Chloride

(d) Covalent Bond

A **covalent bond** is formed by the sharing of electron between two atoms by weak intermolecular forces of attraction. Covalent bonds are formed when non-metal reacts with one another.

The bond can be formed between atoms of the same element (e.g., H_2, O_2 and N_2 molecules) or between atoms of the different elements (e.g., CO_2, H_2O, NH_3 and CH_4 molecules).

When a pair of electrons is shared, a single covalent bond is formed. When two pairs of electrons are shared, a double covalent bond is formed.

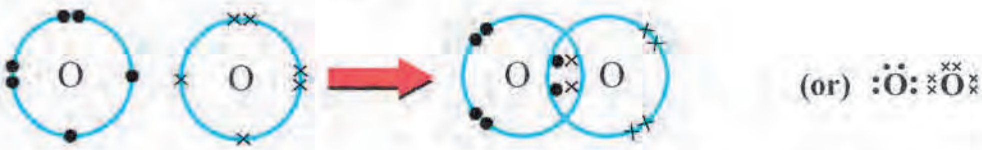
Dot-cross diagrammatic representation is used to explain more explicitly for the bond formation between atoms.

(i) Covalent bond in same elements

H_2 molecule contains a single covalent bond.

two hydrogen atoms | one hydrogen molecule

O_2 molecule contains a double covalent bond.



two oxygen atoms one oxygen molecule

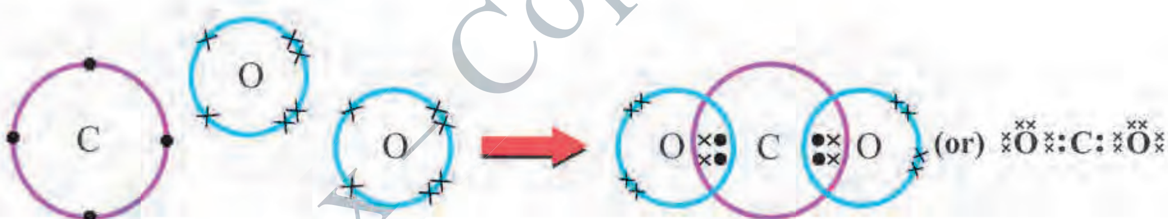
N_2 molecule contains a triple covalent bond.

two nitrogen atoms one nitrogen molecule

(ii) Covalent bond in different elements

When atoms of different elements are joined together by covalent bonding, a covalent compound or molecular compound is formed.

