CHEMISTRY AND ITS IMPORTANCE, MEASUREMENT AND SCIENTIFIC METHODS, AND STRUCTURE OF THE ATOM

CHEMISTRY
GRADE 9

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Module - I

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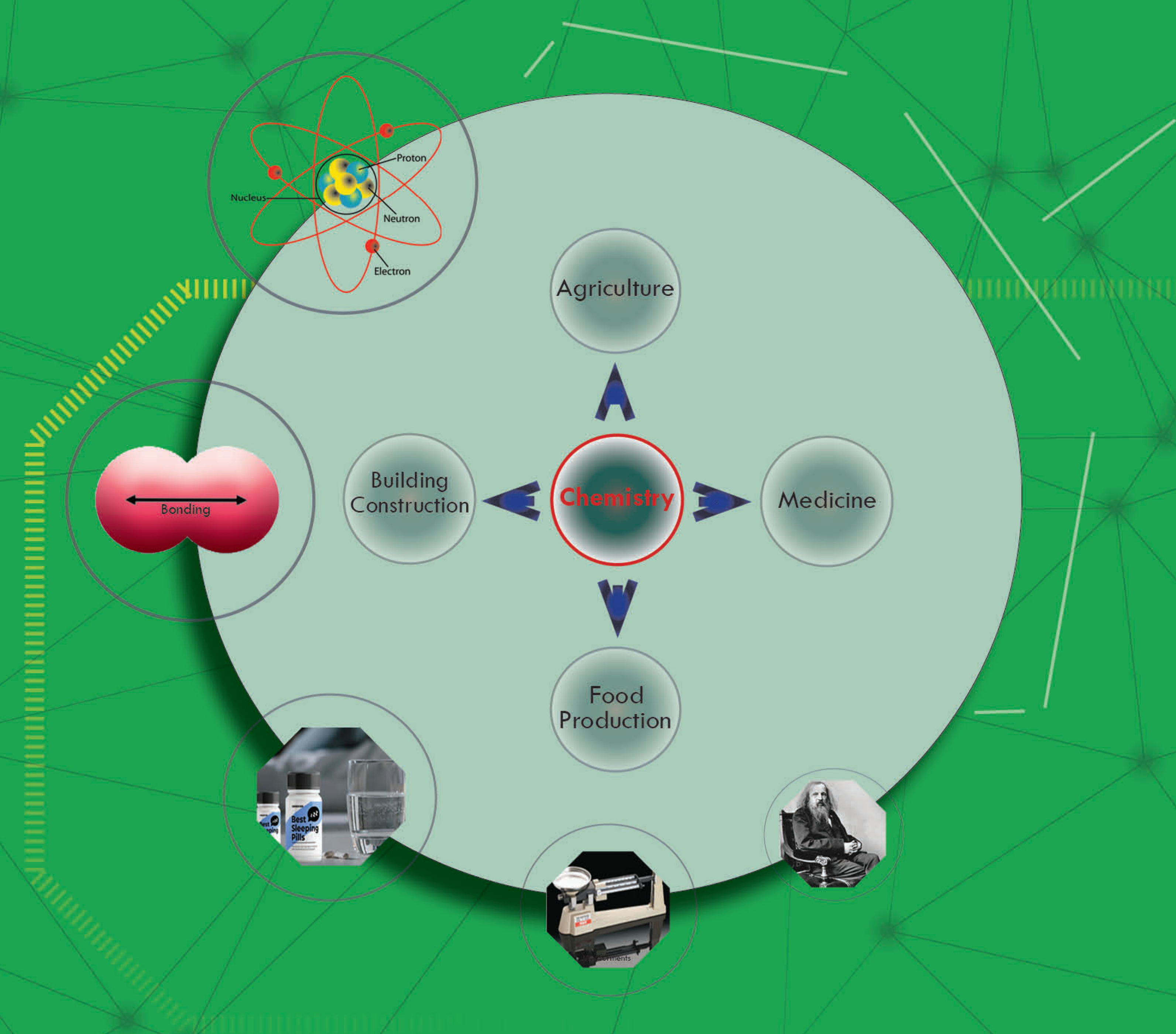

Federal Democratic Republic of Ethiopia
Ministry of Education

CHEMISTRY

MODULE - I
GRADE 9

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Introduction to the Grade 9 Chemistry

Dear student, welcome to the grade 9 chemistry course. This is a course designed to introduce you to the basic concepts you will need in your study of high school chemistry. Structure of the course material

The course has two modules. Module 1 consists of the first three units of the course and module 2 consists two units of related topics.

Module 1: Chemistry and its Importance, Measurement and Scientific Methods and Structure of the Atom

Module 2: Periodic Classification of Elements and Chemical Bonding

Each unit of the course, in turn, divided in to sections. In studying each unit you will be asked to carry out one or more "activities". Activities involve either solve practical problems or answering thought providing questions that are directly or indirectly related to what has been discussed in the preceding topic. At the end of every section, you will find sets of self-test questions. Answers to activities and self test questions are given at the end of the module. Some selected laboratory experiments accompany the course. There are five assignments for submission corresponding to each of the units in the two modules.

How to Study the Course

Your success in any course depends upon the time you spend on it and the concentration you put into studying each section. Here is some advice which we hope will help you in your study.

1. Set a program to study Chemistry and your other subjects each day. Find a time that is convenient for you.
2. Choose a quiet and well-lit corner in your home to study undisturbed.
3. Do not try to learn by heart what you read, try to understand what it means and relate it to things happening around you.
4. Do all the activities, self-test exercises and self-assessment before you look at the suggested answers unless and until you have done through them completely. You will learn a lot by doing the activity. You will learn only a little by looking up the answers.
5. If you don't understand something, read again carefully. You can always seek the help of friend or your tutor if something remains unclear. Do all the activities, self-test exercises and self-assessments by yourself or own a group of friends.
6. Review the units you have covered before starting a new unit. This will enable you to link the previous ideas with ideas in the present unit. Another advantage of reviewing units is that it will prepare you to handle the questions in the assignment for submission and in the examinations.

Activities, Self-test Exercises and Self-assessment Exercises

Each section is followed by a self-test exercise. Also following some topics you find "activities". Your achievement in the activities and self-test exercises would enable you to realize how much of the given lesson you have mastered. Do all questions before you refer to the answers, given at the end of the module. If some answers are wrong search for the answers in the text again. If all fail to get the answers, you can contact your tutor for help. We will be happy to hear from you about your problems and will reply to you.

Assignment for Submission

The assignment for submission contains a set of questions based on the lesson given in a unit. They have to be submitted to the tutorial center. The questions in the assignment for submission are to be answered only when you are sure you have learned the sections within the units of the module thoroughly.

Based on your tutor's suggestions, you have to patiently revise the section carefully again and make sure that you have understood it. After this, I think you have already made yourself ready for the next module.

Keep all assignment for submissions together as they can be used as references during your final examination.

Laboratory Experiments

There are a number of laboratory experiments to be conducted during your residential session at nearby high school. Laboratory reports will be written for each experiments done.

Examination

There will be one final examination at the end of the course.

The Final result of the course

The final result of the course you get depends upon your achievements in the assignments for submission, the laboratory reports, and the final examination.

The contribution of each of these is as follows:

1	Assignment for submission	30%
2	Laboratory reports	20%
3	Final Examination	50%
	Total	**100%**

Recommended Books

1. **Beran J. A. (2011)**. Laboratory Manual for Principles of General Chemistry, 9th ed., John Wiley & Sons, Inc., USA.
2. **Brady James E. (1982)**. General Chemistry: Principles and structure. 2nd ed., Newyork: John wiley and Sons.
3. **Ebbing, D. (2007).** General chemistry. 9th ed, USA: Houghton Miffl in company.
4. **Gramham Hill & John Holman (2000)**. Chemistry in context. 5th ed., China: Gramham Hill, John Holman.
5. **Greenwood N. N. and Earnshaw A.**, Chemistry of the Elements, 2nd ed., School of Chemistry, University of Leeds, U.K.
6. **Lee, J.D. (2020).** Concise Inorganic Chemistry. 4th ed., England: John Wiley & Sons, Inc. Wiley India Pvt. Ltd., New Delhi.
7. **Raymond Chang (2008)**. General Chemistry: The Essential Concepts, 5th ed., McGraw-Hill Book Company, New York.

8. **Silberberg, M. S. (2007).** Principles of General Chemistry, McGraw-Hill Book Company, New York.
9. **Smith R. N, (1980).** Solving General Chemistry Problems, 5th ed., W. H. Freeman and Co, San Francisco.
10. **Spencer L. Seager, Michael R. Slabaugh (2011).** Safety-Scale Laboratory Experiments for Chemistry for Today: General, Organic, and Biochemistry, 7th ed., Brooks/Cole, Cengage Learning, California, USA.

There are a number of icons, or symbols in this teaching material. The meanings of each icon is as follows.

☸ This tells you there is an overview of the unit and what the unit is about.
? This tells you there is an in-text question to answer or think about in the text.
☞ This tells you to take note of or to remember an important point.
⚒ This tells you there is a self-test for you to do.
☑ This tells you there is a checklist.
✍ This tells you there is a written assignment.
⚷ This tells you that this is the key to the answers for the self-tests.

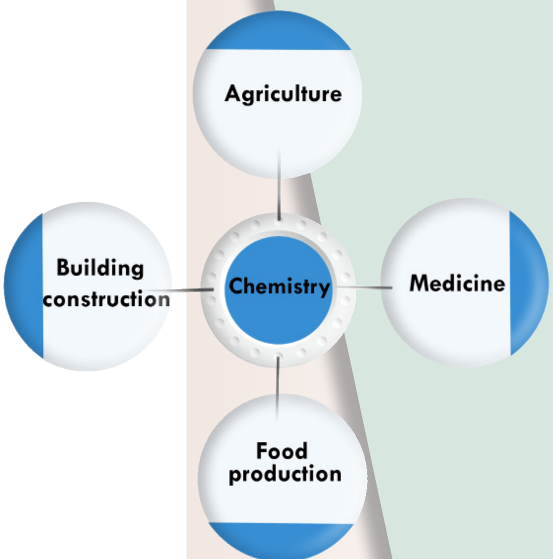
Objectives of the Module

After completing this course, you will be able to

- Describe chemistry and its importance.
- Develop an understanding of the science of chemistry.
- Describe structure of an atom and explain the basic scientific laws, theories, methods, and terminologies of chemistry.
- Delate the properties the element based on electronic structure and the periodic table of the elements.
- Predict the types of chemical bonds between elements.

MODULE CONTENTS

UNIT 1



CHEMISTRY AND ITS IMPORTANCE

Introduction

Dear learner, greetings and welcome to the study of this subject called Chemistry!

> ? Have you ever heard of the term "Chemistry"? What do you think is the reason to learn Chemistry as a school subject? What do you expect to gain from exposure of learning Chemistry? What is the importance of Chemistry to society?

Well, dear learner, here is what chemistry is all about, and the major reasons for learning it as a school subject!

Chemistry is involved in different facets of life. Since chemistry is so fundamental to our world, it plays a role in everyone's lives and touches almost every aspect of our existence in some way. Chemistry is essential for meeting our basic needs, such as food, clothing, shelter, health, energy, clean air, clean water, and fertile and productive soil. The question is how? In this unit, you will learn about the importance of chemistry in your day-to-day life. You will also learn first by studying the meaning and scope of chemistry and its relationships with other natural sciences. Following this, you will study the role chemistry plays in production and in society. Finally, you will study some common chemical industries found in Ethiopia and their products.

Unit Outcomes

Dear student, at the end of this unit, you are expected to

- Define chemistry.
- Explain the scope of chemistry.
- Discuss the connection between Chemistry and other sciences, such as physics, biology and geology.
- Describe the application of chemistry in the field of agriculture, medicine, food production and building construction.
- Name some common chemical industries in Ethiopia and their products.

Unit Contents

In this unit, you are going to cover the following sections:

Section 1.1: The Definition and the Scope of Chemistry

Section 1.2: The Relationship Between Chemistry and Other Natural Sciences

Section 1.3: The Role Chemistry Plays in Production and in the Society

Section 1.4: Some Common Chemical Industries in Ethiopia

The Required Study Time

From the date of your registration, you have a maximum of 10 months to complete the course, but the pace at which you proceed is up to you. This course has a total of five units. Proportionally dividing the period allotment for the teacher-guided lesson (4 periods out of 61) into 10 months, you need to finish studying this unit in three weeks.

Unit Learning Strategies

As a learner enrolled in an independent study course, you have taken on the dual role of a learner and a teacher. As a learner, you are responsible for mastering the lessons and completing the four learning activities, the four self-test exercises, the unit self-assessment

questions, and the assignment. As a teacher, you are responsible for checking your work carefully, noting areas in which you need to improve, and motivating yourself to succeed. Hereunder are the strategies you should follow in your study. Read the components of each section and follow the instructions to get the maximum knowledge out of it.
Each section in this unit consists of the following components:

Section Title

The section title simply provides you with the title of the section.

Section Overview

Each section begins by outlining what you will be learning in that specific section. This will give you an idea of what you are going to learn in the section. Please read it and get an impression of what you are going to learn in the section before you look into the main contents of the section.

Section Learning Outcomes

Each lesson focuses on learning outcome(s), which are competencies you should have accomplished by the end of the lesson. You should, therefore, make sure that you have achieved them before moving on to the next section.

Study Notes and Important Points

The main body of the lesson is made up of the content that you need to learn. It contains definitions of terms, explanations, diagrams, and fully completed examples. You need to read and understand the definitions and explanations of the concepts and ideas.

Resources

You do not need a textbook for this course. All the content is provided directly within the course. You will, however, need access to a variety of resources on the internet. One or more URLs (web page links) are provided under each section to help you get more information on the topic under study. Copy the URL and paste it into Google Drive so that a page with more information about the topic will be displayed. Read the information on the website and get a better understanding. When you are having difficulty with something in this unit, contact your learning partner or tutor or marker, who is there to help you.

A note about Internet sites: All of the URLs listed in this unit were working when this unit was written, but, since internet sites come and go, you might find that some of these sites are no longer active or appropriate. If that happens, you could use a search engine (e.g., google) to find the information that you are looking for.

Learning Activities

In this unit, there are four learning activities. These learning activities include questions that you should complete to help you practise what you have learned in each section, prepare you to complete your assignment and the examination successfully, and most importantly, achieve the learning outcomes of the sections. Make sure that you have completed all the learning activities. Once you have completed the learning activities, you should check your answers with the answer key provided at the end of the unit. You will not submit the completed learning activities to the Distance Learning Unit.

Definition

A summary of the definitions of terms is provided in each section following the resources. This is to help you get all the definitions of the terms being summarized. Make sure that you can define all terms orally and in writing, and that you clearly understand their meaning.

Self-Test Exercise

In this unit, there are four self-test exercises. The self-test exercises are provided to help you achieve the learning outcomes of each section. The questions may not be found directly in the study notes because they are comprehensive. You may need to consult the internet and the resources given under each section. You must do all the exercises and then check the answers at the end of the unit. You don't need to give the solutions to your tutor or marker.

Checklist

To help you check whether or not you have done everything that is required of you and mastered the learning outcomes of each section, there is a checklist in each section that you need to go through. Fill out the checklist honestly. Revise the things you did not perform very well until you are clear about them.

Unit Summary

The unit ends with a brief review of the main points of what you just learned. You are advised to read it so that you can get a summary of the main points of the unit.

Self-Assessment

In this unit, there is one self-assessment that contains 19 questions. The questions are categorized into three levels: basic, intermediate and challenge levels. To help you succeed in your examination, you will have an opportunity to complete the self-assessment questions. The self-assessment is similar to the actual examination you will be writing. The answer key enables you to check your answers. This will give you the confidence you need to do well on your examination.

Assignment

In this unit, there is one assignment. It is an industrial visit project. The assignment has a format for writing your report after you visit the industries. You need to provide the necessary information on the format. You will be required to present it orally to your tutor or marker as well. You need to submit the report to your tutor or marker for correction.

Answer Keys

At the end of the unit, there are answers to section-level activity questions, self-test, and self-assessment exercises. Do not refer to these answers before you do all the activity questions and a self-test and a self-assessment exercise questions by yourself. Do not also leave without checking out your answers after you have done all the exercises.

Section 1.1: Definition and Scope of Chemistry

- Dear learner, Chemistry has an unlimited application to our day-to-day lives. There is no aspect of life that is independent of the application of chemistry or its rules. In this section, you are going to deal with two aspects of chemistry. They are the definition of chemistry and the scope of chemistry. Let us first define chemistry, and then briefly explain the scope of chemistry. When you have finished studying this section, the following learning outcomes are expected of you.

Learning Outcomes

Dear learner, when you have finished studying this section, you are expected to

- Define chemistry.
- Explain the scope of chemistry.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the activity and self-test exercise questions. Make sure that you are clear with the meanings of the concepts, terms, and definitions. After doing so, check whether you achieved the learning outcomes indicated above.

1.1.1 Definition of Chemistry

Dear student, I believe that this is not your first exposure to the concept 'Chemistry' as you have learned general science in the previous grades. Now, however, you will learn the meaning of chemistry in depth. In order to understand the definition of chemistry, read first the definition given below and then try to be clear with the terminologies incorporated into the definition.

Chemistry is the science that deals with the properties, compositions, and structures of substances (elements and compounds), the transformations they undergo, and the energy that is released or absorbed during these processes.

Note that in this definition there are terms like substance, property, composition, structure, transformation, and energy. Without understanding the meanings of these terms, you cannot understand the correct meaning of chemistry. The meanings of each one of them are given below. Go through all of them and grasp their meaning.

A substance is a particular kind of matter with uniform properties. Example, gold, silver, water, soap, table salt, etc. ***(Figure 1.1)***.

Salt Sulphur Gold Silver

Figure 1.1 Substances around us.

The property of a substance is its attribute, quality, or characteristic.

Every substance in the universe in which we live in has its own properties by which we can distinguish it from other substances. This is because every substance has its own unique composition and structure. For example, water is a substance that has no color, taste, and shape. These are some of the properties of water.

Composition is the nature of something's ingredients or constituents, or how a whole or mixture is made up. For example, table salt is chemically composed of the elements sodium and chlorine. The stainless-steel spoons are a solid solution (alloy) of chromium, carbon, and other elements.

The arrangement and relationships between the parts or elements of something complex is known as its **structure**.

Example: The school buildings are made up of a roof, a ceiling, doors, windows, walls, and floors arranged in a certain order. The arrangement of these parts as a unit will provide us with the structure of the school building. The different elements in certain compounds are arranged in a unique fashion, and we call this the structure of the compounds.

The transformation of a substance is a marked change in form, nature, or appearance.

Every substance in our environment is continuously changing from time to time due to external and internal forces. Due to this change, it transforms from one form into the other. For example, if you leave a bar of iron in a wet and well ventilated place for a certain period of time, it will be covered with a reddish colored substance known as rust. We call this the bar of iron that is transformed into a substance known as rust.

Energy is the ability to bring about transformation upon the application of force to a certain substance.

These transformations are accompanied by energy changes. The conversion of one form of energy into another is known as energy change. For example, burning wood would convert the chemical energy found in the wood into ash, heat, and light energy.
Dear learner, now you have become familiar with the terms incorporated in the definition of chemistry, and I believe you have understood its correct meaning. Take three minutes to think over the terms and then define chemistry both orally and in writing.

1.1.2 The Scope of Chemistry

Dear learner, at this stage, you are familiar with the definition of chemistry and I believe that you are in a better position to study and understand the scope of chemistry. The scope of chemistry is, however, so vast that you cannot cover all of it under this sub-section. You, however, will study the general aspects of the scope of chemistry. There are no limits to the scope of chemistry in everyday life, industry and society. Many of our day-to-day activities involve chemistry to some extent, and there are many simple things that we could not do without it.

First of all, it will be good if you study the branches of chemistry and what they are dealing with. The study of modern chemistry has many branches, but can generally be broken down into five main disciplines, or areas of study. Hereunder are the definitions and scope of each branch of chemistry.

Physical chemistry: It is the study of macroscopic properties, atomic properties, and phenomena in chemical systems.

A physical chemist may study such things as the rates of chemical reactions, the energy transfers that occur in reactions, or the physical structure of materials at the molecular level.

Organic chemistry: It is the study of substances containing carbon.

Carbon is one of the most abundant elements on Earth, and it is capable of forming a tremendously vast number of chemicals (over twenty million so far). Most of the chemical substances produced by all living organisms are based on carbon.

Inorganic chemistry: It is the study of substances that, in general, are not primarily based on carbon.

Inorganic chemicals are commonly found in rocks and minerals. One current important area of inorganic chemistry deals with the design and properties of materials involved in energy and information technology.

Analytical chemistry: It is the study of the composition of matter.

It focuses on separating, identifying, and quantifying chemicals in samples of matter. An analytical chemist may use complex instruments to analyze an unknown material in order to determine its various components.

Biochemistry: It is the study of chemical processes that occur in living things.

It covers anything from basic cellular processes up to understanding disease states, so that better treatments can be developed.

Dear learner, note that all the aforementioned disciplines of chemistry are highly engaged in taking measurements, in making observations, and in using them to draw conclusions. Chemistry is about looking for patterns in the way substances behave. Because living and non-living things are made up of matter, chemistry affects all aspects of life, and most natural events. The scope of chemistry can, therefore, be extended to explaining the natural world, preparing people for career opportunities, and producing informed patriot citizens with regard to keeping nature safe for the survival of living things.

The above mentioned areas are not the only scopes of chemistry. The scope of chemistry could also be further extended to agriculture, medicine, food production, and building construction. ***Figure 1.2*** shows some of the chemical products produced in different factories. These products would not have been produced without the application of chemistry.

Figure 1.2 Some chemical products.

Disadvantages of Chemistry

Dear learner, chemistry, however, is not only involved in providing useful substances in the aforementioned areas, but it can also result in very dangerous substances that can negatively affect the safety of living things and the environment. For example, the excessive production and release of nitrogen, carbon, and sulphur oxides, and toxic chemicals like mercury, lead, asbestos, pesticides and fluorochlorohydrocarbons into the environment can cause environmental pollution.

> **?** What types of pollution have you observed in your locality? How is it possible to protect the environment from these dangers?

Don't worry, I will help you by providing a brief answer to the above question. It is advisable either to replace the toxic or hazardous chemicals and chemical products with environmentally friendly substances, minimize their production, or totally avoid producing and releasing them into the environment. You will study in depth about environmental pollution and its protection in grade 12. In order to get a further understanding of the definition and scope of chemistry from the internet, you can read the information on the websites given below.

Resource

Dear learner, please go to the internet and copy and paste these website links so that you can get a better understanding of the definition and scope of chemistry.

1. https://byjus.com/chemistry/
2. https://homeworkdoer.org/chemistry/importance-of-chemistry-in-society.html

Activity 1.1

Dear learner, provide correct answers to the following questions based on your understanding of the above- presented study notes and important points. Do not go directly to the answer keys without giving your own answers for each question. After that, you can consult the answer key to see if your answers were correct.

1. Explain the meaning of the following terms and phrases and give examples (other than those given above) from your daily life, in each case:
   - Substance
   - Property of a substance
   - Composition of a substance
   - Structure of a substance
   - Transformation of a substance
   - Energy change
2. Define the term 'chemistry'.
3. List examples of chemicals or chemical products that are used in the following areas:
   - agriculture
   - food production
   - medicine
   - building construction

Hint: Refer to ***Figure 1.2*** above. You may also search the internet for answers. This question is broad and can have several answers. Your answers could be different from the answer given in the activity questions answer key. This, therefore, does not mean that your answers are wrong.

4. Search on the internet or go to the environment protection agency office in your locality and write down some of the problems caused by dangerous chemicals affecting human health and the environment.
   Note: Refer to the hint given under question #3.
5. Which of the problems listed in question #4 above are observed in your locality?
   Note: The answer to this question will highly depend on the chemical processing industries in your locality. Therefore, you will not get a definite answer to this question in the activity questions answer key section.
6. How does the local environment protection unit or department mitigate these problems? What do you think is the solution to the problem(s) observed? Remember that you are an Ethiopian citizen, and have the responsibility of protecting the nation from the problems caused by chemical substances.

Self-Test Exercise 1.1

Dear learner, test yourself to see if you achieved the learning outcomes of the section by giving correct answers to the following questions, and check the answer keys to see if you have answered them correctly or not.

1. Explain how the scope of chemistry can be extended to changing civilizations.
2. Explain how chemistry can be extended to protecting the environment and finding solutions for pollution problems.

Checklist 1.1

Dear learner, check yourself on the following aspects before wrapping up studying this section. Put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it, in the table given below. You must answer all the questions and revise those with an "X'' mark. Can I ...

Competencies	Yes	No
define chemistry?		
explain the scope of chemistry?		

Section 1.2: The Relationship Between Chemistry and Other Natural Sciences

- Dear learner, in the previous section, you studied about the definition and scope of chemistry. In this section, you are going to study the relationship between chemistry and the natural sciences, such as biology, physics, and geology. The section deals with the relationships between chemistry and the aforementioned natural sciences, making chemistry at the center. You may have little understanding of the branches of science (chemistry, biology, geology, and physics) and their relationships from grade 7 unit 1 lessons. In this section, however, you will have an in-depth study on this topic as it is presented below. When you have finished studying this section, the following learning outcome is expected of you.

Learning Outcome

- Dear learner, when you have finished studying this section, you are expected to discuss the relationship of chemistry with physics, biology, and geology.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the activity and self-test exercise questions. Make sure that you are clear on the meanings of the concepts, terms, and definitions. After doing so, check whether you achieved the learning outcome indicated above.

Dear learner, in grade seven, you have learned that chemistry is one branch of natural science. It will be helpful for you to understand each branch of natural science and its relationship with chemistry. Let me first define the term science for you.

Science is the process by which we learn about the natural universe by observing, testing, and then generating models that explain our observations.

Dear learner, because the physical universe is so vast, there are many different branches of science. At this level, however, I will discuss only three of them and their relationship with chemistry. Now let me define the three branches of natural science.

Biology is the scientific study of living things.

Geology is the study of the Earth, the materials of which it is made, the structure of those materials, and the processes acting upon them.

Physics is the branch of science concerned with the nature and properties of matter and energy.

Dear learner, although scientists divide science into different fields, there is much overlap among them. For example, some biologists and chemists work in both fields so much that their work is called biochemistry. What is biochemistry?

Biochemistry is the study of the chemical processes occurring in living matter.

To give you a specific example, medicinal plants produce chemical substances through biochemical processes. Plants also produce their own food (glucose) through a chemical process known as photosynthesis.

Similarly, geology and chemistry overlap in the field called geochemistry. Do you know the meaning of geochemistry? Let me define it for you.

Geochemistry is defined as the study of the processes that control the abundance, composition, and distribution of chemical compounds and isotopes in geologic environments.

Let me give you good examples that will make the term geochemistry clear to you. Carbon dating is used by geologists in the determination of the ages of Luci (3.18 million years old) and Ardi (4.4 million years old), which proved, Ethiopia, to be the cradle of mankind. The composition of ores and the methods of concentrating the essential minerals from the ores is an activity that involves chemistry and geology.

Dear learner, chemistry and physics do also overlap in the areas of atomic and small molecule properties. Both of them deal with matter and energy. The relationship between chemistry and physics, however, can be expressed in two ways. Do you know what they are?

Let me briefly present the two possible relationships between chemistry and physics, followed by their definitions. They are physical chemistry and chemical physics. How do we define them? What examples can we mention in each case? Hereunder are the definitions and examples of both of them.

Physical chemistry is the branch of chemistry concerned with the application of the techniques and theories of physics to the study of chemical systems.

For example, the study of the rate (speed) of a chemical reaction is physical chemistry.

Chemical physics, on the other hand, is a sub-discipline of chemistry and physics that investigates physicochemical phenomena

It studies chemical processes from the point of view of physics. Physicochemical properties are the basic physical and chemical characteristics of a substance. These include appearance, boiling point, density, volatility, water solubility, flammability, etc. For example, the physicochemical properties of water could be studied in chemical physics.

Dear learner, in ***Figure 1.3***, you can see graphically how the individual fields of science are related. Based on its relationship to other natural sciences, chemists put chemistry at the center of the natural sciences.

? Why do you think they are doing this?

Here is the brief answer to the above question: At some level, all of these branches of natural science depend on chemical processes, as they all involve chemistry. Because of this, chemistry has been called the '**central science**' linking all together.

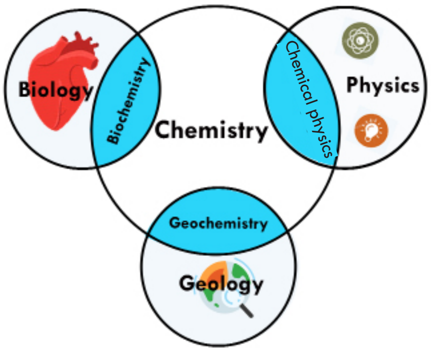


Figure 1.3 The relationships between natural sciences and chemistry.

Resource

Dear learner, please go to the internet and copy and paste these website links so that you can get a better understanding of the relationships between other natural sciences and chemistry.

1. https://byjus.com/chemistry/
2. https://www.lifepersona.com/what-is-the-relationship-of-chemistry-with-other-sciences

Activity 1.2

1. What aspects of nature are studied in;
   - Physics?
   - Biology?
   - Geology?
   - Geochemistry?
   - Biochemistry?
   - Physical chemistry?
   - Chemical physics?
2. What are the regions of overlap between;
   - Chemistry and biology?
   - Chemistry and physics?
   - Chemistry and geology?

Self-Test Exercise 1.2

1. In relation to other natural sciences, chemistry is considered a "central science". Explain.
2. In your biology course, you may have studied how plants produce food. Explain how chemistry is involved in the food production of plants.
3. Explain the two aspects of the relationship between chemistry and physics in a chemical reaction that takes place between two substances.
4. Consider the weathering of rocks and discuss the relationship between chemistry and geology.

Checklist 1.2

Dear learner, check yourself on the following aspects before wrapping up studying this section. Put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it, in the table given below. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
discuss the relationship of chemistry with physics, biology, and geology?		

Section 1.3: The Role Chemistry Plays in Production and in the Society

❁ Dear learner, in the previous sections, you studied the scope of chemistry and its relationship with other natural sciences. This section will elaborate more on the scope of chemistry concerning production and its application in society's day-to-day life. The section focuses specifically on the role chemistry plays in the production of useful materials. The central role of chemical knowledge in improving agricultural productivity, production and processing of food, contribution to improved health (medicine), and production of building construction materials is briefly discussed. When you have finished studying the study notes and important points given below, the following learning outcomes are expected of you.

Learning Outcome

Dear learner, when you have finished studying this section, you are expected to describe the applications of chemistry in the fields of agriculture, medicine, food production, and building construction.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the activity and self-test exercise questions. Make sure that you are clear on the meanings of the concepts, terms, and definitions. After doing so, check whether you achieved the learning outcomes indicated above.

? Dear learner, have you ever thought about how applicable the knowledge of chemistry is in your daily life and in the society you are living in? Do you know that chemistry is essential for meeting our basic needs of food, clothing, shelter, health, energy, and clean air, water, and soil?

In section 1.1 under the scope of chemistry, you got some understanding regarding the provision of knowledge of the nature of chemicals and chemical processes and insights into a variety of physical and biological phenomena. Knowing something about chemistry is worthwhile because it provides an excellent basis for understanding the physical universe we live in. For better or for worse, everything is chemical!

Dear learner, in your everyday life, there are many instances where you knowingly or unknowingly apply the knowledge of chemistry and its rules. Let me present some of them to you.

Agriculture

I guess you know the fact that the study of chemistry has brought the world chemical fertilizers such as calcium superphosphate, urea, ammonium sulphate, and sodium nitrate. Why do you think that farmers apply fertilizer during crop production?

I will answer this question briefly for you. Here it is. These chemicals (fertilizers) have assisted greatly in increasing the yield of fruits, vegetables, and other crops (***Figure 1.5***). In addition to this, chemistry has been effective in the manufacture of pesticides, which have lessened crop damage by various pests.

? What are pests?

Dear learner, let us define the term pest and related terms so that you can understand pesticides.

Pests are animals or plants that damage crops, livestock, and forest, or cause a nuisance to people, especially in their homes (***Figure 1.4***).

Figure 1.4 Pests destroying crops and a man applying pesticides.

Depending on the targeted pest, pesticides include fungicides, herbicides, and insecticides. Below are their definitions.

Fungicides are chemical substances that destroy the fungus.
Herbicides are chemical substances that destroy unnecessary herbs.
Insecticides are chemical substances that kill insects that destroy crops.

I hope now you understand the meaning of pesticides. Thus, by using pesticides, we can supply the ever-growing demand for food.

? Dear learner, do you think that agriculture is the only area where the knowledge of chemistry is applied?

Chemistry also plays an important role in the manufacture of better-quality plastic pipes (polymers) for irrigation and plastic sheets for water reservoirs which are commonly used in farming. This has massively increased irrigation, resulting in a better climate in which the crops can grow. Have you ever visited a mechanized farm where farmers grow crops through irrigation? I advise you to go and visit.

Figure 1.5 Homegrown agricultural products.

Food Production

Dear learner, other than its great contribution to the production of different agricultural products, chemistry has led to the discovery of different kinds of food preservatives.

? Do you know what food preservatives are?

Let me help you with the answer to the above question. Here it goes. Food preservatives are chemicals that have greatly assisted in preserving food products for a longer period. It has given methods to test for the presence of adulterants, which ensure the supply of pure foodstuffs. Consumers have benefited from new technologies that have increased their food's availability, appearance, nutritional content and flavor. A local example of food processing and keeping it for a longer period is the preservation of raw meat.

? Do you know any other traditional food preservation methods?

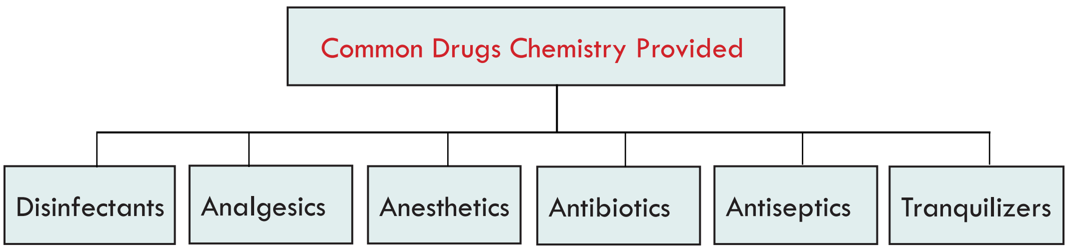
Medicine

Dear learner, chemistry is not only involved in increasing agricultural productivity and in preserving food, but it has also provided mankind with a large number of life-saving medicines.

? What types of medications have you ever used? For which diseases did you use them?

Dear learner, I hope you know that scientists found a cure for dysentery and pneumonia as a result of the discovery of sulphur drugs and penicillin. Besides this, life-saving drugs like cisplatin and taxol are effective for cancer therapy, and AZT is used for AIDS victims. Although AZT does not cure HIV-AIDS, it fights the multiplication of the virus, thereby prolonging the life of the victim. HIV-AIDS, as you know, is a pandemic that has no curative medication. You need to protect yourself from this killer disease by applying the ABC rule, i.e., by Abstaining, Being faithful to your sex partner, and using a Condom.

Dear student, the diagram below lists some of the various classes of drugs that chemistry has provided for society. The definition of each class of drug is given following the diagram shown below.



Disinfectants: These are drugs used to kill the microbes present in toilets, floors, and drains.

The sanitizers we use for COVID-19 belong to this group.

Analgesics: An analgesic or painkiller is any member of the group of drugs used to achieve analgesia, or relief from pain.

Paracetamol could be one of these drugs you may have used for relieving headaches.

Anesthetics: These are a group of drugs used for extremely painful illnesses to create numbness (unconsciousness) in the patient.

An epidural could be one example that is used to ease the pain of a woman during childbirth or a cesarean section (C-section), a spinal for hip or knee surgery, or an arm block for hand surgery.

Antibiotics: These are group of drugs used to control infection and cure diseases.

Amoxicillin could be one of the antibiotic medications the doctor ordered for you to get a cure for a cough.

Antiseptics: These are a group of drugs used to stop the contamination of wounds by bacteria.

You may have used disinfectant soaps for washing your hands before eating meals. Chlorhexidine is a very effective antiseptic drug used in disinfectant soaps.

Tranquillizers: These are a group of drugs used to reduce tension and bring about calm and peace to patients suffering from mental diseases, anxiety, acute stress reactions, and panic attacks.

You may have come across diazepam, which is one of the tanquilizers.

As a general rule, prevention is better than cure. This is the motto the Ministry of Health is following. It is also important to know that every drug has side effects.

Building Construction Materials

? Dear student, have you noticed the materials that were used in the construction of the house you are living in?

Every building construction material either directly or indirectly involves the application of chemistry. Here are some examples. By providing building resources such as glass, steel, and cement, chemistry is involved in the construction of safer houses and multi-storey structures. These building resources will be used in the construction of long-lasting and durable dams and bridges. The best example here could be the Grand Ethiopian Renaissance Dam (GERD), which is under construction in the Benishangul Gumuz Region of Ethiopia (***Figure 1.6***). The GERD is a 6,450 MW hydropower project nearing completion on the Abay (Blue Nile) river in Ethiopia, located about 30 km upstream of the border with Sudan. It will be the largest hydropower project in Africa. It is, therefore, a project you need to be proud of.

Figure 1.6 The Grand Ethiopian Renaissance Dam, Benishangul Gumuz Region, Ethiopia.

Dear learner, ***Figure 1.7*** gives you a simplified pictorial impression of the role chemistry plays in production and in society. You can browse the website indicated below for additional information on the role chemistry plays in production and in society.

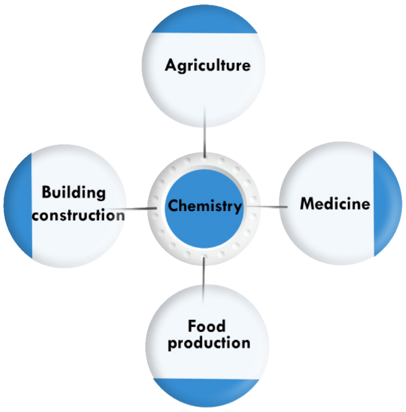


Figure 1.7 The role of chemistry in different sectors.

Resource

Dear learner, please go to the internet and copy and paste these website links so that you can get a better understanding of the role chemistry plays in production and in society.

1. https://www.uwlax.edu/chemistry-and-biochemistry/student-resources/why-study-chemistry/
2. https://homeworkdoer.org/chemistry/importance-of-chemistry-in-society.html
3. https://science.blurtit.com/989983/what-is-the-role-of-chemistry-in-industry-and-society

Activity 1.3

1. List down the chemical products found in your locality. Draw a spider diagram of your own by categorizing them into agriculture, food production, medicine, construction and building construction materials at the center of the spider diagrams. ***Figure 1.6*** can be considered an example of a spider diagram.
2. Concerning the topic under discussion, what problems do you think will be observed in the livelihood of human beings in the absence of enough knowledge of chemistry and its application?
3. In your opinion, what roles, other than the ones mentioned in this section, can chemistry play? You may need to consult the internet in this regard. Note that your answer may not be the same as the one found in the answer key.

Self-Test Exercise 1.3

1. What are the common pests (herbs, insects, and fungi) that damage crops in your locality? How do farmers control them?
2. What are the commercial and traditional pesticides and herbicides used by Ethiopian farmers?
3. Go to a pharmacy in your locality (town) and find drugs that are used as analgesics, antibiotics, tranquilizers, antiseptics, disinfectants, anesthetics, and insecticides.
4. Describe the composition and preparation of 1000 ml (1 liter) of WHO- standard hand disinfectant or hand sanitizer.

   Note: You may need to search the internet or consult a pharmacist to get the answers to the above questions.
5. Describe the chemistry involved in the preparation of 'arake' or 'katikala', 'tej', and 'tella'.

Note: You can consult local professionals who produce the above-mentioned local beverages.

Checklist 1.3

Dear learner, check yourself on the following aspects before wrapping up studying this section. Put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it, in the table given below. You must answer all the questions and revise those with an "X' mark. Can I ...

Activity	Yes	No
describe the applications of chemistry in the fields of agriculture, medicine, food production, and building construction?		

Section 1.4: Some Common Chemical Industries in Ethiopia

- Dear learner, in the previous section, you thoroughly studied the applications of chemistry in the areas of agriculture, food production, medicine, and the production of building construction materials. The production of all of the materials you have discussed under the aforementioned areas of application, however, involves manufacturing industries. Whether it is on a large scale or a small scale, every material is produced in industries. In this section, you are going to study the list of some common chemical industries found in Ethiopia and their products. The manufacturing of valuable products will be covered in Grade 12, Unit 3: "Industrial Chemistry". When you have finished studying this section, the following learning outcome is expected of you.

Learning Outcome

Dear learner, when you have finished studying this section, you are expected to name some common chemical industries found in Ethiopia and their products.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the activity and self-test exercise questions. Make sure that you are clear on the meanings of the concepts, terms, and definitions. After doing so, check whether you achieved the learning outcome indicated above.

? Dear learner, I believe you have heard the term "industry" from someone. But do you know what the industry is?

Let me begin by defining the term "Industry" for you.