CO_2 molecule

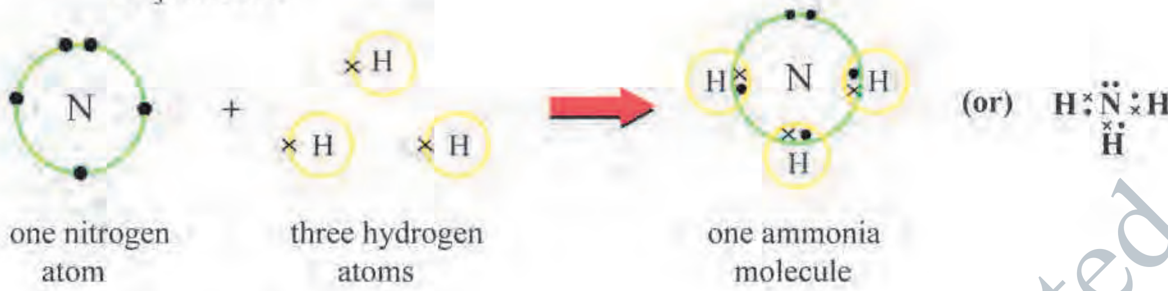


one carbon atom two oxygen atoms one carbon dioxide molecule

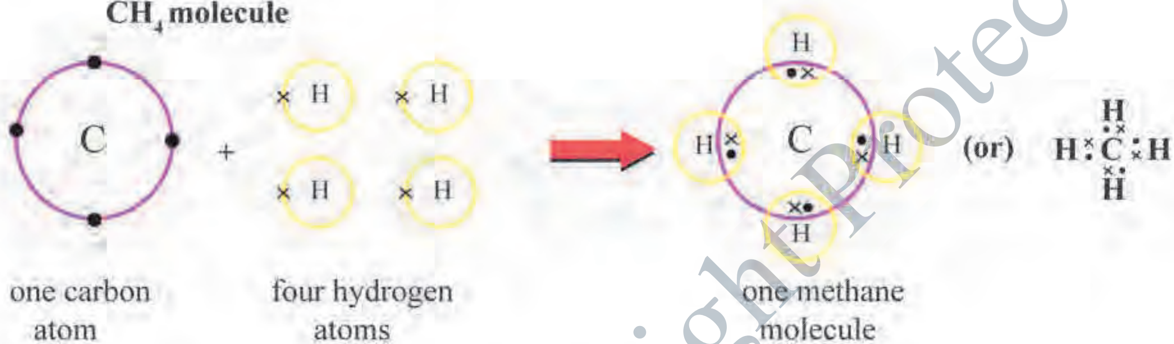
H_2O molecule

one oxygen atom two hydrogen atoms one water molecule

NH_3 molecule



CH_4 molecule



(e) The Physical Properties of Ionic and Covalent Compounds

The physical properties of compounds depend on the type of bonding in the compounds. The physical properties of ionic and covalent compounds are shown in Table 3.2.

Table 3.2 The Physical Properties of Ionic and Covalent Compounds

No.	Ionic Compounds	Covalent Compounds
1	Ionic compounds do not contain molecules. They consist of aggregates of oppositely charged ions.	Covalent compounds consist of molecules.
2	Ionic compounds are solids and do not vaporise easily.	Simple covalent compounds are gases or volatile liquids (e.g., ammonia, carbon dioxide, ethanol).
3	They conduct electricity when molten or in aqueous solution.	Most of simple covalent compounds do not conduct electricity.
4	Most ionic compounds have high melting points and high boiling points.	Simple covalent compounds have low melting points and low boiling points.
5	Most ionic compounds are soluble in water but not usually soluble in organic solvents such as toluene, ether, benzene, etc.	Simple covalent compounds are usually insoluble in water and soluble in covalent organic solvents, such as toluene, ether, benzene, etc.

Chemistry in Daily Life

Ionic compounds are extremely common in daily life, but not before humans were able to discover, extract and use these compounds. Table salt (NaCl, sodium chloride); baking soda ($NaHCO_3$, sodium hydrogen carbonate); milk of magnesia ($Mg(OH)_2$, magnesium hydroxide) (to treat indigestion); limestone, chalk, marble ($CaCO_3$, calcium carbonate); rust (Fe_2O_3, iron(III) oxide); are examples of ionic compounds. Methane (CH_4, main ingredient in natural gas), hydrochloric acid (HCl), water (H_2O) and ammonia (NH_3) are some examples of covalent compounds.


table salt


baking soda


milk of magneisa

Review Questions

(1) Lithium has the electronic structure 2.1. Fluorine has the electronic structure 2.7. Lithium and fluorine react together to form an ionic lithium fluoride. Draw the arrangement of electrons in fluorine and lithium. Explain how ionic bond is formed in lithium fluoride.

(2) Carbon has the electronic structure 2.4. Chlorine has the electronic structure 2.8.7. Draw the structure of the compound formed between carbon and chlorine.

Key Terms

- A charged particle is an **ion**.
- **Cation** is a positively charged ion.
- **Anion** is a negatively charged ion.
- In forming a chemical bond, atoms gain, lose or share electrons in such a way to attain the stable electronic structures of the noble gases, i.e., to have eight electrons in the outermost shell. This is known as the **octet rule**.
- An **ionic bond** is formed by the complete transfer of an electron or electrons from one atom to another resulting in the formation of cations and anions. These oppositely charged ions are held together by a force of electrostatic attraction known as ionic bond.
- A **covalent bond** is formed by sharing of electrons between two atoms by weak intermolecular force of attraction.