An industry is defined as an economic activity concerned with the processing of raw materials and the manufacture of goods in factories.

It can also be interpreted as a group of companies that are linked based on their primary business activities. Individual companies are generally categorized into an industry based on their largest sources of revenue.

I hope that you have heard the phrase "Industrial park".

? Do you know where these parks are found? Can you name some of them? Did you get the opportunity to visit any of them? Which chemical products do they manufacture?

The largest industries in Ethiopia are classified into food processing, beverages, textiles, chemicals, metals processing, and cement. In this section, however, you are going to study some of the common chemical industries found in Ethiopia.

Dear learner, I hope you know that the Ethiopian government has been highly engaged in expanding industries for the past two decades. As part of this expansion, several industrial parks have been under construction (***Figure 1.8***). In short, an **industrial park** is a park where several manufacturing industries have got shades and produce material goods.

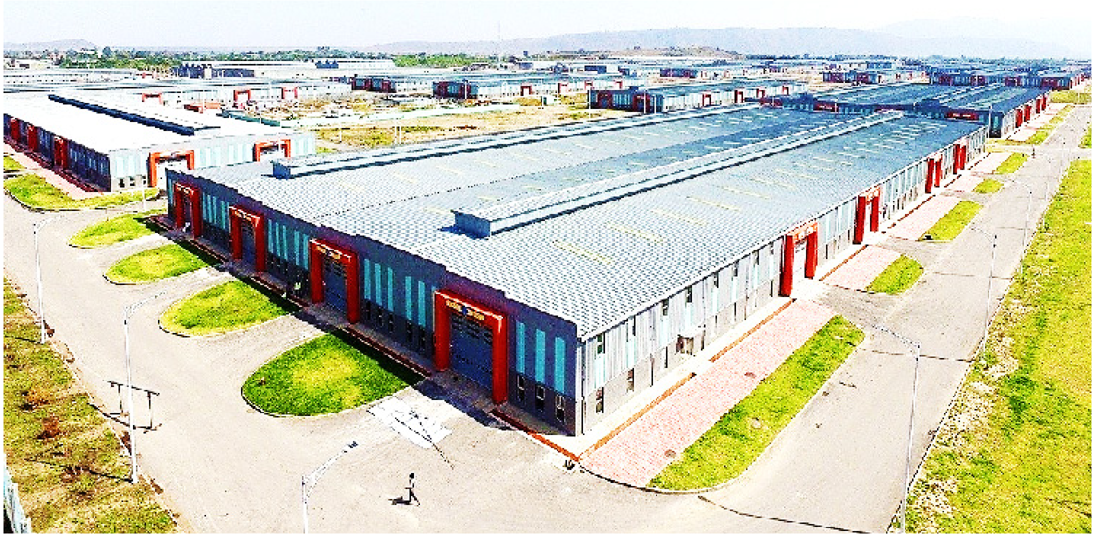


Figure 1.8 One of the industrial parks found in Ethiopia.

Now you are familiar with the meaning of the term industry. It is, therefore, not so difficult for you to guess the meaning of "chemical industry". I encourage you to try to define it before referring to the definition I am going to give you below.

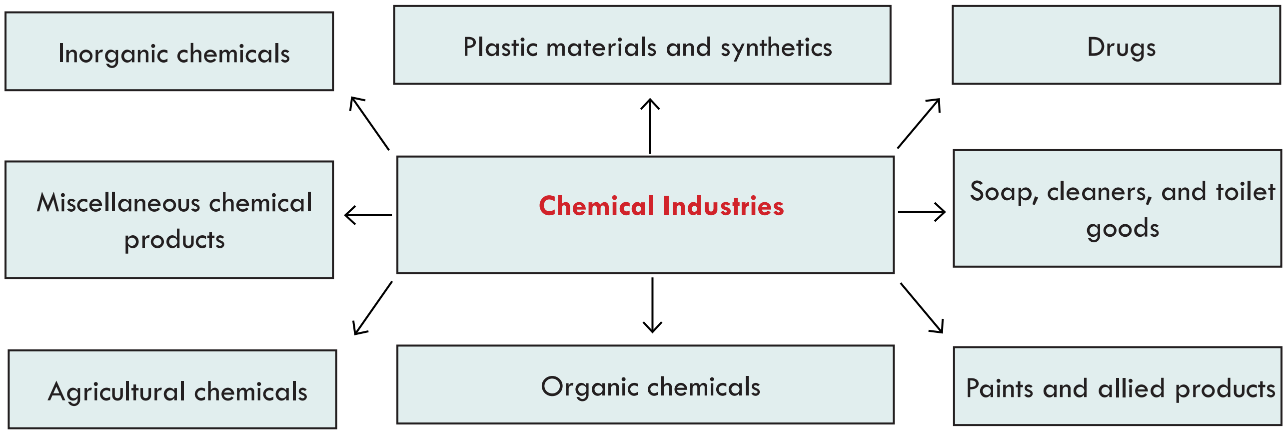
Chemical industries are the companies that manufacture inorganic and organic industrial chemicals, explosives, fragrances, agrochemicals, polymers and rubber, ceramic products, petrochemicals, oleochemicals (oils, fats, and waxes), and flavors.

? How does your definition of the term "**Chemical industries**" fit with the definition given above? I hope it is not far and not different. Did you know what resources the chemical industry uses? What do you think they will do with these resources?

Let me briefly answer these questions. Central to the Ethiopian economy, chemical industries convert natural resources such as oil, natural gas, air, water, metals, and minerals into diverse products that can bring in foreign currency.

? Dear learner, do you know the categories of chemical industry?

They are categorized into: (i) industrial inorganic chemicals; (ii) plastic materials and synthetics; (iii) drugs; (iv) soap, cleaners, and toilet goods; (v) paints and allied products; (vi) industrial organic chemicals; (vii) agricultural chemicals; and (viii) miscellaneous chemical products. Can you give an example of a chemical product in each category? Perhaps you should know the meaning of the term "Chemical product" before you answer this question. Hereunder is the definition of the term "Chemical product".



The chemical products are products manufactured, processed, sold, or distributed by the company that produce chemical substances, or that contained chemical substances. Now you know the meaning of chemical products and you can therefore answer the above question.

Let me give you the classes of chemical products. The three general classes of products are (1) **basic chemicals**, such as alkalis, acids, organic chemicals, and salts (2) **chemical products to be used in further manufactures** such as plastic materials, synthetic fibers, pigments, and dry colors, and (3) **finished chemical products to be used for ultimate consumption** such as cosmetics, drugs, and soaps; or to be used as materials or supplies in other industries such as fertilizers, paints, and explosives.

? Can you classify the examples of chemical products you have listed above in these three general categories?

I don't think it is difficult if you carefully examine the list of chemical substances listed under each class.

? Dear learner, have you ever visited a chemical industry before? If so, which chemical industry? Was it a large-, medium- ,or small-scale chemical industry or a chemical product industry? How many chemical or chemical product industries are there in your town, woreda, zone or region? Do you know the number of medium- and large-scale chemical and chemical product industries in Ethiopia?

I know it will be difficult for you to answer the last question. Don't worry, I will give you the details below.

Currently, there are more than 51 medium- and large-scale chemical and chemical product industries (enterprises) in Ethiopia (***Table 1.1***). These enterprises produce chemicals like aluminum sulphate, caustic soda, soda ash, carbon dioxide, bleaching chemicals, magnesium oxide, pesticides, and chemical products; like soap and detergent, cement, paints, building materials, cosmetics, plastic, natural gum, candles, glass, sugar, tyres, pulp and paper, pharmaceuticals, and tobacco. ***Table 1.1*** gives you a list of some of these industries and their locations.

Table 1.1. Some of the large- and medium-scale chemical enterprises and their chemical products in Ethiopia

No	Name of the Enterprise	City	Product
1	Chorra Gas & Chemical Products	A.A	Plastic, chemicals, petroleum products
2	Awash Melkasa Aluminum Sulphate Factory	AM	Aluminum sulphate and sulphuric acid
3	Ziway Caustic Soda Factory	Ziway	Sodium hydroxide
4	Abijata Soda Ash Factory	Bulbula	Trona ($Na_3H(CO_3)_2.2H_2O$)
5	Repi Soap & Detergent P.L.C	A.A	Soap and detergent
6	Adola Magnesium Oxide Factory	Adolla	Magnesium oxide
7	Adami Tulu Pesticide Processing Plant	Adami-Tulu	Formulates malathion, endosulfan, diazinon, fenitrothion and dimethoate
8	Nefas Silk Paints Factory	A.A	Paints, varnishes, antirusts and glues
9	Modern Building Industries	A.A	Cement and cement products, ceramics, paints, sanitary ware, adhesives, glues, plastic rubber, terrazzo tiles, cultured marble
10	Kadisco Chemical Industry	A.A	Paints, coatings and adhesives
11	Tadesse Filatea PLC	Woliso	Soap, detergent, corrugated iron, nails, infant milk formula,
12	Etab Laundry Soap Factory	Hawassa	Soap and detergent
13	Get-Eshet Detergent Manufacturing and Packing P.L.C	Bishoftu	Detergent products and leather chemical inputs
14	Ethio-Asia Industries S.C.	A.A	Soap and detergent
15	Y.B Cosmetics	Sheger city	Cosmetics and perfume
16	Mekab PLC (Cosmetics)	A.A	Hair oil, shampoo, conditioner, body oil, vaseline, body lotion, detergents and plastic mouldings
17	BEKAS Chemicals PLC	A.A	Detergents, cosmetic products, plastic packing materials, industrial surfactants and putty
18	Arbaminch Textile Share Company	Arbaminch	Textile and fabric products
19	Teamco Soap Factory	Burayu	Soap and detergent

Note: A.A stands for Addis Ababa; AM stands for Awash Melkasa.

Other large-scale chemical product industries in Ethiopia are as follows:

Cement (Mugher, Diredawa, Mesobo, Derba, Midroc, Dangote)

Sugar (Metehara, Wonji, Finchaa, Omokuraz)

Paper and pulp (Wonji)

Pharmaceuticals (Addis, Ethiopia, Adigrat)

Tyre (Horizon Addis Tyre)

Resource

Dear learner, please go to the internet and copy and paste these website links so that you can get a better understanding of the chemical industries found in Ethiopia and their products.

1. https://addisbiz.com/business-directory/manufacturing-industry/chemicals
2. https://www.ethyp.com/category/Chemicals
3. https://www.dnb.com/business-directory/company-information.basic_chemical_manufacturing.et.html
4. http://www.ethiopianembassy.org.in/investment/new/Opportunity%20in%20Chemical%20Sector%202015.pdf

Activity 1.4

1. List the common names together with the chemical names, formulas, and uses of 10 household chemicals.
2. Browse the internet or use other sources to find out about10 other household chemicals that are commonly used in different homes, along with their corresponding molecular formulas, chemical names, and uses.
3. List at least 15 chemical industries (enterprises) that are found in Ethiopia.

Self-Test Exercise 1.4

1. What is the difference between a chemical substance and a chemical product?
2. Mention the three general classes of products and classify the large- and medium-scale chemical enterprises listed in Table 1, under these classes.
3. What are the classifications of the largest industries in Ethiopia?

Dear learner, test yourself to see if you achieved the learning outcomes of the section by giving correct answers to the following questions ,and check the answer keys to see if you have answered them correctly or not.

1. What is the difference between a chemical substance and a chemical product?
2. Mention the three general classes of products and classify the large- and medium-scale chemical enterprises listed in Table 1, under these classes.
3. What are the classifications of the largest industries in Ethiopia?

Checklist 1.4

Dear learner, check yourself on the following aspects before wrapping up studying this section. Put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it, in the table given below. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
name some common chemical industries found in Ethiopia and their products?		

Unit Summary

Chemistry is the science that deals with the properties, compositions, and structures of substances, the transformations they undergo, and the energy that is released or absorbed during these processes.

The study of modern chemistry has many branches, but can generally be broken down into five main disciplines, or areas of study: Organic chemistry, Inorganic chemistry, Physical chemistry, Analytic chemistry and Biochemistry.

The scope of chemistry includes agriculture, food production, improving health and sanitation facilities, environmental protection, and preparing people for career opportunities. Because living and non-living things are made up of matter, chemistry affects all aspects of life, and most natural events.

Chemistry is the central science in the natural sciences. Being one of the basic sciences, Chemistry is related to other natural sciences like biology, physics, geology, and medicine.

Chemistry and biology are related through the metabolic processes occurring inside living matter, known as Biochemistry. Chemistry and geology are related by the processes that control the abundance, composition, and distribution of chemical compounds and isotopes inside the crust of the earth, known as geochemistry. A sub-discipline of chemistry and physics that investigates physicochemical phenomena using techniques from atomic and molecular physics and condensed matter physics is known as Chemical physics.

Since chemistry is so fundamental to our world, it plays a role in everyone's lives and touches almost every aspect of our existence in some way. Chemistry is essential for meeting our basic needs, such as food, clothing, shelter, health, energy, and clean air, water, and soil. Chemistry can also help us comprehend, monitor, protect and recover the environment around us.

Chemistry, however, can also negatively affect our environment through the production of toxic substances. The release of these toxic substances into the environment results in climate change, the primary issue the world is facing currently. It is, therefore, high time to seek a solution to this problem by using our chemical knowledge.

Chemistry plays a significant role in the advancement and growth of many industries. Several chemical and chemical products industries produce a number of chemicals and chemical products.

The Ethiopian government is working hard to establish industrial zones throughout the nation. Currently, there are more than 51 medium- and large-scale chemical and chemical product industries (enterprises) in Ethiopia. These enterprises produce chemicals like aluminium sulphate, caustic soda, soda ash, carbon dioxide, bleaching chemicals, magnesium oxide, pesticides; and chemical products like soap and detergent, cement, paints, building materials, cosmetics, plastic, natural gum, candles, glass, sugar, tyres, pulp and paper, pharmaceuticals, and tobacco.

Self-Assessment Exercise

Dear student, there are 19 questions that are categorized into basic, intermediate, and challenge levels. The questions will help you check your understanding of the unit as a whole. You are expected to give answers to all questions before referring to the answers. The answers to all questions are found at the end of the unit. Follow the instructions provided for each level of questions and respond accordingly.

Part I: Basic Level Questions

Identify each of the following statements as 'true' or 'false'. Give your reason(s) for saying 'false'.

1. Chemistry is a science that deals with the study of the way living things behave.
2. Every substance in the universe, where we live, has its own properties by which we can distinguish it from other substances.
3. The transformation of a substance is a marked change in form, nature, or appearance.
4. The study of chemistry involves only microscopic information.
5. Organic chemistry is the study of chemicals that are not based on carbon.

Part II. Intermediate- Level Questions

Fill in the blank spaces.

6. The property of a substance is its ______________, ____________ or _______________.
7. ________________ is the nature of something's ingredients or constituents; how a whole or mixture is made up.
8. The arrangement and the relationships between the parts or elements of something complex is known as its _____________________.
9. ________________ is a power derived from the utilization of physical or chemical resources, especially to provide light and heat.
10. _______________ is the study of the macroscopic properties, atomic properties, and phenomena in chemical systems.
11. _______________ is the study of the composition of matter.

Part III. Challenge- Level Questions

Provide appropriate answers to the following questions.

12. Define the terms industry, chemical industry, and chemical products.
13. What roles can chemistry play in production and in society?
14. How does chemistry play a role in increasing comfort, pleasure, and luxury?
15. Mention at least ten chemical industries found in Ethiopia and their chemical products.
16. Which branch of chemistry has the highest scope? Why?
17. What are the five fields of chemistry?
18. What will be the future efforts in chemistry?
19. What jobs can you perform with chemistry?

Assignment for Submission

Project work: An industrial trip to the local industries

Dear learner, arrange an industrial tour to a minimum of two or three industries so that you can observe the raw materials, the chemical processes involved, and the finished products in the industries that are located in your vicinity. Fill out the format indicated below in your industrial tour, and submit it to your tutor or marker. You will also present your observations to your tutor or marker.

Name ______________________ Roll number ______________________

Date ______________________ Assignment number ______________________

City/town ____________________

Name of industry	Name of town/city	Raw materials and name of the chemical process used	Finished product

Answer Key to Exercises

Answers to Activity 1.1

1. Meanings of the terms:

A substance is a particular kind of matter with uniform properties. Example: copper, oxygen (air), soap, cooking oil, gasoline, etc.

The property of a substance is its attribute, quality, or characteristic. One of the properties of copper, for example, is its reddish color. Oxygen is gas and has no color. Soap is solid and cleans dirt. Cooking oil is liquid and gives the food good taste and flavor. Gasoline is a liquid substance and is volatile. It has a certain aroma.

The composition of a substance is the nature of something's ingredients or constituents; how a whole or mixture is made up. Example: Air is composed of oxygen, nitrogen, carbon dioxide, and other gases. Gasoline is a mixture of many hydrocarbons. Soap is composed of carbon, hydrogen, oxygen, and sodium or potassium.

The structure of a substance is the arrangement of and relations among the parts or elements of the substance. Example: The body structure of every human being is made up of a skeleton. The skeletons of every part of the body (e.g., leg, hand, finger, head, etc.) are arranged and give our body structure.

The transformation of a substance is a marked change in the form, nature, or appearance of the substance. Example: Freezing water will change it from a solid state to a liquid state, while boiling water will change it from a liquid state to a gaseous state. We call this, the transformation of water from one state to another.

Energy change is the conversion of one form of energy into another. Example: Burning a candle changes the chemical energy into heat and light energy.

2. **Chemistry** is the science that deals with the properties, composition, and structure of

substances (elements and compounds), the transformations they go through, and the energy that is released or absorbed during these processes.

3. Examples of chemicals or chemical products that are used in the following areas:

Agriculture: Farmers use fertilizers, pesticides, herbicides, etc. to increase food productivity.

Food production: Preservative chemicals are used to protect food from deterioration.

Medicine: Health professionals use different medicines for different diseases and disinfectants to prevent infections.

Building construction: By providing building resources such as glass, steel, gypsum and cement, chemistry helps in the construction of safer houses and multi-storey structures.

4. Some of the problems caused by dangerous chemicals affect human health and the environment.

i. Potential health effects, such as:

organ damage
weakening of the immune system
development of allergies or asthma
reproductive problems and birth defects
effects on the mental, intellectual, or physical development of children
mercury is carcinogenic
nuclear energy is useful, but the disposal of nuclear waste poses a serious problem to humanity.
Phonograph records have added to our pleasure of listening to music, but we make them of polyvinyl chloride. We produce them from vinyl chloride, which can cause liver cancer in industrial workers.
Antibiotics have eliminated infectious diseases, but their overuse is very harmful.
Chemistry has given us drugs like LSD (lysergic acid diethylamide), cocaine, and brown sugar. These prove to be a curse for society.

ii. Environmental effect

Oxides of nitrogen, sulphur, and carbon cause environmental pollution.
Global warming is caused by the excessive emission of carbon dioxide into the environment.
Flourochlorohydrocarbons can damage the ozone layer.
Chlorinated pesticides and herbicides are toxic to living organisms.

Note: Your answer might not be exactly the same as the above. This, however, does not mean that you are wrong.

5. The answer to this problem will depend on the problems observed in your locality.

6. The solution to the problem caused by any toxic or hazardous chemical is either to avoid using it, or to replace it with another environmentally friendly chemical.

Answers to Self-Test Exercise 1.1

1. Since chemistry involves the transformation of substances through chemical and physical changes, the degree to which chemistry has changed civilization is clear

everywhere. A good part of the clothing we wear, the automobiles we drive, the airplanes we fly, the computers we are using, the smartphones we are using today, the televisions in our homes, and the other products we encounter daily compose of materials that simply involve the knowledge of chemistry. In recent years, the realization that a living organism is a complex chemical 'factory' has generated a strong interest in the study of biochemistry, and brought great advances in our knowledge of life. Medicines, which were synthesized through chemical reactions in the chemical laboratories and manufactured in the pharmaceutical industries, have made us healthier and, through the cure of disease, have prolonged our lives. Generally, all industries that produce material goods involve chemical knowledge.

2. Chemistry is not only involved in providing useful substances in the areas of development and technology, but it can also result in very dangerous substances that can negatively affect a human's life and the environment (e.g., fluorochlorohydrocarbons, oxides of nitrogen, carbon, and sulphur). It has been only recently, however, that we have also realized a host of problems arising from this growth of technology. It solves such problems that pose much of the challenge for chemistry now and in the future. It is, therefore, first and foremost highly recommended to minimize the production of such types of chemicals. Secondly, we need to reduce the utilization of those environmentally unfriendly substances. Thirdly, replacing them with environmentally friendly substances will keep humanity and our Planet, in particular, and the Universe in general, safe.

Answers to Activity 1.2

1. The aspects of nature are studied in;

   Physics: properties of matter and energy.

   Biology: the scientific study of living things.

   Geology: the study of the Earth, the materials of which it is made, the structure of those materials, and the processes acting upon them.

   Geochemistry: the study of the processes that control the abundance, composition, and distribution of chemical compounds and isotopes in geologic environments.

   Biochemistry: the study of the chemical processes occurring in living matter.

   Physical chemistry: concerned with the application of the techniques and theories of physics to the study of chemical systems.

2. The regions of overlap between;

   Chemistry and biology: the chemical processes of living organisms.

   Chemistry and physics: chemical systems.

   Chemistry and geology: the processes that control the composition and distribution of chemical compounds and isotopes in geologic environments.

Answers to Self-Test Exercise 1.2

1. The three disciplines of natural science, namely biology, geology and physics are related to chemistry in the following ways: Biology and geology are engaged in

chemical processes, and hence biochemistry and geochemistry are derived from this relationship. Chemical physics, being a branch of both chemistry and physics, involves the investigation of physicochemical phenomena. Chemistry, therefore, became the central element that overlaps with biology, geology and physics; hence, it is called the "central science".

2. Plants produce food from carbon dioxide and water in the presence of sunlight and chlorophyll. This is called photosynthesis. Photosynthesis is the chemical process by which plants use sunlight, water, and carbon dioxide to produce glucose (plant food), oxygen, and energy as of heat.

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow[\text{Sunlight}]{\text{Chlorophyll}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} + \text{Heat}$$

The above reaction is a chemical process, and hence the involvement of chemistry is clear in the production of food in plants.

3. The two aspects of the relationship between chemistry and physics in a chemical reaction are the speed (rate) of the chemical reaction and the energy changes that take place in the chemical's course reaction.

4. The weathering of rocks will take place during the exposure of rocks to fluctuating heat, air, acid, and moisture. The important processes of chemical weathering are solution, carbonation, hydration, oxidation and reduction. These processes act on the rocks to decompose, dissolve, or reduce them to fine rock particles through chemical reactions involving oxygen, surface and/or soil water, and other acids.

Answers to Activity 1.3

1. Try to be honest and list the chemical products found in your locality. Categorize them under agriculture, food production, medicine, and building construction materials. Put agriculture at the center of the spider diagram, and arrange those chemical products you have listed around it. Do likewise for food production, medicine and building construction materials.

2. Human life would be tough, full of problems ,or challenges. Different diseases, especially pandemic diseases like COVID-19, SARS, HIV/ AIDS, Ebola, etc., would have killed more than we can imagine. The scarcity of food could have caused famine, and children would have been affected by deficiency diseases. The problem of air and water pollution would have been rampant. In general, life would have been much more challenging than it is today.

3. In order to replace dangerous and toxic chemicals that harm the environment and endanger human life with safer and environmentally friendly compounds, chemical understanding must increase. Chemical processes need to be efficient and effective. This needs the discovery of novel catalysts. The knowledge and application of chemistry could realize this.

Answers to Self-Test Exercise 1.3

1. Go to the local farmers and ask them for answers.

2. The most common pesticides used in Ethiopia include organophosphates, carbamates, and to some extent, organo-chlorines. For traditional pesticides, consult the local farmers and get the answer.

3. Your answer may or may not be the same as the answer written hereunder. However, these are some of the commonly sold groups of drugs in pharmacies:

   Disinfectants: alcohol, chlorine and chlorine compounds, formaldehyde, glutaraldehyde, hydrogen peroxide, iodophors, ortho-phthalaldehyde (OPA), and peracetic acid.

   Analgesics: aspirin, panadol, acetaminophen, ibuprofen, naproxen, tramadol, and paracetamol.

   Anesthetics: sevoflurane, desflurane, isoflurane, propofol (Diprivan®), ketamine, and etomidate.

   Antibiotics: phenoxymethylpenicillin, flucloxacillin, amoxicillin, cefadroxil, cefalexin, and gentamicin.

   Antiseptics: chlorhexidine, povidone-iodine, chloroxylenol, isopropyl alcohol, hexachlorophene, benzalkonium chloride, and hydrogen peroxide.

   Tranquillizers: phenelzine, noradrenaline, chlordiazepoxide, and iproniazid.

   Insecticides: lindane, aldrin, dieldrin, Dichlorodiphenyldichloroethane (DDD) and Dichlorodiphenyldichloroethylene (DDE).

4. Preparation of WHO- standard hand sanitizer:

   To produce WHO- standard hand sanitizer, one can use ethanol at 80% v/v, glycerol at 1.45% v/v, and hydrogen peroxide (H_2O_2) at 0.125% v/v composition. In other words, in order to prepare 1000 ml or one of liter sanitizer, you need to mix up 96% ethanol (833.3 ml), 3% H_2O_2 (41.7 ml), 98% glycerol (14.5 ml), and distilled or bottled water(110.5 ml).

5. Arake or katikala is made by creating malt (bikil) from corn, sorghum, teff, wheat or barley, fermenting or oxidizing the sugar into alcohol (ethanol), and then distilling the alcohol to separate from the base combination.

   The preparation of 'tella' is more or less the same as that of 'katikala' preparation. The only difference between preparing the two is that the fermentation mass with 'katikala' is more concentrated, and there is no distillation with 'tella'. Therefore, the chemistry involved in the production of 'tella' is the oxidation of the sugar into alcohol. The final alcohol content of 'tella' is 2 to 4%, while that of the filtered drink is 5–6%.

   'Tej' is a home-processed, but also commercially available as honey wine. It is prepared from honey, water, and the leaves of gesho. Sometimes, when widely produced for commercial purposes, a mixture of honey and sugar could be used for its preparation. The chemistry involved in the preparation of 'tej' is fermentation or oxidation of the sugar into alcohol and filtration of the mixture.

Answers to Activity 1.4

1. See the table "Common chemicals used at home" given below.
2. See the table "Common chemicals used at home" given below.

Common name	Chemical name	Molecular formula	Use
Alcohol	Ethanol	C_2H_6O	Components of alcoholic beverages and in thermometers
Antiperspirant	Aluminum chlorohydrate	$Al_2Cl(OH)_5$	Used in antiperspirants and deodorants
Antifreeze	Ethylene glycol	$C_2H_6O_2$	Used as an automotive antifreeze
Aspirin	Acetylsalicylic acid	$C_9H_8O_4$	pain killer
Baking powder	Sodium bicarbonate	$NaHCO_3$	Baking bread
Battery acid	Sulphuric acid	H_2SO_4	Lead-acid battery for cars
Bleach	Sodium hypochlorite	$NaClO$	Domestic bleach (berekina)
Caustic soda	Sodium hydroxide	$NaOH$	Unblocking sinks
Chalk	Calcium carbonate	$CaCO_3$	Writing on a blackboard
Diamond	Alloy of carbon	C	Ornament and glass cutting
Glycerin	Glycerol	$C_3H_5(OH)_3$	Ingredients of toothpastes, mouthwashes, skincare products, shaving creams, hair care products, and soaps
Graphite	Carbon	C	The "lead" in pencil
Gypsum	Calcium sulphate hydrate	$CaSO_4.2H_2O$	Used in the construction of interior walls and roofs of houses
Liquid paper	Titanium oxide	TiO_2	Correction fluid
Magnesia	Magnesium oxide	MgO	Antacid used to treat heartburn and stomach ulcers
Marble	Calcium carbonate	$CaCO_3$	Construction of the house and floor
Margarine	Partially saturated fatty acid	Various	Used as an ingredient in cooking, and with bread
Plaster	Calcium hydroxide	$Ca(OH)_2$	Used in construction, including interior walls in houses
Potash	Potassium carbonate	K_2CO_3	Fertilizer
Salt (table salt)	Sodium chloride	$NaCl$	Food additives, and preservatives
Sand	Silicon dioxide	SiO_2	Construction
Silica	Silicon dioxide	SiO_4	Desiccant is used for absorbing moisture in different product packaging, including cloth.

Common name	Chemical name	Molecular formula	Use
Sugar (table sugar)	Sucrose	$C_{12}H_{22}O_{11}$	Food additive as sweetener
Teflon	Polymer of tetrafluoroethylene	$(C_2F_4)_n$	Non-stick coating for cookware
Vinegar	Acetic acid/ ethanoic acid	$C_2H_4O_2$	Food seasoning (an additive) and various household cleaning

3. Refer to ***Table 1.1*** in the learnertext.

Answers to Self-Test Exercise 1.4

1. A chemical substance is a matter having a constant chemical composition and characteristic properties. Chemical products, on the other hand, chemical products are products created, processed, sold, or distributed by the company that produce chemical substances.
2. The three general classes of products are:
   i. Basic chemicals
   ii. Chemical products to be used in further manufacturing
   iii. Finished chemical products to be used for ultimate consumption

Chemical enterprises that produce basic chemicals:

No	Name of the Enterprise	City	Product(s)
1	Chorra Gas & Chemical Products	A.A	Plastic, chemical, and petroleum products
2	Awash Melkasa Aluminum Sulphate factory	AM	Aluminum sulphate and sulphuric acid
3	Zeway Caustic Soda Factory	Ziway	Sodium hydroxide
4	Abijata Soda Ash Factory	Bulbula	Trona ($Na_3H(CO_3)_2.2H_2O$)
5	Adola Magnesium Oxide Factory	Adolla	Magnesium oxide
6	Adami Tulu Pesticide Processing Plant	Adami-Tulu	Formulates malathion, endosulfan, diazinon, fenitrothion and dimethoate

A.A stands for Addis Ababa,and AM stands for Awash Melkassa.

Chemical enterprises that produce products to be used in further manufacturing:

No	Name of the Enterprise	City	Product(s)
1	Modern Building Industries	A.A	adhesives, glues, and plastic rubber
2	Get-Eshet Detergent Manufacturing and Packing P.L.C	Bishoftu	Leather chemical inputs
3	Mekab PLC (Cosmetics)	A.A	Plastic mouldings
4	BEKAS Chemicals PLC	A.A	Plastic packing materials, industrial surfactants, and putty
5	Arbaminch Textile Share Company	Arbaminch	Textile and fabric products

A.A stands for Addis Ababa.

Chemical enterprises that produce finished chemical products to be used for ultimate consumption:

No	Name of the Enterprise	City	Product(s)
1	Repi Soap & Detergent P.L.C	A.A	Soap and detergent
2	Nefas Silk Paints factory	A.A	Paints, varnishes, antirusts, and glues
3	Modern Building Industries	A.A	Cement and cement products, ceramics, paints, sanitary ware, adhesives, glues, plastic rubber, terrazzo tiles, cultured marble
4	Kadisco Chemical Industry	A.A	Paints, coatings, and adhesives
5	Tadesse Filatea PLC	Woliso	Soap, detergent, corrugated iron, nails, infant milk formula
6	Etab Laundry Soap Factory	Hawassa	Soap and detergent
7	Get-Eshet Detergent Manufacturing and Packing P.L.C	Bishoftu	Detergent products and leather chemical inputs
8	Ethio-Asia Industries S.C	A.A	Soap and detergent
9	Y.B Cosmetics	A.A	Cosmetics and perfume
10	Mekab PLC (Cosmetics)	A.A	Hair oil, shampoo, conditioner, body oil, vaseline, body lotion, detergents and plastic moulds
11	BEKAS Chemicals PLC	A.A	Detergents, cosmetic products, plastic packing materials, industrial surfactants and putty
12	Teamco Soap Factory	Burayu	Soap and detergent

A.A stands for Addis Ababa.

3. We can classify the largest industries in Ethiopia into food processing, beverages, textiles, chemicals, metals processing, and cement.

Answers to the Self-Assessment Questions

Part I: True/False Type Questions

1. False –, because it deals with the properties, composition, structure, and transformation of substances.
2. True
3. True
4. False – because it also involves macroscopic information.
5. False – because it is the study of carbon compounds.

Part II. Fill in the Blank Spaces.

6. Attribute, quality, or characteristics
7. Composition
8. Structure
9. Energy
10. Physical chemistry
11. Analytical chemistry

Part III. Short Answer Type Questions

12. We can define industry as an economic activity concerned with the processing of raw materials and manufacturing goods in factories.

    The chemical industries comprise the companies that produce inorganic and organic industrial chemicals, ceramic products, petrochemicals, agrochemicals, polymers and rubber (elastomers), oleo-chemicals (oils, fats, and waxes), explosives, fragrances, and flavors.

    Chemical products are products manufactured, processed, sold, or distributed by the company or companies.

13. Supply of food, contribution to improved health and sanitation facilities, saving the environment, increase in comfort, pleasure and luxuries, industry, and war.

14. By producing synthetic fibers, building materials, supplies of metals for ornamental purposes, articles of domestic use, entertainment, transport and communication, and nuclear atomic energy.

15. Please take a look at ***Table 1.1*** for an answer. Since the number of chemical industries is too large, it is difficult to list them all here.

16. Analytical chemistry has the maximum scope because quality control and analysis are required in every type of industry.

17. Traditionally, we can classify chemistry into five main sub-disciplines: organic, analytical, physical, inorganic, and biochemistry.

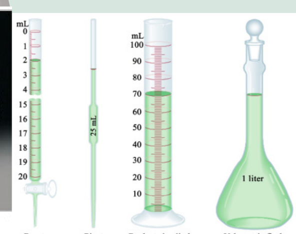
18. The chemical sciences will probably be increasingly required to solve challenges in health, energy and climate change, water and food production. Chemistry might have a greater role in biochemistry and the pharmaceutical industry, as well as in the maintenance, and development of infrastructure.

19. Some of the careers in chemistry:

    Analytical chemist
    Accountant or auditor pertinent to chemicals
    Chemical engineer
    Chemical development engineer
    Lecturer/teacher
    Environmental chemist
    Forensic researcher
    Forensic scientist

UNIT 2

Triple-beam balance



MEASUREMENTS AND SCIENTIFIC METHODS

Introduction

- Dear learner, this unit will concentrate on how some of the physical properties are described. Quantitative physical properties such as mass, volume, density, temperature and length are discussed in detail. The system of the units accepted internationally and the techniques used to convert one kind of units to another are the main concern of this unit.

One other important aspect of measurement considered is reliability. In this unit you will see how to express results of measurement readings and mathematical operation properly. Convenient mechanisms for expressing the very large and very small numbers that are used in chemistry will also be discussed.

Unit Outcomes

After completing the unit, you will be able to

- Use proper SI units.
- Identify the causes of uncertainty in measurement.
- Express the result of any calculation involving experimental data to the appropriate number of decimal places or significant figures.
- Apply scientific methods in solving problems.
- Demonstrate an understanding of experimental skills in chemistry.
- Demonstrate a knowledge of basic laboratory apparatuses and safety rules.
- Describe scientific inquiry skills along this unit: observing, inferring, predicting, comparing & contrasting, communicating, analyzing, classifying, applying, theorizing, measuring, asking question, developing hypothesis, designing experiment, interpreting data, drawing conclusion, making generalizations and problem solving.

Unit Content

In this unit you are going to cover the following sections:

Section 2.1: Measurements and Units in Chemistry

Section 2.2: Chemistry as Experimental Science

The Required Study Time

Starting from the first day of your enrollment, you have a maximum of 10 months to complete the grade 9 chemistry modules, but the pace at which you proceed is up to you. Grade 9 chemistry consists of five units and this is the unit 2 of this course. You are expected to finish studying this unit in six weeks.

Section 2.1: Measurements and Units in Chemistry

Learning Competencies

At the end of this section, you should be able to

- List the seven SI units and their prefixes.
- Describe the seven SI units and their prefixes.
- Write the names and symbols of derived SI units.
- Use the factor label method for solving problems and making conversion of SI

units.
- Describe uncertainty of measurement.
- Identify the digits that are certain and the ones that are uncertain given a number representing measurement.
- Identify causes of uncertainty in measurement.
- Define precision and accuracy.
- Estimate the precision possible for any instrument they use in the laboratory.
- Explain systematic and random errors.
- Analyze given data in terms of precision and accuracy.
- Define significant figures.
- Determine the number of significant figures in a calculated result.
- Use the scientific notation in writing very large or very small numbers.

Activity 2.1

Time allocated for activity _ 10 minutes
Dear learner, conduct the following activity.
1. Discuss and list down different traditional ways of measuring mass of solid and liquid substances sold in the market places in your area.
2. Mention indigenous methods of measurements (length, mass, time, volume)

Dear learner, measurement is the comparison of a physical quantity to be measured with a unit of measurement that is, with a fixed standard of measurement. On a centimeter scale, the centimeter unit is the standard of comparison. In traditional markets people buy and sell goods by estimating their size in traditional way or use traditional measurement method. ***Figure 2.1*** shows traditional market and people exchanging goods by estimating their size using indigenous methods of measurements.

Figure 2.1 Traditional market.

Dear learner, the study of chemistry depends heavily on measurement. For instance, chemists use measurements to compare the properties of different substances and to assess changes resulting from an experiment. A number of common devices enable us to make simple measurements of a substance's properties: The meter stick measures length; the burette, the pipette, the graduated cylinder, and the volumetric flask measure volume (see ***Figure 2.2***); the balance measures mass; the thermometer measures temperature. The instruments illustrated on ***Figure 2.2*** provide measurements of macroscopic properties, which can be determined directly. Microscopic properties, on the atomic or molecular scale, must be determined by an indirect method. A measured quantity is usually written as a number with an appropriate unit. To say the distance between Addis Ababa and Hawassa by car along a certain route is 275 is meaningless. We must specify that the distance is 275 kilometers. In science, units are essential to state measurements correctly.

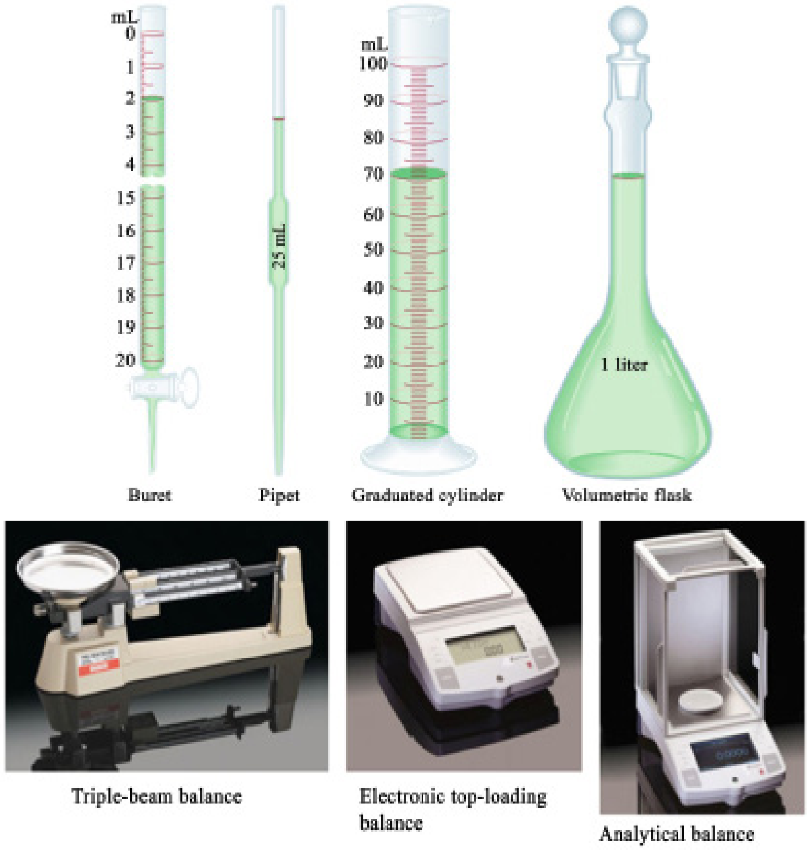


Figure 2.2 Some common measuring devices found in a chemistry laboratory.

? Is it meaningful to say the volume of a liquid is "three"? Three what?

The statement does not give you any information about the volume unless a specific unit is stated. Quantitative properties of a sample are measured by comparing the measured property with standard unit of that property. Scientists have found the system of metric units to be convenient one. They have adopted and recommended it for worldwide with few modifications.

The international system of units (abbreviated as SI) is the complete collection of rules, symbols and definitions of physical quantities. The SI specifies a set of seven base units, from which all other units are constructed.

2.1.1 SI Units (The International System of Units)

Dear leaner, for many years, scientists recorded measurements in metric units, which are related decimally, that is, by powers of 10.

Table 2.1 shows the seven SI base units. Measurements that we will utilize frequently in our study of chemistry include time, mass, volume, density, and temperature.

Table 2.1 SI Base Units.

Base Quantity	Name of Unit	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electrical current	Ampere	A
Temperature	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd

Much of chemistry relies on the measurement of mass, volume, temperature and time.

i. **Mass:** mass is very common measurement in laboratory. Its SI base unit is kilogram (kg). one kilogram (1 kg) is defined as the mass of a certain block of platinum-iridium alloy kept at the international bureau of weight and measures in France. People are often confused between the terms "mass" and "weight". Remember that **mass is the quantity of matter that a sample contains.** It is an invariable quantity, that means, it is the same for the sample taken anywhere in the universe. On the other hand, **the weight of a sample is a measure of the attraction of gravity to the sample.** It is variable since the attraction depends on the distance from the center of the earth. If this book were taken up in an airplane, it would weigh less than it does at sea level. Far out of space, its weight would be almost nothing. However the mass of the book doesn't change as the distance from the center of the earth changes. For this reason scientists measure quantities of matter in terms of mass rather than weight.

ii. **Length:** The SI unit of length is meter(m). A meter is convenient measure of length for every day use.

? Dear learner, do you know your height in meters? Most laboratory samples have dimensions much smaller than 1 m. therefore a more convenient unit for laboratory work is centimeter (cm). 1 cm = 10^{-2} m.

iii. **Time:** The SI unit of time is second (s). there are bigger units like minutes, hours and so on. There are 60 seconds in 1 minute and there are 60 minutes in 1 hour.

iv. **Heat and Temperature:** Temperature measures the intensity of heat, the "hotness" or "coldness" of a body. Heat is a form of energy that always flows spontaneously from a hotter body to a colder body — never in the reverse direction.

Dear learner, relationships among the three temperature scales are illustrated in ***Figure 2.4***. Between the freezing point of water and the boiling point of water, there are 100 steps (°C or Kelvins, respectively) on the Celsius and Kelvin scales. Thus, the "degree" is the same size on the Celsius and Kelvin scales. But every Kelvin temperature is 273.15 units above the corresponding Celsius temperature. The relationship between these two scales is as follows:

☞ $$\mathbf{K = {}^0C + 273.15\ {}^0C \text{ or } {}^0C = K - 273.15^0}$$

In the SI system, "degrees Kelvin" are abbreviated simply as K rather than °K and are called kelvins. Any temperature change has the same numerical value whether expressed on the Celsius scale or on the Kelvin scale. For example, a change from 25°C to 59°C represents a change of 34 Celsius degrees. Converting these to the Kelvin scale, the same change is expressed as (273 + 25) = 298 K to (59 + 273) = 332 K, or a change of 34 kelvins.

Comparing the Fahrenheit and Celsius scales, we find that the intervals between the same reference points are 180 Fahrenheit degrees and 100 Celsius degrees, respectively. Thus, a Fahrenheit degree must be smaller than a Celsius degree. It takes 180 Fahrenheit degrees to cover the same temperature interval as 100 Celsius degrees. From this information, we can construct the unit factors for temperature changes:

$$\frac{180\ ^oF}{100\ ^oC} \text{ or } \frac{1.8\ ^oF}{1.0\ ^oC} \text{ and } \frac{100\ ^oC}{180\ ^oF} \text{ or } \frac{1.0\ ^oC}{1.8\ ^oF}$$

But the starting points of the two scales are different, so we cannot convert a temperature on one scale to a temperature on the other just by multiplying by the unit factor. In converting from °F to °C, we must subtract 32 Fahrenheit degrees to reach the zero point on the Celsius scale (*Figure 2.3*).

$$^oF = \left(x^oC \times \frac{1.8^oF}{1.0^oC} \right) + 32^oF = \left(x^oC \times \frac{9^oF}{5^oC} \right) + 32^oF \quad \text{and} \quad ^oC = \frac{1.0^oC}{1.8^oF}\left(x^oF - 32^oF\right) = \frac{5^oC}{9^oF}\left(x^oF - 32^oF\right)$$

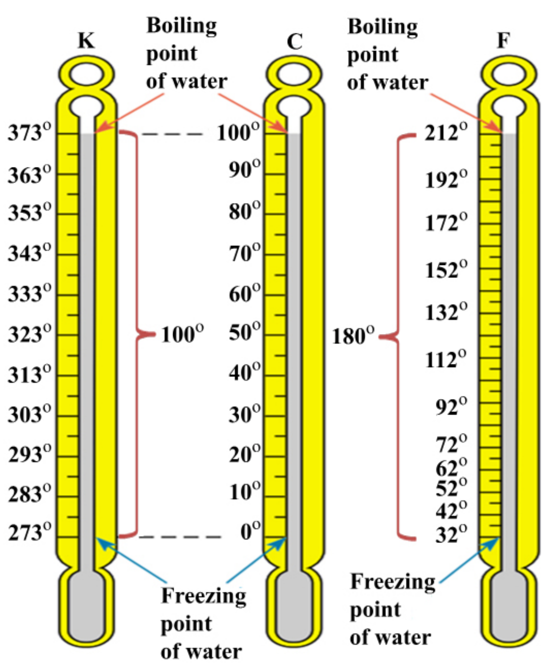


Figure 2.3 The relationships among the Kelvin, Celsius (centigrade), and Fahrenheit temperature scales.

Example 2.1: Temperature conversion

When the temperature reaches "100.°F in the shade," it's hot. What is this temperature on the Celsius scale?

Solution

We use the relationship $^oC = \frac{1.0^oC}{1.8^oF}\left(x^oF - 32^oF\right)$

to carry out the desired conversion. $^{o}C = \frac{1.0^{o}C}{1.8^{o}F}\left(100^{o}F - 32^{o}F\right) = \frac{1.0^{o}C}{1.8^{o}F}(68^{o}F) = 38^{o}C$

Check whether you have understood how to use these formula by doing the ***Activity 2.1***.

Activity 2.2

Time allocated for activity 10 min

Dear learner, use the same formula and complete the following table.

Table 2.2 Unit conversion

T(°C)	T(°F)	T (K)
15.56	60	288.56
(a)________	________	546
(b)________	424	________
(c) 200	________	________

2.1.2 Derived Units

Dear learner, in the SI Units for quantities such as area, volume and density are obtained by appropriate combination of the base units. Such units obtained by combination of the base units are called **derived units**.

i. Area

? How can you calculate the area of a rectangular carpet? (***Figure 2.4***)

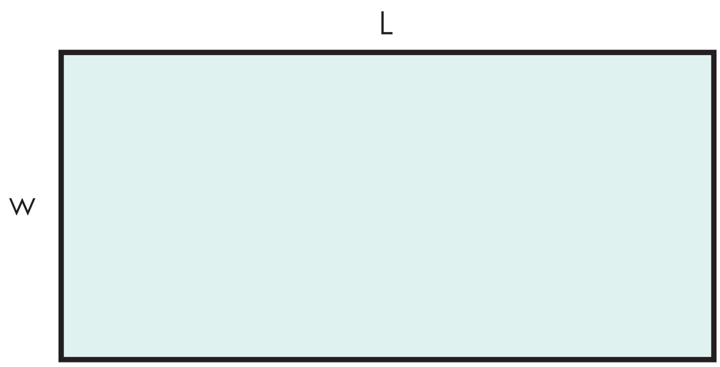


Figure 2.4 Rectangular carpet.

The unit of area is obtained as the product of units of length and width.

Table 2.3 shows some of the common derived units. Once base units have been defined for a system of measurement, you can derive other units from them. You do this by using the base units in equations that define other physical quantities. For example, area is defined as length times width. Therefore,

SI unit of area = (SI unit of length) × (SI unit of width)

From this, SI unit of area is meter × meter, or m^2. Similarly, speed is defined as the rate of change of distance with time; that is, speed = distance/time. Consequently,

$$\textbf{SI unit of speed} = \frac{\textbf{SI unit of distance}}{\textbf{SI unit of time}}$$

The SI unit of speed is meters per second (that is, meters divided by seconds). The unit is symbolized m/s or m s^{-1}. The unit of speed is an example of an SI derived unit, which is a unit derived by combining SI base units. ***Table 2.2*** displays a number of derived units. Volume and density are discussed in this section.

ii. Volume

? How can you calculate the volume of a rectangular box (***Figure 2.5***)?

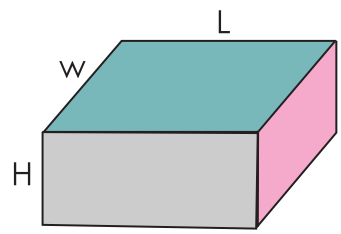


Figure 2.5 Rectangular box.

The volume can be found by combining three measurements of the same physical property (length) whose SI unit is the meter.

$$V = \text{length} \times \text{width} \times \text{height} = m \times m \times m = m^3$$

? Dear learner, can you define volume?

Volume is defined as length cubed and has the SI unit of cubic meter (m^3). This is too large a unit for normal laboratory work, so we use either cubic decimeters (dm^3) or cubic centimeters (cm^3, also written cc). Traditionally, chemists have used the liter (L), which is a unit of volume equal to a cubic decimeter. In fact, most laboratory glassware (***Figure 2.2***) is calibrated in liters or milliliters (1000 mL = 1 L). Because 1 dm equals 10 cm, a cubic decimeter, or one liter, equals (10 cm)3 = 1000 cm^3. Therefore, a milliliter equals a cubic centimeter. In summary, 1 L = 1 dm^3 and 1 mL = 1 cm^3.

This unit of volume- the cubic centimeter (1cm^3) is sometimes abbreviated as 1 cc. 1cm^3 (1cc) can be too small for describing large volumes of fluids (liquids and gases) used in laboratories and everyday life.

? What is the amount of oil your family uses in making 'wat' every month? Did you answer this question in cubic centimeter? I am sure you didn't. you probably said one , two, three liters?

For large volumes liter (L) can be used. A liter is defined as exactly 1000cm^3.
1 L= 1000 cm^3 = 10^3 cm^3

Table 2.3 Derived units.

Quantity	Definition of Quantity	SI unit
Area	Length squared	m^2
Volume	Length cubed	m^3
Density	Mass per unit volume	Kg/m^3
Speed	Distance travelled per unit time	m/s
Acceleration	Speed changed per unit time	m/s^2

Force	Mass times acceleration of object	Kg.m/s^2(= Newton,N)
Pressure	Force per unit area	Kg/(ms^2) (= Pascal, Pa)
Energy	Force times distance travelled	Kg.m^2/s^2(=Joule, J)

iii. Density

? Dear learner, how do you find density?

The density of an object is its mass per unit volume. You can express this as

$$d = \frac{m}{v}$$

where d is the density, m is the mass, and V is the volume. Suppose an object has a mass of 15.0 g and a volume of 10.0 cm^3. Therefore, the density will be

$$d = \frac{15.0\ g}{10.0\ cm^3} = 1.50\ g/cm^3$$

The density of the object is 1.50 g/cm^3

Density is an important characteristic property of a material. Water, for example, has a density of 1.000 g/cm^3 at 4 °C and a density of 0.998 g/cm^3 at 20 °C. Lead has a density of 11.3 g/cm^3 at 20 °C.

Density can also be useful in determining whether a substance is pure. Consider a gold bar whose purity is questioned. The metals likely to be mixed with gold, such as silver or copper, have lower densities than gold. Therefore, an adulterated (impure) gold bar can be expected to be far less dense than pure gold.

Example 2.2: Calculating the density of a substance

A colorless liquid, used as a solvent (a liquid that dissolve other substances), is believed to be one of the following (***Table 2.3***):

Table 2.3 Density of different liquids.

Substance	Density (in g/mL)
n-butyl alcohol	0.810
ethylene glycol	1.114
isopropyl alcohol	0.785
toluene	0.866

To identify the substance, Chaltu determined its density. By pouring a sample of the liquid into a graduated cylinder, she found that the volume was 35.1 mL. She also found that the sample weighed 30.5 g. What was the density of the liquid? What was the substance?

Solution

The solution to this problem lies in finding the density of the unknown substance. Once the density of the unknown substance is known, you can compare it to the list of known substances presented in the problem and look for a match. Density is the relationship of the mass of a substance per volume of that substance. Expressed as an equation, density is the mass divided by the volume: d = m/V.

You substitute 30.5 g for the mass and 35.1 mL for the volume into the equation.

$$d = \frac{m}{v} = \frac{30.5\ g}{35.1 mL} = 0.869\ g/mL$$

The density of the liquid equals that of toluene (within experimental error).

Answer Check: Always be sure to report the density in the units used when performing the calculation. Density is not always reported in units of g/ml org/cm^3, for example; gases are often reported with the units of g/L.

2.1.3 Common Prefixes Used in SI Units

Dear learner, the international system makes use of a series of prefixes like kilo (k) and milli (m) that may be applied to any unit. Each prefix multiplies its unit by some power of 10. The most important prefixes are listed in ***Table 2.5***. In this table the factor expressed as a factor to the power of ten, SI/ metric prefix, the symbol used and the actual decimal number are tabulated. They are widely used and are easy to add to the basic units. Like metric units, SI units are modified in decimal fashion by a series of prefixes, as shown in ***Table 2.5***. Measurements that we will utilize frequently in our study of chemistry include time, mass, volume, density, and temperature.

Table 2.5 SI/ Metric Units, Symbols and Numbers.

Factor	Prefix	Symbol	Decimal	Example
10^{12}	Tera	T	1,000,000,000,000	1 Terameter (Tm)= 1×10^{12} m
10^{9}	Giga	G	1,000,000,000	1 Gigameter (Gm)= 1×10^{9} m
10^{6}	Mega	M	1,000,000	1 Megameter (Mm)= 1×10^{6} m
10^{3}	Kilo	k	1,000	1 kilometer (km) = 1×10^{3} m
10^{2}	Hecto	h	100	1 hectometer (hm) = 1×10^{2} m
10^{1}	Deca	da	10	1 decameter (dam)= 1×10^{1} m
10^{-1}	Deci	d	0.1	1 decimeter (dm)= 1×10^{-1} m
10^{-2}	Centi	c	0.01	1 centimeter (cm) = 1×10^{-2} m
10^{-3}	Milli	m	0.001	1 millimeter (mm) =1×10^{-3} m
10^{-6}	Micro	μ	0.000 001	1 micrometer (μm) = 1×10^{-6} m
10^{-9}	Nano	n	0.000 000 001	1 nanometer (nm) = 1×10^{-9} m
10^{-12}	Pico	p	0.000 000 000 001	1 picometer (pm) = 1×10^{-12} m

Examples of SI prefixes

The SI prefixes/ metric prefixes are easily used as demonstrated by the few simple examples given below:

1 Megawatt = 1,000,000 watts; 1 kilogram = 1,000 grams and 1 μF = 1 microFarad = 1/1,000,000 Farad

Along with these the abbreviations or symbols can also be used. For example, kV for kilovolts, kW for kilowatts, and km for kilometer. The other symbols or abbreviations can be used in exactly the same manner.

2.1.4 Uncertainty in Measurements

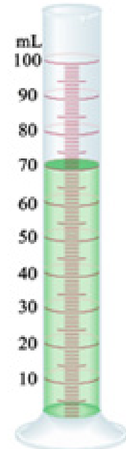


Figure 2.6 Volume of a liquid.

> ? What is the volume of a liquid in the measuring cylinder indicated in Figure 2.6? Would you please ask some of your friends (at least three) to read the volume of the liquid? Record their results. Is there a difference in the reading?

Dear learner, three people looking at the same cylinder might report the volume as 70.10 mL, 70.11mL or 70.12 mL. All three people would agree that it is 70.1 something mL, but might disagree about the something (the last digit). The last digit is uncertain, that is no one is sure about it. The uncertainty in a measurement is an estimate of how much larger of smaller another measurement of the same quantity in likely to be.

For example, the uncertainty in measuring the volume of a liquid show by the three people in my example is 0.01 mL, means any given measurement could be either 0.01 mL larger or 0.01 mL smaller. It is sometimes reported along with the value of the measurement itself as 70.11±0.01 mL. What was the uncertainty of the people you asked?

Activity 2.3

1. Make a chain of paper clips or other objects of uniform length. Then use a meter stick or ruler to measure a series of lengths on the chain. For example, measure sections containing one, two, three, etc., clips. Record your results.
2. Using laboratory scale, take several mass reading for one, two, three objects of uniform size. You can use any convenient objects you find in the laboratory. Record your results and write the report of your observation. Focus especially on the similarities and differences in your measurement. Did you find the same reading for the same object? What do you think are the cause of the uncertainties, if any?

Whenever you measure something, there is always some uncertainty. There are two categories of uncertainty: systematic and random.

1. Systematic uncertainties are those which consistently cause the value to be too large or too small. Systematic uncertainties include such things as reaction time, inaccurate meter sticks, optical parallax and miscalibrated balances. In principle, systematic uncertainties can be eliminated if you know they exist.

2. Random uncertainties are variations in the measurements that occur without a predictable pattern.

Dear learner, if you make precise measurements, these uncertainties arise from the estimated part of the measurement.

Random uncertainty can be reduced, but never eliminated. We need a technique to report the contribution.

The uncertainty shall rather be understood as an interval within which the result can be found with a given probability. Thus, the result will be within the interval but all values within the interval have the same probability to represent the result.

Except when all the numbers involved are integers (for example, in counting the number of students in a class), obtaining the exact value of the quantity under investigation is often impossible. For this reason, it is important to indicate the margin of error in a measurement by clearly indicating the number of significant figures, which are the meaningful digits in a measured or calculated quantity. When significant figures are used, the last digit is understood to be uncertain. For example, we might measure the volume of a given amount of liquid using a graduated cylinder (***Figure 2.7***) with a scale that gives an uncertainty of 0.1 mL in the measurement. If the volume is found to be 6.0 mL, then the actual volume is in the range of 5.9 mL to 6.1 mL. We represent the volume of the liquid as (6±0.1) mL. In this case, there is only two significant figures (the digit 6.0) that is uncertain by either plus or minus 0.1 mL. For greater accuracy, we might use a graduated cylinder that has finer divisions, so that the volume we measure is now uncertain by only 0.01 mL. If the volume of the liquid is now found to be 6.00 mL, we may express the quantity as (6.00± 0.01) mL, and the actual value is somewhere between 5.99 mL and 6.01 mL. We can further improve the measuring device and obtain more significant figures, but in every case, the last digit is always uncertain; the amount of this uncertainty depends on the particular measuring device we use and the user's ability.

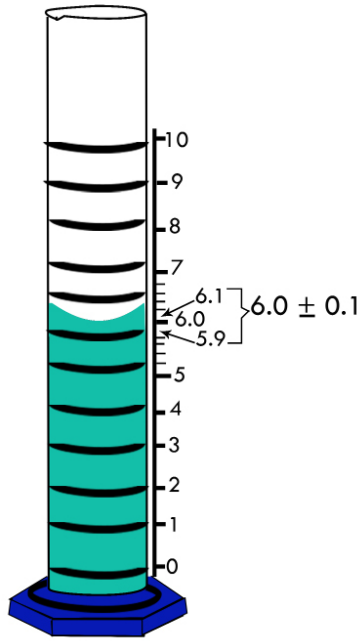


Figure 2.7 Uncertainty in volume measurement using a measuring cylinder.

Calculating uncertainties

Dear learner, there are several techniques that will produce an estimate of the uncertainty in the value of the mean. Since we are expecting students to produce an estimate of the uncertainty any suitable value that indicates half the range is acceptable.

Example 2.3: A learner measures the diameter of a metal canister using a ruler graduated in mm and records these results:

Table 2.6 Diameter of a metal canister Measurement result

Diameter/mm			
Reading 1	Reading 2	Reading 3	Mean
66	65	61	64

The uncertainty in the mean value (64 mm) can be calculated as follows:

a. Using the half range

The range of readings is 61 mm – 66 mm so half the range is used to determine the uncertainty.

Uncertainty in the mean diameter = (66 mm – 61 mm)/2 = 2.5 mm

Therefore, the diameter of the metal canister is 64 mm ± 2.5 mm.

Since a ruler graduated in mm could easily be read to ± 0.5 mm, it is acceptable to quote the uncertainty as ± 2.5 mm for this experiment.

b. Using the reading furthest from the mean

In this case, the measurement of 61 mm is further from the average value than 66 mm therefore we can use this value to calculate the uncertainty in the mean.

Uncertainty in the mean diameter = 64 mm – 61 mm = 3 mm.

Therefore, the diameter of the metal canister is 64 mm ± 3 mm.

c. Using the resolution of the instrument

This is used if a single reading is taken or if repeated readings have the same value. This is because there is an uncertainty in the measurement because the instrument used to take the measurement has its own limitations. If the three readings obtained above were all 64 mm then the value of the diameter being measured lies somewhere between 63.5 mm and 64.5 mm since a meter rule could easily be read to half a millimeter. In this case, the uncertainty in the diameter is 0.5 mm. Therefore, the diameter of the metal canister is 64 mm ± 0.5 mm. This also applies to digital instruments. An ammeter records currents to 0.1 A. A current of 0.36 A would be displayed as 0.4 A, and a current of 0.44 A would also be displayed as 0.4 A. The resolution of the instrument is 0.1 A but the uncertainty in a reading is 0.05 A.

The typical uncertainty of a top loading balance is 0.05 g. How would you report on weighing of 23.25 g made on this top loading balance? The result should be reported as 23.25 g ± 0.05 g. Such an item of data means that the correct reading lies between 23.20 g and 23.30 g.

The uncertainty in a measurement can be expressed in two useful ways:

a. as the absolute uncertainty in the last digit written
b. as the percent uncertainty calculated as follows

$$\% \text{ uncertainty} = \frac{\text{absolute uncertainty}}{\text{measurement}} \times 100$$

% uncertainty = (0.05 g)/(23.25 g) × 100 = 0.2%
Therefore the answer may be reported as:
Absolute uncertainty: 23.25 g ± 0.05 g
Percent uncertainty: 23.25 g ± 0.2%

2.1.5 Precision and Accuracy

Dear learner, measurements may be accurate, meaning that the measured value is the same as the true value; they may be precise, meaning that multiple measurements give nearly identical values (i.e., reproducible results); they may be both accurate and precise; or they may be neither accurate nor precise. The goal of scientists is to obtain measured values that are both accurate and precise.

If you repeat a particular measurement, you usually do not obtain precisely the same result, because each measurement is subject to experimental error. The measured values vary slightly from one another. Suppose you perform a series of identical measurements of a quantity. The term precision refers to the closeness of the set of values obtained from identical measurements of a quantity. Accuracy is a related term; it refers to the closeness of a single measurement to its true value.

Example 2.4: Precision and Accuracy

The archery targets in ***Figure 2.8*** show marks that represent the results of four sets of measurements.

a. a precise but inaccurate set of measurements.
b. an accurate but imprecise set of measurements.
c. a set of measurements that is both precise and accurate.

d. a set of measurements that is neither precise nor accurate.

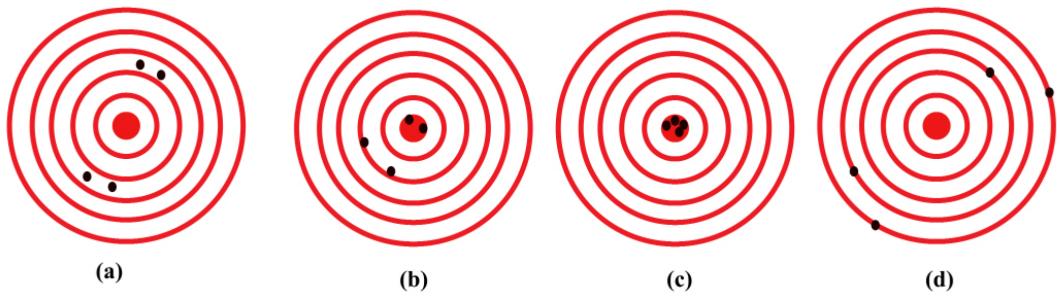


Figure 2.8 The distribution of darts on a dart board showing the difference between precise and accurate.

Activity 2.4

Time allocated for the activity: 10 minutes

Discuss and write a report of your conclusion.

1. Mohammed measured the mass of a sample of gold using one balance and found 1.896 g. On a different balance, the same sample was found to have a mass of 1.125 g. Which measurement was correct the first or the second measurement?

   Careful and repeated measurements made by Mohammed, including measurements on a calibrated third balance, showed the sample to have a mass of 1.895 g. The masses obtained from the three balances are in the ***Table 2.7***:

Table 2.7 Mass measurement

Balance 1	Balance 2	Balance 3
1.896 g	1.125 g	1.893 g
1.895 g	1.158 g	1.895 g
1.894 g	1.067 g	1.895 g

2.1.6 Significant Figures

Dear learner, the digits that are obtained as a result of a measurement are called significant figures. For example the measurements of a liquid in my example (70.10 mL, 70.11 mL, 70.12 mL) all have four significant figures.

Activity 2.5

Time allocated for the activity: 20 minutes

Look at the ***Figure 2.9*** and answer the question which follows.

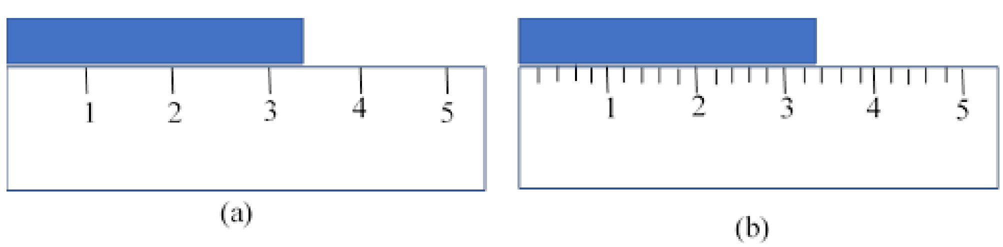


Figure 2.9 measuring length of a block of wood. Measuring of the length of the same block of wood with two different rulers.

1. A. What is the length of wood in diagram (a)?

   B. how many significant figures are there?
2. A. What is the length of the same block of wood measured with a ruler subdivided by additional graduations (diagram (b))?

   B. How many significant figures are there?

   C. Specify the digit you are not sure about?
3. What is the uncertainty in measuring the length of a block of wood in Figure (a) and (b)?
4. In which case do you have more uncertainty?
5. In which value of measurement do you have more confidence? Is that on the value of measurement with less or higher number of significant figure?

From ***Activity 2.4*** I hope you have noticed the importance of significant figures. They indicate to us the reliability of measurements. We can place more confidence in the value with the greater number of significant figures.

In general, the more significant figures there are in a measured quantity, the greater the precision of measurement. The term precision refers to how closely measurements of the same quantity come to each other.

In scientific measurement the most precise number is generally the most accurate. Accurate refers to how close the value of a measurement in to the true value.

Activity 2.6

Time allocated for activity: 5 minutes

Identify the most precise value of measurement in the following datas and give your answer in the blank space.

a. 75.2 lb	74.212 lb	75 lb	____________
b. 4.530 m	4.5 m	4.42 m	____________
c. 50 gal	50.06 gal	52 gal	____________

Dear learner, the following are guide lines for using siginificant figures. We must always be careful in scientific work to write the proper number of significant figures. In general, it is fairly easy to determine how many significant figures a number has by using the following rules:

1. Any digit that is not zero is significant. Thus, 845 cm has three significant figures, 1.234 kg has four significant figures, and so on.
2. Zeros between nonzero digits are significant. Thus, 606 m contains three significant figures, 40,501 kg contains five significant figures, and so on.
3. Zeros to the left of the first nonzero digit are not significant. Their purpose is to indicate the placement of the decimal point. For example, 0.08 L contains one significant figure, 0.0000349 g contains three significant figures, and so on.

4. If a number is greater than 1, then all the zeros written to the right of the decimal point count as significant figures. Thus, 2.0 mg has two significant figures, 40.062 mL has five significant figures, and 3.040 dm has four significant figures. If a number is less than 1, then only the zeros that are at the end of the number and the zeros that are between nonzero digits are significant. This means that 0.090 kg has two significant figures, 0.3005 L has four significant figures, 0.00420 min has three significant figures, and so on.

For numbers that do not contain decimal points, the trailing zeros (that is, zeros after the last nonzero digit) may or may not be significant. Thus, 400 cm may have one significant figure (the digit 4), two significant figures (40), or three significant figures (400). We cannot know which is correct without more information. By using scientific notation, however, we avoid this ambiguity. In this particular case, we can express the number 400 as 4×10^2 for one significant figure, 4.0×10^2 for two significant figures, or 4.00×10^2 for three significant figures.

A second set of rules specifies how to handle significant figures in calculations.
In addition and subtraction, the answer cannot have more digits to the right of the decimal point than either of the original numbers.
Consider these examples:

$$\begin{array}{rcl} 89.332 & & \\ \underline{+1.1} & \leftarrow & \text{one digit after the decimal point} \\ 90.432 & \leftarrow & \text{round off to 90.4} \\ 2.097 & & \\ \underline{-0.12} & \leftarrow & \text{two digits after the decimal point} \\ 1.977 & \leftarrow & \text{round off to 1.98} \end{array}$$

The rounding-off procedure is as follows. To round off a number at a certain point we simply drop the digits that follow if the first of them is less than 5. Thus, 8.724 rounds off to 8.72 if we want only two digits after the decimal point. If the first digit following the point of rounding off is equal to or greater than 5, we add 1 to the preceding digit. Thus, 8.727 rounds off to 8.73, and 0.425 rounds off to 0.43.

In multiplication and division, the number of significant figures in the final product or quotient is determined by the original number that has the smallest number of significant figures. The following examples illustrate this rule:

$$2.8\times4.5039=12.61092 \quad \rightarrow \quad \text{round off to 13}$$

$$\frac{6.85}{112.04} = 0.0611388789 \rightarrow \text{round off to 0.0611}$$

Keep in mind that exact numbers obtained from definitions (such as 1 ft, 12 in, where 12 is an exact number) or by counting numbers of objects can be considered to have an infinite number of significant figures.

Example 2.5 Significant figures

Determine the number of significant figures in the following measurements: (a) 394 cm, (b) 5.03 g (c) 0.714 m, (d) 0.052 kg, (e) 2.720×10^{22} atoms, (f) 3000 mL.

Solution: (a)Three, because each digit is a nonzero digit. (b) Three, because zeros between nonzero digits are significant. (c) Three, because zeros to the left of the first non zero digit do not count as significant figures. (d) Two. Same reason as in (c). (e) Four, because the number is greater than one, all the zeros written to the right of the decimal point count as significant figures. (f) This is an ambiguous case. The number of significant figures may be four (3.000×10^3), three (3.00×10^3), two (3.0×10^3), or one (3×10^3). This example illustrates why scientific notation must be used to show the proper number of significant figures.

2.1.7 Scientific Notation and Decimal Places

Dear learner, we use scientific notation when we deal with very large and very small numbers. For example, 197 grams of gold contains approximately 602,000,000,000,000,000,000,000 gold atoms.

The mass of one gold atom is approximately 0.000 000 000 000 000 000 000 327 gram. In using such large and small numbers, it is inconvenient to write down all the zeros. In scientific (exponential) notation, we place one nonzero digit to the left of the decimal.

$$602{,}000{,}000{,}000{,}000{,}000{,}000{,}000 = 6.02\times10^{23}$$

23 places to the left, therefore exponent of 10 is 23

$$0.000\ 000\ 000\ 000\ 000\ 000\ 000\ 327 = 3.27\times10^{-22}$$

22 places to the right, therefore exponent of 10 is -22.
The reverse process converts numbers from exponential to decimal form.

2.1.8. Conversion of units by the Factor Label Method

? How do you convert 2 m length into cm?

The factor label method uses the units associated with numbers as a guide in working out the calculations. It is based on the fact that the units associated with numbers undergo the same kind of mathematical operations of multiplication and division as the numbers themselves. The units are also canceled in the course of the calculations.

Firstly a conversion factor is constructed from a valid relationships between units. A conversion factor is a fraction that we use to convert a given quantity to a desired quantity by multiplication.

The general procedure of a one-step conversion by a factor-label method is:

(Given quantity)×(Conversion factor) = (Desired or requested quantity)
Conversion factors=(Units required)/(units given)

In most calculations the proper conversion factor that converts "given" to "requested" has the unit of what is given in the denominator (the old unit) and the unit of what is requested in the numerator (the new unit). In this way, the old unit cancels, as would an identical numerical quantity. This leaves the new unit in the numerator.

(given quantity)old unit × (conversion factors quantity) (new unit)/(old unit) = (requested quantity)new unit

The key, then, is to select the conversion factor that does the right job (that is the one that cancels the old unit).

Example 2.6. Unit conversion

Convert 4 m into centimeters.

Plan

Step 1: Given 4 m. Requested: __?___ cm.

Step 2: Procedure: use a conversion factor that cancels **m** and leaves **cm** in the numerator. We can sum up the procedure like this.

$$m \rightarrow cm$$

Step 3: Relationship: 1 m = 100 cm

Step 4: Conversion factor: two possible conversion factors originate from the above relationship, that is:1m/100cm and 100cm/1m. We need the one with cm (requested) in the numerator and m (given) in the denominator. That is 100 cm

Solution:

(Given quantity)×(Conversion factor) = (requested quantity)

i.e. 4m × (100cm/1m) = 400m

Example 2.6 Unit Conversions

The Ångstrom (Å) is a unit of length, 1×10^{-10} m,that provides a convenient scale on which to express the radii of atoms. Radii of atoms are often expressed in nanometers. The radius of a phosphorus atom is 1.10 Å. What is the distance expressed in centimeters and nanometers?

Plan

We use the equalities 1 Å= 1×10^{-10}m, 1 cm = 1×10^{-2} m, and 1nm = 1×10^{-9} m to construct the unit factors that convert 1.10 Å to the desired units.

Solution: Let x be the length in cm unit and y the length in nm.

$$x\ cm = 1.10\ {}^0A \times \frac{1 \times 10^{-10}\ m}{1{}^0A} \times \frac{1cm}{1 \times 10^{-2}\ m} = 1.10 \times 10^{-8}\ cm$$

$$y\ nm = 1.10\ {}^0A \times \frac{1 \times 10^{-10}\ m}{1{}^0A} \times \frac{1nm}{1 \times 10^{-9}\ m} = 1.10 \times 10^{-1}\ nm$$

Checklist 2.1

Dear learner, check yourself on the following aspects before wrapping up studying this section. Put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it, in the table given below. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
list the basic SI units and their symbols?		
give examples of derived units?		
recall the formula relating Celsius and Fahrenheit temperature scales?		
recall how to convert Celsius to Kelvin?		
differentiate between precision and accuracy?		
use the factor label method for connecting a measurement in one unit to another?		

Self-Test Exercise 2.1

1. When the absolute temperature is 400 K, what is the Fahrenheit temperature?
2. A piece of metal wire has a volume of 20.2 cm^3 and a mass of 159 g. What is the density of the metal? We know that the metal is manganese, iron, or nickel, and these have densities of 7.21 g/cm^3, 7.87 g/cm^3, and 8.90 g/cm3, respectively. From which metal is the wire made?
3. Absolute uncertainty and percent uncertainty in a single reading: Use the given uncertainty to calculate the % uncertainty in each of the following readings and report the result of measurement in terms of absolute uncertainty and percent uncertainty:
   a. A barometer reading of 723.5 torr. The absolute uncertainty is 0.1 torr
   b. 2.75 g weighed on a top loading balance. The absolute uncertainty is 0.05 g
   c. 2.7413 g weighed on an analytical balance. The absolute uncertainty is 0.0002 g
   d. A temperature reading of 75.6 °C on a thermometer graduated to the nearest degree. The absolute uncertainty is 0.2 °C
   e. 18.6 ml measured in 100 ml graduated cylinder. The absolute uncertainty is 0.4 mL
   f. 43.7 ml measured in 100 ml graduated cylinder. The absolute uncertainty is 0.4 mL
4. a. A 2-carat diamond has a mass of 400.0 mg. When a jeweler repeatedly weighed a 2-
   b. carat diamond, he obtained measurements of 450.0 mg, 459.0 mg, and 463.0 mg. Were
   c. the jeweler's measurements accurate? Were they precise? A single copper penny was tested three times to determine its composition. The first analysis gave a composition of 93.2% zinc and 2.8% copper, the second gave 92.9% zinc and 3.1% copper, and the third gave 93.5% zinc and 2.5% copper. The actual composition of the penny was 97.6% zinc and 2.4% copper. Were the results accurate? Were they precise?

5. Determine the number of significant figures in each of the following measurements:
   a. 35 mL
   b. 2008 g
   c. 0.0580 m^3
   d. 7.2×10^4 molecules
   e. 830 kg.
6. Arithmetic operations: Carry out the following arithmetic operations to the correct number of significant figures:
   a. 11,254.1 g + 0.1983 g
   b. 66.59 L – 3.113 L
   c. 8.16 m × 5.1355cm.
   d. 0.0154 kg ÷ 88.3 mL
   e. 2.64×10^3 cm + 3.27×10^2 cm
7. a. Add 37.24 mL and 10.3 mL.
   b. Subtract 21.2342 g from 27.87 g.
8. What is the area of a rectangle 1.23 cm wide and 12.34 cm long?
9. Assuming a phosphorus atom is spherical; calculate its volume in Å^3, cm^3, and nm^3. The formula for the volume of a sphere is $V = \frac{4}{3}\pi r^3$. Refer example above for radius of phosphorous atom.
10. State the number of significant figures in the following quantities.
    a. 2.009 g of silver ______________
    b. 0.0200 s ______________
    c. 2.00×10^2 mL of water ______________
    d. 0.0023 °C ________________
11. The masses of Cu, Zn, and Mn in a sample of alloy were measured as 2.011 g, 1.02 g and 1.4 g respectively. What is the total mass of the alloy? _______________
12. To how many significant figures should the result of the following calculation, be reported? (0.08206×(273.15+1.2))/(1.23×7.004)
13. Round off the following numbers to the significant figures indicated in the bracket
    a. 40.234 (3 significant figures)____________
    b. 2.85 (2 significant figures) ____________
    c. 10.67 (3 significant figures) ____________
    d. 45.56(2 significant figures) ____________
    e. 46.4(2 significant figures) ____________

Section 2.2: Chemistry as Experimental Science

- Dear learner, suppose you are going by bus. The engine of the bus suddenly stops. How does a mechanic solve this problem? First, the mechanic tries to find the cause of the problem by observing the results of one or more tests. Next, a suspect part is replaced or adjustments are made to the engine, and then he tries to start the bus. If the mechanic is correct in judging the cause of the problem, then job done. If not, other tests are performed and repairs made until the bus is finally starts to properly work.

Learning competencies

At the end of this section, you should be able to

- Define scientific method.
- Describe the major steps of the scientific method.
- Use scientific methods in solving problems.
- Demonstrate some experimental skills in chemistry.
- Describe the procedures of writing laboratory report.

Chemistry is largely an experimental science, and a great deal of knowledge comes from laboratory research. In addition, however, today's chemist may use a computer to study the microscopic structure and chemical properties of substances or employ sophisticated electronic equipment to analyze pollutants from auto emissions or toxic substances in a soil. Many frontiers in biology and medicine are currently being explored at the level of atoms and molecules the structural units on which the study of chemistry is based.

Chemists participate in the development of new drugs and in agricultural research. What's more, they are seeking solutions to the problem of environmental pollution along with replacements for energy sources. And most industries, whatever their products, have a basis in chemistry. For example, chemists developed polymers (very large molecules) that manufacturers use to make a wide variety of goods, including clothing, cooking utensils, artificial organs, and toys.

Chemistry is evidence based. All chemical statements are based on experiment. Chemistry is part of the body of modern science. It shares the experimental method of all sciences. It improves in time also using new discoveries and concepts from other sciences. In turn, it provides both theoretical and experimental tools to different sciences. Biology and Geology cannot be studied without a thorough understanding of chemical phenomena. Indeed, because of its diverse applications, chemistry is often called the "central science."

2.2.1 The Scientific Method

Activity 2.7

Time allocated for the activity _ 10 minutes. Conduct the following activity.

a. Collect a plastic bag filled with different items provided by your teacher.
b. Decide on the question you would like to answer about your bag. Write it down. (Do not open the bag)
c. Guess what the answer to your question might be. Write down. (Do not open the bag)
d. Open your bag and answer the questions.
e. Be sure to count the total number of items. Now, discuss which part of the activity (a, b, c, d, or e) introduces the scientific terminology: hypothesis, data collection, experimentation, etc.

Dear learner, when we approach a problem in science, we use a scientific method. It proceeds in much the same way as the activity of the mechanic described above. Scientific method is defined as a systematic process of scientific investigation. It involves a series of steps. The first step is collection of data by making observations and measurements on a small sample of matter. When a pattern is observed in a series of data, it is summarized in a scientific law. A scientific law is statement that clearly summarizes facts that come from many observations. In the next step you develop a hypothesis. A hypothesis is a tentative explanation of this law that can be tested by experiments. To form hypothesis, requires insight (understanding), imagination, and creativity.

If the results of repeated experiments support the hypothesis, then we create a theory, a formal explanation of a law. Theories always serve as guides to new experiments and are constantly being tested. If theory is proved to be incorrect by experiments it must either be abandoned in favour of a new or be modified so that all the experimental observations can be explained. Chemistry develops, therefore, by a process of theory and experiment.

What is Scientific Method? The Scientific method is a process with the help of which scientists try to investigate, verify, or construct an accurate and reliable version of any natural phenomena. They are done by creating an objective framework for the purpose of scientific inquiry and analyzing the results scientifically to come to a conclusion which either supports or contradicts the observation made at the beginning.