EXERCISES

1. Identify whether each of the following statement is TRUE or FALSE. Give your reasons for considering a statement which is FALSE.
   (a) Atoms of the same element have the same number of neutrons.
   (b) Atoms of different elements can have the same number of nucleon.
   (c) The *s*-subshell contains 2 electrons.
   (d) The 4*s*-sublevel comes before the 3*d* sublevel.
   (e) The fundamental particle not present in a hydrogen atom is the proton.
   (f) The mass of an electron is almost equal to the mass of a proton.

2. Match each of the items given in List A with the appropriate correct item shown in List B.

List A	List B
(a) proton	(i) increases down the group
(b) alkali metals	(ii) covalent bond
(c) sharing electrons	(iii) $2 \times n^2$ (n = shell number)
(d) number of electrons in the main n^{th} shell	(iv) lowest electron affinity
(e) atomic size	(v) in the nucleus

3. Fill in the blanks with the correct word(s), phrase, term etc., as necessary.
   (a) Atoms of the same element that have same atomic number but different atomic masses are _____.
   (b) Isobars are the elements with same number of _______.
   (c) From top to bottom in a given group, the atomic number increases and the size of the atom _____.
   (d) Second ionisation energy is _____ than first ionisation energy.
   (e) The number of electrons in outermost shell of $_{11}Na$ is _____ .
   (f) The mass of an atom is mainly concentrated in _____.

4. Select the correct word(s), notation(s), term(s) etc. given in the brackets.
   (a) The atom without neutron(s) is [hydrogen; helium; caesium; lithium].
   (b) In Periodic Table, valence electrons are indicated by [group number; shell number; period number; atomic mass].
   (c) The element at the group VII and the period 3 in the Periodic Table is [X (2.7); Y (2.8.3); Z (2.8.7); Q (2.8.8.2)].
   (d) If number of protons and electrons are 8 respectively, valence electrons are [2; 4; 6; 8] in number.
   (e) [Cl^-; Cl^+; Cl; Cl^{2-}] is stabilised by electron octet.

5. (a) How many electrons, neutrons and protons are there in the following elements? Write down their complete electronic structures.
   $^{12}_{6}C$, $^{56}_{26}Fe$, $^{35}_{17}Cl$, $^{40}_{20}Ca$, $^{48}_{22}Ti$, $^{55}_{25}Mn$, $^{45}_{21}Sc$

   (b) Write the complete symbol for the atom with the given atomic number (Z) and atomic mass (A).
   (i) Z = 17, A = 35 (ii) Z = 12, A = 24 (iii) Z = 4, A = 9 (iv) Z=19, A=39

6. (a) Draw diagrammatic representation of the following atoms by using shell or energy level:
   (i) ${}^{9}_{4}Be$ (ii) ${}^{19}_{9}F$ (iii) ${}^{28}_{14}Si$ (iv) ${}^{39}_{19}K$
   (b) For the elements in above question, give the valence electrons and the number of neutrons for each.

7. (a) Rewrite the correct complete electronic structures given below.
   (i) $1s^2\ 2s^2\ 2p^4\ 3s^2$ (ii) $1s^2\ 2s^1\ 2p^6$ (iii) $1s^2 2s^2\ 2p^6\ 3p^3\ 3s^2$ (iv) $1s^2\ 2s^2\ 2p^6 3s^2\ 3p^5\ 4s^2$
   (b) What are the atomic numbers of elements whose outermost electrons are represented by (i) $3s^1$ (ii) $2s^2\ 2p^3$ and (iii) $3s^2\ 3p^5$?