Scientific Method Steps

Dear learner, the aim of all scientific methods is the same, that is, to analyze the observation made at the beginning but there are various steps adopted as per the requirement of any given observation. However, there is a generally accepted sequence of steps of scientific methods as it is shown in ***Figure 2.10.***

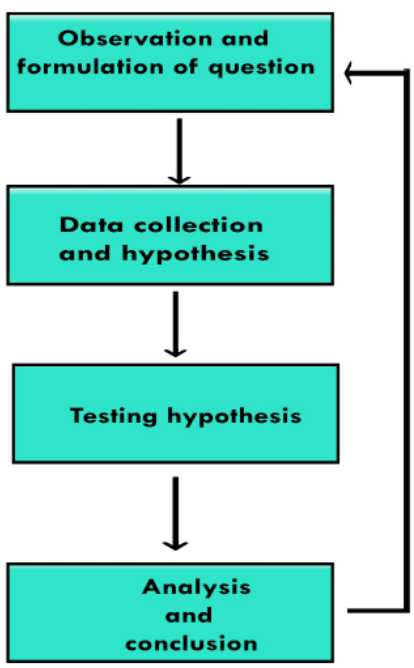


Figure 2.10 The four main steps of the research process in studying chemistry and their relationships.

i. **Observation and formulation of a Question:** This is the first step of a scientific method. In order to start one, an observation has to be made into any observable aspect or phenomena of the universe and a question needs to be asked pertaining to that aspect. For example, you can ask, "Why is the sky black at night? or "Why is air invisible?"

Many of our observations of the physical properties of different substances such as their color, smell or physical condition are **qualitative**. We use our own judgement to decide if something is green, sweet or bad smelling, big or small rough or smooth. We don't measure any thing. **Qualitative observation** of what happens when two chemicals, say sodium and chlorine, are mixed. You focus on the changes in color smell, and whether the reaction is vigorous or not. But to discover the specific amount of sodium and chlorine reacted, you will need to make **quantitative observation**.

Advances in science often depend on quantitative observation. **Quantitative observations** themselves depend on the measurements and the reporting of **numerical information**. A key part of any measurement is the units in which the quantity is measured.

ii. **Data Collection and Hypothesis:** The next step involved in the scientific method is to collect all related data and formulate a hypothesis based on the observation. The hypothesis could be the cause of the phenomena, its effect, or its relation to any other phenomena.

iii. **Testing the Hypothesis:** After the hypothesis is made, it needs to be tested scientifically. Scientists do this by conducting experiments. The aim of these experiments is to determine whether the hypothesis agrees with or contradicts the observations made in the real world. The confidence in the hypothesis increases or decreases based on the result of the experiments.

iv. **Analysis and Conclusion:** This step involves the use of proper mathematical and other scientific procedures to determine the results of the experiment. Based on the analysis, the future course of action can be determined. If the data found in the analysis is consistent with the hypothesis, it is accepted. If not, then it is rejected or modified and analyzed again.

It must be remembered that a hypothesis cannot be proved or disproved by doing one experiment. It needs to be done repeatedly until there are no discrepancies in the data and the result. When there are no discrepancies and the hypothesis is proved beyond any doubt, it is accepted as a 'theory'.

2.2.2 Some Experimental Skills in Chemistry

Laboratory Safety Rules

Dear learner, in your day-to-day activity you may have observed that people get accidents because of not following proper safety precaution. In the home, the kitchen and bathroom are the sites of most accidents. The chemical laboratory poses similar hazards and yet it can be no more dangerous than any other classroom if the following safety rules are always observed. Most of them are based on simple common sense.

Dear learner, if you get a chance of doing experiments in the laboratory it is mandatory to follow the following safety rules. Having Responsible behavior is essential. The dangers of spilled acids and chemicals and broken glassware created by thoughtless actions are too great to be tolerated. Wear approved eye protection at all times in the laboratory and in any area where chemicals are stored or handled. The only exception is when explicit instructions to the contrary are given by your teacher.

1. Perform no unauthorized experiments. This includes using only the quantities instructed, no more. Consult your teacher if you have any doubts about the instructions in the laboratory manual.
2. Do not smoke in the laboratory at any time. Not only is smoking a fire hazard, but smoking draws chemicals in laboratory air (both as vapours and as dust) into the lungs.
3. In case of fire or accident, call the teacher at once. Note the location of fire extinguishers and safety showers now so that you can use them if needed.
4. Report all injuries to your instructor at once. Except for very superficial injuries, you will be required to get medical treatment for cuts, burns, or fume inhalation.
5. Do not eat or drink anything in the laboratory. Avoid breathing fumes of any kind. Never use mouth suction in filling pipets with chemical reagents. Always use a suction device.
6. Never work alone in the laboratory. There must be at least one other person present in the same room. In addition, your teacher should be quickly available.
7. Wear shoes in the laboratory. Bare feet are prohibited because of the danger from broken glass. Sandals are prohibited because of the hazard from chemical spills. Confine long hair and loose clothing (such as ties) in the laboratory. They may either catch fire or be chemically contaminated.
    a. A laboratory apron or lab coat provides protection at all times. A lab apron or lab coat is required when you are wearing easily combustible clothing (synthetic and light fabrics).
    b. It is advisable to wear old clothing to laboratory, because it is both generally not as loose and flammable as new clothing, and not as expensive to replace.
8. Be careful when heating liquids; add boiling chips to avoid “bumping”. Flammable liquids such as ethers, hydrocarbons, alcohols, acetone, and carbon disulfide must never be heated over an open flame.
9. Always pour acids into water when mixing. Otherwise the acid can spatter, often quite violently. Pour acid into water.
10. Do not force a rubber stopper onto glass tubing or thermometers. Lubricate the tubing and the stopper with glycerol or water. Use paper or cloth towelling to protect your hands. Grasp the glass close to the stopper.
11. Dispose of excess liquid reagents by flushing small quantities down the sink. Consult the teacher about large quantities. Dispose of solids in crocks. Never return reagents

to the dispensing bottle.

12. Carefully read the experiment and answer the questions in the prelab before coming to the laboratory. An unprepared learneris a hazard to everyone in the room.

13. Spatters are common in chemistry laboratories. Test tubes being heated or containing reacting mixtures should never be pointed at anyone. If you observe this practice in a neighbour, speak to him or her or the teacher, if needed.

14. If you have a cut on your hand, be sure to cover with a bandage or wear appropriate laboratory gloves.

15. Finally, and most important, think about what you are doing. Plan ahead. Do not cookbook. If you give no thought to what you are doing, you predispose yourself to an accident.

Do you have any diagnosed allergies or other special medical needs (check one)?
Yes________ No___________

If yes, please list them in this space. I have read and understand the Laboratory Safety Rules and have retained a copy for my reference.

_______________________________________ ___________________

(Name) (Date)

The first and foremost rule of any laboratory is to be safe! This may seem obvious, but people often disregard safety protocols for one reason or another, putting themselves and those around them in danger. The best thing you can do is to make sure you follow all safety protocols at all times.

Safety goggles are required wear in all chemistry labs. Not wearing them puts you in danger of eye irritation and possibly blindness in the case of an accident.

A small droplet of acid could splash out of the container at any time. Better safe than permanently blinded! Latex gloves should be used when there is a possibility of corrosive chemicals spilling onto your hands. A lab apron or coat can also prevent injury in case of spills or splashes.

A beaker is a common container in most labs. It is used for mixing, stirring, and heating chemicals. Most beakers have spouts on their rims to aid in pouring. They also commonly have lips around their rims and markings to measure the volume they contain, although they are not a precise way to measure liquids. Beakers come in a wide range of sizes.

Because of the lip that runs around the rim, a lid for a beaker does not exist. However, a watch glass can be used to cover the opening to prevent contamination or splashing. ***Figure 2.11*** shows some of the commonly used laboratory equipments.

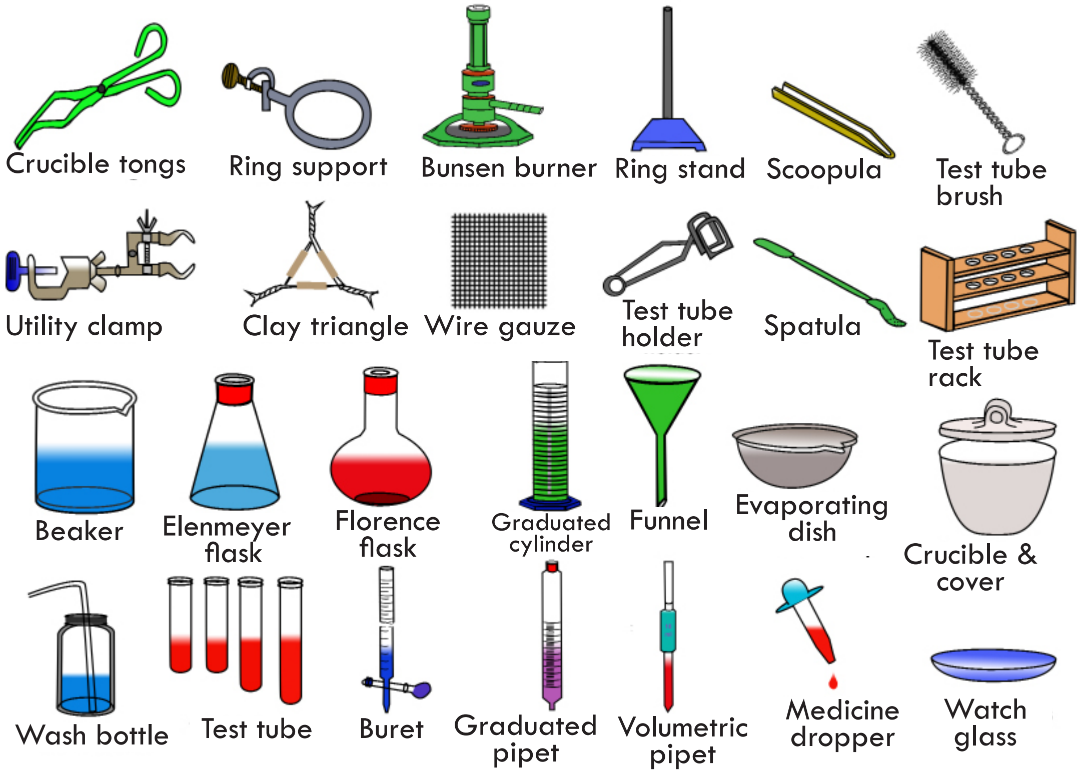


Figure 2.11 Commonly used Laboratory Equipment.

Activity 2.8

Time allocated for this activity 10 minutes

Conduct the following activity.

a. Write the names of the laboratory equipments in chemistry laboratory of your nearby school.

b. List down laboratory equipment you know and that are not shown in ***Figure 2.11***. Describe their use. Which of them are used for measurement?

2.2.3 Writing a Laboratory Report

A. The Pre-laboratory Report

Dear learner, each experiment in this manual includes a pre-laboratory (prelab) report. The prelab report is to be completed before the experiment is begun in the laboratory. Its purpose is to ensure familiarity with the procedure and provide for a more efficient utilization of limited laboratory time. The prelab questions can be answered after a careful reading of the introduction and procedure of the experiment. Sample calculations are sometimes included to provide awareness of data that needs to be collected and how it is treated. Your teacher may prefer to administer prelab quizzes instead of collecting prelab reports.

B. The Laboratory Report

A good laboratory report is the essential final step in performing an experiment. It is in this way that you communicate what you have done and what you have discovered. Since it is the only means, in many instances, of reporting results, it is important that it be prepared properly.

A laboratory report is a final draft. As such it is always written in ink or typed. A typed laboratory report is necessary if your handwriting is hard to read. There must be no erasures or crossed out areas. The initial draft of a laboratory report belongs in your laboratory notebook for two reasons.

1. It is unlikely that you will get everything correct on the first attempt and, thus, a first draft written on the report form itself could be very messy.
2. If the report itself is lost or destroyed, you can easily and quickly rewrite the report from the notebook.

It is essential that a laboratory report be neat. Studies have shown that when the same work is submitted in both neat and sloppy form, the neat version makes the better impression. Neat work indicates that the writer knows and cares about the subject matter.

All data should be presented with the correct significant figures and units. The omission of units makes it difficult for the reader to know the size of the numbers being reported. And writing down the wrong number of significant figures amounts to lying about the precision of the data. Too many significant figures imply that you know a number more precisely than you actually do. All questions should be answered with complete and grammatically correct sentences.

Abbreviations should not be included in written answers. Read the sentence out loud to make sure that it makes sense.

Your sample computations should be labeled with their purpose, for example; "mass of the liquid". Within the computation, all numbers must have the correct units and the correct number of significant figures.

Laboratory reports that extend to more than one page should either be stapled together or have your name and the page number at the top right of each page. For example: Terhas Asgedom, page 2 of 4 pages. This makes it more difficult for the instructor to inadvertently misplace pages. Using a paper clip or tearing corners to hold pages together is not acceptable. Reports should also be dated.

Graphs

Graphs are used to present the data in picture form so that they can be more readily grasped by the reader. Occasionally, a graph is used to follow a trend. Notice that the best smooth curve is drawn through the data points. This is not the same as connecting the dots; all of the data points will not fall on the line. Often, however, a graph is used to show how well data fit a straight line. The line drawn may either be visually estimated ("eyeballed") or computed mathematically. There are many essential features of a good graph.

1. The axes must be both numbered and labeled. The abscissa is the right-to-left or the horizontal axis or x-axis.
2. The graph must have a title. When we speak of graphing, we always mention the quantity plotted on the ordinate first.
3. The data points are never graphed as little dots. One may use small circles, small circles with a dot inside, crosses, asterisks, or X's. If dots are used, data are too easily lost on the graph or "created" by stray blobs of ink.

4. Any lines that appear on the graph in addition to data points should be explained. Thus, the line drawn is explained in the title as "(visually estimated best straight line)."
5. The scales of the axes should be adjusted so that the graph fills the page as much as possible.

Measurements and Density

Dear learner, chemistry is very much an experimental science in which careful and accurate measurements are the very essence of meaningful experimentation. It is, therefore, essential for the beginning learnerto learn how scientific measurements are carried out properly through the use of common measuring instruments. It is equally important for the learnerto acquire an appreciation of the significance of measurements and to apply learned technique to a common specific experiment.

In the following experiment you will become familiar with how mass and volume measurements are carried out and how an evaluation of the measurements is reflected in the number of significant figures recorded. These mass and volume measurements will then be used to determine the density of (1) a metal bar and (2) a salt solution by two different methods. Finally, the results of the density measurements will be evaluated with respect to their precision and accuracy.

The density of an object is one of its most fundamental and useful characteristics. As an intensive property it is independent of the quantity of material measured since it is the ratio of the mass of an object to its volume. The density of an object can be determined by a variety of methods. In this experiment you will practice using a balance to measure mass. In addition, you will learn how to measure volume using a graduated cylinder and a pipet and learn how to calibrate the pipet. A comparison of the results allows for the calculation of the relative average deviation, which is a measure of the precision of the experiment.

Also, in the case of the metal bar, the results of measuring the density of the bar may be compared with the accepted density value for the bar. Thereby the relative error (a measure of accuracy) for the density of the bar may be determined. The sections in the Introduction to this laboratory manual pertaining to precision, accuracy, significant figures, and the laboratory notebook should be studied carefully before performing this experiment.

Materials and Chemicals

Cylindrical metal bars (Al, Cu, brass), approximately 51 cm (diameter), measuring rules (graduated in mm), 20or 25 mL transfer pipets, 50 mL beaker, graduated cylinders (10 and 50 mL or 100 mL), 125 mL Erlenmeyer flask, stopper, thermometers, and balances with precision to 1 mg. Saturated salt solutions ($NaCl$ and/or KCl are convenient) – about 36 g $NaCl$ is required/100 mL. Estimated Time: 2-3 hours

Safety Precautions

Review the safety rules. Take special care in inserting the bar into the graduated cylinder. Do not drop it in! The glass cylinder may break. Pipeting should always be done using a suction device. Never suction by mouth.

Procedures

Record all measurements in your laboratory notebook in ink. The proper use of a sensitive balance is critical to useful mass measurements. Also, pipeting is a very useful, accurate, and common method for transferring exact volumes of liquids.

Therefore, the instructor should demonstrate good balance and pipet techniques to the class at the beginning of the laboratory period. Please note that when a portion of the experiment contains the instruction "Repeat . . . twice," each portion is to be performed all the way through three times: initially and two repetitions.

Part I: Measurements

A. Mass Measurements

After balance instruction, you will be assigned or allowed to select a balance for use during the experiment.

1. Zero the balance after cleaning the pan.
2. Measure the mass of a clean dry 50 mL beaker to the nearest ±0.001 g.
3. Record, in ink, your observation directly into the lab notebook.
4. Remove the beaker from the pan. Again, clean the balance pan and zero the balance.
5. Weigh the same beaker as before (step 2) and record the result.
6. Repeat steps 4 and 5 one more time.
7. From the three mass measurements, calculate the average mass of the beaker.
8. Repeat steps 4 and 5 using a second balance (just one weighing).
9. Repeat steps 4 and 5 using a third balance (just one weighing).

B. Volume Measurements

Use of a pipet: In order to accurately measure a liquid volume using a pipet, you must consider several things. Most volumetric pipets are designed to deliver rather than to contain the specified volume. Thus, a small amount of liquid remains in the tip of the pipet after transfer of liquid. This kind of pipet is marked with the letters "TD" somewhere on the barrel above the calibration line. Also, for purpose of safety, never pipet by mouth; that is, never use your mouth to draw liquid into the pipet. Always use a suction device.

Use a clean but not necessarily dry 20 or 25 mL pipet. Rinse the pipet several times with small portions of the liquid to be transferred. To measure the desired volume, a volume of liquid greater than that to be measured is needed in order to keep the pipet tip under the liquid surface while filling.

While holding the pipet vertically, squeeze the air out of the suction device and hold it against the large end of the pipet, tight enough to obtain a seal. Keep the suction device evacuated and dip the pipet tip below the surface of the liquid, but do not touch the bottom of the container (A chipped tip causes error). Now release the suction device gently and allow liquid to fill the pipet until it is one to two cm above the calibration line etched onto the upper barrel. Quickly remove the suction device and cover the end with your index finger before the liquid level falls below the line (some practice may be necessary). Wipe the outside of the tip with a clean piece of towel or tissue. With the tip touching the wall of the source container above the liquid level, allow it to drain until the meniscus rests exactly on the line. Now hold the pipet over the sample container and allow it to drain, but be careful to avoid loss from splashing.

When the swollen part of the pipet is nearly empty, touch the tip to the wall of the container and continue draining. When the liquid level falls to the tip area, hold the tip to the glass for an additional 20 seconds and then remove. Do not blow out the remaining liquid.

1. Measure the temperature in the laboratory. Your teacher will provide you with the density of water at this temperature.
2. Use the same 50 mL beaker from Section A for determining the mass of each aliquot of water. Rather than re-weighing the empty beaker, the average mass of the beaker determined in Section A may be used as the mass of the dry beaker.
3. Measure 20 or 25 mL of water (depending on the size of pipet available) into the 50 mL beaker.
4. Record the volume of water measured with the pipet to the appropriate number of significant figures.
5. Record the number of significant figures in the volume measurement.
6. Weigh the beaker and water to the nearest mg (±0.001 g).
7. Calculate the mass of water in the beaker.
8. Use the mass and density of water to determine the volume of water measured.
9. Repeat steps 3 – 8 using a 50 or 100 mL graduated cylinder instead of the pipet to measure the 20 or 25mL of water. Repeat steps 3 – 8 again using a graduated 50 mL beaker to measure the water.

PART II: Density

A. Density of a Metal Bar (Use the same metal bar for all trials.)

1. Zero your balance. Weigh a metal bar on a balance sensitive to the nearest mg (±0.001 g).Repeat the entire weighing operation twice. Do not allow the first measurement that you obtain to influence subsequent measurements that you make. Make sure you zero the balance before proceeding with each measurement.
2. Determine the volume of the metal bar by each of the following methods, making at least three measurements for each method. Do not allow the first measurement to influence subsequent measurements as your data will then be less significant for the purpose of measuring the precision of this experiment.

Method I

Insert the bar into a graduated cylinder filled with enough water so that the bar is immersed. Note and record as precisely as possible the initial water level, and the water level after the bar is immersed. Read the lowest point of the meniscus in determining the water level and estimate the volume to one digit beyond the smallest scale division. Discard the water and repeat this measurement twice with a different initial volume of water. Calculate the average density of the bar.

Method II

Measure the dimensions of the bar with a measuring stick ruled in centimetres. Repeat these measurements twice. Calculate the volume of the bar from these dimensions. Because the bar is cylindrical in shape, note that the formula for the volume of a cylinder should be used ($V= \pi r^2 h$).Calculate the average density of the bar.

3. For each method, determine the relative error of your result comparing it with the accepted value as provided by your instructor or as found in a reference such as the Handbook of Chemistry and Physics.

Which one of the two methods is more accurate? Explain.

B. Density of a Salt Solution

1. Weigh a 125 mL Erlenmeyer flask and stopper. With a clean 20.00 or 25.00 mL volumetric pipet, pipet the salt solution into the flask and reweigh. Repeat this measurement twice, with a different sample of the same solution. Calculate the average density of the salt solution.
2. Weigh an empty, dry 10 mL graduated cylinder. Fill with about 9-10 mL of salt solution, record the volume as precisely as possible, and reweigh. Repeat this measurement twice, with a different sample of solution each time. Calculate the average density of the salt solution.
3. For each method determine the relative average deviation of your results. Which method is more precise? Explain.

Disposal

Salt solutions: Do one of the following, as indicated by your teacher.

a. *Recycle*: Return the salt solution to its original container.
b. *Treatment/disposal:* Dilute the salt solution 1:10 with tap water and flush down the sink with running water.
c. *Disposal*: Put the salt solution in a waste bottle labeled inorganic waste.

Report

Name ______________________ **Section** _________

Questions

1. From your data, calculate the volume occupied by 100 g of the following:
   b. salt solution
   c. metal bar
2. From your answers to question 1 determine whether the metal bar or the salt solution occupies the larger volume. Explain your answer in the context of the densities of solids and liquids in general.
3. Define the terms precision and accuracy in such a way as to distinguish between them.
4. Are your results for the metal bar more precise or more accurate? Explain.
5. From your data for the salt solution, evaluate the two methods in terms of their precision. Which method should lead to greater precision? Which method actually is more precise? Explain.

Prelab

Measurements and Density

The following data were obtained in order to determine the density of a cylindrical metal bar.

Trial 1	1	2	3
Height (cm)	6.50	6.45	6.44
Diameter (cm)	1.25	1.26	1.22
Mass (g)	46.683	46.332	47.014

In the following calculations on this data, show the formula used, the substituted numbers, and the result.

1. Calculate the average density of the bar.
2. Calculate the percent relative average deviation of the measurements.
3. If the accepted value for the density of the bar is 6.70 g/cm^3, what is the percent relative error?
4. Are these measurements more precise or more accurate? Explain.
5. What is the purpose of repetition in measurements?

Self-Test Exercise 2.2

1. Classify the following observations as qualitative or quantitative
   a. The chalk I am using for writing has white color _______________
   b. The mass of the chalk I am using for writing is 5 grams_______________
   c. Lemon juice has sour test____________________
2. The following data were obtained in order to determine the density of a cylindrical metal bar.

Trial 1	1	2	3
Height (cm)	6.50	6.45	6.44
Diameter (cm)	1.25	1.26	1.22
Mass (g)	46.683	46.332	47.014

In the following calculations on this data, show the formula used, the substituted numbers, and the result.

   a. Calculate the average density of the bar.
   b. Calculate the percent relative average deviation of the measurements.
   c. If the accepted value for the density of the bar is 6.70 g/cm^3, what is the percent relative error?
   d. Are these measurements more precise or more accurate? Explain.
   e. What is the purpose of repetition in measurements?

Check List 2.2

Dear learner, check yourself on the following aspects before wrapping up studying this section. Put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it, in the table given below. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
define scientific method?		
describe the major steps of the scientific method?		
differentiate what qualitative and quantitative observation mean?		
demonstrate mass and volume measurement skills in chemistry?		
describe the procedures of writing laboratory report?		

Unit Summary

The International System (SI) uses a particular selection of metric units. It employs seven base units combined with prefixes to obtain units of various sizes. Units for other quantities are derived from these.

To obtain a derived unit in SI for a quantity such as the volume or density, you merely substitute base units into a defining equation for the quantity.

SI units are used to express physical quantities in all sciences, including chemistry.

Scientific notation helps us handle very large and very small quantities. Most measured quantities are inexact to some extent.

The number of significant figures indicates the exactness of the measurement.

Accuracy is defined as how closely a measured value agrees with the correct value. Precision is defined as closely repeated measurements of the same quantity agree with one another.

Chemistry is an experimental science in that the facts of chemistry are obtained by experiment.

The scientific method is a systematic approach to research that begins with the gathering of information through observation and measurements. In the process, hypotheses, laws, and theories are devised and tested.

The key to significance in experimental measurements is repetition. Only with repeated measurements of the density, concentration, or other quantities can the experimenter have some confidence in the significance of measurements.

Self-Assessment Exercise

Indicate True or False for the following Statements.

1. There is always a degree of uncertainty involved with every measurement.
2. Multiplication of 36,000 and 52.00 give the significant value 1872.000.
3. There are four significant numbers in 70.03.
4. While adding or subtracting a quantity, the answer contain no more decimal places than the least accurate measurement.
5. The significant figures in a number include all of the certain digits plus one doubtful digit.
6. In the following expression 0.01208 0.0236 , the answer should be reported up to four decimal places.
7. It is desirable for the sides of a graduated cylinder to be perfectly vertical.

Part II: Intermediate Level Questions.

For each question, four alternative choices are given, of which only one is correct. You have to select the correct alternative and mark it in the appropriate option.

8. Calculate the following using proper number of significant figures: (20.035×0.03120)/(4×0.333)
   a. 0.47
   b. 0.40
   c. 0.469
   d. 0.4692
9. A sample of nickel weighs 7.5425 g and has a density of 8.8 g/cm^3. What is the volume with the correct number of significant figures?
   a. 1.33 cm^3
   b. 9.2 cm^3
   c. 0.86 cm^3
   d. None o f the above
10. The mass of copper is 0.063546 kg and the density is 8.940 g/cm^3. Calculate the volume using scientific figures.
    a. 7.108 cm^3
    b. 7.10 cm^3
    c. 7.1080 cm^3
    d. 7.1 cm^3
11. Which of the following statements are correct for a burette?
    a. The burette is designed to accurately deliver a volume of liquid
    b. The burette is used for measuring the volume of liquid used from the burette
    c. The burette volume can be measured to the hundredths place
    d. All of the above
12. When expressed as 7.5×10^4, only the significant figures of _____ are to be considered.
    a. 7.5
    b. 7.05
    c. 7.005
    d. None of the above
13. The mass of an element is $.007502 \times 10^{-26}$ g. Find the number of significant figures when the mass is converted to mg. (Both mass values have same order of magnitude)
    a. 4
    b. 5
    c. 3
    d. 2
14. A cube like crystal structure has length 6.000 cm, width 6.00 cm and height 0.0600 m. Calculate its volume with correct significant figures.
    a. 216 cubic cm
    b. 21.600 cubic cm
    c. 18.00 cm
    d. None of the above
15. What is the sum of 22.82 + 2.2457 with the correct number of significant figures.
    a. 25.065
    b. 25.09
    c. 25.06
    d. 25.0651
16. The weights of sodium chloride salt in three petri dishes are 99.99 g, 100.13 g, and 100.23 g respectively. Which of the following is the average mass of salt?
    a. 100.1166 g
    b. 100.116 g
    c. 100.11 g
    d. 100.1 g
17. Which of the following expresses the one millionth of one in 3 significant places?
    a. 0.01×10^{-6}
    b. 0.10×10^{6}
    c. 0.001×10^{-6}
    d. 1.00×10^{-6}
18. Calculate the number of significant figures up to which (2.36×0.07251)/(2.103) will be expressed.

a. 2
b. 3
c. 4
d. 5

Part III: Advanced Level Questions.

Answer the following questions.

19. Give the SI units for expressing these:
   a. length
   b. area
   c. volume
   d. mass
   e. time
   f. force
   g. energy
   h. temperature
20. Write the numbers for these prefixes:
   a. mega-
   b. kilo-
   c. deci-
   d. centi-
   e. milli-
   f. micro-
   g. nano-
   h. pico-
21. Define density. What units do chemists normally use for density?
22. Write the equations for converting degrees Celsius to degrees Fahrenheit and degrees Fahrenheit to degrees Celsius.
23. Carry out the following arithmetic operations to the correct number of significant figures:
   a. 12,343.2 g + 0.1893 g
   b. 55.67 L – 2.386 L
   c. 7.52 m × 6.9232
   d. 0.0239 kg ÷ 46.5 mL
   e. 5.21×10^3 cm + 2.92×10^2 cm
24. Carry out the following arithmetic operations and round off the answers to the appropriate number of significant figures:
   a. 26.5862 L + 0.17 L,
   b. 9.1 g – 4.682 g,
   c. 7.1×10^4 dm × 2.2654×10^2 dm
   d. 6.54 g ÷ 86.5542 mL,
   e. (7.55×10^4 m) – (8.62×10^3m).
25. Carry out each of the following conversions.
   a. 18.5 m to km;
   b. 16.3 km to m;
   c. 247 kg to g;
   d. 4.32 L to mL;
   e. 85.9 dL to L;
   f. 8251 L to cm^3
26. Express
   a. 283°C in K;
   b. 15.25 K in °C;
   c. 32.0°C in °F;
   d. 100.0°F in K.
27. Express
   a. 0°F in °C;
   b. 98.6°F in K;
   c. 298 K in °F;
   d. 11.3°C in °F.
28. Percent error is often expressed as the absolute value of the difference between the true value and the experimental value, divided by the true value:

$$\text{Percent error} = \frac{|\text{True value - Experimental value}|}{|\text{True value}|} \times 100$$

Where the vertical lines indicate absolute value. Calculate the percent error for these measurements:

a. The density of alcohol (ethanol) is found to be 0.802 g/mL. (True value: 0.798 g/mL.)

b. The mass of gold in an earring is analyzed to be 0.837 g. (True value: 0.864 g.)

Assignment for Submission

Direction: Attempt all questions. Show all the necessary steps.

1. A lead sphere has a mass of 1.20×10^4 g, and its volume is 1.05×10^3 cm^3. Calculate the density of lead.
2. Mercury is the only metal that is a liquid at room temperature. Its density is 13.6 g/mL. How many grams of mercury will occupy a volume of 95.8 mL?
3. (a) Normally the human body can endure a temperature of 105 ^{0}F for only short periods of time without permanent damage to the brain and other vital organs. What is this temperature in degrees Celsius? (b) Ethylene glycol is a liquid organic compound that is used as an antifreeze in car radiators. It freezes at -11.5 ^{0}C. Calculate its freezing temperature in degrees Fahrenheit. (c) The temperature on the surface of the sun is about 6300 ^{0}C. What is this temperature in degrees Fahrenheit? (d) The ignition temperature of paper is 451 ^{0}F . What is the temperature in degrees Celsius?
4. (a) Convert the following temperatures to kelvin: (i) 113 ^{0}C, the melting point of sulfur, (ii) 37 ^{0}C, the normal body temperature, (iii) 357 ^{0}C, the boiling point of mercury. (b) Convert the following temperatures to degrees Celsius: (i) 77 K, the boiling point of liquid nitrogen, (ii) 4.2 K, the boiling point of liquid helium, (iii) 601 K, the melting point of lead.
5. Express these numbers in scientific notation: (a) 0.000000027, (b) 356, (c) 0.096.
6. Express the answers to these in scientific notation:
   a. $145.75 + (2.3 \times 10^{-1})$
   b. 79,500÷ (2.5 102)
   c. $(7.0 \times 10^{-3}) - (8.0 \times 10^{-4})$
   d. $(1.0 \times 10^{4}) \times (9.9 \times 10^{6})$
7. What is the number of significant figures in each of these measured quantities? (a) 4867 miles, (b) 56 mL, (c) 60,104 tons, (d) 2900 g.
8. Carry out these operations as if they were calculations of experimental results, and express each answer in the correct units and with the correct number of significant figures:
   a. 5.6792 m + 0.6 m + 4.33 m
   b. 3.70 g - 2.9133 g
   c. 4.51 cm × 3.6666 cm
   d. $(3 \times 10^4$ g + 6.827 g)/ (0.043 cm^3 - 0.021 cm^3)
9. A gas station in Hawassa charges 2205.37 Birr for 39.5 Liters of kerosene. (a) Convert this rate to birr per liter of kerosene. (b) If it takes 50.4 milliliters of kerosene to boil a liter of water, starting at room temperature (25 ^{0}C), how much would it cost to boil a 2.1-L kettle of water?
10. At what temperature does the numerical reading on a Celsius thermometer equal that on a Fahrenheit thermometer?
11. The surface area and average depth of the Pacific Ocean are 1.8×10^8 km^2 and 3.9×

10^3 m, respectively. Calculate the volume of water in the ocean in liters.

12. A silver (Ag) object weighing 194.3 g is placed in a graduated cylinder containing 242.0 mL of water. The volume of water now reads 260.5 mL. From these data calculate the density of silver.
13. The experiment described in Problem 12 is a crude but convenient way to determine the density of some solids. Describe a similar experiment that would enable you to measure the density of ice. Specifically, what would be the requirements for the liquid used in your experiment?

Answer Key to Exercises

Answer Key to Self Test Exercise 2.1

1. a. 4 significant figures b. 3 significant figures c. 3 significant figures d. 2 significant figures
2. 4.4 g (1.4 determines number os significant figures in the result)
3. The factor 1.23 has the least number of significant figures, so the result should be reported to 3 significant figures (273.15 + 1.2 has 4 significant figures).
4. a. 40.2 b. 2.8 c. 11 d. 46 e. 46

Answer Key to Self Test Exercise 2.2

1. (a) qualitative (b) quantitative (c)qualitative

Answers to the Self-Assessment Exercise

True/False Item	Multiple Choice	
1. TRUE	8. (a) 0.47	15. (c) 25.06
2. FALSE	9. (c) 0.86 cm^3	16. (c) 100.11 g
3. TRUE	10. (a) 7.108 cm^3	17. (d) 1.00×10^{-6}
4. TRUE	11. (d) All of the above	18. (b) 3
5. TRUE	12. (a) 7.5	
6. FALSE	13. (a) 4	
7. TRUE	14. (a) 216 cm^3	

19. (a) meter (m), (b) square meter (m^2) (c) cubic meter (m^3) (d) kilogram (kg) (e) second (s), (f) Newton (N), (g) Joule (J), (h) Kelvin (K).
20. (a) 10^6, (b) 10^3, (c) 10^{-1}, (d) 10^{-2}, (e) 10^{-3}, (f) 10^{-6} (g) 10^{-9}, (h) 10^{-12}
21. The density of an object is its mass per unit volume. You can express this as

$$d = \frac{m}{V}$$

where d is the density, m is the mass, and V is the volume. Some of the units chemists use include g/cm^3, g/mL etc.

22.

$$^{o}C = \frac{1.0^{o}C}{1.8^{o}F}\left(x^{o}F - 32^{o}F\right) = \frac{5^{o}C}{9^{o}F}\left(x^{o}F - 32^{o}F\right) \text{ and } \, ^{o}F = \left(x^{o}C \times \frac{1.8^{o}F}{1.0^{o}C}\right) + 32^{o}F = \left(x^{o}C \times \frac{9^{o}F}{5^{o}C}\right) + 32^{o}F$$

23. (a) 12343.2 g
  + 0.1893 g
  12343.3893 g round off to 12343.4 g

 (b) 55.67 L

$\underline{\ \ -2.36\ L}$

53.31 L

(c) 7.52m × 6.9232 =52.062464m round off to 52.1 m

(d) 0.0239 kg ÷ 46.5 mL

= 0.000513978494624 kg/mL round off to 0.000514 kg/mL

= 5.14×10^{-4} kg/mL

(e) 5.21×10^3cm + 2.92×10^2cm

= 52.1×10^2 cm + 2.92×10^2 cm = $(52.1+2.92) \times 10^2$ cm

=55.02×10^2 cm round off to 55.0×10^2 cm

24. (a) 26.5862 L

$\underline{+\ 0.17\ L}$

26.7562 L round off to 26.76 L

(b) 9.1 g

$\underline{-\ 4.682\ g}$

4.418 g round off to 4.4 g

(c) 7.1×10^4 dm × 2.2654×10^2 dm

= 1.608434×10^7 dm^2 round off to 1.6×10^7 dm^2

(d) 6.54 g ÷ 86.5542 mL

= 0.075559591562 g/mL round off to 0.0756 g/mL

= 7.56×10^{-2} g/mL

(e) $(7.55 \times 10^4$ m$) - (8.62 \times 10^3$ m$) = (7.55 \times 10^4$ m$) - (0.862 \times 10^4$ m$)$

= $(7.55-0.862) \times 10^4$ m = 6.688×10^4 m round off to 6.69×10^4 m

25. (a) 1 km = 10^3 m therefore, $18.5m = 18.5m \times \frac{1km}{10^3 m} = 1.85 \times 10^{-2} km$

(b) 1km = 10^3 m therefore, $16.3km = 16.3km \times \frac{10^3 m}{1km} = 1.63 \times 10^4 m$

(c) 1 kg = 10^3 g therefore, $247kg = 247kg \times \frac{10^3 g}{1kg} = 2.47 \times 10^5 g$

(d) 1 L = 10^3 mL therefore $4.32L = 4.32L \times \frac{10^3 mL}{1L} = 4.32 \times 10^3 L$

(e) 1dL = 10^{-1}L therefore $85.9dL = 85.9dL \times \frac{10^{-1} L}{1dL} = 85.9 \times 10^{-1} dL = 8.59dL$

(f) 1L=10^3mL=10^3cm^3 therefore, $8251L = 8251L \times 10^3 mL \frac{\times 1cm^3}{1mL} = 8251 \times 10^3 cm^3 = 8.251 \times 10^3 cm^3$

26. (a) $K =^o C + 273.15^o = 283 + 273.15 = 556.15K$

(b) $^{,}C = K - 273.15^o = 15.25K - 273.15 = -257.9^0 C$

(c) $^{o}F = \left(x^{o}C \times \frac{9^{o}F}{5^{o}C} \right) + 32^{o}F = \left(32^{o}C \times \frac{9^{o}F}{5^{o}C} \right) + 32^{o}F = 89.6^{0}F$

(d) First ^{0}F has to be converted to ^{0}C and then convert from ^{0}C to K. Therefore, 1000F in ^{0}C, $^{o}C = \frac{5^{o}C}{9^{o}F}\left(100^{o}F - 32^{o}F\right) = 37.78^{0}C$ in K units,

$K = {}^{o}C + 273.15^{o} = 37.78 + 273.15 = 310.93K$

27. (a) $^{o}C = \frac{5^{o}C}{9^{o}F}\left(0^{o}F - 32^{o}F\right) = -17.78^{0}C$

(b) First ^{0}F has to be converted to ^{0}C and then convert from ^{0}C to K. Therefore, 98.6 ^{0}F in ^{0}C,

$^{o}C = \frac{5^{o}C}{9^{o}F}\left(98.6^{o}F - 32^{o}F\right) = 37^{0}C$ in K units becomes

$K = {}^{o}C + 273.15^{o} = 37 + 273.15 = 310.15K$

(c) First K has to be converted to ^{0}C and then convert from ^{0}C to ^{0}F. Therefore, 298K in ^{0}C, $^{o}C = 298K - 273.15 = 24.85^{0}C$. Convert the result in ^{0}C to ^{0}F

$$^{o}F = \left(24.85^{o}C \times \frac{9^{o}F}{5^{o}C} \right) + 32^{o}F = 76.73^{0}F$$

(d) $^{o}F = \left(11.3^{o}C \times \frac{9^{o}F}{5^{o}C} \right) + 32^{o}F = 52.34^{0}F$

28. (a)

$$\text{Perecent error} = \frac{|\text{True value - Experimental value}|}{|\text{True value}|} \text{x100}$$

$$\text{Perecent error} = \frac{|0.798\text{g/mL} - 0.802\text{g/mL}|}{|0.798\text{g/mL}|} \text{x100}$$

= 0.5%

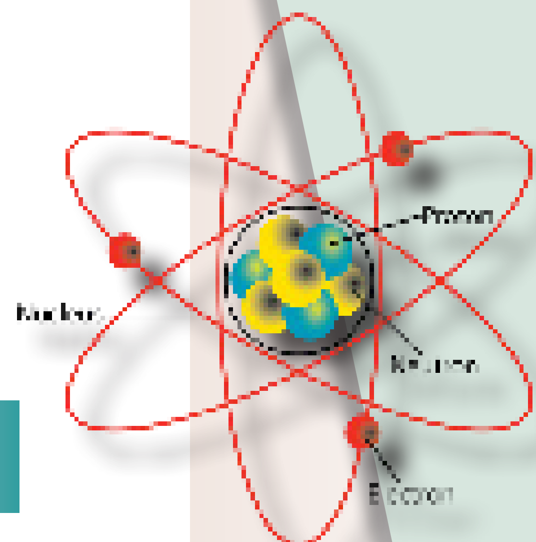
(b)

$$\text{Perecent error} = \frac{|\text{True value - Experimental value}|}{|\text{True value}|} \text{x100}$$

$$\text{Perecent error} = \frac{|0.864\text{g/mL} - 0.837\text{g/mL}|}{|0.864\text{g/mL}|} \text{x100}$$

= 3.1%

UNIT 3



STRUCTURE OF THE ATOM

Introduction

- Every physical object around us is material. This means the world in which we live is made up of matter.

? What do you think is the smallest possible substance that matter is made up of?

The existence of the smallest particle from which matter is made has been proposed since the time of early Greek philosophers. According to them, the continued sub-division of matter would ultimately yield atoms that would not be further divisible. These ideas remained dormant for a very long time and were revived again by John Dalton at the beginning of the nineteenth century. The atomic theory of matter was first proposed on a firm scientific basis by John Dalton, a British schoolteacher, in 1808. In this unit, you are going to study the historical development of the atomic theories of matter, the fundamental laws of chemical reactions derived from the atomic theories, Dalton's and Modern Atomic Theories, the discovery of sub-atomic particles, the composition of an atom, and the isotopes of atoms.

Unit Outcomes

Dear learner, after studying this unit, you should be able to

- Discuss the development of Dalton's Atomic Theory and Modern Atomic Theory;
- Explain the discovery of the proton, electron, neutron and the nucleus.
- Differentiate terms like atomic number, mass number, atomic mass, isotope, energy level, valence electrons, and electron configuration.
- Develop skills in determining the number of protons, electrons and neutrons in atoms from atomic numbers and mass numbers.
- Develop skills in
  - calculating the atomic masses of elements that have isotopes.
  - writing the ground-state electron configurations of atoms using the main energy levels and drawing diagrammatic representations of atoms.
- Demonstrate scientific inquiry skills: observing, comparing and contrasting, communicating, asking questions, and applying concepts.

Contents

Section 3.1: Historical Development of the Atomic Theories of Matter
Section 3.2: Fundamental Laws of Chemical Reactions
Section 3.3: Atomic Theory
Section 3.4: Discoveries of the Fundamental Sub-atomic Particles
Section 3.5: Composition of an Atom and the Isotopes

The Required Study Time

From the date of your registration, you have a maximum of 10 months to complete the course, but the pace at which you proceed is up to you. This course has a total of five units. Proportionally dividing the period allotment for the teacher-guided lesson (15 periods out of 61) into 10 months of self-study, you need to finish studying this unit in ten weeks.

Section 3.1: The Historical Development of the Atomic Theories of Matter

Overview

? Dear learner, you are living in a material world. However, do you know the smallest particle from which every matter is made?

As a chemist, what importance do you think knowing the smallest possible particle, from which every matter is made? In your day- to- day activities, you are experiencing different chemical and physical phenomena, some of which are very complex and abstract because of their microscopic nature.

? Do you think you can explain these complex and abstract phenomena without knowing the smallest particles of matter? For example, can you explain what is really going on with the burning charcoal when you boil coffee?

I know for sure you can't give me a brief answer. Chemistry is about explaining the physical and chemical phenomena occurring in this material world. Scientists spent a lot of time and energy trying to explain these abstract and microscopic phenomena.

Dear learner, I know that you have some understanding about the concept of matter and its properties, the particle nature of matter, and a little about the atom from your lessons in Grade 7, Unit 2. You also came across information about the composition of matter in your Grade 8 science, Unit 2 lessons. These, however, did not enable to you explain the abstract and complex phenomena in your day- to -day life. In this section, therefore, you are going to see the historical development of the Atomic Theories of matter in more detail.

Section Outcome

Dear learner, when you have finished studying this section, you should be able to briefly state the historical development of the atomic nature of substances.

Study Notes and Important Points

Dear learner, before you go into the historical development of atoms, let me clarify the importance of a scientific theory and its difference from a hypothesis, for you.

A scientific theory is a well-tested, broad explanation of a natural phenomenon.

In everyday life, we often use the word **theory** to mean a hypothesis or educated guess, but **a theory in the context of science is not simply a guess**. It is an explanation based on extensive and repeated experimentation. Atomic theory was, therefore, developed to fulfill these requirements of a scientific theory.

? What do you think is the importance of a scientific theory?

Because it is so well supported, a scientific theory has a very good chance of being a correct explanation for events in nature. Since it is a broad explanation, it can explain many observations and pieces of evidence. In other words, it can help connect and make sense of many phenomena in the natural world. Chemistry is full of abstract concepts that deal with the microscopic world. In order to explain this microscopic world, you need to know the microscopic particles from which every material is made up. This section therefore deals with the historical development of the discovery of the theory of the microscopic particle known as the atom.

? Dear learner, how did you feel when you heard the fact that every substance is made up of small particles called atoms in the previous grades? Are you convinced by this idea?

All modern scientists accept the concept of the atom, but when the concept of the atom was first proposed about 2,500 years ago, the ancient philosophers laughed at the idea. It has always been difficult to convince people about the existence of things that are too small to see. You will, therefore, spend some time considering the evidence (observations) that convinced scientists about the existence of atoms. I hope that this evidence will convince you as well.

The Indivisible Atom

? Dear student, I hope you have heard something about the Greek philosophers. Can you mention the names of some of the Greek philosophers you know and what they did?

In this section, I want you to take note of the names of the philosophers and their contributions to the atomic theory of matter. Greek philosophy emerged early in the 6th century BC, centered in the city of Miletus on the Ionian coast in Asia Minor (now called Turkey).

? Did you know what the ancient Greek philosophers thought about the universe?

- About 2,500 years ago, early Greek philosophers believed the entire universe was a single huge entity. In other words, "**everything was one.**" They believed that all objects, all matter, and all substances were connected as a single, big, unchangeable 'thing'. Were they right? I don't think so! Empedocles, a Greek philosopher who lived in the middle of the 5^{th} century BC, believed that the four so-called elements_ earth, air, water and fire_ make up all substances.

? Dear learner, have you ever heard the name **Plato** before? What is his contribution to chemistry?

Do not worry if you don't know. I will introduce you to him and his contribution to chemistry. **Plato** was a student of **Socrates** and a teacher of **Aristotle**. He adopted **Empedocles'** Theory, and coined the term **element** to describe the four substances of Empedocles. His successor, **Aristotle**, also adopted the concept of four elements, from which all materials are made of. He introduced the idea that elements can be differentiated based on properties such as hot versus cold, and wet versus dry. For example, heating clay in an oven could be thought of as driving off water and adding fire, transforming clay into a pot. Similarly, water (cold and wet) falls from the sky as rain when air (hot and wet) cools down. Did you know how many years the Greek philosophers' concept of four elements existed? The Greek philosophers' concept of four elements existed for more than two thousand years.

Democritus was a Greek philosopher born in Abdera, in the north of Greece. He was a student of Leucippus, who proposed the atomic theory of matter for the first time. There is little documentation on the philosophy of Leucippus. It was Democritus who elaborated extensively on his theories on the atomic structure of the physical world, the universe, and the void of space. Although Democritus was a philosopher, he has been included on the list of great pioneers of physics and chemistry of the 19th and 20th centuries.

? But why was he called one of the great pioneers of chemistry?

This is because many of his teachings on the structure of matter were demonstrated by scientists over 2000 years after his death.

? What were his teachings on the structure of matter? Dear learner, do you know who named the smallest, indivisible, and indestructible substance called the atom? What does the word atom mean?

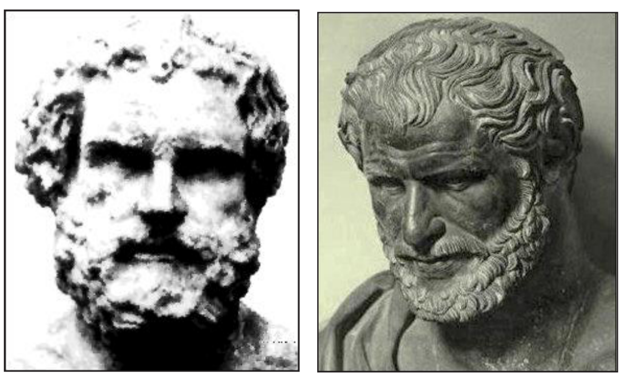


Figure 3.1 From left to right: Democritus, and Leucippus.

The Greek Concept of 'Atomos'

? Dear learner, if you were given the right to name the smallest thing you obtained after splitting a substance to the possible limit, what would you call it? Why did you give it that name? Do you think it is the appropriate term to describe the smallest particle from which every substance is made up? Why? Where do you think is the origin of the word "atom"? Who is the scientist that coined this term?

Let me answer the questions I raised regarding the origin of the term "atom". Around 440 BC, **Leucippus** originated the atom concept. He and his pupil, **Democritus,** refined and extended it in future years. **Democritus** taught the theory of atomism, which held the belief that indivisible and indestructible atoms are the basic components of all matter in the universe. Their work was further developed by **Epicurus of Samos** (341–270), who made the ideas more generally known. There are five major points to their atomic idea. Try to memorize and understand the statements in bold and italic fonts below.

> **All matter is composed of atoms, which are bits of matter too small to be seen. These atoms cannot be further split into smaller portions.**

This is the idea of Democritus. He reasoned that if matter could be infinitely divided, it was also subjected to complete disintegration, from which it could never be put back together. In Greek, the prefix '**a**' means '**not**' and the word '**tomos**' means '**cut**'. Our word atom, therefore, comes from **atomos**, a Greek word meaning **uncuttable** or **indivisible.** Do you think that this is true?

> **There is a void, which is an empty space between atoms.**

This is the idea of **Leucippus**. But what was his belief? **Leucippus** believed in the existence of an empty space between atoms. Given that all matter is composed of atoms, all changes must be the result of the movement of atoms. However, to move, there must be a void; a space entirely empty of matter through which atoms can move from place to place. What do you think is the problem with this assumption? The problem with this assumption is that if there is an entirely void space between atoms, then what holds the atoms together? Leucippus and Democritus did not answer this question. I would appreciate it if you could answer this question. But I don't think you can answer it at this stage.

> **Atoms are completely solid.**

This means that there can be no void inside an atom itself. An atom would be subjected to changes from outside and could disintegrate otherwise. Then, it would not be an atom. Do you think this is true? If not, why not? Don't worry; you will come to know more in the following sections.

> **Atoms are homogeneous, with no internal structure.**

What does this mean? The absolute solidity of the atoms also leads to the notion that atoms are homogeneous, or the same all the way through. Another way to express this is that an atom would have no internal structure. What can you say about this idea based on your previous grade level knowledge about the internal structures of atoms?

> **Atoms are different in their sizes, shapes, and weights.**

Democritus then reasoned that changes occur when the atomos (now known as atoms) in an object are reconnected or recombined in different ways. He extended this theory, suggesting that there were different varieties of atomos with different shapes, sizes, and masses. He thought, however, that shape, size, and mass were the only properties differentiating the different types of atomos. The generally accepted atomic model of Democritus is called '**the solid sphere**'. What kind of model can you draw from this?

? Dear learner, was Democritus and Leucippus atomic model correct? Or was it challenged by other philosophers of the time?

Aristotle and **Plato**, however, strongly opposed their atomic theory on philosophical grounds rather than scientific ones. Hence, their theory was disregarded and essentially buried until the 16th and 17th centuries. In time, **Lavoisier's** innovative 18th-century experiments accurately measured all substances involved in the burning process, proving that "**when substances burn, there is no net gain or loss of weight.**" Lavoisier established **the science of modern chemistry**, which gained greater acceptance. Why? This is because of the efforts of **John Dalton**, who modernized the ancient Greek ideas of element, atom, compound, and molecule. **Dalton** also provided a means of explaining chemical reactions in quantitative terms.

Drawbacks of the Early Greek Philosophers

Dear learner, I have shown you some of the problems with Democritus and Leucippus's atomic theory. Now I will give you the basic problems the Greek philosophers have. The early Greek philosophers tried to understand the nature of the world through **reason** and **logic**, but not through **observations, measurements, tests, or experiments**. As a result, they had some very thought-provoking ideas, but they felt no need to justify their ideas based on life experiences. In a lot of ways, you can think of the Greek philosophers as being **"all thought and no action."** It's truly amazing how much they achieved using their minds, but because they never performed any experiments, they missed or rejected a lot of discoveries that they could have made otherwise. Greek philosophers dismissed Democritus' Theory entirely. Sadly, it took over two millennia before the theory of atomos (or 'atoms' as they are known today) was fully appreciated.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a further understanding of the historical development of atomic theory.

1. https://www.britannica.com/science/atom/Development-of-atomic-theory
2. https://www.thoughtco.com/history-of-atomic-theory-4129185
3. https://www.compoundchem.com/2016/10/13/atomicmodels/
4. https://www.youtube.com/watch?v=fwhjCw-IUu0

Activity 3.1

1. According to the Greek philosopher Empedocles, what are the four elements that all materials are made up of?
2. What is the contribution of Plato and Aristotle to the Atomic Theory?
3. Where, by whom, and when was the concept 'atom' originated?
4. What does the word 'atom' mean?
5. What are the five major points of Democritus and/or Leucippus's atomic theory?
6. According to the ancient Greek philosophers, what do you think an atom is like? Can you draw it in your exercise book?
7. What example can you give from a local material around you that you think looks like an atom according to "the solid sphere" atomic model of Democritus?

Self-Test Exercise 3.1

Dear learner, test yourself to see if you achieved the learning outcomes of the section by giving correct answers to the following questions, and check the answer keys to see if you have answered them correctly or not.

1. What is the importance of a scientific theory?
2. As a chemist, what is the importance of knowing the smallest possible particle from which every substance is made?
3. Why was the concept of the atom difficult for the ancient Greek philosophers to accept?
4. Who is the philosopher that proposed the theory of matter for the first time?
5. What was Democritus's major contribution with regard to atomic theory?
6. Why was Democritus called one of the great pioneers of physics and chemistry of the 19^{th} and 20^{th} centuries?
7. What were the major drawbacks of the atomic theory of the ancient Greek philosophers that led to its rejection?

Checklist 3.1

Dear learner, check yourself on the following aspects before wrapping up studying this section. In the table given below, put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
briefly state the historical development of the atomic nature of substances.		

Section 3.2: Fundamental Laws of Chemical Reactions

? Dear learner, did you know that you are living in a world full of laws? What laws are you using in your family? Which chemical laws did you know? What does the word 'law' mean?

In the previous section, we saw that the explanation of a phenomenon is called a **scientific theory**. Is there a difference between a law and a theory? Let me define the term law so that you can answer this question. **A law** is a generalized observation about a relationship between two or more things in the natural world.

? If this is the meaning of a law, then what are scientific laws?

Scientific laws or **laws of science** are statements based on repeated experiments or observations that describe or predict a range of natural phenomena. They don't explain why the phenomenon exists or what causes it.

Chemical laws are those laws of nature relevant to chemistry.

Dear learner, in your 7th grade, Unit 3 lessons, you were introduced to how to write chemical formulas, name simple chemical compounds, write simple chemical reactions, and write chemical equations. You have also studied the definition of The Law of Conservation of Mass. In Grade 8, Unit 2, you were introduced to molecules as well. In this section, you are going to study three well-known fundamental laws of chemical reactions in chemistry. The Law of Conservation of Mass, the Law of Definite Proportions, and the Law of Multiple Proportions are the sub-sections I will be discussing for you. There are two experiments that will help you observe The Law of Conservation of Mass.

Learning Outcomes

Dear learner, when you have finished studying this section, you are expected to

- State the law of conservation of mass and illustrate it using examples.
- Describe the Law of Conservation of Mass using simple experiments.
- State the Law of Definite Proportions.
- State the Law of Multiple Proportions.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the experiments, the activity and the self-test exercise questions. The study notes and activity questions are presented in three sub-sections. Make sure that you are clear on the meanings of the concepts, terms, and definitions of the laws. After doing so, check whether you achieved the learning outcomes indicated above.

3.2.1 The Law of Conservation of Mass

? Let me begin presenting the study notes by asking you some questions that will lead you to the topic under study. Which direction is water flowing in your locality, from an altitude of high to low or from low to high? Will the direction of flow of water change in places other than your locality? Why? If you dissolve 3g of sugar in 20 g of water, how many grams of sugar solution will you get? Am I correct if I write the equation: sugar (3g) + water (20 g) = sugar solution (23 g)? Why? What will happen to the mass of pieces of campfire wood after burning it? Do you think the mass of the pieces of the campfire wood is equal to the mass of the ash we get from burning it? Why?

Dear learner, in science, a law is a general statement that explains a large number of observations.

Do you think that stipulating a scientific law is easy? Why? Before being accepted, a scientific law must be verified many times under many conditions. Laws are, therefore, considered the highest form of scientific knowledge, and are generally supposed to be unbreakable. Scientific laws form the core of scientific knowledge.

? Dear learner, which scientific laws did you know?

One scientific law that provides the foundation for understanding chemistry is **The Law of Conservation of Mass.**

? Can you state this law based on your 7th Grade lesson?

The Law of Conservation of Mass is also known as the **'Law of Indestructibility of Matter'.**

It states that in any given system that is closed to the transfer of matter (in and out), the amount of matter in the system stays unchanged. A simple way of expressing this law is to say that the amount of matter in a system is conserved or remains constant.

? When do you think is The Law of Conservation of Mass was initiated?

The Law of Conservation of Mass dates from **Antoine Lavoisier's** 1789 discovery that mass is neither created nor destroyed in chemical reactions. In other words, the mass of any substance at the beginning of a reaction will equal the mass of that substance at the end of the reaction. If we account for all reactants and all products in a chemical reaction, the total mass will be the same at any point in time in any closed system. These laws are called **The Laws of Chemical Combination**. Lavoisier's finding laid the groundwork for modern chemistry and revolutionized science.

Let me present this law in a simplified way. According to the Law of Conservation of Mass, during any chemical change, the total mass of the products remains equal to the total mass of the reactants. The mass of the sum of reactants **1** and **2** is equal to the mass of the sum of products **1** and **2**.

Reactant **1** + Reactant **2** → Product **1** + Product **2**

? Do you think the above equation is true if we consider the aforementioned burning of a campfire?

Let's assume that the wood is reactant **1** and the oxygen used for burning is reactant **2**. **The Law of Conservation of Mass** holds true because naturally occurring elements are very stable under the conditions found on the surface of the Earth. In the everyday world of Earth, from the top of the highest mountain to the lowest point of the deepest ocean, elements are not changed into other elements during ordinary chemical reactions.

? By whom and when was The Law of Definite Proportions proposed? What does the law state?

Joseph Louis Proust proposed **The Law of Definite Proportions**, which states that the masses of elements in a compound always occur in the same proportion. So the focus of the law is on the proportion of elements in a compound rather than on the masses of the reactants and the products.

Let me now show you how **John Dalton** developed The Law of Multiple Proportion based on the above-mentioned laws. Although all three of the aforementioned laws didn't mention atoms, **John Dalton** built upon them to develop **The Law of Multiple Proportions**, which states that the ratios of masses of elements in a compound are small whole numbers. Dalton drew this law from experimental data. He proposed that each chemical element consists of a single type of atom that cannot be destroyed by any chemical means. But is Dalton right in saying so about elements and atoms? This ultimately formed the basis of **Dalton's Atomic Theory of Matter**, which will be discussed in later sections. His work marked the beginning of scientific Atomic Theory.

Experiments on The Law of Conservation of Mass

Dear learner, your tutor arranges a laboratory session in one of the secondary schools in your locality so that you can do the following experiments: You need a technical assistant and a tutor to help you conduct the experiments. Never try to do the experiments yourself. The objective of the experiments is to show you practically how to apply the Law of Conservation of Mass in chemical reactions. These experiments could help you develop a scientific attitude toward working together and being honest.

Experiment 3.1 The reaction between silver nitrate solution and dilute hydrochloric acid.

$$HCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + HNO_3(l)$$

Materials you need: a conical flask, thread, cotton, a test tube, safety goggles, gloves, a balance, and a glass road.

Chemicals: hydrochloric acid, and silver nitrate solution.

Caution: HCl and HNO_3 are corrosive. Avoid contact with the skin. If it spills on your skin, wash thoroughly with ample water immediately.

Procedure: Please follow the following procedure:

1. Place dilute HCl in a conical flask to a depth of about 1 cm.
2. Tie a thread of cotton around the top of a test tube.
3. Half- fill the test tube with silver nitrate solution.
4. Place the test tube inside the conical flask so that it is held on a slant by the thread, and place a stopper in the top of the flask to hold the thread in place (see ***Figure 3.2***).
5. Weigh the conical flask and its contents using a balance.

6. Tilt the flask so that the silver nitrate solution is poured into the dilute hydrochloric acid. In a few minutes, a white precipitate of silver chloride is produced (see ***Figure 3.2***).
7. Reweigh the conical flask and its contents using a balance.
8. Remove the test tube from the inside of the conical flask. Discard the contents of the conical flask into the waste tank prepared for this purpose. Discard the thread, the cotton, and the gloves in the proper dust bin prepared for this purpose.
9. Wash the test tube and the conical flask and dry them in an oven. Put them in their proper places.

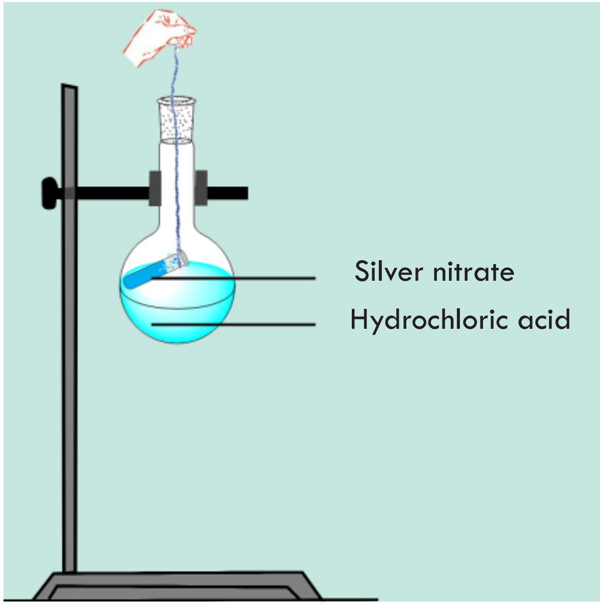


Figure 3.2 Set up for the reaction between silver nitrate ($AgNO_3$) and dilute hydrochloric acid (HCl).

Observation and analysis questions:

Give the correct answer for the following questions on its proper place, on the laboratory report.

1. What is the mass of the conical flask and its contents before the reaction?
2. What is the mass of the conical flask and its contents after the reaction?
3. Does this experiment confirm the Law of Conservation of Mass?

Experiment 3.2 The reaction between barium nitrate and sodium sulphate

$$Ba(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaNO_3(aq)$$

Materials you need: beakers (250 and 150 mL), Whatman filter paper, Erlenmeyer flask, funnel, sand bath, metal stand, metal ring, clamps, Bunsen burner, balance, and glass road.

Chemicals: Barium nitrate, sodium sulphate, distilled water.

Caution: $NaNO_3$ should not be dried completely because it will cause explosions, otherwise.

Procedure: You need to refer to ***Figure 3.3*** while following the procedure.

1. To a 150 ml beaker, add 100 ml of distilled water and 2.61 g of $Ba(NO_3)_2$ and stir vigorously until it dissolves. This will make a 0.1M $Ba(NO_3)_2$ solution.

2. To a 150 ml beaker, add 100 ml of distilled water and 1.42 g of Na_2SO_4, and stir vigorously until it dissolves.
3. Mix the solutions in a 250 ml beaker and stir the contents very well.
4. Filter off the white insoluble $BaSO_4$ using filter paper and dry it in an oven at 40 °C. Weigh the $BaSO_4$.
5. Evaporate the water from the filtrate on a sand bath and weigh the residue of $NaNO_3$. Do not heat it to dryness.
6. Keep the $BaSO_4$ and $NaNO_3$ in separate bottles, label them, and put them on the chemical shelf.
7. Clean, dry, and put the beakers in the cupboard.

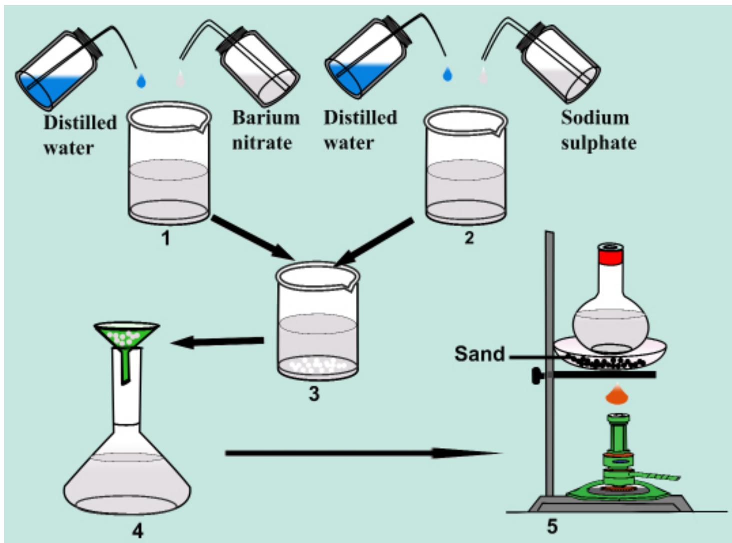


Figure 3.3 Set up for the reaction between barium nitrate ($Ba(NO_3)_2$) and sodium sulphate (Na_2SO_4).

Observation and analysis questions:

Give the correct answer for the following questions in their proper place on the laboratory report.

1. What is the mass of the barium sulphate?
2. What is the mass of the sodium nitrate?
3. What is the mass of the water used in the experiment?
4. Is this experiment in agreement with the Law of Conservation of Mass?
5. Express the Law of Conservation of Matter in your own words.
6. Explain why the concept of conservation of matter is considered a scientific law.
7. Potassium hydroxide (KOH) readily reacts with carbon dioxide (CO_2) to produce potassium carbonate (K_2CO_3) and water (H_2O). How many grams of potassium carbonate are produced if 224.4 g of KOH reacts with 88.0 g of CO_2? The reaction also produced 36.0 g of water.

Dear learner, you are required to write a laboratory report for both experiments, separately. Use the format below for the report. You need to give the report to your tutor or marker for correction.

Laboratory report format

Group Number ________________ Date of experiment: ________________

Name of student(s):

1. ______________________
2. ______________________
3. ______________________

Experiment number: ________________

Title of experiment: ______________________________________

Materials used in the experiment: ____

Chemicals: ____

Objective of the experiment: ____

Chemical reaction: ____

Observation:

Mass of reactant: ________________

Mass of product: ________________

Colour of reactant(s): ________________

Colour of product(s): ________________

Physical state of product(s) ________________

Conclusion: ____

____

____.

Answers to observation and analysis questions.

1.
2.
3.
4.

Etc.

Activity 3.2

1. Define the term 'law'.
2. What is a 'scientific law'?
3. What is the difference between a 'scientific law' and a 'scientific theory'?
4. What is a Chemical Law?
5. Who discovered the Law of Conservation of Mass?

3.2.2 The Law of Definite Proportions

Dear learner, before you directly go into The Law of Definite Proportions, I will show you how to calculate the molecular weights and moles of molecules. Let me begin with how to calculate the molecular weights of molecules. In the previous unit, you came across the concept of the average atomic mass of elements (details will be discussed in 3.5.3).

? What do you think the molecular weight of a substance is?

The **molecular weight** (molecular mass) of a substance is the sum of the atomic masses of all atoms in a molecule.

Based on a standard scale, scientists fixed the atomic masses of hydrogen, carbon, nitrogen, and oxygen at 1, 12, 14, and 16, respectively.

Example: Calculate the molecular weight of the ammonium ion (NH_4^+).

Solution

First, calculate the atomic masses of the atoms in ammonium ion.

Mass of nitrogen = 14, and there is only one nitrogen atom in ammonium ion.

Mass of hydrogen = 1, but ammonium ion has four hydrogens, so the total mass of hydrogen in ammonium ion will be 1 x 4 = 4.

Now, add all the atomic masses.

Mass of ammonium ion = mass of nitrogen + mass of hydrogen = 14 + 4 = **18**.

Therefore, the molecular mass of ammonium ion is 18.

Law of Definite Proportions, also known as **Proust's Law** or the **Law of Constant Composition**, states that every chemical compound contains fixed and constant proportions (by mass) of its constituent elements.

To help you understand this law, let me consider the following examples.

Follow the examples given below:

Carbon dioxide (CO_2) is composed of one carbon atom and two oxygen atoms. Therefore, by mass, carbon dioxide can be described by the fixed ratio of 12 (mass of carbon):32 (mass of oxygen) or, in a simplified form, as 3:8.

Let me take a water molecule (H_2O) as a second example. Whatever the source of water, its composition is that of two atoms of hydrogen and one atom of oxygen. The atomic mass of oxygen is 16. If I calculate the molecular weight/mass of water, I come up with 18 g/mol.

? Can you calculate the molecular mass of water and confirm my result?

In 1 mole of water, there are 2 grams of hydrogen and 16 grams of oxygen. In other words, hydrogen and oxygen are in a ratio of 2:16, which will become 1:8 when simplified in water. The Law of Definite Proportions illustrates that whatever the amount of water, whether it be 2 g or 54 g, the ratio of the amount of hydrogen to oxygen by weight will always be the same.

Activity 3.3

1. Calculate the molecular masses of H_2SO_4, H_3PO_4, and H_2CO_3. **Hint**: the atomic masses of H, C, O, P, and S are 1, 12, 16, 31, and 32 g/mol , respectively.
2. What is the ratio of hydrogen to oxygen (by weight) in 25 g of H_2O?
3. What is the ratio of carbon to hydrogen to oxygen (by weight) in 25 g of ethanol (C_2H_6O)?

3.2.3 The Law of Multiple Proportions

? Dear learner, can you mention two compounds that are formed from hydrogen and oxygen? Based on your previous section study, can you calculate the mass ratios of hydrogen to oxygen (H:O)? From your mathematics course, do you know what a whole number is? Can you give examples of small whole numbers?

Before answering these questions, let me define The Law of Multiple Proportions for you.

The Law of Multiple Proportions states that, when two different compounds are formed from the same two elements, the masses of one element, which react with a fixed mass of the other, are in a ratio of small whole numbers.

Let me show you what this means by considering the following examples:

Here is the first example: Let me consider the two compounds formed by carbon and oxygen. Carbon and oxygen can form carbon monoxide (CO) and carbon dioxide (CO_2). In CO, 1.33 g of oxygen is combined with 1.00 g of carbon, while in CO_2, 2.66 g of oxygen is combined with 1.00 g of carbon. What is the ratio of the masses of oxygen in CO and CO_2 that combine with a fixed mass of carbon (1.00 g)?

Solution: You will observe the ratio of small whole numbers by dividing the masses of oxygen by the smaller of the two. i.e., by 1.33
In CO (1.33 g) = 1.33/1.33 = **1**; and
In CO_2 (2.66 g) = 2.66/1.33 = **2**

Therefore, the ratio of the masses of oxygen in CO and CO_2 is 1:2, which is a small whole number. This is consistent with the atomic theory if we consider that CO contains one atom of carbon and one atom of oxygen, whereas CO_2 contains one atom of carbon and two atoms of oxygen. Since carbon dioxide has twice as many oxygen atoms bound to a carbon atom as does carbon monoxide, the weight of oxygen in a molecule of carbon dioxide must be twice the weight of oxygen in a molecule of carbon monoxide (see ***Figure 3.4***).

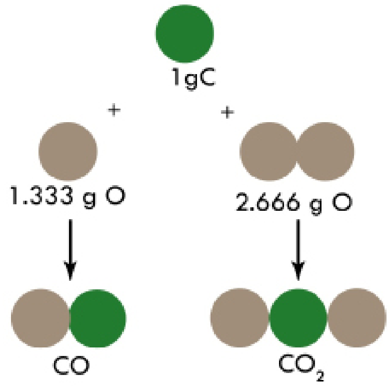


Figure 3.4 The Law of Multiple Proportions in CO and CO_2.

Let me give you a third example: Nitrogen forms seven different compounds with oxygen. In one of its compounds, it is observed that 2.62 g of nitrogen are combined with 1.50 g of oxygen, while in the other, 0.656 g of nitrogen are combined with 1.50 g of oxygen. Let me show you that these data demonstrate the Law of Multiple Proportions.

Solution:

In both cases, I am dealing with a mass of nitrogen that combines with 1.50 g of oxygen. If these data are in agreement with the Law of Multiple Proportions, the ratio of the masses of nitrogen in the two compounds should be a ratio of small whole numbers. Let me divide the numerator and denominator by the smallest mass of nitrogen, i.e., 0.656 for the two compounds. This will give me 2.62/0.656 and 0.656/0.656, which means 4:1, which is indeed a ratio of small whole numbers.

Activity 3.4

1. State the Law of Conservation of Mass.
2. State the Law of Definite Proportions.
3. State the Law of Multiple Proportions.
4. If 2 g of sugar is enough to make 30 ml of tea, how many grams of sugar are needed to make 300 ml of tea?

Self-Test Exercise 3.2

1. What is the importance of knowing the Law of Conservation of Mass in Chemistry?
2. Given 1 mole each of H_2O_2 and H_2O, fill in the blank columns or rows reagarding thier ratios.

Required	H_2O_2	H_2O
Mass of H:O		
Ratio of mass of H:O		
Ratio of mass of O that combines with g of H		

3. Fill in the blank columns/rows of N in the table below.

Required	NO	NO_2	N_2O	N_2O_4	N_2O_5
Ratio of molar masses N:O					
Grams of oxygen combining with 1g					
of N					
Ratio of small whole numbers of O:N					

4. When 32.0 grams (g) of methane are burned with 128.0 g of oxygen, 88.0 g of carbon dioxide and 72.0 g of water are produced. Which law is this an example of?
5. 8.00 grams (g) of methane are burned in 32.00 g of oxygen. The reaction produces 22.00 g of carbon dioxide and an unmeasured mass of water. What mass of water is produced?
6. Two experiments using sodium and chlorine are performed. In the first experiment, 4.36 grams (g) of sodium were reacted with 32.24 g of chlorine, using up all the sodium. 11.08 grams of sodium chloride were produced in the first experiment. In the second experiment, 4.20 g of chlorine reacted with 20.00 g of sodium, using up all the chlorine. 6.92 grams of sodium chloride were produced in the second experiment. Show that these results are consistent with the law of constant composition.

Checklist 3.2

Dear learner, check yourself on the following aspects before wrapping up studying this section. In the table given below, put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
state the law of conservation of mass and illustrate it using examples?		
describe the Law of Conservation of Mass using simple experiments?		
state the Law of Definite Proportions?		
state the Law of Multiple Proportions?		

Section 3.3: Atomic Theory

❁ Dear learner, in the previous sections, I defined a scientific theory in its simplified form.

Because I am going to deal with atomic theory now, I will give you a more elaborate definition of it.

A scientific theory is an explanation of an aspect of the natural world and universe that can be repeatedly tested and verified by the scientific method using accepted protocols of observation, measurement, and evaluation of results.

The word '**theory**' refers to the way we interpret facts. **Atomic theory** is, therefore, the way we interpret facts about atoms. In this section, we are going to discuss the historical development of atomic theory.

Learning Outcomes

Dear learner, when you have finished studying this section, you are expected to

- Describe Dalton's atomic theory.
- Describe the modern atomic theory.
- Compare and contrast Dalton's atomic theory with modern atomic theory.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the activity and self-test exercise questions. Make sure that you are clear on the meanings of the concepts, terms, definitions, and atomic theories. After doing so, check whether you achieved the learning outcomes indicated above. This section is further divided into two sub-sections, namely Dalton's atomic theory and Modern atomic theory. Let me begin with Dalton's atomic theory.

3.3.1 Dalton's Atomic Theory

Dear learner, in the previous sections, you have studied the concept that atoms are the fundamental building blocks of matter. The ideas regarding atoms of ancient times, however, had no experimental evidence and continued as mere speculation. These ideas, therefore, had to lay dormant for a long period until the Englishman John Dalton (***Figure 3.5***) proposed his atomic theory around 1803, based on certain observations and experimental results.

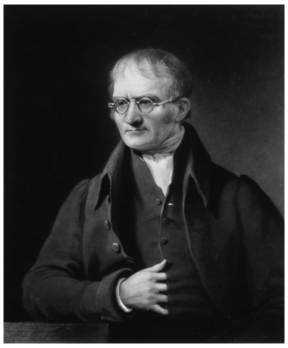


Figure 3.5 John Dalton, an English chemist, a meteorologist, and a physicist.

Although Democritus and many other scientists, philosophers, and others studied the composition of matter, they did not answer the questions raised by their atomic theories.

? Do you remember some of the questions raised against the atomic theory of Democritus and Leucippus?

In this section, you are going to study how these questions got answers because of the relentless efforts of scientists, including John Dalton.

? Dear learner, have you ever heard the name John Dalton before?

Let me introduce him and his contribution to atomic theory to you. The British scientist John Dalton was one of the renowned scientists who made a major leap forward in our understanding of the composition of matter in the 1800s. Dalton studied the weights of various elements and compounds. He perceived that matter is always combined in fixed ratios based on weight or volume, as in the case of gases. Chemical compounds always contain the same proportion of elements by mass, regardless of their amount. Dalton also observed that there could be more than one combination of two elements when forming compounds.

Let me ask you one question at this point.

? Of the three chemical laws studied in the previous sections, which laws does John Dalton's work support?

Don't worry if it is difficult to respond because I will give the answer for you. Dalton's work provided further support for the Law of Conservation of Mass and Proust's Law of Definite Proportions. From his experiments and observations, as well as the work of peers of his time, Dalton proposed a new theory of the atom. This later became known as Dalton's Atomic Theory.

☞ Dalton's atomic model is referred to as "the billiard ball model" because he defined an atom as having a ball-like structure.

Hereunder are the summarized general tenets of Dalton's atomic theory:

1. Elements are made of small particles called atoms.
2. Atoms can neither be created nor destroyed.
3. All atoms of the same element are identical and have the same mass and size.
4. Atoms of different elements have different masses and sizes.
5. Atoms combine in small whole numbers to form compounds.

? Dear learner, can you see the differences between Democritus's theory of matter and Dalton's atomic theory? What do you think is the contribution of Dalton's atomic theory in light of modern chemistry?

You can get the answer below.

☞ **Merits of Dalton's Atomic Theory**

The atomic theory explains the Law of Conservation of Mass and the Law of Multiple

Proportions.

Dalton was the first to recognize a workable distinction between the fundamental particle of an element (an atom) and that of a compound (a molecule).

Dear learner, Dalton's effort was not only limited to formulating atomic theory; he also proposed symbols for elements and compounds (***Figure 3.6***).

> ? Based on your previous grade knowledge of the symbols of elements, what do you comment on Dalton's symbols? Are they better than the symbols of elements you know? Why? Did you know who proposed the use of alphabets for symbols of elements you have studied in previous grades?

In unit four, you will study in detail the symbols of elements.

Here are the answers to the above-mentioned questions: The symbols of elements proposed by Dalton were difficult to remember and draw. Therefore, an alternative method of representing elements was proposed by Berzelius. He suggested that alphabets could be used as symbols to represent elements. Below are some of the symbols proposed by Dalton. Please take note of them.

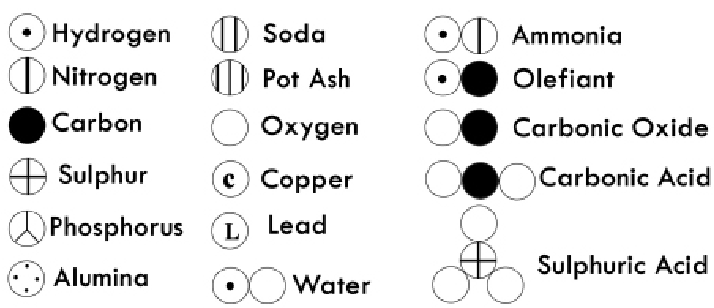


Figure 3.6 Dalton's 1808 AD symbols and formulae.

Activity 3.5

1. What is the basic difference between Democritus and Dalton in terms of discovering an atom?
2. State the five tenets of Dalton's Atomic Theory.
3. What led Dalton to his atomic theory?
4. What are the successes of Dalton's Atomic Theory?
5. Write Dalton's symbols and formulas for the following elements and compounds: carbon, sulphur, oxygen, copper, carbon dioxide, and carbonic acid.
6. Why are Dalton's symbols rejected by the scientific community these days?
7. Dalton thought that atoms were the smallest particles of matter. Scientists now know that atoms are composed of even smaller particles. Does this mean that the rest of Dalton's Atomic Theory should be thrown away?

3.3.2 Modern Atomic Theory

Dear learner, in the previous sections you have studied about the improvements made by John Dalton on the atomic theory of Democritus.

? How about Dalton's atomic theory? Was it acceptable in light of your eighth grade knowledge of sub-atomic particles? Which tenets of Dalton's atomic theory have problems in your understanding?

In this section, I will discuss the main points that will help you answer these questions.

At this stage, you are well aware of the ancient Greeks proposal that matter consists of extremely small particles called **atoms**. On the other hand, Dalton refined the ancient Greek proposal of atoms by clarifying that each element has a characteristic type of atom that differs in properties from the atoms of all other elements. Although Dalton's attempt to describe the concept of an atom was good, atoms were wrongly understood by him.