8. Which atoms are indicated by the following configurations?
   (a) [He] $2s^1$ (b) [Ne] $3s^2\ 3p^3$ (c) [Ar] $4s^2$

9. (a) Write the complete and essential electronic structures using noble gases as a core for Li, O, Mg, Al, Cl, Ca.
   (b) Give the group, period and valence of the above elements.
   (c) Which of the above element is in period 3 and group II?

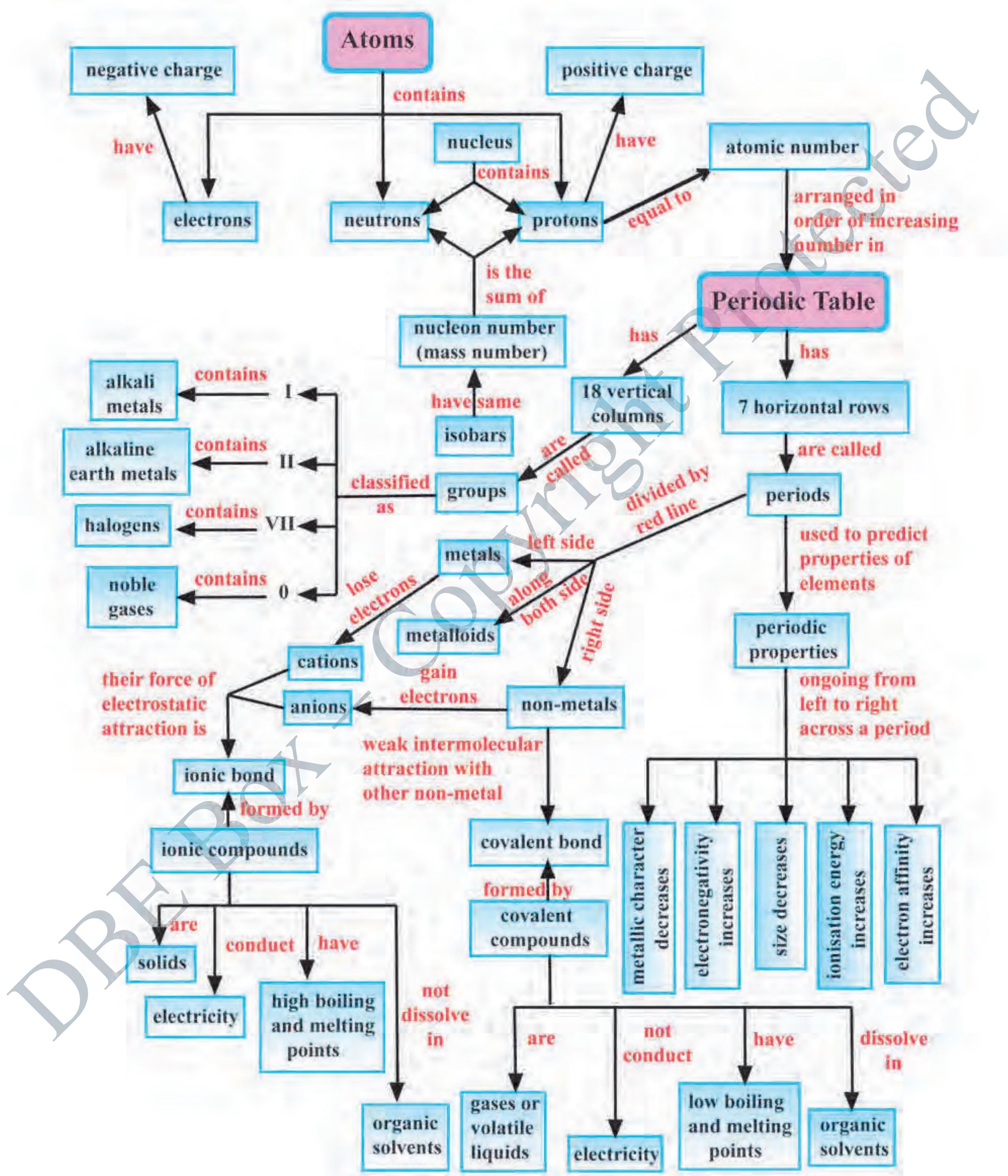
10. An element **X** in period 3 of the Periodic Table has six outer shell electrons.
   (a) In which group of the Periodic Table is **X**?
   (b) What is the name and symbol of **X**?
   (c) How many electron shells are there in an atom of **X**?
   (d) Is the element **X** a metal or non-metal?
   (e) What is the atomic number of the element **X**?