? What do you think is wrong with Dalton's perception of the atom?

Several other scientists were engaged in determining the essence of atoms, and a better understanding of atoms was reached. The Modern Atomic theory establishes the concepts of atoms, and how they compose matter. The sub-topic below narrates the historical development of modern atomic theory.

Development of the Modern Atomic Theory:

Dear learner, the modern atomic theory was built on John Dalton's atomic theory, and I want you to take note of which scientist did what and when. Several scientists have conducted many experiments and made various observations on atoms. The chronological discoveries of some of them are presented hereunder.

- The presence of protons was predicted by Eugene Goldstein in his canal ray experiment, in 1886.
- The first person to discover the electron as a sub-atomic particle and its charge-to-mass ratio was the British physicist J.J Thomson in 1897.
- Following this, in 1904, Thomson developed the 'Plum Pudding' model of the atom.
- Subsequently, in 1909, the American scientist Robert Millikan found the charge and mass of the electron.
- The British physicist Ernest Rutherford and his students Geiger and Marsden discovered the planetary model of an atom in 1911.
- In 1913, Niels Bohr, a learnerof Rutherford, proposed that electrons are arranged in concentric circular orbits around the nucleus.
- Subsequently, in 1920, Rutherford discovered the existence of the proton in the nucleus.
- In 1932, James Chadwick discovered the neutron, which is another sub-atomic particle.

Dear learner, the detailed discussions of all the aforementioned discoveries of the sub-atomic particles are presented in Section 3.4, below.

? Did you see how Dalton's atomic model was disproved?

All of these discoveries proved Dalton's Atomic Model wrong by revealing the following facts about the atom.

Drawbacks of Dalton's Atomic Theory

The indivisibility of an atom was proved wrong: an atom can be further subdivided into protons, neutrons, and electrons. However, an atom is the smallest particle that takes part in chemical reactions.

According to Dalton, the atoms of the same element are similar in all respects. However, the atoms of some elements vary in their masses and densities. These atoms of different masses are called isotopes. For example, chlorine has two isotopes with mass numbers 35 and 37.

Atoms of different elements differ in mass. This has been proven wrong in certain cases: argon and calcium atoms each have an atomic mass of 40. These atoms are known as isobars.

According to Dalton, atoms of different elements combine in simple whole number ratios to form compounds. This is not observed in complex organic compounds like sugar ($C_{12}H_{22}O_{11}$) and protein molecules.

Dalton's atomic theory did not consider allotropes. Allotropes are different forms of the same element, where the atoms combine in different ways, so at the same temperature and pressure they can exist in different forms. The most striking allotropes are carbon in the forms of diamond, graphite, and buckminsterfullerene.

Dear learner, the discoveries of the above facts about atoms led to the modified Modern Atomic Theory postulates. Below are the postulates of modern atomic theory. Take note of them and examine their differences from Dalton's atomic theory tenets.

☞ **Modern Atomic Theory Postulates:**

1. Elements are made of small particles called atoms.
2. Atoms cannot be created or destroyed during ordinary chemical reactions.
3. All atoms of the same element have the same atomic number, but may vary in mass number due to the presence of different isotopes.
4. Atoms of different elements are different.
5. Atoms combine in whole numbers to form compounds.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of an atomic theory.

1. https://www.britannica.com/science/Rutherford-model
2. https://opentextbc.ca/introductorychemistry/chapter/atomic-theory/
3. https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Atomic_Theory/Atomic_Theory

Activity 3.6

Choose the correct answer.

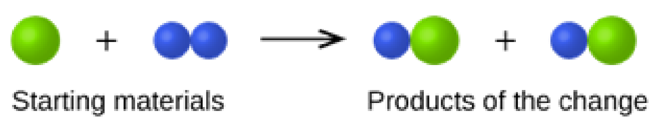
1. Near the end of the 18th century, the first atomic theory was developed. Which of the following was not part of that early understanding?
   A. All matter is made up of atoms.
   B. Elements are composed of only one type of atom.
   C. Atoms can combine with other atoms to make more complex substances.
   D. Electrons orbit the nucleus in electron clouds.
   E. All of the above concepts were understood in the 18th century.

Answer the following questions.

2. State the postulates of Modern Atomic Theory.
3. Compare and contrast Dalton's Atomic theory with Modern Atomic Theory.
4. What are the major drawbacks of Dalton's Atomic Theory?

Self-Test Exercise 3.3

1. In th following drawing, the green spheres represent atoms of a certain element. The blue spheres represent atoms of another element. If the spheres of different elements touch, they are part of a single unit of a compound. Which of these spheres represent a chemical change that may violet the ideas of Dalton's Atomic Theory?



2. Which postulate of Dalton's theory is consistent with the following observation concerning the weights of reactants and products? When 100 grams of solid calcium carbonate are heated, 44 g of CO_2 and 56 g of CaO are produced.
3. Samples of componds X, Y, and Z are analyzed, with results shown here. Do these data provide examples of the law of definite proportions, the law of multiple proportions, neither, or both? What do these data tell you about compounds X, Y, and Z?

Compound	Description	Mass of C	Mass of H
X	clear, colorless, liquid with a strong odor	1.776 g	0.148 g
Y	clear, colorless, liquid with a strong odor	1.974	0.329 g
Z	clear, colorless, liquid with a strong odor	7.812 g	0.651 g

4. Give examples of at least five isotopes of elements (other than the ones mentioned in this book) by browsing the internet.
5. Define the term isobar and provide a group of isobars (five different elements) with an atomic mass of 40 from the internet.

Checklist 3.3

Dear learner, check yourself on the following aspects before wrapping up studying this section. In the table given below, put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
describe Dalton's atomic theory?		
describe the modern atomic theory?		
compare and contrast Dalton's atomic theory with modern atomic theory?		

Section 3.4 Discoveries of the Fundamental Sub-atomic Particles and the Atomic Nucleus

- Dear learner, in the previous sections, you have seen how modern atomic theory has been developed.

? Who were the originators of the atom concept? Who improved it significantly? How did he improve it?

Following Dalton's Atomic Theory, however, several scientists investigated the nature of the atom by performing several experiments. This section deals with the discoveries of the sub-atomic particles known as electrons, protons, neutrons, and the nucleus. It was the discovery of these particles that dismissed Dalton's atomic model known as, "the billiard ball model".

Learning Outcomes

Dear learner, when you have finished studying this section, you are expected to

- Explain the discovery of the proton.
- Describe the discovery of the electron.
- Narrate the discovery of the nucleus.
- Discuss the discovery of the neutron.

Study Notes and Important Points

Dear learner, study the following notes and important points before you do the activity and self-test exercise questions. Make sure that you are clear on the meanings of the concepts, terms, and definitions. After doing so, check whether you achieved the learning outcomes indicated above.

This section is divided into four sub-sections. The first section is about the discovery of protons. The second sub-section deals with the discovery of electrons. The discoveries of the nucleus and neutron are in the third and fourth subs-sections, respectively.

3.4.1 Discovery of the Proton

? Dear learner, you have the information about the sub-atomic particles from your previous grade level lessons. What do you think is the charge of an atom? What do you think is the reason that the electrons revolve around the nucleus of an atom?

In this sub-section, I am going to describe these phenomena. Please follow who did what and how he/she did it attentively.

This is how the proton was discovered. Eugen Goldstein (1886) predicted the presence of positively charged particles in an atom based on the electrical neutrality of an atom. His discovery of proton was based on the cathode ray experiment conducted by using a discharge tube containing a perforated cathode (***Figure 3.7***) and filled with gas. In this electric discharge experiment, some faint luminous rays were found to travel from the direction of the positively charged anode and pass through the perforations in the negatively charged cathode without deflection by the cathode. These rays are called canal rays because they passed through the holes or canals in the cathode. Later on, they are called anode rays. These rays were further analysed, which led to the discovery of a positively charged sub-atomic particle called a "proton".

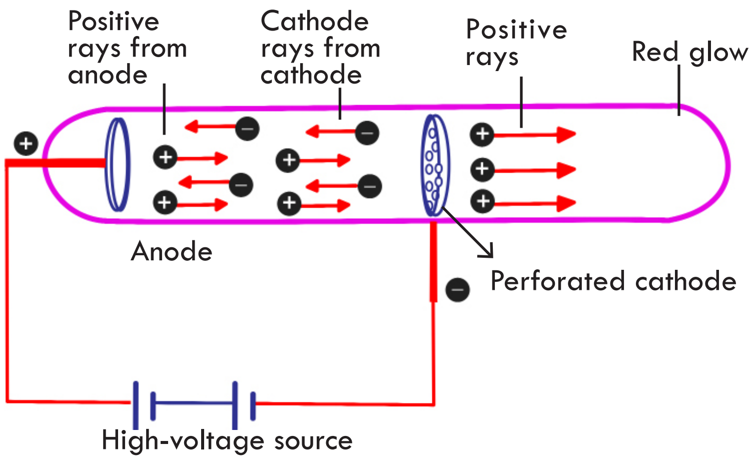


Figure 3.7 Anode rays travelling through perforations in the cathode, resulting in a red glow on the cathode ray tube.

Dear learner, at the time of the discovery of the canal rays, no one knew about electrons, and it was difficult to explain this phenomenon. Nowadays we understand Goldstein's experiment as follows: When an electric discharge is passed through the gas, some of the molecules of the gas are ionised and produce cathode rays. Cathode rays consist of electrons. These electrons move with high speed towards the anode.

? Why do you think they move towards the anode? Do you remember the principle "opposite charges attract each other" from your physics lesson?

As they move, they collide with the remaining molecules of the gas in the tube, causing them to lose electrons, resulting in positive ions. The positive ions formed are attracted by the perforated cathode. The stream of these positive ions causes a glow on the glass wall located at the opposite end of the discharge tube. On the other side of the discharge tube, the cathode rays produce a green light when they hit the fluorescent-coated end of the discharge tube. The stream of positive ions, so formed, constitutes the positive or **anode rays**.

? The question is, how did they come to know that these anode rays are protons? Who identified them as protons?

When the cathode ray tube contained hydrogen gas, the particles of the canal rays obtained were the lightest, and their charge-to-mass ratio (e/m) was the highest. Rutherford showed that these particles were identical to the hydrogen ion (hydrogen atom from which one electron has been removed). Due to this fact, these particles were named protons and were shown to be present in all matter. This is the first leap towards the discovery of the positively charged proton as part of the atomic structure. Today, we know that the only positively charged species in an atom is the proton.

Properties of canal rays:

1. Canal rays travel in straight lines.
2. They consisted of material particles.
3. They are deflected in an electric and magnetic fields opposite to that of cathode rays.
4. The nature or e/m ratio of canal rays depends upon the nature of the gas present in the cathode ray tube.
5. They (particles of canal rays) are simply positively charged gaseous ions.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of the discovery of protons.

1. https://www.vedantu.com/chemistry/canal-ray-experiment
2. https://byjus.com/chemistry/canal-ray-experiment/
3. https://www.youtube.com/watch?v=1JX7iTm3Uw8

Activity 3.7

1. What are canal rays?
2. How do canal rays form?
3. Mention the properties of anode rays.

3.4.2 Discovery of the Electron

? Dear learner, what happens to the fluorescent electric bulb when you turn on the switch in your home? What do you think happened inside the bulb? Why do some electric bulbs give off yellowish light and others white light?

In this section, I will briefly describe these phenomena. Carefully follow me.

The Crooke's Discharge Tube or Cathode Ray Tube

? Dear learner, do you know who discovered the discharge tube that Goldstein used in his canal-ray experiment?

In 1855, the German inventor Heinrich Geissler developed the mercury pump and produced the first good vacuum tubes. These tubes, as modified by **Sir William Crookes**, became the first to produce cathode rays, eventually leading to the discovery of the electron.

Sir William Crookes was the first scientist to design the discharge tube, which was later called the Crooke's Discharge Tube or Cathode Ray Tube.

Can you define a discharge tube? The discharge tube consists of a glass tube from which most of the air has been evacuated, with two metal plates sealed at both ends. These metal plates are called electrodes. These electrodes are connected to the positive and negative terminals of a battery. The electrode connected to the positive terminal is known as the anode and the electrode connected to the negative terminal is known as the cathode (***Figure 3.8***).

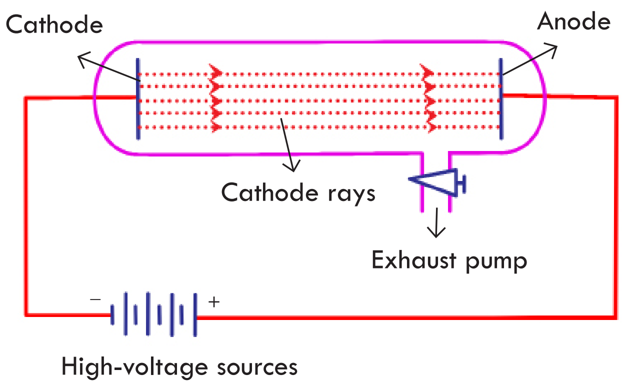


Figure 3.8 The Crooke's Discharge Tube or Cathode Ray Tube.

The electrodes are connected to a high voltage for the current to flow. The high voltage provides energy for the atoms of a gas to further split or break up. When both electrodes are connected to a high voltage (10,000 - 20,000 volts), the current starts flowing. At high pressure no electricity flows through the air in the discharge tube, so low pressure is used. Low pressure helps in the conduction of electricity. At high voltage and at normal atmospheric pressure, there is no effect. But keeping the same voltage and reducing the pressure to 0.0001 mm of Hg, a greenish glow was observed at the anode. This shows that some rays are emitted from the direction of the cathode, and are called **cathode rays**. A good example of a cathode ray tube would be a **fluorescent bulb** in your home (***Figure 3.9***). These bulbs give white light, where as those with tungsten filaments give yellowish light due to the glowing of the tungsten filament when an electric current passes through them.

Figure 3.9 Compact fluorescent lamps

? Dear learner, from your previous grade level knowledge, can you define an electron? Who do you think was the scientist that discovered the electron? How has he discovered?

The electron was one of the fundamental sub-atomic particles that was discovered by the British physicist Joseph John Thomson in 1897. In the discovery of electrons, J.J. Thomson performed several experiments, which are presented below. Please follow me and learn how Thomson discovered the electron.

Thomson's Experiment on the Path of Cathode Rays

Thomson conducted some experiments with a discharge tube to study the properties of cathode rays.

? Can you tell me what the cathode rays are from Goldstein's experiment?

The first experiment he has performed is studying how cathode rays travel in the discharge tube by placing a small object between the cathode and the anode. The cathode rays travel towards the node because they are attracted by the positively charged anode. When an object is placed opposite the direction of the cathode rays, a sharp shadow having the shape of the object is formed on the surface of the discharge tube glass (***Figure 3.10***). Why? Thomson concluded that cathode rays travel in straight lines.

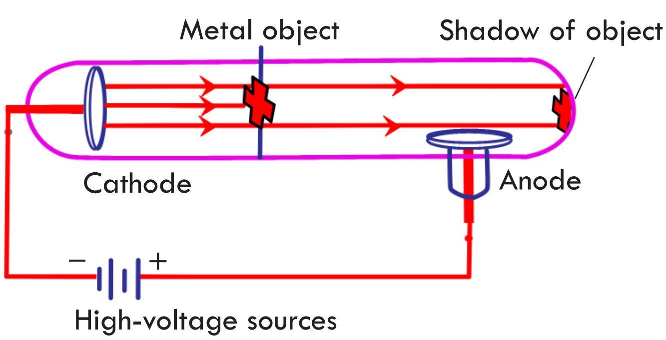


Figure 3.10 Cathode rays creating a shadow of a small object on the cathode ray tube screen.

Thomson's Experiment on the Particle Nature of the Cathode Rays

Thomson's second experiment was performed by placing a light paddle wheel between the cathode and the anode in the discharge tube to study the particulate nature of the cathode rays (***Figure 3.11***).

? What do you think will happen if the electrons have a particle nature?

Thomson expected to see if the cathode rays could move the paddle wheel. If they do so, then they have a particle nature. He observed the rotation of the light paddle wheel, which revealed that the cathode rays are small particles with mass and kinetic energy.

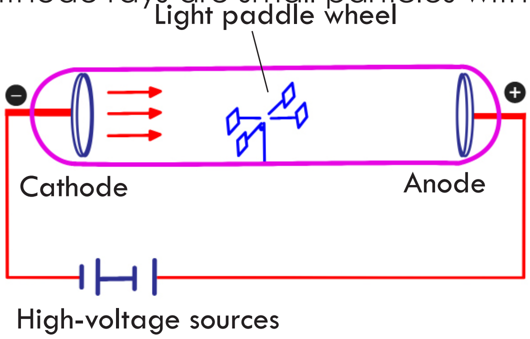


Figure 3.11 Cathode rays rotating light paddle wheel between the cathode and anode.

? When cathode rays are allowed to fall on a paddle wheel, it rotates. What does this tell you? What do you conclude from this?

This is possible only when the rays striking it have material particles. From this, it can be concluded that cathode rays consist of some material particles. Today we know that the electron has both a particle and a wave nature (the wave nature of electrons will be discussed in grade 11). Its weight, however, is too small compared to the other sub-atomic particles. Therefore, Thomson's contribution to modern atomic structure is significant in this regard.

? But what do you think the charge of the electron is? Who proved it to be so?

Thomson's Experiment on the Charge of the Cathode Ray

William Crookes experimented with the interactions of cathode rays and magnets for the first time. His observations on the deflection of the cathode rays by magnetic fields led him to conclude that they were composed of **negatively charged molecules**. Years later, Thomson determined the molecules hypothesized by Crookes were actually negatively charged subatomic particles that he called **corpuscles**, but which were eventually named **electrons**.

In 1899, Thomson performed the third experiment to investigate the charge of the cathode ray by passing cathode rays through electric and magnetic fields (***Figures 3.12*** and ***3.13***). ON passing through an electric field, the cathode rays bent towards the positive plate. This proved that cathode rays are negatively charged particles. Thomson concluded that the particles had a net negative charge; these particles are now called electrons. You know from your knowledge of electricity in physics that when an electric field is applied perpendicularly to the path of a negatively charged species, it deflects towards a positive plate. Today, we know that the only negatively charged fundamental particle in an atom is the electro[illegible]nmense in this regard.

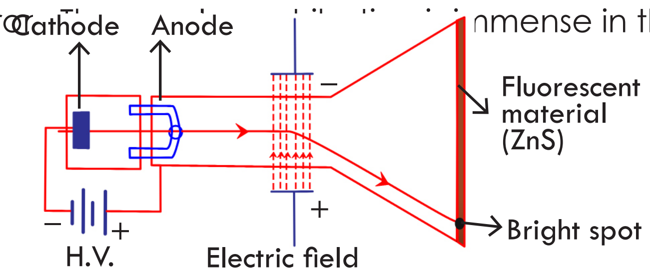


Figure 3.12 Cathode rays bend while passing through an electric field.

? Dear learner, from your electromagnetism lesson in physics, what do you think will happen to the electron upon passing through a magnetic field?

Passing cathode rays through a magnetic field applied perpendicular to the path of the cathode rays (***Figure 3.13***) resulted in the deflection of the cathode rays perpendicular to the applied magnetic field. From your electromagnetism lessons in physics, you know that a moving electric charge generates a magnetic field. A magnetic field induces electric charge movement, producing an electric current. In an electromagnetic wave, the electric field and magnetic field are perpendicular to one another. When the magnetic field is applied perpendicularly to the path of cathode rays, they get deflected towards the north pole of the magnet, which is expected of negatively charged particles. This further confirmed that cathode rays are negatively charged.

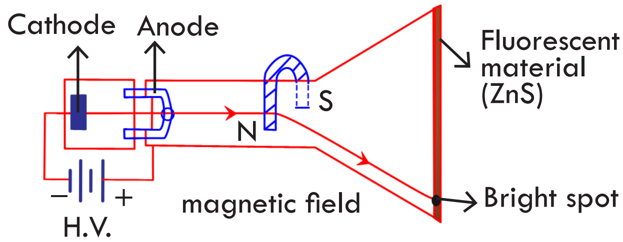


Figure 3.13 Cathode rays bend while passing through a magnetic field.

Thomson carried out the above experiments with different gases at low pressure to decrease the interaction between gas molecules in the discharge tube. No change in the properties of the cathode rays was observed despite the use of different gases in the discharge tube. He also used a cathode, which is made up of different materials, and got the same result. He demonstrated that cathode rays could move a paddlewheel placed between two electrodes, and could be deflected, or bent, by a magnetic or electric field, which indicated that cathode rays consist of charged particles. By measuring the extent of the deflection of the cathode rays in a magnetic or electric fields of various strengths, Thomson was able to calculate the charge-to-mass ratio of the particles to be 1.76×10^8 *coulomb per gram (C/g)*. These particles, emitted from the negatively charged cathode and repelled by the negative terminal of an electric field, had a net negative charge. He finally concluded that electrons are sub-atomic particles.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of the discovery of the electrons.

1. https://www.britannica.com/science/atom/Discovery-of-electrons
2. https://padakshep.org/otp/subjects/chemistry/physical-chemistry/discovery-of-electrons-protons-and-neutrons/
3. https://www.youtube.com/watch?v=vXOeehVTcRA

Activity 3.8

1. Why did Thomson take gas at low pressure while conducting the experiments?
2. How did Thomson discover the particle nature of electrons?
3. What happened to the cathode rays when they were allowed to pass through electric and magnetic fields? What does this prove?
4. Why did Thomson conclude that electrons could be found in the atoms of all elements?

J.J. Thomson's Atomic Model

Dear learner, in the previous sections you have studied Democritus's atomic model.

? What is a model?

You have also studied the discovery of the electron by Thomson. Based on your knowledge of the discovery of electrons by Thomson, what does Thomson's atomic model look like? Here is Thomson's atomic model prediction.

Following the discovery of the electron, J.J. Thomson developed what became known as the 'plum pudding' model in 1904 (***Figure 3.14***). Plum pudding is an English dessert similar to a blueberry muffin.

Thomson's model of the atom shows electrons as negatively charged plums in a positively charged pudding. In other words, the electrons were embedded in a uniform sphere of positive charge, like blueberries stuck into a muffin. The positive matter was thought to be jelly-like or similar to a thick soup. The electrons were somewhat mobile. As they got closer to the outer portion of the atom, the positive charge in the region was greater than the neighbouring negative charges, and the electron would be pulled back more toward the centre region of the atom. The best example of locally available material for Thomson's Model is watermelon. The seeds of the watermelon would mimic the electrons, and the watery, soft, reddish part is the positively charged matter (***Figure 3.14***).

? How valid is Thomson's atomic model prediction? Can we accept it as the right atomic model? Why?

Figure 3.14 J.J. Thomson's Atomic Model (left); the 'plum pudding' model (centre); watermelon (right).

Validity of Thomson's Atomic Model

? Dear learner, what do you think of the validity of Thomson's atomic model? What about its failure?

Thomson's Atomic Model could successfully explain the electrical neutrality of an atom. It, however, failed to explain how the positively charged particles are shielded from the negatively charged electrons without getting neutralized. Atomic neutrality means the presence of equally positive and negative charges in specific area. Today, we know that positively charged protons exist in the nucleus of an atom, which of course, is at the centre of the atomic structure, and the electrons are revolving around them. Therefore, Thomson's prediction is not negligible although it lacks some knowledge.

Millikan's Oil Drop Experiment

? Dear learner, who do you think is the scientist that discovered the charge (in coulombs) and the mass of the electron? How did he discover these properties of an electron?

Follow the answers to these questions.

An American scientist, Robert Millikan (1909), carried out a series of experiments using electrically charged oil droplets. In this experiment, some fine oil droplets were allowed to be sprayed into the chamber by an atomizer. The air in the chamber is subjected to ionization by X-rays. The electrons produced by the ionization of the air attach themselves to the oil drops. When a sufficient amount of electric field is applied, which can just balance the gravitational force acting on an oil drop, the drop remains suspended in the air.

? Dear learner, what information could Millikan's experiment provide regarding electrons?

From this experiment, Millikan observed that the smallest charge found on the cathode rays was approximately 1.59×10^{-19} coulombs, and the charge on each drop was always an integral multiple of that value. Based on this observation, he concluded that 1.59×10^{-19} coulombs is the smallest possible charge, and considered that value to be the charge of the electron. With this information and Thomson's charge-to-mass ratio (1.76×10^{8} C/g), Millikan determined the mass of an electron (***Figure 3.15***) as follows:

Mass of electron = e/(e/m)

$$(1.59 \times 10^{-19}\ C)/(1.76 \times 10^{8}\ C/g) = 9 \times 10^{-28}\ g$$

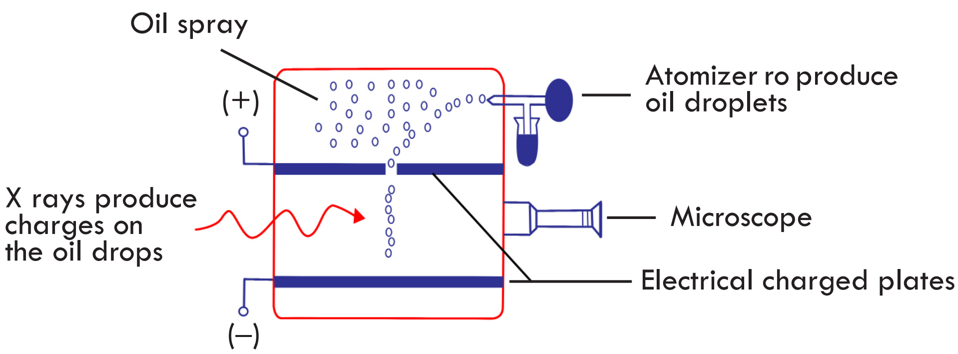


Figure 3.15 The apparatus used by Millikan to determine the charge of an electron.

? Dear learner, what do you understand from your electricity lesson in physics about the relationship between force and charge in an electric field?

From our understanding of electricity today, it is obvious that the force on any electric charge in an electric field is equal to the product of the charge and the electric field. Millikan was able to measure both the amount of electric force and the magnitude of the electric field on the tiny charge of an isolated oil droplet. From this data, he determined the magnitude of the charge itself.

Summary of the properties of cathode rays:

They travel in a straight line from the cathode and cast shadows on metallic objects placed in their path.

They cause the mechanical motion of a small puddle-wheel placed in their path; they possess kinetic energy and must be material particles.

Their properties are independent of the electrodes, and the gas present in the cathode- ray tube. Hence, they are found in all atoms.

The charge/mass ratio of the rays is constant.

Upon passing through an electric field, the cathode rays bend towards the positive plate, showing that they are negatively charged.

Cathode rays are negatively charged and affected by the magnetic field.

Cathode rays affect the ZnS screen. When cathode rays are allowed to strike the ZnS screen, they produce a faint greenish fluorescence.

Cathode rays ionise gases. When cathode rays are allowed to pass through gases, different glows are seen in the tube. These different glows are due to the ionisation of gases.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of Thomson's atomic model and Millikan's oil drop experiments.

1. https://padakshep.org/otp/subjects/chemistry/physical-chemistry/discovery-of-electrons-protons-and-neutrons/
2. https://www.toppr.com/ask/question/who-discovered-the-charge-on-electron/

Activity 3.9

1. What is the magnitude of the absolute charge of the electron?
2. What is the absolute mass of an electron in kilograms?
3. Who discovered the charge on an electron?
4. Who determined the e/m ratio of an electron? How?
5. Describe Thomson's atomic model. Give examples.

3.4.3 Discovery of the Nucleus

Dear learner, so far, you have studied the discoveries of protons and electrons. You have also seen the negligible mass of an electron.

? What can you say about the mass of an atom based on these facts? Based on your previous grades science lessons, can you define what the nucleus is? Where is it found in an atom? Who discovered it? When was it discovered? How was it discovered?

Follow me carefully to get answers to these questions.

In 1920, with the discovery of the electrons and protons, it was thought that the inner structure of the atom was complete. The mass of the electron is negligible; hence, the mass of an atom should be equal to the mass of protons concentrated inside the nucleus. Different atoms have different numbers of protons, hence different atomic masses. However, it was observed that there was a discrepancy between the actual atomic mass and the calculated atomic mass.

For example, an atom of carbon has six protons; therefore, its mass should be six times that of a hydrogen atom, which has one proton. But, experimentally, it was found that the mass of carbon atoms is twelve times that of the hydrogen atom. A similar problem was encountered with regard to the mass of other atoms.

? The question is, what was the reason for this discrepancy?

This is the question that led to the discovery of the nucleus and, of course, the neutron as well.

? Who answered this question for the first time?

Ernest Rutherford was the first scientist to predict the reason for this discrepancy. He predicted that, along with protons, there were some other neutral particles present inside the nucleus. In a single famous experiment, the British physicist **Ernest Rutherford** showed explicitly that Thomson's model of the atom was incorrect. He used α-particles in his experiment. But what are α-particles?

α-Particles are composite particles consisting of two protons and two neutrons tightly bound together.

In 1920, Rutherford targeted a stream of positively charged α-particles at a very thin gold foil target (***Figure 3.17a***) and inspected how the α-particles were scattered by the foil. The particles were produced by a sample of radium. Gold was chosen since it could be easily hammered into very thin sheets, minimizing the number of atoms in the target. If Thomson's model of the atom were correct, the positively charged α-particles should smash through the regularly dispersed mass of the gold target like cannonballs (***Figure 3.16***).

Figure 3.16 Regularly distributed cannonballs.

They might have been traveling a little slower when they appeared, but they should pass essentially straight through the target (***Figure 3.17b***). However, a small fraction of the α-particles were deflected at large angles, and some were reflected directly back at the source (***Figure 3.17c***).

? Why do you think that these deflections occur? What do they tell you?

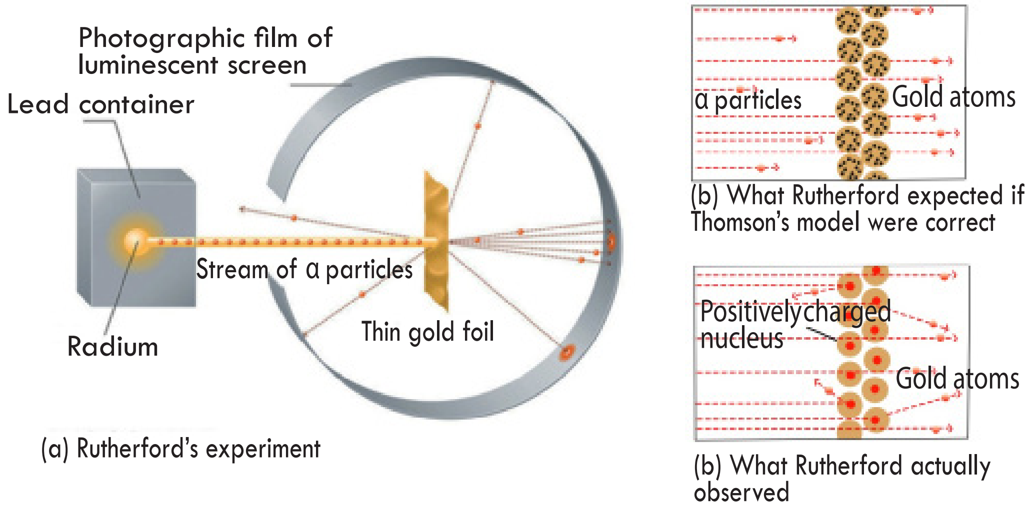


Figure 3.17 Summary of Rutherford's Experiments.

? Dear learner, were Rutherford's results consistent with Thomson's atomic model? Why? What do Rutherford's results suggest about the atomic model?

Rutherford's results were not consistent with Thomson's atomic model, in which the mass and positive charges are distributed regularly throughout the volume of an atom. Instead, they strongly suggested that both the mass and positive charge are concentrated in a minute fraction of the volume of an atom, which Rutherford called the nucleus. It made sense that a small fraction of the a-particles bumped into the dense, positively charged nuclei. This resulted in large deflections, or almost head-on deflections, causing them to be reflected straight back at the source.

? If Rutherford's prediction is correct, i.e., that the positively charged protons are located in the nucleus of an atom, what holds them together?

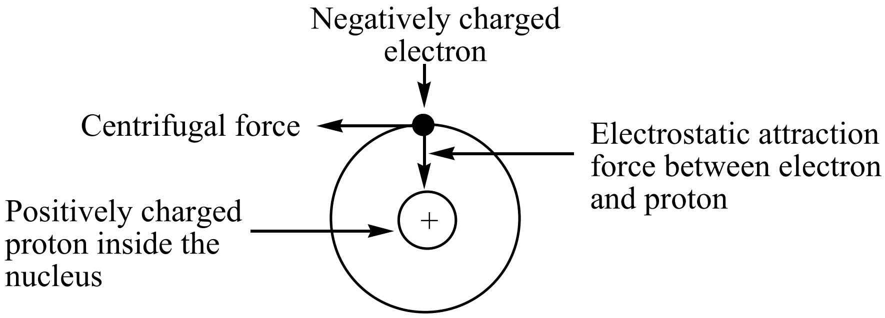
Rutherford's explanation for the stability of the nucleus and atom: After the success of bringing out a successful atomic model, Rutherford was cornered by the other scientists by the question: "Why does the nucleus not disintegrate due to the repulsion among the protons?" To explain the stability of the nucleus, Rutherford predicted the presence of neutral particles. The presence of these **neutrons** between the protons neutralises the repulsion among the protons. Rutherford predicted the presence of the **neutron** even before it was discovered, which he proved later on.

? Can you draw Rutherford's atomic model before you move on to the next note?

Coming to the stability of the atom, Rutherford explained that the revolving electron is under the influence of two types of forces.

i. The electrostatic force of attraction between the nucleus and the electron and
ii. The centrifugal force directed away from the revolving electron.

These two forces are equal and opposite and hence keep the electron in equilibrium in the path. This is the reason why electrons do not fall into the nucleus in spite of the inward nuclear pull, according to Rutherford.



Today, it is known that strong nuclear forces, which are much stronger than electrostatic interactions, hold the protons and the neutrons together in the nucleus. For this and other insights, Rutherford was awarded the Nobel Prize in Chemistry in 1908.

Rutherford's Atomic Model:

Dear learner, let me summarize the findings of Rutherford's experiment and show you his atomic model. The atom is mostly composed of empty space. The whole positive charge and mass of the atom are concentrated in a small central part known as the nucleus. The size of the nucleus is so small that its diameter is 10^5 times less than that of an atom. The diameter of the nucleus has been estimated by Rutherford as 10^{-13} cm, in contrast to that of an atom, which is 10^{-8} cm. The electrons existing outside the nucleus rotate around the nucleus with high velocities to counterbalance the electrostatic forces of attraction between protons and electrons. Rutherford's atomic model bears a resemblance to the planetary motion in the ***solar system*** (grade 8). Rutherford's model of an atom is, therefore, also called **the Planetary Model** (*Figure 3.18*).

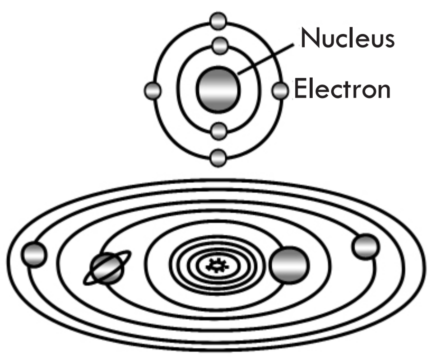


Figure 3.18 Rutherford's Model (above) of an Atom in comparison to the Planetary Model(below).

Rutherford's Atomic Model also became known as **the nuclear model.** Why? In the nuclear atom, the protons and neutrons, which contain nearly all of the mass of the atom, are situated in the nucleus at the centre of the atom. The electrons are dispersed around the nucleus and occupy most of the volume of the atom. It is worth stressing just how small the nucleus is compared to the rest of the atom. What things can you compare to show the relative size of an atom and its nucleus? If we could inflate an atom to the size of a large professional football stadium, the nucleus would be about the size of a cat's eye.

? Can you imagine how small the nucleus of an atom is? Do you think that Rutherford's atomic model is complete? Why?

Rutherford's Model proved to be a significant step towards a full understanding of the atom. It did not, however, fully address the nature of the electrons, and how they reside in the vast space around the nucleus. It was not until some years later that a full understanding of the electron was realized. This proved to be the key to understanding the chemical properties of elements.

Rutherford's model increased our understanding of the atom by suggesting the following:

- The nucleus is a very small, dense, positively charged core of the atom.
- All of the atom's positively charged particles, called protons, are located in the nucleus of the atom.
- Mostly, empty space surrounds the nucleus.
- Rapidly moving, negatively charged electrons are scattered outside the nucleus around the atom's edge in what is referred to as the 'electron cloud'.

Legitimacy of Rutherford's Atomic Model

Rutherford's Atomic Model could wonderfully explain the presence of a positively charged nucleus and the presence of electrons outside the nucleus in an atom. The failure of Rutherford's theory, however, stemmed from two major objections:

This model is inconsistent with the principles of classical electro-dynamics. According to classical electro-dynamics, any charged particle in circular motion releases energy uninterruptedly. The electron, being a charged particle in circular motion, loses energy. This should finally result in its curved path towards the nucleus, and the atom should then collapse.

The second major objection to Rutherford's model came from the pattern of atomic spectra. A detailed explanation of this would be dealt within the syllabus of Grade 11.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of Rutherford's atomic model.

1. https://youtu.be/5pZj0u_XMbc
2. https://flexbooks.ck12.org/cbook/ck-12-chemistry-flexbook-2.0/.
3. https://chem.libretexts.org/Courses/Anoka-Ramsey_Community_College/Introduction_to_Chemistry/04%3A_Atoms_and_Elements/4.03%3A_Discovery_of_the_Nucleus

Activity 3.10

1. Why is Rutherford's Model called the nuclear model?
2. Who discovered the protons? Based on what experiment was he able to discover them?
3. According to Rutherford's Atomic Model, where are the protons and electrons located in an atom?
4. Describe Rutherford's Atomic Model.
5. If Rutherford's Atomic Model is correct, then the atom should collapse. Explain?

The Niels Bohr Atomic Model:

Dear student, you have seen the limitations of Rutherford's atomic model. Now I will briefly discuss the Niels Bohr atomic model that brought the solution to Rutherford's model. In 1913, a Danish scientist, Niels Bohr, could effectively overcome the limitations of Rutherford's atomic model based on the Quantum Theory of Radiation proposed by **Max Planck**. The concept of Quantum Theory is, however, beyond the scope of this section. You will learn about it in Grade 11. At this level, I will only present the principles associated with Bohr's Atomic Model.

Bohr, a learnerof Rutherford's, developed a new model of the atom. The following five principles can summarize the Bohr's Model.:

Electrons are arranged in concentric circular orbits around the nucleus (see ***Figure 3.19***).

Electrons occupy only certain orbits around the nucleus. Those orbits are stable and are called 'stationary' orbits or shells.

Each orbit or shell is associated with a fixed amount of energy. Hence, these are also called energy levels and are designated K, L, M, and N, respectively.

The energy associated with a certain energy level increases with its distance from the nucleus. Hence, if the energies associated with the K, L, M, N shells are E1, E2, E3, . . ., etc., respectively, then E1 < E2 < E3, . . ., etc.

As long as the electron rotates in a particular orbit, it does not lose its energy.

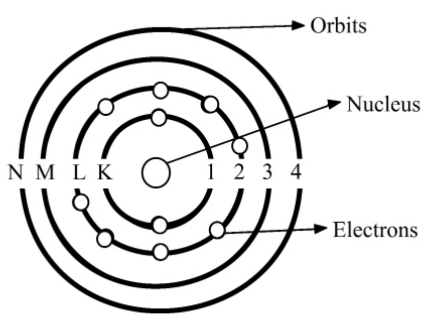


Figure 3.19 Neil Bohr's Atomic Model.

Resource

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding Bohr's atomic model.

1. https://byjus.com/chemistry/bohrs-model/

Activity 3.11

Choose the correct answer for the following question:

1. Which model can be described as negatively charged electrons orbiting a positively charged nucleus in definite paths?

A. The Bohr Model
B. The J.J. Thomson Model
C. The Rutherford Model.
D. The Democritus Model
E. The Leucippus Model

Fill in the blank space.

2. The circular paths in which electrons revolve are called __________.

Answer the following questions.

3. On what basis did Bohr propose his atomic model?
4. What are the orbits, and why are they called stationary orbits?

3.4.4 Discovery of the Neutron

Dear learner, in Rutherford's atomic model discovery, he predicted the presence of neutrons.

? Did you remember when he predicted the presence of neutrons?

In this section, I am going to present who discovered neutrons and how they were discovered. Please follow me carefully.

After the discovery of the proton, physicists predicted that there were likely other particles in the atomic nucleus. This was seen in the fact that elements heavier than hydrogen had a larger atomic mass than their atomic number (the number of protons).

? Did you know why hydrogen has the same atomic number and atomic mass but other elements do not?

Theories for the additional sub atomic particles included proton whose charge was shielded by electrons in the nucleus or an unknown neutral particle.

In 1932, the French physicists **Frederic** and **Irene Joliot-Curie** did an experiment by bombarding beryllium nuclei with a-particles. In this experiment, they observed the release of unknown radiation, which ejected protons from the nuclei of various substances. Joliot-Curies hypothesized that this radiation was **γ-ray**. Since γ-rays are well known, they discarded their experimental result and did not proceed with it. So who discovered neutrons?