11. Complete the following table and answer the following questions:

	Element **X**	Element **Y**	Element **Z**
atomic number	11	6	-
number of protons	-	-	16
number of neutrons	12	6	16
mass number	-	12	32
electronic structure	2.8.1	-	-
valence	-	4	-
position in Periodic Table	-	-	groupVI, period 3

   (a) Which of the above elements **X**, **Y** and **Z** is a metal?
   (b) What type of bonding exists between **X** and **Z**?
   Write down the most likely formula of this compound using the symbols **X** and **Z**.

CHAPTER REVIEW
(Concept Map)



CHAPTER 4 THE QUANTITIES OF SUBSTANCES: CHEMICAL CALCULATIONS

The state of the art of chemistry lies on the chemical calculations, which are mainly based on the quantities of chemical terms (especially the chemical symbol and the Mole) and other relevant data. In this modern day, chemical ingredients and their percent amounts have to be labelled under rules and regulations. For instance, a farmer must not only know the soil fertiliser symbols, such as N P K, but also the percent amount of soil nutrients. Therefore, chemical calculations have many important uses and applications in chemistry.

Learning Outcomes

After completing this chapter, students will be able to:

- distinguish among the relative atomic mass of sample elements, the relative molecular mass and the relative formula mass of sample substances;
- write chemical symbols, formulae, word equations and chemical equations based on information provided;
- solve calculations based on chemical equations;
- solve the molar volume of a gas based on information provided;
- explain the connection between the mole and Avogadro's constant;
- solve mole calculations and the mole ratio of the reactants and products based on balanced chemical equations.

4.1 RELATIVE MASSES OF ATOMS AND MOLECULES

Atoms and molecules are particles that make up matter. They have mass. For example, the quantity of a cube (1 cm^3) of gold is heavier than a cube (1 cm^3) of aluminium. However, in chemical calculations, chemists use relative masses of atoms and molecules on the basis of a designated standard unit mass, called atomic mass unit (amu).

(a) Relative Atomic Mass

Atoms of different elements have different masses. Therefore, when chemical calculations are performed involving different atoms, we need to know how one atom is heavier or lighter than the other atoms.The mass of a single atom is so small that it is impossible to weigh it directly. To overcome this problem, we then compare this mass of atoms with the mass of the same number of 'standard' atoms. Now, scientists have chosen to use the isotope carbon-12 as the new standard because carbon-12 is the most abundant isotope than carbon-13 and carbon-14.

The mass of an atom is called its **atomic mass**. For the fact that the size of an atom is too small to be weighed practically, **relative atomic mass (A_r)** is therefore used to represent the mass of an atom of an element. Thus, the relative atomic mass of an element is the average mass of one atom of the element compared with one twelfth the mass of one atom of the carbon-12 (^{12}C) isotope whose mass is exactly 12.

$$\text{Relative atomic mass of an element} = \frac{\text{average mass of one atom of the element}}{\frac{1}{12}\text{ of the mass of one atom of carbon-12}}$$

Atomic mass unit (amu)

Atomic mass unit (amu) is precisely one twelfth the mass of one atom of carbon-12. **1 amu equals one twelfth the mass of one atom of C-12 exactly.**

Example 1: A magnesium atom has twice the mass of a ^{12}C atom. What is the relative atomic mass of magnesium? (C = 12)

$$\text{Relative atomic mass of an element} = \frac{\text{average mass of one atom of the element}}{\frac{1}{12}\text{ of the mass of one atom of carbon-12}}$$

$$\text{Relative atomic mass of magnesium} = \frac{2 \times \text{mass of one atom of carbon-12}}{\frac{1}{12} \times \text{mass of one atom of carbon-12}}$$

$$\text{Relative atomic mass of magnesium} = \frac{2 \times 12}{\frac{1}{12} \times 12} = 24$$

Average relative atomic masses

To calculate the relative atomic mass of an element, we must know (a) the isotopic masses of the various isotopes present in the element and (b) the relative abundance of the isotopes in nature.