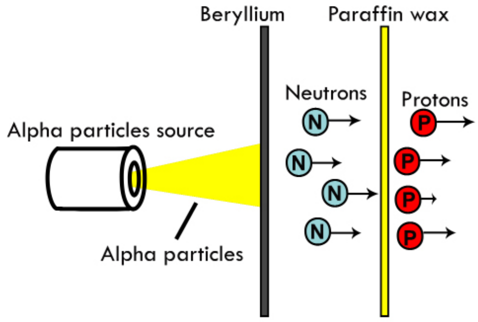


Figure 3.20 James Chadwick's beryllium bombardment experiment.

In 1932, the English physicist **James Chadwick** (*Figure 3.21*) was convinced that a-particles did not have sufficient energy to produce such powerful γ-rays. In his beryllium bombardment experiment, he exposed the radiation that emits from beryllium to an electric field and observed no deflection of the radiation. Based on his experimental results, Chadwick made the following observations:

A paddle wheel was placed behind the Beryllium nucleus and the nucleus was bombarded with a-particles. It was observed that the paddle wheel rotates. From this, it was concluded that the beryllium nucleus emits some invisible radiation with material particles.

When these invisible radiations were allowed to pass through an electric field, no deviation was seen. This confirmed the fact that these rays contained neutral particles. These neutral particles were called neutrons by James Chadwick.

This discovery provided a new tool for atomic disintegration, and led to a new model of the atomic nucleus, which is composed of protons and neutrons (*Figure 3.22*). Neutrons could be captured by hydrocarbons or wax as, shown in *Figure 3.20*.

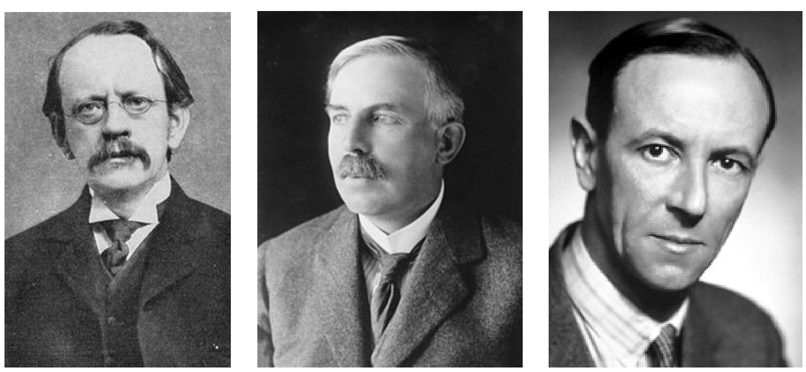


Figure 3.21 J.J. Thomson (left), Ernest Rutherford (centre), and James Chadwick (right).

Dear learner, the discovery of fundamental particles has ultimately resulted in the formation of a basic atomic model. Chadwick conceived that the atom was understood as a nucleus with protons and neutrons, assuming almost the entire mass of the atom, with the electrons orbiting the nucleus at their corresponding energy levels. For this discovery, he received the Nobel Prize in 1935.

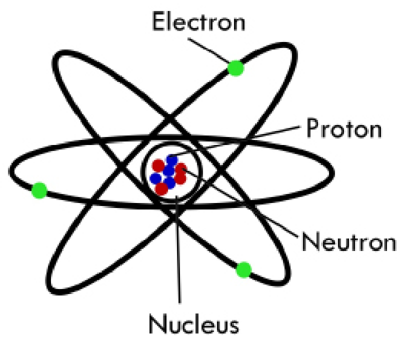


Figure 3.22 James Chadwick's Atomic Model.

Resource

Dear learner, please go to the internet and copy and paste this URL (website link) so that you can get a better understanding of the discovery of neutrons.

1. https://study.com/academy/lesson/james-chadwick-biography-atomic-theory.html

Activity 3.12

Fill in the blank space.

1. Neutrons were discovered by bombarding beryllium with ___________.

Answer the following questions.

2. Who discovered neutrons?
3. Why was the presence of neutrons in an atom predicted?
4. How were the neutrons discovered?

Self-Test Exercise 3.4

1. What is Eugen Goldstein's contribution to the atomic structure?
2. How did JJ Thomson contribute to the atomic model?
3. What is Millikan's contribution to the atomic structure?
4. How did Rutherford contribute to the atomic model?
5. How did the French physicists Frederic and Irene Joliot-Curie contribute to Chadwick's discovery of the neutron?
6. How did Niels Bohr contribute to the atomic model?
7. How did James Chadwick contribute to the atomic model?

Checklist 3.4

Dear learner, check yourself on the following aspects before wrapping up studying this section. In the table given below, put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it. You must answer all the questions and revise those with an "X' mark. Can I ...

Competencies	Yes	No
explain the discovery of the proton?		
describe the discovery of the electron?		
narrate the discovery of the nucleus?		
discuss the discovery of the neutron?		

Section 3.5 Composition of an Atom and the Isotopes

☸ Dear learner, in the previous section you saw the discoveries of the fundamental sub-atomic particles.

? Can you mention them? What electrical charges does each one of them possess? Which sub-atomic particles are responsible for the mass of an atom?

Atoms have different properties based on their arrangement and the number of their subatomic particles. Atoms of some elements have the same number of protons, but a different number of neutrons. This resulted in the same elements with different masses, which in turn led to different properties.

Dear learner, you are familiar with the concepts of relative mass, the charge and location of subatomic particles, atomic number and mass number, determination of electrons, protons and neutrons in an atom for the first 10 elements of the periodic table from your Grade 8 Science, Unit 2 lessons.

? Can you mention five of these elements with their electron numbers? Can you define the terms atomic number and mass number?

In this section, the electrons, protons, neutrons, atomic number, mass number, atomic mass, isotope, main energy levels, the electronic configuration on main shells, and the valence electrons of the first 20 elements in the periodic table are briefly described. These are further divided into six sub-sections. The first sub-section is about electrons, protons, and neutrons. The second sub-section deals with the calculation of atomic and mass numbers. Atomic mass and isotopes are the third sub-section. Main energy levels and electronic configuration on main shells are discussed in the fourth and fifth sub-sections, respectively. The last sub-section is about valence electrons.

Learning Outcomes

Dear learner, when you have finished studying this section, you should be able to

- Write the relative charges of an electron, a proton and a neutron.
- Tell the absolute and relative masses of an electron, a proton and a neutron.
- Distinguish the number of protons and electrons in an atom from the atomic number of the element.
- Calculate the number of neutrons from the given values of atomic numbers and mass numbers.
- Explain the terms ‘atomic mass’ and’ isotope’.
- Calculate the atomic masses of elements that have isotopes.
- Describe the main energy level.
- Define the electronic configuration.
- Write the ground- state electronic configuration of the elements.

- Draw diagrams to show the electronic configuration of the first 20 elements.
- Write the electronic configuration of the elements using noble gas as a core.
- Describe valence electrons.

3.5.1 Electrons, Protons and Neutrons

Dear learner, from your previous lessons, you understood that the mass of a proton and a neutron is far greater than the mass of an electron.

> ? What local materials can you give as an example that represents these three sub-atomic particles? Can you describe how these three sub-atomic particles coexist in an atom, by considering their charge and mass?

The Electrons

Electrons are one of three fundamental particles that make up atoms (***Figure 3.24***). Electrons are extremely small (***Figure 3.23***). The mass of an electron is only about 1/2000 the mass of a proton or a neutron, which is about 0.00054897 atomic mass units (amu) or 9 x 10^{-31} Kg. So, electrons contribute almost nothing to the total mass of an atom. The electric charge of an electron is −1, which is equal to but opposite to the charge of a proton. All atoms have identical numbers of electrons and protons, so the positive and negative charges 'cancel out' making atoms electrically neutral.

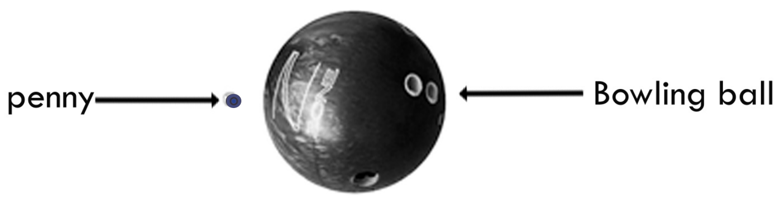


Figure 3.23 Comparison of an electron (penny or cent) with a proton (bowling ball).

The Protons

The proton is one of the three sub-atomic particles that make up the atom. Protons are found in the nucleus of the atom (***Figure 3.24***). Protons have a positive electrical charge of one (+1) and a mass of 1.0073 amu, which is about 1.67×10^{-27} kg. Together with neutrons, they make up virtually all of the mass of an atom.

The Neutrons

All atoms of all elements except most atoms of hydrogen (protium) have neutrons in their nucleus (***Figure 3.24***). Unlike protons and electrons, which are electrically charged, neutrons have no charge. That's why the neutrons in ***Table 3.1***are labeled n^0. The zero superscript stands for 'zero charge'. The mass of a neutron (1.0087 amu) is a little greater than the mass of a pro ... uals about 1.67 × 10-27 kg. A neutron also has ... 7 × 10-15 meters.

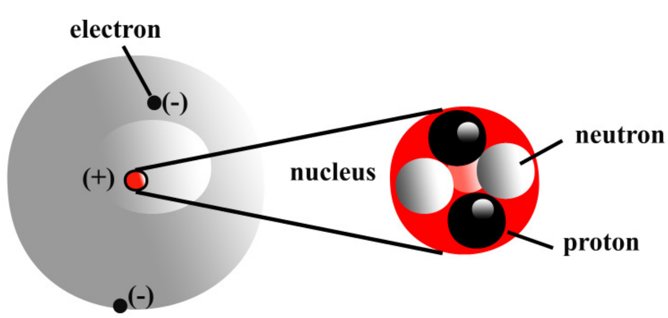


Figure 3.24 The sub-atomic particles.

Table 3.1 Physical properties of sub-atomic particles.

Particle	Symbol	Charge (coulombs)	Mass (Kg)	Relative charge	Mass (amu)	Location
Proton	P^+	$+1.59 \times 10^{-19}$	1.673×10^{-27}	+1	1.0073	Inside the nucleus
Neutron	n^0	No charge	1.675×10^{-27}	0	1.0087	Inside the nucleus
Electron	e^-	-1.59×10^{-19}	9×10^{-31}	-1	5.4858×10^{-4}	Outside the nucleus

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of the electrons, protons and neutrons.

1. https://www.adda247.com/school/mass-of-electron-proton-neutron/
2. https://www.middleschoolchemistry.com/lessonplans/chapter4/lesson1

Activity 3.13

1. Write the mass and charge of the fundamental particles of an atom.
2. Compare the masses of protons and neutrons.
3. Compare the charges of electrons and protons.
4. Neutrons are neither attracted to nor repelled by protons and electrons. Explain?
5. Why does the mass of an atom depend only on the mass of protons and neutrons?

3.5.2 Atomic Number and Mass number

Dear student, in the previous subsection, we discussed the masses of electrons, protons and neutrons.

? So, which particles account for the mass of an atom? How is it possible to distinguish atoms of one element from atoms of another element?

It is important to be able to differentiate atoms of one element from atoms of another element. Elements are pure substances that make up all other matter, so each one is given a different name. From your 7^{th} Grade science lessons, you know that the names of elements are represented by unique one- or two-letter symbols, such as H for hydrogen, C for carbon, or He for helium. However, it would be more authoritative if these names could be used to identify the numbers of protons and neutrons in the atoms. That's where atomic numbers and mass numbers are useful.

? Dear learner, did you know what an atomic number is? What do you think it is used for?

Scientists are always interested in atomic number and how it differs between different elements since an atom of one element can be distinguished from an atom of another element by the number of protons in its nucleus. The number of protons in an atom is called its atomic number (Z). This number is very important because it is unique for atoms of a given element.

All atoms of an element have an identical number of protons, and every element has a unique number of protons in its atoms (***Table 3.2***). If an atom has only one proton, we know that it's a hydrogen atom. An atom with two protons is always a helium atom. If scientists count four protons in an atom, they know it's a beryllium atom. An atom with three protons is a lithium atom; an atom with five protons is a boron atom; an atom with six protons is a carbon atom; the list goes on.

Table 3.2 Atomic number and mass number of atoms of the first six elements

Name	Protons	Neutrons	Electrons	Atomic Number (Z)	Mass Number (A)
Hydrogen	1	0	1	1	1
Helium	2	2	2	2	4
Lithium	3	4	3	3	7
Beryllium	4	5	4	4	9
Boron	5	6	5	5	11
Carbon	6	6	6	6	12

Dear learner, did you know the relationship between atomic number and the number of electrons? Of course, since neutral atoms have the same number of electrons as that of proton atoms, an element's atomic number also tells you how many electrons are in a neutral atom of that element.

? Why do you think atoms are neutral?

Atoms are neutral in electrical charge because they have the same number of negative electrons as positive protons (***Table 3.2***). For example, hydrogen has an atomic number of 1. This means that an atom of hydrogen has one proton and, if it's neutral, one electron as well. Carbon, on the other hand, has an atomic number of 6, which means that an atom of carbon has 6 protons and, if it's neutral, has 6 electrons as well.

Mass Number

? Dear learner, can you define 'mass number' based on your previous grade knowledge?

The mass number (A) of an atom is the total number of protons and neutrons in its nucleus. It is also known as the total number of nucleons in the atom's nucleus. Do not confuse atomic mass with mass number because atomic mass is the average weight of an element. Counting the number of protons and neutrons tells scientists about the total mass of an atom.

Mass number A = (number of protons) + (number of neutrons)

Now let me show you how to calculate the mass number of an atom, using examples. An atom's mass number is very easy to calculate, provided that you know the number of protons and neutrons in the atom.

Example

1. What is the mass number of an atom of helium that contains two neutrons?

Solution

(Number of protons) = 2 (Remember that an atom of helium always has two protons)

(Number of neutrons) = 2

Mass number = (number of protons) + (number of neutrons)

Mass number = 2 + 2 = **4**

2. How many protons, electrons, and neutrons are in a neutral atom of potassium (K; mass number 40 and atomic number 19)?

Solution

Atomic number = number of protons = 19

For all atoms with no charge, the number of electrons is equal to the number of protons.

Therefore, number of protons = number of electrons = 19

The mass number 40, is the sum of the number of protons and neutrons.

To find the number of neutrons, subtract the number of protons from the mass number.

Number of neutrons = 40 –19 = **21**

3. What is the atomic number, number of electrons, and the number of neutrons in a neutral atom of zinc with a mass number of 65 and 30 protons?

Solution

Number of protons = Atomic number = 30

For all atoms with no charge, the number of electrons is equal to the number of protons.

Number of protons = Number of electrons = 30

The mass number, 65, is the sum of the number of protons and neutrons.

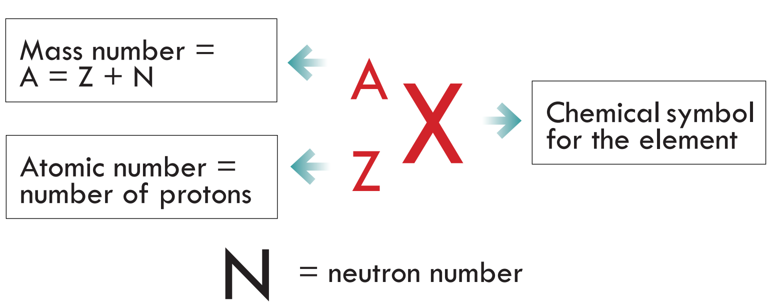
To find the number of neutrons, subtract the number of protons from the mass number.

Number of neutrons = 65 – 30 = **35**

The Nuclear Symbol of an Element

There is a common way in which scientists commonly express the mass number and the atomic number of an atom.

To write a nuclear symbol, the mass number is placed at the upper left (superscript), and the atomic number is placed at the lower left (subscript) of the chemical symbol of the element.



Let me show you how to write the complete nuclear symbol for hydrogen mass number 1, helium mass number 4, lithium mass number 7, beryllium mass number 9, boron mass number 11, and carbon mass number 12.

$$^{1}_{1}H,\ ^{4}_{2}He,\ ^{7}_{3}Li,\ ^{9}_{4}Be,\ ^{11}_{5}B,\ ^{12}_{6}C$$

In the carbon nucleus represented above, the atomic number 6 indicates that the nucleus contains 6 protons, and therefore, it must contain 6 neutrons to have a mass number of 12. The beryllium nucleus has 4 protons and 5 neutrons in order to have a mass number of 9. How many neutrons do H, He and Li have?

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of an atomic number and mass number.

1. https://byjus.com/chemistry/atomic-number-mass-number/
2. https://study.com/learn/lesson/mass-number-vs-atomic-number.html

Activity 3.14

Choose the correct answer for the following question.

1. Which of the following pairs has almost similar masses?
   A. Proton and electron
   B. Neutron and electron
   C. Electron and hydrogen (protium)
   D. Neutron and hydrogen (protium)

Answer the following questions.

2. Aluminium has 13 protons and 14 neutrons. What is its mass number?
3. Silicone's mass number is 28 and its atomic number is 14. What are its proton and neutron numbers?
4. Chlorine has 18 neutrons and a mass number of 35. What is its proton number?
5. Write the nuclear symbols of aluminium, silicon and chlorine.

3.5.3 Atomic Mass and Isotope

Dear learner, in the drawbacks of Thomson's Atomic Theory, we have seen that atoms of the same element are not always alike.

? What was the reason for this? Do you think the atomic mass of an element will always be the same? Why?

In the previous sections, we have thoroughly discussed the fact that the mass of an atom is concentrated in the nucleus. So, how is it possible to get the atomic mass of an element? What is the difference between the mass number and the atomic mass of an element? In the preceding study notes, I will give answers to the above- mentioned questions. Please follow me carefully.

All atoms of the same element have the same number of protons, but some may have different numbers of neutrons.

For example, all carbon atoms have six protons, and most have six neutrons as well. But some carbon atoms have seven or eight neutrons instead of the usual six. Atoms of the same element that differ in their numbers of neutrons are called isotopes. Many isotopes occur naturally. Usually, one or two isotopes of an element are the most stable and common. Different isotopes of an element generally have the same physical and chemical properties because they have the same number of protons and electrons.

Example: Hydrogen isotopes.

Hydrogen is an example of an element that has three isotopes. These isotopes are modelled in ***Figure 3.25***. Most hydrogen atoms have just one proton, one electron, and lack a neutron. These atoms are called hydrogen or protium. Some hydrogen atoms have one neutron as well. These atoms are the isotope named deuterium. Other hydrogen atoms have two neutrons. These atoms are the isotope tritium. They are also known as heavy hydrogen.

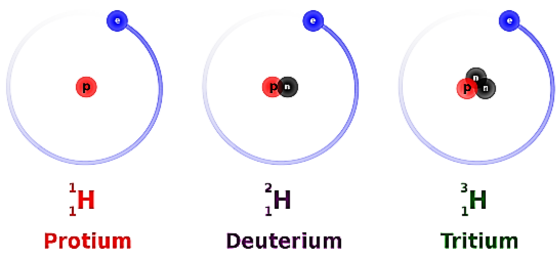


Figure 3.25 The three most stable isotopes of hydrogen are protium (A = 1), deuterium (A = 2), and tritium (A = 3).

> For most elements other than hydrogen, isotopes are named by their mass number.

For example, carbon atoms with the usual 6 neutrons have a mass number of 12 (6 protons + 6 neutrons = 12), so they are called carbon-12. Carbon atoms with 7 neutrons have an atomic mass of 13 (6 protons + 7 neutrons = 13). These atoms are the isotope called carbon-13. What other properties differentiate isotopes of the same element? Find the answer in the note below.

Stability of Isotopes

Atoms need a certain proportion of neutrons to protons to have a stable nucleus. Too many or too few neutrons relative to protons results in an unstable or radioactive nucleus that will sooner or later breakdown into a more stable form. This process is called **radioactive decay**.

> Many isotopes have radioactive nuclei, and these isotopes are referred to as **radioisotopes.**

When they decay, they release particles that may be destructive. This is why radioactive isotopes are risky and why working with them requires special suits for protection. The isotope of carbon known as carbon-14 is an example of a radioisotope. In contrast, the carbon isotopes called carbon-12 and carbon-13 are stable.

> ? Dear learner, why do you think studying isotopes is essential?

Please follow me carefully so that you can get the answer to this question. This whole discussion of isotopes brings us back to Dalton's Atomic Theory. According to Dalton, the atoms of a given element are identical. But if atoms of a given element can have different numbers of neutrons, then they can have different masses as well. How did Dalton miss this? It turns out that elements found in nature exist as constant, uniform mixtures of their naturally occurring isotopes. In other words, a piece of lithium metal always contains both types of naturally occurring lithium (the isotope with 3 neutrons and the isotope with 4 neutrons). Moreover, it always contains the two isotopes in the same relative abundance. In a lump of lithium, 93% will always be lithium with 4 neutrons, while the remaining 7% will always be lithium with 3 neutrons.

Calculating the Mass Number of Isotopes

Problem: Lithium Isotopes

a. What are the atomic number and the mass number of an isotope of lithium containing 3 neutrons and 3 electrons?

b. What are the atomic number and the mass number of an isotope of lithium containing 4 neutrons?

Solution

A lithium atom contains 3 protons in its nucleus, irrespective of the number of neutrons or electrons.

a. Given: (number of neutrons) = 3

Atomic number = (number of protons) = (number of electrons) = 3

Mass number = (number of protons) + (number of neutrons)

Mass number = 3 + 3 = **6**

b. Given: (number of neutrons) = 4

Atomic number = (number of protons) = (number of electrons) = 3

Mass number = (number of protons) + (number of neutrons)

Mass number = 3 + 4 = **7**

Note that because the lithium atom always has 3 protons, the atomic number for lithium is always 3. The mass number, however, is 6 in the isotope with 3 neutrons, and 7 in the isotope with 4 neutrons. Naturally, only certain isotopes exist. For instance, lithium exists as an isotope with 3 neutrons, and as an isotope with 4 neutrons, but it doesn't exist as an isotope with 2 neutrons, or as an isotope with 5 neutrons.

Atomic Mass

? Dear learner, how do you define the atomic mass of an element?

The mass of a single atom is very, very small.

Atomic mass is the actual or measured weight of an atom in grams.

Using a modern device called a **mass spectrometer** it is possible to measure such tiny masses. An atom of oxygen-16, for example, has a mass of 2.66×10^{-23} g. While comparisons of masses measured in grams would have some utility, it is far more practical to have a system that will permit us to more easily compare **relative atomic masses**. Scientists decided on using the carbon-12 nuclide as the reference standard by which all other masses would be compared.

By definition, one atom of carbon-12 is assigned a mass of 12 atomic mass units (amu). An atomic mass unit is defined as a mass equal to one-twelfth the mass of an atom of carbon-12 or $1.992646547 \times 10^{-23}$ g, which is assigned 12 amu.

In this scale, 1 amu corresponds to $1.660539040 \times 10^{-24}$ g. The atomic mass unit is also called the Dalton (Da), after English chemist John Dalton. The mass of any isotope of any element is expressed in relation to the carbon-12 standard. For example, one atom of helium-4 has a mass of 4.0026 amu. An atom of sulfur-32 has a mass of 31.972 amu. Dear student, did you know how this was calculated? Please follow me.

Average Atomic Mass

? Dear learner, if the atoms of some elements differ in their masses, then how is it possible to have a certain fixed atomic mass of an element?

Since many elements have isotopes, chemists use the average atomic mass. If we know the natural abundance and the mass of all the isotopes, we can find the average atomic mass. The **natural abundance of an isotope** of an element is the percent of that isotope as it occurs in a sample on earth. The average atomic mass is merely a weighted average of the masses of all the isotopes. We can calculate this using the following equation:

Average Atomic Mass = [(%isotope 1)(mass of isotope 1) ÷100] + [(%isotope 2)(mass of isotope 2) ÷100] + ...

Problem: Find the average mass of lithium (Li-7, 93%, and Li-6, 7%).
Solution: We follow the following calculation:
Lithium with 4 neutrons has a mass of 7 amu and its percentage abundance is 93%.
Lithium with 3 neutrons has a mass of 6 amu, and its percentage abundance is 7%.
Average mass of lithium = [(7amu x 93) ÷100] + [(6amu x 7) ÷100]
= 6.51amu + 0.42amu = **6.93 amu**
The average atomic mass of lithium is, therefore, 6.93 amu.

Problem: Boron has two naturally occurring isotopes. In a sample of boron, 20% of the atoms are B-10, which is an isotope of boron with 5 neutrons and a mass of 10 amu. The other 80% of the atoms are B-11, which is an isotope of boron with 6 neutrons and a mass of 11amu. What is the atomic mass of boron?
Following the same approach as lithium, the average atomic mass of boron is:
Atomic mass of boron = [(10amu x 20) ÷100] + [(11amu x 80) ÷100]

= 2 amu + 8.8 amu = **10.8 amu**

The average atomic mass of boron is, therefore, 10.8 amu.
Problem: Neon has three naturally occurring isotopes. In a sample of neon, 90.92% of the

atoms are Ne-20, which is an isotope of neon with 10 neutrons and a mass of 19.99amu. Another 0.3% of the atoms are Ne-21, which is an isotope of neon with 11 neutrons and a mass of 20.99amu. The remaining 8.85% of the atoms are Ne-22, which is an isotope of neon with 12 neutrons and a mass of 21.99 amu. What is the atomic mass of neon?

Solution

Neon has three isotopes. We will use the equation:

Atomic mass = [(% isotope 1)(mass of isotope 1)] ÷100 + [(% isotope 2)(mass of isotope 2)] ÷100 + [(% isotope 3)(mass of isotope 3)] ÷100

Substituting these into the equation, we get:

Atomic mass of neon = [(90.92)(19.99amu)÷100] + [(0.3)(20.99amu)÷100] + [(8.85)(21.99amu)÷100] = **20.18amu**

The average atomic mass of neon is, therefore, 20.18amu.

? So what do you think was Dalton's problem?

Dalton always experimented with large elemental chunks that contained all of the naturally occurring isotopes of that element. As a result, when he performed his measurements, he in fact perceived the averaged properties of all the different isotopes in the sample. We will do the same thing for most of our purposes in chemistry, and deal with the average mass of the atoms. Fortunately, other than having different masses, most other properties of different isotopes are similar.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of an atomic mass and isotopes.

1. https://www.khanacademy.org/science/chemistry/atomic-structure-and-properties/introduction-to-the-atom/v/atomic-weight-calculation
2. https://saylordotorg.github.io/text_general-chemistry-principles-patterns-and-applications-v1.0/s05-06-isotopes-and-atomic-masses.html

Activity 3.15

1. In an element that has isotopes, which of the sub-atomic particles are different, and which remain unchanged?
2. How many protons, electrons, and neutrons are there in each of the following atoms?

   a. $^{60}_{27}Co$ b. 3. Na-24 c. $^{45}_{20}Ca$ d. Sr-90

4. Calculate the average atomic mass of copper: Cu-63, 69.15% and Cu-65, 30.85%.
5. Calculate the average atomic mass of chlorine: Cl-35, 75% and Cl-37, 25%.

3.5.4 Main Energy Levels

Dear learner, based on the previous lessons, I hope you can answer the following questions that will lead you to the lesson under this subtopic.

? Who discovered energy levels? What is the other name for energy levels? In Bohr's atomic model, why do electrons disperse themselves? According to Bohr's atomic model, how do electrons arrange themselves?

Don't worry if you cannot answer all the questions at this stage because I will briefly describe some of the answers below. Please follow me.

The concept of orbits, in which electrons revolve around the nucleus, was proposed by a learnerof Rutherford named Niels Bohr in1913. Refer to the five principles of Bohr's atomic model discussed under Section 3.4.3. Today, in chemistry, the principal energy level or the main energy level of an electron refers to the shell in which the electron is located relative to the atom's nucleus. This level is denoted by the principal quantum number n. The principal number could also be denoted by the whole numbers 1, 2, 3, 4, etc., or by the letters K, L, M, N, etc. (***Figure 3.26***).

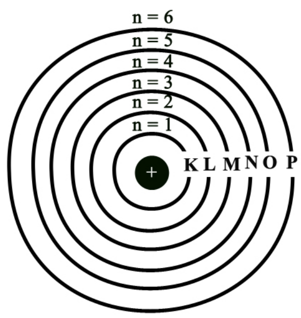


Figure 3.26 Main energy levels.

The energy of the orbit, sometimes known as the shell, increases upon moving away from the nucleus, i.e., it follows the increasing order K < L < M < N or 1 < 2 < 3 < 4, etc.

Activity 3.16

1. What is the main energy level of an electron?
2. How many main energy levels does each of the first twenty elements (H to Ca) have? Name the energy levels.

3.5.5 Electronic Configuration on Main Shells

Dear learner, try to answer the following questions that would help you understand how electrons arrange themselves in the main shells. In a certain class room, there are 2 seats in the first row, 8 seats in the second row, 18 seats in the third row, and 32 seats at the back of the room.

? If the rows with small seats are closer to the teacher, i.e., 2, 18, 32, respectively, and all students must sit beginning from the seats closer to the teacher, how will 35 students take seats? How would you arrange 20 electrons on an atom that can hold 2 electrons on the K-shell, 8 electrons on the L-shell, 18 the electrons on the M-shell, and 32 electrons on the N-shell? (Hint: begin arranging electrons from the lowest shell in energy.)

Dear learner, I hope you remember energy levels from your previous lesson. We picture an atom as a small nucleus surrounded by a much larger volume of space containing the electrons. This space is divided into regions called principal energy levels. Each principal energy level can contain up to $2n^2$ electrons, where n is the principal quantum number of the level (n = 1, 2, 3, etc.). Thus, the first level can contain up to 2 electrons, $2(1^2) = 2$; the second up to 8 electrons, $2(2^2) = 8$; the third up to 18, $2(3^2) = 18$, and so on. Only seven energy levels are needed to contain all the electrons in an atom of any of those elements known thus far.

The systematic arrangement of electrons in the various shells or orbits of an atom is called **electronic configuration.**

? The question is, how do electrons arrange themselves on the various shells?

Electronic configurations of atoms in the main energy levels follow a standard notation in which the number of electrons arranged in all electron-containing atomic shells is placed in a sequence. Filling energy levels with electrons begins with the lower energy or the shell closer to the nucleus, i.e., K shell, and goes on sequentially to L, M, N, etc.

The last shell, or the outermost shell from the nucleus, is called the **valence shell.** The shell inner to this is called the **penultimate shell**, and the one inner to the penultimate shell is called the **anti-penultimate shell**.

Shell	$2n^2$
K	2
L	8
M	18
N	32
O	50

The maximum number of electrons that can be filled in the valence shell is 8, that in the penultimate shell is 18, and the anti-penultimate shell has a maximum capacity of 32 electrons. The filling of electrons until atomic number 30 follows the following pattern:

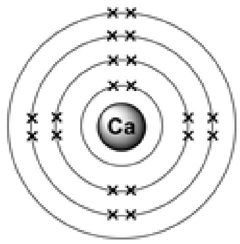
K	L	M	N
2			
2	8		
2	8	8	
2	8	8	2
2	8	18	2

Example: The atomic number of calcium is 20. Write the electronic configuration of calcium.

Solution:

The first shell (K) can hold 2(12) = 2,

The second shell (L) can hold 2(22) = 8, The third shell (M) can hold 2(32) = 18, but since calcium has only 20 electrons, the first two shells held 10 (2 + 8) electrons. Hence, the number of electrons left in these shells will be 20-10 = 10. Therefore, the M shell is left with 10 electrons. However, according to the above rule, the valence shell cannot hold more than 8 electrons. The M shell therefore holds the 8 electrons, and the remaining 2 electrons will be filled in the N shell. We can then write the electronic configuration of calcium as follows: Ca = 2, 8, 8, 2. Diagrammatically this could be depicted as shown below:



Example: Write the electronic configuration of argon (electrons 18).

Solution: Following the same procedure as calcium, the electronic configuration of argon will be: Ar = 2, 8, 8 (see ***Figure 3.27***).

Dear learner, the electronic configuration of the elements could also be drawn using atomic diagrams. For example, the diagrammatic representation of the electronic configurations of some elements is shown in ***Figure 3.27***, below.

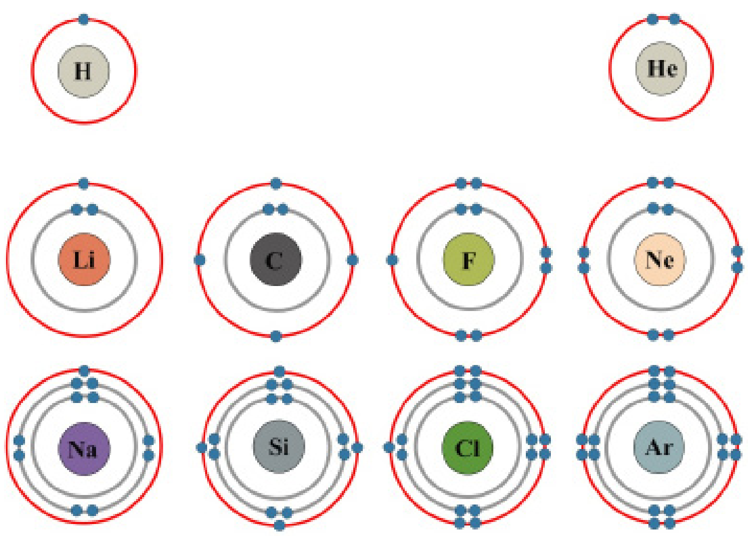


Figure 3.27 Electronic configuration of H, He, Li, C, F, Ne, Na, Si, Cl, and Ar using energy diagrams.

Activity 3.17

1. Define the term 'electronic configuration' of an element.
2. Write the electronic configurations of the first 20 elements (H to Ca) in the periodic table.
3. Draw the electronic configuration of the first 20 elements (H to Ca) using the energy diagrams.

3.5.6 Valence Electrons

Dear learner, in Section 3.5.5, we have discussed writing the electronic configuration of elements.

The electrons that occupy the outermost shell of an atom are called **valence electrons.**

Valence electrons are the electrons that are furthest from the nucleus of the atom. They are the most easily lost, and the ones that determine the element's chemical properties, and how an atom will undergo a chemical reaction. Atoms lose, gain, or share their valence electrons during chemical reactions. By writing an electronic configuration, you will be able to see how many electrons occupy the highest energy level. Let me show you some examples of valence electrons.

Example: The electronic configuration of silicon (Si) is 2, 8, and 4. The first two electrons occupy the inner shell (K shell), the next 8 electrons occupy the middle shell (L shell), and the remaining 4 electrons occupy the outermost shell (M shell), known as the valence shell (***Figure 3.28***). Hence, the electrons on the M shell are called valence electrons.

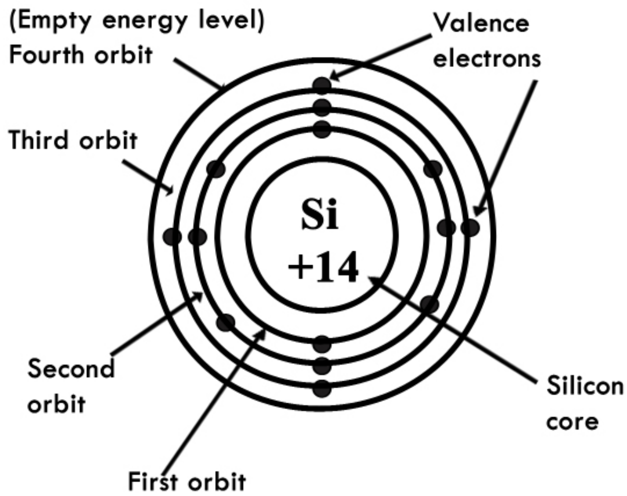


Figure 3.28 An energy diagram showing the valence electrons of silicon.

Example: The electronic configuration of argon (Ar) is 2, 8, 8. The valence shell of the argon atom is the M shell with 8 valence electrons (***Figure 3.29***).

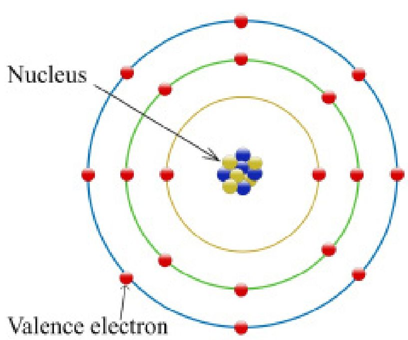


Figure 3.29 Energy diagram showing the valence electrons of argon atom.

Resources

Dear learner, please go to the internet and copy and paste these URLs (website links) so that you can get a better understanding of the main energy levels and electronic configuration of elements.

1. https://www.biologyonline.com/dictionary/valence-electron

2. https://www.youtube.com/watch?v=8LLOGOvsBjU

Activity 3.18

1. What are valence electrons?
2. What is the purpose of identifying valence electrons?
3. Identify the number of valence electrons for the first 20 elements (H to Ca).
4. Which electron is more difficult to remove from a neutral atom, the inner or outer electron?

Self-Test Exercise 3.5

1. Describe where protons, neutrons, and electrons are located in an atom.
2. Why are all atoms electrically neutral?
3. How many protons are in the nucleus of neon (Ne), gold (Au), strontium (Sr), and uranium (U) atoms?
4. A certain atom contains 28 protons, 28 electrons, and 31 neutrons. Provide the atomic number, mass number, and name of the element. Hint: Refer to the periodic table.
5. How many protons, neutrons, and electrons are in an atom of cesium-133?
6. How many protons, neutrons, and electrons are there in the atom 9F19?
7. A certain atom has an atomic number of 36 and a mass number of 84. Write out the designation for this isotope in both nuclide symbol form and in hyphenated (eg. sodium-23) form. Hint: Refer to the periodic table to find the element.
8. Fill in the table below.

Isotope	Symbol	Atomic no	Mass no	#Protons	Nuclear symbol
Hydrogen-1					
Hydrogen-2					
Beryllium-9					
Sodium-23					
Aluminium-27					
Calcium-40					

9. Complete the following table for ^{22}Ne. The average atomic mass of neon (Ne) is 20.1797 amu.

Isotope	Percent Abundance (%)	Atomic Mass (amu)
Ne20	90.92	19.9924
Ne21	0.257	20.9940
Ne22	?	?

Checklist 3.5

Dear learner, check yourself on the following aspects before wrapping up studying this section. In the table given below, put "✓" in the "Yes" column if you are quite sure that you have done it and "X" in the "No' column if you are not sure or did not do it. You must answer all the questions and revise those with an "X' mark. Can I ...

Comptencies	Yes	No
write the relative charges of an electron, a proton and a neutron?		
tell the absolute and relative masses of an electron, a proton and a neutron?		
distinguish the number of protons and electrons in an atom from the atomic number of the element?		
calculate the number of neutrons from the given values of atomic numbers and mass numbers?		
explain the terms 'atomic mass' and' isotope'?		
calculate the atomic masses of elements that have isotopes?		
describe the main energy level?		
define the electronic configuration?		
write the ground- state electronic configuration of the elements?		
draw diagrams to show the electronic configuration of the first 20 elements?		
write the electronic configuration of the elements using noble gas as a core?		
describe valence electrons?		

Unit Summary

In this unit, we have discussed how the atomic structure was proposed in conjunction with the discoveries of the atom and the fundamental subatomic particles known as protons, neutrons, electrons and the nucleus. This then led us to the definitions of terms like atomic number, mass number, isotope, energy level, valence electrons, and electronic configuration of atoms. We have also discussed how to calculate the number of protons, electrons, and neutrons in atoms from their atomic and mass numbers. We have discussed the calculation of the atomic masses of elements that have isotopes. Finally, we have briefly seen how to arrange electrons on the main energy levels of the atoms, which is commonly known as the electronic configuration of atoms.

In the middle of the 5th century BC, an ancient Greek philosopher, Empedocles, thought that all materials were made up of four things called elements: earth, air, water, and fire. The Greek philosophers' concept of four elements existed for more than two thousand years. Democritus proposed that matter consists of indestructible, indivisible units called atoms. However, since Aristotle and other prominent thinkers of the time strongly opposed their idea of the atom, their theory was disregarded and essentially buried until the 16th and 17th centuries.

In 1789, Antoine Lavoisier formulated the Law of Conservation of Mass. Ten years later, Joseph Louis Proust proposed the Law of Definite Proportions. These theories didn't reference atoms, yet John Dalton built upon them to develop the Law of Multiple Proportions.

In 1897, J.J. Thomson discovered the electron. Thomson also discovered the charge-to-mass ratio of the electron. He believed atoms could be divided. Because the electron carried a negative charge, he proposed a plum pudding model of the atom in 1904. Subsequently, in 1909, the American scientist Robert Millikan found the charge and mass of the electron in his oil drop experiment.

Ernest Rutherford, one of Thomson's students, disproved the plum pudding model (in 1909) and found that the positive charge of an atom and most of its mass were at the center, or nucleus, of the atom. In 1911, Rutherford, together with his students Geiger and Marsden, described the planetary atomic model. Rutherford was on the right track, but his model couldn't explain why the electrons didn't crash into the nucleus. In 1920, Rutherford discovered the existence of the proton in the nucleus. In 1913, Niels Bohr proposed the Bohr model. According to his model, electrons couldn't spiral into the nucleus but could make quantum leaps between energy levels.