Example 2: Magnesium consists of three isotopes. One isotope has the relative mass 24 and its relative abundance is 78.6 %. The second isotope has relative mass 25 and its relative abundance is 10.1 %. The third isotope has relative mass 26 and its relative abundance is 11.3 %. Calculate the average relative atomic mass of magnesium.

The average relative atomic mass of magnesium $= (78.6\ \% \times 24) + (10.1\ \% \times 25) + (11.3\ \% \times 26)$

$$= (\frac{78.6}{100} \times 24) + (\frac{10.1}{100} \times 25) + (\frac{11.3}{100} \times 26)$$

$$= 18.86 + 2.53 + 2.94 = 24.33$$

(b) Relative Molecular Mass and Relative Formula Mass

The **relative molecular mass (M_r)** of a molecule is the mass of one molecule of a substance on a scale where the carbon-12 isotopes has a mass of exactly 12 units (12 amu). Thus, the relative molecular mass (M_r) can be found by adding up the relative atomic masses of all the atoms present in the molecule.

Hence, the relative molecular mass (M_r) is defined as the average mass of one molecule of a substance when compared with one twelfth the mass of one atom of carbon-12.

$$\text{Relative molecular mass of a molecule} = \frac{\text{average mass of one molecule of a substance}}{\frac{1}{12}\text{ of the mass of one atom of carbon-12}}$$

Ionic compounds, such as sodium chloride and magnesium oxide consist of ions and not molecules. For ionic compounds, we use the term **relative formula mass** instead of relative molecular mass.

Example 3: What is the relative molecular mass of carbon dioxide, CO_2? The relative atomic masses of carbon and oxygen are 12 and 16, respectively.

Relative molecular mass of carbon dioxide	=	Relative atomic mass of one carbon atom	+	Relative atomic mass of two atoms of oxygen
	=	12	+	2 × 16
	=	12	+	32
	=	**44**		

Example 4: Calculate the formula mass of copper(II) sulphate, $CuSO_4$.
(Given: Cu = 63.5 amu, S = 32 amu, O = 16 amu)

Formula mass of copper(II) sulphate	=	atomic mass of one copper atom	+	atomic mass of one sulphur atom	+	atomic mass of four atoms of oxygen
	=	63.5 amu	+	32 amu	+	4 × 16 amu
	=	63.5 amu	+	32 amu	+	64 amu
	=	**159.5 amu**				

Review Questions

(1) Calculate the relative formula mass of sodium chloride, NaCl. (Na = 23 and Cl = 35.5)
(2) Calculate the relative molecular mass of glucose, $C_6H_{12}O_6$.
(Relative atomic masses: H = 1, C = 12 and O = 16)

Key Terms

- **Relative atomic mass** is the average mass of one atom of that element compared to one twelfth the mass of one atom of carbon-12. **The relative molecular mass** is the sum of the relative atomic masses of all the atoms in the molecule.
- **Relative molecular mass** is the mass of one molecule of a substance compared to one twelfth the mass of one atom of carbon-12.
- **The relative formula mass of an ionic compound** is the sum of the relative atomic masses of all the atoms in the formula.

4.2 CHEMICAL SYMBOLS, FORMULAE, WRITING AND NAMING FORMULAE

Every compound has a formula as well as a name. The formula is made up of the symbols for the elements. Symbols, formulae and equations are bits of chemical shorthand, useful because of a large amount of information which they contain.