In 1932, James Chadwick discovered the neutron, which is another sub-atomic particle. His atomic model encompasses a small positively charged nucleus where protons and neutrons reside at the centre of the atom and the electrons revolve around the nucleus in orbits, which is the basic atomic model. The discoveries of the above facts about atoms led to the modified Modern Atomic Theory postulates.

In 1886, Goldstein predicted the presence of positively charged particles (protons) in an atom based on the electrical neutrality of an atom. The electron was discovered by the British physicist J.J. Thomson in 1897. In the discovery of electrons, J. J. Thomson performed several experiments on cathode rays.

In 1920, in his discovery of the nucleus, Rutherford strongly suggested that both the mass and positive charge are concentrated in a minute fraction of the volume of an atom. Rutherford, however, was cornered by the other scientists by the question: "Why does the nucleus not disintegrate in spite of repulsion among the protons?" To explain the stability of the nucleus, Rutherford predicted the presence of neutral particles inside the nucleus.

The English physicist James Chadwick bombarded Beryllium nuclei with a-particles and observed the presence of neutral particles inside the nucleus. He called these neutral particles neutrons.

Electrons are extremely small (5.4858×10^{-4} amu) and contribute almost nothing to the total mass of an atom. The electric charge of an electron is -1. Protons have a positive electrical charge of one (+1) and a mass of 1.0073 atomic mass unit s(amu). Neutrons have no charge. The mass of a neutron is a little greater (1.0087 amu) than the mass of a proton. Together with protons, they make up virtually all of the mass of an atom.

Scientists are always interested in atomic number and how it differs between different elements since an atom of one element can be distinguished from an atom of another element by the number of protons in its nucleus. They developed a simplified way of writing the mass and atomic numbers of elements, known as the nuclear symbol.

All atoms of the same element have the same number of protons, but some may have different numbers of neutrons. Atoms of the same element that differ in their numbers of neutrons are called isotopes. Different isotopes of an element generally have the same physical and chemical properties because they have the same number of protons and electrons.

The mass of a single atom is very, very small. Using a modern device called a mass spectrometer; it is possible to measure such tiny masses. By definition, one atom of carbon-12 is assigned a mass of 12 atomic mass units (amu). 1 atomic mass unit (amu) corresponds to $1.660539040 \times 10^{-24}$ g. The mass of any isotope of any element is expressed in relation to the carbon-12 standard.

Since many elements have isotopes, chemists use the average atomic mass. The average atomic mass is merely a weighted average of the masses of all the isotopes. We can calculate this using the following equation:

Average Atomic Mass = [(%isotope 1)(mass of isotope1)] ÷100 + [(%isotope2)(mass of isotope 2)] ÷100 + ...

Today, in chemistry, the principal energy level or the main energy level of an electron refers to the shell in which the electron is located relative to the atom's nucleus. This level is denoted by the principal quantum number n (1, 2, 3, etc., or K, L, M, N, etc.). The electronic configuration of an element describes how electrons are distributed in their energy levels or shells. Filling energy levels with electrons begins with the lower energy shell, or the shell closer to the nucleus, i.e., the K shell, and goes on sequentially to L, M, N, etc. The electrons that occupy the outermost shell of an atom are called valence electrons. They are the most easily lost, and the ones that determine the element's chemical properties, and how an atom will undergo a chemical reaction.

Self-Assessment Exercise

Dear learner, there are about 46 questions categorized into basic (13), intermediate (4), and challenge levels (23). The questions will help you check your understanding of the unit as a whole. You are expected to give answers to all questions before referring to the answers. The answers to all questions are found at the end of the unit. Follow the instructions provided for each level of questions and respond accordingly.

Part I: Basic- Level Questions

Choose the correct answer from the given alternatives.

1. Which of the following concepts was considered in Rutherford's Atomic Model?
   A. The electrical neutrality of an atom.
   B. The quantization of energy.
   C. The electrons revolve around the nucleus at very high speeds.
   D. The existence of nuclear forces of attraction on the electrons.
   E. All except B.
2. When alpha particles are sent through a thin metal foil, only one out of ten thousand of them is rebounded. This observation led to the conclusion that
   A. Positively charged particles are concentrated at the centre of the atom.

B. A larger number of electrons are revolving around the nucleus of the atom.
C. A unit positive charge is only present in an atom.
D. The massive sphere with a more negative charge and a unit positive charge is present at the center of the atom.

3. The canal ray experiment led to the discovery of ________.
   A. protons
   B. neutrons
   C. electrons
   D. nucleus
4. In which of the following pairs of shells the energy difference between two adjacent orbits is minimum?
   A. K, L
   B. L, M
   C. M, N
   D. N, O
5. Assertion A: An electron in the inner orbit is more tightly bound to the nucleus. Reason B: The greater the absolute value of the energy of an electron ,the more tightly the electron is bound to the nucleus.
   A. Both A and B are true, but B is not the appropriate reason for A.
   B. Both A and B are individually correct, and B is the correct reason for A.
   C. A is correct, but B is not correct.
   D. Both A and B are not correct.
6. If two naturally occurring isotopes of an element are ${}^{15}_{7}X$ and ${}^{11}_{7}X$, what is the percentage composition of each isotope of X occurring, respectively, if the average atomic weight accounts for 14?
   A. 95, 5
   B. 80, 20
   C. 75, 25
   D. 65, 35
7. An element has two isotopes with mass numbers 16 and 18. The average atomic weight is 16.5. The percentage abundance of these isotopes is ________and ______ respectively.
   A. 75, 25
   B. 25, 75
   C. 50, 50
   D. 33.33, 66.67
8. Which of the following are isobars?
   A. ${}^{a}_{b}X$, ${}^{a+1}_{b}Y$ B. ${}^{a}_{b}X$, ${}^{b}_{c}Y$ C. ${}^{a}_{b}X$, ${}^{a}_{b+1}Y$ D. ${}^{a}_{b}X$, ${}^{a-1}_{b-1}Y$
9. Some of the elements have fractional atomic masses. The reason for this could be
   A. the existence of isobars.
   B. the existence of isotopes.
   C. the nuclear reactions.
   D. the presence of neutrons in the nucleus.
10. Which of the following concepts was not considered in Rutherford's atomic model?
   A. The electrical neutrality of an atom.
   B. The quantization of energy.
   C. Electrons revolve around the nucleus at very high speed.
   D. The existence of nuclear forces of attraction on the electrons.
11. ${}^{15}_{7}X$ and ${}^{11}_{7}X$ are two naturally occurring isotopes of the element X. What is the

percentage of each isotope of X if the average atomic mass is 14?

A. 95, 5
B. 80, 20
C. 75, 25
D. 65, 35

12. Rutherford's a-particle scattering experiment eventually led to the conclusion that
    A. Mass and energy are related.
    B. The point of impact with matter can be precisely determined.
    C. Neutrons are buried deep in the nucleus.
    D. Electrons are distributed in a large space around the nucleus.
13. The number of electrons present in the valence shell of an atom with atomic number 38 is
    A. 2
    B. 10
    C. 1
    D. 8

Part II: Intermediate - Level Questions

Tell whether the following statements are true or false.

14. According to Thomson's Atomic Model, electrons revolve around the nucleus.
15. In a discharge tube, anode rays originate when electrons collide with gas molecules.
16. $^{16}_{8}O$ and $^{18}_{8}O$ are isotopes while $^{40}_{20}Ca$ and $^{40}_{18}Ca$ are isobars.
17. A-ray scattering experiment proved that the positive particles are present in the extra nuclear part of an atom.

Fill in the blanks.

18. Anode rays are deflected towards the negative plate in the presence of an electric field because they consistof___________ particles.
19. Some of the a-rays' deflection at acute and obtuse angles is due to the presence of the _________ in the center of the atom.
20. The energy of an electron present in the first orbit of an atom is ________ than the energy of an electron in the other orbits.

Part III: Challenge- Level Questions

Provide a short answer to the following questions.

21. Which postulate of Dalton's Atomic Theory is considered correct even today?
22. "Like atoms are identical in all respects". This statement of Dalton's Atomic Theory was contradicted. What discovery contradicted this?
23. What was the basis for Dalton's Atomic Theory?
24. List the three statements that make up the Modern Atomic Theory.
25. Explain how atoms are composed.
26. Why Thomson took gas at low pressure while experimenting?
27. Tell the mass and charge of the fundamental particles of an atom.
28. Which is larger, a proton or an electron?
29. Which is larger, a neutron or an electron?
30. What is an atomic model?
31. Who discovered the protons? Based on what experiment was he able to discover these protons?

32. Where is the majority of the mass of an atom located?
33. With the increase in the radius of the orbit, the energy of an electron _______.
34. What is an a particle?
35. Describe J. J. Thomson's Atomic Model.
36. What are the observations and conclusions drawn by J.J. Thomson while conducting experiments with dischage tube for studying the properties of cathode rays?
37. Sketch a diagram of a boron atom, which has five protons and six neutrons in its nucleus.
38. Sketch a diagram of a helium atom, which has two protons and two neutrons in its nucleus.
39. Define an atomic number. What is the atomic number of a boron atom?
40. What is the atomic number of helium?
41. Define an isotope and give example(s).
42. What is the difference between deuterium and tritium?
43. Which pair represents isotopes?

A. ${}^{4}_{2}He$ and ${}^{3}_{2}He$ B. ${}^{56}_{26}Fe$ a nd ${}^{56}_{25}Mn$ C. ${}^{28}_{14}Si$ and ${}^{31}_{15}P$

D. ${}^{40}_{20}Ca$ and ${}^{40}_{19}K$ E. ${}^{56}_{26}Fe$ and ${}^{58}_{26}Fe$ F. ${}^{238}_{92}U$ and ${}^{235}_{92}U$

44. Write the complete symbols of each atom, including their atomic number and mass number.
    A. An oxygen atom with 8 protons and 8 neutrons
    B. A potassium atom with 19 protons and 20 neutrons
    C. A lithium atom with 3 protons and 4 neutrons
    D. A magnesium atom with 12 protons and 12 neutrons
    E. A magnesium atom with 12 protons and 13 neutrons
    F. A xenon atom with 54 protons and 77 neutrons
45. Americium-241 (Am-241) is an isotope used in smoke detectors. What is the complete symbol for this isotope?
46. Carbon-14 is an isotope used to perform radioactive dating tests on previously living material. What is the complete symbol for this isotope?

Assignment for Submission

You are required to give answers to all the questions given below and submit them to your tutor or marker. There are 12 'True/False' items, and 25 'short answer' type questions. All questions are related to the contents of this unit. Do not forget to keep a copy for yourself.

True False items

Write 'True' for the correct statements and 'False' for the wrong statements.

1. About 2,500 years ago, early Greek philosophers believed the entire universe was a single, huge entity.
2. Democritus thought that all materials were made up of four things called elements: earth, air, water, and fire.

3. Aristotle introduced the idea that elements can be differentiated based on properties such as hot versus cold, and wet versus dry.
4. Thomson proposed that the nucleus of an atom contains protons and neutrons.
5. An electron has a mass that is much less than that of a proton.
6. There is no particle of matter smaller than an atom.
7. Atoms of an element may have more or less neutrons or electrons than other atoms of the same element.
8. The innermost atomic shell can hold a maximum of 18 electrons.
9. The first subatomic particle discovered was the proton.
10. Bohr's atomic model is better than Rutherford's atomic model.
11. Laws are considered the highest form of scientific knowledge and are generally supposed to be unbreakable.
12. J.J. Thomson proposed the Law of Definite Proportions.

Short Answer Items

Give answers to the following questions.

13. Why was Democritus called one of the great pioneers of chemistry?
14. Who was the Greek philosopher that gave the term 'atom' to the smallest, indivisible, and indestructible substance?
15. What are the five major points of Democritus's atomic idea?
16. What was Lavoisier's innovative 18th century experiment that led the world into the science of modern chemistry?
17. What are the major drawbacks of the early Greek philosophers in terms of the atomic theory of matter? What positive aspect does their speculation on atomic structure have?
18. What is the basic difference between a 'scientific theory' and a 'scientific law'?
19. What is the basic difference between the Law of Conservation of Mass, the Law of Definite Proportions, and the Law of Multiple Proportions?
20. Which shell is closest to the nucleus of an atom?
21. Which energy level would accommodate the 17^{th} electron?
22. Select the isotopes from the following. Assume that A, B, C, and D represent atoms.

    $^{21}_{10}A$; $^{22}_{10}B$; $^{23}_{11}C$; $^{23}_{12}D$
23. If an atom contains one electron and one proton, will it carry any charge or not?
24. If the K and L shells of an atom are full, then what would be the total number of electrons in the atom?
25. Hydrogen exists in three isotopic forms. Why are the isotopes of hydrogen chemically alike?
26. Why a- particle scattering experiment possible by using only gold foil and not foil of any other metal?
27. Write the electronic configuration of the following elements and predict their valence electrons. The numbers indicated in front of the element are electron numbers.
    A. Fluorine: 9
    B. Aluminum: 13

C. Argon: 18

28. What are the characteristic features of the Rutherford model of an atom? What is the limitation of this model?
29. What are the main postulates of Bohr's atomic theory?
30. What is the difference between the mass number and the atomic mass of an element?
31. Write the electronic configurations of the following elements:

    $^{16}_{8}O$, $^{28}_{14}Si$, and $^{40}_{18}Ar$

32. What are the conclusions to be drawn from Rutherford's experiment of a-particles scattering by a gold foil?
33. Name the elements that have the following electronic configuration:

    i. 2, 6
    ii. 2, 7
    iii. 2, 8, 1
    iv. 2, 8, 7
    v. 2, 8
    vi. 2, 4

34. What will be the composition of the nucleus of the atom of an element with atomic number 19 and mass number 39? Also, write its electronic configuration both using the main energy levels and draw its atomic diagram.
35. An element has an electronic configuration of 2, 8, 7.

    A. What is the atomic number of the element?
    B. What is the name of the element?

36. Answer the following questions based on the following information: N has seven electrons; F has nine electrons; P has fifteen electrons; and Ar has eighteen electrons.

    A. Which of the above- mentioned elements has same number of valence electrons?
    B. Draw the electronic diagram for the above -mentioned atoms.
    C. Write the nuclear symbols for the above- mentioned atoms.

37. State the reasons for the following statements:

    A. Some elements possess fractional atomic mass.
    B. Isotopes of an element have similar chemical properties.

Answer Key to Exercises

Answers to Activity 3.1

1. Air, water, earth and fire.
2. Plato adopted Empedocles theory and coined the term element to describe these four substances. His successor, Aristotle, also adopted the concept of four elements. He introduced the idea that elements can be differentiated based on properties such as hot versus cold and wet versus dry. Both of them attacked the atomic theories of Democritus and Leucippus, which led to their rejection in the end.
3. Around 440 BC, Leucippus of Miletus originated the atom concept. He and his pupil, Democritus of Abdera, refined and extended it in future years.
4. In Greek, the prefix "a" means "not" and the word "tomos" means "cut". The word atom, therefore, comes from atomos, a Greek word meaning uncuttable or indivisible.

5. The five ideas of Democritus and Leucippus are:
   i. All matter is composed of atoms, which are bits of matter too small to be seen. These atoms cannot be further split into smaller portions.
   ii. There is a void, which is an empty space between atoms.
   iii. Atoms are completely solid.
   iv. Atoms are homogeneous, with no internal structure.
   v. Atoms are different in their sizes, shapes and weights.
6. A very small and indivisible solid sphere. 
7. Seed of "Habesha gommen" also known as "gommen zer".

Answers to the Self-test Exercise 3.1

1. Because it is so well supported, a scientific theory has a very good chance of being the correct explanation for events in nature. Since it is a broad explanation, it can explain many observations and pieces of evidence. In other words, it can help connect and make sense of many phenomena in the natural world.
2. Since chemistry is full of abstract concepts that deal with the microscopic world, in order to explain this microscopic world, a chemist needs to know the microscopic particles from which every material is made.
3. Because, it is always difficult to convince people about the existence of things that are too small to be seen and perceived by their sense organs.
4. Leucippus was the first philosopher to propose the first theory of matter.
5. Democritus refined and extended Leucippus's atomos concept and taught the theory of atomism. He is also called one of the pioneers of physics and chemistry of the 19^{th} and 20^{th} centuries.
6. People regard Democritus as one of the great pioneers of physics and chemistry in the 19^{th} and 20^{th} centuries due to the fact that many of his teachings on the structure of matter were confirmed by scientists over 200 years after his death.
7. The major drawbacks of the early Greek philosophers were their attempts to understand the nature of the world through reason and logic, rather than through observations of nature, measurements, tests, or experiments.

Answers to Activity 3.2

1. Laws are generalized observations about a relationship between two or more things in the natural world.
2. Scientific laws or laws of science, are statements based on repeated experiments or observations that describe or predict a range of natural phenomena.
3. The difference between a scientific law and a scientific theory is that a scientific law doesn't explain why the phenomenon exists or what causes it. The explanation of a phenomenon is called a scientific theory. A scientific law is just a proven statement of a natural phenomenon. A scientific theory can be changed, but a scientific law will never change.
4. Chemical laws are those laws of nature relevant to chemistry.
5. Antony Lavoisier discovered the law of conservation of mass.

Answers to Activity 3.3

1. The molecular mass calculation of:

Molecular mass of H_2SO_4:

Mass of H = 1x2 = 2 g/mol

Mass of S = 32 g/mol

Mass of O = 16x4 = 64 g/mol

Mass of H_2SO_4 = mass of H + mass of S + mass of O

= 2 g/mol + 32 g/mol + 64 g/mol

= **98 g/mol**

Molecular mass of H_3PO_4:

Mass of H = 1x3 = 3 g/mol

Mass of P = 31 g/mol

Mass of O = 16x4 = 64 g/mol

Mass of H_3PO_4 = Mass of H + Mass of P + Mass of O

= 3 g/mol + 31 g/mol + 64 g/mol

= **98 g/mol**

Molecular mass of H_2CO_3:

Mass of H = 1x2 = 2 g/mol

Mass of C = 12 g/mol

Mass of O = 16x3 = 48 g/mol

Mass of H_2CO_3 = mass of H + mass of C + mass of O

= 2 g/mol + 12 g/mol + 48 g/mol

= **62 g/mol**

2. Solution:

Mass of H_2O = 18 g; Mass of H in 18g of H_2O = 2 g; Mass of O in 18g of H_2O = 16 g

Mass of H in 18g H_2O = 2g

Mass of H in 25 g H_2O = ?

Mass of H in 25 g of H_2O = (25 g x 2 g) ÷ 18 g = 2.78g

Therefore, the mass of O in 25 g H_2O = 25 g – 2.78 g = **22.22 g**

Now divide the mass of H and O by 2.78 to get the mass ratios. This will result in a hydrogen –to- oxygen ratio of 1:8.

3. Solution:

Mass of ethanol (C_2H_6O) = mass of C_2 + mass of H_6 + mass of O = 24 g + 6 g + 16 g = **46g**

Mass of C in ethanol 46 g = 24 g

Mass of C in 25 g ethanol = ?

Mass of C in 25 g ethanol = (25 g x 24 g) ÷ 46 g = **13.04 g**

Mass of H in ethanol 46 g = 6 g

Mass of H in 25 g ethanol = ?

Mass of H in 25 g ethanol = (25 g x 6 g) ÷ 46 g = **3.26 g**

Therefore, the mass of O in 25 g ethanol = 25 g - (13.04 g + 3.26 g) = 8.7 g

Now divide the masses of the three elements by the smallest number, i.e., 3.26, to get the ratio of carbon to hydrogen to oxygen. This will result in 4:1:2.7 (C:H:O).

Answers to Activity 3.4

1. The law of conservation of mass states that in any given system that is closed to the transfer of matter (in and out), the amount of matter in the system stays unchanged. In other words, the mass of any one element at the beginning of a reaction will equal the mass of that element at the end of the reaction.
2. The Law of Definite Proportions states that the masses of elements in a compound always occur in the same proportion.
3. The Law of Multiple Proportions states that the ratios of masses of elements in a compound are small whole numbers.
4. Amount of sugar needed to make 300 ml of tea:

Solution:

30 ml of tea = 2 g of sugar

300 ml of tea = ?

By the criss-cross mathematical method:

Amount of sugar needed = 300 ml x 2 g ÷ 30 ml = **20 g**

Answers for Self-Test Exercise 3.2

1. The importance of knowing the Law of Conservation of Mass in chemistry is associated with chemical reactions. Every chemical reaction has substances that react and substances that will be formed at the end of the reaction. If one is interested to produce a certain amount of chemical product, he/she must know the amount of reactant that is needed. This will be possible with the knowledge of the Law of Conservation of Mass. In short, it helps to know the stoichiometry of any chemical reaction.

2. Answer:

Question	H_2O_2	H_2O
Mass of H:O	2:32	2:16
Ratio of mass of H:O	1:16	1:8
Ratio of mass of O that combines with g of H	2	1

3. Answers:

Question	NO	NO_2	N_2O	N_2O_4	N_2O_5
Ratio of molar masses N:O	14:16	14:32	28:16	28:64	28:80
Mass of oxygen combining with 1g of N	16/14 = 1.14	32/14 = 2.29	16/28 = 0.571	64/28 = 2.28	80/28 = 2.86
Ratio of small whole numbers of O:N	1.14/0.571 = 2	2.29/0.571 = 4	0.571/0.571 = 1	2.28/0.571 = 4	2.86/0.571 = 5

4. Law of Conservation of Mass. The number of grams of reactants (32.0 g of methane and 128.0 g of oxygen = 160.0 g total) is equal to the number of grams of product (88.0 g of carbon dioxide and 72.0 g of water = 160.0 g total).

5. The answer is 18.00 g of water. Because the only products are water and carbon dioxide, their total mass must equal the total mass of the reactants, methane and oxygen. 8.00 g of methane + 32.00 g of oxygen = 40.00 total g of reactants. Because

the total mass of the reactants equals the total mass of the products, the total mass of the products is also 40.00 g. Thus, 40.00 total g of products = 22.00 g carbon dioxide + unknown mass water. 40.00 total g of products - 22.00 g carbon dioxide = 18.00 g water.

6. To solve this problem, first determine the % Na in each sample of sodium chloride. In the first experiment, there was 4.36 g sodium for every 11.08 g of sodium chloride. The amount of sodium in the sodium chloride for the second experiment must be found. This is found by subtracting the known amount of reacting chlorine (4.20 g) from the amount of sodium chloride (6.92 g). 6.92 g sodium chloride - 4.20 g chlorine = 2.72 g sodium.

Thus, the % Na in each sample is represented below:
% Na = (4.36 g Na)/(11.08 g NaCl) x 100% = 39.4%
% Na = (2.72 g Na)/(6.92 g NaCl) x 100% = 39.3%

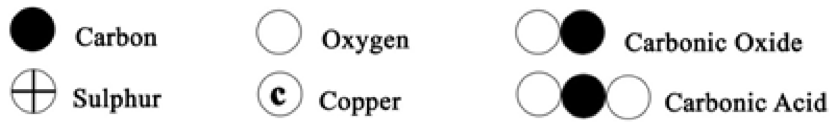
The slight difference in compositions is due to significant figures: each percent has an uncertainty of 0.01% in either direction. The two samples of sodium chloride have the same composition.

Answers for Activity 3.5

1. Dalton's findings were based on experiments and the laws of chemical combination, whereas Democritus' discovery of an atom was mere speculation.
2. The five tenets of Dalton's atomic theory are:
   i. Elements are made of small particles called atoms.
   ii. Atoms can neither be created nor destroyed.
   iii. All atoms of the same element are identical and have the same mass and size.
   iv. Atoms of different elements have different masses and sizes.
   v. Atoms combine in small whole numbers to form compounds.
3. Dalton proposed a new atomic theory based on his experiments and observations as well as the work of peers of his time. His experiments include these:
   i. Studies of the weights of various elements and compounds; from which he noticed that matter always combined in fixed ratios based on weight, or volume in the case of gases.
   ii. He also noticed that chemical compounds always contain the same proportion of elements by mass, regardless of amount.
   iii. Dalton also observed that there could be more than one combination of two elements.
4. Successes of Dalton's Atomic Theory:

The atomic theory explains the Law of Constant Composition and the Law of Multiple Proportions.

Dalton was the first person to recognize a workable distinction between the fundamental particle of an element (atom) and that of a compound (molecule).

5. 

6. Because they are difficult to remember and draw.
7. The discovery of particles smaller than an atom doesn't mean that we should scrap the entire theory. Atoms are still known to be the smallest particles of elements that have the properties of the elements. Also, it is atoms, not particles of atoms that combine in fixed proportions in compounds. Instead of throwing out Dalton's theory, scientists have refined and expanded on it.

Answers to Activity 3.6

1. D
2. The postulates of modern atomic theory are

    Elements are made of small particles called atoms.

    Atoms cannot be created or destroyed during ordinary chemical reactions.

    All atoms of the same element have the same atomic number but may vary in mass number due to the presence of different isotopes.

    Atoms of different elements are different.

    Atoms combine in whole numbers to form compounds.
3. Comparison of Dalton's and Modern atomic theories.

Dalton's atomic theory	Modern atomic theory
Matter consists of small, indivisible particles called atoms.	The atom is no longer indivisible, but consists of neutrons, protons and electrons.
Atoms of the same element are alike in all respects.	All atoms have isotopes. It means some of the atoms of the same element have different atomic weights.
Atoms of different elements are different in all respects.	Atoms of different elements are sometimes similar in some respects. For example, atoms of argon and calcium have the same atomic weight.
Atoms combine in small whole numbers to form compound atoms (molecules).	Atoms in organic compounds do not combine in a small whole number ratio. The molecules of proteins are highly complex.
Similarity, an atom is the smallest unit of matter that takes part in a chemical reaction.	

i. divisibility of atoms into the three sub-atomic particles known as protons, neutrons and electrons;
ii. the concept of isotopes is not considered;
iii. the concept of isobars is not considered;
iv. in complex molecules like sugar ($C_{12}H_{22}O_{11}$) and protein molecules, atoms combine in high whole number ratios;
v. the theory fails to explain the existence of allotropes. Allotropes are different forms of the same element, where the atoms combine in different ways, so at the same temperature and pressure they can exist in different forms. The most striking allotropes are carbon in the forms of diamond, graphite, and buckminsterfullerene.

Answers to Self-Test Exercise 3.3

1. The starting materials consist of one green sphere and two blue spheres. The products

consist of two green spheres and two blue spheres. This violates Dalton's postulate that atoms are not created during a chemical change, but are merely redistributed

2. Atoms are neither created nor destroyed during a chemical change, but are instead rearranged to yield substances that are different from those present before the change (based on the Law of Conservation of Mass).
3. Consider the ratios of C:H and you will get the following results:

   X and Z are similar compounds (same ratios of C and H), aligning with the Law of Definite Proportions.

   X and Y and Y and Z are different compounds (differing ratios of C and H), aligning with the Law of Multiple Proportions.
4. Isotopes of hydrogen: hydrogen-1 (Protium), hydrogen-2 (deuterium), and hydrogen-3 (tritium); isotopes of carbon: carbon-12, carbon-13, and carbon-14; isotopes of chlorine: chlorine-35, chlorine-36, and chlorine-37; isotopes of oxygen: oxygen-16, oxygen-17, and oxygen-18; Isotopes of uranium: uranium-235, and uranium-238, etc.
5. Examples of a group of isobars having mass number 40 are chlorine-40, argon-40, sulfur-40, calcium-40, and potassium-40.

Answers to Activity 3.7

1. Canal rays are faint luminous rays in a discharge tube that travel from the direction of the positively charged anode and pass through the perforations in the negatively charged cathode, without deflection by the cathode.
2. When very high voltage is applied in a discharge tube filled with gas, it ionises the gas and it is the positive ions of the gas that constitute the canal ray.
3. i. Anode rays travel in straight lines. ii. They consisted of material particles. iii. They are deflected in an electric and magnetic field opposite to that of cathode rays. iv. The nature or e/m ratio of anode rays depends upon the nature of the gas present in the cathode ray tube. v. They are simply positively charged gaseous ions.

Answers to Activity 3.8

1. Because at high pressure, no electricity flows through the air in the discharge tube.
2. J.J. Thomson's second experiment was performed by placing a light paddle wheel between the cathode and anode to study the particulate nature of the cathode rays. The movement of the paddle wheel proved the particulate nature of the cathode rays.
3. Upon passing through an electric field, the cathode rays bent towards the positive plate. Passing cathode rays in a magnetic field resulted in the deflection of the cathode rays perpendicular (towards the north pole of the magnet) to the applied magnetic field. This proved that cathode rays are negatively charged particles.
4. As part of his experiments with cathode ray tubes, Thomson tried changing the cathode material, which was the source of the particles. Since the same particles were emitted even when the cathode materials were changed to different metals, Thomson concluded that the particle was a fundamental part of all atoms.

Answers to Activity 3.9

1. The magnitude of the absolute charge of an electron is 1.6×10^{-19}C.

2. The absolute mass of an electron is 9×10^{-31} kg.
3. Sir J. J. Thomson discovered the electron, but he could only deduce the charge to mass ration, but Robert Millikan, through his oil drop experiment found the value of charge on the electron.
4. J.J. Thomson determined the e/m value of an electron using a cathode ray tube apparatus.
5. i) Uniformly distributed positive charge ii) Electrons embedded. Examples include watermelon and/or plum pudding.

Answers to Activity 3.10

1. Because Rutherford discovered the nucleus.
2. Goldstein discovered protons in the discharge tube experiment.
3. i) The proton is located at the centre of the atom ii) Electrons are located on the extra nuclear part.
4. i) Mostly empty space ii) Nucleus iii) Electrons revolve around the nucleus in circular paths.
5. i) An accelerating charged particle loses energy ii) Spiral path of electron iii) The collapse of the atom

Answers to Activity 3.11

1. A) The Bohr Model
2. Orbits or shells.
3. Based on Plank's Quantum theory.
4. i) Specified paths of electrons ii) Energy remains constant.

Answers to Activity 3.12

1. a-particles.
2. James Chadwick.
3. The difference between the predicted atomic mass and the actual atomic mass led scientists to predict the presence of a particle other than the proton in the nucleus.
4. Bombardment of the beryllium nucleus with a-particles led to the emanation of radiation that did not deflect up on exposing it to an electric field. In addition to this, these neutral particles rotated a paddle wheel.

Answers to Self-Test Exercise 3.4

1. Goldstein did the cathode ray experiment and discovered the canal rays. He called these canal rays positive or anode rays.
2. JJ Thomson's contribution: the straight line motion of cathode rays; the particle nature of cathode rays; the negative charge of cathode rays; the cathode rays being electrons. These findings led him to the plum pudding atomic model, in which the electrical neutrality of an atom is shown. In addition to this, Thomson was able to calculate the mass-to-charge ratio of the particles to be 1.76×10^{8} Coulomb per gram (C/g).
3. In his oil drop experiment, Millikan observed that the smallest charge found on the cathode rays was approximately 1.59×10^{-19}coulombs, which is the charge of an

electron. With this information and Thomson's charge-to-mass ratio (1.76×10^8 C/g), Millikan determined the mass of an electron to be 9×10^{-28} g.

4. Rutherford showed that the canal/anode rays of Goldstein were identical to the hydrogen ion (proton). Due to this fact, these particles were named protons, and were shown to be present in all matter. In his α-particle experiment, he predicted the presence of neutral particles (neutrons) inside the tiny central part of the atom called the nucleus. This led him to propose the planetary model of the atom, in which the protons and neutrons reside inside the nucleus and the electrons revolve around the nucleus just like the planets revolve around the sun. This model is also known as the nuclear model.
5. The French physicists Frederic and Irene Joliot-Curie did an experiment by bombarding beryllium nuclei with α-particles. In this experiment, they observed the release of unknown radiation, which ejected protons from the nuclei of various substances. They mistakenly called these radiations γ-rays.
6. Niels Bohr developed an atomic model that improved Rutherford's atomic model. Bohr's atomic model consists of electrons, which move in concentric circular orbits around the nucleus. Each electron occupies certain orbits. Each orbit or shell has a fixed amount of energy called energy levels.
7. James Chadwick's contribution to the atomic model was his discovery of the neutron by further studying the "γ-rays" of Frederic and Irene Joliot-Curie. Chadwick was able to discover the neutron. This discovery led him to the atomic model where the atom was understood as a nucleus with protons and neutrons, assuming almost the entire mass of the atom, with the electrons orbiting the nucleus at their corresponding energy levels.

Answers to Activity 3.13

1. Electron: mass (kg) = 9×10^{-31} or 5.4858×10^{-4} amu; charge (in coulombs) = -1.59×10^{-19} or -1.
2. The masses of protons and neutrons are fairly similar, although technically, the mass of a neutron is slightly larger than the mass of a proton.
3. Electrons have an electric charge of -1, which is equal but opposite to the charge of a proton, which is +1.
4. Because neutrons are electrically neutral.
5. Because the mass of electrons is too small or negligible.

Answers to Activity 3.14

1. D
2. Mass number of aluminium = protons + neutrons = 13 + 14 = **27**
3. Silicon: atomic number = number of protons = **14**

Mass number of silicon = proton + neutron

Neutron number of silicon = mass number of silicon – proton

= 28 – 14

= **14**

4. Mass number of chlorine = proton + neutron

Proton number of chlorine = mass number of chlorine – neutron number

= 35 – 18

= **17**

5. The nuclear symbols of Al, Si, and Cl:

$^{27}_{13}Al$ $^{28}_{14}Si$ $^{35}_{17}Cl$

Answers to Activity 3.15

1. The neutron is different while electrons and protons remain unchanged in an element that has isotopes.
2. The answers are as follows:

   : Protons 27, electrons 27, neutrons 33;

   b. Na-24: Protons 11, electrons 11, neutrons 13;

   : Protons 20, electrons 20, neutrons 25;

   d. Sr-90: Protons 38, electrons 38, neutrons 52.
3. The average mass of copper: Cu-63, 69.15% and Cu- 5, 30.85%.

   [(63 x 69.15) ÷ 100] + [(65 x 30.85) ÷ 100] = **63.61 amu**
4. Calculate the average mass of chlorine: Cl-35, 75% and Cl-37, 25%.

   [(35 x 75) ÷ 100] + [(37 x 25) ÷100] = **35.5 amu**

Answers to Activity 3.16

1. The main energy level of an electron refers to the shell or orbital in which the electron is located relative to the atom's nucleus.
2. H and He have only one energy level; Li, Be, B, C, N, O, F, and Ne have two energy levels (K and L); Na, Mg, Al, Si, P, S, Cl, and Ar have three energy levels (K, L, and M); K,and Ca have four energy levels (K, L, M and N).

Answers to Activity 3.17

1. The electron configuration of an element describes how electrons are distributed in their energy levels or shells.
2. See the table below.

Electronic configuration of the first 20 elements

Atomic Number	Name of the Element (symbol)	Electronic Configuration
1	Hydrogen (H)	1
2	Helium (He)	2
3	Lithium (Li)	2, 1
4	Beryllium (Be)	2, 2
5	Boron (B)	2, 3
6	Carbon (C)	2, 4
7	Nitrogen (N)	2, 5
8	Oxygen (O)	2, 6
9	Fluorine (F)	2, 7
10	Neon (Ne)	2, 8
11	Sodium (Na)	2, 8, 1
12	Magnesium (Mg)	2, 8, 2

13	Aluminum (Al)	2, 8, 3
14	Silicon (Si)	2, 8, 4
15	Phosphorus (P)	2, 8, 5
16	Sulphur (S)	2, 8, 6
17	Chlorine (Cl)	2, 8, 7
18	Argon (Ar)	2, 8, 8
19	Potassium (K)	2, 8, 8, 1
20	Calcium (Ca)	2, 8, 8, 2

3. It is very difficult to draw all of the energy diagrams due to the limited space. Please check for yourself according to the examples given in ***Figure 3.27.***

Answers to Activity 3.18

4. Valence electrons are the electrons found in the outermost shell of an atom.
5. Understanding the number of valence electrons in an atom will help us know how it reacts with other atoms.
6. Refer to **Activity 3.17** answer #2 (Table).
7. The inner electron is held by the positively charged nucleus due to strong electrostatic force and hence difficult to remove it from a neutral atom.

Answers to Self-Test Exercise 3.5

1. Protons and neutrons are in the nucleus, and electrons are located outside the nucleus.
2. All atoms are electrically neutral because the sum of the charges on the total number of electrons and the total number of protons will become zero.
3. The number of protons in Neon = 10, gold = 79, strontium = 38, and uranium = 92.
4. The atomic number of the element is 28; its mass number is 59, and the name of the element is nickel.
5. An atom of cesium-133 has 55 protons, 78 neutrons, and 55 electrons.
6. $^{19}_{9}F$ has 9 protons, 10 neutrons, and 9 electrons.
7. $^{84}_{36}Kr$, krypton-84
8. Refer to the table below:

Isotope	Symbol	Atomic no.	#Protons	#Electrons	#Neutrons	Mass no	Nuclear symbol
Hydrogen-1	H	1	1	1	0	1	$^{1}_{1}H$
Hydrogen-2	H	1	1	1	1	2	$^{2}_{1}H$
Beryllium-9	Be	4	4	4	5	9	$^{9}_{4}Be$
Sodium-23	Na	11	11	11	12	23	$^{23}_{11}Na$

Aluminium-27	Al	13	13	13	14	27	${}^{27}_{13}Al$
Calcium-40	Ca	20	20	20	20	40	${}^{40}_{20}Ca$

9. In order to find the percent abundance of ${}^{22}Ne$:

Add first the percent abundance of 20Ne and ${}^{21}Ne$ and subtract the sum from 100. i.e., 90.92 + 0.257 = 91.177

$\%{}^{22}Ne = 100 – 91.177 = 8.823\%$

To find the atomic mass of ${}^{22}Ne$ use the average atomic mass formula:

Average atomic mass of Ne = $[(\%{}^{20}Ne \times {}^{20}Ne\ amu)\div100] + [(\%{}^{21}Ne \times {}^{21}Ne\ amu)\div100] + [(\%{}^{22}Ne \times {}^{22}Ne\ amu)\div100]$

20.1797 = [(90.92 x 19.9924)÷ 100] + [(0.257 x 20.9940)÷ 100] + [(8.823 x amu22Ne)÷ 100]

Now calculate for ${}^{22}Ne$ amu:

$20.1797 = 18.1771 + 0.0540 + 0.0882\ amu$

${}^{22}Ne\ amu = (20.1797 – 18.2311)\div 0.0882$

${}^{22}Ne$ amu = **22.0930 amu**

Isotope	Percent Abundance (%)	Atomic Mass (amu)
${}^{20}Ne$	90.92	19.9924
${}^{21}Ne$	0.257	20.9940
${}^{22}Ne$	**8.823**	**22.0930**

Answers to Self-Assessment Questions

Part I: Basic level questions

Multiple choice questions.

1. E
2. A
3. A
4. D
5. A
6. C
7. A
8. C
9. B
10. B
11. C
12. D
13. A

Part II: Answers for the intermediary level questions

True or False items.

14. False
15. True
16. True
17. False

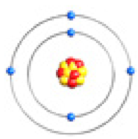
Fill in the blanks.

18. positively charged;
19. positively charged;
20. less

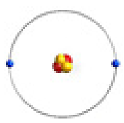
Part III: Answers to the challenge- level questions

21. Atoms are the tiniest particles of matter that take part in a chemical reaction.
22. The discovery of isotopes.
23. Laws of chemical combination.
24. All matter is composed of atoms; atoms of the same element are the same, and atoms of different elements are different; atoms combine in whole-number ratios to form compounds.

25. Atoms are composed of electrons and a nucleus. The electrons are revolving around the nucleus. The nucleus consists of a positively charged proton and a neutral neutron bound together by nuclear energy called binding energy.
26. Less intermolecular attraction.
27. Electron: charge -1.6 x 10^{-19}c, mass 9.1 x 10^{-28} g; proton: charge 1.6 x 10^{-19}c, mass 1.673 x 10^{-24} g; neutron: charge 0, mass 1.675 x 10^{-24} g
28. A proton is larger than an electron.
29. Neutron is larger
30. Arrangement of the fundamental particles.
31. Goldstein, discharge tube.
32. The mass of an atom is located in the nucleus.
33. Increases
34. a doubly ionized helium ion.
35. i) Uniformly distributed positive charge; ii) electrons embedded
36. i) Formation of shadow-travel in straight lines ii) Rotation of paddle wheel-mass and kinetic energy iii) Bending of rays in electric and magnetic field-charged particles iv) Properties do not depend on the nature of gas and cathode
37. A diagram of a boron atom,



38. A diagram of the helium atom,



39. The atomic number is the number of protons in a nucleus. Boron has an atomic number of five.
40. The atomic number of helium is two.
41. Isotopes are atoms of the same element but with different numbers of neutrons. Examples
42. Deuterium has two neutrons, and tritium three neutrons. So, they have different masses.
43. A. isotopes, E. isotopes; F. isotopes
44. A. $^{16}_{8}O$; B. $^{39}_{19}K$; C. $^{7}_{3}Li$, D. $^{12}_{12}Mg$; E. $^{13}_{12}Mg$; F. $^{77}_{54}Xe$
45. $^{241}_{95}Am$
46. $^{14}_{6}C$